International Pacific Halibut Commission

Established by a Convention between
Canada and the United States of America

Report of Assessment and Research Activities 2014

Executive Director
Bruce M. Leaman

Produced by IPHC Staff
2015

International Pacific Halibut Commission
2320 West Commodore Way, Suite 300
Seattle, WA 98199-1287
(206) 634-1838
www.iphc.int

When referencing articles within this document, please use the following guideline:

Author(s). 2015. Report title. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: page numbers.

Note: This document contains a series of reports on current research and the data contained within may have been updated since publication. Prior to using data from these reports, please check with the primary author for updates.

Cover artwork

Joan Forsberg

Document editors

Lara Erikson
Joan Forsberg
Steve Keith
Tom Kong
Bruce Leaman
Tim Loher
Lauri Sadorus
Eric Soderlund

Compilation

Huyen Tran
Lauri Sadorus

Contents

2015 Annual Research Plan - November 2014.....7
IPHC Staff

The Fishery

2014 commercial fishery and regulation changes.....23
Heather L. Gilroy, Lara M. Erikson, and Kirsten A. MacTavish

2014 halibut sport fishery review.....37
Steve Kaimmer

Incidental mortality of halibut in the commercial halibut fishery (Wastage).....47
Heather L. Gilroy and Ian J. Stewart

The personal use harvest of Pacific halibut through 2014.....55
Heather L. Gilroy and Gregg H. Williams

Retention of U32 halibut in the 2014 Area 4D/4E CDQ halibut fisheries.....61
Gregg H. Williams

Commercial catch sampling.....65
Lara M. Erikson and Kirsten A. MacTavish

Age distribution of the commercial halibut catch for 2014.....79
Joan E. Forsberg

Population Assessment

Overview of data sources for the Pacific halibut stock assessment and related analyses....87
Ian J. Stewart

Assessment of the Pacific halibut stock at the end of 2014.....161
Ian J. Stewart and Steven Martell

Setline survey-based apportionment estimates 181
Raymond A. Webster and Ian J. Stewart

Regulatory area harvest policy calculations and catch tables 195
Ian J. Stewart

Evaluation of commercial logbook records: 1991-2013.....213
Cole C. Monnahan and Ian J. Stewart

Accounting for and managing all Pacific halibut removals 221
Ian J. Stewart, Bruce M. Leaman, and Steven J. D. Martell

Reports of the IPHC Scientific Review Board, 2014.....267
Sean P. Cox, James Ianelli, Marc Mangel

Developments in Management Strategy Evaluation/Management Strategy Advisory Board.....277
Steve J.D. Martell, Bruce M. Leaman, Stephen W. Keith, and Ian J. Stewart

Recent developments in the IPHC Management Strategy Evaluation process and size-limit implications.....299
Steven Martell, Bruce Leaman, and Ian Stewart

Incidental catch of halibut

Incidental catch and mortality of Pacific halibut, 1962-2014 313
Gregg H. Williams

Halibut bycatch limits in the 2014 Alaska groundfish fishery 337
Gregg H. Williams

The Alaska groundfish trawl fishery Prohibited Species Donation program: Preliminary results for 2014 347
Gregg H. Williams

Research

General

IPHC oceanographic monitoring program 2014.....351
Lauri L. Sadorus and Jay Walker

Estimating hooking success for large halibut on circle hooks 359
Stephen M. Kaimmer

Juvenile halibut distribution and abundance in the Bering Sea and Gulf of Alaska 367
Lauri L. Sadorus, Ian J. Stewart, and Thomas Kong

Re-ageing of archived otoliths from the 1920s to the 1990s 405
Joan E. Forsberg and Ian J. Stewart

Clean otolith archive collection.....429
Robert S. Tobin and Joan E. Forsberg

Development of a method for marking Pacific halibut by sex onboard commercial fishing vessels 435
Orion McCarthy[1]

Tagging

Tagging studies.....465
Joan E. Forsberg

Captive holding to develop long-term archival tagging protocols in Pacific halibut.....469
Timothy Loher and Tracee O. Geernaert

Trawl tag releases of small halibut in the Bering Sea.....475
Raymond A. Webster

Modelling mortality and migration as functions of age using PIT tagging data 511
Raymond A. Webster

Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal dispersal of Pacific halibut in the southern Salish Sea 523
Timothy Loher

Surveys

2014 Standardized stock assessment survey.....531
Ed Henry, Eric Soderlund, Claude L. Dykstra, Tracee Geernaert, Aaron M. Ranta, and Tom Kong

Age distribution of Pacific halibut in the 2014 IPHC stock assessment setline survey 569
Joan E. Forsberg

Trends in seabird occurrence on stock assessment surveys (2002-2014) 577
Tracee O. Geernaert

Setline survey expansion and complementary data sources 587
Raymond A. Webster, Ian J. Stewart, Bruce M. Leaman, Lauri L. Sadorus, Ed Henry, and Claude L. Dykstra

Setline survey expansions in 2014 and use of sablefish longline survey data for a deep-water density index.....603
Raymond A. Webster, Claude L. Dykstra, Ed Henry, Eric Soderlund, and Tom Kong

Cruise report for the 2014 NMFS Bering Sea trawl survey.....619
Lauri L. Sadorus and Robert Lauth

Size and age composition of Pacific halibut in NMFS Bering Sea shelf trawl surveys.....627
Lauri Sadorus, Robert Lauth, and Aaron Ranta

Results from the NMFS Aleutian Islands biennial bottom trawl survey in 2014.....635
Lauri L. Sadorus, Wayne A. Palsson, and Aaron Ranta

Prior hook injuries: results from the 2014 IPHC SSA and NMFS trawl surveys.....645
Stephen M. Kaimmer

2015 Annual Research Plan - November 2014

IPHC Staff

Executive summary

The fishery for Pacific halibut (*Hippoglossus stenolepis*) is one of the most valuable and geographically largest in the northeast Pacific Ocean. Industry participants from Canada and the United States have prosecuted the fishery and have depended upon the resource since before the turn of the 20th century. Annual removals have been as high as 100 million pounds, while the long term average of removals is 64 million pounds.

Management of the Pacific halibut resource and fishery has been the responsibility of the International Pacific Halibut Commission (IPHC) since its creation in 1923. Assessing, forecasting, and managing the resource and fishery requires accurate assessments, continuous monitoring, and research responsive to the needs of managers and stakeholders.

The IPHC staff has developed a series of research studies for 2015 which it recommends to the Commission for adoption through this Annual Research Plan. The recommended studies require a funding level of approximately $0.329 M during fiscal year 2015. Several studies will contribute towards greater understanding of three issues currently facing the Commission and industry stakeholders, notably the decline in size at age, understanding the sex ratio of the catch and the accurate characterization of the spawning biomass, and improving our understanding of the scope and timing of migration.

Objective 1: Stock identification, monitoring and assessment

The staff is recommending two high-priority studies designed to develop methodology for accurate determination of the sex ratio of the commercial landings. The sex ratio of commercial landings cannot be determined directly because landed fish are dressed at sea, so a genetic method of determining the sex of fish will be developed. The staff will also continue with collection of juvenile abundance data from trawl surveys, which is incorporated into the annual assessment. Fishery-independent and -dependent data will also be collected by the annual stock assessment survey and the commercial fishery port sampling program, respectively.

Objective 2: Harvest policy and management

Research by the staff and stakeholders on the harvest policy is ongoing through the Management Strategy Evaluation (MSE) effort with the Management Strategy Advisory Board (MSAB) and other staff work. In particular, the MSE process will be focusing on the impacts of changing the current minimum commercial size limit for halibut.

Objective 3: Biology, physiology, and migration

Investigation will continue into the declining trend in size at age, taking advantage of IPHC's extensive historical otolith archives dating to the 1920s. This study would also integrate with external research involving IPHC, which is supported by the North Pacific Research Board (NPRB). Second, as part of the continued focus on understanding halibut migration, the staff proposes to continue with the development of the geomagnetic archival tag technology, which involves several

projects to resolve tag attachment, geomagnetic data resolution, and release locations in Area 4B. In addition, data collection will continue in 2015 into the halibut length-weight relationship study, both at sea and in ports, in order to accurately estimate the removals from the stock. The staff will also complete a limited examination of halibut movements within the southern Salish Sea, using PAT tags.

Objective 4: Ecosystem interactions and environmental influences

Three studies are proposed which are continuations of studies currently underway: oceanographic monitoring with the profilers from the survey platforms, mercury and contaminant assessment, and assessment of *Ichthyophonus* prevalence. These studies strive to describe halibut habitat in order to assess the effect of a changing climate on stock dynamics, and also address possible environmental threats facing the population.

The staff notes that this Annual Research Plan does not describe all research activities conducted by IPHC. Various studies are conducted as a matter of routine work by the staff, some in collaboration with other agencies. The research recommendations included in this Plan are based on identified research gaps, to supplement research already underway and advance the IPHC mission.

Introduction

The Pacific halibut resource has been the target of exploitation for centuries. Commercial harvests have been recorded since the late 1800s, and more recently a sport fishery has grown in popularity throughout its range. Annual removals have varied throughout history and have reached nearly 100 million pounds in 1990 and again in 2004. At the turn of the 20th century, the resource status suffered a serious decline, leading the halibut industry to petition the U.S. and Canadian governments for creation of a multilateral management agency to institute fishery restrictions aimed at stock recovery for the benefit of fishers from both countries. The IPHC was created in 1923 by a convention between the two countries. The 1923 Convention was also noteworthy in that it was the first international treaty to be concluded anywhere for the conservation of a depleted deep-sea fishery. The Commission was charged with studying the life history of halibut and with recommending regulations for the preservation and development of the fishery.

The IPHC, as an intergovernmental fisheries organization, receives monies from both the U.S. and Canadian governments to support an Executive Director and staff. Annually, the IPHC meets to conduct the business of the Commission. At this annual meeting the budgets, research plans, stock assessment, catch recommendations, as well as regulatory proposals are discussed and approved. Approved regulations and recommendations are then forwarded to the respective governments for implementation. The IPHC staff and offices are currently located in Seattle, Washington.

The IPHC conducts numerous projects annually to support both major scientific mandates: stock assessment and basic halibut biology. Current projects include standardized stock assessment fishing surveys from northern California to the end of the Aleutian Islands and into the Bering Sea, as well as field sampling in major fishing ports to collect scientific information from the halibut fleet. In conjunction with these ongoing programs, the IPHC conducts numerous biological and scientific experiments to further the understanding and information about Pacific halibut.

The Commission staff prepares a Five Year Research Plan and an Annual Research Plan (ARP). The plans derive directly form Commission objectives, with an accompanying process for

input and periodic reviews by the Commission, interested stakeholders, the Research Advisory Board (RAB), and the Scientific Review Board (SRB). The IPHC staff is tasked with developing the preliminary ARP for presentation to the Commission at the Interim Meeting, where discussion of overall research priorities, individual studies, and associated budgets will occur. The staff develops a final ARP following the Interim Meeting and this is presented at the Annual Meeting for Commission approval.

Research priorities

Staff research is conducted within the four areas of study identified by the IPHC Five Year Research Plan. These areas, which connect to the IPHC mandate and support the assessment and management objectives of the Commission are: 1) Stock identification and assessment; 2) Harvest policy and management; 3) Biology, physiology, and migration; and 4) Ecosystem interactions and environmental influences. In each of these areas the work program applies the best information and methods available, and the research program aims to improve the information and methods by answering the most important outstanding questions.

The ARP is based on management and assessment needs as prioritized by the IPHC staff and Commission. It is the Commission's long-term goal to also obtain the views and advice of its SRB and RAB in the design and prioritization of research within the ARP. The RAB discussed several areas of research during its November 2015 meeting, and its comments are contained within the report of the meeting. The SRB reviewed the Commission's draft Five Year Research Plan during 2014.

For the past several years, two primary topics have been at the forefront of discussions about the halibut resource. The first has been the continuing decline in size at age, with the resulting effects and impacts on the harvest policy and stock status. The IPHC staff is continuing with an externally-funded (NPRB) project examining multiple influences on halibut size at age. Allied with this is the need to accurately estimate the removals from the stock through conversion of landed fish weight into the quantities required for the stock assessment. The second issue has been the migratory behavior of the stock, specifically seasonal and ontogenetic migration, including sex- and age-specific differences in spawning migration timing and duration. Understanding migration patterns is the overarching goal of the archival tag program, which has several aspects examining tag type, location, tag shedding, and resolution of geomagnetic location data (projects 650.xx).

Research into both areas is of high priority for the Commission and staff. In the following section, studies for 2015 will be presented which address both topics. In addition, the staff proposes to undertake a genetic study designed to establish a validation procedure for estimating the sex ratio of the commercial catch. Sensitivity analyses have shown that the estimate of stock biomass is very sensitive to the estimated sex ratio.

Ongoing and proposed for 2015

Research proposed by IPHC staff goes through an internal review process by the staff Science Board. This year, the Board met in early October to review staff proposals for 2015 research. For each proposal, the Board discussed the merits, objectives, design, and coherence with the Commission's research goals and objectives. The Principal Investigator (PI) subsequently joined the Board for a broad discussion of the project. Concerns, questions and need for refinements or revisions, if any, about the proposal were communicated to the PI at that time. Following a full

review of all proposals, the Board assigned a priority rating to each project, based on the following criteria:

High – Research which has a direct bearing on the assessment or its inputs, harvest policy, or current management structure. Postponement of a high priority project would have a significant and immediate impact on management or IPHC operation.

Medium – Research which addresses an assessment issue or management question/need. Postponement will not have an immediate significant impact on fishery management or IPHC operation but may impact future analyses.

Low – Research which addresses current issues of any subject but is not considered having a timely need or being crucial to current IPHC management or operation.

Based on the Science Board discussions and the topics previously outlined, the following sections describe the upcoming work by IPHC staff and also provide descriptions of recommended research studies for funding in FY2015.

OBJECTIVE 1: STOCK IDENTIFICATION, MONITORING, AND ASSESSMENT

Research in this area focuses on stock identification, monitoring, assessment, forecasting, and incorporation of uncertainty in both data and processes into management advice. The staff seeks to understand the underlying Pacific halibut stock structure and the influence of age, size, and sex on movement as they relate to stock components. Additionally, monitoring occurs through the IPHC Port Sampling program (fishery removals), standardized setline stock assessment survey (fishery-independent stock indices), and trawl surveys (pre-recruits).

The most significant work is the annual stock assessment, which produces estimates of abundance based on a comprehensive suite of fishery-dependent and -independent variables. The assessment also forecasts short-term trends in the stock to support the IPHC decision-making process. Assessment staff also works at determining and reducing the level of uncertainty associated with stock assessments through advanced analytical techniques. Where needed, improved data collection or other studies are recommended.

For 2015, in addition to the annual assessment, the staff is proposing studies to address the accurate determination of both the sex ratio of the catch, and the spawning biomass of the stock, as well as a cooperative project on hooking behaviour.

Funded research - Proposed

Project 2015-01: Genetic Sexing via Single Nucleotide Polymorhpisms (SNPs)
Priority: High
Budget: $ 176,525
Start: 2015
Anticipated Ending: 2016
Personnel: T. Loher, L. Hauser (UW)

The work will allow for direct and reliable monitoring of sex ratios within the commercial catch in the face of potentially changing sex ratios due to decreasing size at age relative to the commercial minimum size limit (MSL). Proposals to reduce the MSL have also been advanced to reduce handling mortality on currently-sublegal fish, to theoretically bring a larger proportion of males into the exploited stock fraction, and to increase the economic efficiency of the harvest. At present, the sex composition of the catch is estimated from IPHC survey data but there is a critical need to directly monitor changes in sex composition of the catch should such actions be invoked.

The sequencing of Restriction site Associated DNA (RAD tags), has revolutionized genetics by allowing the discovery and genotype-calling of thousands of SNPs (Single Nucleotide Polymorphisms) in multiple individuals at relatively low cost. The technique takes advantage of the large number of sequences (millions of reads per run) produced by the Illumina HiSeq 2000 sequencer. Briefly, RAD tag sequencing focuses on sequencing the regions (tags) directly adjacent to specific restriction sites genome-wide. It is therefore possible to sequence a large and reproducible subsection of the genome in many individuals. Given the high success in sexing halibut with microsatellites, we expect to identify several dozens of sex specific SNPs that will allow the development of rapid assays for large samples. Once SNPs highly diagnostic for sex have been identified, we will develop high-throughput assays to allow the screening of larger samples. We will identify about 20 SNPs and re-sequence them in additional individuals. We will optimize these SNPs for use with low quality DNA, allowing the elimination of costly and laborious DNA extraction methods in routine sex surveys. In addition, we will minimize the number of SNPs necessary for 100% sex identification by picking highly discriminatory SNPs from our panel.

Project 2015-02: Commercial Sex Marking Pilot
Priority: High
Budget: $ 2,000
Start: 2015
Anticipated Ending: 2016
Personnel: T. Loher, I. Stewart, J. Marx

This project has three primary objectives: a) test a single method of sex-marking aboard a small sample of commercial fishing trips in order to determine its feasibility from a fleet perspective; b) evaluate the additional workload that processing sex-marked catch, and obtaining tissue samples for subsequent genetically-based QA/QC of the physical marking process, is likely to have upon the IPHC's port sampling program; c) generate a small tissue archive that can be subjected to subsequent genetic analysis, as an element of Project 2015-01, above.

We plan to sample six offloads from Area 3A, equally distributed amongst spring, summer (during the survey period), and fall. The study will use volunteer vessel captains who are willing to mark fish during selected commercial trips, and we will also work with interested RAB members

during the selection process. We will attempt to identify vessels and trips that plan relatively small landings (preferably in the 2000-3000-pound range), with an eye toward scaling the process upwards in the future. We expect that obtaining a broad temporal distribution of landings for each area may require collaboration from two, or even three, vessels in one or more areas.

Participating vessels will be briefed on the appropriate method for marking males and females during dressing, and asked to mark every fish retained during the designated fishing trip(s). The initial plan is to use the marks identified by McCarthy (2015), which consisted of two vertical cuts in the dorsal fin for females and one vertical cut in the white-side operculum for males.

For each sampled offload, the port sampler will record the length and marked sex of each fish (including unmarked individuals) and collect and preserve a tissue sample. Analysis will include:

- A post-participation 'debrief' with each harvester regarding the marking process, time requirements, ideas for alternate marks and general willingness to participate again in the future.
- A comparison of the sex-ratio at age among the sampled trips with the sex-ratio at age among survey legs during the same year.
- Genetic samples will be stored, pending the development of SNIP assays when they can be assigned a sex and the accuracy of fishermen's marks can be tested directly following the approach used by McCarthy (2015).

Tissue samples will be archived until such time as a definitive genetically-based indicator of sex has been developed and is ready for use. When ready, the samples will be subjected to analysis and the resultant sex ratios compared to those obtained by at-sea catch-marking.

Project 2015-03: čibu·d hook research
Priority: Low
Budget: $ 1,080
Start: 2015
Anticipated Ending: 2016
Personnel: E. Henry

In 2014, Makah Fisheries Management performed a study on the čibu·d, a traditional halibut hook used in the past by the Makah tribe. They were testing whether the traditional hooks could both fish effectively (maintain a similar catch-rate) and reduce the rate of non-halibut bycatch relative to commonly used circle hooks. Though it was shown from the Makah's original study that the čibu·d was not as effective at catching halibut in a commercial longline operation using circle hooks, there was a significant reduction in the observed rate of bycatch. A major uncertainty in the study was the actual fishing configuration and hooking process, which may have resulted in lower halibut catch rates. Although the mechanism of hooking can be inferred from the design of the čibu·d and location of the hook in captured fish, there are no recorded observations of halibut behavior when encountering the čibu·d, or of a halibut actually being hooked by one. Also, there is no information on the hooking success of čibu·d in comparison to circle hooks when deployed in a manner consistent with recreational rather than longline fisheries. The purpose of this study would be to record video of čibu·d hooking behavior, and to compare hooking behavior differences between čibu·d and circle hooks in a controlled aquarium setting. This could improve the understanding of the results already obtained by the Makah Fisheries Management program and help to better identify promising avenues for use of the čibu·d in future halibut fisheries.

This project has two primary goals: 1) establish the first video record of hooking behavior for halibut encountering metal čibu·d. This will include qualitative analysis of how the hook is attacked, where it becomes embedded in the jaw, and how many interactions are required for successful hooking, and 2) compare the rate of hooking success for metal čibu·d with modern 14/0 circle hooks.

OBJECTIVE 2: HARVEST POLICY AND MANAGEMENT

Work to support this objective involves annual evaluations of IPHC's harvest policy with regard to the current stock dynamics and management goals. The staff develops stock projection procedures which incorporate a realistic range of alternative hypotheses about stock behavior, environmental influences, and fishing effects on stock abundance and halibut characteristics. The staff also provides harvest management advice to the Commission and user groups in a form which allows the consideration of uncertainty in the assessment and forecasting processes.

In 2013 the Commission approved the formation of the MSAB to oversee the MSE process and to advise the Commission and Staff on the development and evaluation of candidate objectives and strategies for managing the fishery. The MSAB has been working with staff over the past 18 months to develop candidate management objectives, procedures to achieve these objectives, and performance metrics with which to measure success. The Board has developed five overarching objectives and a number of specific stock and fishery objectives. Progress and results of the Board's meetings are posted on the MSAB website (http://www.iphc.info/msab). The group is currently working on a coastwide operating model of the halibut stock and in the future will develop more spatially explicit modelling.

The staff is not proposing any additional research for 2015 requiring separate funding. All work will be done within current staff work assignments.

OBJECTIVE 3: BIOLOGY, PHYSIOLOGY, AND MIGRATION

Staff research within this objective seeks to collect and monitor primary biological characteristics of all sizes of halibut throughout the species' range. This includes directed studies but also involves incorporating studies monitoring the size at age of halibut within ongoing data programs wherever possible. IPHC also collaborates with other institutions and agencies to obtain biological and ecosystem information on halibut not otherwise available through IPHC programs and to incorporate that information into understanding and prediction of halibut population dynamics. Specific migration research objectives focus on the impacts of ontogenetic and seasonal movements on long-term yield, spatial distribution of spawning biomass, impact of fishing seasons on interceptions, and temporal variations in fish movement.

Research specific to halibut migration and movement was requested by the Commission in 2001 (Leaman et al. 2002). Dr. T. Loher of the IPHC staff has designed a tag study to provide information on seasonal migration of halibut that can provide input for discussing appropriate fishing seasons with four objectives. These objectives will be accomplished by quantifying, for the eastern Pacific halibut population, on regional bases:

1) the active spawning season for Pacific halibut, defined as the period over which eggs are released into the water column;

2) depth-specific spawning habitat, defined as the range of bottom depths over which halibut initiate active spawning behavior;

3) the fall and spring migratory periods, including estimates of the proportion of stock in a state of seasonal migration by date; and

4) where possible, timing of seasonal movement among regulatory areas, and the proportion of the spawning stock likely to be located out-of-area, by date.

Since 2009, the IPHC staff has been actively engaged in studies explicitly designed to establish protocols for the proposed work. This includes selection of appropriate tag type, tagging attachment and location protocols on the fish, and reliable, cost-effective tag technology. The ongoing studies outlined below support this work.

Also, in 2013 the IPHC embarked on an extensive set of studies to examine the recent decline in halibut size at age. The work encompasses several focused pieces of research, including those being conducted by IPHC staff and others in a collaborative study with the National Marine Fisheries Service (NMFS), the University of Washington (UW), and the Alaska Department of Fish and Game (ADF&G). Work will continue in 2015 as the decadal samples are identified and extracted from the archives, and aging/measuring of the growth increments begins.

The staff has also initiated a study of halibut movements within the southern Salish Sea (Puget Sound) in response to proposed hypotheses from Washington tribes about the nature of the population in that region. There has been a suggestion that the fish in this region are isolated and may require unique management. A demonstration of the movement of halibut from inside and outside waters will address the hypotheses.

Funded Research - Ongoing

Project 636.00: Evaluation of Pacific halibut macroscopic maturity stage assignments
Priority: High
Budget: $ 6,000
Start: 2008
Anticipated Ending: 2016
Personnel: K. MacTavish, other staff as needed

The staff believes it is necessary to re-evaluate our classification criteria for female gonad maturity stage. The method currently used on the assessment surveys is based on visual criteria established in the early 1990s and modified in 1995. These survey data combined with the age data are important components in the stock assessment model. Four maturity stages are presently assigned to female halibut; immature (F1), maturing (F2), spawning (F3), and resting (F4). The assumption is that once a female halibut has spawned, the gonad transitions to a resting phase, back to maturing, and then to spawning again. Our criteria for classification also assume that the F1 stage is only seen with immature fish but we are seeing anomalies during the survey that suggest a fish may go back to this stage after achieving other maturity stages, and is therefore not truly immature. Gonad samples were collected in 2004 from which to base this study. In 2015, research will include:

- Determining the maximum precision for oocyte diameter measurements by oocyte maturation stage
- Conducting assessment of the prepared slides from the archived gonads using the sampling protocols developed in 2014.
- Developing the sampling plan required to characterize seasonal maturation, including determination of the value of current summer assessment of halibut maturity stages.

Project 650.13: Archival tags: mounting protocols (OCA)
Priority: High
Budget: $ 5,750
Start Date: 2009
Anticipated ending: 2015
Personnel: T. Loher

For 2015, the staff intends to terminate the captive holding of halibut in tanks at the Oregon Coast Aquarium (OCA) in Newport, OR. Staff believes that we have obtained all the necessary information from this study with the finding that neither the dart-and-tether nor the surgical implantation methods show signs of shedding. This portion of the project will be terminated in late fall, although the fish may be used for project 2015-03 prior to sacrificing. Costs are for partial-year holding.

Project 650.16: Archival tags: Area 4B site selection
Priority: High
Budget: $ 1,000
Start date: 2010
Anticipated ending: 2015
Personnel: T. Loher, J. Forsberg, survey team

In 2009, a total of 773 fish were tagged in Area 4B to evaluate tag recovery rates in preparation for a future release of archival tags in the area. Recovery rates of PIT tags released in the Aleutians were quite low, without evidence of recovery hotspots. This suggested that if archival tags were deployed in the Aleutians, we would likely recover relatively few of those tags. This project deployed tags on four sites, and recoveries to date (41 with 70% from two sites) indicate that the two sites would provide suitable locations for subsequent recoveries. The requested budget for 2015 is to cover the rewards for the anticipated recoveries.

Project 650.18: Archival tags: tag attachment protocols
Priority: High
Budget: $ 4000
Start Date: 2013
Anticipated ending: 2017
Personnel: T. Loher

Recovery rates of archival tags affixed to halibut using four different external mounting protocols (three dart-and-tether configurations; one wired to the operculum) are being tested in a field release of "dummy" archival tags. During the summer of 2013, a total of 900 fish were tagged off northern Kodiak Island (Area 3A), with an equal number of fish tagged with each tag attachment type. Fish carrying a dart-and-tether tag were also tagged with a bright pink cheek tag, and rewards of $100 will be given for all tags recovered. Expenses in 2015 will consist of tag rewards.

Project 665.11: Estimate of length/weight relationship and head/ice/slime adjustment
Priority: High
Budget: $ 17,370
Start: 2013
Anticipated Ending: Continuing
Personnel: R. Webster, L. Erikson, K. MacTavish, H. Gilroy

The purpose of this study is to reexamine the relationship between fork length and net weight, including the estimation of adjustments necessary to convert head-on weight to net weight. The current length-net weight relationship was estimated in 1926. If the relationship varies among regulatory areas, there may be systematic bias in regulatory area estimates of weight or WPUE derived from length measurements. Seasonal variation could affect weight estimates that are made from data collected during only a small part of the year. Therefore, we are collecting data coastwide throughout the season in order to estimate spatial and seasonal variation in the length to weight relationship. Data will be collected in 2015 from ports staffed with IPHC samplers throughout the fishing season. The goal is to determine whether seasonal or area-specific L-W relationships are warranted, or whether the effect of any variation can be incorporated via variation about the existing relationship.

The current relationship used by IPHC between fork length and net weight also includes adjustments for the weight of the head, and of ice and slime: gross landed weight (gutted, with head, ice and slime) is assumed to include 12% head weight and 2% ice and slime, which combine to give a multiplier of 0.8624 to convert gross to net weight. However, the industry standard for head, ice and slime deduction is a total of 12%. Therefore we are also collecting data to provide direct estimates of adjustment factors to compare with the currently assumed values, and to assess variability in the weight of heads and ice and slime.

Work will continue to be carried out within work schedules of existing staff, and will not require additional funding of salaries. The 2014 budget included funds for a contract to custom build measurement tables, along with associated shipping costs. The prototype was built and shipped in September 2014. The 2015 budget includes funds for the contract to build the additional measuring tables (12 tables at $1000 each), associated shipping costs (around $335 per table), and for the purchase of any additional tags that may be needed for tracking fish within processing plants.

Project 646.13: Archival tags: Salish Sea PAT tags
Priority: Low
Budget: $ 4,500
Start: 2014
Anticipated Ending: 2015
Personnel: T. Loher

This study is a test of several hypotheses regarding halibut movements within Area 2A. Specifically, that halibut found in the southern Salish Sea, i.e., Puget Sound, are an isolated stock component requiring management independent of the larger outer coast population. Six of the tags (at sites south of the San Juan Is.) were deployed in June from the IPHC survey platform. During July we attempted to formalize collaboration with a Lummi Nation vessel to deploy the remainder of the tags but this was unsuccessful and the six remaining tags were deployed from an alternate vessel in early October. The tags are programmed to pop up in January 2015 and June 2015.

Funded Research - Proposed

Project 2015-04: Length-weight relationship at sea
Priority: High
Budget: $ 10,000
Start: 2015
Anticipated Ending: 2016
Personnel: E. Soderlund

This project integrates with the 665.11 port sampling project and obtains the two missing pieces of information on length-weight relationships: estimating shrinkage factors from fresh at-sea lengths and weights, to landed lengths and weights. It is particularly important for estimating removals from bycatch, recreational, and subsistence fisheries where no storage process occurs from capture to weight estimation.

The purpose of this study is to collect data on IPHC's SSA Survey for use in estimating the relationship between fork length and net weight, including the estimation of adjustments necessary to convert head-on weight to net weight, as well as estimation of shrinkage (potentially occurring in both length and weight) from time of capture to time of offload. This project will complement an on-going project (665.11), in which samples from commercial deliveries are measured and weighed at the dock, by providing length to weight data that is not available at commercial offloads: from U32 fish, round fish, and freshly killed and dressed fish, as well as measurements of shrinkage from the time of capture to final weighing at the offload. The current length to net weight relationship was estimated in 1926. If the relationship varies among regulatory areas, there may be systematic bias in regulatory area estimates of weight or WPUE derived from length measurements. The current relationship between fork length and net weight also includes adjustments for the weight of the head, and of ice and slime: We also plan to collect data to provide direct estimates of adjustment factors to compare with the currently assumed values, and to assess variability in the weight of heads and ice and slime to supplement data collected in project 665.11.

OBJECTIVE 4: ECOSYSTEM INTERACTIONS AND ENVIRONMENTAL INFLUENCES

Research on this objective seeks to advance the understanding of the ecological context for halibut, including predation and competition, as well as fishing and environmental effects on recruitment and distribution. This also includes understanding the relationship between environmental influences and halibut distribution and behavior. This is primarily accomplished with broad-scale monitoring programs, some of which can occur on IPHC research platforms. Additionally, IPHC seeks to share its environmental data set with other researchers and institutions. Collaborative research is sought out whenever possible.

IPHC is actively involved in a large-scale monitoring program from the setline assessment survey using water column profilers. The program is making environmental data available to other researchers through a public access portal with the Pacific Marine Environmental Laboratory (PMEL). Other monitoring is occurring from the survey platform, including an appraisal of contaminants in halibut and the prevalence of *Ichthyophonus*. These three programs are proposed to continue in 2015, and are discussed below.

Funded research - Ongoing

Project 610.13: Oceanographic monitoring of the north Pacific and Bering Sea continental shelf with water column profilers

Priority: Medium
Budget: $ 92,300
Start date: 2009
Anticipated ending: Continuing
Personnel: L. Sadorus, J. Walker, P. Stabeno (NMFS PMEL)

The goal of this project is to measure oceanic properties in the waters over the Alaskan, B.C., and the U.S. west coast continental shelf that can be correlated to catch per unit effort (CPUE) of halibut as well as incidence of other groundfish species. The IPHC operates a survey that covers the area, and water column profilers that measure temperature, salinity, dissolved oxygen, pH, and florescence are deployed at each station. These data provide an annual snapshot of near shore oceanic conditions as well as valuable observational data for studying halibut distributions in relation to environment, addressing environmentally-related catchability in the survey, modeling and biological studies on recruitment and growth variability.

In particular, understanding the dynamics of the structure of the mixed layer depth – a major GLOBEC goal - requires in situ vertical profiling. Since 2001, IPHC has successfully deployed a SeaBird SBE-19 water column profiler during the annual stock assessment survey. A second profiler was added to the program in 2007. In 2009, a NOAA grant provided for the complete outfitting of all chartered survey vessels, resulting in a complete coastwide deployment. Annual costs are directed towards maintenance and calibration of the profilers, and data preparation necessary for submission to the National Ocean Data Center.

Funding in 2015 includes replacing one profiler, upgrading an older profiling unit to come into compliance with the newer units, the replacement of four profiler control/recording units, as well as maintenance and calibration of all units. An ancillary element of the proposal includes the construction of an environmental database, including the profiler and other data, at the IPHC for direct use by IPHC staff.

Project 642.00: Assessment of mercury and contaminants in Pacific halibut

Priority: Medium
Budget: $ 4,700
Start Date: 2002
Anticipated ending: Continuing
Personnel: C. Dykstra, B. Gerlach (ADEC)

The staff proposes to continue IPHC's collaboration with the Alaska Department of Environmental Conservation (ADEC) in 2015, collecting halibut tissue samples for analysis of heavy metal and organic pollutant loading. This work has been ongoing since 2002. Results from a 2002 collection of halibut samples led the Alaska Division of Public Health in 2003 to conclude that the concentrations of heavy metals in Alaskan Pacific halibut were not a public health concern. In 2004 the first results regarding organic pollutants (PCB's, pesticides) were released demonstrating that halibut had the lowest concentrations of the five species (including salmon and sablefish) examined. The Alaska Division of Public Health updated their advice on fish consumption in 2007 with some restrictions on the number of meals of halibut for women of child bearing age

and young children. Since 2002 the IPHC has submitted 1,293 samples for testing by ADEC. The IPHC and ADEC are continuing to qualify the data with physical parameters (age, size, and weight) and additional analyses will be done on the samples. ADEC and EPA planned on going ahead with this study regardless of IPHC input. Our involvement in the project has allowed us to provide input on study design and sampling protocols in the field, which will make the resultant information much more robust.

Reporting in 2014 included joint analyses with ADEC staff in presentations at the International Flatfish Symposium and the 2014 EPA National Forum on Contaminants in Fish. Funds for 2015 include sampling costs and travel.

Project 661.11: *Ichthyophonus* prevalence in halibut
Priority: Low
Budget: $ 3,866
Start Date: 2012
Anticipated ending: ongoing
Personnel: C. Dykstra, G. Williams, J. Gregg (USGS), P. Hershberger (USGS)

Ichthyophonus is a protozoan parasite from the class Mesomycetozoea, a highly diverse group of organisms having characteristics of both animals and fungi. It has been identified in many marine fish, and is considered a causative agent in herring fishery collapses world-wide, and there is concern over its effects on the success of salmon spawning on major rivers such as the Yukon.

During 2011-2013, samples were collected from halibut caught on the IPHC setline assessment survey over a broad geographic range, with a goal of describing the spatial and temporal distribution of *Ichthyophonus* prevalence. Limited sampling of small (<50 cm) halibut from the NMFS trawl survey recorded a very low prevalence rate of 2.4%, suggesting that infections establish after some ontogenetic shift in diet, habitat, or behavior. Sampling of larger, adult halibut have shown a wide range of rates, with Prince William Sound showing some of the highest observed in fish.

The prevalence of infection is higher than that which has been observed in studies of other sympatric fish species, including other pleuronectids, suggesting that either susceptibility and/or infection pressures are higher in halibut. While *ichthyophoniasis* has been shown to reduce growth rate, decrease swimming stamina, and cause mortality in other fish hosts, its effects on Pacific halibut are unknown.

Results to date were presented, in conjunction with USGS co-authors, at the International Flatfish Symposium in the fall of 2014. Funds in 2015 are for sample processing.

Alternative research packages

The Commission has requested to see options for research which would be contingent on various funding levels. The full suite of projects outlined by the IPHC staff is summarized in Table 1, with a total budget of $325,791.

One approach to constructing the alternative research packages is to consider the proposals based on priority and/or area of study. Project budgets can be summed up within these strata for evaluation, which is shown in the following table. This type of presentation enables the Commission to consider those groups of projects of a prescribed priority and/or area of study which could be conducted if budgetary limitations were present.

	Priority			
Research Plan Objective	**High**	**Medium**	**Low**	**Total**
1. Stock identification/assessment	$ 178,525	0	$ 1,080	**$ 179,605**
2. Harvest policy & management	0	0	0	**$ 0**
3. Biology, physiology, migration	$ 44,120	0	$ 4,500	**$ 48,620**
4. Ecosystem interactions	0	$ 97,000	$ 3,866	**$ 100,866**
Total	**$ 222,645**	**$ 97,000**	**$ 9,446**	**$ 329,091**

Note that many of the studies proposed for 2015 were initiated in previous years and are considered as ongoing research initiatives. Some have been structured as multi-year studies of a fixed duration, whereas others have more of a long term focus. For reference, the total proposed research program for 2015 has the following split between ongoing and new studies:

Study type	**No. of studies**	**Budget**
Ongoing	9	$ 139,486
New for 2015	4	$ 189,605
Total	**13**	**$ 329,091**

Future research directions

1. Recruitment
    a. Application of environmental (profiler) data to recruitment scenarios and year class strength.
    b. Recruitment drivers – what processes affect recruitment, and what are their relative contributions?
2. Size composition and mortality of released/discarded fish. Currently, little is known about the size/age of discards for some directed fisheries or the appropriate discard mortality rate to be applied. In addition, the increasing use of size restrictions in sport fishery management to more fully achieve harvest goals increases discards, but data collection programs are lacking, and implications to the IPHC harvest policy are unclear. Lastly, changes in harvest policy, such as changes in the minimum commercial size limit, require data collection programs so that the impact of the changes in management procedures can be assessed.
3. Full catch accounting. Information on removals from all sources is needed for the best assessment of stock status. Identification of gaps in reporting programs and impediments to progress in achieving full accounting goals are necessary to reach these goals.
4. Migration studies
    a. An improved understanding of U26 migration, i.e., rates and timing by area and size of fish, as well as inter- and intra-annual variability.
    b. Improvements to archival tag technology for application to smaller halibut. Currently, pop-up satellite tags are limited to fish larger than 75 cm (~8 pounds), and archival tags to fish larger than 50 cm (~2.2 pounds). Being able to place similar or newer technology tags on smaller halibut would enable collection of movement data for a size range over which data are currently lacking.
5. Economic analyses. This would have a wide application, both within the MSE process in evaluation of alternative management scenarios, and in examining other fishery policy issues, e.g., bycatch, sport/commercial. The IPHC currently has no expertise in economic analysis on staff; previous studies have used contractors hired for specific one-time proposals.

Recommendations for changes to the Five Year Research Plan

The staff has no recommendations for changes to the Five Year Plan at this time.

References

Leaman, B. M., Geernaert, T. O., Loher, T., and Clark, W. G. 2002. Further examination of biological issues concerning an extended commercial fishing season. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001:53-73.

Table 1. Summary of research proposed for 2015.

Project #	Project Name	Priority	Five Year Plan Objectives				Budget (US$)	Lead/PI	Begin/End Dates
			Stock ID, Monitoring & Assessment	Harvest Policy & Management	Biology, Physiology & Migration	Ecosystem Interactions			
Ongoing									
610.13	Oceanographic monitoring of the north Pacific and Bering Sea continental shelf with water column profilers	Medium				•	92,300	Sadorus	2009/Ongoing
636.00	Evaluation of Pacific halibut macroscopic maturity stage assignments	High			•		6,000	MacTavish	2008/2016
642.00	Assessment of mercury and contaminants in Pacific halibut	Medium				•	4,700	Dykstra	2002/Ongoing
646.13	Salish Sea PAT tags	Low			•		4,500	Loher	2015
650.13	Archival tags: mounting protocols (OCA)	High			•		5,750	Loher	2009/2016
650.16	Archival tags: Area 4B site selection	High			•		1,000	Loher	Open ended
650.18	Archival tags: tag attachment protocols	High			•		4,000	Loher	2016
661.11	*Ichthyophonus* prevalence in halibut	Low				•	3,866	Dykstra	2012/Ongoing
665.11	Length-weight relationship	High			•		17,370	Webster	2013/Ongoing
Proposed									
2015-01	Genetic sexing via SNPs	High	•				176,525	Loher	2015/2016
2015-02	Commercial sex marking project	High	•				2,000	Loher/Stewart	2015/2016
2015-03	čibu·d hook research	Low	•				1,080	Henry	2015
2015-04	Length-weight relationship at sea	High			•		10,000	Soderlund	2015/2016
	Total – Ongoing Projects						**$139,486**		
	Total – Proposed Projects						**$189,605**		
	Overall Total (all projects)						**$329,091**		

2014 commercial fishery and regulation changes

Heather L. Gilroy, Lara M. Erikson, and Kirsten A. MacTavish

Abstract

Represented in this document are the regulations and the results of the 2014 commercial Pacific halibut fishery. The total commercial catch of 22,921,000 pounds was less than 1% under the International Pacific Halibut Commission (IPHC) set catch limit; in addition, 766,000 pounds were landed from the IPHC stock assessment surveys. The commercial halibut fisheries in Area 2A consisted of the incidental halibut catch during the salmon troll and limited-entry sablefish fisheries, the directed commercial fishery with fishing period limits, and the treaty Indian fisheries. Farther north, the commercial fisheries consisted of the Individual Vessel Quota fishery in Area 2B, the Individual Fishing Quota system in Alaska, and the Metlakatla fishery in SE Alaska. All 2014 catch data presented in this document are preliminary.

Regulatory areas for 2014

Boundary lines for the International Pacific Halibut Commission ("Commission" or IPHC) regulatory areas (Fig. 1) have remained the same since 1990. The southeastern flats in the Bering Sea, excluding the upper reaches of Bristol Bay, remained closed in 2014 to all commercial halibut fishing. A brief description of the regulatory areas and the Bering Sea closed area for the 2014 halibut fishery follows:

Area 2A - all waters off the coast of the States of California, Oregon, and Washington.

Area 2B - all waters off the coast of British Columbia.

Area 2C - all waters off the coast of Alaska, south and east of Cape Spencer.

Area 3A - all waters between Cape Spencer and Cape Trinity, Kodiak Island.

Area 3B - all waters between Cape Trinity and a line extending southeast from Cape Lutke, Unimak Island.

Area 4A - all waters west of Area 3B and the Bering Sea closed area that are south of 56°20' N and east of 172°00' W.

Area 4B - all waters in the Gulf of Alaska and the Bering Sea west of Area 4A and south of 56°20' N.

Area 4C - all waters in the Bering Sea north of Area 4A and the closed area that are east of longitude 171°00' W, south of 58°00' N, and west of 168°00' W.

Area 4D - all waters in the Bering Sea north of Areas 4A and 4B, north and west of Area 4C, and west of 168°00' W.

Area 4E - all waters in the Bering Sea north and east of the closed area, east of Areas 4C and 4D, and south of 65°34' N. Closed area to commercial fishing - All waters in the Bering Sea north of 55°00′00′′ N latitude in Isanotski Strait that are enclosed by a line from Cape Sarichef Light (54°36′00′′ N latitude, 164°55′42′′ W longitude) to a point at 56°20′00′′ N latitude, 168°30′00′′ W longitude; thence to a point at 58°21′25′′ N latitude, 163°00′00′′ W longitude; thence to Strogonof Point (56°53′18′′ N latitude, 158°50′37′′ W longitude); and then along the northern coasts of the Alaska Peninsula

and Unimak Island to the point of origin at Cape Sarichef Light are closed to halibut fishing and no person shall fish for halibut therein or have halibut in his/her possession while in those waters except in the course of a continuous transit across those waters. All waters in Isanotski Strait between 55°00′00′′ N latitude and 54°49′00′′ N latitude are closed to halibut fishing.

Changes to the regulations for 2014

The regulations for the 2014 fishery were adopted at the Commission's 2014 Annual Meeting in Seattle, Washington, and were later approved by the Canadian and the United States governments, with one exception: since 1999, the Canadian government has allowed the landing of live halibut caught in British Columbia waters by choosing not to approve the regulation that required commercially-caught halibut to have their gills and entrails removed before being offloaded from a vessel.

Seasons

At the 2014 Annual Meeting, the Commission continued its discussions on season length and received recommendations to open the fishery on a Saturday to facilitate marketing. The Canadian Individual Vessel Quota (IVQ) fishery in Area 2B and the United States Individual Fishing Quota (IFQ) and Community Development Quota (CDQ) fisheries in Areas 2C, 3A, 3B, 4A, 4B, 4C, 4D, and 4E commenced at 12 noon local time on March 8 and closed at 12 noon local time on November 7. The Area 2A commercial fisheries, including the treaty Indian commercial fisheries, were required to occur during the same calendar period (March 8 to November 7).

For Area 2A, seven potential 10-hour fishing periods for the non-treaty directed commercial fishery were adopted: June 25, July 9, July 23, August 6, August 20, September 3, and September 17, 2014. All fishing periods were to begin at 8:00 AM and end at 6:00 PM local time, were further restricted by fishing period limits, and would apply only until the commercial allocation was estimated to have been reached.

Catch limits and licensing

The Commission adopts catch limits for all individual regulatory areas and for Areas 4CDE combined (Tables 1 - 4). Catch Sharing Plans (CSP) allocate catch limits by user groups in Areas 2A, 2B, 2C, and 3A and within areas for Area 4CDE; the following paragraphs provide information by area. For information on the sport fisheries and regulations see the report titled 2014 halibut sport fishery review (Kaimmer 2015).

The Commission determines the total allowable combined catch for all user groups in Area 2A, and the Pacific Fishery Management Council's (PFMC) CSP allocates halibut catch limits among user groups. The PFMC CSP stated that a primary limited-entry longline sablefish (*Anoplopoma fimbria*) fishery north of Point Chehalis, Washington (46°53'18"N) would be allocated part of the Washington sport allocation poundage, provided that the Area 2A total catch limit was over 900,000 pounds and the amount available to the incidental fishery was over 10,000 pounds. These parameters were met for the third time since 2009, and an incidental halibut fishery during the limited-entry sablefish fishery occurred in 2014. The 2014 Area 2A fisheries included: two treaty Indian fisheries (a ceremonial and subsistence use fishery with a catch limit of 28,500 pounds, and a commercial fishery with a catch limit of 307,500 pounds); three non-treaty commercial fisheries,

with 168,137 pounds allocated to the directed fishery, 29,671 pounds to the incidental halibut fishery during the salmon troll season, and 14,274 pounds to the incidenta1 halibut fishery during the limited-entry sablefish fishery; and two sport fishery catch limits (Washington and Oregon/ California). The total 2014 Area 2A catch (not including IPHC research) of 948,500 pounds was within 1% of the catch limit (Table 1).

Part of the Area 2A licensing regulations for non-treaty fisheries remained the same as in 2013: all vessels required an IPHC license, fishers were required to choose one license type, and the commercial fisheries license applications had a deadline date. Two changes to the 2A licensing regulations were made in 2014. The license application deadline dates for the incidental halibut in the salmon troll and the sablefish fisheries were changed to March 15 in 2014 from March 31 in past years. The deadline date for the directed commercial fishery remained the same (April 30). The second change is that each commercial fishery had a unique license, whereas in the past, there was only one license for vessels that participated in both the directed commercial and the incidental halibut in the sablefish fisheries.

The IPHC adopted an Area 2B combined sport and commercial catch limit of 6,850,000 pounds that was allocated by the Canadian Department of Fisheries and Oceans (DFO) by a ratio of 85% commercial to 15% sport (Table 2). The 6,850,000 pound combined catch limit was arrived at after 200,000 pounds of commercial wastage for halibut over 26 inches had been deducted from the Area 2B constant exploitation yield, with no sport fishery wastage or mortality estimates available at this time. DFO added back the previously deducted wastage (200,000 pounds) and partitioned this new total by the 85%/15% allocation. The commercial wastage amount was then deducted solely from the commercial portion. The newly calculated catch limits allocated to the commercial and sport fleets were 5,792,500 pounds and 1,057,500 pounds, respectively. DFO made additional adjustments to the quotas, which included pounds available from the underage/overage plan, quota leased from the commercial fishery to the sport fishery, and quota held for First Nations, and for Use of Fish allocation. The total 2014 Area 2B commercial catch of 6,691,000 million pounds was under the catch limit (6,850,000 pounds) by 2% (Table 2).

For the first time, the North Pacific Fishery Management Council (NPFMC) recommended a CSP for Areas 2C and 3A that included the commercial and sport charter fisheries. Consequently, the Commission's adopted catch limits for Areas 2C and 3A included the commercial and charter fishery catch limit, plus discard and lost gear mortality estimates. In both areas, to maintain the sport charter catch within the catch limit, daily bag limits and length restrictions were recommended by the NPFMC and adopted by IPHC as IPHC regulations (Kaimmer 2015). The removals accounted for in the CSP were over the catch limits in Areas 2C and 3A by 3% and 5%, respectively (Table 3).

The individual catch limits adopted for Regulatory Areas 4C, 4D, and 4E are determined by a NPFMC CSP. The NPFMC CSP and IPHC regulations allowed Area 4D CDQ to be harvested in Areas 4D or 4E, and Area 4C IFQ and CDQ to be harvested in Areas 4C or 4D. These commercial fisheries are discussed in the section below.

Commercial catch and fishery landing patterns

Commercial catch (including IPHC research catch) and catch limits by regulatory area for the 2014 fishing season are shown in Table 4. Commercial catch limit, as referred to here, is the IPHC commercial catch limit set by the Commissioners at the Annual Meeting. The adjusted commercial catch limit represents the IPHC catch limit with adjustments from the underage

and overage programs from the previous year's quota share programs, and in Area 2B, it also includes relinquishment of quota and quota leasing programs among sectors and the Use of Fish allocation. Historical catches and catch limits from 2005 through 2014 are shown in Table 5. The following sections review commercial catch, seasons, and trends for each area. The data sources were the IPHC, National Marine Fisheries Service (NMFS), DFO, Metlakatla Indian Community, Washington treaty Indian tribal fisheries management departments including the Northwest Indian Fisheries Commission, Makah, Lummi, Jamestown, Swinomish, Port Gamble, Quileute and Quinault Indian tribes, and state agencies including Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), and California Department of Fish and Wildlife (CDFW).

Area 2A

In 2014, IPHC issued 724 Area 2A vessel licenses, including 133 licenses for sport charter vessels, 424 licenses for retaining incidental halibut during the salmon troll fishery, 162 licenses for the directed commercial fishery, and 29 licenses for incidental halibut during the sablefish fishery (of which 24 vessel received licenses for both the directed commercial and incidental halibut during the sablefish fishery). The largest change in number of licenses issued compared to 2013 was for the incidental halibut during the salmon troll fishery which increased by 91 licenses. The number of licenses issued for the directed commercial fishery and incidental halibut during the sablefish fishery increased by 18 while the number for the sport charter fishery increased by six.

The Area 2A directed commercial fishery closed after two 10-hour openings with fishing period limits (Table 6). The fishing period limits were assigned by vessel class; the H-class vessels received 9,000 pounds for the June 25 opening and 2,000 pounds for the July 9 opening (Table 5). The total directed commercial catch of 163,000 pounds was 3% under the catch limit (168,137 pounds). The remaining 4,000 pounds were made available to the incidental fishery during the salmon season as stipulated in the CSP.

The allowable incidental catch ratio of halibut during the salmon troll fishery, at the start of the season on April 1, was one halibut per four Chinook (*Oncorhynchus tsawytscha)*, plus an "extra" halibut per landing, and a vessel trip limit of 12 fish. The landing restrictions were changed to one halibut per trip, effective at 1201 AM North of Falcon, Oregon and 1159 PM South of Falcon, Oregon on May 30. On July 25, the landing restrictions were increased to one halibut per four Chinook, plus an "extra" halibut per landings. From July 25 on, the ratio of halibut per salmon remained the same with changes in trip maximum including: July 25 trip limit of 3; August 8 trip limit of 7; August 22 trip limit of 3. The numerous changes that occurred in-season were made with the goal of extending the fishing opportunity through the summer. The incidental halibut retention closed on September 11, with a total catch of 34,000 pounds which was 1% over the catch limit including the roll over (33,671 pounds).

Incidental halibut retention during the limited-entry sablefish fishery remained open from April 1 to October 31, closing at the end of the sablefish fishery season. The allowable landing ratio was 75 pounds (net weight) of halibut to 1,000 pounds (net weight) of sablefish, and up to two additional halibut in excess of the ratio limit. The 2014 landing restrictions are the same as the landing restrictions for 2013 and are less conservative than the 2012 requirements of 50 pounds of halibut to 1,000 pounds of sablefish, plus two additional halibut in excess of the ratio limit. The total catch of 12,000 pounds was 15% under the catch limit (14,274 pounds).

In Area 2A-1 (north of Point Chelalis) the treaty Indian tribes manage the commercial catch by allocating 75% to an open access fishery and 25% to a restricted fishery with daily and vessel limits. There was one unrestricted, open access fishery from March 11-13; two restricted fisheries, including vessel per day limits of 500 pounds for the March 20-21 opening and a 400 pound vessel and trip limit on the 10-hour May 8 opening. The 2014 tribal commercial season closed to all parties on May 9, 2014 with a total catch of 309,000 pounds, less than 1% over the catch limit (307,500 pounds).

Area 2C Metlakatla fishery

The Metlakatla Indian Community was authorized by the United States government to conduct a commercial halibut fishery within the Annette Islands Reserve. There were 13 two-day openings between April 17 and October 5 for a total catch of 79,800 pounds (Table 7). This was 25,300 pounds higher than the 2013 catch, and within the historical catch range that has varied over time from a low of 12,000 pounds in 1998 to a high of 126,000 pounds in 1996.

The Quota Share fisheries

The Quota Share (QS) fisheries of British Columbia (Area 2B) and Alaska (Areas 2C, 3, and 4) were open from March 8 to November 7. The following section discusses the fisheries by area.

Area 2B

Each vessel was allocated a fixed poundage of halibut, or an IVQ, as calculated by DFO. In 1991, when the halibut IVQ program was implemented, 435 vessels received IVQs. Each initial IVQ was split into two shares called blocks. Numerous changes have been made since then, including first allowing temporary block transfers (1993) and then permanent block and IVQ transfers (1999). Since 1999, the number of active halibut licenses (L licenses), and First Nations communal commercial licenses (FL licenses), has decreased from a high of 257 (in 1999) to a low of 146 in 2014; the previous low occurred in 2011 with 148 active halibut licenses. In addition, halibut can be landed as incidental catch in other licensed groundish fisheries. Therefore, halibut was landed from a total of 222 active licenses in 2014, with 76 of these licenses from other fisheries. This is a decrease from 236 active licenses in 2013.

The Groundfish Integrated Fisheries Management Plan (IFMP) has been in effect in British Columbia since 2006. The IFMP was implemented to meet conservation needs, including addressing rockfish conservation concerns and improving catch monitoring. The IFMP includes quota shares for all hook and line groundfish fisheries, transferability with limits between license holders, 100% at-sea and dockside monitoring, and vessel accountability for all catch, both landed and discarded. There is 100% monitoring through logbook recordings, video camera coverage, and dockside monitoring.

The 2014 commercial catch of 5,776,000 pounds was less than 1% under the catch limit (5,792,500 pounds; Table 2).

Alaska

The IFQ halibut and sablefish fisheries have been in effect in Alaska since 1995. NMFS Restricted Access Management (RAM) allocated halibut QS to recipients by IPHC Regulatory Area. Quota share transfers were permitted with restrictions on the amount of QS a person could hold and the amount that could be fished per vessel. As of November 19, 2014, RAM reported that 2,471 persons held quota shares, down from the initial 4,831 persons at the start of the program.

The total 2014 catch from the IFQ/CDQ halibut fishery for the waters off Alaska was 16,627,000 pounds, less than 1% under the catch limit (Table 4). For comparison, the 2013 commercial catch was 5% under the catch limit. For Areas 2C and 3B, the commercial QS catches were under the catch limits by less than 1%. For Area 3A, the catch was less than 1% over the catch limit and yet under the adjusted catch limit by 2%. For Areas 4A, and 4B, the catches were 3%, and 4% under the catch limits, respectively. As mentioned previously, the NPFMC CSP allowed Area 4D CDQ to be harvested in Areas 4D or 4E and Area 4C IFQ and CDQ to be fished in Areas 4C or 4D. These two regulations were the reason the catches in Areas 4D and 4E exceeded the catch limits. The total combined Area 4CDE commercial catch of 1,245,000 pounds was 3% under the combined Area 4CDE catch limit (1,285,000 pounds).

Landing patterns and highlights

Commercial trips from Area 2B were delivered into 12 different ports in 2014. The ports of Port Hardy (including Coal Harbour and Port McNeill) and Prince Rupert/Port Edward were the major landing locations, receiving 89% of the Area 2B commercial catch. Prince Rupert and Port Hardy each received 44% (2,570,000 and 2,546,000 pounds, respectively) of the Area 2B commercial catch. Ucluelet and Vancouver received the third largest landing volumes (231,000 and 217,000 pounds), both representing 4% of the Area 2B commercial catch. In the past, Vancouver had received the third largest landing volume; however, landings into that port decreased by 48% from 2012 to 2013, and have remained low in 2014. All of the IVQ catch was landed in Area 2B.

Homer and Kodiak each received approximately 17% (2,762,000 pounds) and 15% (2,515,000 pounds) of the commercial Alaskan catch, respectively. Landed pounds for these two ports were closer than in 2013 (20% and 15% respectively). Seward received the third largest landing volume (1,754,000 pounds) at 11% of the Alaskan commercial catch. In SE Alaska, the three largest landing volumes were received in Sitka, Petersburg, and Juneau, in that order, and their combined landings represented 19% of the commercial Alaskan catch. Pounds landed in these ports are not listed due to confidentiality of the data. The Alaskan QS catch that was landed outside of Alaska was 3 %.

The 2014 QS fishery landings were spread over eight months of the year (Table 8). On a month-to-month comparison, March took the lead as the busiest month for total poundage (15%) landed from Area 2B. Prior to 2011, the Area 2B catch was landed earlier in the season in British Columbia with 49% landed by the end of May in 2010, compared to only 41% in 2014. On a month-to-month comparison, May was the busiest month for total poundage (19%) from Alaska, as it was in 2013. In 2012, August was the busiest month for total poundage from Alaska, but ranked second for 2014 landings.

The 2014 landing of live halibut from Area 2B was legally allowed by DFO and resulted in a total landed weight of 2,913 pounds; this is slightly down from 3,643 pounds in 2013. Live landings of halibut have ranged from a high of 103,000 pounds in 1999 to a low of 1,026 pounds in 2011.

References

Kaimmer, S. 2015. 2014 halibut sport fishery review. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 37-46.

Table 1. The Area 2A 2014 catch limits allocated by the Pacific Fishery Management Council Catch Sharing Plan and preliminary catch estimates (net weight).

Area	Catch Limit	Catch
Non-treaty directed commercial	168,137	163,000
Non-treaty incidental commercial with salmon troll fishery	29,671[1]	34,000
Non-treaty incidental commercial with sablefish fishery	14,274	12,000
Treaty Indian commercial	307,500	309,000
Treaty Indian ceremonial and subsistence	28,500	28,500[2]
Sport fisheries	411,918	402,000
Total allocation and catch	960,000	948,500
IPHC research catch		21,000
Total	960,000	969,500

[1] Does not include 4,000 pound roll-over from the directed commercial fishery after it closed as allowed in Catch Sharing Plan.
[2] Ceremonial and subsistence allocation amount.

Table 2. The 2014 Area 2B catch limits as allocated by the Canadian Department of Fisheries and Oceans and estimated catches (thousands of pounds, net weight).

Fishery	Allocation	Catch
Commercial fishery	5,793	5,776
Sport fishery[1]	1,057	915
Total allocation and catch	6,850	6,691
IPHC research catch		106
Total	6,850[2]	6,797

[1] An experimental permit program allowed sport operators to lease quota from commercial operators. A total of 2,900 pounds were leased from commercial quota holders in 2014.
[2] The total allocation does not include adjustments totaling -121,100 pounds made to the commercial fishery catch limit which included carryover from the previous year's underage/overage plan, quota held by DFO for First Nations through relinquishment processes, and the Use of Fish allocation.

Table 3. Areas 2C and 3A catch limits, including incidental mortality, as allocated by the North Pacific Fishery Management Council Catch Sharing Plan and estimated landings, incidental mortality, and total pounds (thousand, net weight).

Area 2C	**Allocation[1]**	**Catch + Incidental Mortality=total**
Commercial fishery	3,399	3,295 + 110 = 3,405
Guided sport fishery	761	825 + 48 = 867
Total allocation and catch	4,160[2]	4,272
IPHC research		146
Total		**4,413**
Area 3A	**Allocation[1]**	**Catch**
Commercial fishery	7,648	7,347 + 410 = 7,757
Guided sport fishery	1,782	2,139 + 44 = 2,183
Total allocation and catch	9,430[2]	9,940
IPHC research		278
Total		**10,218**

[1] The combined total includes estimated mortality from regulatory discards of sublegal halibut and lost gear in the commercial fishery, plus discard mortality in the guided sport fishery, as mandated in the U.S. Catch Sharing Plan.
[2] This does not include adjustments, made to the commercial fishery catch limit as a result of the carryover from the previous year's underage/overage plan or the guided angler fishing program allowing sport quided operators ot lease quota from commercial operators.

Table 4. Commercial fishing periods, number of fishing days, catch limit, commercial, research and total catch (thousands of pounds, net weight) by regulatory area for the 2014 Pacific halibut commercial fishery (preliminary, as of November 11, 2014).

Area 2A	Fishing Period	Catch Limit	Length of Opening	Commercial Catch	Research Catch	Total Catch
Treaty Indian	Unrestricted:					
	3/11–13		48 hours	227		227
	Restricted:					
	3/20-21; 5/8		30 hours	59		59
	Late Season:					
	5/8		10 hours	23		23
Total		307.5				309
Incidental in Salmon Fishery	4/1 – 9/11	29.7[1]	163 days	34		34
Incidental in Sablefish Fishery	4/1 – 10/31	14.3	184 days	12		12
Directed[2]	6/25		10-hours	133		
	7/9		10-hours	30		
Directed Total		168.1		163		163
2A Total		519.6		518	21	539
Area	**Fishing Period**	**Catch Limit**	**Adjusted Catch Limit[3,4]**	**Commercial Catch**	**Research Catch**	**Total Catch[4]**
2B	3/8 – 11/7	5,793	5,671	5,776[5]	106	5,882
2C	3/8 – 11/7	3,319	3,368	3,295[6]	146	3,441
3A	3/8 – 11/7	7,318	7,526	7,347	278	7,625
3B	3/8 – 11/7	2,840	2,937	2,824	101	2,925
4A	3/8 – 11/7	850	885	827	73	900
4B	3/8 – 11/7	1,140	1,195	1,089	28	1,117
4C	3/8 – 11/7	596.6	619	397	5	402
4D	3/8 – 11/7	596.6	611	696[7,8]	8	704
4E	3/8 – 11/7	91.8	92	152[8]	0	152
Alaska Total		16,751.0	17,233	16,627	639	17,266
Grand Total		23,063.6	23,424[9]	22,921	766	23,687

[1]Does not include 4,000 pound roll-over from the directed commercial fishery.
[2]Fishing period limits by vessel class.
[3]Includes adjustments from the underage/overage programs, and in 2B, quota held by DFO for First Nations through relinquishment processes, and the Use of Fish allocation.
[4]Includes pounds from Nov. 11, 2014 Prior Notice of Landings in Alaska & hail-ins from Fishery Operations System in B.C.
[5]Includes the pounds that were landed by Native communal commercial licenses (FL licenses).
[6]Includes the pounds taken in the Metlakatla fishery within the Annette Island Reserve.
[7]Area 4C IFQ and CDQ could be fished in Area 4D by NMFS and IPHC regulations.
[8]Area 4D CDQ could be fished in Area 4E by NMFS and IPHC regulations.
[9]Includes Area 2A catch limit.

Table 5. Commercial catch (including IPHC research catch) and catch limits of Pacific halibut (in thousands of pounds, net weight) by IPHC regulatory area, 2005 - 2014.

Regulatory Area	Commercial Catch[1]									
	2005	2006	2007	2008	2009	2010	2011	2012	2013[2]	2014[3]
2A[4]	803	829	789	682	490	418	541	573	542	539
2B	12,331	12,005	9,772	7,756	6,637	6,729	6,692	5,983	6,043	5,882
2C	10,625	10,492	8,473	6,206	4,955	4,486	2,454	2,694	3,033	3,441
3A	26,033	25,714	26,493	24,521	21,755	20,502	14,669	12,032	11,077	7,625
3B	13,171	10,792	9,249	19,748	10,781	10,114	7,321	5,045	4,091	2,925
4A	3,404	3,332	2,828	3,015	2,528	2,325	2,351	1,583	1,233	900
4B	1,975	1,590	1,416	1,763	1,593	1,829	2,054	1,738	1,253	1,117
4C[5]	534	493	551	724	645	789	790	563	512	402
4D[5,6]	2,578	2,368	2,720	2,552	2,210	2,116	2,182	1,431	979	704
4E[6,7]	369	366[7]	579	600	455	410	457	347	280[7]	152
Total	71,823	67,981	62,870	58,567	52,049	49,718	39,511	31,989	29,043	23,687
Regulatory Area	Commercial Catch Limits[8]									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A[4]	788.6	818.5	799.2	718.4	511.2	420.0	480.7	546.6	539.7	519.6
2B	11,658.0	11,631.0	10,089.4	7,918	6,711.6	6,598.6	6,702.2	5,953.4	5,958	5,793
2C	10,930.0	10,630.0	8,510.0	6,210.0	5,020.0	4,400.0	2,330.0	2,624.0	2,970	3,319
3A	25,470.0	25,200.0	26,200.0	24,220.0	21,700.0	19,990.0	14,360.0	11,918.0	11,030	7,318
3B	13,150.0	10,860.0	9,220.0	10,900.0	10,900.0	9,900.0	7,510.0	5,070.0	4,290	2,840
4A	3,440.0	3,350.0	2,890.0	3,100.0	2,550.0	2,330.0	2,410.0	1,567.0	1,330	850
4B	2,260.0	1,670.0	1,440.0	1,860.0	1,870.0	2,160.0	2,180.0	1,869.0	1,450	1,140
4C	1,815.0	1,610.0	1,866.5	1,769.0	1,569.0	1,625.0	1,690.0	1,107.0	859	596
4D	1,815.0	1,610.0	1,866.5	1,769.0	1,569.0	1,625.0	1,690.0	1,107.0	859	596
4E	359.0	330.0	367.0	352.0	322.0	330.0	340.0	250.0	212	92
Total	71,685.6	67,709.5	63,248.6	58,816.4	52,722.8	49,378.6	39,692.9	32,012.0	29,497.7	23,063.6

[1] Commercial catch includes IPHC research catch and, in Area 2C, the Metlakatla fishery catch.
[2] Poundage figures have been updated from previous publications.
[3] Preliminary (as of November 11, 2014).
[4] Does not include treaty Indian ceremonial and subsistence fish.
[5] Area 4C IFQ and CDQ could be fished in Area 4D (since 2005).
[6] Area 4D CDQ could be fished in Area 4E.
[7] Area 4E includes research catch in the IPHC Closed Area.
[8] Additional carryover from the underage/overage plans is not included.

Table 6. The fishing period limit (pounds, net weight) by vessel class used in the 2014 directed commercial fishery in Area 2A.

Vessel Class		Fishing Period & Limits	
Letter	**Feet**	**June 25**	**July 9**
A	0-25	755	200
B	26-30	945	210
C	31-35	1,510	335
D	36-40	4,165	925
E	42-45	4,480	995
F	46-50	5,365	1,190
G	51-55	5,985	1,330
H	56+	9,000	2,000

Table 7. Metlakatla community fishing periods, number of vessels, and preliminary halibut catch (net weight), 2014.

Fishing Period Dates	Number of Vessels	Catch (Pounds)
April 17 – 19	7	2,871
May 2 – 4	16	6,142
May 16 – 18	14	6,456
May 30 – June 1	13	6,315
June 13 – 15	12	6,200
June 27 – 29	14	10,207
July 11 – 13	13	10,623
July 25 – 27	9	6,265
August 8 – 10	10	7,059
August 22 – 24	15	9,971
September 5 – 7	14	6,290
September 17 – 19	5	955
October 3 – 5	2	465
13 Fishing Periods		79,819

Table 8. The total pounds (thousands, net weight, preliminary) of 2014 commercial landings (not including research catch) of Pacific halibut for Alaska and British Columbia by regulatory area and month.

Regulatory Area	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
2B[1]	864	798	721	556	731	699	509	735	163	5,776
2C[2]	535	688	539	394	160	365	375	222	17	3,295
3A[2]	757	1,333	1,728	687	448	1,043	862	448	41	7,347
3B[2]	50	209	431	399	342	689	395	244	65	2,824
4A[2]			148	153	91	246	131	58[4]		827
4B[2]			162[3]	200	290	222	150	65[4]		1,089
4CDE[2]			211	228	410	232	139	25[4]		1,245
Alaska Total	1,342	2,230	3,219	2,061	1,741	2,797	2,052	1,062	123	16,627
Total	2,206	3,028	3,940	2,617	2,472	3,496	2,561	1,797	286	22,403

[1] Based on landings from DFO Fishery Operations System (FOS).
[2] Based on landings from NMFS Restricted Access Management (RAM) Division.
[3] Weight combined with the previous months for confidentiality purposes.
[4] Weight combined with the following month for confidentiality purposes.

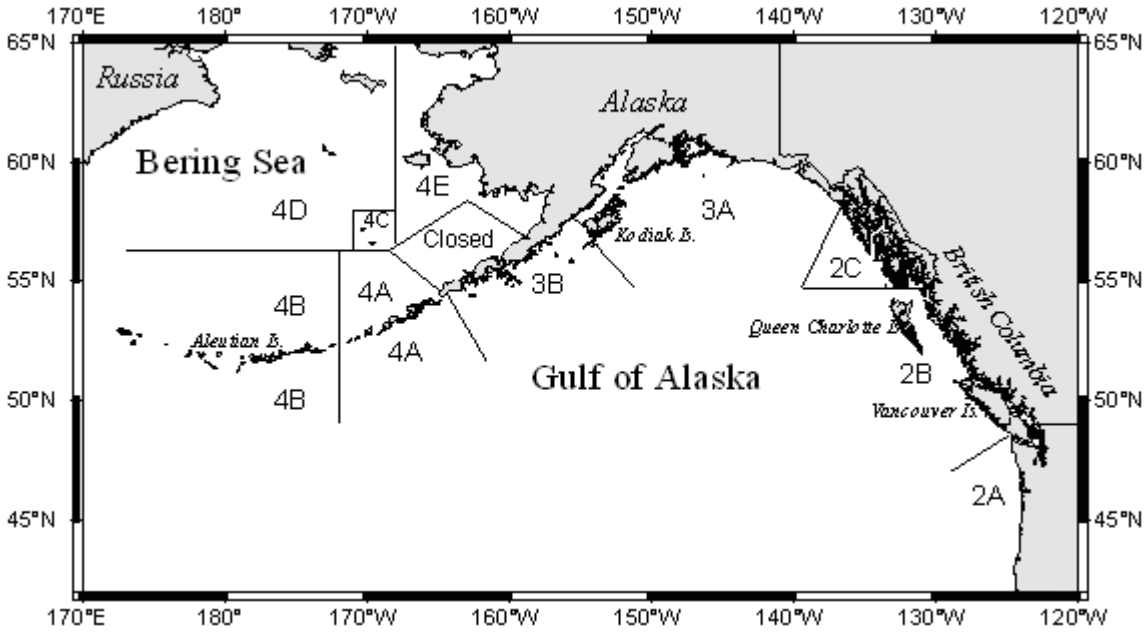


Figure 1. IPHC regulatory areas for the 2014 fishery.

2014 halibut sport fishery review

Steve Kaimmer

Abstract

The 2014 sport harvest of Pacific halibut was estimated at 6.903 Mlbs, a 7.2% decrease from 2013 and substantially below the 10.7 Mlb average of 2004-2008. The northern California region was separated from the southern Oregon area by the Pacific Fishery Management Council so that it could receive its own catch limit. Changes in harvests varied across areas; in some cases, in response to changes in size restrictions. A major change in both Areas 2C and 3A was the implementation of a catch limit for the charter fisheries through a catch sharing plan. A reverse slot limit allowing for the retention of halibut, if ≤45 inches or ≥76 inches (increased from 68 inches in 2013) in total length, was continued by the International Pacific Halibut Commission for the charter fishery in Area 2C. In Area 3A, charter anglers were allowed to retain two fish, but only one could exceed 29 inches in length. Alaska initiated a Guided Angler Fish program which allows charter operators to purchase commercial halibut quota, which can then be used to retain a larger second fish in Areas 2C and 3A. In another change, the Canadian Department of Fisheries and Oceans continued a set of size and annual bag limit restrictions to constrain the sport harvest in Area 2B to the fishery allocation. Major sport fishery restrictions, such as daily bag and possession limits, for other areas and sectors remained unchanged from 2013.

Introduction

The International Pacific Halibut Commission (IPHC) depends on state and federal agencies for estimates of Pacific halibut sport fishery harvests. Management and data collection methods vary by area. For the sport fishery in Area 2A, dockside sampling by state agencies supplies information for catch estimation needed for in-season management and post-season harvest estimation. Harvest estimates for the Canadian sport fishery are based on a combination of self-reporting by some lodges, overflights conducted by the Canadian Department of Fisheries and Oceans (DFO), lodge logbooks, and creel monitoring programs conducted by DFO or First Nations. For the Alaska sport fishery, different methodologies are used for estimating harvests in the current year versus the previous year, and also between the unguided (private) and guided (charter) fisheries. Charter vessel operators are required to record client catches in a daily logbook to assist in providing timely catch estimates. In addition, a sample of licensed anglers receives a post-season mail survey, administered by the Alaska Department of Fish and Game (ADF&G), for estimating sport fishery harvests of all species, including halibut. Data on the size of halibut caught are collected through an ADF&G dockside creel sampling program in major ports, which excludes many lodges in Area 2C due to the remoteness of their locations.

Preliminary coast-wide sport harvest estimates for 2014 indicate a decrease (7.2%) from the sport harvest in 2013, to 6.90 Mlbs (Table 1). Coastwide harvest remains below the historic high levels seen during 2004-2008. Harvests in Areas 2B, 3B, and 4 increased, whereas decreases were observed in Areas 2A, 2C, and 3A. Harvests in Area 2B and by the Area 2C and 3A guided fishery were managed with size limit restrictions in 2014, which will be described in subsequent sections.

Daily bag and possession limit regulations were unchanged from 2013 for all other areas. Initial season length extended through December 31 for the Alaskan and Canadian sport fishery (Table 2). Season length within the Area 2A sport fishery varied by sport fishery management subarea.

Area 2A – US West Coast

The 2013 Area 2A sport allocation was 411,917 pounds, based on the Pacific Fishery Management Council (PFMC) Catch Sharing Plan formula which divides the overall fishery catch limit among all sectors. The sport allocation was further subdivided to seven subareas, resulting in 208,162 pounds to Washington subareas, 185,820 pounds to Oregon subareas, and 11,895 pounds shared in the Columbia region. In addition, California was given an allocation of 6,240 pounds. The Area 2A harvest totaled 402,334 pounds, or 9,583 pounds (2.3%) under the sport allocation, with the harvest in the Washington coast subareas above their respective allocations and in the Oregon subareas below their allocations. Allocations and preliminary catch estimates for each subarea are shown in Table 3.

Fishery harvest trends in 2014 generally followed those observed in previous years. The Washington Inside Waters (i.e., Puget Sound) fishery operated on a fixed season, with the season length based on catch rates from previous years. The 2014 season was open for only 11 days. The Washington North Coast fishery was even shorter, lasting just four days, with 103.7% of the subarea's allocation caught. In the Washington South Coast subarea, the primary fishery lasted just five days during May. The nearshore fishery was allowed only in waters east of a line approximating the 30 fathom depth contour, and was open for just 13 days. In the Columbia River subarea fishery about two thirds of the subarea allocation was caught. The Central Oregon subarea had fishery openings in May, June, and August totaling 16 days in the all-depth fishery and 104 days in the <40-fathoms fishery. The total subarea harvest was 7.7% under the allocation of 179,208 lbs. Harvest for the South of Humbug subarea was 4.8% under the 6,412 pound allocation. Harvest in the newly formed California area will not be known until estimates of the harvest from California are available. As in past years, effort for halibut in all Area 2A subareas was heavily dependent upon the availability of other fishing opportunities, especially for salmon and albacore (*Thunnus alalunga*). This year was noted as an especially good salmon year for recreational anglers.

Area 2B – British Columbia

DFO estimates harvest from a mix of data sources which differ by area and year. Aircraft overflights, on-water vessel counts, creel sampling, and lodge logbooks provide effort data. Piece counts are estimated from lodge logbooks, and creel sampling by DFO and the Haida Fisheries Program. Halibut weight data, when collected, come from the creel programs or from the self-reported lodge logbooks. The lodge data are largely un-validated.

The Area 2B sport fishery had an allocation of 1.057 million pounds in 2014, which was 15% of the total catch limit for the area adopted by IPHC after adjustments for commercial wastage. This reflected a revised allocation plan announced by DFO in February 2012, which allocated 85% of the fishery catch limit to the commercial fishery, and 15% to the sport fishery; the previous split was 88% commercial and12% sport. DFO implemented several restrictions in 2014 to slow the pace of the harvest and lengthen the season within the constraints of the allocation. A length restriction was enacted, effective on April 1, which stated that the one fish allowed in the daily limit must not be larger than 133 cm in total length (increased from 126 cm in 2013). In addition, the possession

limit for halibut is two, of which one must be smaller than 90 cm (increased from the 83 cm in 2013). DFO also continued an annual limit of six fish per angler. Lastly, there was a prohibition on halibut retention in DFO Area 121 seaward from 12 nm. DFO reported a preliminary harvest estimate of 915,000 pounds which will be used until final data from DFO become available.

Sport fishing was also allowed under conditions of an experimental DFO program which allowed commercial quota to be leased to sport fishers. No information on the number of licenses or harvest taken in this program was available at time of writing.

Areas 2C, 3A, and 4 – Alaska

Management of the guided fishery in 2014 was conducted with a catch sharing plan for the guided sport (charter) and commercial fisheries for Pacific halibut in waters of IPHC Regulatory Areas 2C and 3A. These limits now include catches as well as mortality associated with fishery discards. This catch sharing plan replaced the Guideline Harvest Level program, defining an annual process for allocating halibut between the charter and commercial fisheries in Area 2C and Area 3A, and establishing allocations for each fishery.

IPHC implemented a U45O76[1] reverse slot limit (RSL) for managing the 2014 guided fishery in Area 2C, based on a recommendation by the NPFMC. This management restriction was developed for the 2013 fishery, through a series of meetings by charter operators and lodge owners. For 2014 management, ADF&G analyzed several options which had been proposed by a committee of charter operators and the committee recommended modifying with the U45O68 RSL used in 2013 to the U45O76 for 2014. In Area 3A, guided anglers had a two fish daily bag limit but only one fish could be greater than 29 inches.

A Guided Angler Fish (GAF) program is new for 2014. Charter vessel operators who choose to participate in the GAF program may offer their clients the opportunity to harvest up to two halibut of any size per day. Effective January 13, 2014 the halibut Catch Sharing Plan (CSP) authorizes annual transfers of commercial halibut IFQ as guided angler fish (GAF) to charter halibut permit holders for harvest in the charter halibut fishery. GAF offers charter halibut permit holders in Area 2C or Area 3A an opportunity to lease a limited amount of IFQ from commercial quota share (QS) holders to allow charter clients to harvest halibut in addition to, or instead of, the halibut harvested under the daily bag limit for charter anglers. Charter anglers using GAF are subject to the harvest limits in place for unguided sport anglers in that area. Currently, there is a two-fish of any size daily bag limit for unguided sport anglers in Areas 2C and 3A. GAF harvested in the charter halibut fishery will be accounted for as commercial halibut IFQ harvest.

A summary of the major sport fishery regulations is shown in Table 4.

ADF&G provides harvest estimates for the Alaska sport fishery. Preliminary estimates of the current year's harvest by the guided and unguided sectors were made using sector-specific approaches because of the influence of management restrictions, which differ between sectors, on the projections. Changes in guided fishery bag limit regulations in recent years led ADF&G to project the 2014 Area 2C and 3A harvest (numbers of fish) using a regression of final Statewide Harvest Survey (SWHS) estimates on logbook data through July 31 for the years 2006-2013. Projections for the unguided fishery are made from several time series methods. For both sectors,

[1]Specifically, the U45O76 RSL specifies that fish retained by a charter angler in Area 2C must be under 45 inches or over 68 inches in total length.

ADF&G projects the number of fish landed through the aforementioned methods and applies an average weight from current year's dockside sampling. A breakdown of guided (charter) and unguided (private) sector harvests since 2003, along with the estimates for 2014, is shown in Table 5.

For Area 2C, the sport harvest is estimated to have decreased slightly this year, to 1.94 million pounds from 2.12 million pounds in 2013. As was seen in 2013, the harvest by the charter fishery increased, whereas the harvest by the private sector dropped slightly. Charter anglers caught more fish in 2014 (67,942 vs. 52,675 in 2013), and at a smaller average weight of 12.1 lb, compared to 14.5 lb in 2013. In contrast, private anglers caught fewer halibut in 2014 (67,942 vs. 78,078 in 2013) and at about the same average weight (17.37 lb vs. 17.47 lb). The average weight of fish caught in the private sector fishery has been fairly stable since 2009, ranging from 16.2 lb to 17.9 lb. In the charter fishery, the reverse slot restriction has resulted in a significant drop in the average weight, from 26 lb in 2010 (final year of no restrictions on size) to the 14.4 lb previously noted. The 2C charter sector harvested 8% over their quota of 0.761 million pounds in 2014.

The Area 3A sport fishery harvest decrease (9.5%) in 2014 is likely the result of the charter size restriction that one fish must not exceed 29 inches. The change was seen entirely in the charter fishery harvest, while the private sector fishery remained unchanged (Table 5). The number of fish caught by each sector was only somewhat lower in 2014. The average weights observed in both fisheries remained low relative to those noted 10-15 years ago. The daily bag limit remained unchanged at two fish per day for both sectors but charter anglers could only keep one fish over 29 inches. The harvest by the charter sector was 20% over the quota of 1.782 million pounds (Table 5).

Estimates of the harvest in Areas 3B and 4 have been based on the various projection methods of SWHS harvests reported in previous years. ADF&G has no dockside creel sampling in those areas, so IPHC has traditionally estimated the weight of the harvest in those areas by applying the average weight of halibut caught in Kodiak. The estimated 2014 harvests for these areas remained relatively low, at 20,000 pounds in Area 3B and 25,000 pounds in Area 4A. Halibut sport fishing is much less common in the western Gulf of Alaska and Bering Sea due to the relative remoteness of the ports. Since 2005, annual harvests have ranged from 14,000 to 30,000 pounds in Area 3B, and 18,000 to 50,000 pounds in Area 4.

Other sport fishery management issues

Area 2A, South of Humbug subarea

At its November 2013 meeting, the Pacific Fishery Management Council (PFMC) decided to divide the former South of Humbug subarea by establishing a new line at the Oregon/California border, thereby creating new northern California and southern Oregon subareas beginning in 2014, with each subarea receiving a small allocation to pursue their fishery. The northern California subarea was assigned 1% of the nontribal fishery allocation for 2014 and was managed with a fixed season, running from May 1 to October 31, closing for the month of August. The southern Oregon subarea was managed in-season by ODFW on an allocation of 2% of the Central Oregon allocation.

Sport fishery discards

Halibut discarded for any reason suffer some degree of discard mortality. The increasing use of size restrictions, such as reverse slot limits, prompted the IPHC in March 2012 to request

the development of data collection programs, from all agencies involved with management of recreational fisheries for halibut, in order to permit the estimation of discard mortality by these fisheries. Mortality estimations or accounting processes were developed for discards within the recreational fisheries for halibut during 2014. Estimates of sport discard mortality have been received from Alaska, Washington, Oregon, and California.

This is the second year that discard mortality estimates from Alaska have been received. Alaska provided estimates of release mortality in the sport fishery by combining statewide harvest survey (SWHS) derived estimates of the numbers of released fish, assumed mortality rates based on hook type data, and modeling of length distributions to derive estimates of the average weight of released fish. Assumed mortality rates were 5% for Area 3A charter-caught halibut, 6% for Area 2C charter and Area 3A noncharter, and 7% for Area 2C non-charter halibut. They were derived by assuming a 3.5% mortality rate for halibut released on circle hooks and a 10% mortality rate for halibut released on all other hook types. In 2013, release mortality accounted for about 3% of total sport removals in Area 2C and about 2% in Area 3A. These same rates were applied in 2014, with a rate of 6% assumed for Areas 3B and 4, in which no data on hook type were collected. Preliminary estimates of release mortality for 2014 were similar in magnitude to 2013. For 2014, total sport removals were 2.011 Mlb in Area 2C and 3.674 Mlb in Area 3A. Release mortality accounted for 3.6% of Area 2C removals and 2.3% of Area 3A removals in 2014.

The DFO did not provide an estimate of release mortality for British Columbia, so a conservative estimate of 34,000 pounds discard mortality was applied, based on their sport fish numbers and the discard mortalities estimated for Area 2C.

The WDFW applied a 7.0% discard mortality rate to halibut discards, following the procedures of the PFMC's Groundfish Management Team. By applying the 7% discard mortality rate to the proportion of released fish in the coastal subareas, WDFW estimates that approximately 150 halibut, or 1.46% of the total coastal catch, are discarded dead. In Puget Sound, applying this same formula to recent catches results in an additional mortality of about 55 halibut, for a total of 205 halibut, or 1.56% of the total statewide recreational halibut catch.

Oregon uses the Oregon Ocean Recreational Boater Survey to estimate numbers of halibut released in recreational fisheries. Using a procedure similar to that developed in Alaska for average weight and discard mortality rates ODFW estimates halibut release mortality in 2014 to be 1,636 pounds.

California used data from their California Recreational Fisheries Survey to estimate the weight of halibut discarded dead and alive. They applied a 100% mortality estimate to the fish discarded dead and 7% to other discards. Their time series estimates 128 pounds of discard mortality in 2014.

Table 1. Harvest of Pacific halibut by sport fishers (millions of pounds, net weight) by IPHC regulatory area, 1977-2014. Estimates for 2014 are preliminary.

Year	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4	Total
1977	0.013	0.008	0.072	0.196	-	-	0.289
1978	0.010	0.004	0.082	0.282	-	-	0.378
1979	0.015	0.009	0.174	0.365	-	-	0.563
1980	0.019	0.006	0.332	0.488	-	-	0.845
1981	0.019	0.012	0.318	0.751	-	0.012	1.112
1982	0.050	0.033	0.489	0.716	-	0.011	1.299
1983	0.063	0.052	0.553	0.945	-	0.003	1.616
1984	0.118	0.062	0.621	1.026	-	0.013	1.840
1985	0.193	0.262	0.682	1.210	-	0.008	2.355
1986	0.333	0.186	0.730	1.908	-	0.020	3.177
1987	0.446	0.264	0.780	1.989	-	0.030	3.509
1988	0.249	0.252	1.076	3.264	-	0.036	4.877
1989	0.327	0.318	1.559	3.005	-	0.024	5.233
1990	0.197	0.381	1.330	3.638	-	0.040	5.586
1991	0.158	0.292	1.654	4.264	0.014	0.127	6.509
1992	0.250	0.290	1.668	3.899	0.029	0.043	6.179
1993	0.246	0.328	1.811	5.265	0.018	0.057	7.725
1994	0.186	0.328	2.001	4.487	0.021	0.042	7.065
1995	0.236	0.887	1.751	4.511	0.022	0.055	7.462
1996	0.229	0.887	2.129	4.740	0.021	0.077	8.083
1997	0.355	0.887	2.172	5.514	0.028	0.069	9.025
1998	0.383	0.887	2.501	4.702	0.017	0.096	8.586
1999	0.338	0.859	1.843	4.228	0.017	0.094	7.379
2000	0.344	1.021	2.251	5.305	0.015	0.073	9.009
2001	0.446	1.015	1.923	4.675	0.016	0.029	8.104
2002	0.399	1.260	2.090	4.202	0.013	0.048	8.012
2003	0.404	1.218	2.258	5.427	0.009	0.031	9.347
2004	0.487	1.613	2.937	5.606	0.007	0.053	10.703
2005	0.484	1.841	2.798	5.672	0.014	0.050	10.859
2006	0.516	1.752	2.526	5.337	0.014	0.046	10.191
2007	0.504	1.556	3.049	6.283	0.025	0.044	11.461
2008	0.481	1.536	3.264	5.320	0.026	0.040	10.667
2009	0.490	1.098	2.382	4.758	0.030	0.024	8.782
2010	0.393	1.156	1.971	4.285	0.024	0.016	7.845
2011	0.401	1.220	1.029	4.408	0.014	0.017	7.089
2012	0.455	1.156	1.583	3.626	0.022	0.028	6.870
2013	0.502	0.822	2,123	3.966	0.015	0.009	7.437
2014[a]	0.402	0.915	1.940	3.591	0.019	0.023	6.890
2013-2014 change							
Pounds	-0.1	0.093	-0.183	-0.375	0.004	0.014	-0.547
Percent	-19.92%	11.31%	-8.62%	-9.46%	26.67%	155.56%	-7.36%

[a] Preliminary

Table 2. Summary of the 2014 Pacific halibut sport fishery seasons. No size limits were in effect unless otherwise noted.

Regulatory Area & Region	Fishing Dates	Fishing Days per week	No. of Fishing Days	Daily Bag Limit
Area 2A - Washington, Oregon & California				
WA Inside Waters				
East of Low Point	May 9-10	2 (Fri – Sat)	2	1
	May 17	1 (Sat)	1	1
	May 22-25	4 (Thu – Sun)	4	1
	May 29-31	3 (Thu - Sat)	3	1
	Jun 7	1 (Sat)	1	1
Low Point to Sekiu River	May 22 – 25	4 (Thu – Sun)	4	1
	May 29 – May 31	3 (Thu - Sat)	3	1
	Jun 7	1 (Sat)	1	1
WA North Coast (Sekiu Rvr to Queets Rvr)	May 15, 17	2 (Thu, Sat)	2	1
	May 22, 24	2 (Thu, Sat)	2	1
WA South Coast (Queets Rvr to Leadbetter Pt.)				
All depths	May 1-18	2 (Sun, Tues)	5	1
Northern nearshore	May 5 – 21	7 (Sun-Sat)	13	1
Columbia River (Leadbetter Pt. to Cape Falcon)	May 1 – Aug 3	4 (Thu-Sun)	56	1
	Aug 7-Sep 28	4 (Thu – Sun)	32	1
Nearshore	May 1 – Sep 28	3 (Mon – Wed)	66	1
OR Central Coast (Cape Falcon - Humbug Mtn.)				
All depths	May 8 – Jun 21	3 (Thu – Sat)[a]	12	1
	Aug 1-2, 15-16	2 (Fri – Sat)	4	1
Less than 40 fathoms	Jul 1 – Oct 12	7 (Sun – Sat)	104	1
Southern OR	May 1 – Oct 31	7 (Sun – Sat)	172	1
CA	May 1 – Oct 31[b]	7 (Sun – Sat)	214	1
Area 2B - British Columbia	Apr 1 – Dec 31	7 (Sun – Sat)	292	1-2[c]
Area 2C - Alaska				
Guided anglers	Feb 1 – Dec 31	7 (Sun – Sat)	334	1[d]
Unguided anglers	Feb 1 – Dec 31	7 (Sun – Sat)	334	2
Area 3A - Alaska				
Guided anglers	Feb 1 – Dec 31	7 (Sun – Sat)	334	2[e]
Unguided anglers	Feb 1 – Dec 31	7 (Sun – Sat)	334	2
Areas 3B and 4 - Alaska	Feb 1 – Dec 31	7 (Sun – Sat)	334	2

[a] Fishing was prohibited during May 15-17, 29-31 and June 12-14. [b] Fishing was prohibited during August.
[c] During Feb 1- Mar 31, the daily bag limit was one fish with a maximum length of 126cm. The possession limit was two fish, but only one fish could be greater than 83 cm. For Apr 1 – Aug 30, the daily limit was one fish with a maximum length of 133 cm and a possession limit of two fish, but only one fish could be greater than 90 cm. From Sep 1 – Dec 31, the daily bag limit was raised to two, only one of which could be greater than 90 cm. An annual limit of six fish was also in effect. Fishing was prohibited during the month of August
[d] A reverse slot limit defining retained halibut as ≤45 inches or ≥76 inches in total length was in effect.
[e] Charter anglers may only keep two fish per day but only one fish may be greater than 29 inches.

Table 3. 2014 IPHC Area 2A sport harvest allocations and preliminary catch estimates (pounds, net weight) by subarea.

Area	Allocation	Harvest Estimate	Pct Taken	Pounds Over/(Under)
WA Inside Waters	57,393	57,393	100.0	-
WA North Coast	108,030	112,002	103.7	3,972
WA South Coast	42,739	45,904	107.4	3,165
WA/OR Columbia River	11,895	9,240	77.7	(2,655)
OR Central Coast[1]	179,208	165,450	92.3	(13,758)
OR South of Humbug[1]	6,412	6,105	95.2	(307)
CA[2]	6,240	6,240	100.0	-
Total	**411,917**	**402,334**	**97.7**	**(9,583)**

[1] After closure of Central OR, 2,700 pounds were transferred to the South OR quota. The original Central quota was 181,908. After transfer that became 179,208. The original South OR quota was 3,712. After transfer that became 6,412
[2]A harvest estimate is not yet available so the allocation is shown as the preliminary harvest.

Table 4. Summary of major U.S. federal and state regulations for the charter (guided) sport halibut fishery in IPHC Areas 2C and 3A.

Area 2C

Year(s)	Regulations
1995-2005	Two-fish bag limit (no size restrictions); no prohibition on crew retention.
2006	Two-fish bag limit (no size limit); State of AK Emergency Order (EO) prohibiting crew harvest May 26 – Dec 31.
2007	Two-fish bag limit (one under 32" eff. June 1). No crew retention May 1- Dec 31 (State EO and Federal Rule).
2008	Two-fish bag limit (one under 32"), except one-fish bag limit June 1-10 (halted by injunction).
2009	One fish (no size limit), no harvest by skipper & crew; line limit (effective June 5).
2010	One fish (no size limit), no harvest by skipper & crew; line limit.
2011	One fish bag limit, under 37" fork length. No harvest by skipper & crew; line limit.
2012-2013	One fish bag limit, retainable if length ≤45" or ≥68". No harvest by skipper & crew; line limit.
2014	One fish bag limit, retainable if length ≤44" or ≥76". No harvest by skipper & crew; line limit.

Area 3A

Year(s)	Regulations
1995-2006	Two-fish bag limit (no size restrictions); no prohibition on crew harvest.
2007	Two-fish bag limit (no size restrictions); state EO prohibiting crew harvest May 1-Dec 31.
2008	Two-fish bag limit (no size restrictions); state EO prohibiting crew harvest May 24-Sept 1.
2009	Two-fish bag limit (no size restrictions); state EO prohibiting crew harvest May 23-Sept 1.
2010-2013	Two-fish bag limit (no size restrictions); no prohibition on crew harvest.
2014	Two-fish bag limit, 29-inch maximum size limit on one fish. Charter vessels may only take one trip during which charter vessel anglers retain halibut per day.

Table 5. Estimated harvest by the private (unguided) and charter (guided) sport halibut fisheries (millions of pounds, net weight) in IPHC Areas 2C and 3A. Also shown are the Guideline Harvest Levels (GHLs) applicable to the guided fishery through 2013. In 2014 these were replaced by quotas for the guided harvests. Harvest estimates for 2014 are preliminary.

	Area 2C				Area 3A			
Year	**Private**	**Charter**	**Total**	**GHL[a]**	**Private**	**Charter**	**Total**	**GHL[a]**
2003	0.846	1.412	2.258	1.432	2.046	3.382	5.427	3.650
2004	1.187	1.750	2.937	1.432	1.937	3.668	5.606	3.650
2005	0.845	1.952	2.798	1.432	1.984	3.689	5.672	3.650
2006	0.723	1.804	2.526	1.432	1.674	3.664	5.337	3.650
2007	1.131	1.918	3.049	1.432	2.281	4.002	6.283	3.650
2008	1.265	1.999	3.264	0.931	1.942	3.378	5.320	3.650
2009	1.133	1.249	2.383	0.788	2.023	2.734	4.758	3.650
2010	0.885	1.086	1.971	0.788	1.587	2.698	4.285	3.650
2011	0.685	0.344	1.029	0.788	1.615	2.793	4.408	3.650
2012	0.977	0.605	1.583	0.931	1.341	2.284	3.626	3.103
2013	1.361	0.762	2.123	0.788	1.452	2,514	3.966	2.734
	Private	Charter	Total	Quota[a]	Private	Charter	Total	Quota[a]
2014	1.114	0.825	1.940	0.761[a]	1.452	2.139	3.591	1.782[a]

[a]In 2014, the guideline harvest levels for Areas 2C and 4A were replaced by sector quotas for the guided sport harvests.

Incidental mortality of halibut in the commercial halibut fishery (Wastage)

Heather L. Gilroy and Ian J. Stewart

Abstract

Incidental mortality of Pacific halibut in the commercial halibut fishery includes the mortality of all halibut that do not become part of the landed catch. This mortality is termed wastage in many International Pacific Halibut Commission (IPHC) publications. The three main sources of mortality include: fish that are estimated to die on lost or abandoned fishing gear, 2) fish that are captured and discarded because they are below the legal size limit of 32 inches (U32), and 3) fish that are discarded for regulatory reasons (e.g., the vessels trip limit has been exceeded). The methods that are applied to produce each of these estimates differ due to the amount and quality of information available. Information on lost gear and regulatory discards are collected through logbook interviews and fishing logs received by mail. The ratio of U32 to O32 halibut is determined from the IPHC stock assessment survey or direct observation in the B.C. fishery. Halibut wastage estimates from the commercial halibut fishery are presented, with 2014 data preliminary at this time.

Overview

The removals of Pacific halibut accounted for in the International Pacific Halibut Commission (IPHC) stock assessment include commercial and sport catch, personal use (ceremonial and subsistence), and the incidental mortality of halibut from the commercial halibut fisheries (wastage) and other commercial fisheries (bycatch). Commercial fishery wastage includes 1) halibut that are smaller than the commercial minimum size (≤81.3 cm or <32 inches) that must be released by regulation but subsequently die, 2) fish of all sizes estimated to have been captured by fishing gear that was subsequently lost or abandoned during fishing operations, 3) fish that are discarded for regulatory reasons (e.g., the vessels trip limit has been exceeded). The methods applied to produce each of these estimates differ due to the amount and quality of the information available. The wastage mortality of halibut 26 inches and longer, including O32 halibut and halibut between 26 and 32 inches (U32/026), are directly deducted to determine the fishery CEY; and the mortality of halibut under 26 inches is accounted for in the removals in the stock assessment and in the exploitation rates in the harvest policy. The intent of the division of U26/O26 is to standardize the treatment of removals, given that sport and personal use fishery removals are directly deducted when setting catch limits.

Wastage from discard mortality of U32 halibut

In the directed commercial halibut fishery direct observations by fisheries observers or electronic monitoring information are not available coastwide, so in most areas the weight of discarded U32 halibut must be estimated by indirect methods. In the current B.C. fishery (2006 to the present), fishers are required to record the number of U32 halibut discarded in their logbooks,

and this information is verified for accuracy via electronic monitoring (video cameras placed on the vessel, which operate during all fishing activities). Therefore, for the B.C. fishery from 2006 to the present there exists a direct estimate of the total number of U32 halibut discarded. The percent of sublegal fish (in numbers) in the surveys and the Area 2B logbook from 2006 forward is shown in Fig. 1. To convert this number for the Area 2B logbooks into a weight, the average observed weight of U32 halibut in the setline survey is used.

In all other cases, since the setline survey uses similar fishing gear, it has been used as a proxy for the expected encounter rates by area and year. It was recognized in previous analyses that some survey stations produce a much lower catch rate of O32 halibut than observed for the average commercial set (Gilroy and Clark 2008). Therefore, to make them more comparable, the setline survey stations are filtered to stations with a higher catch rate (by weight) of O32 halibut. Following the previous analyses, the top 33% was used for Areas 3A-4CDE, and individually estimated percentages for Areas 2A-2C (Fig. 2). These percentages make the observed O32 halibut catch rates of filtered stations reasonably similar to those reported in commercial fishery logbooks. It is then inferred that the catch rate of U32 halibut would also be similar; however, this inference cannot be directly tested. Although the comparison is useful, there is considerable uncertainty with regard to the actual spatial and temporal patterns of the directed fishery, and direct estimates of U32 discards would be considerably better.

A mortality rate of 16% was applied to all discards since the beginning of individual quota fisheries (1991 in Canada, 1995 in Alaska). For the earlier years of derby fishing, and for all years in Area 2A, a 25% rate was applied (Gilroy 2007). The Area 2A commercial catch numbers used included the catch from the directed commercial fishery (and when open, the incidental halibut fishery during the sablefish season), but did not include catch from either the tribal fishery (because U32 halibut are accounted for as part of the ceremonial and subsistence fishery), or from the incidental halibut during the salmon fishery (because it is incidental to a troll fishery).

To estimate the pounds of U32 halibut captured in the commercial halibut fishery, the area-specific U32:O32 ratio was multiplied by the estimated commercial catch in each regulatory area, for each year. The resulting poundage was then multiplied by the discard mortality rate to obtain the estimated poundage of U32 halibut killed in the commercial fishery (Table 1).

Wastage from lost or abandoned gear

During the 'derby' fishery of the 1980s and early 1990s in Alaska and B.C., there were extremely short fishing periods which resulted in a competitive race to catch as many halibut as fast as possible. This led to a considerable quantity of lost fishing gear. Since the implementation of the quota share fisheries lost gear is much less common. Information on the amount of gear lost or abandoned by the halibut longline fishery was collected through logbook interviews or from fishing logs received via mail. Fishery-wide estimates were then extrapolated to total catch values using standardized logbook catch and effort statistics. Standardization corrects for differences in the length of skates, hook size, and hook spacing. Some log data could not be standardized because there were missing data or because the gear type was assumed to fish differently than "standard" gear. With the concurrent halibut and sablefish (*Anoplopoma fimbria*) IFQ fisheries in Alaska and the Groundfish Integrated Fisheries in B.C. there are directed halibut trips as well as trips which target other species and land incidentally-caught halibut. Gear using small hooks and short gangion/hook spacing is considered a non-standard halibut gear that fishes differently, and therefore was not included in the calculations of wastage reported here.

Wastage for O32 halibut was calculated from the ratio of effective skates lost to effective skates hauled, multiplied by total landed catch. Effective skates are skates for which no data (skate length, hook spacing, number of hooks per skate) are missing and gear type meets the standardization criteria. The ratio was calculated using both fixed-hook and snap gear in all areas. The Area 2A catch has always included the non-treaty directed commercial catch, treaty commercial catch, and, when open, incidental catch during the longline sablefish fishery. In addition, the quantity of U32 halibut captured by the lost gear is also estimated using the method described above. All fish estimated to have been captured by the lost gear are assumed to die. Wastage from lost gear was first calculated in 1985 and estimates are provided by regulatory area in Table 2. The amount of gear lost varies by year but it is much lower with the quota share fisheries, and in some instances very few skates are reported lost, which was the case in Areas 3B and 4 in 2014. The 2014 data are preliminary and it is expected that some gear was lost in those areas and when final log data are available the numbers will be updated. We will be reviewing the procedure for determining the mortality of halibut from the lost gear in 2015.

Wastage from discard mortality for regulatory reasons

The directed commercial fisheries in Area 2A are still managed using derby fishing seasons; there the quantity of halibut for a vessel is limited by a fishing period limit. This results in catches that may exceed the vessel or trip limits, and therefore regulatory discards of O32 halibut, which are reported in the fishery logbooks. The ratio of discards to landings from the trips with logbook records available is used to estimate the O32 discards for all landings reported on fish tickets. In addition, the quantity of U32 halibut captured along with these discarded fish is estimated following the methods described above. The estimates for regulatory discards start in 1993 when fishing period limits were first used and vary from 1,000 to 18,000 pounds per year, probably varying due to weather, the number of fishing seasons, and number of vessels fishing. The Area 2A incidental halibut retention fisheries during the salmon and sablefish fisheries are not included as they are accounted for under bycatch mortality estimates. The quota share fisheries in Alaska and B.C. are not included, as their discards are from the last fishing trip of the season, and are not significant due to the underage/overage programs allowing some leeway on limits.

Total wastage in the commercial fishery

Based on these methods, wastage in the commercial fishery is estimated to have been highest in the early 1980s, subsequently declining (particularly in Area 3A in 1995 when the derby fishery was converted to a quota system), and then increasing from 1995 to 2010 as the size-at-age of halibut declined and more fish at older ages remained below the minimum size limit. The estimates of wastage cannot be delineated within Regulatory Area 4 prior to 1981 (Table 3), but there is very little wastage estimated prior to that time (Fig. 3).

References

Gilroy, H.L. 2007. Wastage in the 2006 Pacific halibut fishery. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2006: 55-58.

Gilroy, H.L. and Clark, W.G. 2008. Re-estimation of sublegal discard mortality in the halibut fishery. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2007: 69-73.

Table 1. Estimated U32, halibut discard mortality in thousands of net pounds, killed in the commercial halibut fishery, by IPHC regulatory area and year, 1974 – 2014.

	Regulary Area											
Year	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.002	0.081	0.042	0.061	0.013	0.002	NA	NA	NA	NA	NA	0.201
1975	0.004	0.143	0.048	0.091	0.021	0.002	NA	NA	NA	NA	NA	0.309
1976	0.002	0.164	0.044	0.107	0.025	0.002	NA	NA	NA	NA	NA	0.344
1977	0.002	0.135	0.026	0.093	0.032	0.004	NA	NA	NA	NA	NA	0.292
1978	0.001	0.113	0.036	0.115	0.014	0.004	NA	NA	NA	NA	NA	0.283
1979	0.001	0.119	0.039	0.130	0.004	0.004	NA	NA	NA	NA	NA	0.297
1980	0.000	0.136	0.029	0.132	0.003	0.002	NA	NA	NA	NA	NA	0.302
1981	0.002	0.152	0.036	0.147	0.006	NA	0.004	0.002	0.002	0.000	0.000	0.351
1982	0.002	0.163	0.033	0.124	0.067	NA	0.010	0.000	0.002	0.000	0.000	0.401
1983	0.003	0.192	0.064	0.117	0.114	NA	0.023	0.009	0.004	0.000	0.000	0.526
1984	0.005	0.363	0.065	0.162	0.104	NA	0.010	0.008	0.006	0.001	0.000	0.724
1985	0.006	0.440	0.129	0.284	0.198	NA	0.021	0.012	0.009	0.004	0.000	1.101
1986	0.007	0.492	0.173	0.517	0.190	NA	0.048	0.002	0.011	0.011	0.000	1.452
1987	0.007	0.513	0.175	0.525	0.172	NA	0.050	0.015	0.014	0.005	0.001	1.479
1988	0.005	0.508	0.179	0.652	0.145	NA	0.024	0.016	0.009	0.002	0.000	1.540
1989	0.004	0.397	0.160	0.644	0.172	NA	0.014	0.028	0.009	0.004	0.000	1.432
1990	0.004	0.320	0.182	0.583	0.198	NA	0.038	0.015	0.010	0.008	0.001	1.359
1991	0.003	0.166	0.173	0.523	0.293	NA	0.035	0.018	0.012	0.011	0.001	1.237
1992	0.004	0.167	0.191	0.587	0.207	NA	0.039	0.028	0.013	0.004	0.001	1.241
1993	0.006	0.224	0.219	0.513	0.185	NA	0.038	0.024	0.013	0.004	0.001	1.227
1994	0.002	0.202	0.215	0.632	0.095	NA	0.028	0.025	0.012	0.004	0.002	1.217
1995	0.002	0.189	0.102	0.292	0.049	NA	0.016	0.013	0.006	0.001	0.001	0.672
1996	0.004	0.182	0.133	0.358	0.061	NA	0.019	0.013	0.014	0.015	0.003	0.800
1997	0.005	0.254	0.148	0.455	0.192	NA	0.031	0.019	0.023	0.023	0.005	1.157
1998	0.006	0.276	0.189	0.522	0.233	NA	0.048	0.035	0.018	0.018	0.003	1.347
1999	0.006	0.281	0.170	0.429	0.251	NA	0.033	0.046	0.015	0.016	0.002	1.249
2000	0.007	0.162	0.160	0.416	0.326	NA	0.066	0.036	0.004	0.004	0.001	1.183
2001	0.011	0.199	0.193	0.391	0.449	NA	0.099	0.047	0.007	0.008	0.002	1.407
2002	0.009	0.168	0.146	0.507	0.481	NA	0.083	0.020	0.003	0.004	0.001	1.423
2003	0.028	0.309	0.171	0.608	0.611	NA	0.085	0.026	0.004	0.008	0.002	1.852
2004	0.009	0.275	0.331	0.682	0.701	NA	0.063	0.022	0.005	0.009	0.002	2.100
2005	0.034	0.298	0.309	0.568	0.546	NA	0.127	0.011	0.005	0.025	0.004	1.927
2006	0.043	0.569	0.404	0.690	0.465	NA	0.095	0.009	0.006	0.031	0.005	2.318
2007	0.030	0.500	0.338	0.913	0.436	NA	0.127	0.019	0.009	0.045	0.010	2.427
2008	0.036	0.432	0.288	0.943	0.672	NA	0.138	0.018	0.018	0.063	0.015	2.623
2009	0.051	0.334	0.292	1.131	0.775	NA	0.145	0.011	0.015	0.050	0.010	2.813
2010	0.026	0.275	0.246	1.429	0.883	NA	0.130	0.030	0.020	0.053	0.010	3.102
2011	0.020	0.256	0.074	0.901	0.763	NA	0.134	0.035	0.041	0.112	0.024	2.359
2012	0.018	0.208	0.082	0.581	0.516	NA	0.090	0.035	0.017	0.044	0.011	1.602
2013	0.014	0.198	0.084	0.498	0.403	NA	0.062	0.032	0.015	0.029	0.009	1,344
2014	00.12	0.233	0.111	0.427	0.325	NA	0.033	0.046	0.016	0.028	0.006	1,345

Table 2. Estimates of Pacific halibut, in millions of net pounds, killed by lost or abandoned longline gear in the commercial halibut fishery, by IPHC regulatory area, 1985 – 2014.

	Regulatory Area										
Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
1985	0.002	0.111	0.236	1.019	0.219	0.065	0.046	0.025	0.027	0.001	1.749
1986	0.004	0.221	0.472	2.036	0.439	0.195	0.014	0.041	0.074	0.002	3.499
1987	0.003	0.188	0.401	1.732	0.373	0.147	0.058	0.037	0.029	0.004	2.974
1988	0.001	0.053	0.225	1.651	0.134	0.030	0.024	0.011	0.008	0.000	2.137
1989	0.007	0.050	0.211	1.599	0.212	0.029	0.072	0.017	0.020	0.000	2.217
1990	0.016	0.127	0.357	1.217	0.237	0.117	0.060	0.026	0.049	0.003	2.209
1991	0.002	0.078	0.378	1.253	0.458	0.098	0.064	0.031	0.066	0.004	2.434
1992	0.007	0.058	0.267	0.705	0.198	0.054	0.046	0.017	0.016	0.001	1.369
1993	0.009	0.104	0.209	0.374	0.069	0.049	0.036	0.017	0.017	0.001	0.886
1994	0.001	0.075	0.249	0.918	0.043	0.038	0.041	0.016	0.016	0.002	1.399
1995	0.003	0.042	0.059	0.138	0.009	0.009	0.009	0.003	0.003	0.001	0.276
1996	0.001	0.032	0.048	0.196	0.024	0.026	0.030	0.011	0.011	0.002	0.382
1997	0.006	0.042	0.044	0.082	0.061	0.028	0.031	0.011	0.011	0.002	0.318
1998	0.001	0.060	0.046	0.173	0.063	0.022	0.018	0.008	0.009	0.001	0.400
1999	0.007	0.045	0.074	0.129	0.079	0.036	0.030	0.015	0.016	0.002	0.433
2000	0.007	0.031	0.042	0.067	0.065	0.028	0.024	0.009	0.010	0.002	0.286
2001	0.003	0.051	0.042	0.072	0.037	0.037	0.031	0.011	0.012	0.003	0.301
2002	0.005	0.039	0.029	0.157	0.040	0.022	0.016	0.005	0.007	0.002	0.323
2003	0.002	0.041	0.028	0.079	0.043	0.022	0.017	0.004	0.008	0.002	0.246
2004	0.000	0.041	0.037	0.089	0.019	0.017	0.013	0.004	0.007	0.001	0.228
2005	0.006	0.042	0.038	0.177	0.033	0.015	0.007	0.002	0.010	0.001	0.330
2006	0.002	0.044	0.026	0.059	0.014	0.008	0.004	0.001	0.005	0.001	0.166
2007	0.003	0.036	0.036	0.064	0.023	0.010	0.004	0.002	0.009	0.002	0.190
2008	0.001	0.026	0.015	0.075	0.006	0.014	0.007	0.003	0.011	0.002	0.163
2009	0.001	0.024	0.014	0.058	0.030	0.016	0.007	0.003	0.011	0.002	0.168
2010	0.001	0.033	0.012	0.030	0.031	0.011	0.008	0.003	0.009	0.001	0.139
2011	0.005	0.031	0.006	0.040	0.012	0.013	0.009	0.004	0.012	0.003	0.134
2012	0.004	0.014	0.013	0.016	0.016	0.007	0.003	0.001	0.001	0.001	0.077
2013	0.002	0.015	0.027	0.027	0.002	0.010	0.003	0.001	0.001	0.001	0.089
2014	0.003	0.014	0.011	0.012	0.003	0.001	0.007	0.000	0.002	0.000	0.053

Table 3. Wastage, millions of pounds net weight, in the commercial halibut fishery, 1974-2014.

	Regulatory Area											
Year	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.002	0.081	0.042	0.061	0.013	0.002	NA	NA	NA	NA	NA	0.201
1975	0.004	0.143	0.048	0.091	0.021	0.002	NA	NA	NA	NA	NA	0.309
1976	0.002	0.164	0.044	0.107	0.025	0.002	NA	NA	NA	NA	NA	0.344
1977	0.002	0.135	0.026	0.093	0.032	0.004	NA	NA	NA	NA	NA	0.292
1978	0.001	0.113	0.036	0.115	0.014	0.004	NA	NA	NA	NA	NA	0.283
1979	0.001	0.119	0.039	0.130	0.004	0.004	NA	NA	NA	NA	NA	0.297
1980	0.000	0.136	0.029	0.132	0.003	0.002	NA	NA	NA	NA	NA	0.302
1981	0.002	0.152	0.036	0.147	0.006	NA	0.004	0.002	0.002	0.000	0.000	0.351
1982	0.002	0.163	0.033	0.124	0.067	NA	0.010	0.000	0.002	0.000	0.000	0.401
1983	0.003	0.192	0.064	0.117	0.114	NA	0.023	0.009	0.004	0.000	0.000	0.526
1984	0.005	0.363	0.065	0.162	0.104	NA	0.010	0.008	0.006	0.001	0.000	0.724
1985	0.008	0.542	0.345	1.213	0.398	NA	0.082	0.056	0.031	0.028	0.001	2.702
1986	0.011	0.695	0.606	2.374	0.591	NA	0.231	0.016	0.048	0.077	0.002	4.652
1987	0.010	0.686	0.543	2.105	0.513	NA	0.188	0.071	0.047	0.031	0.005	4.201
1988	0.006	0.557	0.385	2.158	0.267	NA	0.052	0.039	0.019	0.009	0.000	3.492
1989	0.011	0.443	0.353	2.102	0.366	NA	0.041	0.098	0.024	0.022	0.000	3.460
1990	0.019	0.437	0.509	1.693	0.414	NA	0.148	0.073	0.033	0.052	0.004	3.382
1991	0.005	0.238	0.520	1.666	0.711	NA	0.127	0.080	0.040	0.070	0.005	3.464
1992	0.011	0.220	0.436	1.230	0.388	NA	0.090	0.072	0.028	0.018	0.002	2.495
1993	0.021	0.320	0.411	0.854	0.248	NA	0.084	0.059	0.028	0.019	0.002	2.047
1994	0.009	0.271	0.443	1.477	0.134	NA	0.064	0.065	0.026	0.018	0.004	2.511
1995	0.009	0.228	0.156	0.420	0.058	NA	0.024	0.022	0.009	0.004	0.002	0.932
1996	0.011	0.211	0.177	0.535	0.083	NA	0.043	0.042	0.024	0.025	0.005	1.154
1997	0.014	0.291	0.188	0.529	0.246	NA	0.057	0.049	0.033	0.033	0.007	1.448
1998	0.019	0.329	0.230	0.676	0.289	NA	0.068	0.052	0.025	0.026	0.004	1.717
1999	0.018	0.321	0.237	0.546	0.322	NA	0.067	0.074	0.029	0.031	0.004	1.649
2000	0.025	0.190	0.198	0.475	0.384	NA	0.092	0.059	0.013	0.014	0.003	1.453
2001	0.026	0.245	0.230	0.456	0.481	NA	0.132	0.076	0.018	0.020	0.005	1.690
2002	0.023	0.204	0.172	0.646	0.515	NA	0.103	0.036	0.008	0.011	0.003	1.722
2003	0.046	0.344	0.196	0.676	0.646	NA	0.105	0.042	0.008	0.016	0.004	2.083
2004	0.017	0.311	0.362	0.758	0.716	NA	0.078	0.034	0.009	0.016	0.003	2.305
2005	0.040	0.335	0.341	0.724	0.572	NA	0.139	0.018	0.007	0.034	0.005	2.215
2006	0.050	0.605	0.425	0.741	0.476	NA	0.102	0.013	0.007	0.036	0.006	2.463
2007	0.041	0.529	0.367	0.966	0.454	NA	0.135	0.023	0.011	0.053	0.012	2.591
2008	0.045	0.454	0.300	1.004	0.676	NA	0.149	0.025	0.021	0.073	0.017	2.764
2009	0.052	0.354	0.302	1.175	0.796	NA	0.157	0.018	0.018	0.060	0.012	2.944
2010	0.028	0.302	0.255	1.450	0.903	NA	0.138	0.037	0.023	0.061	0.011	3.208
2011	0.025	0.283	0.079	0.930	0.770	NA	0.144	0.043	0.044	0.121	0.026	2.464
2012	0.025	0.220	0.093	0.593	0.526	NA	0.095	0.038	0.018	0.045	0.012	1.666
2013	0.025	0.211	0.107	0.519	0.404	NA	0.070	0.035	0.016	0.030	0.010	1.429
2014	0.023	0.245	0.120	0.436	0.327	NA	0.034	0.052	0.016	0.030	0.006	1.289

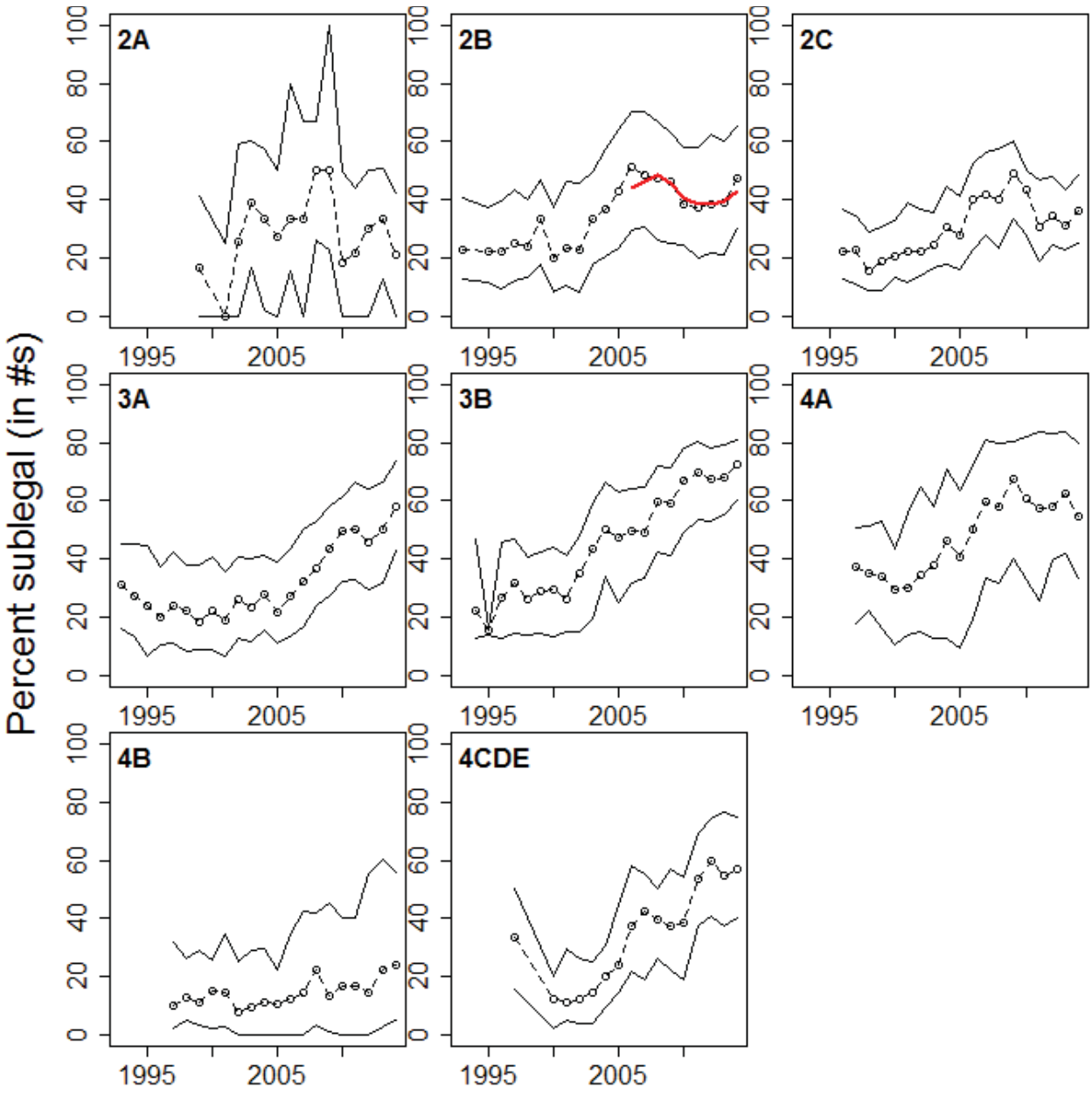


Figure 1. Setline survey percentage sublegals by number, 1996-2014. Circles represent the median station observed each year in the survey and the lines indicate the 25th and 75th percentiles. Thick black line in Area 2B since 2006 represents the percent sublegals reported in the logbooks.

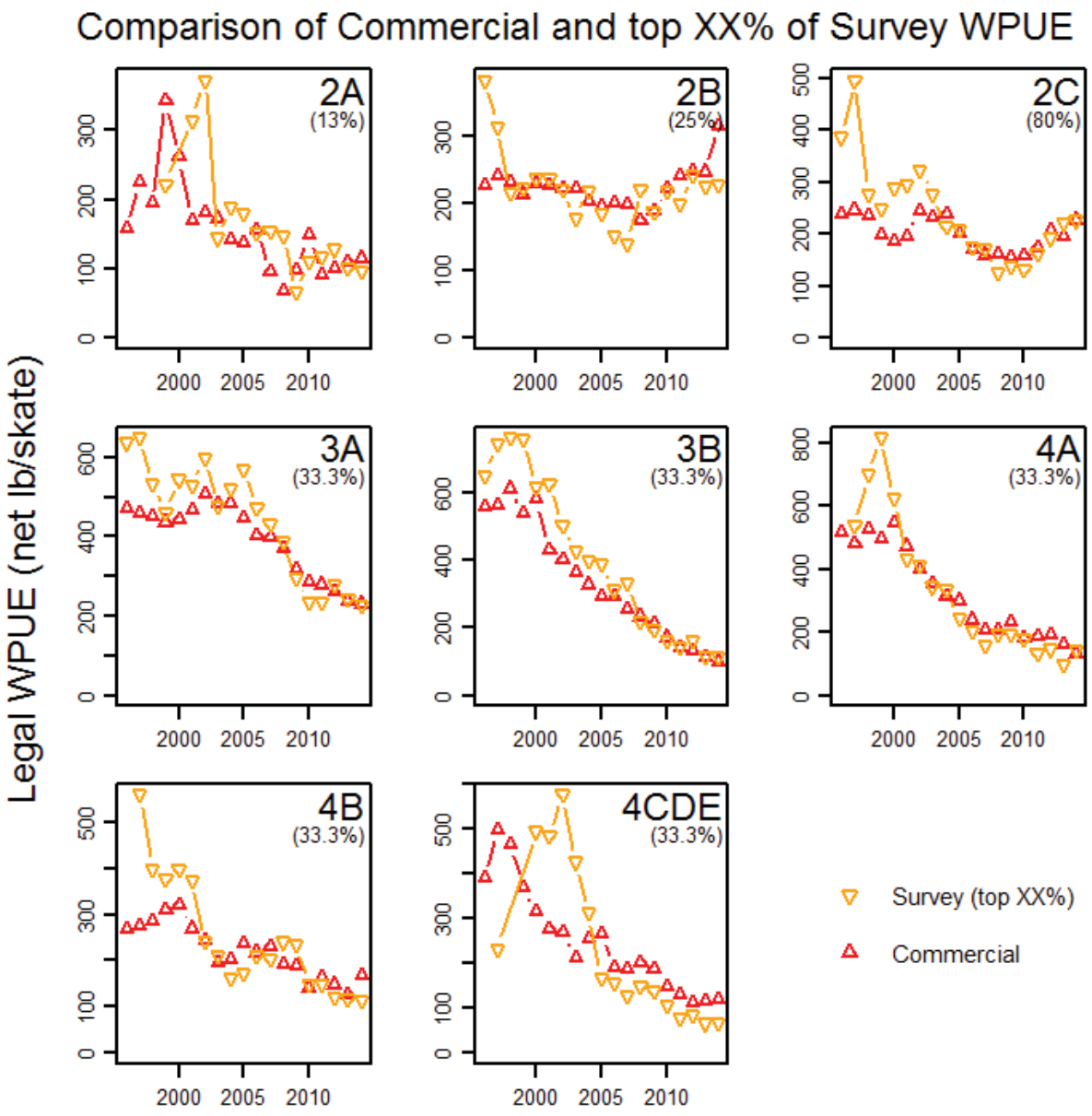


Figure 2. 032 WPUE for the commercial fishery versus setline survey filtered to the top XX%, 1997-2014.

The personal use harvest of Pacific halibut through 2014

Heather L. Gilroy and Gregg H. Williams

Abstract

Pacific halibut is taken throughout its range as a personal use harvest by several fisheries. The primary harvests are taken in the treaty Indian ceremonial and subsistence fishery occurring in the waters off northwest Washington State, the First Nations food fish fishery in British Columbia, and the subsistence fishery by rural residents and federal-recognized native tribes off Alaska. The coastwide personal use estimate for 2014 is 1.1 Mlbs. New estimates for all areas are not available so the allocation was used for the treaty Indian ceremonial and subsistence fishery and the previous year's estimate was used for Alaska, with the exception the Area 4D/E Community Development Quota U32 fishery is current. The estimate for Area 2B remains unchanged.

Introduction

The removals of Pacific halibut which are accounted for in the stock assessment include commercial and sport catch, incidental mortality of halibut during the sport and commercial (wastage) fisheries, incidental mortality in other fisheries (bycatch), and personal use. Personal use categories are: (1) ceremonial and subsistence removals in Area 2A treaty Indian fishery, (2) the sanctioned First Nations Food, Social and Ceremonial (FSC) fishery conducted in British Columbia, (3) federal subsistence fishery in Alaska, and (4) U32 halibut retained in Areas 4D and 4E under International Pacific Halibut Commission (IPHC) regulations.

Estimated harvests by area

The coastwide personal use harvest was estimated by the IPHC at more than two million pounds in 1991, declined rapidly through 1995, and became relatively stable over the following two years (Table 1). Harvest estimation methods were revised in 1998, and the resulting estimates were somewhat higher and remained fairly stable through 2002. The estimates of harvest took another jump in 2003 (Table 2) following the implementation of new subsistence fishery regulations in Alaska and a more comprehensive harvest estimation survey. Many of the changes seen in the harvest estimates prior to 2003 were due primarily to changes in estimation methods and not necessarily actual changes in harvest levels. The total estimate for the 2014 subsistence fishery is 1.1 Mlbs with the majority of the coastwide personal use harvest taken from waters off Alaska (Table 3).

In the commercial halibut fisheries coastwide, the state and federal regulations require that take-home halibut caught during commercial fishing be recorded as part of the commercial catch on the landing records (State fish tickets or B.C. validation records). This is consistent across areas, including within the quota share fisheries in B.C. and Alaska, and as part of fishing period limits and halibut ratios in the incidental fisheries in Area 2A. Therefore, these personal use fish or take-home fish within the commercial fisheries are accounted for as commercial catch.

Washington, Oregon, and California

In Area 2A (Washington, Oregon, and California), the Pacific Fishery Management Council's catch sharing plan allocates the catch limit to commercial, sport, and treaty Indian users. The treaty tribal catch limit is further sub-divided into commercial and ceremonial and subsistence (C&S) fisheries. The 2013 final estimate of C&S was 28,500 pounds and this catch estimate becomes the 2014 C&S allocation. The estimate of the 2014 catch is not available so it is assumed the treaty tribal C&S allocation was fully harvested.

British Columbia

The source of personal use harvest in British Columbia is the First Nations FSC fishery. The IPHC receives some logbook and landing data for this harvest from the Canadian Department of Fisheries and Oceans (DFO) but those data have not been adequate for the IPHC to make an independent estimate of the FSC fishery harvest. DFO estimated the First Nations FSC harvest to be 300,000 pounds annually until 2006, and since 2007, the yearly estimate has been provided as 405,000 pounds.

Alaska

The IPHC began estimating the personal use harvest in Alaska in 1991. Documentation of estimation methods cannot be located. The available estimates indicated that personal use in Alaska totaled 1.95 million pounds that year. The estimate for 1992 dropped in half, to one million pounds. Estimates were subsequently made for each IPHC area independently and annually for most areas.

Trumble (1999) developed a new methodology to estimate personal use using halibut catch information gathered by household interviews and postal surveys conducted by the Alaska Department of Fish and Game (ADF&G). The surveys did not distinguish between sport and personal use harvests, so Trumble made assumptions regarding the relative amount of sport and personal use in native and non-native households. The resulting estimates were used for Alaska for 1998-2002, with the only annual change being the amount of sublegal poundage retained by the Area 4E Community Development Quota (CDQ) fishers.

In 2003, the subsistence halibut fishery off Alaska was formally recognized by the North Pacific Fishery Management Council, and implemented by IPHC and National Marine Fisheries Service (NMFS) regulations. The fishery allows the customary and traditional use of halibut by rural residents and members of federally-recognized Alaska native tribes to retain halibut for non-commercial use, for food, or customary trade. The NMFS regulations defined legal gear, number of hooks, and daily bag limits, and IPHC regulations set the fishing season. Prior to subsistence fishing, eligible persons registered with NMFS RAM to obtain a Subsistence Halibut Registration Certificate (SHARC). For ten years, Division of Subsistence at ADF&G was contracted by NMFS to estimate the subsistence harvest in Alaska. Each year an annual voluntary survey of fishers, with some onsite visits, was used to estimate annual harvest. New estimates are not available for 2013 or 2014 so 2012 estimates have been rolled forward. Results for 2012, reported by Fall and Koster (2014), totaled 687,000 pounds (net weight) in Areas 2C through 4E (Table 2). This represents a 1.5% decrease from 2011 for these fisheries. Yearly reports are available at http://www.fakr.noaa.gov/ram/subsistence/halibut.htm.

In addition to the SHARC harvest, IPHC regulations allow U32 halibut to be retained in the Area 4D and 4E commercial CDQ fishery as long as the fish are not sold or bartered. The CDQ

organizations are required to report to the IPHC the amounts retained during their commercial fishing operations (Williams 2015). This harvest is not included in the SHARC program harvest so are report separately. In 2014, 5,533 pounds of U32 halibut in Area 4D and 4E were landed, half of the 2013 harvest.

References

Fall, J. A. and Koster, D. S. 2014. Subsistence harvests of Pacific halibut in Alaska, 2012. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 388. Anchorage.

Trumble, R. J. 1999. 1998 estimates of personal use. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1998: 61-64.

Williams, G. H. 2015. Retention of U32 halibut in the 2014 Area 4D/4E CDQ fisheries. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 61-64.

Table 1. Estimates of the personal use harvest (thousands of pounds, net weight) of Pacific halibut by IPHC regulatory area from 1991-2002.

	Regulatory Area						
Year	2A	2B	2C	3A	3B	4	Total
1991	10.0	50	720	-------1,000-------		230	2,010
1992	14.2	100	----------1,000----------				1,114
1993	15.8	300	108	328	59	121	932
1994	10.9	300	108	328	59	121	927
1995	14.2	300	n/a	97	37	94	542
1996	15.0	300	n/a	97	37	94	543
1997	14.8	300	n/a	97	37	94	543
1998	10.5	300	170	74	20	166	741
1999	10.5	300	170	74	20	170	745
2000	17.5	300	170	74	20	175	757
2001	16.0	300	170	74	20	192	772
2002	27.0	300	170	74	20	180	771

Table 2. Estimates of the personal use harvest (thousands of pounds, net weight) of Pacific halibut by IPHC regulatory area since 2003.

Year	2A[a]	2B	2C	3A	3B	4A	4B	4C	4D	4E	4D/4E CDQ	Total
2003	19.4	300.0	628.0	279.6	27.6	20.7	2.5	23.8	4.4	54.5	14.3	1,374.8
2004	38.0	300.0	677.1	403.6	33.5	28.9	0.9	9.7	10.9	28.5	16.2	1,547.3
2005	36.0	300.0	598.1	429.3	46.2	35.6	1.4	7.7	5.8	54.0	23.2	1,537.3
2006	33.0	300.0	580.1	381.9	48.6	27.0	2.8	8.5	8.3	70.7	19.7	1,480.6
2007	30.0	405.0	524.9	372.2	47.7	14.9	2.0	15.0	3.2	52.1	19.0	1,486.0
2008	30.0	405.0	458.4	337.4	42.2	19.6	4.7	5.7	3.1	15.9	21.8	1,343.8
2009	30.4	405.0	457.0	328.5	25.5	33.5	1.2	6.3	0.6	8.7	10.3	1,307.0
2010	25.3	405.0	424.8	312.7	23.0	14.5	0.5	10.9	1.2	10.1	9.5	1,237.5
2011	25.3	405.0	387.0	266.1	22.0	13.6	0.5	1.6	0.6	6.2	16.9	1,144.8
2012	32.0	405.0	396.0	253.5	16.0	9.5	1.7	1.2	0.7	8.4	20.2	1,144.2
2013[b]	28.5	405.0	396.0	253.5	16.0	9.5	1.7	1.2	0.7	8.4	10.0	1,130.5
2014[b]	28.5	405.0	396.0	253.5	16.0	9.5	1.2	1.2	0.7	8.4	5.3	1,125.3

[a] Some of Area 2A numbers were updated in 2014, also changing total

[b] 2013 Alaska and 2014 estimates are preliminary.

Table 3. Summary of personal use harvest (thousands of pounds, net weight) of Pacific halibut by region.

Year	West Coast	B.C.	Alaska	Total
1991	10.0	50.0	1,950.0	2,010.0
1992	14.2	100.0	1,000.0	1,114.2
1993	15.8	300.0	616.0	931.8
1994	10.9	300.0	616.0	926.9
1995	14.2	300.0	228.0	542.2
1996	15.0	300.0	228.0	543.0
1997	14.8	300.0	228.0	542.8
1998	10.5	300.0	430.0	740.5
1999	10.5	300.0	434.0	744.5
2000	17.5	300.0	439.0	756.5
2001	16.0	300.0	456.0	772.0
2002	27.0	300.0	444.0	771.0
2003	19.4	300.0	1,055.4	1,374.8
2004	38.0	300.0	1,209.3	1,547.3
2005	36.0	300.0	1,201.3	1,537.3
2006	33.0	300.0	1,147.6	1,480.6
2007	30.0	405.0	1,051.0	1,486.0
2008	30.0	405.0	908.8	1,343.8
2009	30.4	405.0	871.6	1,307.0
2010	25.3	405.0	807.2	1,237.5
2011	25.3	405.0	714.5	1,144.8
2012	32.0	405.0	707.2	1,144.2
2013	28.5	405.0	697.0[a]	1,130.5[a]
2014[a]	28.5	405.0	691.8	1,125.3

[a] Estimates are preliminary.

Retention of U32 halibut in the 2014 Area 4D/4E CDQ halibut fisheries

Gregg H. Williams

Abstract

Since 1998, commercial halibut vessels fishing for certain Community Development Quota (CDQ) organizations in Area 4E have been permitted by the International Pacific Halibut Commission (IPHC) to retain U32 halibut (<32 inches), under an exemption requested by the North Pacific Fishery Management Council. Beginning in 2002, the retention allowance was expanded to also include vessels that land all of their annual catch in IPHC Regulatory Areas 4D or 4E. The amount of retained U32 halibut has ranged from 3,590 pounds in 1998 to as much as 30,267 pounds in 2001. In 2014, a total of 5,533 pounds was reported by three CDQ organizations, a decrease of 45% from 2013. This harvest is in addition to the subsistence harvest reported by the Alaska Department of Fish and Game for these IPHC regulatory areas.

Program history

At its 1998 Annual Meeting, the International Pacific Halibut Commission (IPHC) approved a two-year exemption to the regulation requiring the discard of U32 halibut (<32 inches in length), applicable only to vessels fishing in Regulatory Area 4E. A reporting requirement was added for the 1999 fishery. Another two-year exemption was approved at the 2000 Annual Meeting, covering the 2000 and 2001 fishing seasons. At the 2002 Annual Meeting, the IPHC agreed to extend the allowance to Community Development Quota (CDQ) organizations with allocations for Regulatory Area 4D, and to amend the regulation to apply only to vessels that land all of their catch in Areas 4D or 4E. The IPHC also agreed to review the regulation at the end of 2002 to see if the exemption was still necessary under the subsistence fishery regulations being drafted, at the time, by the North Pacific Fishery Management Council and National Marine Fisheries Service.

In 2007, IPHC made a minor change in the reporting requirements. In previous years, the organizations were required to report their retained amounts to IPHC by November 15. This date was originally established as it coincided with the closure of the IFQ fishery at that time, and was believed to provide sufficient time for data compilation and subsequent submission by the affected organizations. In later years, it became apparent that local fishers in Areas 4D and 4E were concluding their fishing well before November. At the same time, IPHC staff found that the original reporting date did not provide sufficient time to receive and compile the reports for Commission review and consideration. At the 2007 Annual Meeting, a proposal to move the reporting date to November 1 was approved and went into effect that year.

The harvests reported herein are reported separately from the household survey conducted by the Alaska Department of Fish and Game for the subsistence harvest, where survey participants are instructed to exclude any U32 halibut retained during commercial fishing. Thus, a complete accounting of subsistence harvests should include the numbers reported in this document.

Results for 2014

Reports for 2014 were received from three organizations: Bristol Bay Economic Development Corporation (BBEDC), Coastal Villages Regional Fund (CVRF), and Norton Sound Economic Development Corporation (NSEDC). The reports are summarized below, and the reported amounts of retained U32 halibut are shown in Table 1. Overall U32 landings in 2014 totaled 5,533 pounds, down 45% from 2013. All three organizations reported lower amounts in 2014, although the reduction was less than 12% for two organizations. Generally, annual changes are a reflection of the amount of effort by the local small boat fleets and the availability of fish in their nearshore fisheries. Additional details are provided in the following sections.

Bristol Bay Economic Development Corporation

BBEDC's report was received on November 7, 2014. BBEDC requires their fishers to record the lengths of retained U32 halibut in a separate log, which are tabulated by BBEDC at the conclusion of the season. The lengths were converted to weights using the IPHC length/weight relationship and summed to estimate the total retained U32 weight. Halibut were landed by BBEDC vessels primarily at Togiak, with a minor amount landed in Dillingham.

BBEDC reported 14 fishers landed 408 U32 halibut for a total of 3,456 pounds (net). This was down just 1% from 2013. The fish had an average size of 8.5 pounds (net) and 96% of the halibut were 26 inches or greater in length.

Coastal Villages Regional Fund

The report from CVRF was received on November 4, 2014. Crews at Coastal Villages Seafood's facilities measured the halibut prior to heading, separating the U32 halibut within offloads, and weighing them separately from the O32 halibut (≥ 32 inches in length). Once this was completed, the plant's record keeper recorded on a tally sheet the fisher's name, number of halibut, and poundage of U32 halibut retained by the fisher. Each plant sent the tally sheets to the Coastal Villages Seafood's headquarters on a weekly basis, where the information was entered into a spreadsheet. CVRF has followed this same procedure for several years.

In 2014, plants on Nunivak Island recorded U32 halibut caught between July 15 and August 10. CVRF reported that 1,092 pounds (head-on, eviscerated, with slime) were landed, resulting in a net weight of 963 pounds, an 82% decrease from 2013. A total of 112 halibut was recorded, for an average weight of 8.6 pounds (net).

Norton Sound Economic Development Corporation

NSEDC's report was received on November 10, 2014. NSEDC required their vessels to offload the U32 halibut for weighing. Ice was removed but the fish were not washed nor the heads removed. The U32 halibut were then returned to the fishers. U32 fish were retained from landings made from August 7 through October 7, similar to previous years. NSEDC reported 115 U32 halibut weighing 1,263 pounds in "head-on with slime" weight, or 1,114 pounds net weight. The fish had an average weight of 9.7 pounds (net). All fish were caught in the local CDQ fishery, and delivered to the Nome plant. The amount retained in 2014 was a decrease of 12% from 2013.

Table 1. Reported annual amount (pounds, net weight) of U32 (<32 inches in length) halibut retained by Community Development Quota harvesters fishing in IPHC Regulatory Areas 4D and 4E.

Year	Bristol Bay Economic Development Corporation	Coastal Villages Regional Fund	Norton Sound Economic Development Corporation	Total
1998	2,690	900	-	3,590
1999	418	7,483	-	7,901
2000	3,772	9,618	-	13,390
2001	10,773	19,494	-	30,267
2002	6,593	7,473	4,371	18,437
2003	6,346	5,034	2,961	14,341
2004	4,826	7,120	4,242	16,188
2005	8,750	11,335	3,136	23,221
2006	2,836	13,467	3,407	19,710
2007	3,135	11,398	4,516	19,049
2008	1,816	12,926	6,924	21,666
2009	922	4,277	6,060	11,259
2010	2,155	3,924	3,438	9,517
2011	2,752	9,909	4,206	16,867
2012	5,095	10,424	4,668	20,187
2013	3,493	5,250	1,290	10,033
2014	3,456	963	1,114	5,533
% Change 2013-2014	-1.1	-81.7	-11.7	-44.7
Average 2010-2014	3,390	6,094	2,938	12,422

Commercial catch sampling

Lara M. Erikson and Kirsten A. MacTavish

Abstract

This paper describes the 2014 International Pacific Halibut Commission commercial catch sampling program for halibut in Alaska, British Columbia, Washington, and Oregon. Commercial catch sampling involves collecting otoliths, halibut lengths, logbook information, and final landing weights. The collected data are used in stock assessment and other research and the collected otoliths provide age composition. Lengths of sampled halibut provide the basis for estimates of mean weight and, in combination with age data, size at age analyses. Mean weights are combined with final landing weights to estimate catch in numbers. Logbook information provides weight per unit effort data, fishing location for the landed weight, and data for research projects. Finally, tags are collected to provide information on migration, exploitation rates, and natural mortality.

Fishery background

Individual quota systems (QS) remained in place in Alaska and British Columbia during 2014. The commercial fisheries off Washington, Oregon, and California (Area 2A) were allocated catch limits by the Pacific Fishery Management Council (PFMC). The PFMC allocates halibut within Area 2A among the sport, commercial, and treaty Indian (designated as Area 2A-1) user groups using a Catch Sharing Plan (CSP). Due to mechanisms in the PFMC CSP and the adopted 2014 total Area 2A catch limit that exceeded 900,000 pounds, there was a non-treaty incidental halibut catch during the limited-entry sablefish (*Anoplopoma fimbria*) longline fishery in 2014. The Area 2A directed commercial fishery was restricted to waters south of Point Chehalis, Washington (46°53'18" N latitude), while the incidental halibut catch during the sablefish fishery and the treaty Indian tribes' commercial fisheries were prosecuted north of Point Chehalis.

Sampling objectives

One of the primary objectives in sampling landings of commercially caught halibut is to obtain samples, composed of sagittal otoliths and corresponding length measurements, which are representative of the total commercial halibut removals. To accomplish this, random sampling techniques are applied, and an equal proportion of the catch (by weight) is sampled within each regulatory area over the entire landing period, using prescribed sampling rates that vary among areas and sometimes ports. In addition to sampling catch, other objectives include collecting recovered tags, and copying information from fishing logs, along with the respective landed weights, for as many halibut trips as possible throughout the entire season.

Inherent in the sampling program is the positioning of field sampling staff in ports where there is an opportunity to sample a majority of the catch for each regulatory area. To ensure that proportional sampling occurs by regulatory area and port, landing patterns are reviewed annually, sampling protocols are established based on the weights landed, and sampling days are assigned to each port. In some cases, different sampling rates for a given regulatory area are assigned by port. Finally, sampling priorities by regulatory area are assigned on a port level to address situations in which multiple concurrent landings preclude the International Pacific Halibut Commission (IPHC) port sampler's ability to obtain samples from all vessels.

Selection of sample days

Sampling protocols are designed to maximize the number of landings available for sample selection and ensure that the sampled halibut are representative of the population of landed halibut. To this end, the weekly sampling schedule (Monday through Saturday) for each port was randomized so that catch landed on each day had an equal chance of being selected for sampling. A restriction to the weekly sampling schedule was that one day per week was set aside for sampling for a length-weight pilot project (see later) and logbook collection only. Regulatory Area 3A was sampled five days per week in all ports. Since the start of the QS fishery in Alaska in 1995, Regulatory Area 3A was sampled for fewer than five days per week in most ports to avoid oversampling, given that only a relatively small proportion of landings needed to be sampled in order to reach the established otolith targets (see sampling rates and priorities). From 2010 to 2013, a subset of Sunday sampling days were added to the sampling schedules for all ports and regulatory areas in an effort to characterize the catch on those days, in particular for length and age distributions. The data from those three years were analyzed (Webster et al. 2014) and evidence was found that Sunday landing catch differed from weekday landing catch in terms of mean length and age. However, sampling on Sundays had little effect on estimates of mean age or length of halibut landed in the commercial fishery. As a result, Sunday sampling days were removed from the 2014 sampling calendars.

Small landings

Until recent years, samples typically were not taken from small landings, yet in some ports they contribute a substantial proportion of the total landed catch. To assess the potential impact of not sampling what is considered a small landing (which differs by port), small landings have been sampled in select ports since 2010 (see Webster et al. 2014). For reference, in 2013, small landings were defined and sampled in the following ports: Petersburg, Sitka, and Juneau landings less than 2,000 lb; and St. Paul less than 1,000 lb.

Sampling rates and priorities

Sampling rates for each regulatory area are port specific. The sampling rates are applied to the hailed weight from each trip landed to arrive at the sample size for that offload. The number of days per week on which sampling should occur for landings from a regulatory area are also port specific. Differences in sampling rates among ports within regulatory areas were due to uneven distributions of projected landings among those ports. Refer to Table 1 for the 2014 sampling rates. Small landings in Petersburg, Sitka, Juneau, and St. Paul were sampled on assigned days at 10% of the hailed weight.

Samplers used their own judgment, based on a hierarchy of objectives, to determine which landings to sample when there were conflicts that precluded sampling all of the landings prescribed by their sampling schedule. For example, it is a frequent occurrence that more than one boat unloads simultaneously from the same regulatory area within a port. In such cases, the vessel with the higher poundage was usually sampled. In instances when this did not occur, a sampler may have been working, in a port with multiple offload facilities, at a facility where there was a constant stream of halibut offloads. The sampler would therefore opt to stay at the one plant rather than travel to another location. Sampling conflicts also arose from simultaneous landings of halibut from different regulatory areas within a port. Sampling priorities by regulatory area were assigned to resolve these conflicts. In Alaskan ports and in Bellingham, Washington, Area 4 landings had

the highest sampling priority, followed by Area 2C (and 2A in Bellingham), then Area 3B, and finally Area 3A. The priority scheme for Area 4 catches was to sample Area 4B first, followed by Areas 4C and 4D, and then Area 4A.

Otolith sampling targets

An objective of the catch sampling program is to collect a target number of otoliths and corresponding fish lengths from each regulatory area. Otolith sampling rates are established to optimize work effort and achieve target sample sizes. In 2014, a target of 1,500 ± 500 otoliths and halibut lengths was set for each of Regulatory Areas 2B, 2C, 3A, 3B, 4A, 4B, and Areas 4C and 4D combined (Tables 2a and 2b). In Area 2A, the target was 1,000 otoliths with corresponding fork lengths. The Area 2A target was further subdivided to obtain adequate sample sizes from the Area 2A-1 treaty Indian fisheries and the directed commercial fishery, relative to each fishery component's proportion of the overall 2A catch limit. This division resulted in a target of 650 otoliths/lengths from the treaty Indian fishery and 350 otoliths/lengths from the non-treaty directed commercial fishery and incidental retention of halibut in the sablefish fishery. The sampling rates detailed above were calculated to meet sampling targets and to obtain otoliths and data from an equal proportion of the catch within areas.

Modifications to sampled ports

Prior to the 2014 season, landings for prior years were reviewed, comparing sampled and unsampled ports by IPHC statistical area, to ascertain whether any statistical areas were being under-sampled. Good coverage was found in Areas 2B, 2C, 3A, 4C, and 4D. However, there were statistical areas in Regulatory Area 3B where the proportion of landings into sampled ports was lower than their total contribution to the Area 3B harvest. Table 3 shows the relative proportion of Area 3B catch landed, for 2013 and 2014 from selected statistical areas, comparing Sand Point, Alaska as a staffed port to Sand Point as an unstaffed port, for the months Sand Point was staffed in 2013 and 2014. In order to correct for this difference and upon review of 2013 landing patterns, the intent was to staff the port of Sand Point for three months during the 2014 season. However, Sand Point was not staffed in August of 2014 due to staffing needs in other ports. Regardless, staffing Sand Point in 2014 resulted in more representative sampling by statistical area than would have been possible without staffing Sand Point. In addition, there is some evidence that there may be a different age distribution of younger fish for Area 3B halibut landed in Sand Point compared to those landed in other staffed ports.

Sampling rate calculations

Sampling rate calculations, the 2014 average halibut weight, and the proportion of catch landed in sampled ports for 2014 for the different regulatory areas are shown in Tables 2a and 2b. The rates were calculated using the following equations:

$$PG = (TSS \cdot \overline{w}) / (PS \cdot CL)$$

where PG = the overall ratio of the landings to be sampled by area in sampled ports;
TSS = the otolith target for each respective area;
$\overline{w}$ = the average halibut weight for each area;

PS = the proportion of landings that were expected to be landed in sampled ports;
CL = the available catch limit set by the IPHC; and

$$sr = PG / ps$$

where *sr* = the sampling rate to be use for each area;
PG = the overall ratio of the landings to be sampled by area in sampled ports;
ps = the previous year's proportion of landed weights with otolith sampling.

Sampling the Alaskan Individual Fishing Quota fishery

To meet Alaskan sampling objectives, the ports of Dutch Harbor, Kodiak, Homer, Seward, Juneau, Sitka, Petersburg, and Bellingham were staffed throughout the entire 2014 Individual Fishing Quota (IFQ) season (March 8 through November 7). St. Paul was staffed during the Area 4C Community Development Quota (CDQ) fishery from July 4 through August 27 and Sand Point was staffed from June 3 through July 26. A sampling effort summary is presented in Table 4. Otolith and length samples for each Alaskan regulatory area met the targets and exceeded the target in Area 3A.

Table 5 presents the proportion of sampled weight to landed weight in each sampled port. In 2014, there was similar variation in these proportions for each area among ports as in 2013. The regulatory area information on the Prior Notice of Landing (PNOL) list aids in minimizing this variation. The PNOL list was compiled from National Oceanic and Atmospheric Administration (NOAA) Restricted Access Management Division data on vessels notifying NOAA's Office of Law Enforcement of their intention to land IFQ fish. The PNOL List included poundage of halibut and sablefish to be landed, by associated vessel name, the accompanying Alaska Department of Fish and Game number, the unloading port, and the unloading location, date, and time. The advance knowledge of which regulatory area the catch was coming from helped samplers set sampling priorities. For landings of catch taken from multiple regulatory areas, the knowledge of the amount of catch from each regulatory area for a given landing would further reduce these variations in proportions.

IPHC samplers copied approximately 2,100 Alaskan fishing logs from ports where the IPHC had a presence, and another 100 logs for Alaskan landings delivered to other ports (Table 6). Samplers had an opportunity to collect logs from other locations when they encountered transient halibut vessels in their own ports.

Sampling the Canadian Individual Vessel Quota fishery

IPHC samplers staffed the ports of Vancouver, Port Hardy, and Prince Rupert from March 8 through November 7, 2014. Most of the Area 2B catch (92%) was landed in the three sampled Canadian ports combined (Table 2a). The samplers collected 1,966 otoliths and fork length samples and were within the target range of 1,000-2,000 (Table 4). The percentage of the catch sampled in all of Area 2B in 2014 was 42%, 6% less than in 2013 (Table 4). Table 5 presents the proportion of sampled weight to landed weight in each sampled port. The proportions of sampled weight to landed weight decreased from last year in Port Hardy, from 0.51 to 0.41, in Prince Rupert, from 0.52 to 0.39, and in Vancouver, from 1.00 to 0.84 (Table 5). Despite these factors, the number of otoliths collected in Area 2B increased in 2014 compared to the number collected in

2013 (1,122 otoliths) because of the 100% increase in the sampling rate in Port Hardy and Prince Rupert compared to the sampling rate for those ports in 2013.

IPHC samplers collected 383 Canadian logs from ports where the IPHC has a presence, and 31 logs for Canadian landings delivered to other ports in British Columbia (Table 6).

Washington and Oregon

Treaty Indian managers worked cooperatively with the IPHC and sampled the Area 2A-1 catch. In 2014, the Jamestown S'Klallam, Port Gamble S'Klallam, Swinomish, Lummi, Makah, and Quinault tribes participated in the IPHC's sampling program. The Quileute tribe has not participated in the sampling program since 2002. In the past, one sampling rate for all the tribes was used to simplify the protocol for the tribal biologists; in 2012, for example, the sampling rate was set at 10% for all tribes. In 2013 and 2014, different sampling rates were used based on the sampling rate calculation detailed in this document, the same as in all non-tribal ports. The sampling rates for the tribes are listed in Table 1. The 2014 otolith and length collections met and exceeded the target of 650 otoliths (Table 4). Sampling by the tribes can only be done opportunistically and is dependent on availability of tribal fisheries staff.

The number of fishing logs collected from the treaty Indian fisheries increased substantially, from 62 in 2013 to 120 in 2014 (Table 6).

In 2014, the Area 2A non-treaty commercial sampling collections were one otolith short of the target of 350 otoliths (Table 4). The IPHC samplers collected otoliths from 39% of the total catch landed in Area 2A (Table 4). The majority (91%) of the Area 2A non-treaty commercial sampling was conducted in Newport, Oregon, during the June 25 and July 9 directed commercial fishery openings. The rest of the samples (9%) were obtained in Bellingham, Washington during the incidental retention of halibut in the sablefish fishery.

In 2014, samplers collected 29 logs from the directed commercial fishery (Table 6), a slight decrease from the 33 collected in 2013. Part of this decrease is likely due to the lower catch limit in 2014 compared to 2013 and consequently, fewer total trips. In 2014, 14 logs were collected from the incidental retention of halibut in the sablefish fishery north of Point Chehalis, Washington.

Halibut tag collection

U.S. and Canadian samplers collected tags from 28 tagged halibut in 2014. Twenty-six of these tag recoveries were from the 2013 tagging project in which halibut were either double-tagged with an internal 'dummy' archival tag and a pink wire cheek tag, or tagged with a single external dummy archival tag on the cheek. Tagged fish from the 2013 dummy archival study were recovered in Port Hardy (one fish), Seward (nine fish), Homer (12 fish), and Kodiak (four fish). One tag from the 2011 archival tag release was recovered in Prince Rupert, and one PAT tag was recovered from a halibut landed in Juneau. The Juneau PAT tag recovery was from a 2013 study in Glacier Bay conducted by a graduate student, Julie Nielsen, from the University of Alaska Fairbanks, Juneau. Tag data collected dockside included fork lengths, otoliths, and capture location of the recovered tagged fish. Additional tag information can be found within this volume (Forsberg 2015).

Additional biological sampling and data collection projects

The projects in this section are biological sampling projects for which the port samplers were tasked with collecting additional data outside of their typical port sampling collection duties. Details on each project are presented below.

Clean otolith archive collection (COAC)

The IPHC otolith archive has, by and large, been created from structures that were collected to be used for age determination for the stock assessment. After being aged, these otoliths have been archived in a solution (glycerin/thymol) that eases age reading, which is a standard preparation for structures used for age determination. As useful as it has been, the IPHC otolith archive has limitations for other research purposes. A glycerin/thymol solution maintains readability in stored otoliths, enabling age determination; however, it renders these structures unusable for research involving some isotopic and all elemental analyses. Therefore, the IPHC has initiated another otolith archive collection: the Clean Otolith Archive Collection (COAC) comprises structures collected from all IPHC otolith collection programs and other research opportunities, including the Standardized Stock Assessment (SSA) Survey, Commercial Port Sampling Collection, NMFS Trawl Survey, and any special charters that sacrifice halibut for research. These otoliths are collected following the established collection procedures of the particular program with the added requirement of collecting the eyed-side otolith as well (collecting otolith pairs). Otoliths for the COAC will not be used for age determination, but will be cleaned, dried, and stored whole in climate-controlled conditions for future analysis (Tobin and Forsberg 2015).

The COAC is primarily supplied via the SSA survey; however, in Areas 2A, 4B, and 4CD the otolith sampling rate for the 2014 SSA is 100%. For this reason, samples from the commercial fleet were collected in these three areas to supply the COAC. In 2014, the target of 100 otoliths from these three areas was almost met (99 in Area 2A) or exceeded (Table 7).

Food, Social, and Ceremonial (FSC) collection

A portion of the Canadian catch is landed as Food, Social, and Ceremonial (FSC). In an effort to obtain biological information from these catches, samplers in Canadian ports have sampled landings of FSC fish since 2013. In 2014, a total of 12 otoliths were collected from FSC landings and four otoliths were collected in 2013.

Electronic log remote data entry (RDE) project

In large part, current port sampling data collection methods are still based on a pencil and paper technology. With recent advancements in the field of ruggedized computing, the IPHC is exploring ways to integrate the new technology to enhance this data collection program. The primary impetus for this project is to create a process that will eliminate or reduce the need for post collection data entry and increase the speed of data editing. Consequently, the data will be provided to the end users (i.e., stock assessment and research scientists) earlier than in the past, allowing more time for data analysis. This also provides greater precision, verification, and timeliness in the collected log data.

The goal was to have an electronic tablet in each Alaskan port and Bellingham, Washington, for entry of fishing data from the IPHC hard cover logbooks directly into the remote data entry (RDE) application. In 2013, testing of the RDE application was performed at the office for the

majority of the season, in conjunction with some testing, in the field, during the last part of the season, on four tablets in select ports. At the start of the 2014 season, tablets were provided to all samplers in Alaskan ports. In early September, a tablet was sent to the Bellingham, Washington port sampler. Samplers were tasked with entering data from as many logs as priorities and time allowed of the logs they collected during the course of their regular port sampling duties.

Modifications and enhancements to the application are still in progress. In 2015, RDE of log data will continue to be a regular part of the port sampling program log collection protocol.

Length-weight project

This is a new project with the purpose of collecting data at sampled IPHC ports for estimating the relationship between fork length and net weight, including the estimation of adjustments necessary to convert head-on weight to net weight. The current length-net weight relationship was estimated in 1926 and was re-estimated using 1989 data by Clark (1992) who found good agreement with the earlier curve. However, when Courcelles (2012) estimated the relationship using data collected in 2011, she found significant differences between her estimated curve and that derived from the 1989 data, although inference was limited to a relatively small part of Area 3A and to the time of the setline survey. The relationship varies both regionally and seasonally (Courcelles, 2012) and may account for the differences between the two curves. If the relationship varies among regulatory areas, there may be systematic bias in regulatory area estimates of weight or WPUE derived from length measurements. Seasonal variation could affect weight estimates that are made from data collected during only a small part of the year. Therefore, there is a need to collect data coastwide throughout the season in order to estimate spatial and seasonal variation in the length to weight relationship. The goal is for data to be collected from all ports staffed with IPHC samplers throughout the fishing season. The current relationship between fork length and net weight also includes adjustments for the weight of the head, and of ice and slime: gross landed weight (gutted, with head and ice and slime) is assumed to include 12% head weight and 2% ice and slime, which combine to give a multiplier of 0.8624 to convert gross to net weight. As a secondary goal, we also plan to collect data to provide direct estimates of adjustment factors to compare with the currently assumed values, and to assess variability in the weight of heads and ice and slime.

In 2013, a pilot phase of the project tested the equipment and methods at a selection of ports (Bellingham, Port Hardy, Prince Rupert, Petersburg, Sitka, Juneau, Seward, and Homer). Three different makes and models of scales were purchased for testing (Citizen CW-300, TitanH 300-16, and Tor Rey EQB-200). The ports of Bellingham and Juneau tested procedures using the scales available at the plants in their ports.

In 2014, most ports had scales, with the exception of Dutch Harbor, Sand Point, and St Paul in Alaska. Sampling for the length-weight project was conducted each week on the randomly selected sampling day designated on each sampler's sampling calendar. Halibut were sampled at different rates depending on length to provide an even distribution of measurements across all possible lengths. Based on overall target sampling rates for each regulatory area, the 2013 length sample data were used to calculate target sampling rates in four length categories for offloads from each regulatory area. Overall sampling rates for each area were calculated in order to target around 100 fish per month in total, with higher target rates for less common size classes. The sampling rates for line sampling were calculated based on some fish passing by while one fish is being measured. In many instances, the sampling rates had to be set at 100% of all available fish to get

as close as possible to sampling targets for length categories. To achieve the goal of estimating adjustment factors for head weight and the weight of ice and slime, samplers were tasked with recording weights of the same fish in different conditions (e.g., head-on with ice and slime present, head off with ice and slime, head-on washed of ice and slime, etc.) on a subsample of fish.

For reference, target sampling rates were provided for line and tote sampling (Table 8a and 8b). Sampling rates depend on the length of the fish, and on the method used for sampling. Sampling was done throughout the offload. If it was more practical to sample the halibut after the fish were sorted into weight categories, this was acceptable with the condition that each fish still had an opportunity to be measured and weighed. A total of 2,351 halibut were measured and weighed in 2014 compared to 831 in 2013. Table 9 indicates the sample size of halibut measured and weighed by regulatory area and month.

Alaska halibut angler release mortality (HARM) reduction pilot project

The survivability of halibut, after being caught and released, improves with less handling and quicker release times. With halibut regulations for charter fishing anglers becoming more restrictive, anglers will be forced to release more halibut either because there are size restrictions on the halibut that can be kept or the need to be selective in the choice of halibut being kept due to reduced bag limits. The HARM Reduction Project aims at reducing handling and release times by providing a means to measure halibut in the water without having to physically bring the halibut aboard a vessel for measurement. The goal is to develop a smartphone application that could be used by charter captains to accomplish this task.

This was not a project initiated by IPHC. However, under a defined memorandum of understanding, the IPHC port sampling program assisted with this project in 2014. Five port samplers from Petersburg, Juneau, Sitka, Seward, and Homer were involved in this pilot project to assess the feasibility of IPHC samplers assisting with the data collection portion of the HARM Reduction Project. They were responsible for collecting data on certain head features of halibut that might correlate to the total length of the halibut. Feedback is being provided to the project director and the port sampling team is currently reviewing how the IPHC port samplers might assist with the collection of these data during the 2015 season.

References

Clark, W. G. 1992. Validation of the IPHC length-weight relationship for halibut. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1991: 113-116.

Courcelles, D. 2012. Re-evaluation of the length-weight relationship of Pacific halibut (*Hippoglossus stenolepis*). Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 459-470.

Forsberg, J. E. 2015. Tagging studies. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 465-468.

Tobin, R. S., and Forsberg, J. E. 2015. Clean otolith archive collection. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Webster, R., Erikson, L. M., and MacTavish, K. A. 2014. Evaluation of port sampling of Sunday landings and small landings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 81-86.

Table 1. 2014 sampling rates and days by regulatory area and port.

Regulatory Area	Sampling Rate (%)	Port(s)	No. Sampling Days Per Week
2A	10	Bellingham, Newport	All days
2A-1	20 12 10 5	Bellingham LaConner Neah Bay Sequim, Port Angeles, Taholah, Westport	As many as possible
2B	2 1	Port Hardy, Prince Rupert Vancouver	5 days
2C	6 4	Sitka All other ports	5 days
3A	2 1.5 1	Petersburg Juneau, Homer All other ports	5 days
3B	4 2.5 2	Dutch Harbor Homer All other ports	5 days
4A	12	All ports	5 days
4B	20 15	Dutch Harbor All other ports	5 days
4C&D	12 8	St. Paul All other ports	4 days 5 days

Table 2a. 2014 otolith targets and data used in determining the sampling rates for IPHC Regulatory Areas 2B, 2C, 3A, and 3B.

	Regulatory Areas			
	2B	2C	3A	3B
Otolith target (no.)	1,500	1,500	1,500	1,500
2013 Average halibut weight (lbs)	25.68	31.11	20.30	19.24
Sample size (000 lbs)	38.5	46.7	30.5	28.9
2014 Catch limit (000 lbs)	5,793	3,319	7,318	2,840
2013 Landings into sampled ports (000 lbs)	5,313	2,093	8,892	3,435
Proportion landed in 2013 sampled ports	0.912	0.732	0.821	0.851
Overall ratio to be sampled in 2014	0.007	0.019	0.005	0.012
Proportion of 2013 landed weight with otolith sampling	0.527	0.444	0.318	0.551
Sampling ratio for estimated weight available for sampling in 2014	0.014	0.043	0.016	0.022
2014 Final sampling rates (%)	1.5	4.0	1.5	2.0
2014 Average halibut weight	24.08	31.62	19.98	18.49
2014 proportion landed in sampled ports	0.923	0.701	0.825	0.823

Table 2b. 2014 otolith targets and data used in determining the sampling rates for IPHC Regulatory Areas 2A-1, 2A, 4A, 4B, and 4C&D.

	Regulatory Areas				
	2A-1	2A	4A	4B	4C&D[1]
Otolith target (no.)	650	350	1,500	1,500	1,500
2013 Average halibut weight (lbs)	20.19	18.38	23.58	26.56	23.03
Sample size (000 lbs)	13.1	6.4	35.4	42.5	34.5
2014 Catch limit (000 lbs)	308	168	850	1,140	1,193
2013 Landings into sampled ports (000 lbs)	283	114	830	539	947
Proportion landed in 2013 sampled ports	0.900	0.622	0.688	0.446	0.638
Overall ratio to be sampled in 2014	0.047	0.057	0.060	0.084	0.045
Proportion of 2013 landed weight with otolith sampling	0.539	0.636	0.535	0.540	0.478
Sampling ratio for estimated weight available for sampling in 2014	0.088	0.090	0.113	0.155	0.095
2014 Final sampling rates (%)	10	10	12	15	8 &12
2014 Average halibut weight	18.93	18.21	21.38	23.42	21.23
2014 proportion landed in sampled ports	0.900	0.592	0.737	0.393	0.750

[1]4C&D includes CDQ

Table 3. The proportion of IPHC Regulatory Area 3B catch that was landed from each of six statistical areas, including and excluding the additional staffing of Sand Point, Alaska, for 2013 and 2014.

Year	Statistical Area	Proportion in staffed ports excluding Sand Point	Proportion in staffed ports including Sand Point	Proportion in all ports
2013	290	55	52	45
2013	300	19	18	16
2013	310	9	9	9
2013	320	8	12	13
2013	330	6	7	11
2013	340	2	3	6
2014	290	52	49	42
2014	300	20	19	16
2014	310	13	14	13
2014	320	6	7	12
2014	330	2	4	8
2014	340	7	7	9

Table 4. Summary of 2014 otolith targets, collected otoliths, vessels sampled and the percentage of the total landed weight, represented by the weight of landings from which otoliths were sampled.

Regulatory Area	Otolith Target	Collected otoliths	No. landings sampled	Percent of catch sampled
2A-1	650	725	130	39
2A	350	349	28	41
2B	1,500	1,966	142	42
2C	1,500	1,492	127	30
3A	1,500	2,165	158	50
3B	1,500	1,624	64	50
4A	1,500	1,993	29	43
4B	1,500	1,013	8	13
4C&D	1,500	1,643	36	34
Totals	**11,500**	**12,970**	**722**	**42**

Table 5. P roportion of total 2014 halibut landings represented by the weight of landings from which otoliths were sampled, separated by IPHC Regulatory Area, and listed by key ports.

Port	2A	2B	2C	3A	3B	4A	4B	4C&D
Newport	0.68							
Bellingham	0.93		0.53	0.78				
Treaty Indian[1]	0.43							
Vancouver		0.84						
Port Hardy		0.41						
Prince Rupert		0.39						
Petersburg			0.51	0.66				
Sitka			0.37	0.57				
Juneau			0.37	0.42				
Seward				0.66	0.57			
Homer				0.52	0.61			
Kodiak				0.63	0.61	0.71	0.60	0.97
Dutch Harbor						0.60	0.28	0.47
Sand Point					0.70	0.65		
St. Paul								0.42

[1]Area 2A-1 tribes that participated in the commercial sampling program.

Table 6. The number of halibut fishing logs collected from landings into key ports in 2014, and the total number of logs collected from all ports.

Key Ports	US	Canada	
Newport	29		
Bellingham	131		
Treaty Indian[1]	120		
Port Hardy		186	
Prince Rupert		184	
Vancouver		13	
Petersburg	244		
Sitka	371		
Juneau	153		
Seward	275		
Homer	336		
Kodiak	285		
Dutch Harbor	124		
Sand Point	57		
St. Paul	207		**Grand total**
Total key ports	**2,332**	**383**	**2,715**
Total all ports	**2,403**	**414**	**2,817**

[1]Area 2A-1 tribes that participated in the commercial sampling program.

Table 7. Summary of 2014 COAC targets and collections.

Year	Regulatory Area	Otolith Target	Collected otoliths
2014	2A	100	99
2014	4B	100	105
2014	4CD	100	124

Table 8a. Sampling rates and weight categories used when line sampling for the 2014 length-weight pilot project.

Fishing area	Sampling rate (%) for line sampling for fish of length L				Overall target sampling rate (%)
	70 < L ≤ 100 cm (under 20 lb)	100 < L ≤ 120 cm (20-40 lb)	120 < L ≤ 150 cm (40-80 lb)	L >150 cm (over 80 lb)	
2A	100	100	100	100	20
2B	2	3	10	100	4
2C	20	25	100	100	11
3A	2	17	100	100	4
3B	3	100	100	100	6
4A	100	100	100	100	20
4B	100	100	100	100	20
4CD	100	100	100	100	20

Table 8b. Sampling rates and weight categories used when tote sampling for the 2014 length-weight pilot project.

Fishing area	Sampling rate (%) for within a tote for fish of length L				Sampling rate (%) for selecting totes
	70 < L ≤ 100 cm	100 < L ≤ 120 cm	120 < L ≤ 150 cm	L >150 cm	
3A	9	33	50	100	20
3B	13	50	50	100	20
4A	50	50	50	100	20
4B	50	50	50	100	20
4CD	50	50	50	100	20

Table 9. Sample sizes of halibut lengthed and weighed by IPHC regulatory area and month in 2014.

Month	2A	2B	2C	3A	3B	4A
March		34	17	101	43	
April	94	24	99	78	27	
May	109	46	78	148	88	118
June		19	60	105	166	
July		35	11	11	16	
August		12	80	79	185	
September	47	48	35	24	25	
October	7	65	24	94	99	
Total	257	283	404	640	649	118

Age distribution of the commercial halibut catch for 2014

Joan E. Forsberg

Abstract

The age distribution of halibut sampled from the 2014 commercial catch is summarized. Fish from six to 40 years old were captured, with 12-year-olds comprising the largest age group in the overall catch. Average age for all areas combined was slightly lower than in 2013.

Age distribution

The 2002 year class (12-year-olds) accounted for the largest proportion (in numbers) of the sampled commercial catch (17%) for all areas combined in 2014 (Table 1). The next most abundant year classes for all areas combined were 2003 and 2001, accounting for 14 and 13% of the sampled catch, respectively. Twelve-year-olds were the most abundant age class in Regulatory Areas 2C, 4A, 4B, and 4D, and the second most abundant in Areas 2B, 3A, and 4C. In Area 4C, 11-year-olds made up the most abundant age class, while 13-year-olds were the most abundant age class in Area 3A. Ten-year-olds (the 2004 year class) accounted for 12% of the sampled catch in numbers and were the most abundant age class in Areas 2A, 2B, and 3B.

The average values for age, length, and estimated weight by regulatory area for 2014 are presented in Table 2. Average size (measured fork length) of sampled halibut increased in Area 2C in 2014, but decreased in all other areas. Average fork length for all areas combined decreased by 2.0 cm in 2014.

The average age of fish sampled from Areas 4B increased in 2014 relative to 2013, while average ages from all other areas decreased (Table 3). The average age from all areas combined in 2014 (13.3 years) was 0.5 years lower than in 2013.

The youngest and oldest halibut in the 2014 commercial, or *market*, samples were determined to be 6 and 40 years old, respectively. There were 20 fish determined to be six years old: 12 from Area 2B measuring between 81 and 113 cm, three from Area 3A measuring between 87 and 102 cm, two each from Areas 2C and 3B measuring between 86 and 100 cm, and one from Area 4A measuring 82 cm. The 40-year-old was captured in Area 4B, and had a fork length of 115 cm. The largest halibut in the 2014 commercial samples was a 218-cm fish from Area 3A, which was determined to be 20 years old. The smallest halibut in the 2014 commercial catch samples was a 73-cm fish from Area 2B, aged at 10 years old. Length frequencies by regulatory area for halibut sampled in the 2014 commercial catch are presented in Table 4.

Table 5 contains percent agreement values for quality control (QC) readings. All QC readings from 2002 through 2013 were conducted on burned or baked otolith sections. QC readings for years prior to 2002 were either surface ages or burned/baked section ages. Ten percent of each year's market samples are read twice for QC. At the time of writing, QC readings for the 2014 commercial samples were not complete. The remainder of the QC readings of 2014 market samples will be performed over the winter of 2014-15.

The commercial otolith collection target is 1,000 for Area 2A and 1,500 (±500) per regulatory area for each of Areas 2B, 2C, 3A, 3B, 4A, and 4B, and Areas 4C/4D combined. Otolith targets were met in all areas in 2013.

In 2014, port samplers reported collecting 12,977 market sample otoliths for stock assessment; however, only 12,606 otoliths were aged. Ages could not be determined for 291 otoliths because they were crystallized, right-sided, or badly broken. Another 80 otoliths were not aged because they became mixed up during transit to the office and could not be matched to the correct sample information.

An additional 334 otolith pairs were collected by port samplers for the clean otolith archive collection; these otoliths were not aged but were dried and stored for future studies (Tobin and Forsberg 2015). The otolith collection numbers presented in the text and tables of this report do not include clean otolith archive samples.

Reference

Tobin, R. S. and Forsberg, J. E. 2015. Clean otolith archive collection. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Table 1. Age distribution of commercial catch of Pacific halibut by regulatory area, 2014.

Age	Regulatory Area									
(years)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
6		12	2	3	2	1				**20**
7	3	17	12	5	7			1	1	**46**
8	49	44	27	18	39	13	3	7	2	**202**
9	180	207	101	55	126	103	18	23	24	**837**
10	211	289	125	140	255	233	54	81	87	**1,475**
11	186	245	176	185	231	320	80	266	131	**1,820**
12	175	285	257	285	230	332	144	222	180	**2,110**
13	101	210	244	292	187	259	131	80	121	**1,625**
14	66	215	192	273	113	131	112	47	72	**1,221**
15	26	155	142	256	135	102	88	23	39	**966**
16	9	96	69	140	78	86	63	10	40	**591**
17	7	50	37	111	53	35	44	2	11	**350**
18	5	38	26	93	30	35	30	6	11	**274**
19	5	26	21	47	24	27	25	7	9	**191**
20	1	15	12	50	20	20	22	1	13	**154**
21	3	10	6	28	10	9	17	2	10	**95**
22		7	4	31	9	15	8	1	9	**84**
23	1	7	2	29	7	15	8	1	4	**74**
24	1	5	1	24	4	16	13	1	9	**74**
25		2	2	17	10	25	28		6	**90**
≥26	2	16	10	43	10	94	94	3	35	**307**
Total	1,031	1,951	1,468	2,125	1,580	1,871	982	784	814	**12,606**

Table 2. 2014 commercial samples by regulatory area: mean age, mean length, mean net weight, and otoliths collected and aged.

Regulatory Area	Mean age (years)	Mean length (cm)	Mean weight (lbs)[1]	Otoliths collected[2]	Otoliths aged[3]
2A	11.2	94.7	18.6	1,069	1,031
2B	12.6	100.8	23.9	1,978	1,951
2C	12.9	110.0	31.6	1,492	1,468
3A	14.5	96.4	20.0	2,165	2,125
3B	12.7	94.2	18.4	1,624	1,580
4A	13.7	98.4	21.5	1,993	1,871
4B	15.9	100.9	23.5	1,013	982
4C	11.9	96.8	21.0	801	784
4D	13.8	98.3	21.6	842	814
All Areas	**13.3**	**99.0**	**22.3**	**12,977**	**12,606**

[1]Weights calculated from measured fork lengths entered through November 25, 2014 (not including clean otolith archive samples)
[2]From market sample data entered through November 25, 2014 (not including clean otolith archive samples)
[3]Numbers of otoliths aged by November 25, 2014

Table 3. Mean age (in years), mean length (cm) and estimated mean net weight[1] (in pounds) of sampled commercially-caught Pacific halibut by regulatory area, 200-2014.

Reg. Area		Year									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A	Age	11.9	13.4	12.3	12.1	11.5	11.4	11.7	11.5	11.6	11.2
	Length	98.3	95.7	96.1	93.5	95.5	94.2	93.2	92.9	96.1	94.7
	Weight	20.9	19.2	19.6	17.7	19.1	18.3	17.7	17.4	19.6	18.6
2B	Age	12.0	11.8	11.8	12.2	11.7	11.6	11.9	12.0	12.6	12.6
	Length	96.9	96.3	97.0	97.0	97.2	98.9	97.9	99.4	103.0	100.8
	Weight	21.0	20.5	20.9	21.2	21.4	22.5	21.5	22.8	25.7	23.9
2C	Age	12.4	12.4	12.7	13.1	12.9	12.2	12.7	12.4	13.0	12.9
	Length	107.3	106.9	105.7	106.7	107.5	105.1	106.5	109.2	109.4	110.0
	Weight	29.3	28.6	28.1	28.9	29.6	27.3	28.6	31.0	31.2	31.6
3A	Age	15.6	15.5	16.0	15.9	15.1	15.2	15.0	15.0	15.1	14.5
	Length	103.3	103.2	100.3	100.3	99.1	97.5	95.7	95.6	96.7	96.4
	Weight	25.2	25.0	22.8	22.9	22.1	20.9	19.4	19.2	20.2	20.0
3B	Age	14.4	14.3	13.8	14.0	12.8	12.7	12.7	12.6	12.8	12.7
	Length	101.4	99.1	99.8	97.1	97.2	96.0	95.2	95.2	95.4	94.2
	Weight	23.8	21.9	22.7	20.3	20.6	19.7	19.1	19.1	19.2	18.4
4A	Age	13.3	14.5	14.5	15.6	15.4	13.9	15.6	15.7	15.0	13.7
	Length	106.0	105.8	102.7	103.4	101.2	99.8	103.4	104.1	100.9	98.4
	Weight	28.7	27.9	25.4	25.9	24.0	22.8	26.0	26.3	23.7	21.5
4B	Age	15.8	15.0	16.0	15.5	16.7	16.4	16.0	16.3	15.8	15.9
	Length	101.9	105.2	108.5	110.6	107.2	107.5	109.0	105.5	104.4	100.9
	Weight	24.0	27.1	30.4	33.3	29.2	29.6	31.1	27.4	26.8	23.5
4C	Age	10.6	10.5	11.0	11.7	12.2	13.2	12.9	12.6	12.5	11.9
	Length	107.7	109.0	105.6	103.8	102.4	101.4	100.4	99.6	99.3	96.8
	Weight	29.8	30.6	27.9	26.3	25.4	23.8	23.3	22.9	23.3	21.0
4D	Age	13.4	16.7	15.3	16.1	15.9	16.1	14.7	14.9	15.9	13.8
	Length	108.7	106.9	104.6	103.2	104.3	102.7	99.3	99.2	100.3	98.3
	Weight	30.5	28.3	26.6	25.5	26.5	25.3	22.1	21.7	22.8	21.6
Total	Age	13.4	14.0	14.1	14.3	13.7	14.0	13.7	13.8	13.8	13.3
	Length	103.4	102.3	102.1	101.2	100.6	100.8	99.1	100.2	101.1	99.0
	Weight	25.9	24.8	24.8	24.2	23.6	23.8	22.4	23.2	24.0	22.3

[1]Weights calculated from measured fork lengths. Excludes clean otolith archive samples.

Table 4. Number of halibut sampled by 5-cm length category in the 2014 commercial catch by regulatory area (not including samples collected for the clean otolith archive). The 80-84 cm category is further divided to designate the U32/O32 split within that category.

Fork length	Regulatory Area									
(cm)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
70-74		2								2
75-79	9	12			1	2	2	50	3	79
80-81[1]	24	58	3	18	40	38	13	59	13	266
82-84[2]	150	218	36	237	269	179	82	92	73	1,336
85-89	255	338	131	518	416	409	185	144	177	2,573
90-94	192	222	179	441	301	349	140	98	146	2,068
95-99	131	230	154	321	205	285	134	86	122	1,668
100-104	120	183	173	189	134	242	126	66	102	1,335
105-109	78	158	147	138	95	149	92	50	68	975
110-114	44	129	137	104	52	113	67	41	35	722
115-119	26	89	106	58	32	74	58	37	35	515
120-124	13	72	101	46	21	36	36	18	13	356
125-129	9	62	72	31	20	31	25	13	22	285
130-134	5	39	61	23	15	24	13	17	12	209
135-139	6	33	60	15	11	18	8	11	6	168
140-144	2	21	39	12	1	10	15	10	3	113
145-149	1	12	22	4	4	10	4	1	2	60
150-154		13	23	3	3	5	3	2	3	55
155-159	3	6	14	3	2	3	4	4	3	42
160-164	1	6	7	1		4	5	1		25
165-169		2	6			2				10
170-174			2					1	2	5
175-179		1	2	1		1	1		2	8
180-184			1			2				3
185-189				1	2	1				4
190-194		1	1							2
210-214		1								1
215-219				1						1
Total	**1,069**	**1,908**	**1,477**	**2,165**	**1,624**	**1,987**	**1,013**	**801**	**842**	**12,886**

[1]U32
[2]O32

Table 5. Between-reader percent agreement for market sample ages 1996-2013 (CV = coefficient of variation, APE = average percent error).

Year	Total aged	No. aged twice	Percent agreement (± 1 year)	CV	APE
1996	13,452	1,839	92.3	2.8	2.0
1997	15,500	2,203	93.6	2.4	1.7
1998	14,395	2,110	91.9	2.6	1.8
1999	12,796	1,117	92.0	2.5	1.8
2000	13,982	1,002	88.8	3.0	2.1
2001	13,181	2,025	86.3	3.9	2.8
2002	17,770	2,135	87.9	3.2	2.3
2003	13,738	984	82.6	3.9	2.8
2004	11,866	809	82.6	3.6	2.5
2005	13,945	1,315	85.9	3.7	2.6
2006	12,330	1,241	88.3	3.5	2.5
2007	13,910	1,488	85.8	3.9	2.8
2008	13,460	1,337	90.3	3.1	2.2
2009	13,718	1,348	91.5	2.9	2.0
2010	16,106	1,617	91.7	2.9	2.1
2011	11,215	1,131	88.4	3.4	2.4
2012	12,981	1,364	90.3	2.8	2.0
2013	11,039	1,259	89.4	2.7	1.9

Overview of data sources for the Pacific halibut stock assessment and related analyses

Ian J. Stewart

Introduction

This document provides a summary of the data sources available for the Pacific halibut stock assessment, apportionment, harvest policy, Management Strategy Evaluation (MSE), and related analyses. It began as background for the 2013 stock assessment, and serves as an ongoing effort to provide transparent documentation and direct evaluation of the data and processing methods employed. For each data source, a narrative is provided which includes the source, steps taken to filter and analyze the data, and the key quantities available for subsequent analysis. Data sources are described within the categories of: fishery-independent, fishery-dependent, and auxiliary sources of information. Some of the detail presented in 2014 (Stewart 2014) has not been repeated here, where there has been no change to the methods or results.

Also provided in this document is a brief synopsis of important changes to various data sources and processing, as well as a list of data sources or analyses that are currently not directly used, but are potentially available for future analysis. The latter includes some comment on avenues for additional data collection and/or analysis.

Fishery-independent data

Fishery independent data are generated each year by the IPHC's setline survey, covering most of the range of Pacific halibut habitat from the northern Bering Sea and Aleutian Islands to California, and depths of 20-275 fathoms (Soderlund et al. 2012, Henry et al. 2015). The setline survey generates catch rate information, as well as biological samples from individual fish sampled randomly from the catch including: sex, length, age, maturity, and presence of prior hooking injury. These data are reprocessed each year for use in the stock assessment as new observations become available (Fig. 1). In 2014 a substantial re-analysis of the survey data, including expanded survey coverage from 10-400 fathoms (in Area 2A and Area 4A), northern California, as well as calibration of the survey catch rates with those observed in the National Marine Fisheries Service (NMFS) sablefish longline survey in Alaska. These changes are described in Webster et al. (2015) and are reflected in all of the data presented here.

Survey WPUE (Weight-Per-Unit-Effort)

The catch-rate information from the setline survey serves as the primary source of trend information (along with commercial catch-rates) for the stock assessment. The area-specific setline survey indices of abundance (weight-per-unit-effort, WPUE) are calculated based on the catch in weight relative to the amount of gear deployed at each station. Survey effort for a particular station is standardized to an effective skate (*ES*) that is 1,800 feet long, with 100 hooks (and therefore an 18-foot average spacing), based on the number of skates fished (*S*), the average number of hooks fished per skate (N_h), and the hook-spacing (H_s; Fig. 2) based on the relationship given by Hamley and Skud (1978):

$$ES = S \cdot \left(\frac{N_h}{100}\right) \cdot 1.52 \cdot (1 - e^{-0.06 \cdot H_s})$$

Because the hook spacing is standardized for all recent survey operations, the only variability in this relationship occurs due to changes in the number of hooks (N_h) as a result of missing or extra hooks on a particular skate or skates. The weight of each halibut caught is estimated from the individual length observations via the weight-length relationship (see Auxiliary inputs section below). The sum of the catch weight is divided by the number of effective skates to obtain a station-level WPUE. These observations are then combined within a regulatory area (Fig. 3).

The area-specific WPUE is summarized via a simple arithmetic mean observed value (and SE) of WPUE for all stations (s) sampled within a regulatory area (a) during each year's (y) survey (Fig. 4):

$$\overline{I}_{a,y} = \sum_{s=1}^{Nstation} \frac{WPUE_{s,a,y}}{N_{a,y}}$$

These annual area-specific means are then weighted by the geographic extent of suitable depths occupied by Pacific halibut within each regulatory area (g_a, 0-400 fathoms) relative to the entire coast (Fig. 4). The weighted values are then summed to generate a coast-wide index of abundance:

$$I_y = \sum_{a=1}^{Areas} \overline{I}_{a,y} * \frac{g_a}{\sum_{a=1}^{Areas} g_a}$$

Due to the expansion of survey efforts into deeper and shallower waters, anomalies in historical survey coverage, a number of calibrated expansions, adjustments are made to the WPUE for specific areas and years in order to make the coast-wide time-series as consistently representative as possible. These have been outlined in previous or concurrent documents (Webster and Hare 2012, Webster et al. 2014a, Webster et al. 2014b, Webster et al. 2015).

After these adjustments have been applied, the coastwide survey legal-size (above the 32 inch minimum size limit, or O32) WPUE index is estimated to have increased by 2% from 2013 to 2014 (Table 1, Fig. 5). Although the O32 WPUE is most directly comparable to the catch rates observed in the commercial fishery, there is potentially important trend information in the catch of sublegal halibut (U32) as well. The total WPUE (including all sizes of halibut captured by the survey) increased by 6% from 2013 to 2014 (Figs. 5-6). Both series reflect a one-year increase across most regulatory areas, and are consistent with a generally flat coastwide trajectory since about 2010. The overall coastwide trend masks important differences in the historical declines, most pronounced in Areas 3A-4B, as well as the relative stability observed in Area 2 (Fig. 7).

In 2014, on the recommendation of the IPHC's Scientific Review Board (SRB), the stock assessment began fitting directly to the Numbers-Per-Unit-Effort (NPUE) from the setline survey. This avoids converting observed lengths to weights based on the length-weight relationship, and provides a delineation between changes in the number of fish and changes in the size of those fish. Broadly, very similar trends have been observed for NPUE when compared to the WPUE;

however both the O32 and total NPUE show more modest historical declines (Fig. 8). When aggregated into geographic regions, the NPUE data also show a flat trajectory for Area 2, and historical declines for Areas 3, 4, and 4B (Fig. 9-10).

Prior to 1997, survey coverage was sparse enough to preclude a more complex approach to estimate coastwide catch rates. However, data are available for at least several regulatory areas in a number of earlier years. These data represent only Areas 2B, 2C, and 3A (the geographic 'core' of the stock) for the years 1982-1996, and only Areas 2B and 3A for the years 1977-1981. In 1984, among other changes to the station design and coverage, the setline survey (following the commercial fishery the year before) converted their standard gear to include circle hooks; this greatly increased catch rates from previous years.

Survey age distributions

Otoliths are collected randomly from halibut captured by the setline survey, with sampling rates adjusted annually by regulatory area to achieve a similar number of samples from each area in each year. All otoliths collected during survey activities are read each year by IPHC age-readers. Because the survey catch is sampled randomly at the same rate for all stations within a given regulatory area and year, the raw frequency of ages is an appropriate estimate of the aggregate for the area. Age distributions differ between male and female halibut and among regulatory areas, with older fish comprised of primarily males, and occurring in much greater numbers in the western and northern regulatory areas (Fig. 11). Area 2 showed a somewhat greater number of age 9-10 halibut in 2014; however these ages were not as pronounced in other regulatory areas, particularly for male halibut.

In order to weight these area-specific distributions, an estimate of the number of halibut in each area is required. This is obtained via weighting the NPUE values by the same geographic proportions used for WPUE. The relative numbers in each regulatory area then provide a weighting for combining the age-frequency distributions into a coastwide aggregate (Fig. 12). In recent years, the strength of the 1987 year class has been particularly evident in these data. The age frequencies over the last five years do not show any signs of strong incoming cohorts (as 6-8 year-old fish).

Ages have been aggregated at age 20 (all ages 20 and older combined) for all data (survey and fishery) collected prior to 2002 when the break-and-bake ageing method was adopted for all halibut age-reading by the IPHC (see section on ageing bias and imprecision below). Most ages read prior to 2002 used surface ageing methods, except for 1998, where a randomly selected subsample of otoliths were re-aged (during 2013) and ages can be more reliably interpreted out to age-25 (see Stewart 2014, and Forsberg and Stewart 2015 for more information on these samples).

As for the catch-rate data, there are some sparse age data available prior to 1997. These age data represent only Areas 2B, 2C, and 3A for the years 1982-1996, and only Areas 2B and 3A for the years 1980-1981. These earlier data do not reveal any particularly strong cohorts, nor do the cohort strengths appear appreciably different for male and female halibut. The age data was also aggregated into geographic regions, revealing important differences in age structure (Fig. 13-14). Specifically, there have been very few halibut greater than age 20 of either sex observed in Area 2, but fish of those ages, and particularly males, become more common in the western and northern portions of the stock. Area 4B shows the highest proportion of age 25+ halibut for both males and females.

Survey weight-at-age

The survey collects individual length observations on all halibut captured, which are then converted to estimated weights via the length-weight relationship (see section below). Age estimates are also available for a random subsample of these lengths.

Ages consist of primarily surface ages prior to 2002, and exclusively break-and-bake ages from 2002 to the present. Prior analyses of weight-at-age attempted to correct for the potential bias of surface ages by converting the weights corresponding to surface ages to the 'true' weight at age given an estimated level of bias (and some assumption of the underlying age structure). Investigation of the data prior to 2002 revealed that many of the surface ages also had corresponding break-and-bake ages that were not being included in the analysis (see summary of ageing bias and precision below). Replacing all surface ages with break-and-bake ages (where available) in the weight-at-age calculations appears to adequately address the differences in the ageing methods for the recent data.

Because the sampling of ages is random within the survey catches for an area each year, the average weight-at-age by area, sex, and year is calculated. Where there are very few individuals in the population of a particular age, the number of survey age samples is also small (the age samples are not length-stratified). This pattern, in combination with incomplete survey sampling for some areas and years, results in a small number of missing weights-at-age within area and year combinations. These are simply interpolated from adjacent years. Because the survey captures few fish younger than age 7 or older than age 25, all fish outside this range are aggregated to these 'minus' and 'plus' groups. Although there has been a very strong trend of declining weight-at-age in recent years, there are marked differences in the magnitude of this decline among regulatory areas (Figs. 15-22, plotted only from ages 7-18 here for clarity). There also appear to be some patterns associated with specific cohorts; e.g., females in Area 2C born in the late-1990s (Fig. 16, upper panel). There do not appear to be consistent or strong trends from 2010-2014 in the area-specific data.

These different trends among areas require appropriate weighting of the areas to create a coastwide time-series that represents the entire stock. The estimates of numbers of fish generated from survey NPUE and geographic extent are used to weight the individual regulatory areas. At the coastwide level the stronger declines observed in the areas for which the greatest number of halibut are estimated to be present are evident, especially for the years prior to 2010 (Fig. 23). A broader comparison of historical observations predicted from a mix of fishery and survey data (See Fishery weight at age section below) indicates that the declines in size-at-age were even more pronounced from the mid-1970s to the mid-1990s than in the recent period covered by the setline survey (Fig. 24).

For input to the stock assessment, a full matrix of weight-at-age by year and sex is required, despite the small number of fish present in the youngest and oldest ages. To complete the matrix, a linear ramp in weight-at-age is applied below age 7. For the plus group (25+), the average age is calculated; this average age is then used to extrapolate the weight-at-age for ages 25-30. This is necessary because the average weight-at-age for all 25+ halibut combined should not be attributed to exactly age 25: the average age must be >25 unless all fish are exactly 25.

Spawning output-at-age

Survey data are also used to define the population-level weight-at-age and spawning biomass. Unlike the survey index calculation, where interannual sampling variability is logically included,

the true population level quantities should be smoother than the raw observations. In analyses previous to 2013, these quantities had been smoothed across ages within each year without regard for sample size, which induced significant correlation among ages, and spurious 'dog-legs' that extended over several adjacent ages. Reanalysis of these quantities in 2013 (Stewart 2014) indicated that applying a smoother across years within each age produced results more consistent with those expected for population level values. These summaries most clearly show the population-level decline in weight-at-age observed for both male and female halibut over the recent time-series available from the survey (Fig. 24). Survey observations of weight-at-age might include some bias relative to the population if size-based selectivity is operating on the distribution of lengths within each age. However, the matrix of population-level weight-at-age is most important in the assessment for those ages that are mature, for halibut mainly ages 11 and higher (see Maturity section below) which are less likely to experience significant bias.

Fishery-dependent data

Commercial fishery landings

An annual estimate of total mortality of halibut from all sources is required for all stock assessment and related analyses. Removals can be categorized into five major components: fishery landings, fishery wastage (a combination of sub-legal and legal-sized fish), sport (recreational), personal use or subsistence removals, and bycatch of halibut in fisheries targeting other species (Fig. 26).

Landings of halibut from the directed fishery are documented through the use of commercial fish tickets, reported to the IPHC (Gilroy et al. 2015). From 1981 to the present, these landings are fully delineated by regulatory area (including all of the portions of Area 4; Fig. 27). Prior to 1981, landings are available only in aggregated form for all of Regulatory Area 4. Landings from 1935 to 1980 are not currently included in the IPHC's database; however previous analysts have left a number of 'flat files' which appear to correspond well with tables published in technical reports, and other IPHC documents. Because the raw data are not able to be reprocessed directly, the landings estimates prior to 1981 are more uncertain than those after 1981. Historical landings prior to 1935 were reconstructed within current regulatory areas from summaries by historical statistical areas (Bell et al. 1952). Reported landings of halibut begin in 1888; however, already over one million pounds were being landed per year at that time. The reconstruction by regulatory area of total landings included some use of ratios between Areas 2A and 2B among adjacent years for ambiguous records, therefore the area-specific distributions are therefore more uncertain than the total landings. Several patterns emerge from the longer time series of landings including: the period of substantially reduced fishing in the 1970s in all areas, and the sequential exploitation of Areas 2, 3, and 4 over the entire time series (Table 2, Fig. 28).

Sport (recreational) removals

Sport or recreational removals are reported to the IPHC by the various agencies in charge of managing these fisheries, including Alaska Department of Fish and Game, the Department of Fisheries and Oceans Canada, and the states of Washington, Oregon, and California (Kaimmer 2015). The scientific basis for data collection programs, analyses, and the quality of the subsequent estimates vary considerably by year and source. The 2014 estimates (and several previous years, where available) include mortality estimates for released fish. This is the first year that recreational

discard mortality has been included in IPHC analyses. It is generally assumed that there was little sport fishing for Pacific halibut prior to the mid-1970s. Sport removals have grown rapidly since that time, with peak harvests estimated at over 10 million pounds annually during the mid-2000s. They have been reduced in recent years as the IPHC has lowered stock-wide mortality (Fig. 29). Among regulatory areas, Area 3A represents over half of the total removals, with Areas 2C, 2B, and 2A each contributing somewhat less (in declining order).

Personal use or subsistence removals

Subsistence harvest estimates are provided to the IPHC by the DFO and NMFS (Gilroy 2015). Estimates are not generated annually in all cases, and therefore some values are applied through intervening years until the next estimate is made available. This has been the case for the most recent several years. There are currently no estimates available prior to 1991. The time-series created from these estimates is relatively noisy, but occurs on a scale much smaller (< 2 million pounds) than other critical inputs to the analyses (Fig. 30).

Commercial fishery wastage

'Wastage' describes all mortality of halibut that occurs during the directed fishery, but that does not become part of the landed catch. There are three main sources of wastage: 1) fish that are estimated to have been captured by fishing gear that was subsequently lost during fishing operations, 2) fish that are discarded for regulatory reasons (e.g., the vessel's trip limit or harvester's IFQ limit have been exceeded), and 3) fish that are captured and discarded because they are below the legal size limit of 32 inches. The methods applied to produce each of these estimates differ due to the amount and quality of information available (see Gilroy and Stewart 2015).

Based on these methods, wastage in the commercial fishery is estimated to have been highest in the late 1980s, subsequently declining (particularly in Area 3A in 1995 when the derby fishery was converted to a quota system), and then increasing from 1995 to 2010 as the size-at-age of halibut declined and more fish at older ages remained below the minimum size limit (Fig. 31, upper panel). The estimates of wastage cannot be delineated within Regulatory Area 4 prior to 1981, but there is very little wastage estimated prior to that time (Fig. 31, lower panel).

Bycatch in non-target fisheries

The estimated bycatch from non-target fisheries by regulatory area is reported to the IPHC by the NMFS and DFO on an annual basis (Williams 2015). These estimates vary greatly in quality and precision depending upon year, fishery, type of estimation method, and many other factors. Bycatch has been delineated among Areas 4A, 4B, and 4CDE only from 1990 to the present, during which time it has declined from a peak of over 20 million pounds to a projected value of approximately 9.3 million pounds in 2014 (Fig. 32, upper panel). Over the last several years bycatch has decreased in most regulatory areas, and stayed relatively flat for all of Area 4 (Fig. 32, lower panel), but has increased in Area 4CDE. Prior to 1991, available bycatch estimates are aggregated for all of Area 4. From the 1960s to 1990s, annual values were variable with a peak in the early 1960s corresponding to the peak of foreign fishing in (currently) Alaska waters, primarily Areas 3A and 3B. There was likely less bycatch prior to the development of the foreign fishery in U.S. waters in the early 1960s; however, bycatch estimates are only available from 1962 to the present.

Summary of total halibut removals

Recent aggregate total removals from all sources reveal that although the directed commercial fishery represents the majority of the anthropogenic mortality, other sources, including bycatch and sport removals, tend to contribute a larger proportion when the total is lower (Fig. 33). Total removals in 2014 are approaching those from the 1970s and below the 100-year average of 64 million pounds. Recent total removals from all sources by regulatory area reveal that Area 3A has been the dominant contributor to total mortality throughout the last five decades, that Area 4 has increased in its proportion of the total, and that the other areas have been somewhat consistent (Table 3, Fig. 34).

The full time-series of estimated removals illustrates that all four of the major peaks in the commercial fishery mortality have been of similar magnitude (around 70 million pounds) but that each peak has been larger than the previous with regard to total mortality from all sources (Table 4, Fig. 35). When the removals by source are compared among regulatory areas, there are a number of differing patterns in magnitude and distribution (Figs. 36-38).

Fishery catch-rate and biological data

Directed commercial fishery data is processed similarly to the setline survey data (Fig. 39), with the important exception that there are no sex-specific biological observations available due to the dressing of halibut at sea.

Directed fishery WPUE

Commercial fishery logbook data is collected by port samplers, and reported directly to the IPHC by fishermen. This dataset represents a valuable source of information about many aspects of the commercial fishery, including seasonal and spatial patterns, gear usage, and other details. A relatively simple method is employed to calculate the annual index of fishery WPUE, and a detailed exploratory analysis of the logbook standardization data and methods was completed during 2014 (Monnahan and Stewart 2015).

The data that are included in the current fishery WPUE standardization are: the regulatory area of fishing (regardless of the port of delivery), the type of fishing gear used (only fixed-hook data are used in Areas 2C, 3A, 3B, 4A, 4B, 4C, 4D; both fixed-hook and snap gear are used in Areas 2A and 2B), the year of fishing (some logbooks are not obtained by port samplers until the following year), the number of skates fished (excluding any gear that was lost), the spacing of the hooks, the number of hooks on each skate, and the pounds of legal-sized halibut captured and landed. Only sets specifically targeting Pacific halibut are included in the analysis and all sets with hook-spacing of less than four feet are assumed to be non-halibut targeting, except in Area 2A.

For each regulatory area and year combination, the sum of the recorded landings is divided by the sum of the effective skates (the calculation of effective skates is identical to that applied to the survey data). Due to the small number of fixed-hook sets in regulatory Areas 2A and 2B, snap gear is included in the calculation for these areas. This is done by dividing the snap gear effort by a factor of 1.35 (Clark 2002). There are too few logs available on an annual basis from Area 4E to include that regulatory area in the WPUE calculations.

The WPUE by regulatory area is combined into a coastwide total by multiplying the area-specific values by the geographic extent of the 0-400 fathom bathymetry in each area (as for survey WPUE). This is consistent with the concept that the commercial WPUE is also a 'survey' of the stock and therefore the estimates are a proxy for density, but diverges from the more common

approach of weighting the commercial WPUE from each area by the catch in that area relative to the total. It may be preferable in the future to explore the use of catch- instead of geographic-weighting.

As has been observed over several previous stock assessments, the final verified record of logbooks available approximately 10-12 months after the end of the annual fishing season (August to September of the following year) have tended to show a lower catch rate than the preliminary data available in November and used in the stock assessment each year. These differences reflect the inclusion of logbooks that were not collected by port samplers during the year of fishing (and subsequently mailed in to the IPHC, or collected by port samplers during the 2013 fishing season), as well as logbooks that had been collected but were not available for analysis in 2012 (the fishing season extended until early November; the stock assessment data were finalized the day the fishery closed). After the development of indices for the 2014 stock assessment an inconsistency in the treatment of unverified logs was also identified in the data processing routines. As a result, preliminary estimates of fishery catch-rates were slightly higher than the final estimates presented here at the coastwide level, with much of the difference occurring in Area 2B where there is a higher proportion of sets targeting mixed-species. Correction of this inconsistency may reduce the *post hoc* change in future years, although the change will continue to be monitored and investigated. Other potential contributing factors could be the combination of a decline in WPUE during the fishing season, and a higher probability of logs from later in the season being unavailable at the time of the assessment. The final 2013 logbook data was 4% lower than estimated for the 2014 process (Stewart 2014). Based on this pattern, since 2013 the variance of the terminal year of the WPUE series has been inflated to reflect this additional uncertainty. Therefore, the 3% increase currently estimated from the revised 2013 value (Table 5, Fig. 40) should be interpreted with caution and tempered by inspection of previous trends, particularly at the area-specific level.

Recent trends in the commercial WPUE series differ substantially among regulatory areas, with Areas 2A, 2B and 2C showing increases, and Areas 3A through 4A showing clear continued declines. In Areas 3A through 4 fishery catch rates were substantially higher in the late 1980s through the late 1990s than at present (Table 5, Fig. 40).

Effort data for years prior to 1981 do not currently exist in the IPHC's database. For historical data, as is the case for other sources of information, there exist flat files from previous analysts that include effort and landed catch by regulatory area. These data have been used for other analyses, and date back to 1907. Prior to 1935, records of effort are reported in various technical and other IPHC reports, and there are a number of differing time-series available. For this summary, total catch and total effort were tabulated from Chapman (1962) for the years 1921-1934, and from Thompson and Bell (1931), although there are differing series in at least Skud (1975) and several others. The oldest historical records do include even earlier years, but have not been included here pending more detailed investigation. It would be preferable to access and process the historical log data directly from data stored in a database with meta-data, but this is not currently possible.

The most dramatic change in the commercial WPUE time series corresponds to the transition from "J" to circle hooks in 1984 (Fig. 41), although there have been many other changes in the definition of effort over the time series (see synopsis in Leaman et al. 2012). Changes in catch rates prior to the 1980s also reflect the historical progression of the fishery from south to north over much of the time-series (Fig. 28). Despite these caveats, it is clear that catch rates were quite low around the time of the formation of the Halibut Commission (in fact, this was the motivation for the original convention), and again in the late 1970s (Table 5, Fig. 41). Additional uncertainty

throughout the historical series is reflected by increased CVs (fixed at 0.1) for all years prior to 1996.

Fishery age distributions

Recent fishery ages are created from otoliths collected by port samplers in proportion to the landings in the ports that are annually staffed by the IPHC (Erikson and MacTavish 2015). Because of this method, the raw ages can be directly aggregated within each area and year to estimate the age composition of the catch. Because port samplers also collect individual lengths, the average weight within each area can also be directly estimated via the length-weight relationship. Dividing the total commercial catch for each regulatory area and year by the average fish weight gives an estimate of the number of fish captured. To aggregate the proportions-at-age from each area into a coastwide or regional total, each regulatory area is weighted by the numbers of fish in the catch relative to the total number of fish captured over all areas. For the period included in recent stock assessments, the coastwide age distribution displays a very similar pattern to that of the setline survey ages: a very strong 1987 cohort moving through the stock (Fig. 42), followed by catches comprised primarily of 9 to 15 year-old halibut.

Commercial fishery ages prior to 1991 have been summarized by several previous analysts, in some cases processed originally by one analyst and then subsequently by another (Clark et al. 2000). For this summary, a file produced for the analysis by Clark et al. (2000) was obtained, which included proportions at age by regulatory area from 1935 to 1990. Additional work could be done to verify which of these proportions can and can't be recreated from the current IPHC database. Weighting of the area-specific proportions followed the method applied to the more recent data, first obtaining an average individual weight (in this case by multiplying the proportions at age by the estimated average weight at age from the historical records), and then dividing the total landings by that weight to get an estimate of the number of fish in the landings by year and area. Again following the survey analysis methodology, the numbers in the landings by area were used to weight the proportions-at-age for a coastwide total.

The resultant fishery age-frequency distributions reveal that halibut in the commercial landings from the 1930s to 1973 (when the current minimum size limit was implemented) have been predominantly age 6 to 14 (Fig. 43). Several strong cohorts can be observed in the data, but none more conspicuous than the 1987 cohort. When the fishery age data are aggregated by geographic region, a similar pattern emerges to that seen in the setline survey data: a greater proportion of older halibut in Areas 4 and 4B than in Areas 2 and 3, but a similar overall age over which much of the catch has been taken and clear evidence that the 1987 cohort was very strong across the entire range of the population (Fig. 44).

Fishery weight-at-age

Both lengths and otoliths are collected by port samplers, and the lengths can be converted into individual weight estimates. No sex information is available from port samples. The average weight of a landed halibut has shown relatively flat trends over Areas 2A, 2B, and 2C, steep declines in Areas 3A and 3B and somewhat less pronounced declines in Area 4 (Fig. 45). Several areas showed an increase in average weight in 2013, but the coastwide trend has been relatively flat over the last five years. These observations accurately reflect the fishery landings, but combine the relative influences of weight-at-age, age- and sex-structure, as well as selectivity relative to the underlying population.

Historical observations of average weight are more problematic. Specifically, from 1963-1990 the IPHC did not collect individual lengths from the commercial landings. It was thought at the time that otoliths measurements could be used to adequately estimate the body size of the fish (Southward 1962), and therefore the weight. Subsequent investigation of the relationship between otolith measurements and individual length (Clark 1992) resulted in the resumption of length sampling in 1991. For this reason, the weights-at-age for most of the historical period should be considered much more uncertain than recent observations. Despite these considerations, there is a clear pattern of increasing fish size in the landings from the 1930s through the 1970s, followed by a subsequent decline to the present (Fig. 46). Also clearly visible is the effect of the implementation of the 32 inch minimum size limit in 1973.

Following the same method applied to the age-composition data (weighting the historical weight-at-age for each regulatory area by the number of fish in the landings for that area), a coastwide weight-at-age can be constructed for the entire time-series. Unfortunately, this series is not sex-specific due to the dressing of fish at sea prior to sampling by port samplers. However, there are similar trends for the best represented ages (8-16) over the historical period. One way to investigate these patterns is to divide the time series of weight-at-age for each age relative to the first year in which we have a coastwide estimate from survey data (1997). Only legal-sized fish from the survey catch are included in these weights-at-age in order to make them comparable to fishery landings. These deviations show very similar temporal patterns, despite expected differences on an absolute scale (see figure in Stewart 2014). As a proxy for sex-specific weights-at-age for the entire time-series, the survey weights-at-age from 1997 were scaled by the time series of annual deviations calculated from the fishery data. This implicitly assumes that male and female halibut have experienced similar trends in size-at-age and recent data that are available by sex support this assumption.

Auxiliary inputs

Several additional sources of information are included in the stock assessment or related analyses and treated as data, even though they represent the products of analyses themselves. These are briefly summarized here but considerable additional background material exists.

Weight-length relationship

The weight-length relationship for Pacific halibut was developed in 1926, re-evaluated in 1991 (Clark), and has been applied as standard practice for al years of IPHC management. The relationship between fork length (L_f), and individual net (headed and gutted) weights (W_n) is given by:

$$W_n = 0.00000692 \cdot {L_f}^{3.24}$$

This relationship reflects the slightly greater than cubic increase in weight with increasing length (Fig. 47). In 2013, the IPHC staff initiated a program to begin sampling individual weights during port sampling. In 2015, this program will include continued data collection during port sampling, as well as sampling on survey vessels. Over the next several years these data should allow for a reanalysis of the length-weight relationship, as well as an improved understanding of the differences in measurements collected on freshly dead fish, fish that have been stored on ice, as well as the relative contributions of head-weights, ice and slime on standardization to net weight.

Maturity schedule

The maturity schedule for Pacific halibut has been investigated several times historically, and maturity-at-age found to be very stable despite long-term changes in length- and weight-at-age (Clark and Hare 2006). Estimates of the age at which 50% of female halibut are sexually mature average 11.6 years among regulatory areas, with very few fish mature at ages less than five and nearly all fish mature by about age-17. The maturity schedule used for stock assessment has not been updated in recent years, and it is represented by a logistic fit that is truncated below age 8 (Fig. 46).

Ageing bias and imprecision

Ages are often treated and referred to as 'data', however they represent estimates of age based (most commonly) on the counting the rings formed annually on otoliths. These estimates are therefore subject to both bias and imprecision depending on the method employed to obtain them. Halibut tend to be relatively easy to age (compared to longer-lived groundfish), and historical estimates of the imprecision of the standard method of 'break-and-bake' ageing showed that the method was very precise (Clark 2004a, b, Clark and Hare 2006). Validation of the method relative to actual age has been performed via analysis of radiocarbon levels observed in known-age otoliths, and the relationship has since been used as the standard for North Pacific groundfish species (Piner and Wischniowski 2004).

Prior to 2002, surface ageing was employed as the primary tool for ageing Pacific halibut, and this method is known to be biased for older individuals and less precise than other methods when applied to many marine species. Estimates of bias and imprecision for break-and-bake and surface ages were updated in 2013 based on re-aging of setline survey samples from 1998 (See Stewart 2014, and Forsberg and Stewart 2015). Analysis of surface ages from each decade back to the 1920s also corroborated those results (Forsberg and Stewart 2015).

Pacific Decadal Oscillation

Previous research identified a strong correlation between the environmental conditions in the northeast Pacific Ocean, specifically the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and recruitment of halibut to the commercial fishery during the 1900s. A description of ongoing PDO research as well as access to the time-series of estimates can be found at: http://jisao.washington.edu/pdo/. For Pacific halibut, the positive 'phase' of the PDO (years up to and including 1947 and 1977-2006) and subsequent recruitment of juveniles into the commercial fishery appears to be correlated (Clark et al. 1999, Clark and Hare 2002). Recent reinvestigation of this analysis revealed that the correlation still appears strong using all available data (Stewart and Martell 2014). It is therefore worthwhile to monitor the recent trends in the PDO time series for qualitative purposes, as this represents some of the only information available related to juvenile halibut abundance prior to their entry into the survey and fishery around age 8-10. Inspection of the most recent PDO values indicates that deviations after 2006 have been negative with the exception of 2014 (Fig. 49). This represents the longest period of negative annual values observed since the late 1970s. The positive value in 2014 should be interpreted cautiously however, as many other environmental indicators were highly anomalous, and it is very unclear whether 2014 represents comparable conditions to previous PDO observations.

Conclusions

Despite the heterogeneous nature of the various datasets, there is a considerable quantity of historical data available for Pacific halibut, perhaps more than for any other single groundfish species in the region. The IPHC has the benefit of an extremely long time-series of data collection, a high degree of cooperation from the commercial fleet, and therefore a unique resource for historical fishery and biological patterns in the northeast Pacific Ocean. The data themselves, after accounting for important known changes in fishery and survey activities, are remarkably coherent and potentially highly informative for stock assessment, harvest policy, and MSE analyses.

Summary data processing in 2014

This document does not attempt to describe all previous data sources and processing methods used for stock assessment. It is intended to provide an overview of what might be considered current 'best practices'. Some of the more important changes to previously employed methods are outlined here along with the rationale for the changes made.

- As in 2013, fishery age data are no longer disaggregated into male and female observations based on survey sex-ratios, but modelled as aggregate age-frequency data for both sexes combined.
- Setline survey total NPUE is now used as the primary index of relative abundance, rather than only the O32 survey WPUE.
- As summarized above, commercial fishery and setline survey data were summarized both at the coastwide level and also by geographic region (Area 2, Area 3, Area 4, and Area 4B) during 2014 for use in assessment modelling (see Stewart and Martell 2015).
- Mortality associated with catch-and-release in the recreational fishery has been included in estimates for 2014 (see Kaimmer 2015).
- Length-frequency data collected by the North Pacific Observer Program have been updated to include the most recent complete year of sampling (2013). These data are important for use in delineating the proportion of the bycatch estimated to be above and below 26 inches for the harvest policy calculations.

Data sources for future analysis and potential research projects

This section represents a 'laundry-list' of potential extensions to current efforts, as well as new analyses that could benefit the halibut stock assessment or related analyses in the future. It is not a prioritized list, nor is it to be comprehensive: there are certainly other datasets not listed here but potentially available for analysis. A number of the projects are already underway.

- New approaches are needed for sampling the sex of commercial fish that have been dressed at sea. The IPHC is continuing this research with both genetic and direct marking projects. At-sea marking will be based on the field work done in 2014 (McCarthy 2015).
- Reevaluation of the historical length-weight relationship to determine whether recent changes in length-at-age are also accompanied by changes in weight-at-length. A pilot study on this topic was begun by IPHC port samplers in 2013.

- A historical investigation on the factors influencing observed size-at-age, and ageing of additional samples from key periods and areas to support this analysis is ongoing at the IPHC as part of a large collaborative North Pacific Research Board project.
- There is the potential that trawl surveys, accessing juvenile halibut habitat and capturing much younger fish than those observed from longline sampling (fishery or survey), could provide information on recruitment strengths for halibut several years prior to currently available sources of data. The NMFS conducts annual trawl surveys in the Bering Sea (Sadorus and Lauth 2015), and biannual surveys in the Aleutian Islands and Gulf of Alaska (Sadorus et al. 2014). The NMFS also conducts annual trawl surveys off the U.S. west coast (Keller et al. 2012) which also enumerate halibut catches. The DFO conducts both trawl and longline surveys off the B.C. coast which could be included in an analysis of juvenile or adult habitat. Analyses of these data are ongoing (See Sadorus et al. 2015, and Cox et al. 2015).
- The NMFS conducts ichthyoplankton surveys in the southwest Bering Sea that could be investigated with regard to potential correlation of planktonic halibut with the distribution and/or abundance of Pacific halibut spawning biomass.
- Mapping of survey catch rates and biological observations is an ongoing project at the IPHC. This should provide greater ability to evaluate and interpret trends in the survey data in the future.
- Recreational catch-rate and length/age-distribution data are available from Alaska Department of Fish and Game. Although these data do not include samples from all potential recreational removals, they could be investigated as inputs to the stock assessment or for comparison with predicted age distributions.
- There is a vast quantity of archived historical data that is currently inaccessible until organized, keypunched and formatted into the IPHC's database with appropriate meta-data. Information on historical fishery landings, effort, and age samples would provide a much clearer (and more reproducible) perception of the historical period.
- Estimates of migration rates by size, and regulatory area are available from the extensive tagging programs that the IPHC has conducted. These data require careful interpretation, as there are many unknown factors (e.g., reporting rates) that could potentially confound the results. However, they may be useful in both a quantitative and qualitative context for establishing migration rates could be further explored in the context of the stock assessment, harvest policy and MSE analyses.
- Additional efforts could be made to reconstruct estimates of personal use or subsistence harvest prior to 1991.
- Standardizing the setline survey catch rates for use in the stock assessment currently includes only gear-related aspects of the data. Model-based estimators, potentially explicitly spatial, might be explored in order to determine the degree to which the time series may be influenced by spatial and other factors relating to exogenous variables.
- There are length-frequency data available for some portions of the bycatch of Pacific halibut captured in fisheries targeting other species. These data have not been included in the fitting of recent stock assessments, although this could be explored. These data have been used to partition the bycatch into U26, and O26 components for apportionment. Such data could be transformed into predicted ages via an annual age-length key and treated as age data for the stock assessment. However, the values themselves are poorly estimated (high

variance and not all contributing sources have length-frequency observations available for appropriate weighting), therefore the accuracy of these values would be suspect. Specifically, the representativeness of the samples relative to the total estimated bycatch would need to be evaluated.

References

Bell, F. H., Dunlop, H. A., and Freeman, N. L. 1952. Pacific Coast halibut landings 1888-1950 and catch according to area of origin. Int. Pac. Halibut Comm. Rep. No. 17.

Chapman, D. G., Myhre, R. J., and Southward, G. M. 1962. Utilization of Pacific halibut stocks: Maximum sustainable yield, 1960. Int. Pac. Halibut Comm. Sci. Rep. No. 31.

Clark, W. G. 1991. Validation of the IPHC length-weight relationship for halibut. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1990: 113-116.

Clark, W. G. 1992. Estimation of Halibut Body Size from Otolith Size. Int. Pac. Halibut Comm. Sci. Rep. No. 75.

Clark, W. G. 2002. Comparison of fixed-hook and snap-hook CPUE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001: 191-196.

Clark, W. G. 2004a. Nonparametric estimates of age misclassification from paired readings. Can. J. Fish. Aquat. Sci. 61:1881-1889.

Clark, W. G. 2004b. Statistical distribution of IPHC age readings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: 99-110.

Clark, W. G. and Hare, S. R. 2002. Effects of Climate and Stock Size on Recruitment and Growth of Pacific Halibut. N. Am. J. Fish. Man. 22:852-862.

Clark, W. G. and Hare, S. R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. No. 83.

Clark, W. G., Hare, S. R., Parma, A. M., Sullivan, P. J., and Trumble, R. J. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hippoglossus stenolepis*). Can. J. Fish. Aquat. Sci. 56:242-252.

Clark, W. G., Vienneau, B. A., Blood, C. L, and Forsberg, J. E. 2000. A review of IPHC catch sampling for age and size composition from 1935 through 1999, including estimates for the years 1963-1990. Int. Pac. Halibut Comm .Tech. Rep. No. 42.

Cox, S. P., Ianelli, J., and Mangel, M. 2015. Reports of the IPHC Scientific Review Board. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 267-276.

Erikson, L. M. and MacTavish, K. A. 2015. Commercial catch sampling. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 65-78.

Forsberg, J., and Stewart, I. J. 2015. Re-ageing of archived otoliths from the 1920s to the 1990s. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 405-428.

Gilroy, H. L., Erikson, L. M., and MacTavish, K. A. 2015. 2014 commercial fishery and regulation changes. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 23-36.

Gilroy, H. L. 2015. The personal use harvest of Pacific halibut through 2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 55-60.

Gilroy, H. L. and Stewart, I. J. 2015. Incidental mortality of halibut in the commercial halibut fishery (Wastage). Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 47-54.

Hamley, J. M. and Skud, B. E. 1978. Factors affecting longline catch and effort: II Hook-spacing. Int. Pac. Halibut Comm. Sci. Rep. No. 62.

Henry, E., Soderlund, E., Dykstra, C. L., Geernaert, T., Ranta, A. M., and Kong, T. 2015. 2014 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 531-568.

Kaimmer, S. 2015. 2014 Halibut sport fishery review. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 37-46.

Keller, A. A., Wallace, J. R., Horness, B. H., Hamel, O. S., and Stewart, I. J. 2012. Variations in eastern North Pacific demersal fish biomass based on the U.S. west coast groundfish bottom trawl survey (2003–2010). Fish. Bull. 110:205-222.

Leaman, B. M., Kaimmer, S. M., and Webster, R. A. 2012. Circle hook size and spacing effects on the catch of Pacific halibut. Bull. Mar. Sci. 88:547-557.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. R., and Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Met. Soc. 78:1069-1079.

McCarthy, O. 2015. Development of a method for marking Pacific halibut by sex on board commercial fishing vessels. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 435-464.

Monnahan, C., and Stewart, I. J. 2015. Evaluation of commercial logbook records: 1991-2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 213-220.

Piner, K. R. and Wischnioski, S. G. 2004. Pacific halibut chronology of bomb radiocarbon in otoliths from 1944 to 1981 and a validation of ageing methods. J. Fish Bio. 64:1060-1071.

Sadorus, L. L. and Lauth, R. 2015. Cruise report for the 2014 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 619-626.

Sadorus, L. L., Palsson, W. A., and Ranta, A. M. 2015. Results from the NMFS Aleutian Islands biennial bottom trawl survey in 2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 635-644.

Sadorus, L.L., Stewart, I. J., and Kong, T. 2015. Juvenile halibut distribution and abundance in the Bering Sea and Gulf of Alaska. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 367-404.

Skud, B. E. 1975. Revised estimates of halibut abundance and the Thompson-Burkenroad debate. Int. Pac. Halibut Comm. Sci. Rep. No. 56.

Soderlund, E., Randolph, D. L., and Dykstra, C. 2012. IPHC Setline Charters 1963 through 2003. Int. Pac. Halibut Comm. Tech. Rep. No. 58.

Southward, G. M. 1962. A Method of Calculating Body Lengths from Otolith Measurements for Pacific Halibut and its Application to Portlock-Albatross Grounds Data between 1935 and 1957. J. Fish. Res. Bd. Can. 19:339-362.

Stewart, I. J. 2014. Overview of data sources for the Pacific halibut stock assessment and related analyses. IPHC Report of Assessment and Research Activities 2013: 95-168.

Stewart, I. J., and Martell, S. 2014. Assessment of the Pacific halibut stock at the end of 2013. IPHC Report of Assessment and Research Activities 2013: 169-196.

Stewart, I. J., and Martell, S. 2015. Assessment of the Pacific halibut stock at the end of 2014. IPHC Report of Assessment and Research Activities 2013: 161-180.

Thompson, C. H., Dunlop, H. A., and Bell, F. H. 1931. Biological statistics of the Pacific halibut fishery (1) Changes in yield of a standardized unit of gear. Int. Pac. Halibut Comm. Rep No. 6.

Webster, R. A. and Hare, S. R. 2012. Examination of the high Area 2B survey WPUE values of 1995-1997. IPHC Report of Assessment and Research Activities 2011: 255-265.

Webster, R. A., Dykstra, C. L., Soderlund, E., and Kong, T. 2014a. Depth and range expansion of the setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 451-456.

Webster, R. A., Dykstra, C., and Kong, T. 2014b. Southern expansion of the Area 2A setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 415-420.

Webster, R. A., Stewart, I. J., Leaman, B. M., Sadorus, L. L., Henry, E., and Dykstra, C. L. 2015. Setline survey expansion and complementary data sources. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 587-602.

Williams, G. H. 2015. Incidental catch and mortality of Pacific halibut, 1962-2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 313-336.

Table 1. Time-series of adjusted setline survey WPUE by regulatory Area (O32; net lb/skate). Years prior to 1984 are based on surveys conducted with "J" hooks. Values from 1995 to 2013 were recalculated in 2014 (see Webster et al. 2015).

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1977	NA	13.7	NA	58.4	NA	NA	NA	NA	NA
1978	NA	19.1	NA	26.9	NA	NA	NA	NA	NA
1979	NA	NA	NA	41.0	NA	NA	NA	NA	NA
1980	NA	25.5	NA	76.2	NA	NA	NA	NA	NA
1981	NA	16.5	NA	131.4	NA	NA	NA	NA	NA
1982	NA	20.6	113.7	130.3	NA	NA	NA	NA	NA
1983	NA	18.0	142.2	119.0	NA	NA	NA	NA	NA
1984	NA	57.4	259.6	361.2	NA	NA	NA	NA	NA
1985	NA	41.7	260.5	377.5	NA	NA	NA	NA	NA
1986	NA	37.8	282.6	305.1	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	NA	NA	NA	NA	NA	NA	NA	NA	NA
1991	NA	NA	NA	NA	NA	NA	NA	NA	NA
1992	NA	NA	NA	NA	NA	NA	NA	NA	NA
1993	NA	95.7	NA	261.1	NA	NA	NA	NA	NA
1994	NA	NA	NA	255.1	NA	NA	NA	NA	NA
1995	24.1	143.9	NA	316.4	NA	NA	NA	NA	NA
1996	26.1	141.2	309.1	313.3	347.0	NA	NA	NA	NA
1997	28.1	129.2	400.2	326.4	408.5	275.3	281.9	20.5	135.5
1998	28.8	81.0	229.2	277.6	428.6	343.6	216.6	26.7	124.9
1999	29.4	86.0	204.3	239.7	433.1	332.3	203.3	24.4	117.6
2000	31.2	89.2	233.7	270.1	368.7	314.6	216.5	23.5	117.1
2001	33.0	99.2	238.5	253.6	352.8	228.0	171.4	23.5	108.3
2002	26.4	90.2	261.1	295.2	292.7	193.0	119.3	24.1	104.7
2003	17.5	71.2	222.4	226.4	257.3	176.4	104.1	21.4	87.2
2004	21.5	84.1	171.2	266.0	232.9	157.7	73.4	20.4	86.5
2005	22.3	70.4	170.8	272.5	207.6	122.6	86.3	13.0	79.3
2006	12.9	57.4	142.8	229.2	178.5	97.6	95.5	14.1	69.1
2007	14.9	56.1	139.3	209.0	188.4	76.5	87.4	12.0	64.6
2008	14.7	87.8	104.3	186.7	124.1	95.5	103.5	10.7	59.2
2009	6.4	84.4	113.3	146.8	111.6	96.3	106.8	12.9	54.4
2010	13.4	86.9	108.1	115.4	89.9	83.6	68.4	11.0	45.6
2011	20.7	78.1	133.6	118.9	78.5	66.3	68.1	9.3	43.9
2012	23.0	101.2	157.1	135.6	85.7	73.2	48.5	10.5	49.3
2013	18.8	91.2	183.0	115.1	62.9	48.1	57.3	9.1	43.4
2014	17.8	90.0	186.5	113.3	64.0	62.2	49.9	10.2	44.2

Table 2. Time-series of fishery landings by regulatory Area (million lb, net wt.).

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1888	0.07	0.89	0.50	0.00	0.00	NA	NA	NA	NA	1.47
1889	0.07	0.79	0.44	0.00	0.00	NA	NA	NA	NA	1.29
1890	0.07	0.84	0.47	0.00	0.00	NA	NA	NA	NA	1.37
1891	0.11	1.30	0.73	0.00	0.00	NA	NA	NA	NA	2.13
1892	0.14	1.69	0.94	0.00	0.00	NA	NA	NA	NA	2.77
1893	0.16	1.96	1.09	0.00	0.00	NA	NA	NA	NA	3.22
1894	0.19	2.29	1.28	0.00	0.00	NA	NA	NA	NA	3.76
1895	0.21	2.59	1.45	0.00	0.00	NA	NA	NA	NA	4.25
1896	0.27	3.31	1.84	0.00	0.00	NA	NA	NA	NA	5.42
1897	0.33	4.02	2.24	0.00	0.00	NA	NA	NA	NA	6.59
1898	0.39	4.73	2.64	0.00	0.00	NA	NA	NA	NA	7.77
1899	0.45	5.45	3.04	0.00	0.00	NA	NA	NA	NA	8.94
1900	0.68	8.17	4.56	0.00	0.00	NA	NA	NA	NA	13.41
1901	0.90	10.90	6.08	0.00	0.00	NA	NA	NA	NA	17.87
1902	1.13	13.62	7.60	0.00	0.00	NA	NA	NA	NA	22.34
1903	1.27	15.37	8.57	0.00	0.00	NA	NA	NA	NA	25.21
1904	1.41	17.12	9.55	0.00	0.00	NA	NA	NA	NA	28.08
1905	1.11	13.41	7.48	0.00	0.00	NA	NA	NA	NA	22.00
1906	1.81	21.95	12.24	0.00	0.00	NA	NA	NA	NA	36.00
1907	2.52	30.48	17.00	0.00	0.00	NA	NA	NA	NA	50.00
1908	2.55	30.86	17.21	0.00	0.00	NA	NA	NA	NA	50.62
1909	2.58	31.23	17.42	0.00	0.00	NA	NA	NA	NA	51.23
1910	2.61	31.61	17.63	0.00	0.00	NA	NA	NA	NA	51.85
1911	2.87	34.71	19.36	0.00	0.00	NA	NA	NA	NA	56.93
1912	3.00	36.29	20.24	0.86	0.04	NA	NA	NA	NA	60.43
1913	2.79	33.80	18.85	10.58	0.52	NA	NA	NA	NA	66.54
1914	2.24	27.11	15.12	21.87	1.08	NA	NA	NA	NA	67.43
1915	2.22	26.84	14.97	23.31	1.15	NA	NA	NA	NA	68.48
1916	1.53	18.46	10.30	18.56	0.92	NA	NA	NA	NA	49.76
1917	1.55	18.78	10.47	16.96	0.84	NA	NA	NA	NA	48.60
1918	1.32	16.02	8.93	10.88	0.54	NA	NA	NA	NA	37.69
1919	1.34	16.22	9.05	12.90	0.64	NA	NA	NA	NA	40.14
1920	1.62	19.73	11.01	13.59	0.67	NA	NA	NA	NA	46.62
1921	3.39	23.37	10.22	14.75	0.73	NA	NA	NA	NA	52.46
1922	2.61	19.02	9.22	11.63	0.02	NA	NA	NA	NA	42.49
1923	2.62	16.71	9.72	21.60	0.67	NA	NA	NA	NA	51.32
1924	1.82	15.14	9.86	24.82	1.50	NA	NA	NA	NA	53.14
1925	2.20	13.65	7.99	22.16	4.66	NA	NA	NA	NA	50.66
1926	2.32	16.12	7.17	21.01	5.85	NA	NA	NA	NA	52.47
1927	2.62	14.09	7.42	22.62	8.20	NA	NA	NA	NA	54.95
1928	2.27	16.63	7.58	22.54	5.25	NA	NA	NA	NA	54.26
1929	2.18	13.77	9.85	22.27	8.86	NA	NA	NA	NA	56.92
1930	1.58	12.12	8.53	18.19	9.09	NA	NA	NA	NA	49.51
1931	1.63	13.53	7.39	14.61	7.06	NA	NA	NA	NA	44.22
1932	1.90	13.25	7.74	16.71	4.89	NA	NA	NA	NA	44.49
1933	1.75	13.37	8.15	19.67	3.97	NA	NA	NA	NA	46.91
1934	2.45	14.12	7.68	15.88	4.58	NA	NA	NA	NA	44.72
1935	1.77	14.21	7.58	19.96	3.82	0.00	NA	NA	NA	47.34
1936	0.90	13.67	8.75	20.09	5.52	0.00	NA	NA	NA	48.92
1937	0.92	15.29	7.87	20.47	5.00	0.00	NA	NA	NA	49.54
1938	0.95	16.00	7.15	20.66	4.79	0.00	NA	NA	NA	49.55
1939	1.36	17.67	6.56	21.16	4.15	0.00	NA	NA	NA	50.90
1940	0.98	17.81	7.62	22.50	4.48	0.00	NA	NA	NA	53.38

Table 2. Continued.

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1941	0.51	16.53	7.25	21.84	6.10	0.00	NA	NA	NA	52.23
1942	0.72	14.37	8.35	21.50	5.46	0.00	NA	NA	NA	50.39
1943	1.24	15.97	8.15	20.51	7.83	0.00	NA	NA	NA	53.70
1944	0.90	15.07	10.38	20.36	6.73	0.00	NA	NA	NA	53.44
1945	0.73	14.58	8.49	20.07	9.52	0.01	NA	NA	NA	53.40
1946	0.90	18.37	9.90	22.40	8.50	0.20	NA	NA	NA	60.27
1947	0.57	17.67	9.50	20.44	7.33	0.19	NA	NA	NA	55.70
1948	0.41	17.67	9.75	19.93	7.50	0.30	NA	NA	NA	55.56
1949	0.62	16.34	9.45	21.12	7.38	0.12	NA	NA	NA	55.03
1950	0.70	17.46	8.84	23.86	6.30	0.08	NA	NA	NA	57.23
1951	0.59	20.04	9.97	20.86	4.54	0.05	NA	NA	NA	56.05
1952	0.62	20.63	9.56	27.27	3.62	0.56	NA	NA	NA	62.26
1953	0.50	23.80	8.41	22.84	3.81	0.48	NA	NA	NA	59.84
1954	0.85	24.90	11.04	29.46	4.21	0.13	NA	NA	NA	70.58
1955	0.61	18.65	8.54	23.06	6.57	0.09	NA	NA	NA	57.52
1956	0.53	20.06	14.51	22.11	9.12	0.26	NA	NA	NA	66.59
1957	0.60	17.69	12.25	22.85	7.43	0.04	NA	NA	NA	60.85
1958	0.52	18.49	11.20	24.52	7.60	2.18	NA	NA	NA	64.51
1959	0.67	16.83	13.03	25.36	11.00	4.31	NA	NA	NA	71.20
1960	0.89	18.16	12.72	21.05	12.90	5.90	NA	NA	NA	71.61
1961	0.50	16.08	12.29	23.07	13.28	4.07	NA	NA	NA	69.27
1962	0.45	15.03	13.24	24.04	13.48	8.62	NA	NA	NA	74.86
1963	0.41	15.52	10.24	22.31	13.98	8.77	NA	NA	NA	71.24
1964	0.28	11.86	7.43	22.56	15.04	2.62	NA	NA	NA	59.78
1965	0.21	11.97	12.07	22.98	14.07	1.88	NA	NA	NA	63.18
1966	0.18	11.04	12.04	25.77	11.05	1.94	NA	NA	NA	62.02
1967	0.20	10.11	9.41	19.66	13.26	2.58	NA	NA	NA	55.22
1968	0.14	10.15	6.11	14.77	15.83	1.60	NA	NA	NA	48.59
1969	0.23	12.82	9.33	20.08	13.92	1.90	NA	NA	NA	58.27
1970	0.16	10.26	9.37	19.91	13.37	1.78	NA	NA	NA	54.84
1971	0.32	9.85	6.61	17.76	11.04	1.08	NA	NA	NA	46.65
1972	0.37	10.13	5.78	16.30	9.28	1.02	NA	NA	NA	42.88
1973	0.23	6.73	5.98	13.50	4.79	0.52	NA	NA	NA	31.74
1974	0.52	4.62	5.60	8.19	1.67	0.71	NA	NA	NA	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	NA	NA	NA	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	NA	NA	NA	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	NA	NA	NA	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	NA	NA	NA	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	NA	NA	NA	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	NA	NA	NA	21.87
1981	0.20	5.66	4.01	14.23	0.45	NA	0.49	0.39	0.31	25.74
1982	0.21	5.54	3.50	13.52	4.80	NA	1.17	0.01	0.25	29.01
1983	0.27	5.44	6.38	14.13	7.76	NA	2.50	1.34	0.58	38.39
1984	0.43	9.05	5.87	19.77	6.69	NA	1.05	1.10	1.01	44.97
1985	0.49	10.39	9.21	20.84	10.89	NA	1.72	1.24	1.33	56.10
1986	0.58	11.23	10.61	32.80	8.82	NA	3.38	0.26	1.95	69.63
1987	0.59	12.25	10.69	31.31	7.76	NA	3.69	1.50	1.69	69.47
1988	0.49	12.86	11.36	37.91	7.08	NA	1.93	1.59	1.17	74.39
1989	0.47	10.43	9.53	33.74	7.84	NA	1.03	2.65	1.26	66.95
1990	0.33	8.57	9.73	28.85	8.69	NA	2.50	1.33	1.59	61.60
1991	0.36	7.19	8.69	22.93	11.93	NA	2.26	1.51	2.22	57.08
1992	0.44	7.63	9.82	26.78	8.62	NA	2.70	2.32	1.59	59.89
1993	0.50	10.63	11.29	22.74	7.86	NA	2.56	1.96	1.73	59.27

Table 2. Continued.

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1994	0.37	9.91	10.38	24.84	3.86	NA	1.80	2.02	1.55	54.73
1995	0.30	9.62	7.77	18.34	3.13	NA	1.62	1.68	1.44	43.88
1996	0.30	9.55	8.87	19.69	3.66	NA	1.70	2.07	1.51	47.34
1997	0.41	12.42	9.92	24.64	9.06	NA	2.91	3.32	2.52	65.20
1998	0.46	13.17	10.20	25.70	11.16	NA	3.42	2.90	2.75	69.76
1999	0.45	12.71	10.14	25.32	13.84	NA	4.37	3.57	3.92	74.31
2000	0.48	10.81	8.45	19.27	15.41	NA	5.16	4.69	4.02	68.29
2001	0.68	10.29	8.40	21.54	16.34	NA	5.02	4.47	3.97	70.70
2002	0.85	12.07	8.60	23.13	17.31	NA	5.09	4.08	3.52	74.66
2003	0.82	11.79	8.41	22.75	17.22	NA	5.02	3.86	3.26	73.14
2004	0.88	12.16	10.23	25.17	15.46	NA	3.56	2.72	2.92	73.11
2005	0.80	12.33	10.63	26.03	13.17	NA	3.40	1.98	3.48	71.82
2006	0.83	12.01	10.49	25.71	10.79	NA	3.33	1.59	3.23	67.98
2007	0.79	9.77	8.47	26.49	9.25	NA	2.83	1.42	3.85	62.87
2008	0.68	7.76	6.21	24.52	10.75	NA	3.02	1.76	3.88	58.57
2009	0.49	6.64	4.96	21.76	10.78	NA	2.53	1.59	3.31	52.05
2010	0.42	6.73	4.49	20.50	10.11	NA	2.33	1.83	3.32	49.72
2011	0.54	6.69	2.45	14.67	7.32	NA	2.35	2.05	3.43	39.51
2012	0.57	5.98	2.69	12.03	5.05	NA	1.58	1.74	2.34	31.99
2013	0.54	6.04	3.03	11.08	4.09	NA	1.23	1.25	1.77	29.04
2014	0.54	5.88	3.44	7.63	2.93	NA	0.90	1.12	1.26	23.69

Table 3. Time-series of total removals by regulatory Area (million lb, net wt.).

Year	2A	2B	2C	3A	3B	4	Total
1888	0.07	0.89	0.50	0.00	0.00	0.00	1.47
1889	0.07	0.79	0.44	0.00	0.00	0.00	1.29
1890	0.07	0.84	0.47	0.00	0.00	0.00	1.37
1891	0.11	1.30	0.73	0.00	0.00	0.00	2.13
1892	0.14	1.69	0.94	0.00	0.00	0.00	2.77
1893	0.16	1.96	1.09	0.00	0.00	0.00	3.22
1894	0.19	2.29	1.28	0.00	0.00	0.00	3.76
1895	0.21	2.59	1.45	0.00	0.00	0.00	4.25
1896	0.27	3.31	1.84	0.00	0.00	0.00	5.42
1897	0.33	4.02	2.24	0.00	0.00	0.00	6.59
1898	0.39	4.73	2.64	0.00	0.00	0.00	7.77
1899	0.45	5.45	3.04	0.00	0.00	0.00	8.94
1900	0.68	8.17	4.56	0.00	0.00	0.00	13.41
1901	0.90	10.90	6.08	0.00	0.00	0.00	17.87
1902	1.13	13.62	7.60	0.00	0.00	0.00	22.34
1903	1.27	15.37	8.57	0.00	0.00	0.00	25.21
1904	1.41	17.12	9.55	0.00	0.00	0.00	28.08
1905	1.11	13.41	7.48	0.00	0.00	0.00	22.00
1906	1.81	21.95	12.24	0.00	0.00	0.00	36.00
1907	2.52	30.48	17.00	0.00	0.00	0.00	50.00
1908	2.55	30.86	17.21	0.00	0.00	0.00	50.62
1909	2.58	31.23	17.42	0.00	0.00	0.00	51.23
1910	2.61	31.61	17.63	0.00	0.00	0.00	51.85
1911	2.87	34.71	19.36	0.00	0.00	0.00	56.93
1912	3.00	36.29	20.24	0.86	0.04	0.00	60.43
1913	2.79	33.80	18.85	10.58	0.52	0.00	66.54
1914	2.24	27.11	15.12	21.87	1.08	0.00	67.43
1915	2.22	26.84	14.97	23.31	1.15	0.00	68.48
1916	1.53	18.46	10.30	18.56	0.92	0.00	49.76
1917	1.55	18.78	10.47	16.96	0.84	0.00	48.60
1918	1.32	16.02	8.93	10.88	0.54	0.00	37.69
1919	1.34	16.22	9.05	12.90	0.64	0.00	40.14
1920	1.62	19.73	11.01	13.59	0.67	0.00	46.62
1921	3.39	23.37	10.22	14.75	0.73	0.00	52.46
1922	2.61	19.02	9.22	11.63	0.02	0.00	42.50
1923	2.62	16.71	9.72	21.60	0.67	0.00	51.32
1924	1.82	15.14	9.86	24.82	1.50	0.00	53.14
1925	2.20	13.65	7.99	22.16	4.66	0.00	50.66
1926	2.32	16.12	7.17	21.01	5.85	0.00	52.47
1927	2.62	14.09	7.42	22.62	8.20	0.00	54.95
1928	2.27	16.63	7.58	22.54	5.25	0.00	54.26
1929	2.18	13.77	9.85	22.27	8.86	0.00	56.93
1930	1.58	12.12	8.53	18.19	9.09	0.00	49.51
1931	1.63	13.53	7.39	14.61	7.06	0.00	44.22
1932	1.90	13.25	7.74	16.71	4.89	0.00	44.49
1933	1.75	13.37	8.15	19.67	3.97	0.00	46.91
1934	2.45	14.12	7.68	15.88	4.58	0.00	44.72
1935	1.77	14.21	7.58	19.96	3.82	0.00	47.34
1936	0.90	13.67	8.75	20.09	5.52	0.00	48.92
1937	0.92	15.29	7.87	20.47	5.00	0.00	49.54
1938	0.95	16.00	7.15	20.66	4.79	0.00	49.55
1939	1.36	17.67	6.56	21.16	4.15	0.00	50.90
1940	0.98	17.81	7.62	22.50	4.48	0.00	53.38

Table 3. Continued.

Year	2A	2B	2C	3A	3B	4	Total
1941	0.51	16.53	7.25	21.84	6.10	0.00	52.23
1942	0.72	14.37	8.35	21.50	5.46	0.00	50.39
1943	1.24	15.97	8.15	20.51	7.83	0.00	53.70
1944	0.90	15.07	10.38	20.36	6.73	0.00	53.44
1945	0.73	14.58	8.49	20.07	9.52	0.01	53.40
1946	0.90	18.37	9.90	22.40	8.50	0.20	60.27
1947	0.57	17.67	9.50	20.44	7.33	0.19	55.70
1948	0.41	17.67	9.75	19.93	7.50	0.30	55.56
1949	0.62	16.34	9.45	21.12	7.38	0.12	55.03
1950	0.70	17.46	8.84	23.86	6.30	0.08	57.23
1951	0.59	20.04	9.97	20.86	4.54	0.05	56.05
1952	0.62	20.63	9.56	27.27	3.62	0.56	62.26
1953	0.50	23.80	8.41	22.84	3.81	0.48	59.84
1954	0.85	24.90	11.04	29.46	4.21	0.13	70.58
1955	0.61	18.65	8.54	23.06	6.57	0.09	57.52
1956	0.53	20.06	14.51	22.11	9.12	0.26	66.59
1957	0.60	17.69	12.25	22.85	7.43	0.04	60.85
1958	0.52	18.49	11.20	24.52	7.60	2.18	64.51
1959	0.67	16.83	13.03	25.36	11.00	4.31	71.20
1960	0.89	18.16	12.72	21.05	12.90	5.90	71.61
1961	0.50	16.08	12.29	23.07	13.28	4.07	69.27
1962	0.45	16.21	13.45	25.96	14.65	12.76	83.47
1963	0.41	16.60	10.45	25.62	16.77	10.81	80.66
1964	0.28	12.96	7.64	31.93	17.30	5.59	75.70
1965	0.21	13.40	12.27	29.08	24.51	5.06	84.54
1966	0.18	12.70	12.25	30.28	19.03	5.34	79.79
1967	0.20	11.76	9.85	24.29	18.16	7.30	71.56
1968	0.14	12.11	6.63	20.25	17.41	7.28	63.81
1969	0.23	15.00	9.79	23.89	15.09	9.50	73.50
1970	0.16	11.73	9.93	23.30	16.21	9.80	71.13
1971	0.32	11.59	7.15	20.74	12.40	14.18	66.37
1972	0.37	11.88	6.54	21.71	10.98	10.69	62.16
1973	0.23	8.24	6.82	17.95	7.49	8.55	49.27
1974	1.00	6.43	6.17	13.50	5.10	8.33	40.54
1975	0.94	9.18	6.93	13.85	4.65	4.28	39.84
1976	0.72	9.51	6.28	14.64	5.20	5.29	41.63
1977	0.70	7.39	3.87	13.02	5.12	4.14	34.24
1978	0.59	6.20	4.82	13.75	3.17	6.38	34.90
1979	0.54	6.84	5.56	17.62	1.33	6.79	38.68
1980	0.52	7.16	4.12	18.44	1.53	9.95	41.72
1981	0.70	7.01	4.87	19.85	2.02	7.62	42.06
1982	0.74	6.60	4.33	18.16	7.04	6.21	43.08
1983	0.81	6.63	7.30	18.15	9.80	8.72	51.41
1984	1.03	10.55	6.86	23.10	8.30	7.89	57.73
1985	1.17	12.33	10.53	24.26	11.86	8.70	68.86
1986	1.40	13.27	12.25	37.92	9.82	11.56	86.22
1987	1.52	14.85	12.31	37.64	9.14	13.00	88.46
1988	1.22	15.28	13.13	46.69	7.40	13.70	97.42
1989	1.29	12.69	11.75	42.11	9.03	12.43	89.29
1990	0.95	11.07	12.42	38.29	11.15	14.36	88.25
1991	0.94	9.76	12.31	34.55	14.48	16.69	88.73
1992	1.15	9.98	12.83	37.11	11.12	17.78	89.97
1993	1.23	13.24	14.36	33.48	9.24	14.39	85.94

Table 3. Continued.

Year	2A	2B	2C	3A	3B	4	Total
1994	1.02	12.03	13.46	35.04	5.46	15.18	82.19
1995	1.17	12.56	10.02	26.33	5.00	13.67	68.75
1996	1.16	11.24	11.52	27.81	5.76	14.09	71.59
1997	1.41	14.12	12.67	33.74	10.82	16.97	89.72
1998	1.95	14.90	13.19	33.81	12.88	17.23	93.96
1999	1.80	14.38	12.45	33.05	15.93	20.01	97.62
2000	1.69	12.55	11.19	28.02	17.34	21.74	92.53
2001	2.00	12.03	10.78	29.75	18.53	21.04	94.14
2002	1.93	14.08	11.09	30.25	19.79	20.35	97.49
2003	1.55	13.90	11.56	32.32	19.64	19.29	98.25
2004	1.71	14.64	14.28	35.61	17.49	16.23	99.95
2005	1.90	15.15	14.41	36.08	14.93	16.93	99.40
2006	2.01	14.96	14.08	35.15	12.73	15.99	94.91
2007	1.75	12.58	12.48	36.96	10.89	15.74	90.40
2008	1.67	10.29	10.29	34.25	12.85	15.61	84.95
2009	1.57	8.71	8.15	30.74	12.93	14.08	76.17
2010	1.21	8.77	7.20	29.08	12.21	13.89	72.36
2011	1.10	8.83	4.00	23.00	9.30	13.40	59.64
2012	1.22	7.85	4.80	18.52	7.07	12.21	51.67
2013	1.17	7.71	5.75	17.47	5.50	10.43	48.04
2014	1.07	7.73	5.98	13.60	4.53	9.61	42.51

Table 4. Time-series of estimated removals by source (million lb, net wt.).

Year	Commercial landings	Commercial wastage	Bycatch	Sport	Personal use	Total
1888	1.47	0.00	0.00	0.00	0.00	1.47
1889	1.29	0.00	0.00	0.00	0.00	1.29
1890	1.37	0.00	0.00	0.00	0.00	1.37
1891	2.13	0.00	0.00	0.00	0.00	2.13
1892	2.77	0.00	0.00	0.00	0.00	2.77
1893	3.22	0.00	0.00	0.00	0.00	3.22
1894	3.76	0.00	0.00	0.00	0.00	3.76
1895	4.25	0.00	0.00	0.00	0.00	4.25
1896	5.42	0.00	0.00	0.00	0.00	5.42
1897	6.59	0.00	0.00	0.00	0.00	6.59
1898	7.77	0.00	0.00	0.00	0.00	7.77
1899	8.94	0.00	0.00	0.00	0.00	8.94
1900	13.41	0.00	0.00	0.00	0.00	13.41
1901	17.87	0.00	0.00	0.00	0.00	17.87
1902	22.34	0.00	0.00	0.00	0.00	22.34
1903	25.21	0.00	0.00	0.00	0.00	25.21
1904	28.08	0.00	0.00	0.00	0.00	28.08
1905	22.00	0.00	0.00	0.00	0.00	22.00
1906	36.00	0.00	0.00	0.00	0.00	36.00
1907	50.00	0.00	0.00	0.00	0.00	50.00
1908	50.62	0.00	0.00	0.00	0.00	50.62
1909	51.23	0.00	0.00	0.00	0.00	51.23
1910	51.85	0.00	0.00	0.00	0.00	51.85
1911	56.93	0.00	0.00	0.00	0.00	56.93
1912	60.43	0.00	0.00	0.00	0.00	60.43
1913	66.54	0.00	0.00	0.00	0.00	66.54
1914	67.43	0.00	0.00	0.00	0.00	67.43
1915	68.48	0.00	0.00	0.00	0.00	68.48
1916	49.76	0.00	0.00	0.00	0.00	49.76
1917	48.60	0.00	0.00	0.00	0.00	48.60
1918	37.69	0.00	0.00	0.00	0.00	37.69
1919	40.14	0.00	0.00	0.00	0.00	40.14
1920	46.62	0.00	0.00	0.00	0.00	46.62
1921	52.46	0.00	0.00	0.00	0.00	52.46
1922	42.49	0.00	0.00	0.00	0.00	42.49
1923	51.32	0.00	0.00	0.00	0.00	51.32
1924	53.14	0.00	0.00	0.00	0.00	53.14
1925	50.66	0.00	0.00	0.00	0.00	50.66
1926	52.47	0.00	0.00	0.00	0.00	52.47
1927	54.95	0.00	0.00	0.00	0.00	54.95
1928	54.26	0.00	0.00	0.00	0.00	54.26
1929	56.92	0.00	0.00	0.00	0.00	56.92
1930	49.51	0.00	0.00	0.00	0.00	49.51
1931	44.22	0.00	0.00	0.00	0.00	44.22
1932	44.49	0.00	0.00	0.00	0.00	44.49
1933	46.91	0.00	0.00	0.00	0.00	46.91
1934	44.72	0.00	0.00	0.00	0.00	44.72
1935	47.34	0.00	0.00	0.00	0.00	47.34
1936	48.92	0.00	0.00	0.00	0.00	48.92
1937	49.54	0.00	0.00	0.00	0.00	49.54
1938	49.55	0.00	0.00	0.00	0.00	49.55
1939	50.90	0.00	0.00	0.00	0.00	50.90

Table 4. Continued.

Year	Commercial landings	Commercial wastage	Bycatch	Sport	Personal use	Total
1940	53.38	0.00	0.00	0.00	0.00	53.38
1941	52.23	0.00	0.00	0.00	0.00	52.23
1942	50.39	0.00	0.00	0.00	0.00	50.39
1943	53.70	0.00	0.00	0.00	0.00	53.70
1944	53.44	0.00	0.00	0.00	0.00	53.44
1945	53.40	0.00	0.00	0.00	0.00	53.40
1946	60.27	0.00	0.00	0.00	0.00	60.27
1947	55.70	0.00	0.00	0.00	0.00	55.70
1948	55.56	0.00	0.00	0.00	0.00	55.56
1949	55.03	0.00	0.00	0.00	0.00	55.03
1950	57.23	0.00	0.00	0.00	0.00	57.23
1951	56.05	0.00	0.00	0.00	0.00	56.05
1952	62.26	0.00	0.00	0.00	0.00	62.26
1953	59.84	0.00	0.00	0.00	0.00	59.84
1954	70.58	0.00	0.00	0.00	0.00	70.58
1955	57.52	0.00	0.00	0.00	0.00	57.52
1956	66.59	0.00	0.00	0.00	0.00	66.59
1957	60.85	0.00	0.00	0.00	0.00	60.85
1958	64.51	0.00	0.00	0.00	0.00	64.51
1959	71.20	0.00	0.00	0.00	0.00	71.20
1960	71.61	0.00	0.00	0.00	0.00	71.61
1961	69.27	0.00	0.00	0.00	0.00	69.27
1962	74.86	0.00	8.61	0.00	0.00	83.47
1963	71.24	0.00	9.42	0.00	0.00	80.66
1964	59.78	0.00	15.91	0.00	0.00	75.70
1965	63.18	0.00	21.36	0.00	0.00	84.54
1966	62.02	0.00	17.77	0.00	0.00	79.79
1967	55.22	0.00	16.34	0.00	0.00	71.56
1968	48.59	0.00	15.22	0.00	0.00	63.81
1969	58.27	0.00	15.23	0.00	0.00	73.50
1970	54.84	0.00	16.29	0.00	0.00	71.13
1971	46.65	0.00	19.72	0.00	0.00	66.37
1972	42.88	0.00	19.28	0.00	0.00	62.16
1973	31.74	0.00	17.53	0.00	0.00	49.27
1974	21.31	0.20	19.03	0.00	0.00	40.54
1975	27.62	0.31	11.91	0.00	0.00	39.84
1976	27.54	0.34	13.75	0.00	0.00	41.63
1977	21.88	0.29	11.78	0.29	0.00	34.24
1978	22.00	0.28	12.24	0.38	0.00	34.90
1979	22.54	0.30	15.28	0.56	0.00	38.68
1980	21.87	0.30	18.70	0.85	0.00	41.72
1981	25.74	0.35	14.86	1.11	0.00	42.06
1982	29.01	0.40	12.37	1.30	0.00	43.08
1983	38.39	0.53	10.88	1.62	0.00	51.41
1984	44.97	0.72	10.19	1.84	0.00	57.73
1985	56.10	2.70	7.70	2.36	0.00	68.86
1986	69.63	4.65	8.76	3.18	0.00	86.22
1987	69.47	4.20	11.28	3.51	0.00	88.46
1988	74.39	3.49	14.66	4.88	0.00	97.42
1989	66.95	3.46	13.65	5.23	0.00	89.29
1990	61.60	3.38	17.68	5.59	0.00	88.25
1991	57.08	3.46	19.67	6.51	2.01	88.74

Table 4. Continued.

Year	Commercial landings	Commercial wastage	Bycatch	Sport	Personal use	Total
1992	59.89	2.50	20.29	6.18	1.11	89.97
1993	59.27	2.05	15.96	7.73	0.93	85.94
1994	54.73	2.51	16.95	7.07	0.93	82.19
1995	43.88	0.93	15.93	7.46	0.54	68.75
1996	47.34	1.15	14.46	8.08	0.54	71.59
1997	65.20	1.45	13.51	9.03	0.54	89.73
1998	69.76	1.72	13.16	8.59	0.74	93.96
1999	74.31	1.65	13.54	7.38	0.75	97.62
2000	68.29	1.45	13.02	9.01	0.76	92.53
2001	70.70	1.69	12.88	8.10	0.77	94.14
2002	74.66	1.72	12.33	8.01	0.77	97.49
2003	73.14	2.08	12.31	9.35	1.38	98.25
2004	73.11	2.30	12.29	10.70	1.55	99.96
2005	71.82	2.22	12.97	10.86	1.54	99.41
2006	67.98	2.46	12.79	10.19	1.48	94.91
2007	62.87	2.59	11.99	11.46	1.49	90.39
2008	58.57	2.76	11.60	10.67	1.34	84.95
2009	52.05	2.94	11.08	8.78	1.31	76.16
2010	49.72	3.21	10.35	7.85	1.24	72.36
2011	39.51	2.46	9.42	7.10	1.14	59.64
2012	31.99	1.67	10.10	6.77	1.14	51.67
2013	29.04	1.43	8.84	7.59	1.14	48.04
2014	23.69	1.29	9.32	7.08	1.14	42.51

Table 5. Time-series of commercial fishery WPUE by regulatory Area (net lb/skate). Years prior to 1984 are based on fishing conducted with "J" hooks.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
1907	NA	NA	NA	NA	NA	NA	NA	NA	NA	280
1910	NA	NA	NA	NA	NA	NA	NA	NA	NA	271
1911	NA	NA	NA	NA	NA	NA	NA	NA	NA	237
1912	NA	NA	NA	NA	NA	NA	NA	NA	NA	176
1913	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1914	NA	NA	NA	NA	NA	NA	NA	NA	NA	124
1915	NA	NA	NA	NA	NA	NA	NA	NA	NA	118
1916	NA	NA	NA	NA	NA	NA	NA	NA	NA	137
1917	NA	NA	NA	NA	NA	NA	NA	NA	NA	98
1918	NA	NA	NA	NA	NA	NA	NA	NA	NA	96
1919	NA	NA	NA	NA	NA	NA	NA	NA	NA	93
1920	NA	NA	NA	NA	NA	NA	NA	NA	NA	96
1921	NA	NA	NA	NA	NA	NA	NA	NA	NA	88
1922	NA	NA	NA	NA	NA	NA	NA	NA	NA	73
1923	NA	NA	NA	NA	NA	NA	NA	NA	NA	78
1924	NA	NA	NA	NA	NA	NA	NA	NA	NA	74
1925	NA	NA	NA	NA	NA	NA	NA	NA	NA	68
1926	NA	NA	NA	NA	NA	NA	NA	NA	NA	67
1927	NA	NA	NA	NA	NA	NA	NA	NA	NA	65
1928	NA	NA	NA	NA	NA	NA	NA	NA	NA	58
1929	NA	NA	NA	NA	NA	NA	NA	NA	NA	51
1930	NA	NA	NA	NA	NA	NA	NA	NA	NA	46
1931	NA	NA	NA	NA	NA	NA	NA	NA	NA	50
1932	NA	NA	NA	NA	NA	NA	NA	NA	NA	60
1933	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
1934	NA	NA	NA	NA	NA	NA	NA	NA	NA	62
1935	NA	NA	NA	NA	NA	NA	NA	NA	NA	76
1936	NA	NA	NA	NA	NA	NA	NA	NA	NA	71
1937	NA	NA	NA	NA	NA	NA	NA	NA	NA	80
1938	NA	NA	NA	NA	NA	NA	NA	NA	NA	88
1939	NA	NA	NA	NA	NA	NA	NA	NA	NA	80
1940	NA	NA	NA	NA	NA	NA	NA	NA	NA	81
1941	NA	NA	NA	NA	NA	NA	NA	NA	NA	85
1942	NA	NA	NA	NA	NA	NA	NA	NA	NA	90
1943	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1944	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1945	NA	NA	NA	NA	NA	NA	NA	NA	NA	102
1946	NA	NA	NA	NA	NA	NA	NA	NA	NA	101
1947	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1948	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1949	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1950	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1950	NA	NA	NA	NA	NA	NA	NA	NA	NA	95

Table 5. Continued.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
1951	NA	NA	NA	NA	NA	NA	NA	NA	NA	96
1952	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1953	NA	NA	NA	NA	NA	NA	NA	NA	NA	131
1954	NA	NA	NA	NA	NA	NA	NA	NA	NA	133
1955	NA	NA	NA	NA	NA	NA	NA	NA	NA	119
1956	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1957	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1958	NA	NA	NA	NA	NA	NA	NA	NA	NA	121
1959	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1960	NA	NA	NA	NA	NA	NA	NA	NA	NA	132
1961	NA	NA	NA	NA	NA	NA	NA	NA	NA	127
1962	NA	NA	NA	NA	NA	NA	NA	NA	NA	115
1963	NA	NA	NA	NA	NA	NA	NA	NA	NA	105
1964	NA	NA	NA	NA	NA	NA	NA	NA	NA	100
1965	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1966	NA	NA	NA	NA	NA	NA	NA	NA	NA	100
1967	NA	NA	NA	NA	NA	NA	NA	NA	NA	101
1968	NA	NA	NA	NA	NA	NA	NA	NA	NA	103
1969	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	91
1971	NA	NA	NA	NA	NA	NA	NA	NA	NA	89
1972	NA	NA	NA	NA	NA	NA	NA	NA	NA	78
1973	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
1974	59	64	57	65	57	NA	NA	NA	NA	61
1975	59	68	53	66	68	NA	NA	NA	NA	61
1976	33	53	42	60	65	NA	NA	NA	NA	55
1977	83	61	45	61	73	NA	NA	NA	NA	63
1978	39	63	56	78	53	NA	NA	NA	NA	71
1979	50	48	80	86	37	NA	NA	NA	NA	75
1980	37	65	79	118	113	NA	NA	NA	NA	94
1981	33	67	144	142	160	158	99	110	NA	111
1982	22	69	146	168	203	103	NA	91	NA	127
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	63	147	284	502	474	366	161	NA	197	291
1985	62	139	345	500	592	337	234	594	330	357
1986	55	118	290	506	506	260	238	427	218	320
1987	53	130	260	498	478	342	220	384	241	321
1988	134	137	281	503	654	453	224	371	201	368
1989	113	133	258	457	590	409	268	333	432	358
1990	168	176	270	354	484	418	209	288	381	319
1991	158	149	233	319	466	471	329	223	399	318
1992	117	171	230	397	440	372	280	249	412	319
1993	147	208	256	393	514	463	218	257	851	373
1994	93	215	207	354	377	463	197	167	480	306
1995	116	219	234	417	476	349	189	286	475	330
1996	159	227	239	473	557	515	269	297	543	392
1997	226	241	246	458	563	483	275	335	671	405
1998	194	232	236	452	611	525	287	287	627	408
1999	342	213	199	437	538	497	310	271	535	393
2000	263	229	187	443	579	548	320	223	556	403

Table 5. Continued.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
2001	171	227	196	469	431	474	270	203	511	362
2002	181	223	244	508	399	402	245	148	503	360
2003	173	221	233	485	365	355	196	105	388	329
2004	143	203	240	486	328	315	202	120	445	319
2005	137	195	203	446	293	301	238	91	379	296
2006	156	201	170	403	292	241	218	72	280	270
2007	96	198	160	398	257	206	230	65	237	252
2008	69	174	161	370	234	206	193	94	247	232
2009	98	188	155	318	211	234	189	88	249	222
2010	149	222	158	285	173	182	142	82	188	204
2011	92	240	175	280	140	189	165	75	166	198
2012	102	248	207	263	133	194	149	60	155	195
2013	110	246	195	238	112	160	127	56	157	179
2014	109	286	228	230	99	132	168	60	167	185

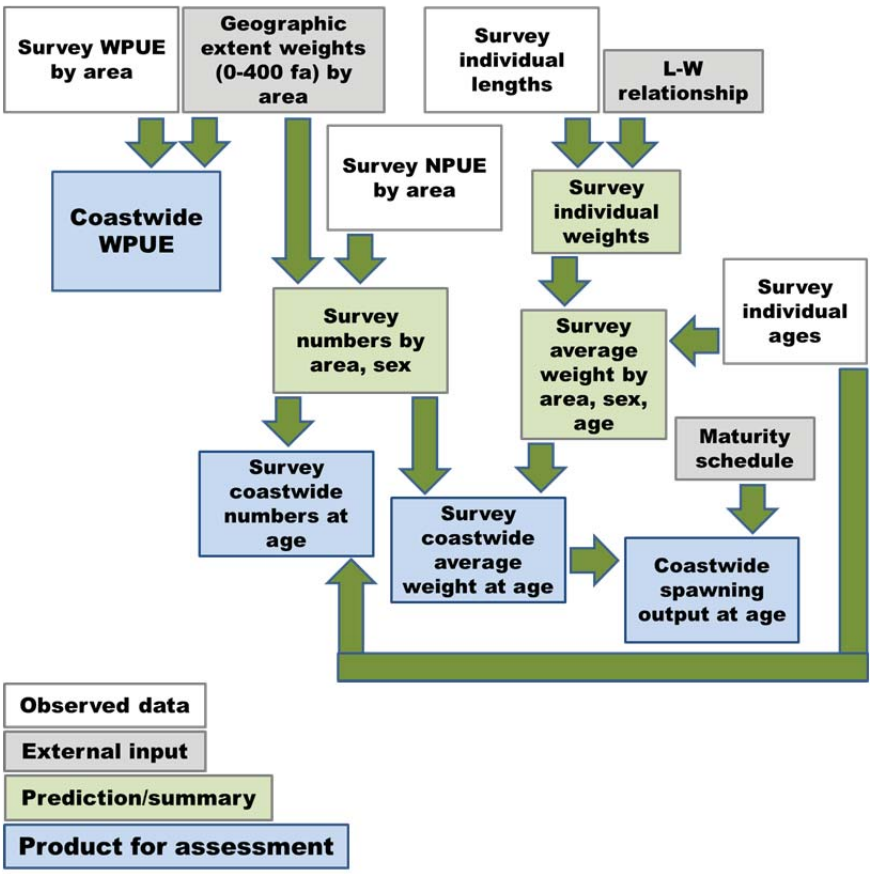


Figure 1. General schematic of the processing of the setline survey data.

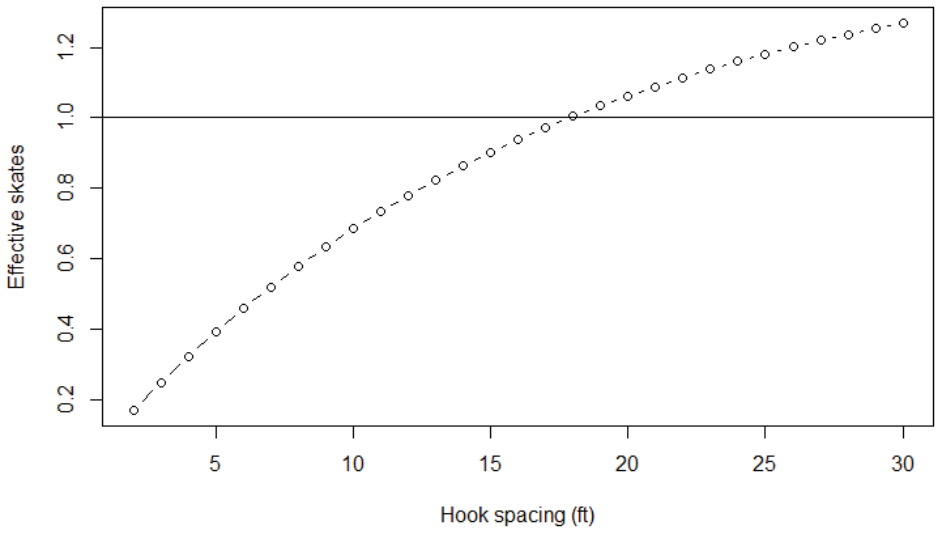


Figure 2. Relationship between hook spacing and the number of effective skates for set line survey and commercial fishery WPUE calculations (From: Hamley and Skud, 1978).

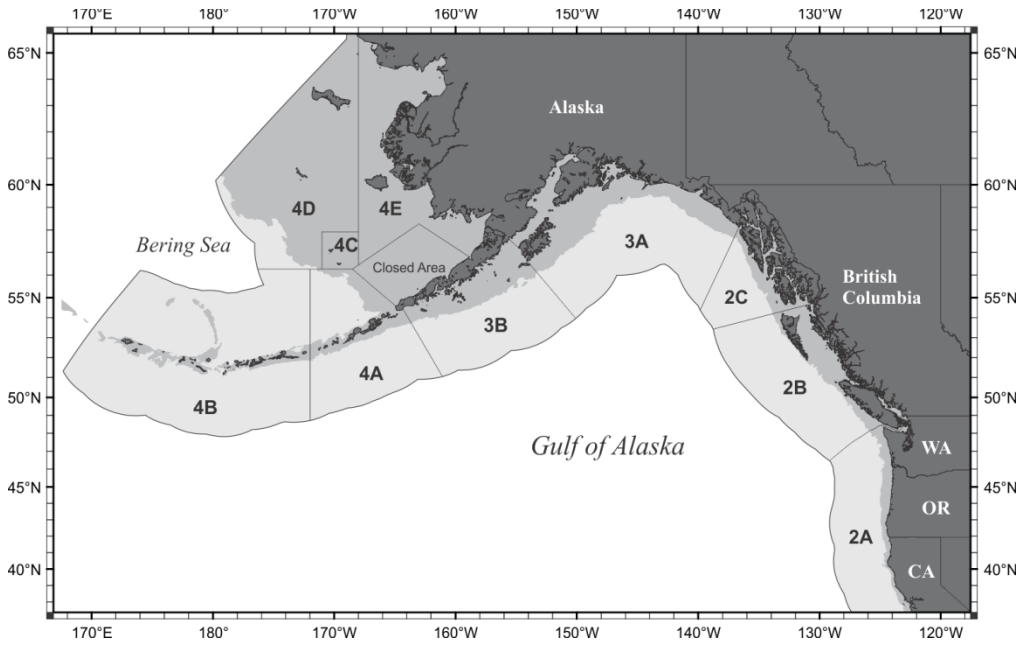


Figure 3. The IPHC's regulatory areas. Shaded region indicates the Exclusive Economic Zone (EEZ) of the United States and Canada.

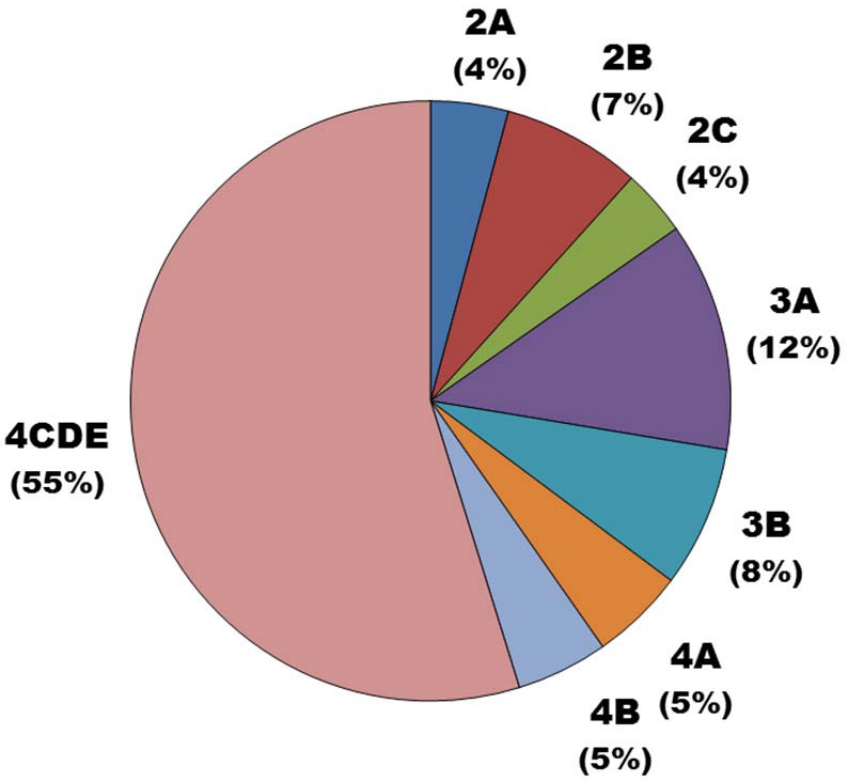


Figure 4. Relative spatial extent of each regulatory area.

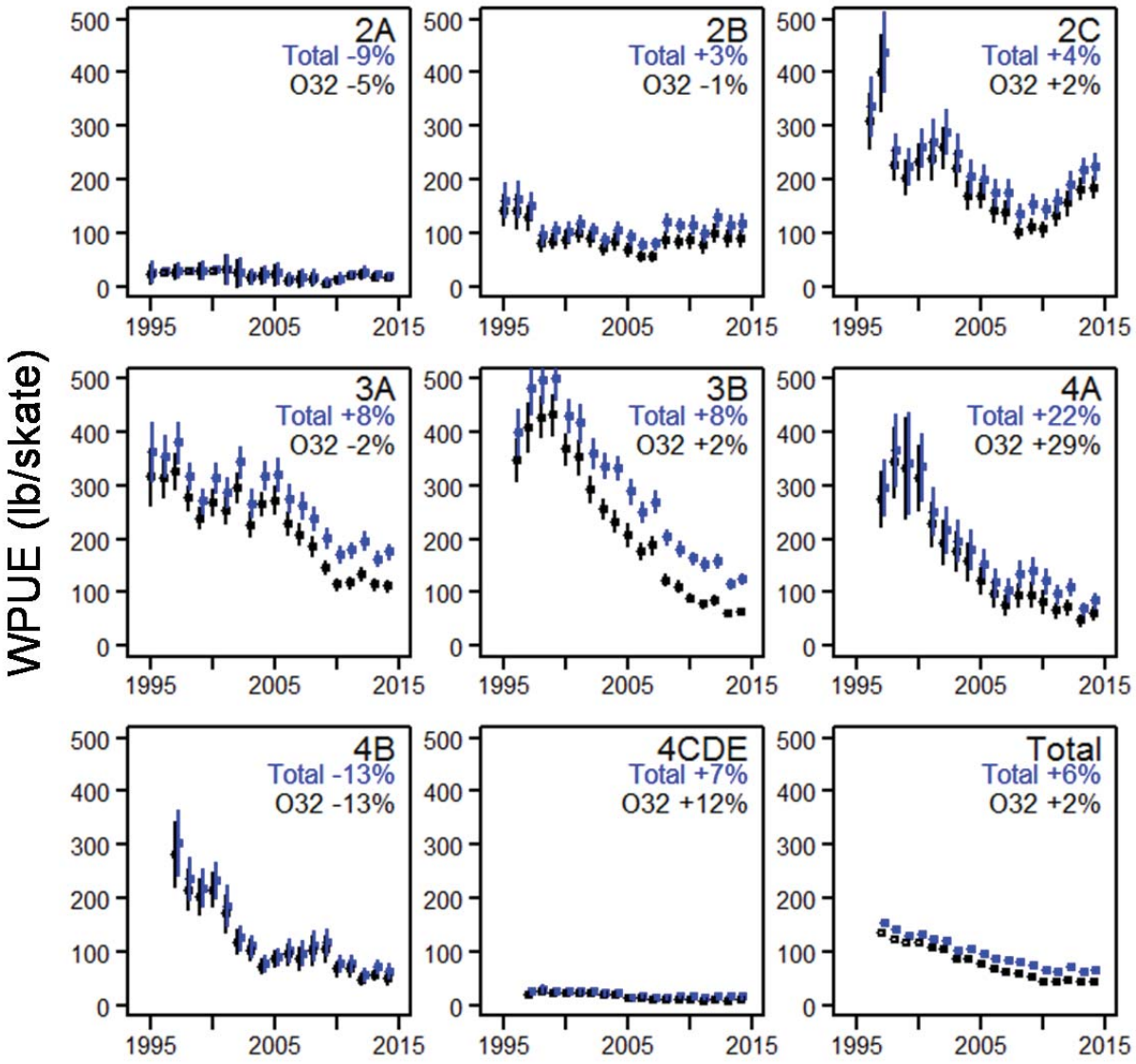


Figure 5. Recent setline survey WPUE (lbs/skate) for all (blue, upper series) and legal-sized fish (black, lower series) by regulatory area and year through 2014. Percentages for each area indicate the change from 2013 to 2014. Total WPUE values have been offset slightly on the x-axis to make the points easier to distinguish.

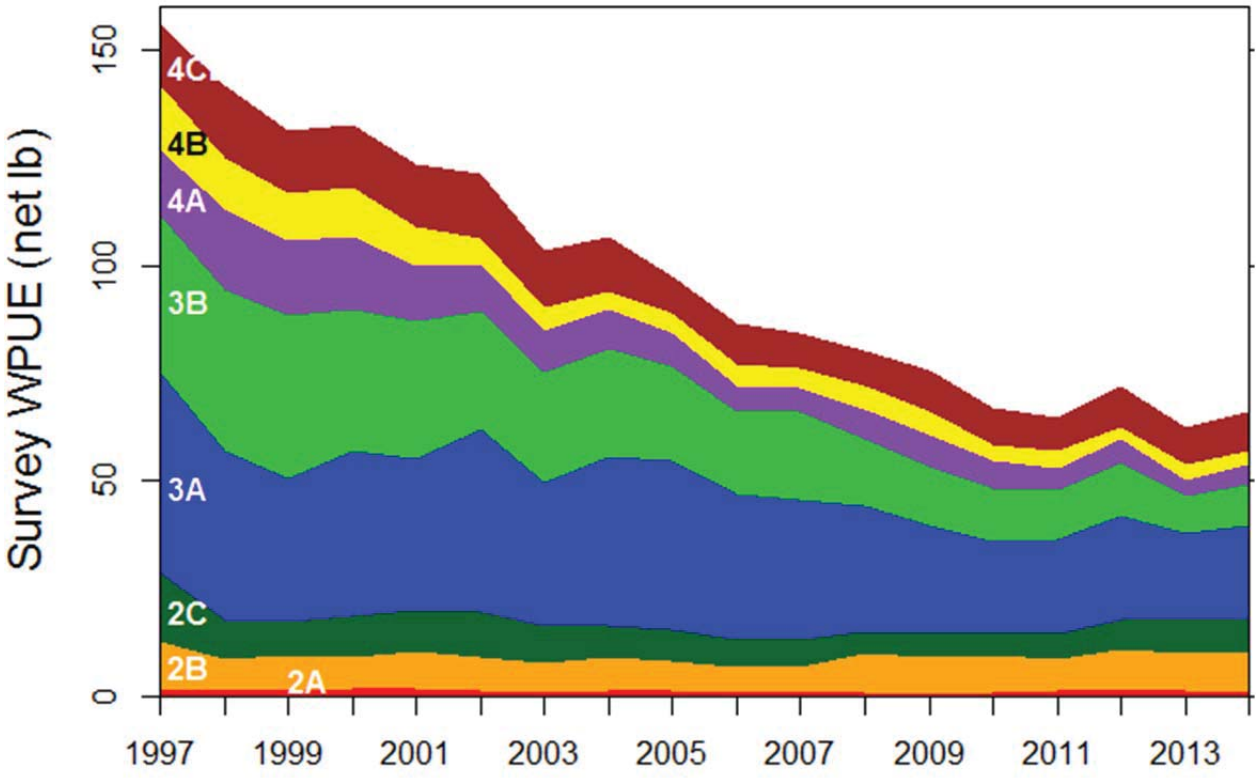


Figure 6. Weighted contributions of the regulatory areas to the coastwide survey total WPUE.

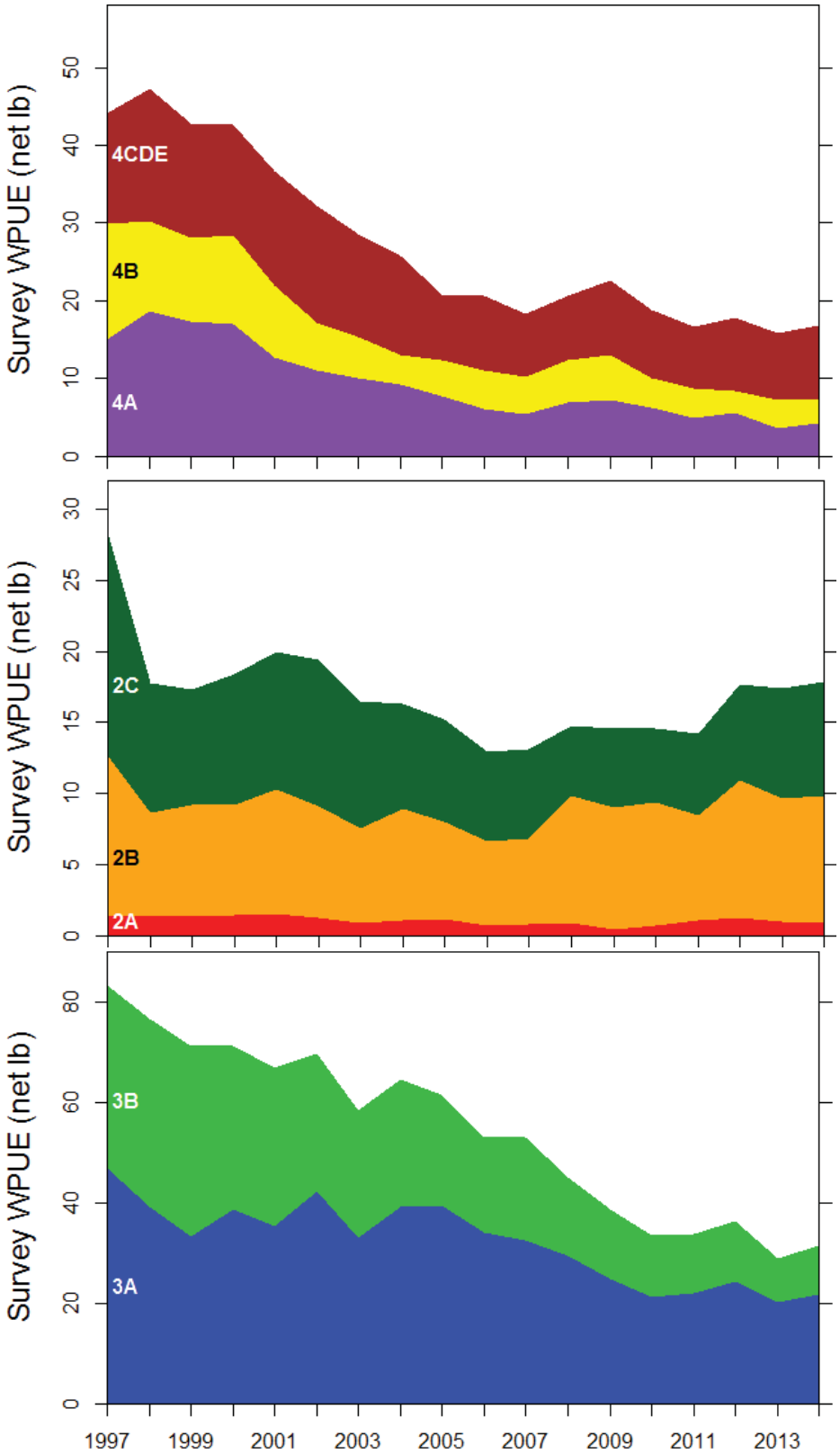


Figure 7. Weighted contributions of the individual regulatory Areas within the survey WPUE for Area 2 (lower panel), Area 3 (middle panel) and Area 4 (upper panel). Note that the y-axes differ among the panels.

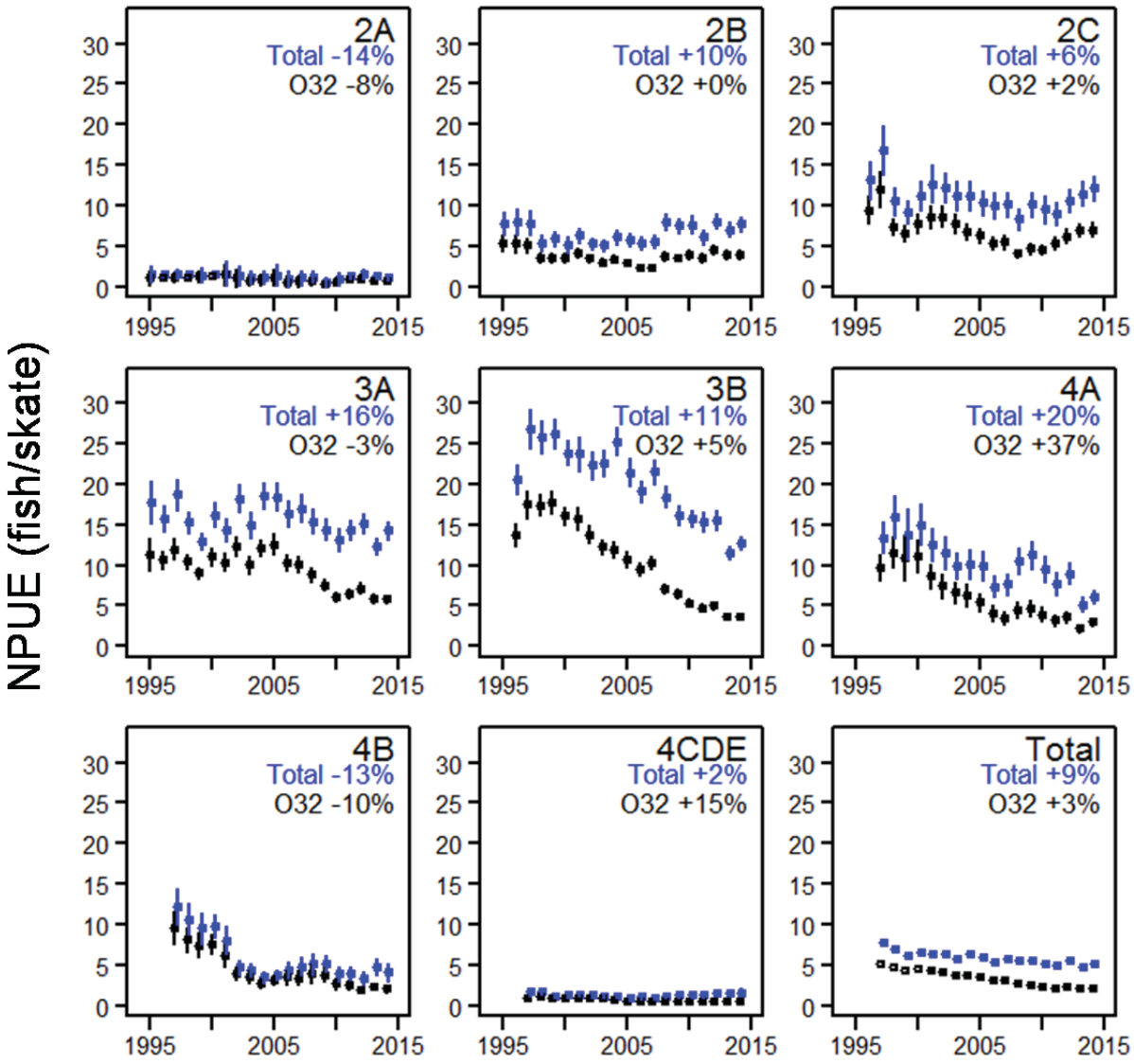


Figure 8. Recent setline survey NPUE (fish/skate) for all (blue, upper series) and legal-sized fish (black, lower series) by regulatory area and year through 2014. Percentages for each area indicate the change from 2013 to 2014. Total NPUE values have been offset slightly on the x-axis to make the points easier to distinguish.

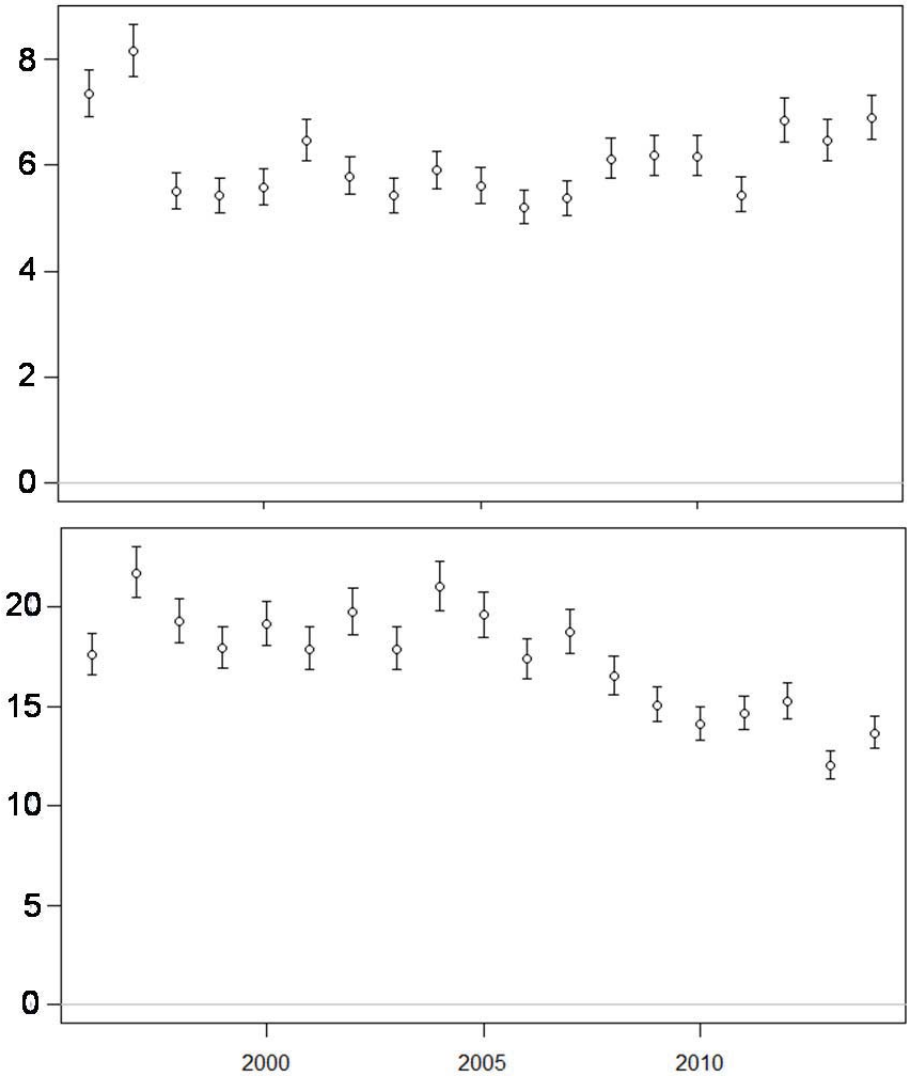


Figure 9. Recent aggregate setline survey total NPUE by geographic region (Area 2, upper panel; Area 3, lower panel).

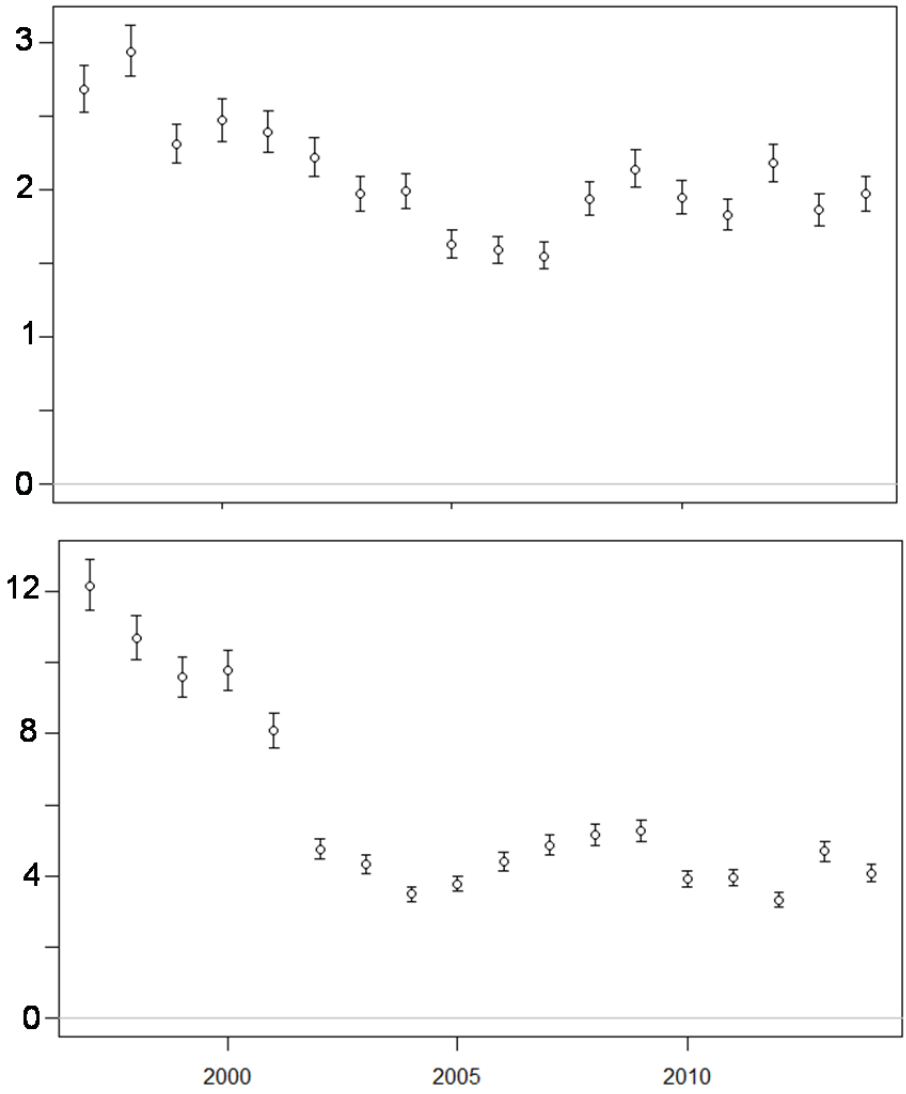


Figure 10. Recent aggregate setline survey total NPUE by geographic region (Area 4, upper panel; Area 4B, lower panel).

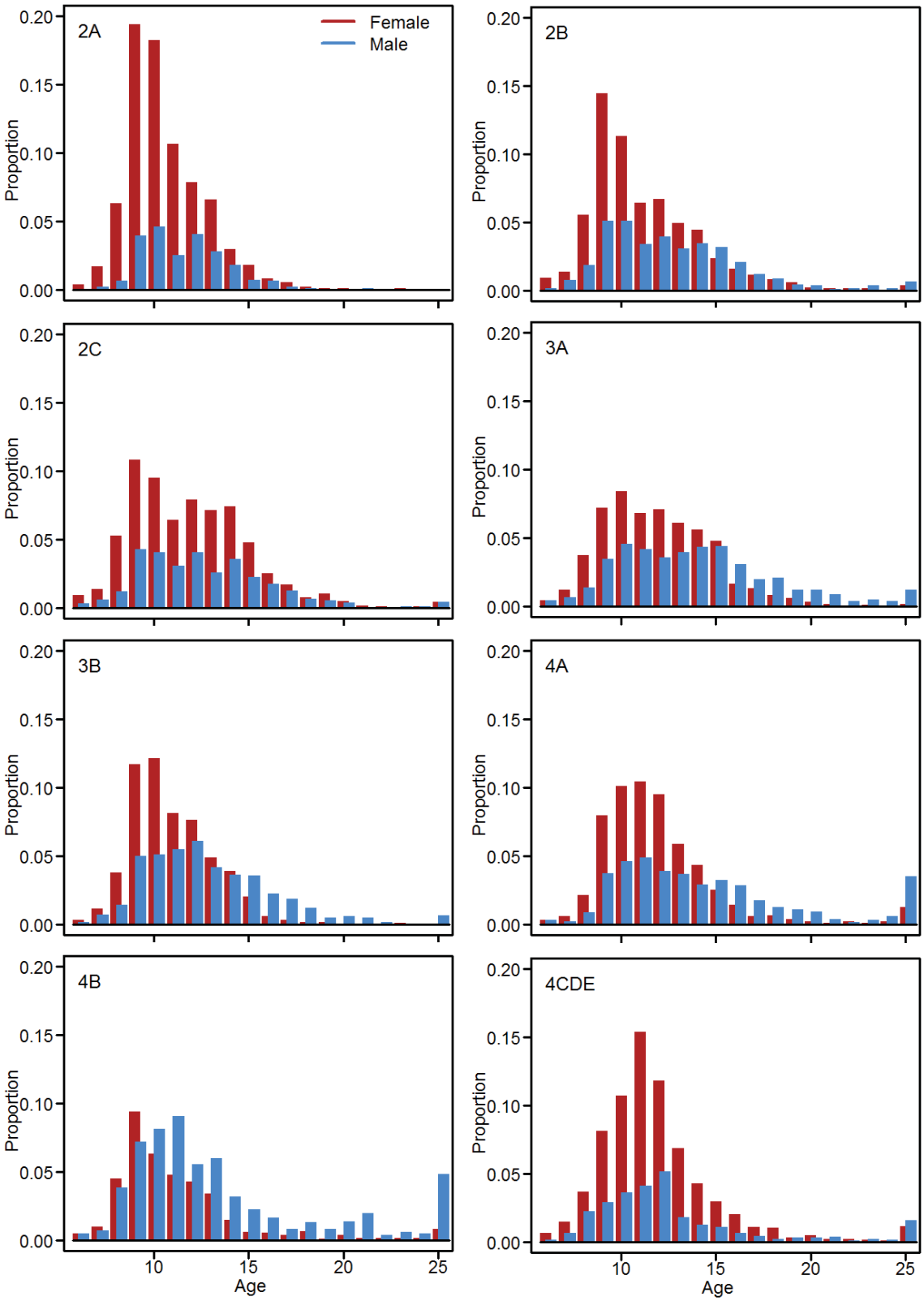


Figure 11. Age distributions from the 2014 setline survey by regulatory area.

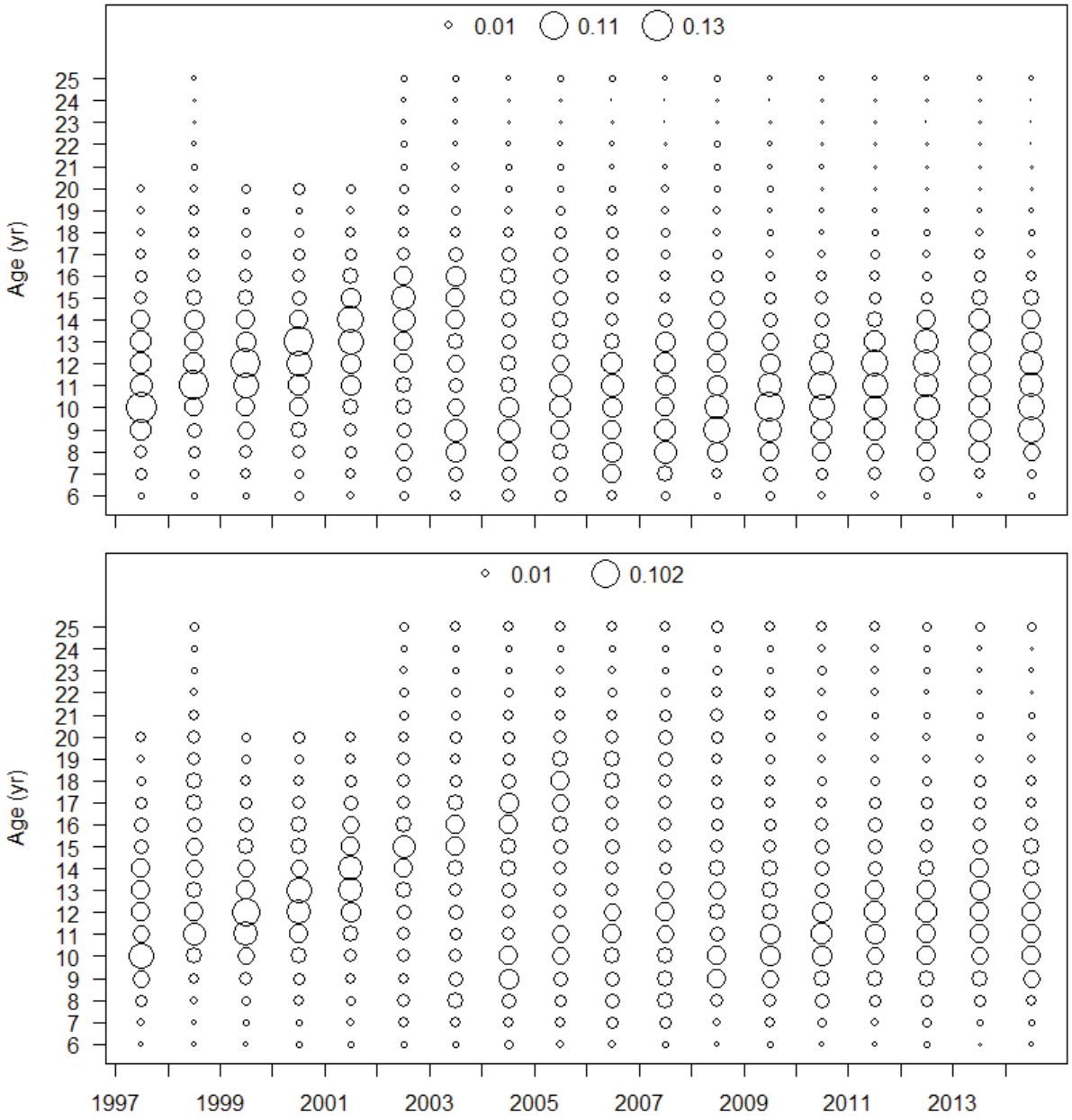


Figure 12. Recent coastwide proportions-at-age for females (upper panel) and males (lower panel) from the setline survey. Proportions sum to 1.0 across both sexes within each year.

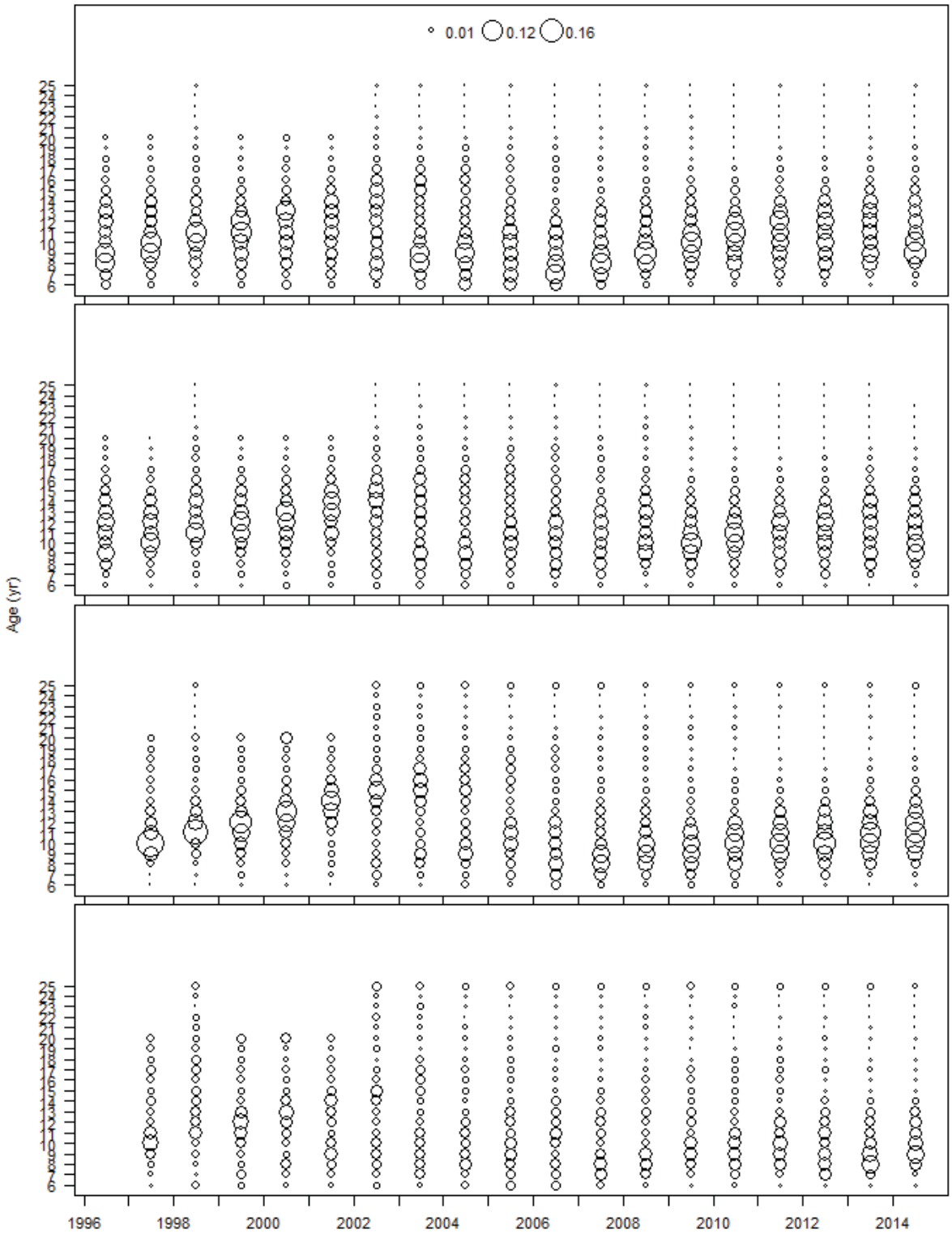


Figure 13. Recent proportions-at-age for female halibut captured by the setline survey by geographic region: Area 2 (upper panel), Area 3 (second panel from top), Area 4 (third panel) and Area 4B (bottom panel) halibut captured by the setline survey. Proportions sum to 1.0 across both sexes within each year.

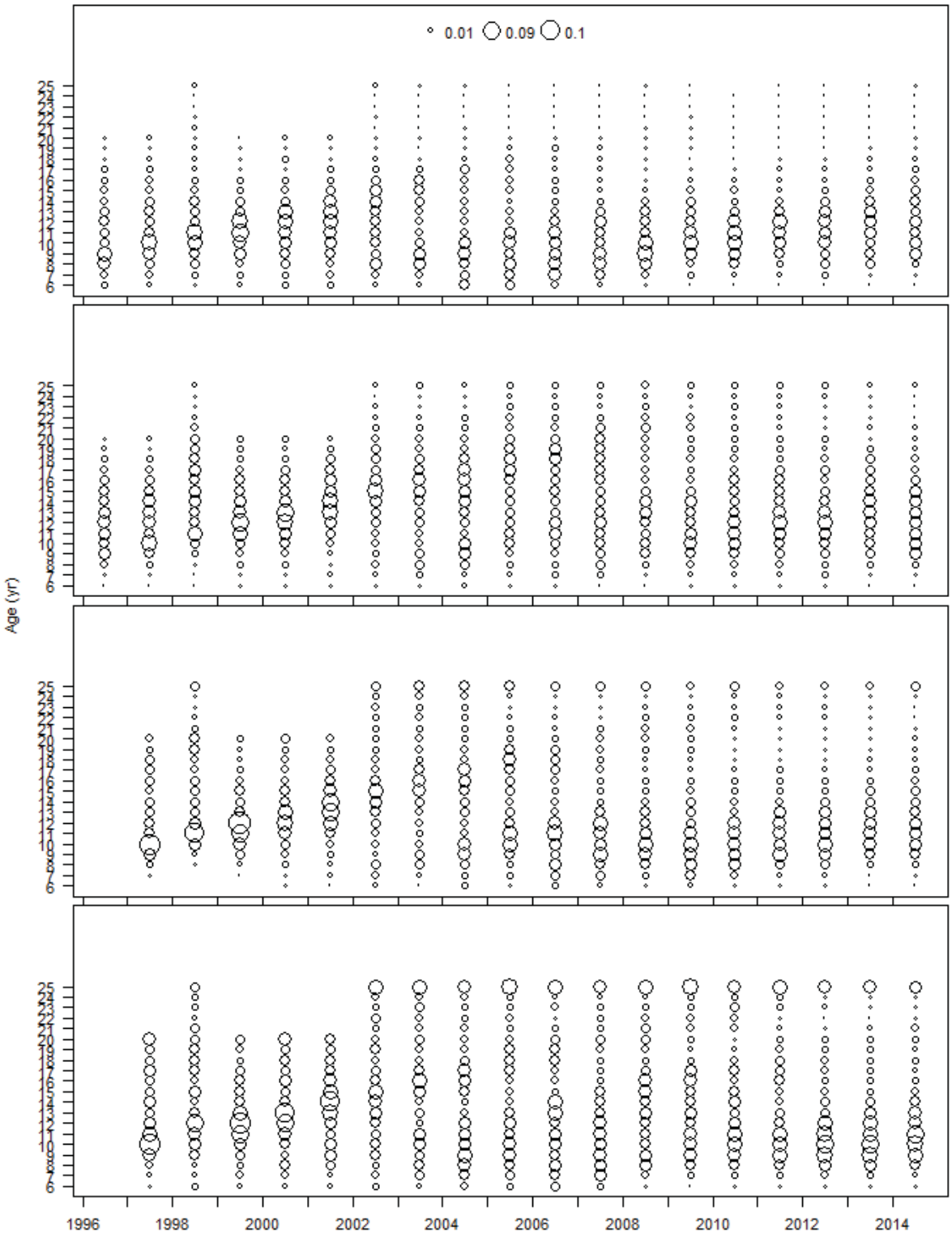


Figure 14. Recent proportions-at-age for male halibut captured by the setline survey by geographic region: Area 2 (upper panel), Area 3 (second panel from top), Area 4 (third panel) and Area 4B (bottom panel) halibut captured by the setline survey. Proportions sum to 1.0 across both sexes within each year.

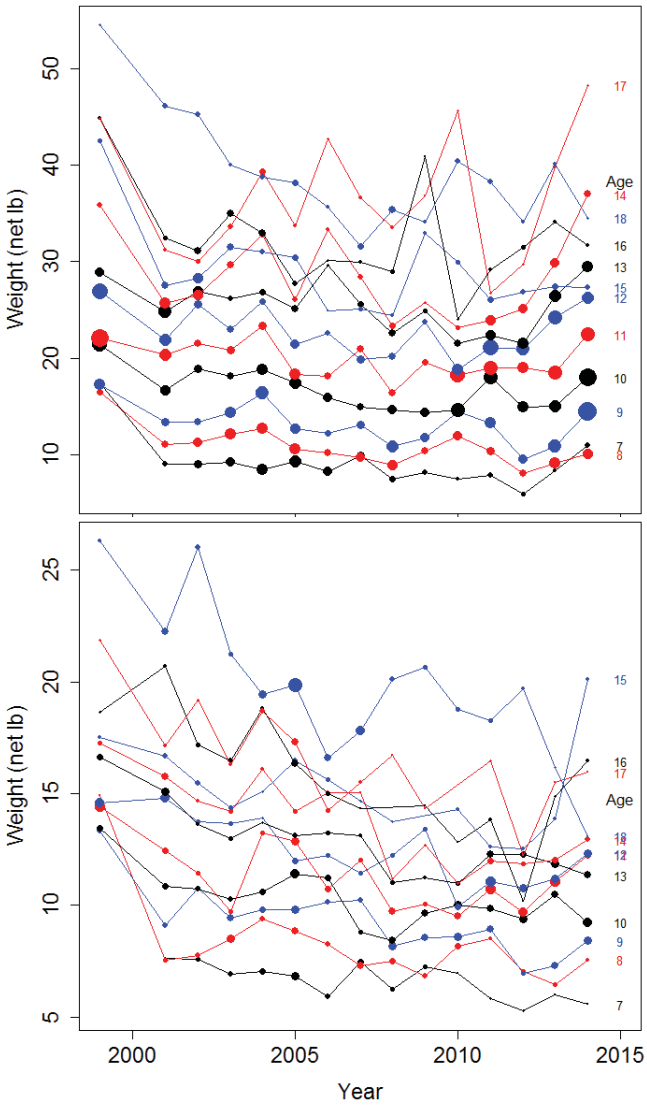


Figure 15. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 2A captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

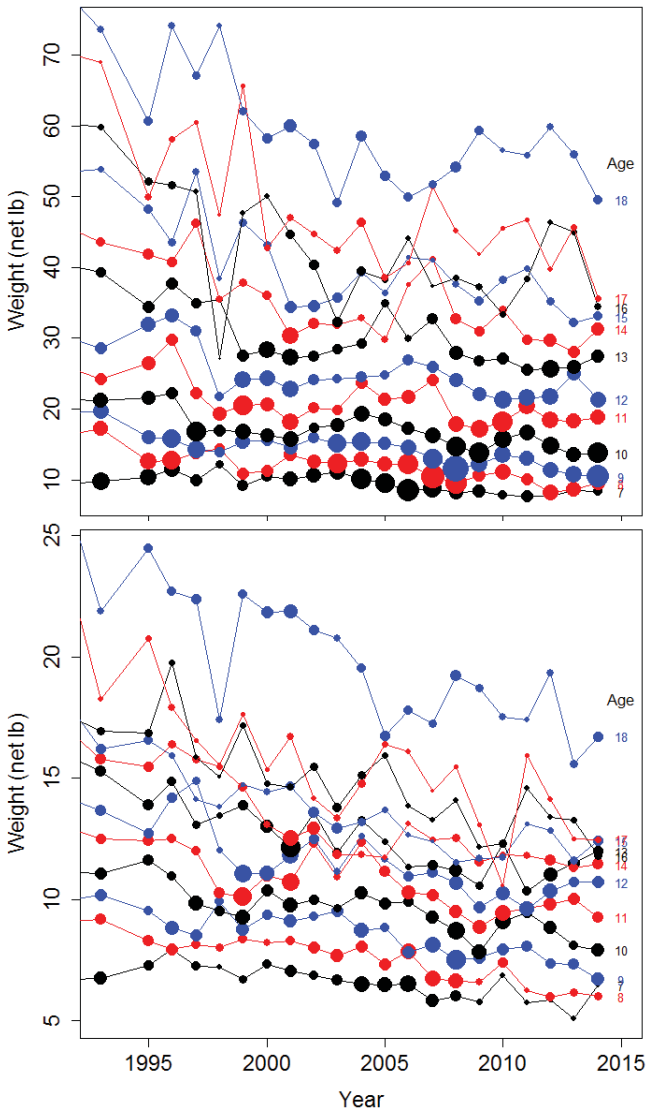


Figure 16. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 2B captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

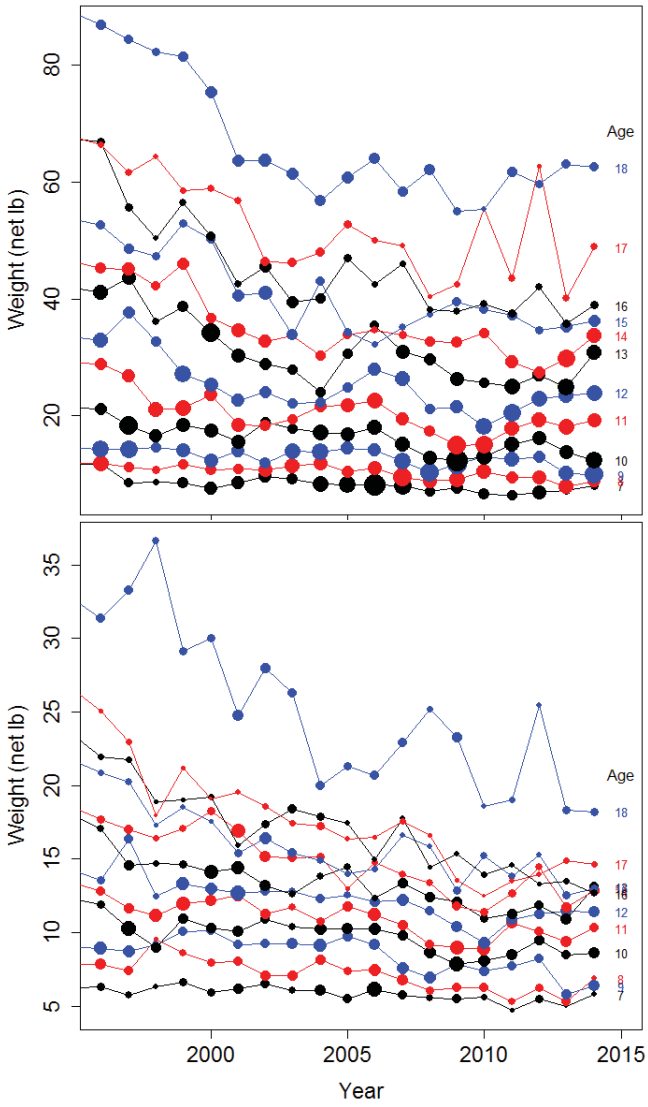


Figure 17. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 2C captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

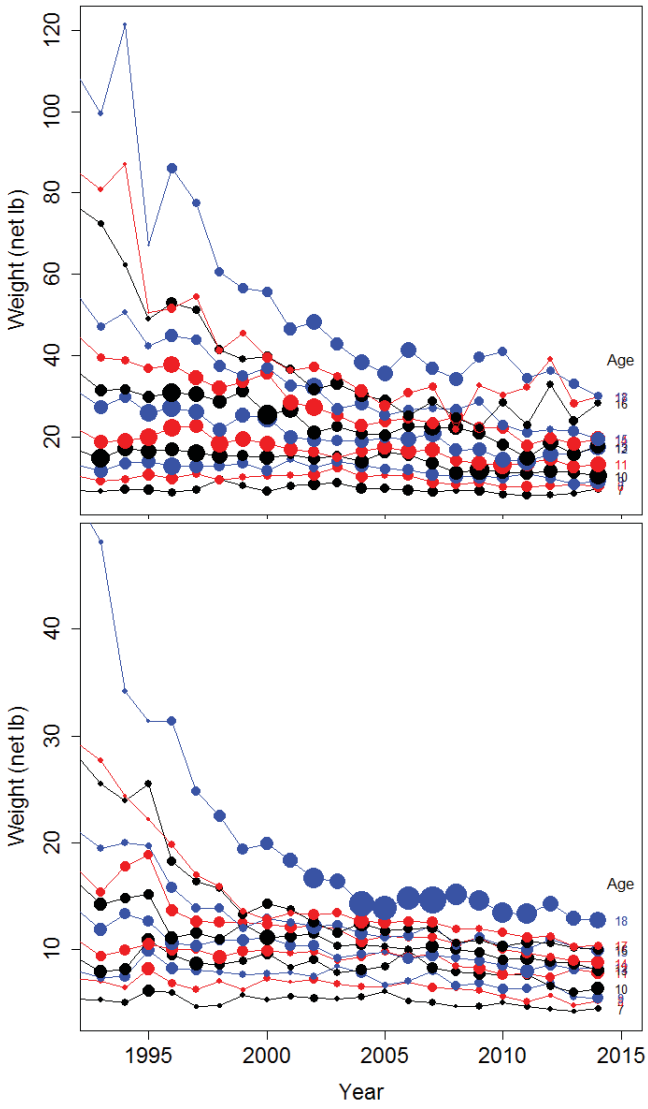


Figure 18. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 3A captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

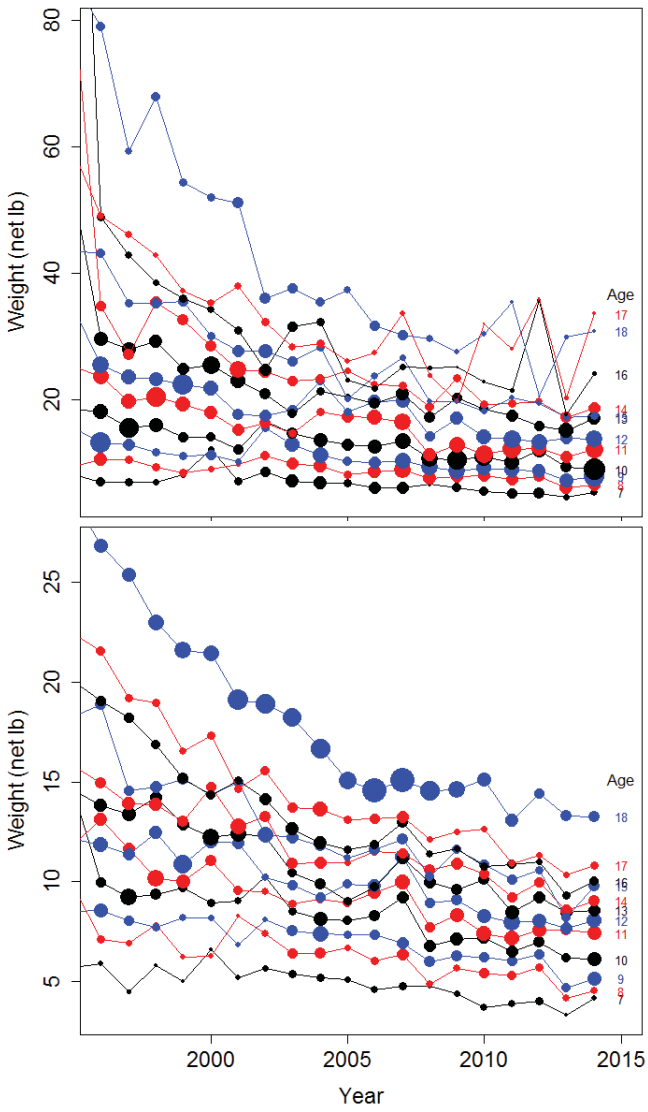


Figure 19. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 3B captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

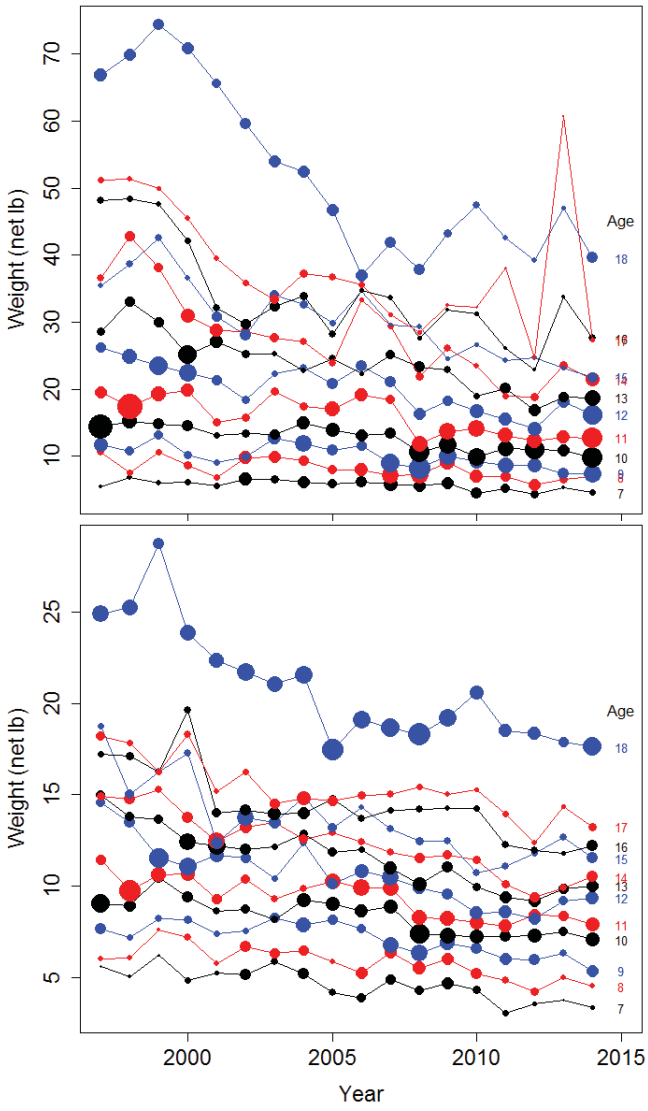


Figure 20. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 4A captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

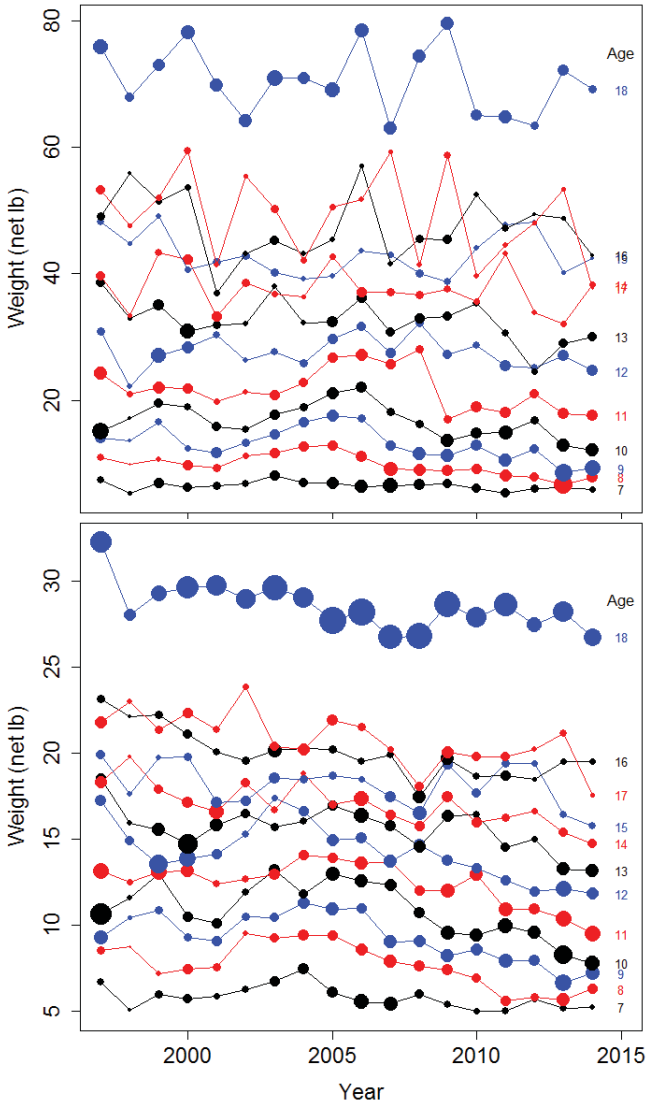


Figure 21. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Area 4B captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

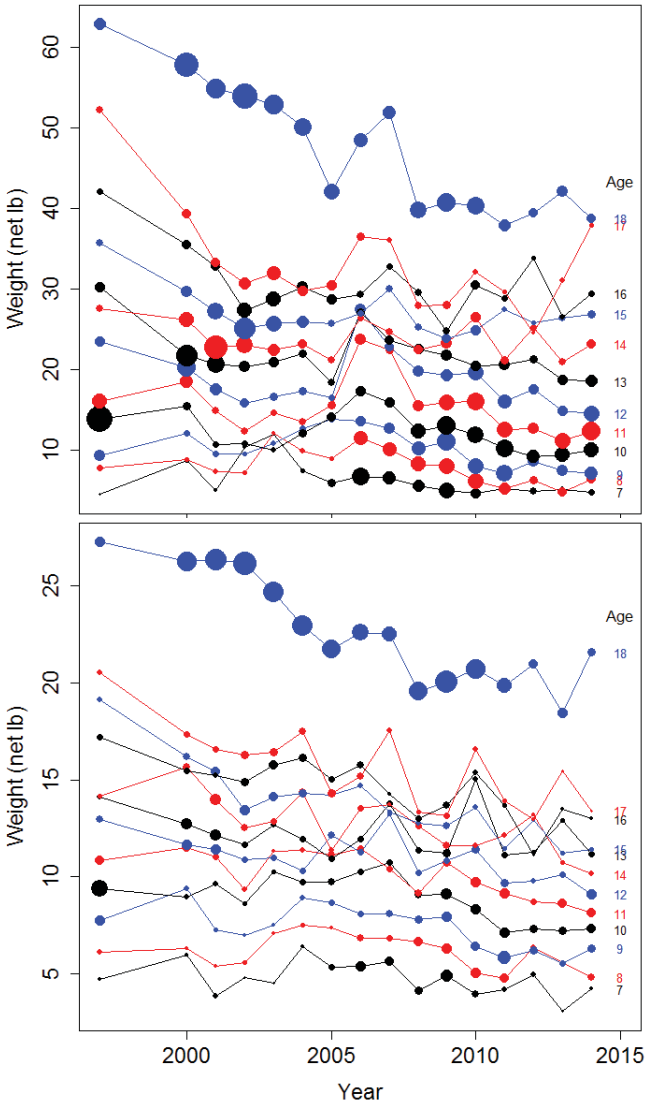


Figure 22. Trends in weight-at-age for female (upper panel), and male (lower panel) halibut from regulatory Areas 4C, 4D and 4E captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

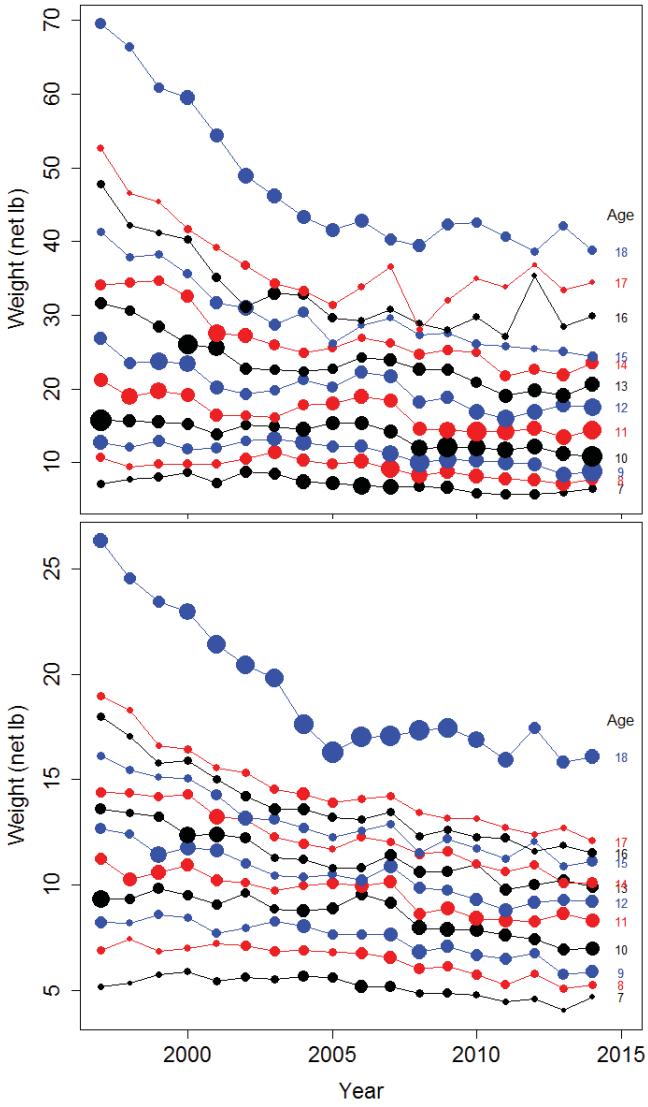


Figure 23. Weighted coastwide trends in weight-at-age for female (upper panel), and male (lower panel) halibut from all regulatory areas captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and greater have been aggregated for clarity.

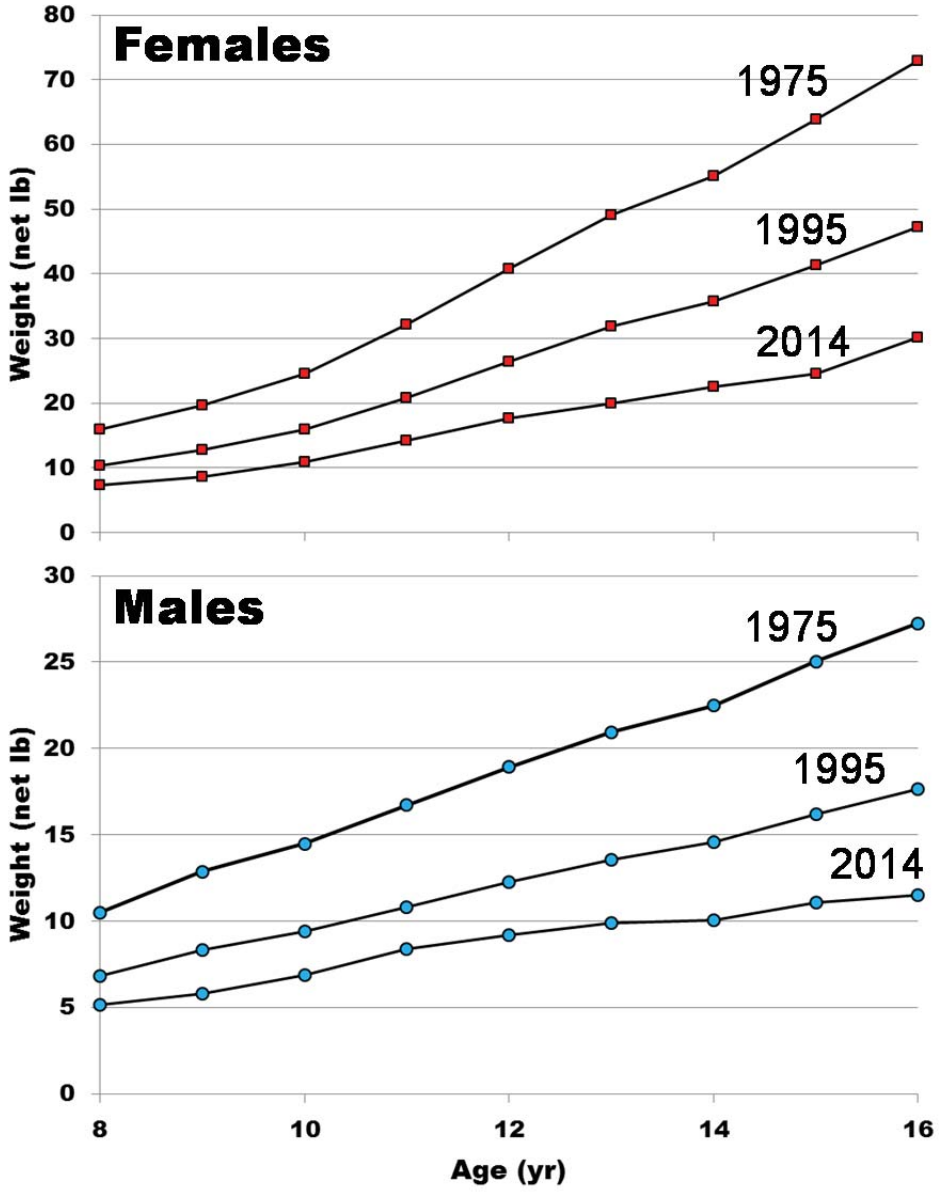


Figure 24. Coastwide aggregate estimated average weight-at-age trends from setline survey and fishery data over the last four decades.

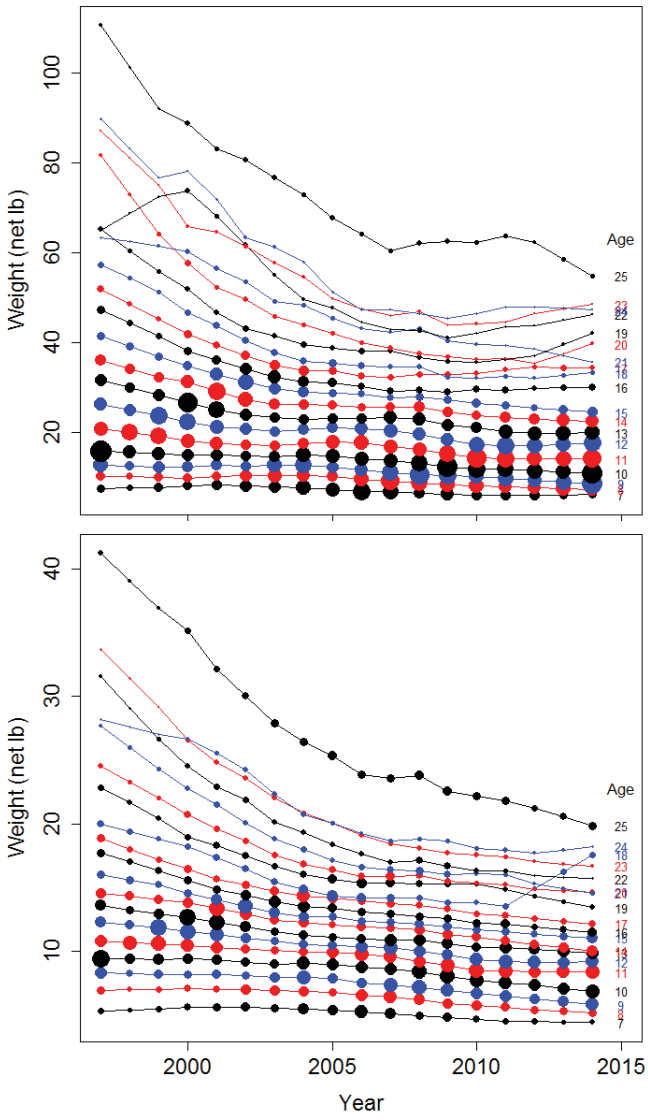


Figure 25. Weighted and smoothed coastwide trends in weight-at-age for female (upper panel), and male (lower panel) halibut from all regulatory areas captured by the setline survey. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 25 and greater have been aggregated.

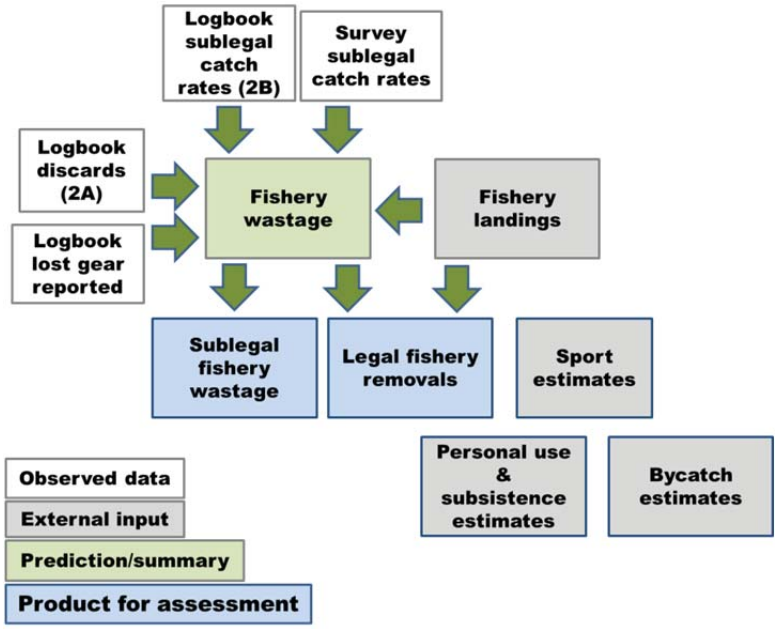


Figure 26. Relationships among estimates halibut mortality by source.

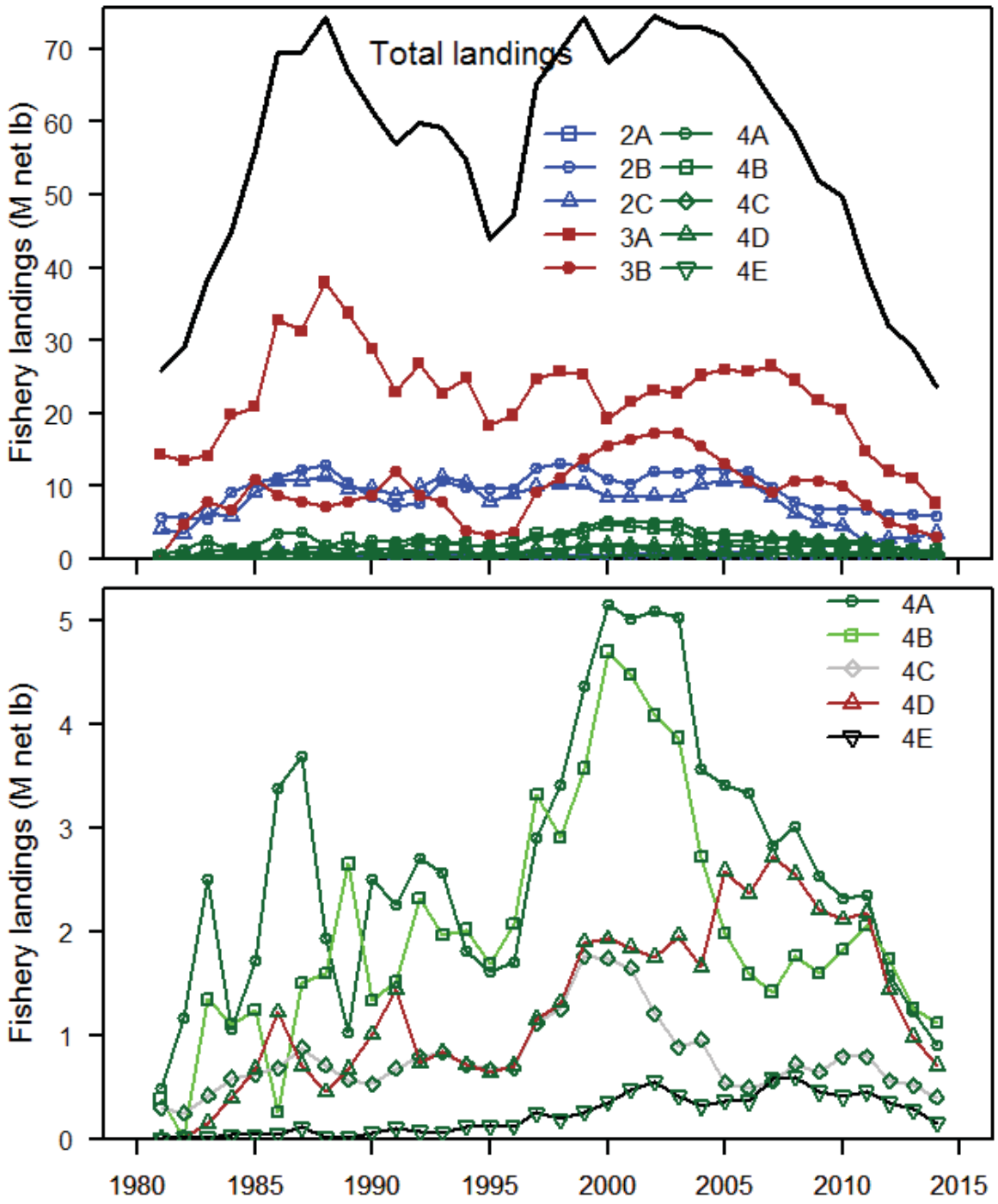


Figure 27. Recent landings of halibut by the directed commercial fishery by regulatory area (upper panel), and within Areas 4A to 4E for better resolution of the trends (lower panel).

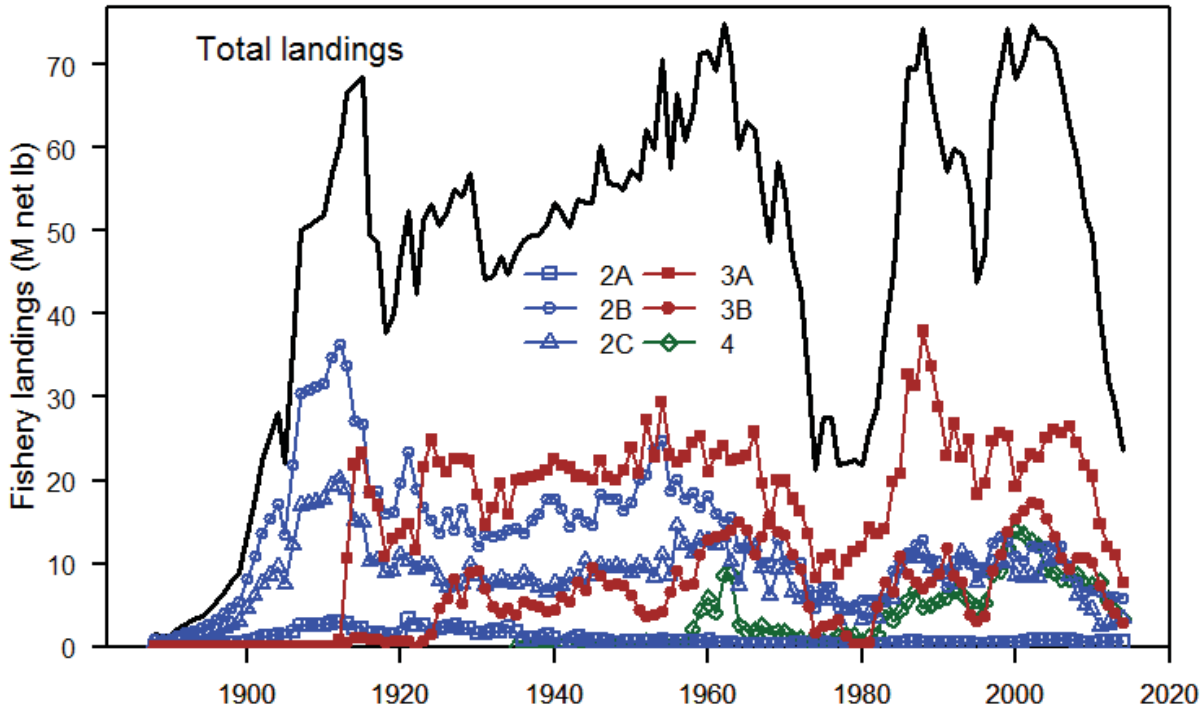


Figure 28. Landings of halibut by the directed commercial fishery by regulatory area.

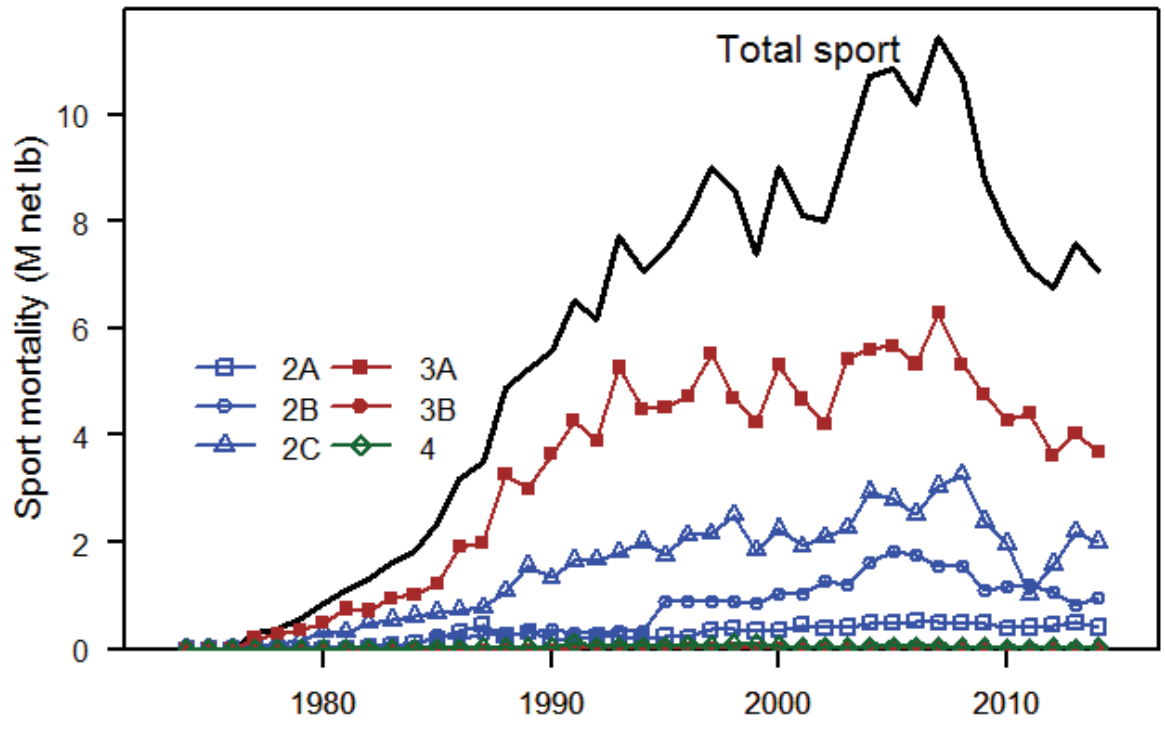


Figure 29. Sport (recreational) removals of halibut by regulatory area.

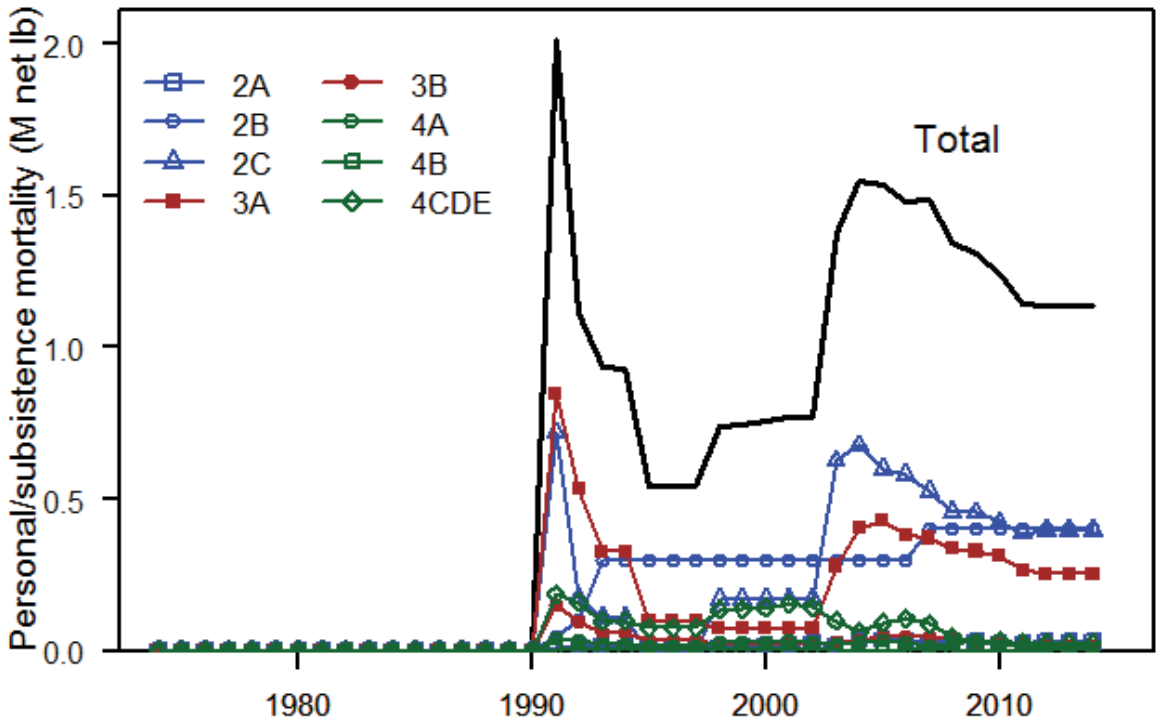


Figure 30. Estimated personal use or subsistence removals by regulatory area.

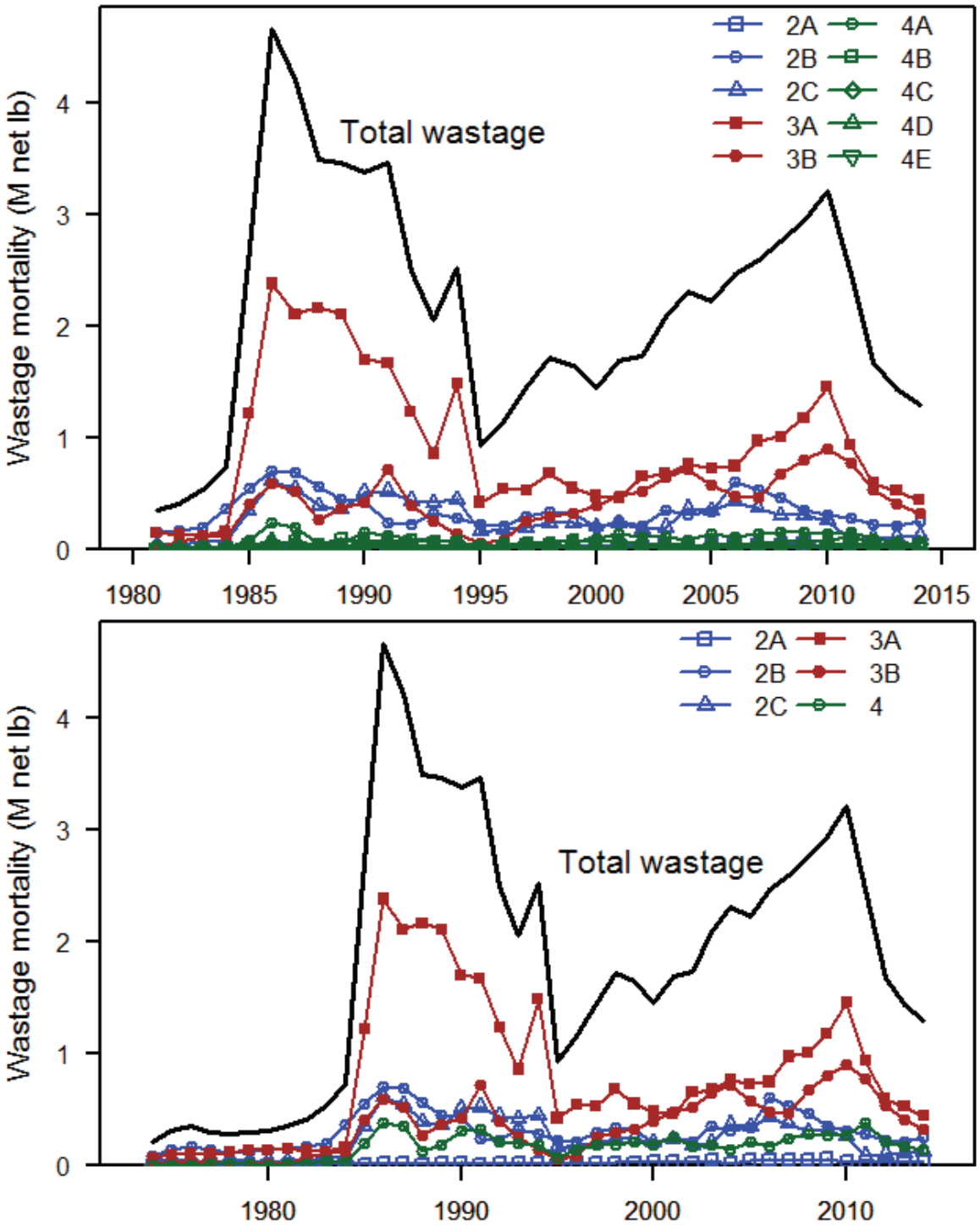


Figure 31. Wastage in the commercial fishery by regulatory area, 1981-2014 (upper panel), and 1974-2014, with all of Area 4 combined (lower panel).

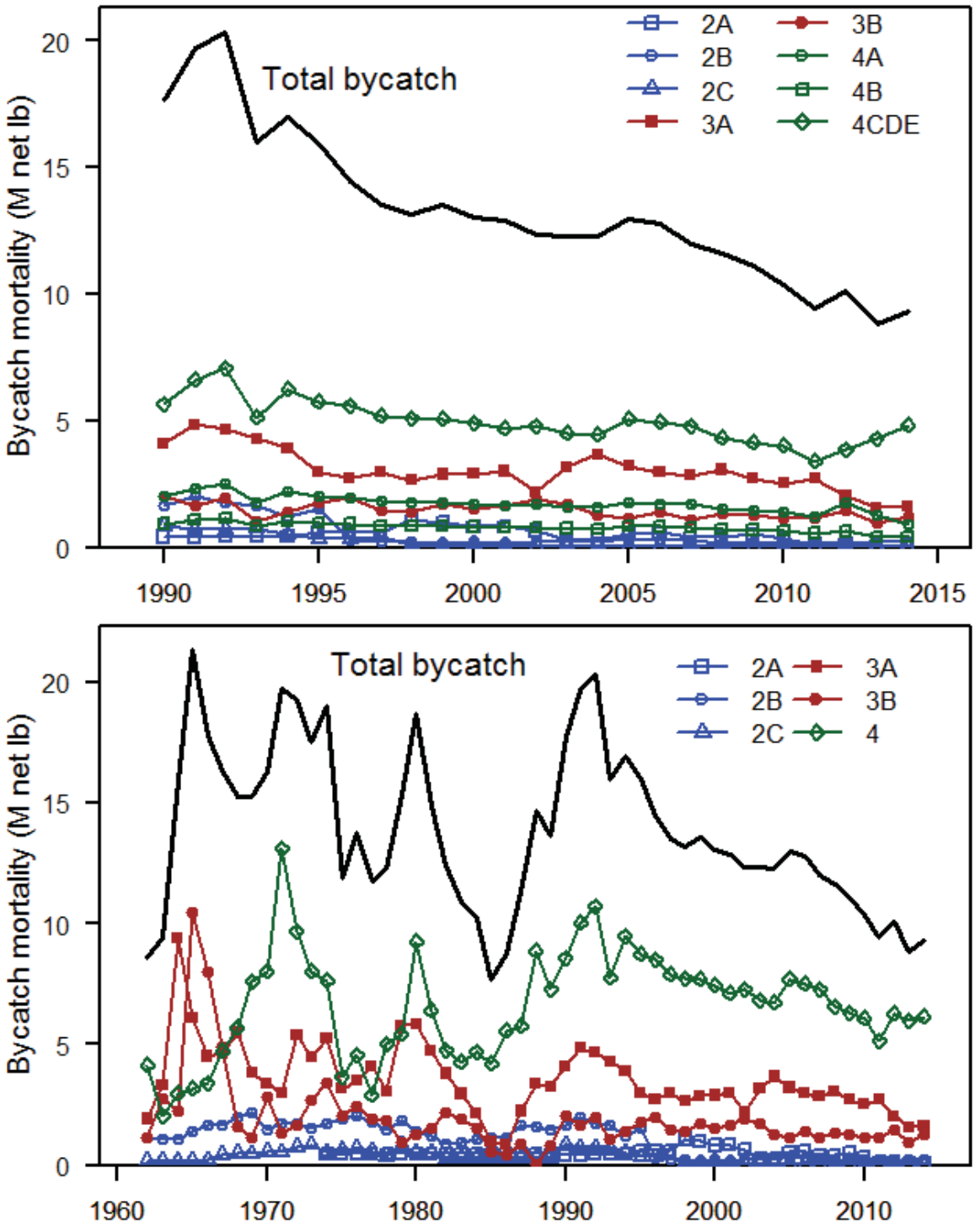


Figure 32. Halibut bycatch estimates by regulatory area, 1990-2014 (upper panel), and 1962-2014, with all of Area 4 combined (lower panel).

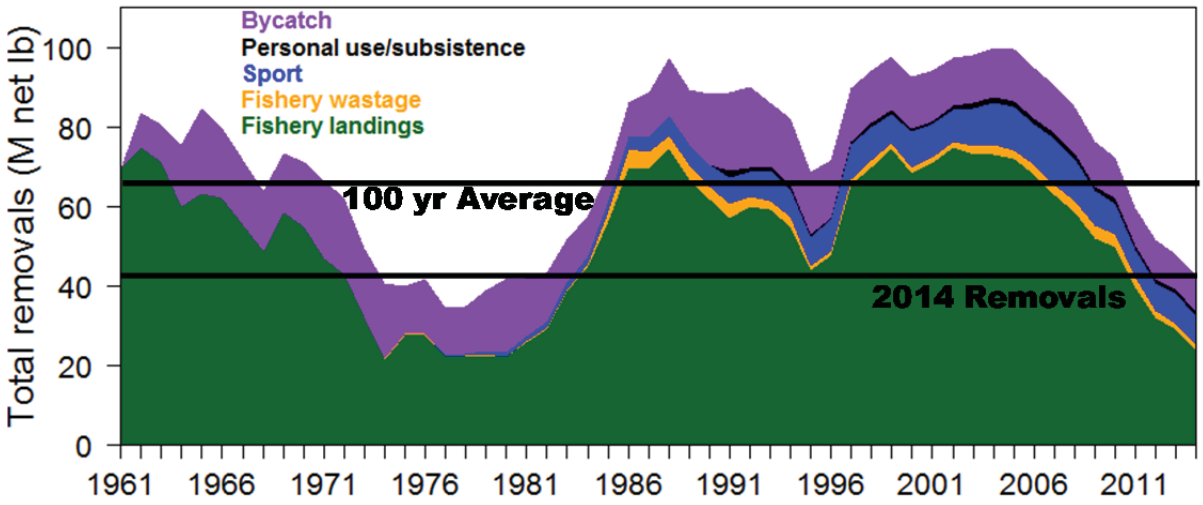


Figure 33. Total halibut removals by source since 1961.

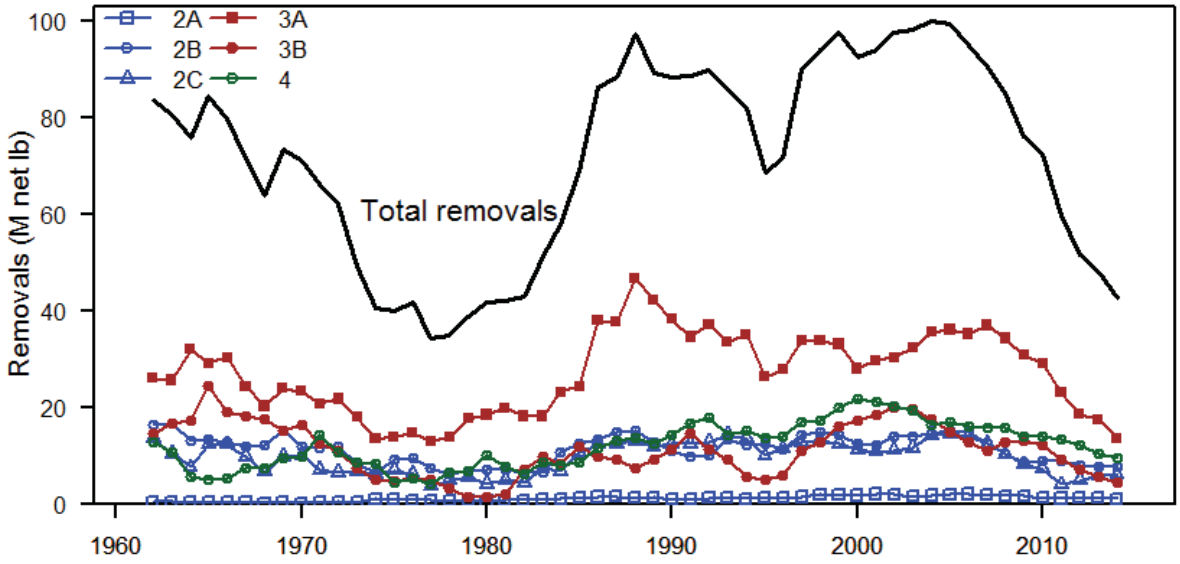


Figure 34. Total halibut removals by regulatory area since 1962.

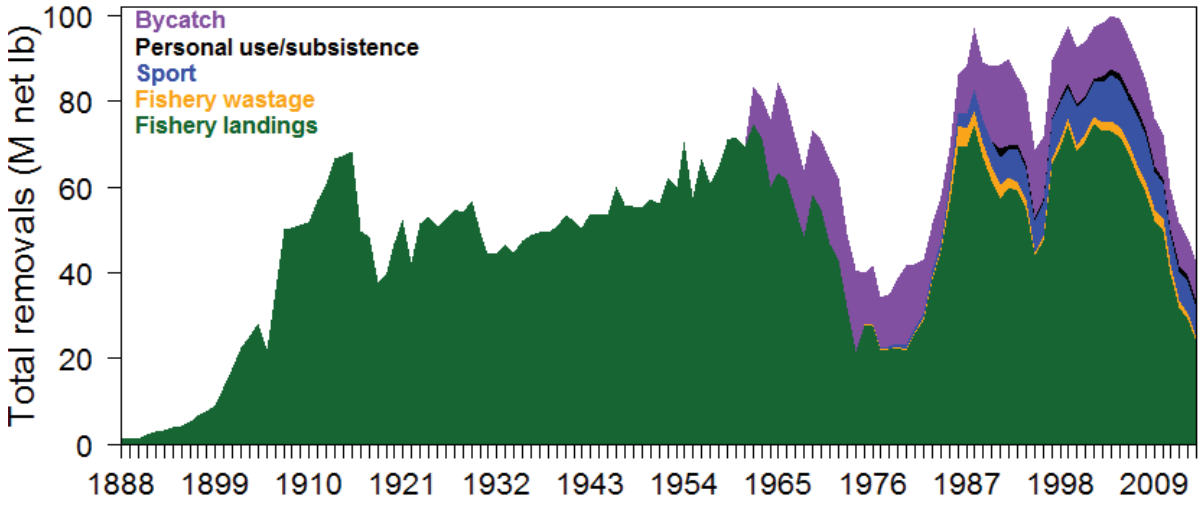


Figure 35. Total estimated halibut removals by source since 1888.

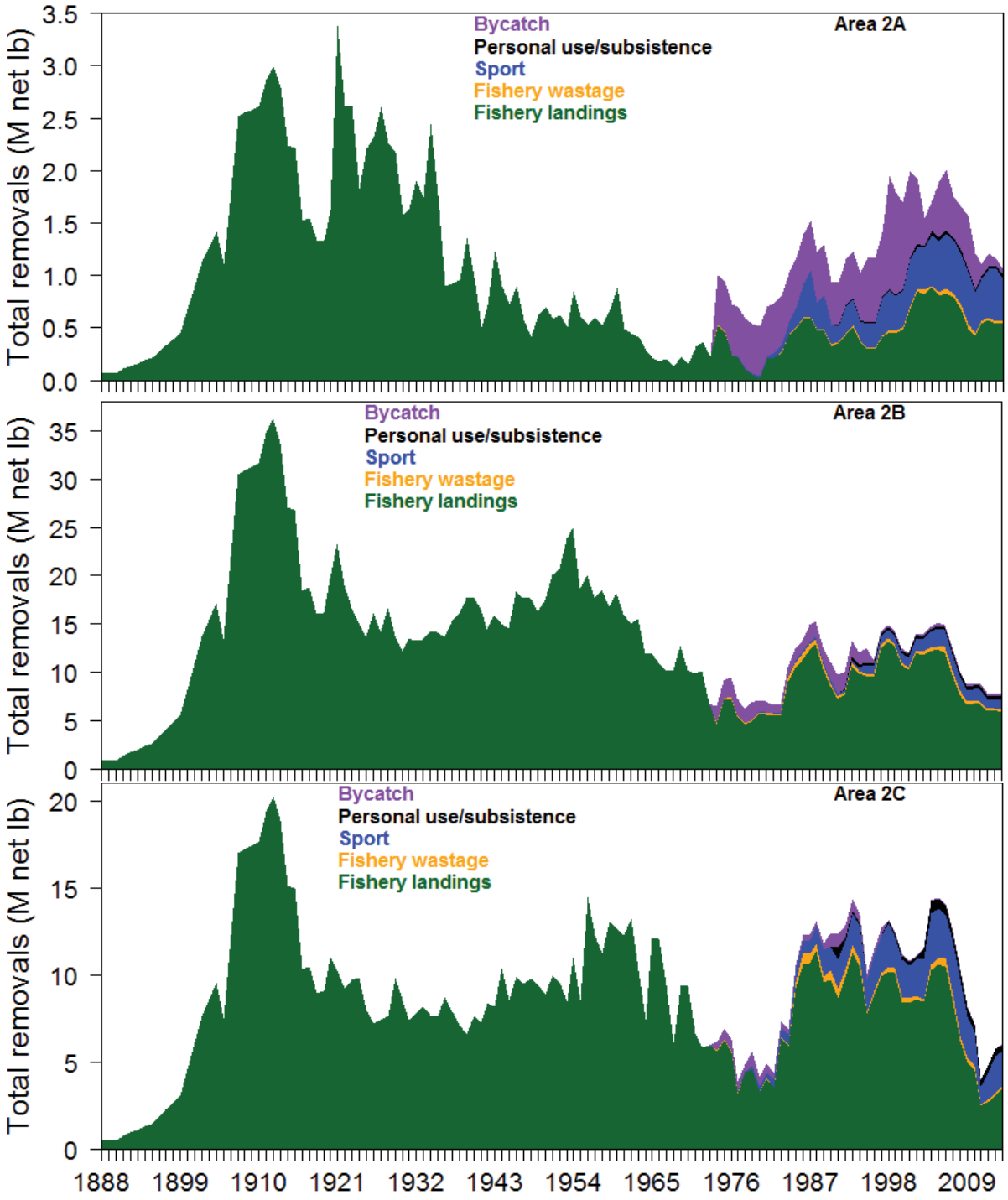


Figure 36. Total estimated halibut removals by source in Areas 2A, 2B, and 2C since 1888. Note that the y axes differ in scale.

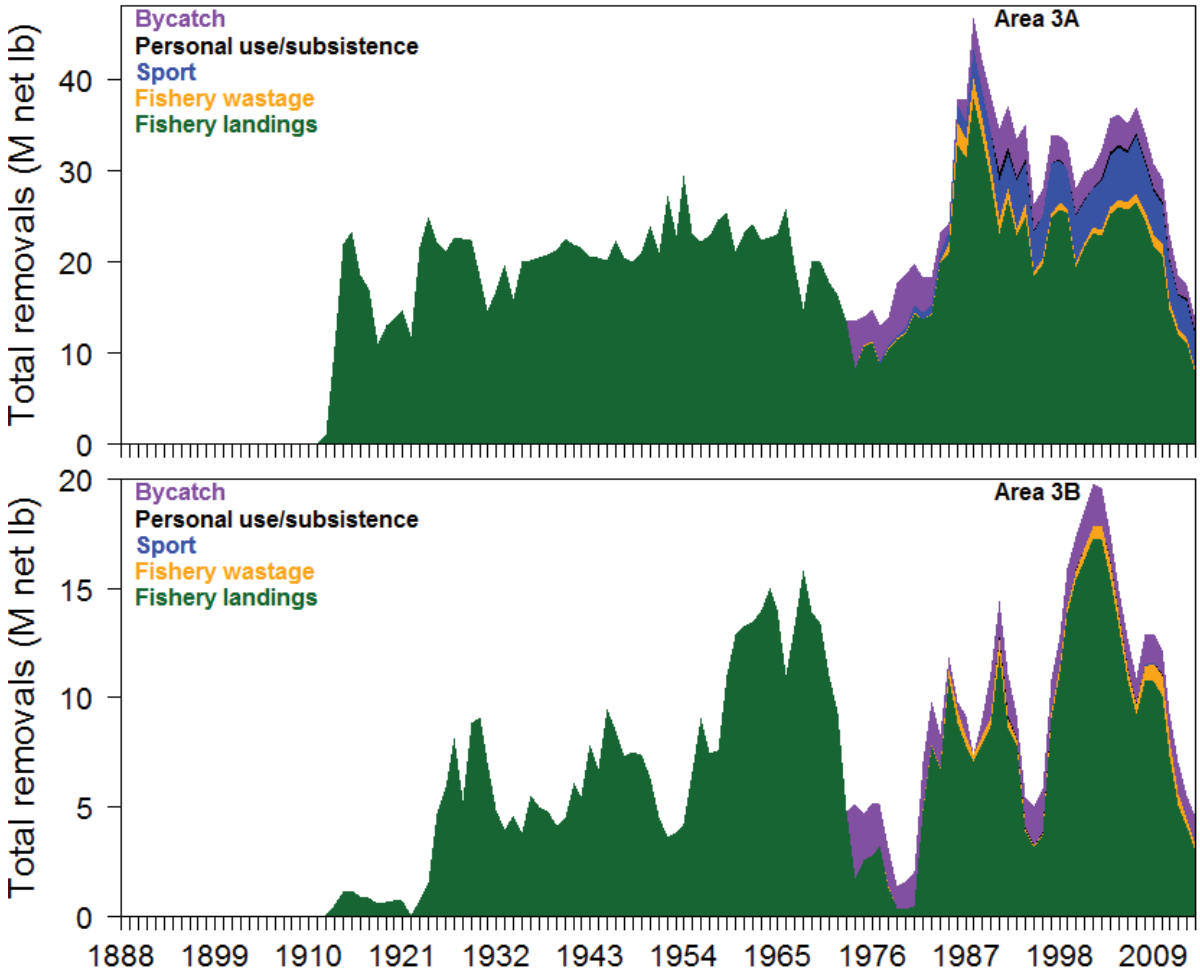


Figure 37. Total estimated removals by source in Areas 3A, and 3B since 1888. Note that the y-axes differ in scale.

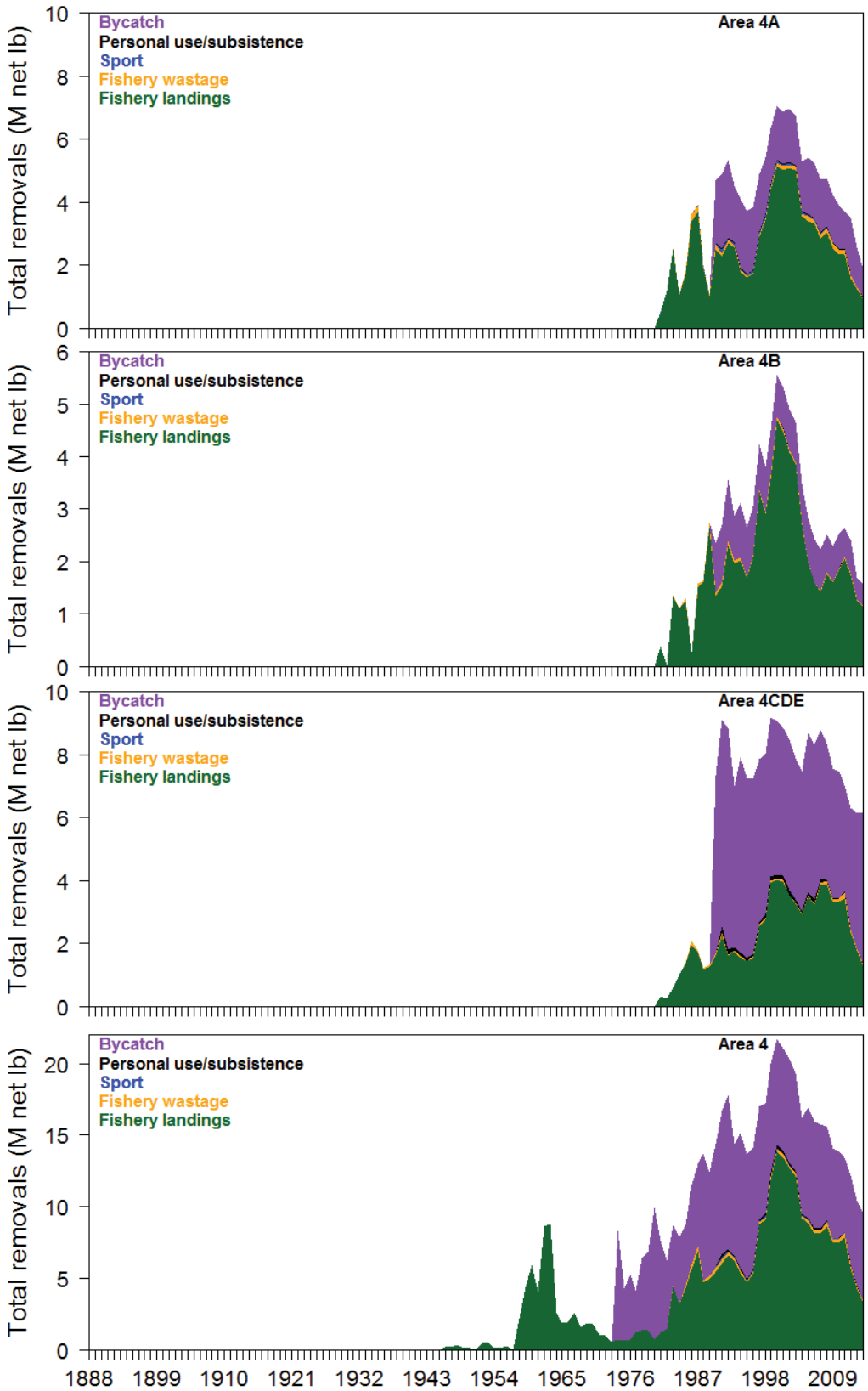


Figure 38. Total estimated removals by source in Areas 4A, 4B, 4CDE, and all of Area 4 combined since 1888. Note that the y-axes differ in scale.

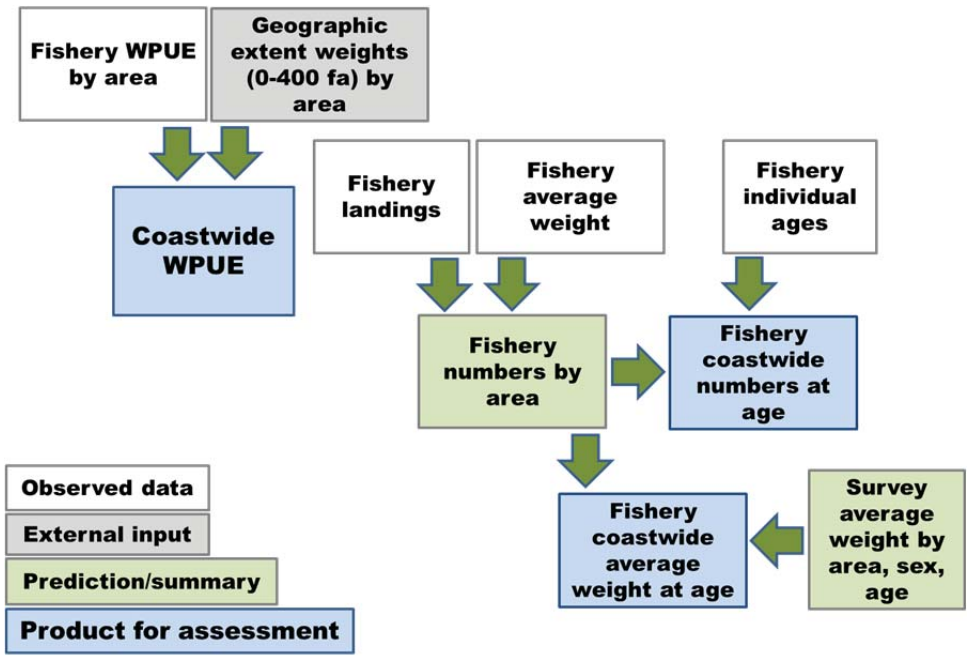


Figure 39. Relationships among fishery-dependent catch-rate and biological data sources.

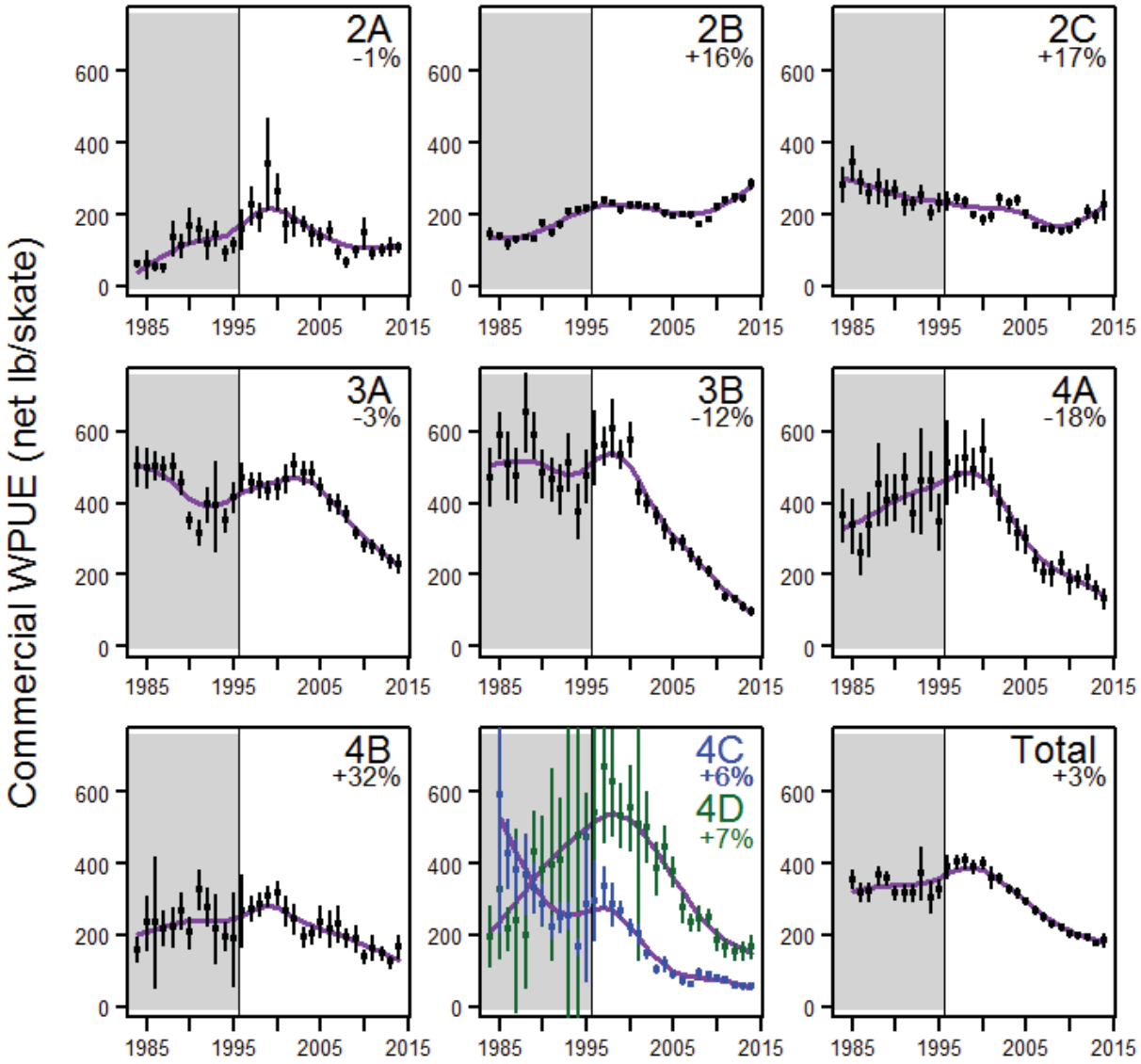


Figure 40. Commercial WPUE summarized by regulatory area and year. Percentages for each Area indicate the change from 2013 to 2014; lines represent a smoother for trend visualization purposes only.

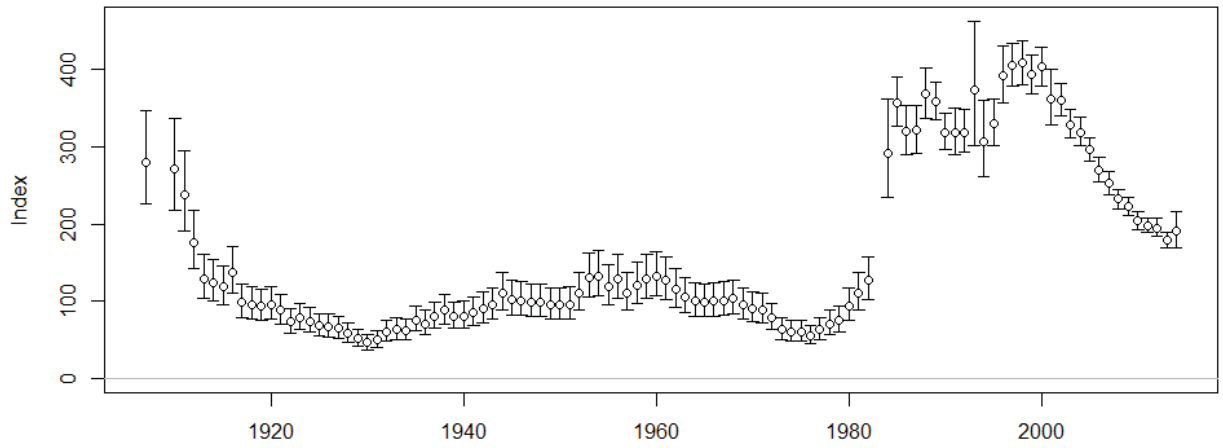


Figure 41. Coastwide commercial WPUE from historical records of effort and catch, as well as more recent direct logbook processing. The large change between 1982 and 1984 coincides with the adoption of circle hooks.

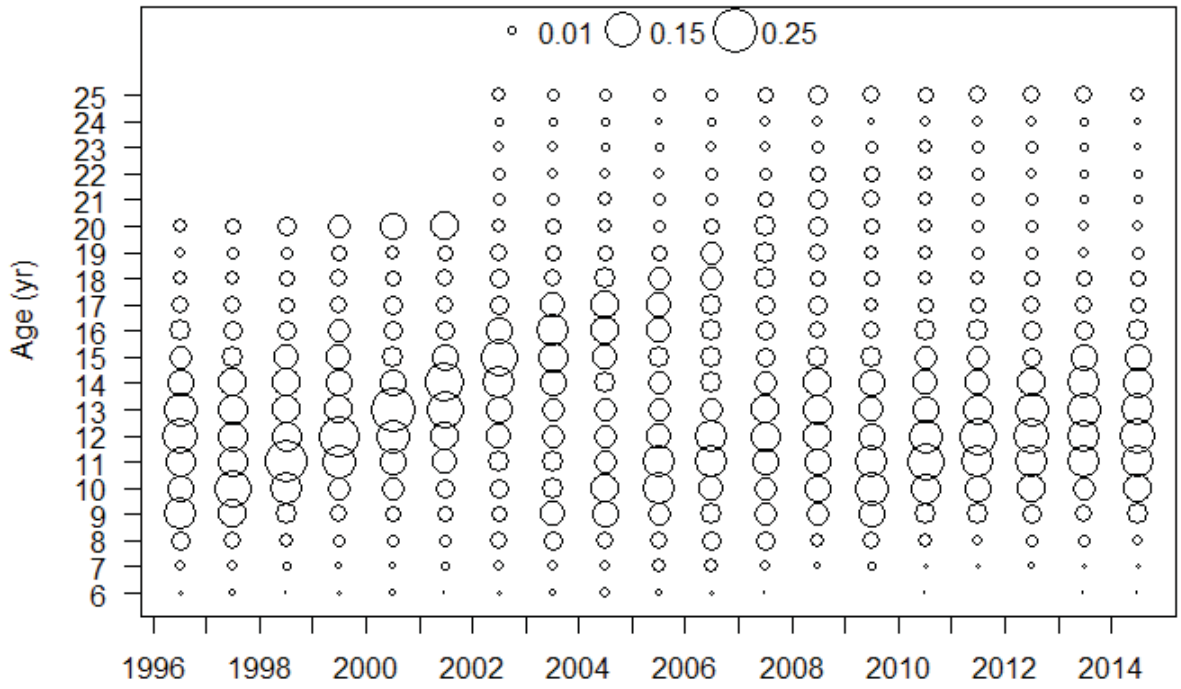


Figure 42. Estimates of recent commercial fishery numbers-at-age.

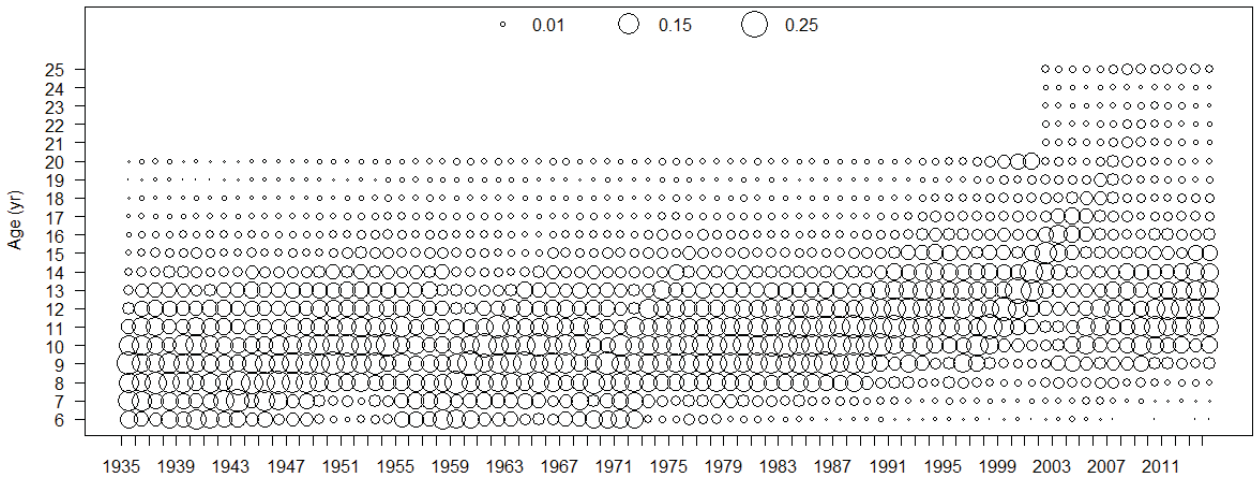


Figure 43. Coastwide commercial fishery proportions-at-age from the retained catch (male and female halibut combined). Note that the current 32 inch minimum size limit was implemented in 1973.

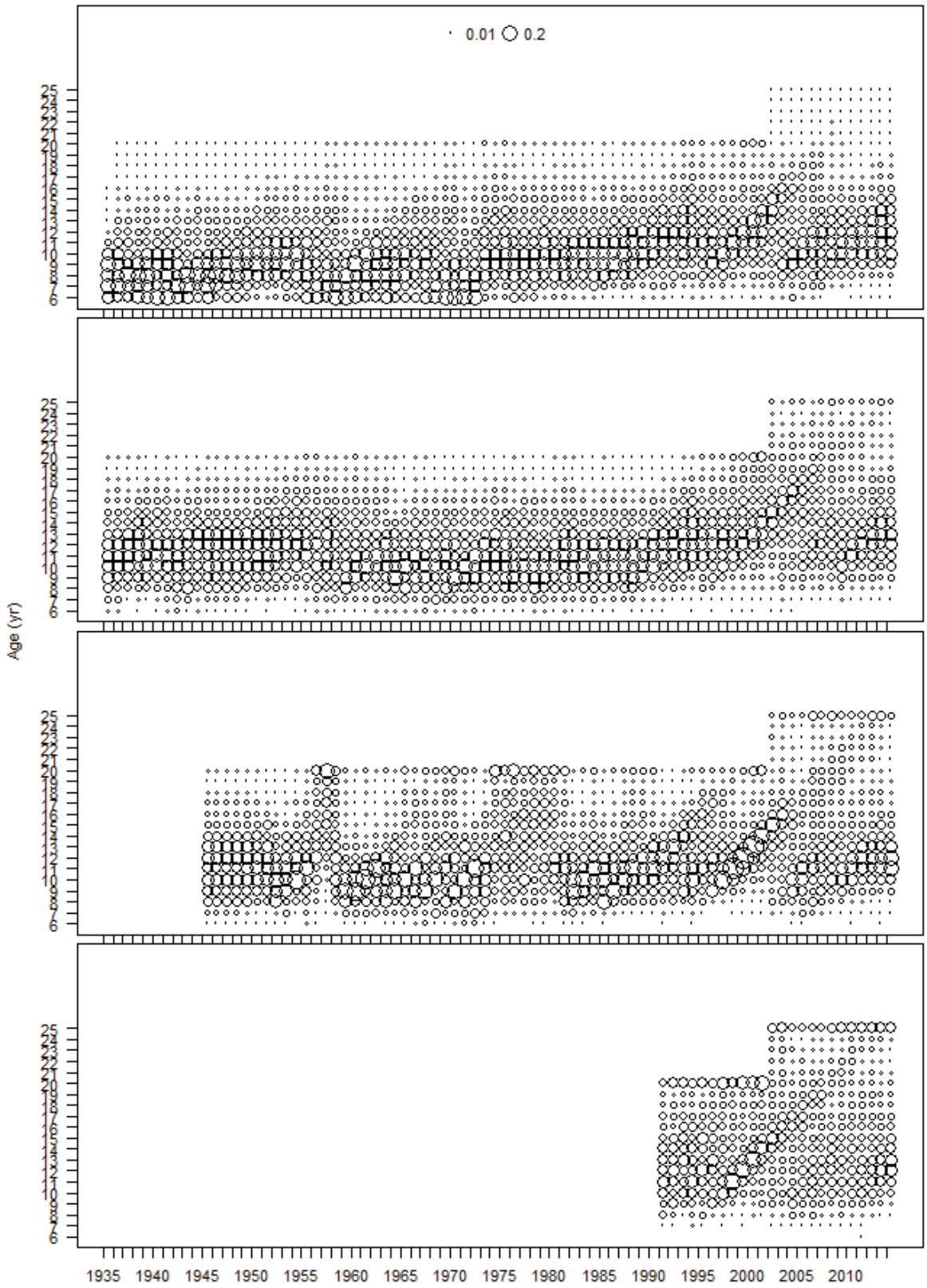


Figure 44. Commercial fishery proportions-at-age by geographic region from the retained catch (male and female halibut combined): Area 2 (top panel), Area 3 (second panel from top), Area 4 (third panel) and Area 4B (bottom panel).

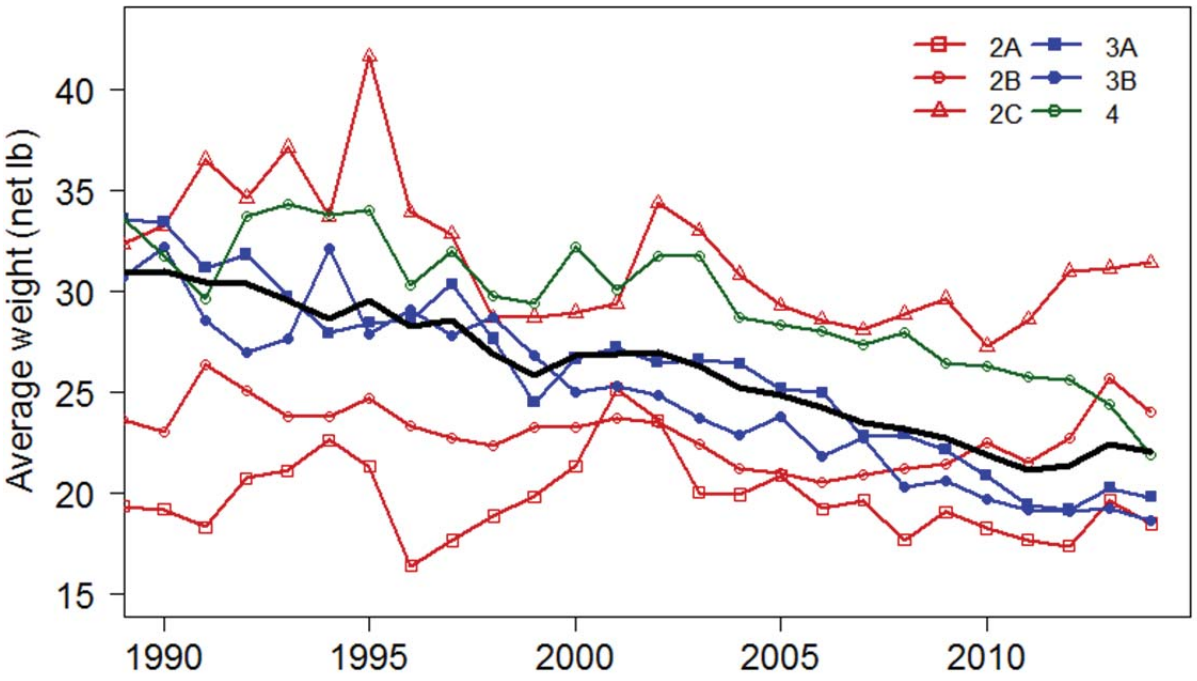


Figure 45. Recent average halibut weight by regulatory area in the directed fishery landings; thick black line indicates the coastwide average.

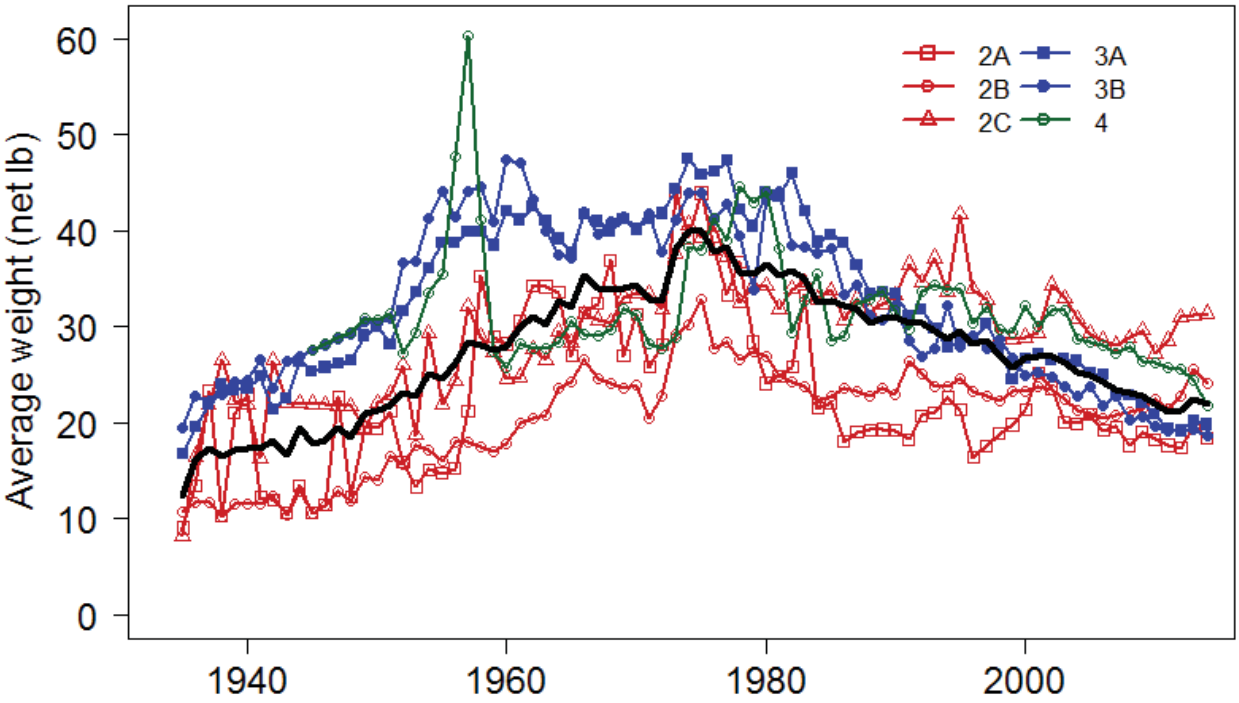


Figure 46. Historical trends in average individual halibut weight in the commercial fishery landings; thick black line indicates the coastwide average. The current 32-inch minimum size limit went into effect in 1974.

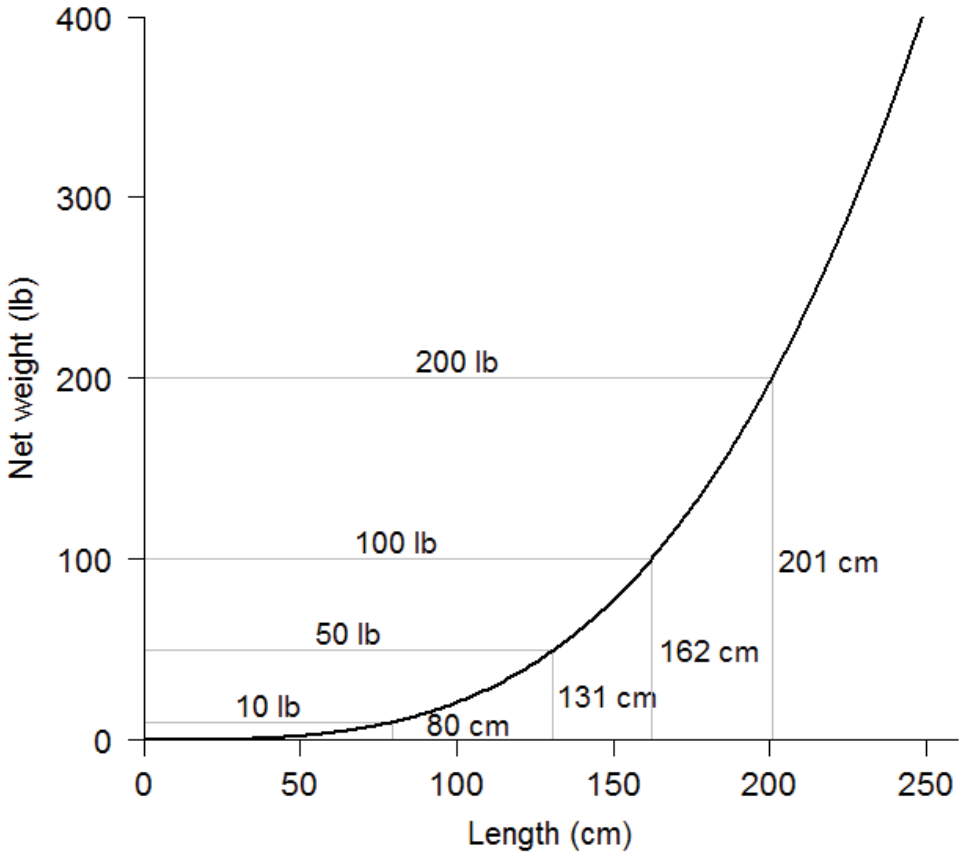


Figure 47. The conversion relationship for length in centimeters to net weight in pounds.

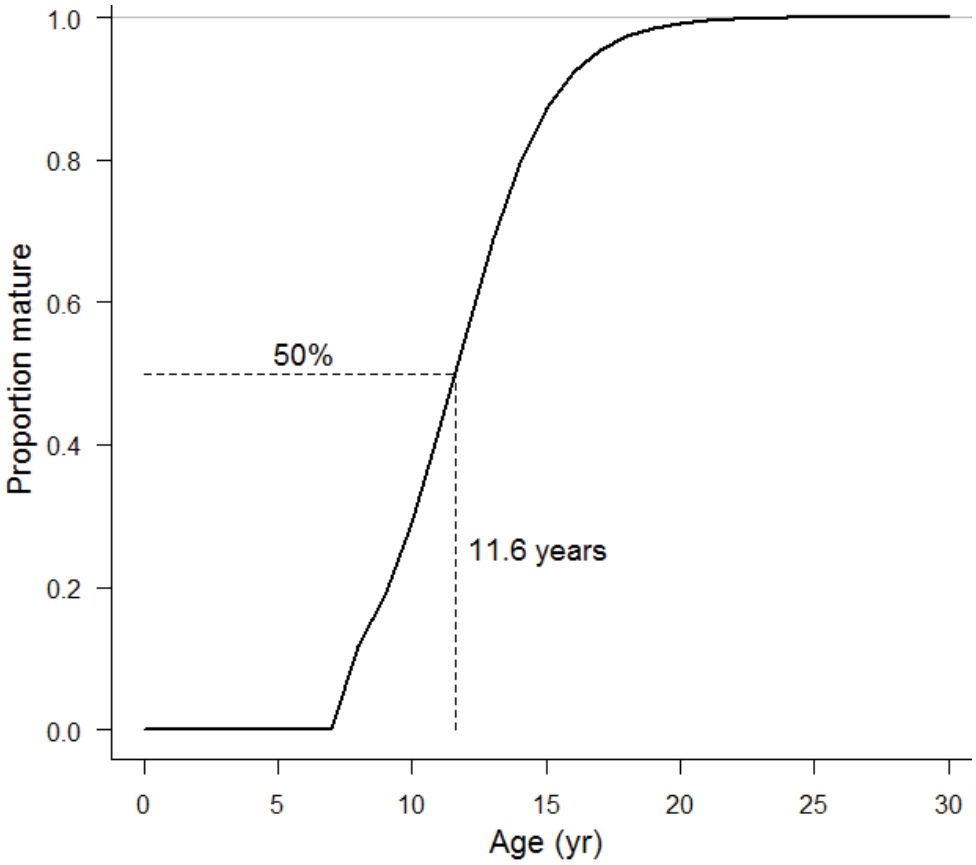


Figure 48. The maturity ogive used in recent halibut assessments. Note that this is a logistic curve, trimmed to be equal to zero below age-8.

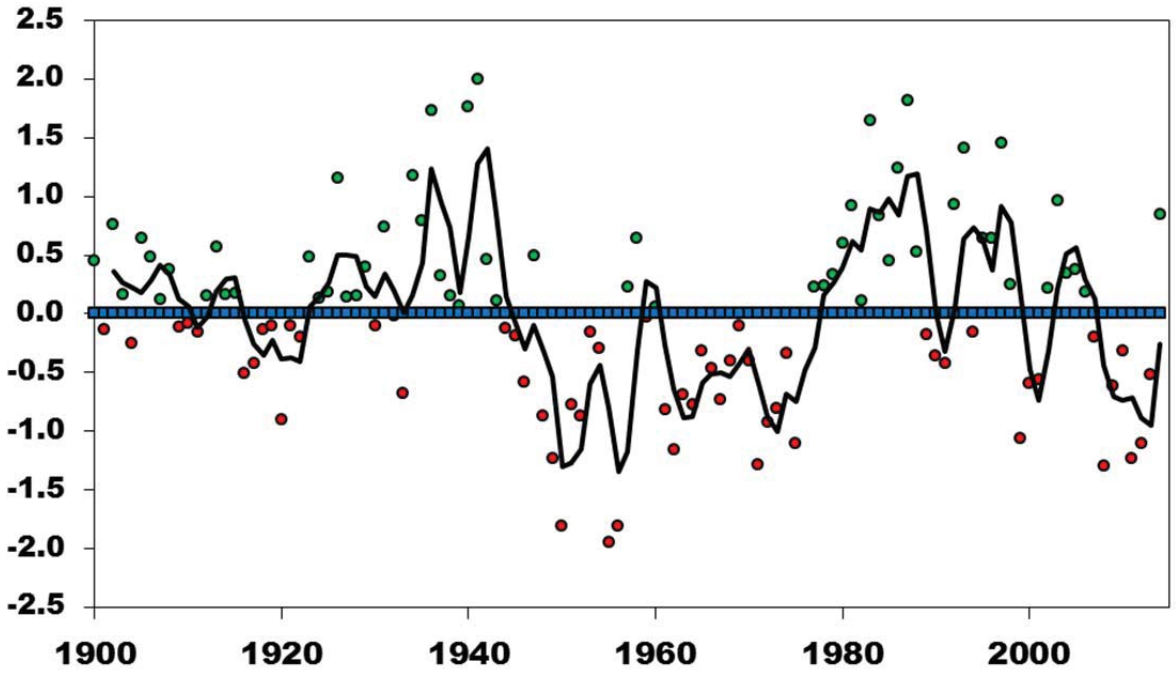


Figure 49. Time series of annual average PDO conditions (deviations from the long-term mean). Monthly means were obtained from (http://jisao.washington.edu/pdo/).

Assessment of the Pacific halibut stock at the end of 2014

Ian J. Stewart and Steven Martell

Abstract

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean. Halibut removals from all sources have ranged annually from 34 to 100 million pounds over the last 100 years, averaging 64 million pounds. After a peak in 2004, annual removals have decreased each year in response to management measures. Total removals in 2014 were estimated to be 43 million pounds, down from 48 million pounds in 2013. The 2014 setline survey total WPUE increased by 6% relative to 2013 (2% for legal-sized halibut only). Observed age distributions continue to indicate a relatively stable stock, but with no clear evidence of particularly strong recruitments in recent years. Individual size-at-age remains low relative to levels observed in the past several decades, although comparable to those estimated for the early portion of the 20th century. The 2014 scientific review process produced a number of important recommendations that have been incorporated into this assessment, including the development and evaluation of several alternative models. Two of these, using the Areas-As-Fleets (AAF) approach were included along with two coastwide models in the 2014 ensemble. The 2014 results therefore represent the integration of four separate stock assessment models, accounting for the uncertainty within each model and among models to generate the final decision table.

The 2014 stock assessment results indicate that the Pacific halibut stock declined rapidly from the late 1990s through 2011, as a result of the decline in the exceptionally strong 1987 year-class, recruitment strengths that are generally smaller than those observed through the 1980s and 1990s, as well as decreasing size-at-age. In the last few years, female spawning biomass is estimated to have stabilized near 200 million pounds, with trends varying among the four assessment models. The median 2015 estimate of exploitable biomass, consistent with the IPHC's current harvest policy, is 181 million pounds. The two long time-series models provided a differing perception of current vs. historical stock sizes. The AAF model suggests that the stock is currently increasing gradually and at 35% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 133% of the minimum values estimated for the 1970s. The coastwide model suggests that the stock is currently stable at 37% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at 211% of the minimum values estimated for the 1970s. These differences represent considerable uncertainty in both the current stock size and trend. Three-year projections were conducted for a range of alternative management actions; and probabilities of various risk metrics are reported in a decision-making table framework. The application of the current harvest policy results in the Blue Line of the decision table with a coastwide TCEY of 33.49 million pounds. The stock is projected to be stable at or near Blue Line levels of future harvest, increase under reduced removals and decrease as removals exceed around 40 Mlb.

Introduction

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean, including the territorial waters of the United States and Canada. As in recent assessments, the resource is modeled as a single stock extending from northern California to the Aleutian Islands and Bering Sea, including all inside waters of the Strait of Georgia and Puget Sound. Potential connectivity with the western Pacific Ocean resource is considered slight and is unaccounted for.

The halibut fishery has been closely managed for nearly 100 years, and much is known about the history of fishery removals, population trends, and biological characteristics. The 2014 assessment continues to make use of the extensive historical time-series, as well as integrating both structural and estimation uncertainty via an ensemble of individual models. These models now include implicit treatment of spatial structuring in the data sources and properties of the fishery and setline survey.

Data sources

A thorough exploration of data sources for the entire historical record, as well as updated 2013 information was completed and reviewed by the Scientific Review Board (SRB) during 2013 (Stewart 2014; Cox et al. 2014). This effort has been extended during 2014 to provide summary datasets by geographic region: Area 2 (2A, 2B, and 2C), Area 3 (3A and 3B), Area 4 (Area 4A and 4CDE), and Area 4B. Briefly, halibut removals (including all sources of mortality: target fishery landings and discards, bycatch in non-target fisheries, research, sport, and personal use) have totaled 7 billion pounds, ranging annually from 34 to 100 million pounds over the last 100 years (Table 3 and Fig. 35 in Stewart (2015); all weights in this document are reported as 'net' weights, head and guts removed; this is approximately 75% of the round weight). The average removal over this period has been 64 million pounds. Annual removals were above the 100-year average from 1985 through 2010. After a peak in 2004, annual removals have decreased each year due to management actions in response to declining survey and commercial catch rates and stock assessment estimates. Total removals in 2014 were estimated to be 43 million pounds, down from 48 million pounds in 2013. The 2014 setline survey total WPUE increased by 6% relative to 2013, and the legal-size (O32) WPUE by 2%. Commercial catch-rates increased in 2014 by 7% at the coastwide level; however, these records were unverified and incomplete at the time of this assessment. Survey and fishery age distributions continue to indicate a relatively stable stock, with no clear evidence of particularly strong recruitments in recent years. Individual size-at-age remains low relative to levels observed in the past several decades, although comparable to those estimated for the early portion of the 20th century.

Assessment

The stock assessment for Pacific halibut has evolved through many different modeling approaches over the last 30 years (Clark 2003). These changes have reflected improvements in fisheries analysis methods, changes in model assumptions, and responses to recurrent retrospective biases and other lack-of-fit (Stewart and Martell 2014). The 2012 stock assessment resolved the most recent retrospective bias (Stewart et al. 2013), and produced estimates of stock size that were considerably lower than previous analyses. This type of abrupt change between annual cycles,

although necessary, is undesirable from a management perspective. The 2013 stock assessment (Stewart and Martell 2014) introduced the ensemble approach which draws from the field of weather and hurricane forecasting (e.g., Hamill et al. 2012). This approach recognizes that there is no "perfect" assessment model, and that robust risk assessment can only be achieved via the inclusion of multiple models in the estimation of management quantities and the uncertainty about these quantities. This approach was also used for the 2012 assessment, albeit in a crude manner, by including alternate models using differing values of natural mortality. For 2014, several alternative models were evaluated for inclusion into the stock assessment ensemble.

The 2014 Ensemble

The IPHC's Scientific Review Board (SRB) met to evaluate modelling progress on 23 June, 2014, and again to review the final set of models for the 2014 ensemble on 22-23 October, 2014 (Cox et al. 2015). These meetings guided the development of a simple stock production model, a Virtual Population Analysis (VPA), and two alternative statistical catch-at-age models, as well as a number of supplementary analyses that provided insight into the dynamics of the halibut population and fishery.

Two models were evaluated but not included directly into the ensemble. The VPA model requires a number of very strong simplifying assumptions in processing the input data and results. These include aggregating all male and female observations, and treating directly the numbers-at-age regardless of sex. Due to the use of surface ageing prior to 2002, the data also had to be aggregated into a plus group at age-15, and fishery and survey catch-at-age must be assumed to be known without error. To produce results comparable to the other models, female spawning biomass had to be estimated via sex-ratio at age from the setline survey. Despite these strong assumptions, VPA models are in use for many fisheries, and therefore provide another check on the scale and trend information from the statistical catch-at-age models. The VPA model estimated a slightly smaller stock size, but very similar trends over the recent and longer time-series (Stewart and Martell, *in review*). Also evaluated in 2014 was a simple surplus production model. This model assumes that change in the setline survey abundance is directly proportional to stock surplus production (the annual yield which can be removed and the stock biomass will remain unchanged). Removals of U26 halibut must be ignored, since these fish are not captured by the survey, thus the surplus yield does not account for all sources of removals. However, this model estimated only four parameters (the initial stock size, the average surplus production or maximum sustainable yield, the stock size producing that yield and the catchability coefficient linking the survey abundance to the population size). This analysis cannot produce estimates of female spawning biomass, or other harvest policy reference points, but did suggest that the surplus production in recent years had been between 40 and 45 Mlb. These values are consistent with both the decision table and harvest policy calculations, and therefore generally corroborate the ensemble results.

Building from the 2013 re-analysis of historical data sources, the summary of data into geographic regions in 2014 (Stewart 2015) provided the basis for creating two AAF models, one using only the most recent and comprehensive data (the short time-series, beginning in 1996), and the second utilizing the full historical record. Briefly, AAF models are commonly applied when biological differences among areas or sampling programs make coastwide summary of data sources problematic. AAF models continue to treat the population dynamics as a single panmictic stock, but fit to each of the spatial datasets individually, allowing for differences in selectivity and catchability of the fishery and survey among regions. In addition, the AAF models accommodate

temporal and spatial trends in where and how data have been collected and fishery catches have occurred because each region need not have data for each year modelled.

For 2014, the final ensemble included four individual models: each of both short and long time-series models based on coastwide and AAF data structures. The short time-series model used in 2012 was not retained in the 2014 ensemble, due to its non-orthogonal and highly processed treatment of input data, as well as the redundancy with the alternative short time-series coastwide model developed in 2013. All of these four models were implemented using the Stock Synthesis software, a widely used modeling platform developed at the National Marine Fisheries Service (Methot and Wetzel 2013). This combination of models included a broad suite of structural and parameter uncertainty, including natural mortality rates (estimated in the long time-series models, fixed in the short time-series models), environmental effects on recruitment (estimated in the long time-series models), fishery and survey selectivity (by region in the AAF models) and other model parameters. These sources of uncertainty have historically been very important to the understanding of the stock, as well as the annual assessment results (Clark and Parma 1999, Clark and Hare 2006, Stewart and Martell 2015). The benefits of the long time-series models include historical perspective on recent trends and biomass levels; however these benefits come at a computational and complexity cost. The short time-series models make fewer assumptions about the properties of less comprehensive historical data, but they suffer from much less information in the short data series as well as little context for current dynamics. In aggregate, these models provide for a risk analysis that is more robust to changes to a single model, or the addition of new models in the future than a single assessment model.

As was the case in 2013, each of the models in the ensemble was equally weighted, and differences in uncertainty within models propagated in the integration of results. In the future it should be possible to refine this weighting based on the lack-of-fit to key data sources, retrospective patterns within models, as well as consistency of the results with biological understanding. It is also anticipated that spatially explicit models will be evaluated for potential inclusion into the ensemble in future years. In this manner, the ensemble approach can be transparently improved in the future as additional models and refinements to existing models become available.

The risk analysis and decision table include the full probability distribution from the assessment. Therefore, key quantities such as reference points and stock size are reported as cumulative distributions, such that the entire plausible range can be evaluated. Where necessary, point estimates reported in this assessment correspond to median values from the ensemble.

Comparison with previous assessments

Comparison with previous stock assessments indicates that the 2014 spawning biomass results are very similar to those from 2012 and 2013, which lie inside the 50% interval of the ensemble in recent years (Fig. 1). Models prior to 2012, which had shown a problematic retrospective pattern, suggested terminal stock sizes in the mid-2000s that are no longer considered plausible. The estimates from these models for the late 1990s now occur at the lower edge of the plausible range: all four of the current models suggest a larger spawning biomass during that period. Point estimates from the 2013 ensemble for 2014 were extremely similar to the current results given the degree of uncertainty (Table 1).

Biomass, recruitment, and reference point results

Ensemble

The results of the 2013 stock assessment indicate that the Pacific halibut stock has been declining continuously over much of the last decade (Fig. 2). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Fig. 3). However, current stock size estimates also differ substantially among the four models (Fig. 4). The differences in both scale and recent trend reflect the structural assumptions, e.g., higher natural mortality estimated in the long coastwide model and dome-shaped selectivity for Areas 2 and 3 in the AAF models. Differences are also apparent in the recent recruitment estimates, which suggest larger recruitments in 1999, 2002 and 2004-2005 than in other recent years (Fig. 5). These recent recruitments are much lower than the 1987 year class, and (in the coastwide model) substantially below those in the late 1970s and early 1980s (Fig. 6). Recruitments after 2008 do not yet have information available in the fishery or survey data, and therefore remain highly uncertain. In addition to recruitment trends, observed decreases in size-at-age have also been an important contributor to recent stock declines. In the last few years, the estimated female spawning biomass appears to have stabilized near 200 million pounds (Table 2, Fig. 2, and Fig. 7), with plausible values ranging from 150 Mlb to 250 Mlb. The estimate of exploitable biomass consistent with the IPHC's current harvest policy is 181 Mlb at the beginning of 2015. The current level of spawning biomass is estimated to be 42% of the equilibrium condition in the absence of fishing, with a 10 out of 100 chance that the stock is below the 30% relative spawning biomass harvest policy threshold. All sources of estimated removals for 2014 correspond to a fishing intensity point estimate of $F_{43\%}$ (Fig. 9). Harvest levels of this magnitude are generally consistent with target rates for many similar stocks.

Long time-series models

The two long time-series models provide historical biomass estimates that are integrated with the current stock assessment results. The two long time-series models provided a differing perception of current vs. historical stock sizes (Fig. 10). The AAF model suggests that the stock is currently increasing gradually and at 35% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 133% of the minimum values estimated for the 1970s. The coastwide model suggests that the stock is currently stable at 37% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at 211% of the minimum values estimated for the 1970s. These differences represent considerable uncertainty in both the current stock size and trend. They are likely attributable to the separation of signals from each region (particularly Area 2, with the longest time-series of data), and allowance for different properties in each region's fishery and survey.

Both of the long time-series models indicate that average halibut recruitment is estimate to be higher (32 and 72% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes, a standard indicator of productivity in the north Pacific. This result is consistent with that of Clark and Hare (2002, 2006). Historically, these regimes included positive conditions prior to 1947, poor conditions from 1947-1977, positive conditions from 1978-2006, and poor conditions from 2007 to 2013.

Major sources of uncertainty

This stock assessment includes significant uncertainty associated with estimation of model parameters, treatment of the data sources (e.g., short and long time-series), natural mortality (fixed vs. estimated), approach to spatial structure in the data, and other differences among the models included in the ensemble. Although this is a substantial improvement over previous assessments, there are important sources of uncertainty that are not included.

A key source of uncertainty is the spatial structure of the assessment model, and the spatial processes in the underlying stock, particularly the distribution of recruitment (juvenile halibut), and their subsequent movement rates among regulatory areas as sub-legal and legal-sized fish. The SRB endorsed the staff's plans to continue development of additional alternative models using explicit spatial structure for future stock assessments, as well as refinement of available models to better accommodate spatial processes influencing population age- and sex-ratios. These efforts may provide alternate models for future inclusion into the ensemble approach.

As was identified in 2013, another source of uncertainty is the sex-ratio of the commercial catch. There is no direct information available (due to dressing of fish at sea prior to observation by IPHC port samplers), and so the assessment relies on sex-ratios observed in the setline survey to inform the relative selectivity for male and female halibut in the commercial fishery catch. All the models are sensitive to this assumption, particularly the coastwide models. Efforts begun in 2014 to test methods for direct marking of fish at sea will continue to be developed in 2015.

The link between halibut recruitment strengths and environmental conditions remains poorly understood, and there is no guarantee that observed correlations will continue in the future. Therefore recruitment variability remains a significant source of uncertainty in current stock estimates due to the substantial lag between birth year and direct observation in the fishery and survey data (6-10 years). Reduced size-at-age in the current stock relative to levels observed in the 1970s is a major contributor to stock trends which is poorly understood. The historical record suggests that size-at-age changes relatively slowly; therefore, although projection of future values is highly uncertain, near-term values are unlikely to be dramatically different than those currently observed.

Since 2012, natural mortality has been an important source of uncertainty included in the stock assessment. In 2012, three fixed levels were used to bracket the plausible range of values. In 2013, the three models contributing to the ensemble included both fixed and estimated values of natural mortality. In the current ensemble, the models again span both fixed (0.15/year for female halibut) and estimated values. The female value estimated in the AAF model (0.14) differs substantially from the value estimated in the coastwide model (0.21). This discrepancy contributes to the difference in scale and productivity for the two models, but is not easily reconciled at present. Although this uncertainty is directly incorporated into the ensemble results, it remains an avenue for future investigation.

Like most stock assessments, estimated removals from the stock are assumed to be accurate. Therefore uncertainty due to bycatch estimation (direct sampling variance where there is low coverage and representativeness for unobserved fishing activity), discard mortality rates, and any other unreported sources of removals in either directed or non-directed fisheries could create significant bias in this assessment.

Future expansion of the ensemble approach will continue to improve uncertainty estimates, and create assessment results that are robust to changes in individual models, data sets and other sources of historical changes in stock assessment results from year to year.

Sensitivity and retrospective analyses

The wide range of sensitivity analyses conducted during the 2013 process remain relevant to the 2014 results, as these were all conducted with the coastwide long time-series model. The most influential source of uncertainty uncovered among sensitivity analyses conducted for 2013 was the sex-ratio of the commercial catch. There is no direct information available (due to dressing of fish at sea prior to observation by IPHC port samplers), and so the 2014 assessment continues to rely on indirect estimates from the sex-ratios observed in the setline survey. Specifically, separate selectivity is estimated for the fishery and setline survey, but the relative difference in selectivity for male and female halibut estimated for the setline survey (using sex-specific data) is assumed to apply to the fishery data. Results in 2013 were found to be very sensitive to this choice: a +/- 10% change in the relative selectivity for males vs. females (and therefore the sex-ratio of the catch) resulted in a 50 million pound range in the estimate of spawning biomass (Fig. 11 in Stewart and Martell 2014).

Three sensitivity analyses were conducted in 2013 to investigate the relative importance of uncertainty in several sources of halibut removals. The results indicated that significantly higher (doubled) and lower (halved) levels of bycatch did not change the relative stock trends, but that adding additional removals suggested a larger stock. This result is expected, as the stock must have been productive enough to support these additional removals and still generate the observed trends. This general result suggests that sources of removals missing from current accounting may positively increase our estimates how much harvest the stock can support. Within the stock assessment models, this can be realized via changes in estimated natural mortality and/or the magnitude of recruitment strengths without appreciably altering the stock trend. Future analyses will be aimed at including uncertainty in discard mortality rates and the magnitude of both wastage and bycatch directly within the stock assessment models.

A retrospective analysis was performed for each of the individual models contributing to this assessment. Both coastwide models showed little pattern in the most recent years, but slightly higher estimates as additional data were removed from each (Fig. 11). The AAF models showed even less retrospective pattern (Fig. 12). All models estimates for the terminal three years of the retrospective analysis were included in the currently estimated confidence intervals.

Forecasts and decision table

Stock projections were conducted using the ensemble assessment (all four models), summaries of the 2014 estimated removals, as well as the results of apportionment calculations and harvest policy application (Webster and Stewart 2015, Stewart 2015). The steps included: 1) apportioning the coastwide estimate of exploitable biomass according to the survey catch rates in each regulatory area (Webster and Stewart 2015), 2) applying the area-specific harvest rates to estimate the total CEY, and all other removals associated with a given level of harvest, and 3) calculating the total mortality and projecting the stock trends one and three years into the future assuming constant values for all sources of removals.

The decision table provides a comparison of the relative risk, using stock and fishery metrics (columns), for a range of alternative harvest levels for 2015 (rows). The block of columns entitled "Stock Trend" (columns a-d) provides for evaluation of the risks to short term trend in spawning biomass, without reference to a particular harvest policy. The remaining columns portray these risks relative to the spawning biomass reference points ("Stock Status"; columns e-h) and fishery

performance identified in the current harvest policy (columns i-m). The alternatives provided include: no mortality (useful to evaluate the stock trend due solely to population processes), no directed mortality (but accounting for bycatch and non-scaling sport and personal use removals), the Blue Line (consistent with the current harvest policy and, historically, IPHC staff advice), the *status quo* removals (repeating the FCEYs adopted for 2014), as well as arbitrary values (at 10 Mlb increments) intended to foster the evaluation of the relative change in risk probability across a range of total mortality levels. For each row, the total mortality of all sizes and from all sources, the total coastwide fishery CEY and the associated median level of fishing intensity (measured via the Spawning Potential Ratio) are reported. Fishing intensity reflects the relative reduction in equilibrium spawning biomass per recruit from all sources and sizes of removals, reported as $F_{xx\%}$, for comparison to other processes in both nations where harvest rate targets and limits are commonly reported in these units. An alternative *status quo* reports the harvest levels that maintain the same fishing intensity estimated in 2014. As in previous years, it is expected that additional alternatives will be produced during the IPHCs annual process such that all management alternatives considered for 2015 can be directly evaluated in terms projected total mortality and risk.

The stock is projected to increase gradually over 2016-2018 in the absence of any removals, and for removals of up to 20 Mlb. For removals around 40 Mlb, projections are relatively flat. The risk of stock declines beings to increase relatively rapidly for levels of harvest above 40 million pounds of total mortality resulted in projected declines in 2016, and becoming more pronounced by 2018 (Table 3; Fig. 13). The Blue Line (38.7 Mlb total removals) corresponds to a 19/100 chance of stock decline in 2016 and a 23/100 chance in 2018, somewhat more optimistic than recent assessment results.

For metrics directly based on current harvest policy (stock status, fishery trend, and fishery status), there is a relatively small chance (<24/100) that the stock will decline below the 30% or 20% reference points in projections for all the levels of removals evaluated. For removals in excess of the Blue Line, there is a greater than 50/100 probability that the fishery CEY would be smaller in 2016-2018 if the current harvest policy were applied in those years. As the stock stabilizes to biomass levels consistent with recent recruitment and size-at-age, it is reasonable to expect a greater response in stock trend to annual management decisions.

Future research

Based on data and model exploration completed during 2014, and recommendations from the SRB, future research will focus on the following topics:

1) Continued expansion of the ensemble of models used in the stock assessment. Specifically, explicit spatial models will be developed that may allow for improved incorporation of the uncertainty due to spatial processes such as migration and recruitment distribution among regulatory areas.
2) As development of additional models for the ensemble is reduced, there will be more emphasis on evaluation and diagnosis of each individual model. A document describing in detail the technical specifications, fits to the data sources and results will be developed for review during 2015.

3) Continued development of methods for sampling the sex-ratio of the commercial catch. The results of the stock assessment are sensitive to the sex-ratio, and therefore this source of uncertainty is a high priority for future data collection.
4) Further investigation of the factors contributing to recruitment strength, recruitment distribution, and the information available from trawl surveys, particularly in the Bering Sea.
5) Explore methods for including uncertainty in wastage and bycatch estimates in the assessment in order to better capture these sources uncertainty.
6) Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within the models contributing to the assessment.
7) Integration of the assessment analyses with ongoing development of the harvest policy and Management Strategy Evaluation process.

Acknowledgements

We thank all of the IPHC staff for their contributions to data collection, analysis and preparation for the stock assessment; particularly Bruce Leaman and Ray Webster contributions throughout the assessment process. The SRB and the Science Advisors also provided extremely helpful guidance during the 2014 review process.

References

Clark, W. G., and Parma, A. M. 1999. Assessment of the Pacific halibut stock in 1998. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1998: 89-112.

Clark, W. G., and Hare, S. R. 2002. Effects of Climate and Stock Size on Recruitment and Growth of Pacific Halibut. N. Am. J. Fish. Man. 22:852-862.

Clark, W. G. 2003. A model for the world: 80 years of model development and application at the international Pacific halibut commission. Nat. Res. Mod. 16:491-503.

Clark, W. G., and Hare, S. R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Hal. Comm. Sci. Rep. No. 83.

Cox, S. P., Ianelli, J., Mangel, M., Martell, S. J. D., Leaman, B. M., Keith, S. W., and Stewart, I. J. 2015. Reports of the IPHC Scientific Review Board. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 267-276.

Hamill, T. M., Brennan, M. J., Brown, B., DeMaria, M., Rappaport, E. N., and Toth, Z. 2012. NOAA's Future Ensemble-Based Hurricane Forecast Products. Bull. Am. Met. Soc. 93: 209-220.

Methot, R. D., and Wetzel, C. R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86-99.

Stewart, I. J., Leaman, B. M., Martell, S. and Webster, R. A. 2013. Assessment of the Pacific halibut stock at the end of 2012. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012: 93-186.

Stewart, I. J., and Martell, S. J. D. 2014. A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment. Fish. Res. 158: 40-49.

Stewart, I. J. and Martell, S. J. D. 2014. Assessment of the Pacific halibut stock at the end of 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 169-196.

Stewart, I. J. and Martell, S. *In review*. Reconciling stock assessment paradigms to better inform fisheries management. ICES J. Mar. Sci.

Stewart, I. J. 2014. Overview of data sources for the Pacific halibut stock assessment and related analyses. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 95-168.

Stewart, I. J. 2015. Overview of data sources for the Pacific halibut stock assessment and related analyses. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 87-160.

Stewart, I. J. 2015. Regulatory area harvest policy calculations and catch tables. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 195-212.

Webster, R. A. and Stewart, I. J. 2015. Setline survey-based apportionment estimates. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 181-194.

Table 1. Comparison of 2014 biomass point estimates (median ensemble value; Mlb) from the 2013 and current assessments.

Quantity	2013 Assessment	2014 Assessment
2014 Exploitable biomass	170	170
2014 Spawning biomass	197	209

Table 2. Median population (Mlb) and fishing intensity estimates (based on median Spawning Potential Ratio) from the 2014 assessment.

Year	Spawning biomass	Fishing intensity ($F_{XX\%}$)	Exploitable biomass
1996	584.6	49%	779.2
1997	605.7	43%	809.6
1998	591.8	42%	762.7
1999	567.1	40%	746.8
2000	529.5	40%	688.3
2001	483.9	38%	603.0
2002	434.5	34%	532.2
2003	382.6	30%	460.5
2004	339.5	28%	403.6
2005	299.5	26%	352.6
2006	266.7	26%	307.9
2007	241.5	25%	266.9
2008	224.4	25%	236.3
2009	204.6	26%	203.9
2010	197.8	27%	186.4
2011	195.3	31%	175.6
2012	197.2	35%	169.2
2013	203.9	38%	168.8
2014	208.5	43%	169.7
2015	215.1	NA	180.6

Table 3. Decision table of yield alternatives (rows) and risk metrics (columns). Values in the table represent the probability, in "times out of 100" of a particular risk.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2016		in 2018		in 2016		in 2018		in 2016		in 2018		in 2015
2015 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Fishing intensity	is less than 2015	is 5% less than 2015	is less than 2015	is 5% less than 2015	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2015	is 10% less than 2015	is less than 2015	is 10% less than 2015	is above target
No removals	0.0	0.0	$F_{100\%}$	<1/100	<1/100	<1/100	<1/100	5/100	<1/100	1/100	<1/100	<1/100	<1/100	<1/100	<1/100	0/100
FCEY = 0	13.1	0.0	$F_{73\%}$	<1/100	<1/100	<1/100	<1/100	5/100	<1/100	2/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	20.0	7.7	$F_{64\%}$	<1/100	<1/100	1/100	<1/100	6/100	<1/100	3/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	30.0	16.5	$F_{54\%}$	3/100	<1/100	17/100	4/100	7/100	<1/100	5/100	<1/100	3/100	2/100	3/100	2/100	4/100
Blue Line	38.7	25.0	$F_{46\%}$	19/100	<1/100	40/100	23/100	8/100	<1/100	8/100	<1/100	37/100	22/100	36/100	23/100	50/100
status quo	41.4	27.5	$F_{45\%}$	26/100	1/100	47/100	30/100	8/100	<1/100	9/100	1/100	57/100	37/100	51/100	38/100	50/100
Maintain 2014 SPR	43.3	29.5	$F_{43\%}$	31/100	1/100	56/100	36/100	8/100	<1/100	10/100	1/100	73/100	51/100	63/100	49/100	88/100
	50.0	36.0	$F_{39\%}$	44/100	5/100	75/100	51/100	9/100	1/100	13/100	1/100	99/100	91/100	95/100	84/100	>99/100
	60.0	45.8	$F_{34\%}$	65/100	22/100	96/100	82/100	11/100	1/100	23/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
				a	b	c	d	e	f	g	h	i	j	k	l	m

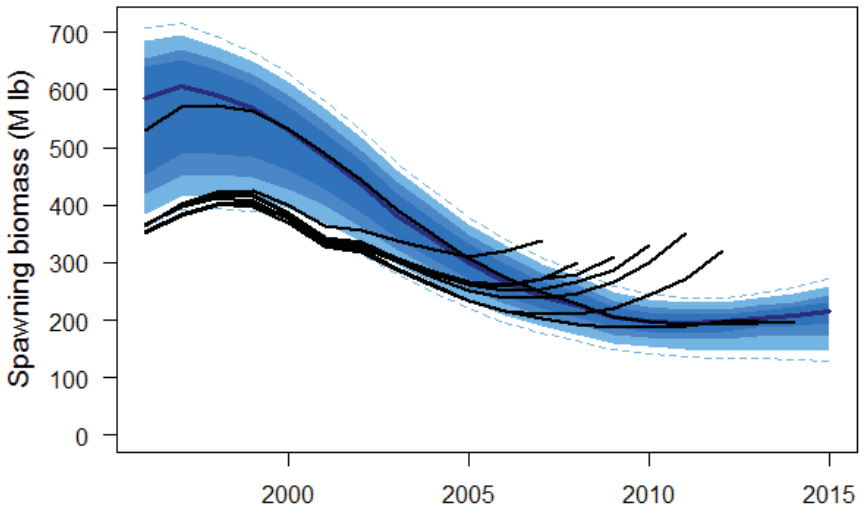


Figure 1. Retrospective comparison among recent stock assessments. The black lines denote point estimates from previous assessments conducted in 2006-2013. The dark blue line indicates the median (or "50:50 line"; with equal probability of the estimate falling above or below that level) from the 2014 assessment; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; outer dashed lines indicating the 99/100 interval.

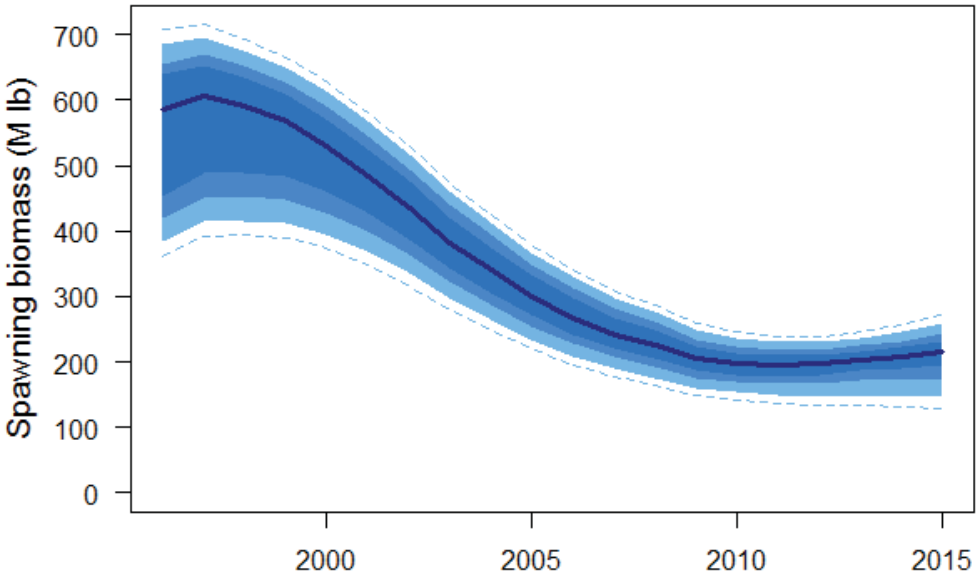


Figure 2. Trend in spawning biomass estimated in the 2014 stock assessment. The dark line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; outer dashed lines indicating the 99/100 interval.

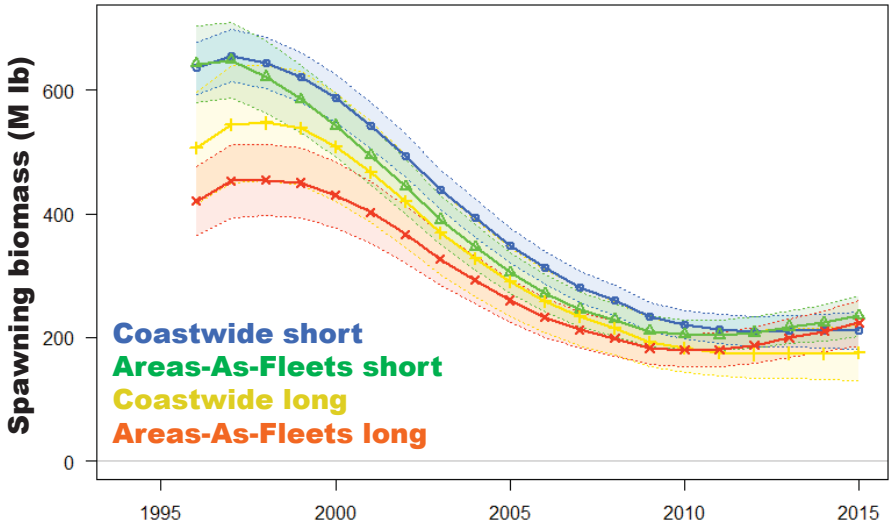


Figure 3. Comparison of models included in the 2014 stock assessment. Solid lines with points indicate point estimates, dashed lines and shading approximate 95% confidence intervals reflecting within-model uncertainty.

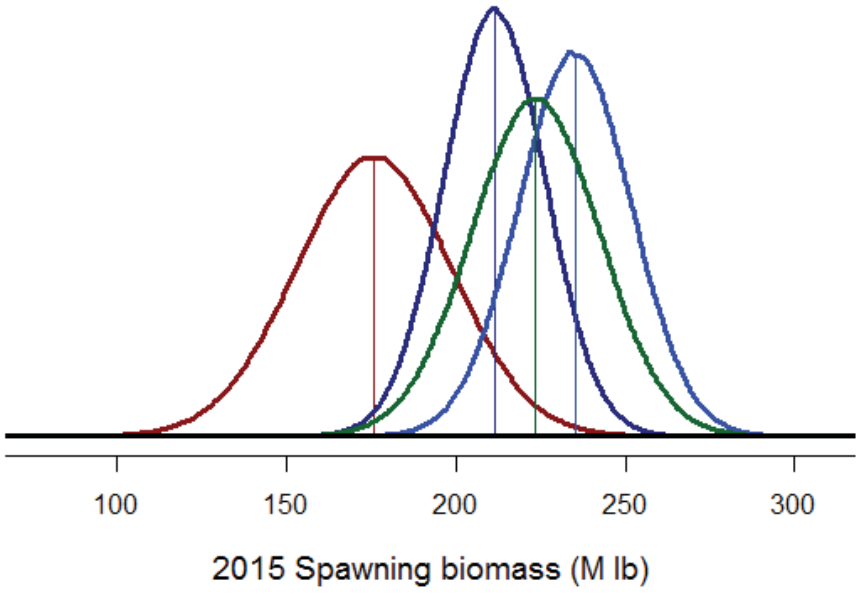


Figure 4. Distribution of individual model estimates for the 2015 spawning biomass. Vertical lines indicate the median values.

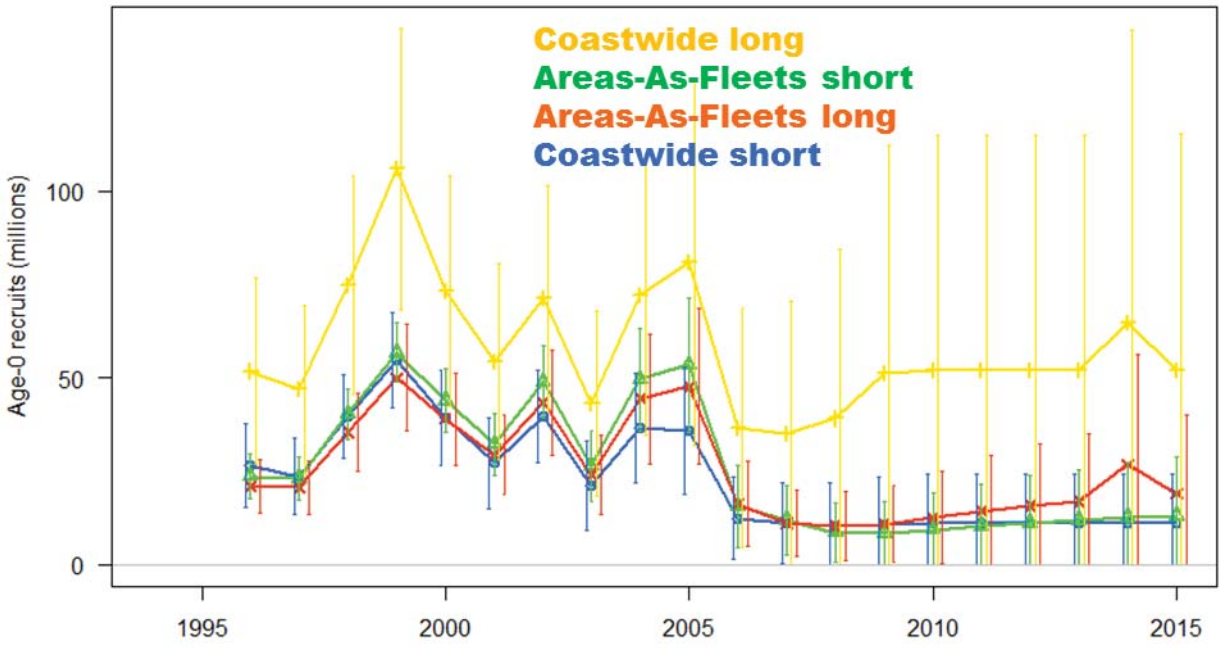


Figure 5. Trend recent recruitment strengths (by birth year) estimated by all four ensemble models. Note that estimates after 2008 are highly uncertain, as they are not yet informed by any direct observations.

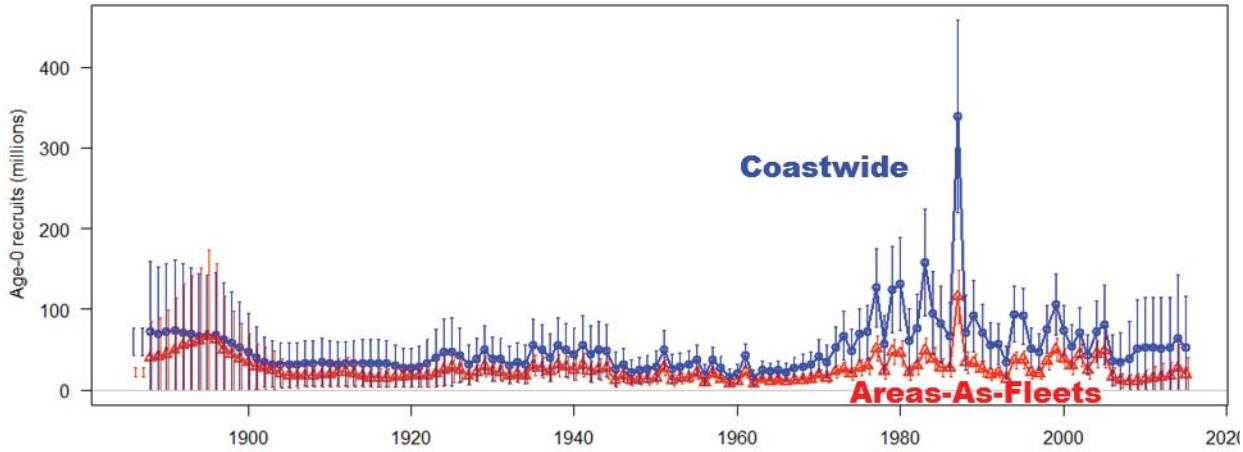


Figure 6. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes. Note that estimates after 2008 are highly uncertain, as they are not yet informed by any direct observations.

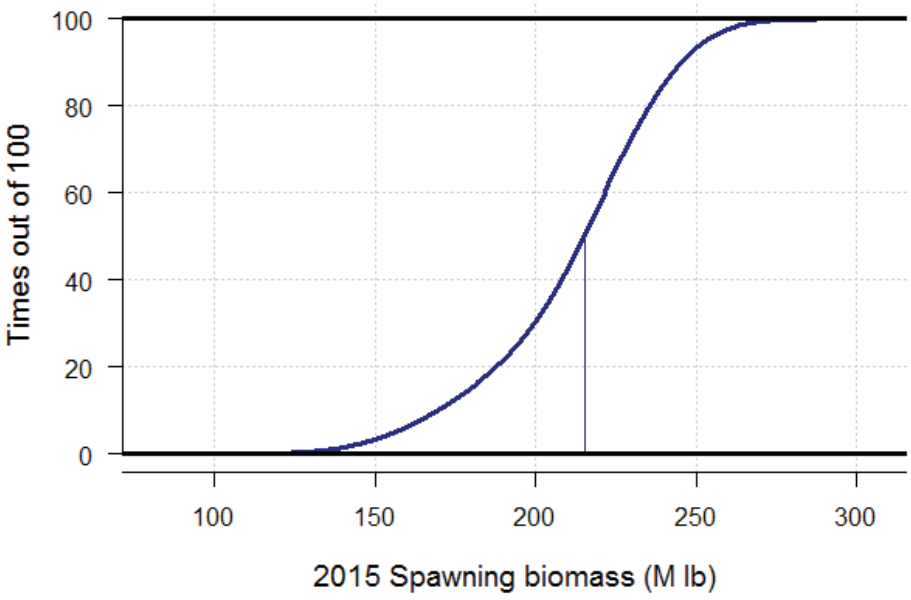


Figure 7. Cumulative distribution of 2015 spawning biomass estimates. Vertical line indicates the median value (215 Mlb).

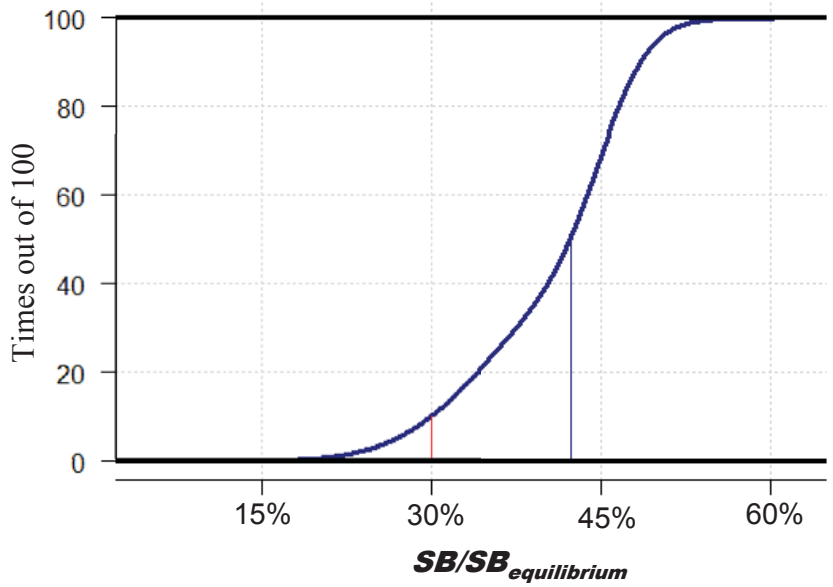


Figure 8. Cumulative distribution of 2015 spawning biomass estimates relative to the equilibrium spawning biomass in the absence of fishing. Vertical lines indicate the median value (42%), and the value corresponding to the IPHC's harvest policy threshold (30%).

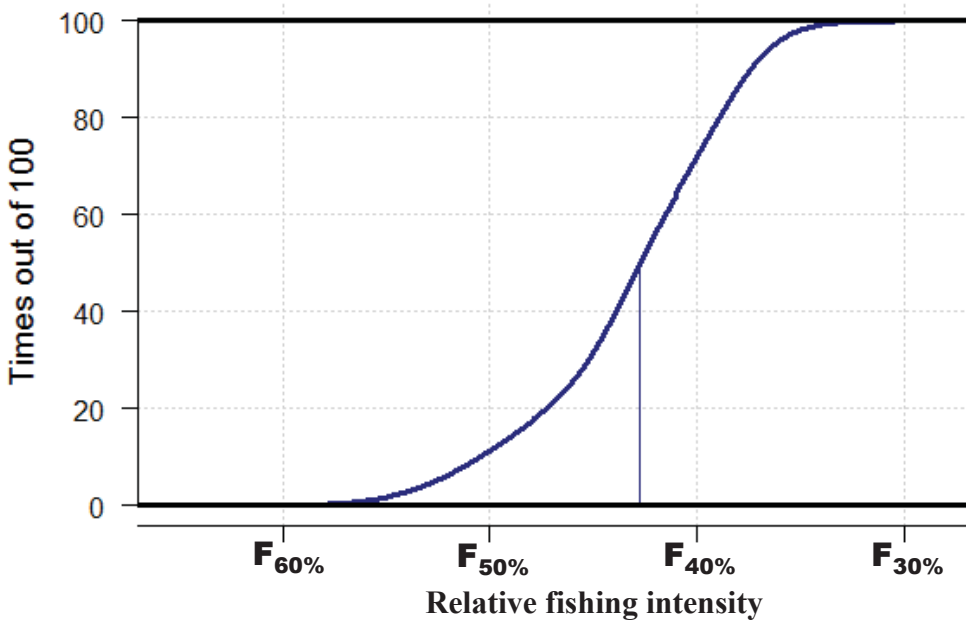


Figure 9. Cumulative distribution of the estimated relative fishing intensity (based on the Spawning Potential Ratio) in 2014. Vertical line indicates the median value (43%).

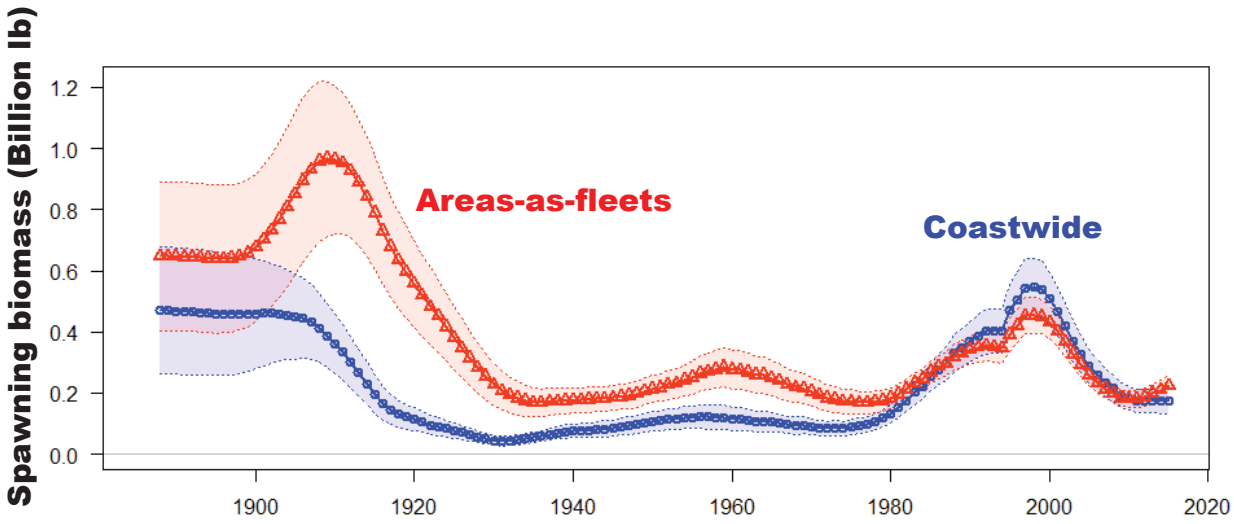


Figure 10. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model confidence interval.

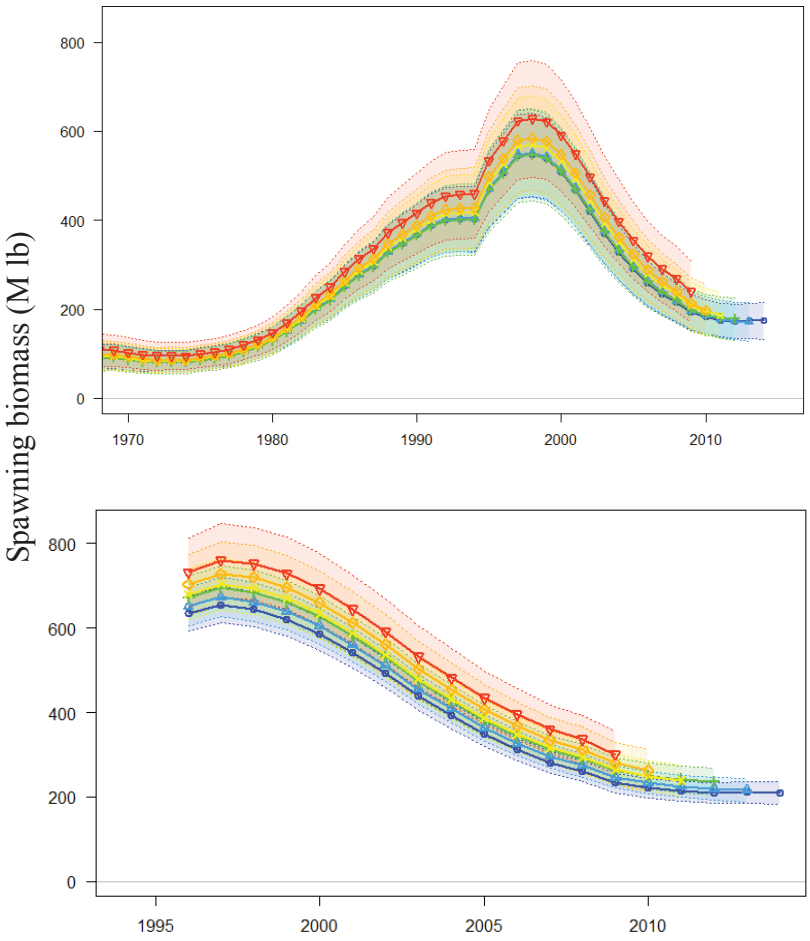


Figure 11. Results of the retrospective analysis on spawning biomass estimates using the coastwide long (upper panel) and coastwide short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.

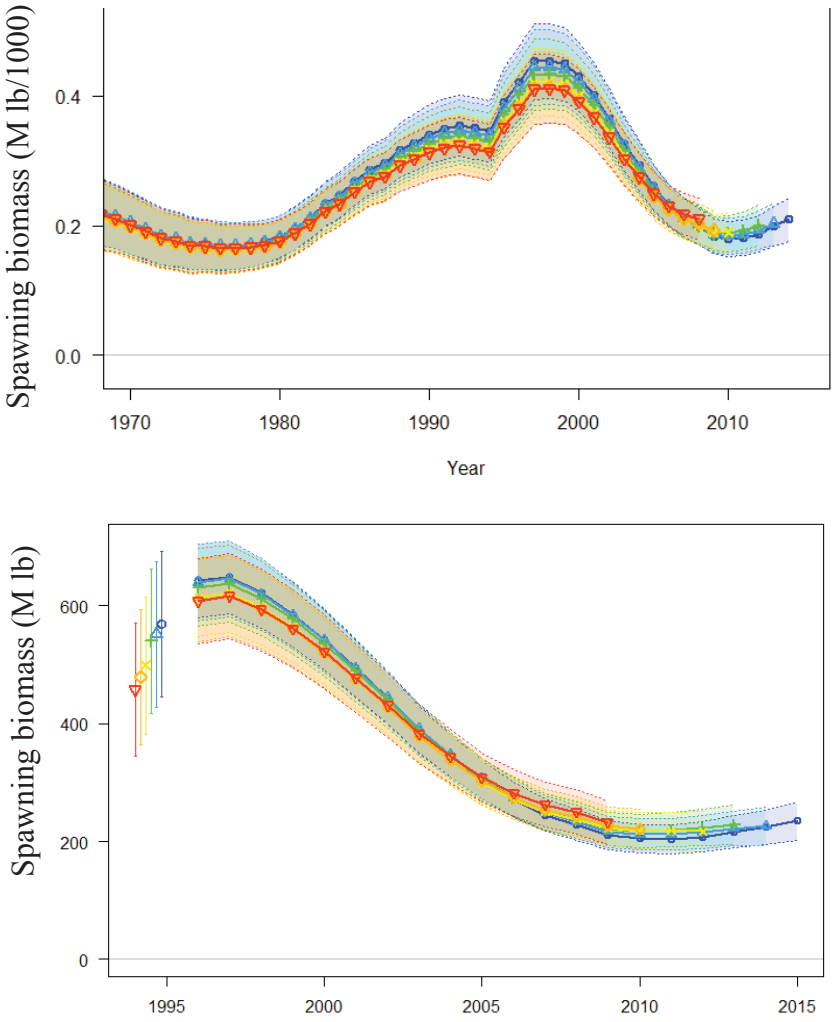


Figure 12. Results of the retrospective analysis on spawning biomass estimates using the Areas-As-Fleets long (upper panel) and Areas-As-Fleets short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.

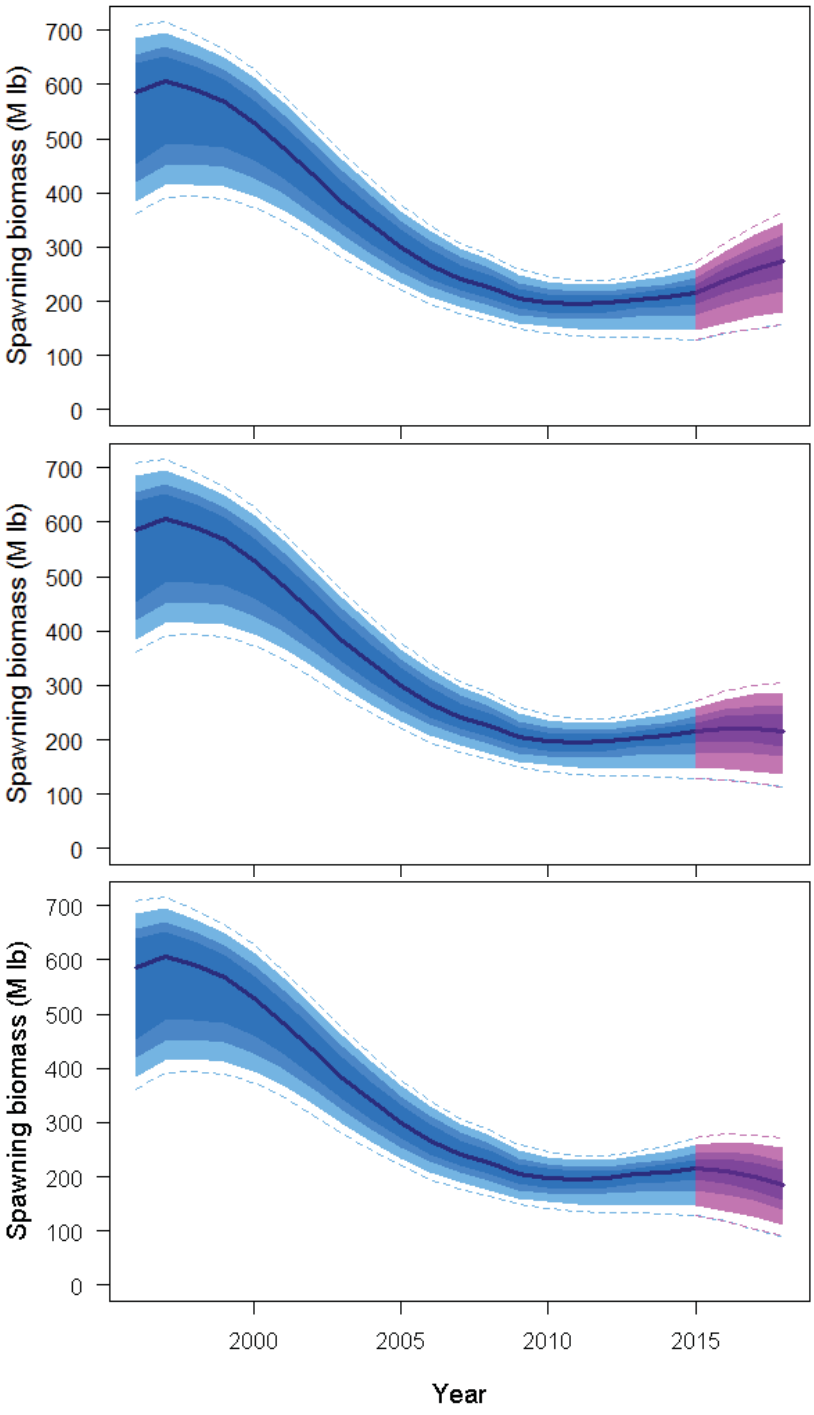


Figure 13. Three-year projections of stock trend under alternative levels of mortality: no removals (upper panel), Blue Line removals (middle panel) and 60 Mlb of total removals (lower panel).

Setline survey-based apportionment estimates

Raymond A. Webster and Ian J. Stewart

Abstract

Setline survey weight per unit effort (WPUE) of halibut is used to estimate how the coastwide stock is distributed among regulatory areas. We describe revisions to the calculation of the survey WPUE time series made in 2014, and review the survey timing and hook competition standardisations, and three-year smoothing, that are applied to WPUE for apportioning the stock. The effects of adjustments to the WPUE index made by these standardisations are described, along with the effect on apportionment of the use of data from deep water habitat in computing WPUE. Apportionment estimates at the beginning of 2015 indicate that Areas 2A, 2B, 2C, and 4CDE are at or near the highest proportions of the coastwide stock estimated since 2000. In contrast, Areas 3B, 4A, and 4B currently comprise much less of the stock than in previous years.

Introduction

Since 2007, the IPHC has used the setline survey mean weight per unit effort (WPUE) index of density for O32 halibut (fish greater than 32 inches in length) weighted by bottom area to estimate the distribution of the stock among regulatory areas, a process known as apportionment. This method was reviewed by the IPHC's Scientific Review Board (SRB) in 2013 (Cox et al. 2014). Two adjustments to the raw WPUE index are made in order to account for important factors known to influence survey catch rates of halibut. Adjustments for survey timing and hook competition are intended to improve standardisation of the WPUE index by accounting for differences among regulatory areas in the timing of the survey relative to the fishery, and in the degree of competition with halibut for baits.

In this report, we briefly describe the two adjustments we make to the survey index, and the three-year reverse weighting applied to produce the WPUE index used for apportionment. The effects of these modifications to the raw index are shown, and the resulting estimates of the proportion of stock in each area are presented. We also discuss the effect on apportionment of survey expansions in Areas 2A and 4A in 2014, and the use of data (IPHC setline survey and sablefish longline survey data) to estimate WPUE in deep waters (Webster et al. 2015).

Revisions in 2014

The computer code for processing setline survey data to calculate WPUE and NPUE indices was completely rewritten in 2014. The following revisions replace quantities that were previously fixed in the code, with calculations from data from IPHC database files, allowing estimates to be updated if any changes are made to the raw data, and making it clear within the code how estimates are derived:

- Correction factors for historical survey expansions are now calculated from the raw data for Areas 2B, 3A, and 4A. Previously these were fixed quantities, the derivation of which was unclear in some cases. Estimates of these correction factors use years up to 2006, so that they reflect spatial patterns of density within each area in the years closest to those

gaps in survey coverage that the adjustments correct for.

- Separate correction factors are now calculated for O32 WPUE and NPUE, and total WPUE and NPUE. Previously, correction factors were calculated only from O32 WPUE data and applied to all WPUE and NPUE indices.
- Estimates from Area 2A stratified surveys in 1995 and 1997 are recalculated from the raw data instead of coded as fixed quantities.
- Missing values in the Area 4D Edge time series (1998 and 1999) are now estimated using linear interpolation, consistent with what has been done for Area 2A. The previous approach was to use values from neighbouring regulatory areas for missing values in the times series of Area 4CDE component areas.
- Survey data from Area 4C in 1997 is used for first time: only stations within current Area 4IC boundaries are included for consistency with data from 2006 onwards.
- Missing values in the Area 4IC and 4ID time series from 1997-2005 are estimated after multiplying the mean ratio of total Area 4CDE values to 4CDE without 4IC and 4ID from 2006-2014, by 4CDE values without 4IC and 4ID from 1997-2005. This approach is consistent with how ratios are used to calculate correction factors for incomplete coverage in other areas, and replaces the use of values of neighbouring areas for missing values in Areas 4IC and 4ID.

As most of the revisions described above apply to historical data, they have no effect on the current apportionment estimates, although they can affect our understanding of the historical distribution of the stock. Other changes and updates that directly affect current and recent WPUE and NPUE indices and, therefore, this year's apportionment calculations are as follows:

- Area 4N (northern Bering Sea) data updated to include new Norton Sound survey data from 2014.
- Bottom area for Area 2A revised to include area from 39-40°N covered by the 2014 setline survey, giving a new bottom area estimate of 17,507 nmi^2**.**
- Data from deep and shallow survey stations (outside of standard 20-275 fm survey depth range) included in calculation of indices and adjustment factors for Areas 2A and 4A.
- For Area 2A, coastal gaps, Puget Sound (Salish Sea), and N California adjustment factors all updated using new data.
- Use of sablefish longline survey data to create indices for halibut density for 275-400 fm.

The final three items on the above list are discussed in more detail in Webster et al. (2015).

Survey timing standardisation

The amount of commercial catch taken prior to the IPHC setline survey varies with both regulatory area and time (Webster 2009). In areas where removals are greater early in the season, expected survey WPUE will be lower on average than in areas where removals occur later in the fishing season. Concern about the effect of removals on survey WPUE is particularly strong in Area 2A, where typically over 80% of the removals are taken prior to the mean survey date, much higher than all other areas (Webster 2009, Webster and Hare 2010). The current approach, detailed in Webster and Hare (2010), is to standardise WPUE to its expected value if 50% of all O32 removals had been taken prior to the mean date of the setline survey in each area. All data inputs for calculating the timing standardisation have been updated in 2014.

Hook competition standardisation

The fraction of baits that remain on the survey gear on retrieval within each regulatory area is used to compute an adjustment factor for hook competition (Clark 2008, Webster et al. 2011). If a smaller than average proportion of baits are returned, an area's WPUE index is adjusted upwards because higher competition for baits in that area would likely have had a negative effective on the halibut catch and therefore on that area's WPUE. Conversely, an area with more than the average rate of baits returned will have its WPUE index adjusted downwards. This approach is intended to avoid the situation where differences in abundance of non-target species among regulatory areas would create bias in the observed WPUE index of density. Methods for calculating the hook competition adjustments followed those used in previous years (Clark 2008, Webster and Stewart 2013).

Three-year weighting

In addition to the two adjustments, WPUE for apportionment is also smoothed using a 75:20:5 reverse weighted averaging of the current and previous two year's adjusted WPUE values for each area derived from a Kalman filter-type analysis of survey data (Webster 2011). This weighting is intended to improve precision of the WPUE estimates, without introducing significant bias from including past observations.

Apportionment results

Current (2015) and revised historical apportionment estimates of stock distribution are presented in Table 1, while 2015 estimates are also shown in Figure 1. Compared to the revised estimates for the start of 2014, the proportions in most areas are estimated to have changed relatively little. Only two areas have a change of greater than 1% of the coastwide stock: Area 3B, down 1.5%, and Area 4CDE, up 1.1%. The current O32 halibut biomass is estimated to be roughly divided into thirds: one-third in Area 2 (2A, 2B, and 2C), one-third in Area 3A, and one-third in Areas 3B-4CDE (Table 1, Fig. 1). This distribution represents a very pronounced change from historical values: we estimate that in 2000, roughly two-thirds of the stock was distributed in Areas 3B-4CDE, and only 12.4% in Area 2. In the intervening 15 years, each of Areas 3B-4B have shown a declining trend in their proportion of the coastwide stock, while the Bering Sea (4CDE) has remained relatively constant, with a slight increase at the end of the series (Table 1, Fig. 2). The biggest change has been the increasing percentage of the stock estimated to be distributed in Area 2, particularly over the last five years. These trends reflect survey WPUE indices in areas Areas 3B-4B that declined more rapidly than in the central and southern Gulf of Alaska, and recent increases in WPUE in Area 2.

Figure 3 compares the 2015 apportionment estimates with the estimates for 2014 calculated from the 2013 apportionment process (Webster and Stewart 2014). For most areas, this comparison agrees closely with the comparison in Table 1 described above, and therefore reflects trends in the underlying WPUE indices. Where it does not, this is due to the inclusion of data for deep water (275-400 fm) regions in the WPUE index for the first time, and to the survey expansion in Area 4A in 2014. Thus, the higher WPUE found on expansion stations in Area 4A this year (Webster et al. 2015), including in deep water, has contributed to the 1% increase in its estimated share of the coastwide stock from the estimate generated last year (5.7% to 6.7%). Area 2A is also affected by

the deep water expansion, with the estimated 0.2% decrease in its share of the stock due to zero survey catch in deep water in 2014 and its relatively high proportion of stations in deep water compared to other areas. The expansion of the survey to include stations between to 39°N and 40°N in Area 2A this year had negligible effect on apportionment, as no halibut were caught on these new expansion stations: the increase in bottom area for Area 2A was cancelled out by the decrease in mean WPUE over the whole area due to zero catch on the stations within this region.

Estimates of the percentage of O32 removals taken prior to the mean survey date are shown in Figure 4. Area 2A again had a high proportion of removals taken prior to the mean survey date in 2014, and the survey timing standardisation only has an appreciable effect on the WPUE index in this area (Fig. 5). Rates of bait returns were highest in Area 4B (Fig. 6), implying that competition with halibut for the baits is lowest in this area. Areas 2A, 3A, and the Area 4 island regions (4IC and 4ID) all showed declines in returned baits, while other areas were either stable (Area 2C) or had decreases in the proportion of hooks returning with bait. These data led to the calculation of positive adjustments due to competition in Areas 2A, 3A, and 3B, a negative adjustment in Area 4B, and little to no adjustment in other areas (Fig. 7).

The effects of the timing and hook competition standardisations, and the three-year weighted averaging, on WPUE for each area are shown in Figure 8. In recent years, the most notable effects of the two standardisations have been to adjust the index upwards in Area 2A, and downwards in Area 4B. The adjusted, three-year weighted averaged WPUE values in Figure 6 are weighted by bottom area in the 0-400 fathom range to produce the survey biomass index for each area used in estimating the apportionment values in Table 1.

References

Clark, W. G. 2008. Effect of hook competition on WPUE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2007: 211-215.

Cox, S. and others. 2014. Report of the SRB's review of Apportionment. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 217-237.

Stewart, I. J. 2015. Regulatory area harvest policy calculations and catch tables. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 195-212.

Webster, R. A. 2009. Further examination of fishery-survey interactions. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2008: 203-211.

Webster, R. A. and Hare, S. 2010. Adjusting IPHC setline survey WPUE for survey timing, hook competition and station depth. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009: 187-207.

Webster, R. A. 2011. Weighted averaging of recent survey indices. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 241-249.

Webster, R. A., Hare, S. R., Valero, J. L., and Leaman, B. M. 2011. Notes on the IPHC setline survey design, alternatives for estimating biomass distribution, and the hook competition adjustment. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 229-240.

Webster, R. A. and Stewart, I. J. 2013. Apportionment and regulatory area harvest calculations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012: 187-205.

Webster, R. A. and Stewart, I. J. 2014. Apportionment and regulatory area harvest calculations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 197-215.

Webster, R. A., Dysktra, C. L., Henry, E., Soderlund, E. and Kong, T. 2015. Setline survey expansions in 2014 and use of sablefish longline survey data for a deep-water density index. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 603-618.

Table 1. Estimated percentages of the coastwide stock in each regulatory area by year. Values were calculated using the adjusted O32 WPUE with the three year weighted averaging described in the text. In some years, row totals do not sum exactly to 100% because of rounding.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
2000	1.3	4.7	6.3	24.5	32.5	13.1	7.8	9.7
2001	1.4	5.4	6.7	26.9	29.1	13.7	6.8	10.0
2002	2.0	7.0	7.7	32.3	24.4	10.4	5.9	10.3
2003	1.3	8.2	8.9	37.0	21.3	9.1	4.4	9.7
2004	1.2	6.2	9.0	38.5	23.1	8.3	3.7	10.0
2005	1.4	6.6	6.6	42.0	21.8	7.9	3.2	10.4
2006	2.2	7.1	8.0	45.2	18.3	7.1	3.5	8.6
2007	1.3	7.3	7.6	42.4	20.0	6.9	4.6	9.8
2008	1.3	7.2	8.1	43.3	20.7	5.8	5.2	8.5
2009	1.5	8.4	7.1	41.2	19.5	7.8	6.1	8.5
2010	1.0	10.6	7.0	35.5	20.2	8.8	6.3	10.5
2011	2.6	13.1	7.7	34.7	18.2	7.7	5.1	10.9
2012	2.3	13.4	10.3	35.6	16.1	6.6	5.6	10.1
2013	2.0	13.1	12.0	37.5	14.2	7.5	3.6	9.9
2014	2.1	15.5	14.3	33.0	13.6	6.5	4.3	10.8
2015	**2.2**	**14.8**	**15.1**	**33.5**	**12.1**	**6.7**	**3.8**	**11.9**

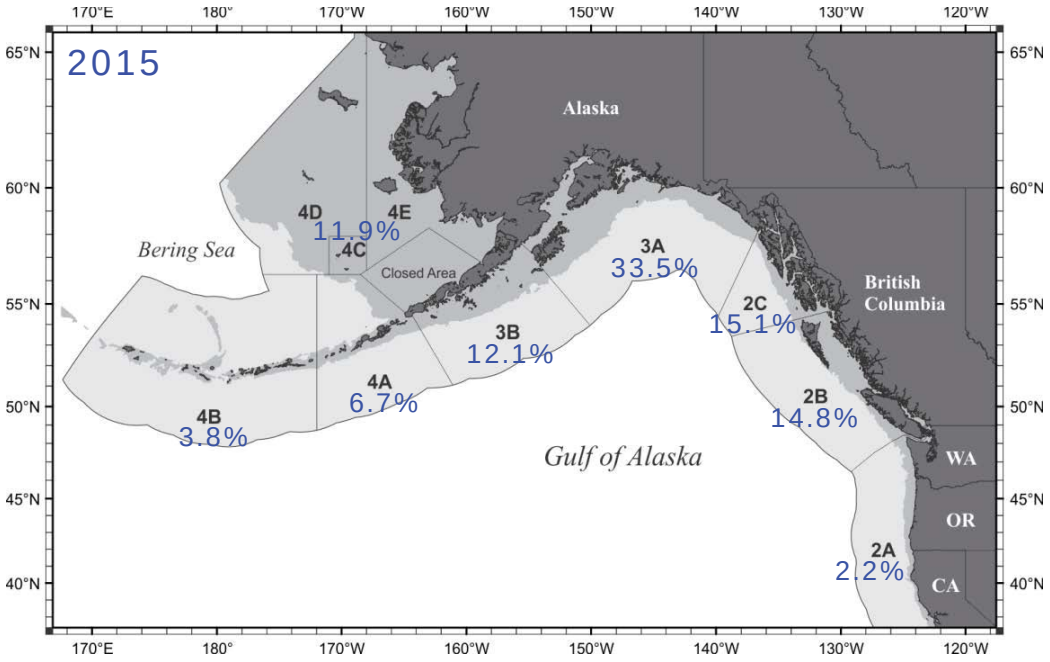


Figure 1. Estimated O32 apportionment percentages for 2015 based on setline survey WPUE.

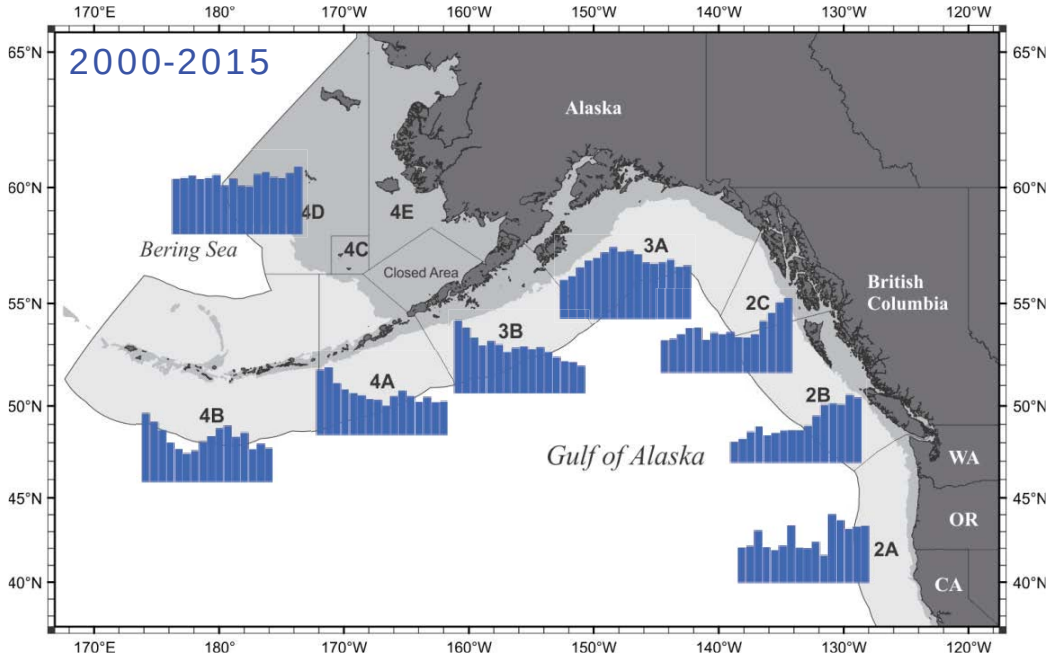


Figure 2. Estimated trends in O32 apportionment percentages over the last 16 years (estimates for 2000-2015).

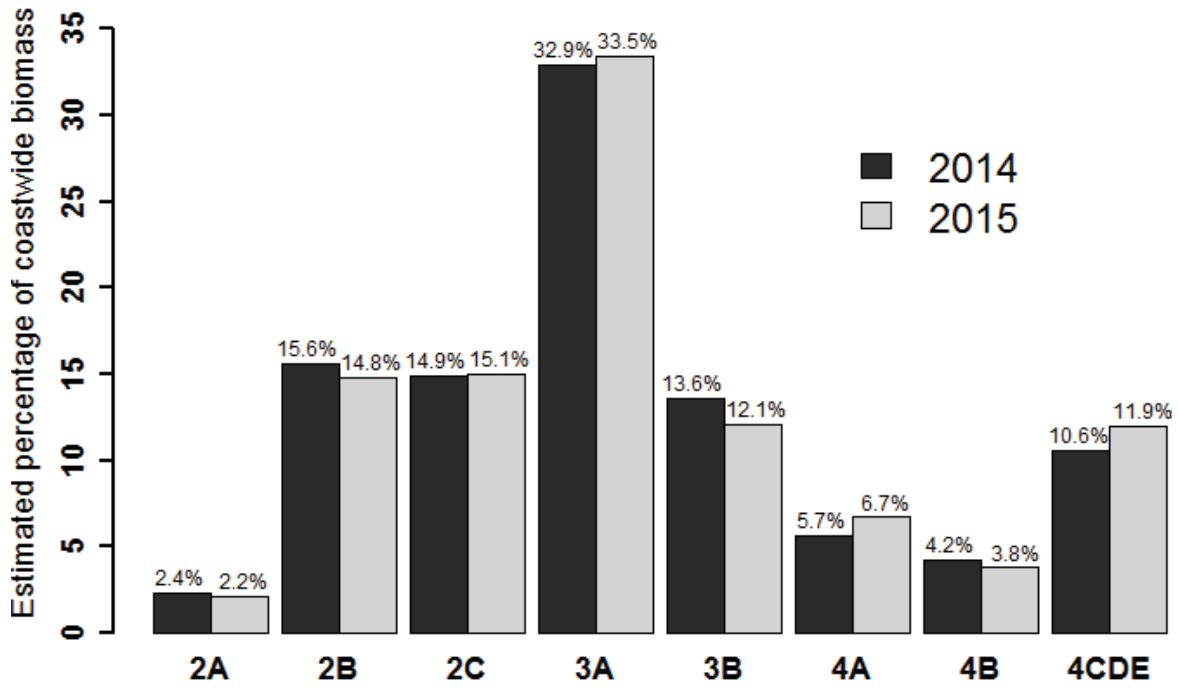


Figure 3. Comparison of apportionment estimates of stock distribution calculated for the beginning of 2014 and 2015. The 2014 values are those estimated during the 2013 apportionment process, and differ from the revised values in Table 1.

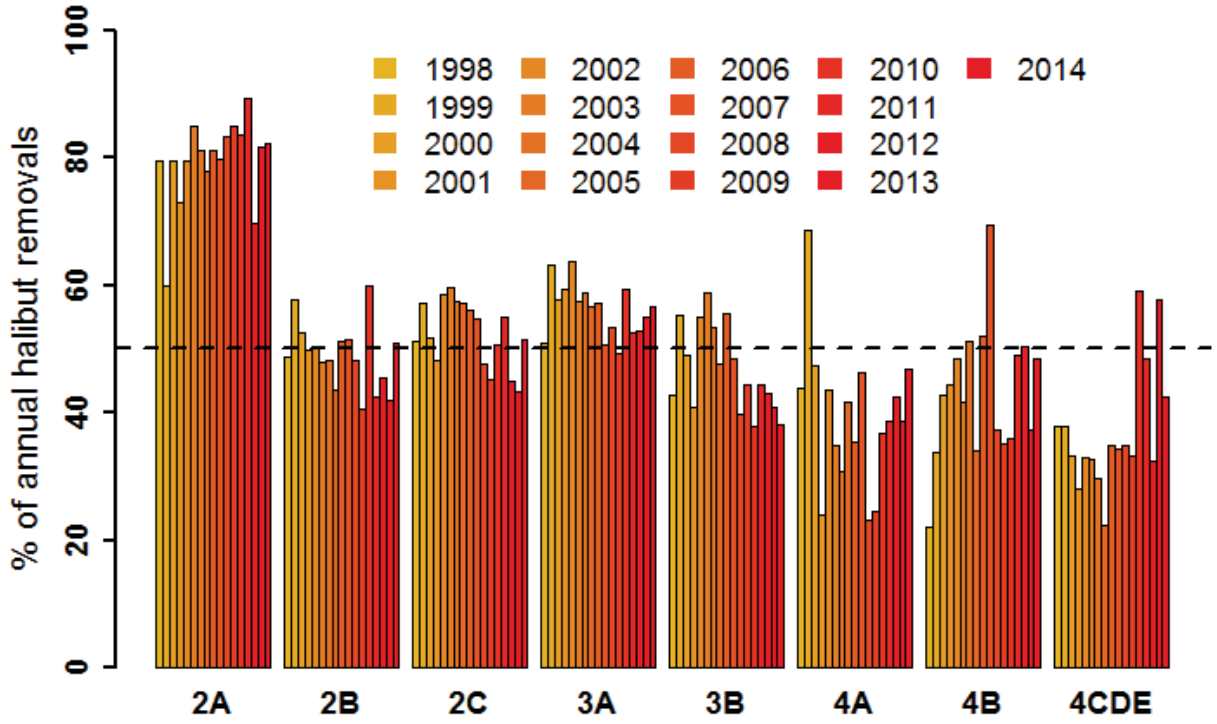


Figure 4. Estimated percentage of O32 halibut removals taken prior to the mean setline survey date, by area and year. Includes commercial catch, wastage, sport catch in Areas 2A, 2B, 2C, and 3A, bycatch, personal use, and survey and other research catch.

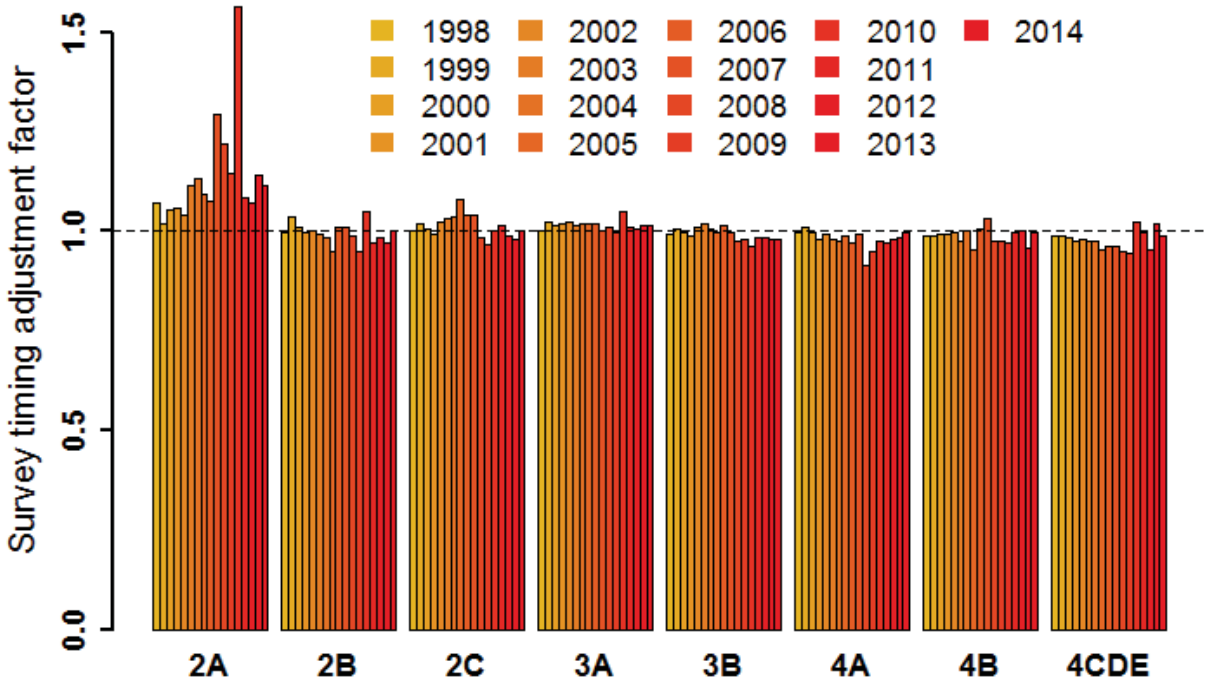


Figure 5. Survey timing adjustment factors that are applied to setline survey WPUE for apportionment, by area and year.

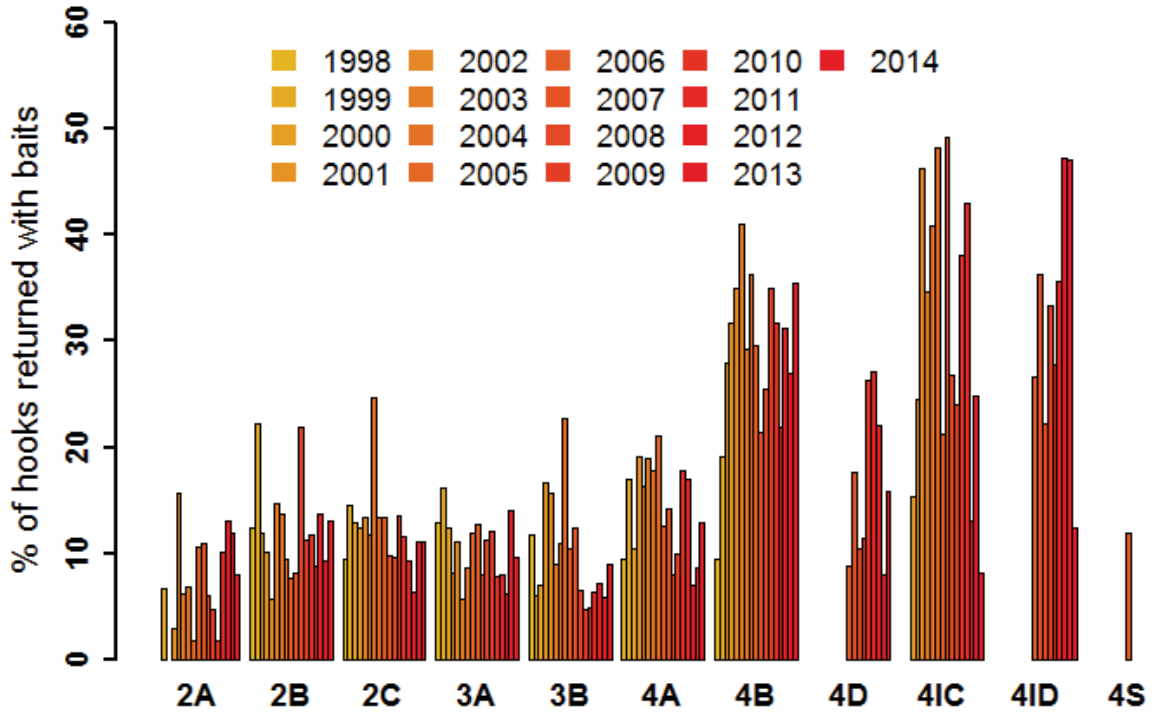


Figure 6. Percentage of setline survey hooks returned with baits by area and year. Area 4S is the southern portion of the eastern Bering Sea, surveyed in 2006 only, while Areas 4ID and 4IC are the island portions (St Matthew, Pribilofs) of Areas 4D and 4C respectively. Here Area 4D means the Area 4CDE Edge.

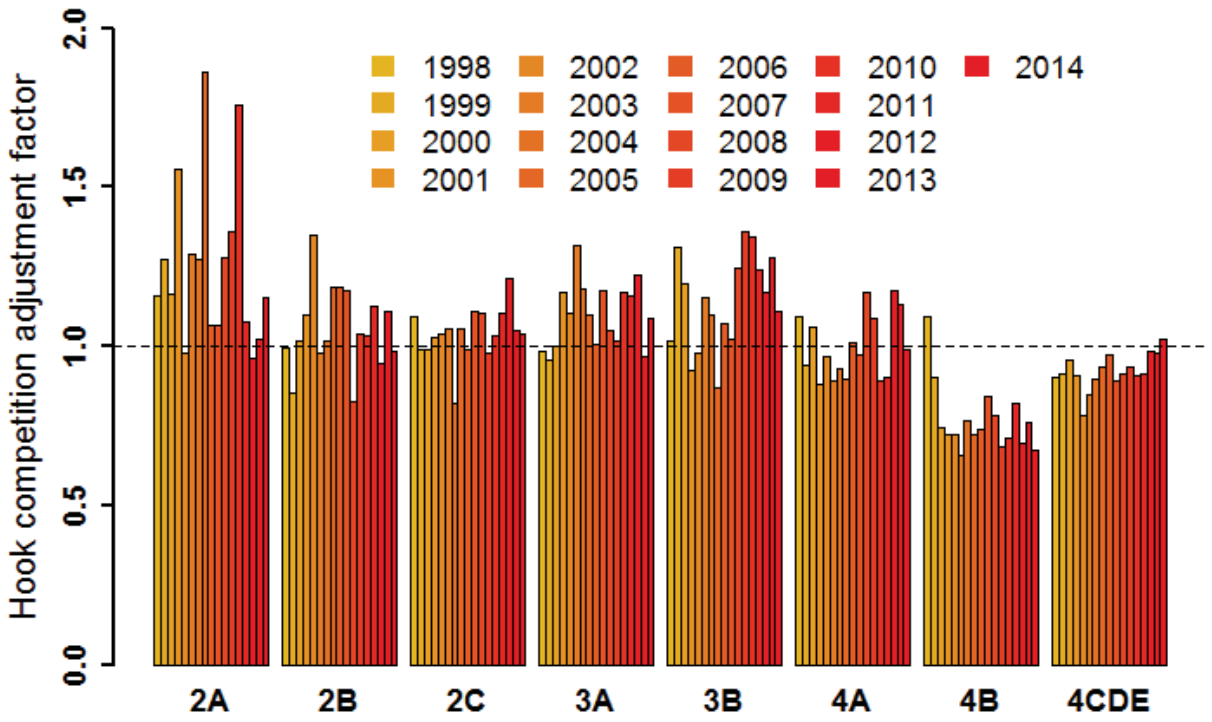


Figure 7. Hook competition adjustment factors that are applied to setline survey WPUE for apportionment.

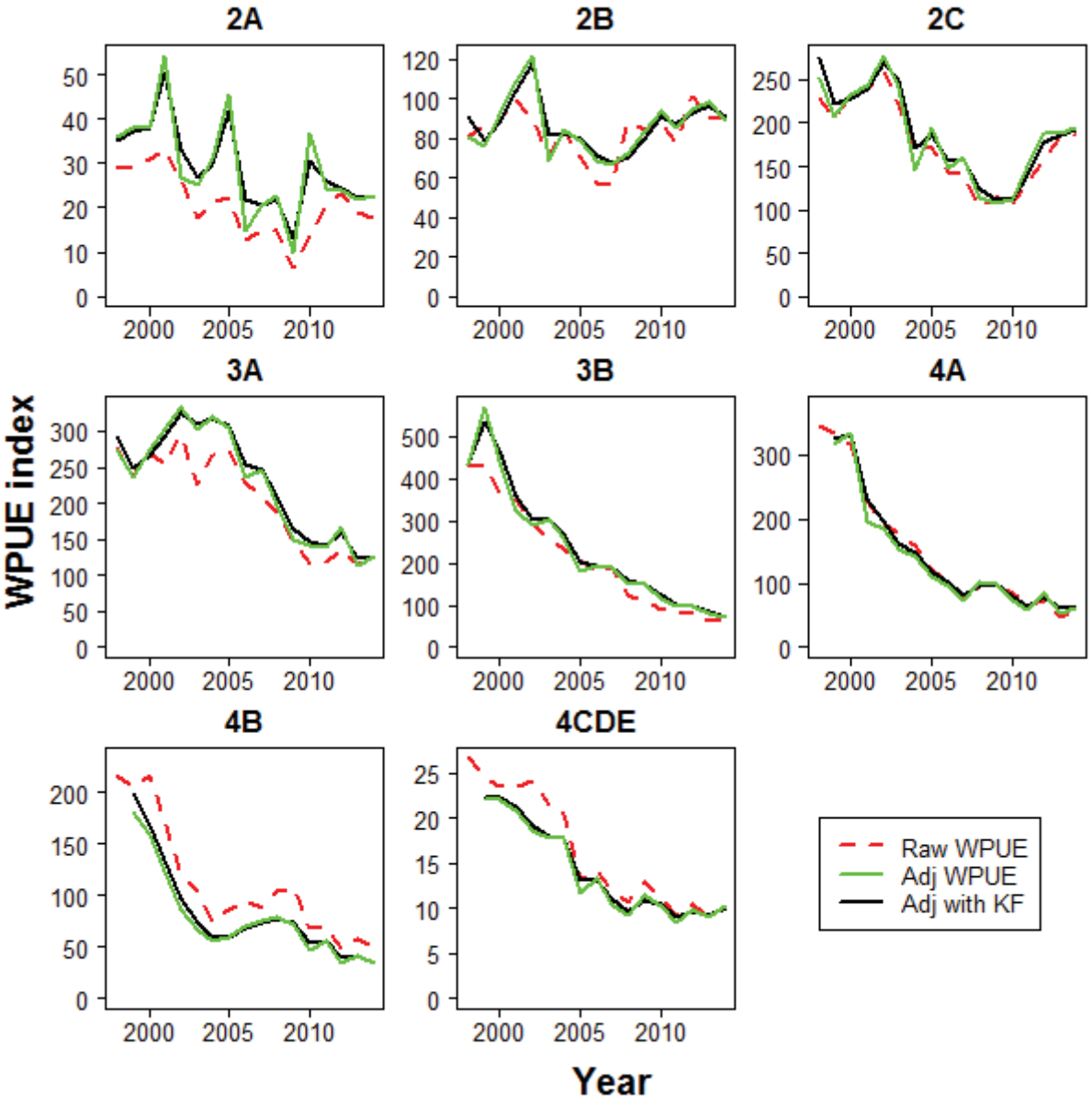


Figure 8. Comparison of survey WPUE without adjustments (Raw WPUE), with both timing and hook competition adjustments applied (Adj WPUE), and with adjustments and a 75:20:5 weighting of the three most recent years' values (Adj with KF).

Regulatory area harvest policy calculations and catch tables

Ian J. Stewart

Abstract

This document reports the results of the application of the current IPHC harvest policy as well as additional information on fishing intensity and management alternatives for 2015. Setline survey legal-size (O32) Weight-Per-Unit-Effort (WPUE) is used to estimate the distribution of the stock available to the directed fisheries each year (Webster and Stewart 2015). The apportionment percentages and the target harvest rates for each regulatory area (21.5% for Areas 2A-3A, and 16.125% for Areas 3B-4CDE) together result in a target distribution for the annual TCEY. The scale of this distribution is based on the estimate of the coastwide exploitable biomass at the beginning of 2015 from the stock assessment. The Blue Line catch tables are calculated by solving for the area-specific Fishery Constant Exploitation Yield (FCEY) values that satisfy both the target scale and distribution of the coastwide Total Constant Exploitation Yield (TCEY) based on projections of all sources of O26 removals. Differing components of the O26 removals are included in the FCEY, along with commercial fishery landings in Areas 2A-3A, depending on the Catch Sharing Plan (CSP) in place for each area. Catch tables based on the fully extended catch accounting approach (Stewart et al. 2015) are presented for the 2015 Blue Line, and several other management alternatives corresponding to higher and lower levels of fishery and total removals. The results of this analysis indicate that the 2015 Blue Line suggests a slightly higher total TCEY (35.48 Mlb) than the Blue Line calculated in 2014 (33.48) due to an increase in the exploitable biomass estimate from the stock assessment (181 Mlb). After accounting for changes in bycatch, wastage, and other sources of removals, the 2015 Blue Line results in increases in target FCEY values for four regulatory areas (2A, 2C, 3A, and 4A) relative to the 2014 results. When compared to the *status quo* (2014 adopted FCEYs), the total 2015 Blue Line TCEY is lower; however larger FCEY values are still projected for three regulatory areas (2C, 3A, and 4A). Additional management alternatives are also presented for comparison.

Introduction

This document reports the results of the application of the current IPHC harvest policy as well as additional information on fishing intensity and management alternatives for 2015 based on the stock assessment results. The analysis uses the results of both the most recent apportionment calculations (Webster and Stewart 2015) and stock assessment (Stewart and Martell 2015).

In 2012, the IPHC began to more transparently delineate the results of scientific analyses (apportionment and the stock assessment) and the application of harvest policy and management decisions resulting in annual catch limits. To that end, the stock assessment now reports estimates of current stock size, recent trends, and projections based on a range of alternative harvest levels and distributions. These results are summarized in a risk assessment, based on the response of several stock and fishery metrics to these management alternatives. To provide consistency with previous year's catch advice, the Blue Line alternative represents the application of the IPHC's current harvest policy to the results of the survey-based apportionment and stock assessment analyses. In addition to the Blue Line, alternative harvest levels representing lower and higher levels of removals are also presented.

Apportionment results

Based on the most recent setline survey observations available (Webster and Stewart 2015), the current O32 halibut biomass is estimated to be roughly divided into thirds: one-third in Area 2 (2A, 2B, and 2C), one-third in Area 3A, and one-third in Areas 3B-4CDE (Table 1). These percentages for 2015 provide the basis for the application of the harvest policy described below.

Harvest policy

The current harvest policy for Pacific halibut is based on two harvest targets: the distribution of harvest among regulatory areas, and the scale of that harvest at the coastwide level. Only O26 removals are explicitly included in these calculations; however, the target harvest rates implicitly include a constant level of U26 mortality consistent with the period over which the rates were developed (Hare 2011). Target harvest rates are area-specific: 21.5% in Areas 2A, 2B, 2C and 3A, and 16.125% to Areas 3B, 4A, 4B, and 4CDE. The combination of the apportionment results and the target harvest rates yields a target distribution for the coastwide TCEY.

Because the harvest policy is defined at the area-specific level, the results of apportionment calculations are needed evaluate the harvest intensity, even though the assessment is conducted at a coastwide scale. Specifically, exploitable biomass is first apportioned to area, and then area-specific catch limits aggregated back to the coastwide level (Fig. 1). The harvest policy also includes a Harvest Control Rule (HCR), which does not change the distribution of harvest among regulatory areas, but reduces the target harvest rates linearly if the stock is estimated to have fallen below 30% of the equilibrium stock size in the absence of fishing, such that there would be no fishing mortality below 20% relative spawning biomass (Fig. 2).

Results for 2015

The 2014 stock assessment (Stewart and Martell 2015) estimated a slightly larger exploitable biomass at the beginning of 2015 (181 Mlb) than was estimated for the terminal year in previous assessments. This value is very uncertain, due to uncertainty within and among individual models included in the assessment. There is no specific accounting for this uncertainty built in to the current harvest policy; however the cumulative probability distribution indicates plausible values ranging from less than 150 Mlb to more than 200 Mlb (Fig. 3). The time-series of assessment results indicate that relative harvest rates have exceeded the harvest policy target at the coastwide level since the early 2000s (Fig. 4). When considered with the apportionment estimates for each year, very high relative exploitation rates are hindcast for Areas 2A, 2B, and 2C (Fig. 5). Rates in all areas are estimated to have been above the target levels in recent years, with only Area 4A estimated to have dropped below the target in 2014.

In both 2013 and 2014, adopted FCEYs were projected to result in harvest levels lower than the preceding years, but still above the coastwide target (Table 2, Fig. 4). The adopted limits for 2014 were projected to have a greater proportion of the TCEY distributed at the northern and southern ends of the halibut distribution, specifically Areas 2A-2B, and 4B-4CDE (Fig. 6). Based the final estimates of removals available for 2014, it became apparent that the realized harvest rates had been larger than those projected (Fig. 4). This was due to larger than projected levels of bycatch (particularly in Area 4CDE), recreational removals (particularly in 3A) and other sources, resulting in almost 3 million pounds of additional mortality (Table 3).

Application of the current harvest policy to the apportionment and assessment results produces area-specific TCEY values consistent with the Blue Line. FCEYs are calculated such that all O26 removals sum to the TCEY target within each regulatory area and at the coastwide level. Based on the distribution of biomass at the beginning of 2015, the effective coastwide harvest rate is estimated to be 19.6%. The coastwide TCEY is therefore 35.48 Mlb (Table 4). In order to calculate the FCEY, it was assumed that the values of bycatch, subsistence and personal use, and unguided recreational removals for 2015 remain constant at 2014 levels. Commercial wastage was scaled proportional to the change in fishery landings. In 2014, an allocation between guided recreational and commercial fishery removals was first applied in Areas 2C and 3A, consistent with the Catch Sharing Plan (CSP). This means that in Areas 2C and 3A, the FCEY is comprised of both sources of removals, and not just the directed fishery landings, as was the case prior to 2014.

The projected total removals for the 2015 Blue Line (Table 4) are slightly larger than those from the 2014 Blue Line (Table 5). Retaining the 2014 FCEYs for 2015 (the *status quo*) would result in additional mortality (Table 6) as well as a distribution of the removals among regulatory areas differing substantially from the distribution target implied by the current harvest policy (Fig. 7). After accounting for changes in bycatch, wastage, and other sources of removals, the 2015 Blue Line results in increases in target FCEY values for four regulatory areas (2A, 2C, 3A, and 4A) relative to the 2014 results (Table 7). When compared to the *status quo* (2014 adopted FCEYs), the total 2015 Blue Line TCEY is lower; however larger FCEY values are still projected for three regulatory areas (2C, 3A, and 4A). The differences between these alternatives for the TCEY vs. the FCEY estimates reflect the contributions of both the updated apportionment and non-directed removals. An example of this is in Area 4CDE, where the TCEY is substantially larger for the 2015 Blue Line (3.48 Mlb) relative to the 2014 Blue Line (2.91 Mlb, Table 8), but the FCEY is much smaller (0.37 Mlb vs. O.64 Mlb, Table 7), due to a much larger projection of O26 bycatch.

Additional management alternatives

Results for alternate rows from the decision table with 30 and 50 Mlb of total mortality are presented in Tables 9 and 10. Based on the analysis of all sources of removals (Stewart et al. 2015), it is possible to use the estimated Spawning Potential Ratio, or SPR, to measure the total fishing intensity exerted on the stock. SPR represents the reduction in equilibrium spawning biomass per recruit for any level of fishing relative to the equilibrium spawning biomass per recruit in the absence of any fishing mortality. SPR is often reported in terms of $F_{xx\%}$, where the percentage refers to the percent reduction; e.g., no fishing mortality would correspond to $F_{100\%}$. Based on the stock assessment results, the 2015 Blue Line has a fishing intensity of $F_{46\%}$; this value would be the analog of the 19.6% exploitation fraction indicated by the current harvest policy. Using the 2015 Blue Line as a relative target, a summary of recent fishing intensity suggest a very similar pattern to that inferred from the current harvest policy: harvest rates in excess of target levels, but decreasing in recent years as management actions have reduced the removals from the population (Fig. 8). SPR can also be used to find the level of harvest in 2015 that would result in the same level of fishing intensity as was estimated to have occurred in 2014; this alternative is reported in Table 11.

At the request of the IPHC's Commissioners during the 2014 Interim Meeting, an additional catch table was produced to evaluate the potential effects of increases in bycatch in both Canadian and Alaskan waters. The 2015 Blue Line was recalculated based on a projection of bycatch up

to the current regulatory caps. For British Columbia, this included an increase in total (O26 and U26) bycatch from 0.24 Mlb to 1.00 Mlb, assuming the ratio of O26 to U26 remained constant. For Alaskan waters, the Prohibited Species Caps (PSC) do not align with IPHC regulatory areas. Further, there are many more constraints on exactly when and in which fisheries the various components of the total cap can be taken. However, this example makes the simple approximation that sum of all IPHC Areas 4A through 4CDE total to the Bering Sea and Aleutian Islands (BSAI) PSC limit (7.3 Mlb), and the estimated proportions of the bycatch in each IPHC area from 2014 remain unchanged. The same logic is applied to the Gulf of Alaska (GOA), where the total combined PSC limit was 3.76 Mlb. The U26 and O26 proportions, as well as the distribution of bycatch among the IPHC areas in the BSAI and GOA are assumed to remain unchanged. Because of these simple approximations, this catch table should not be interpreted as a prediction, but just an example of how the FCEY calculations might change under large increases in bycatch possible under current regulations. The most salient result of this analysis is that the Area 4CDE TCEY would be insufficient to accommodate the increased bycatch, and therefore the TCEYs in other regulatory areas would need to be proportionally reduced to achieve the target total coastwide TCEY (35.48 Mlb; Table 12). All other regulatory areas would be projected to have reductions in both the FCEY and TCEYs.

References

Hare, S. R. 2011. Potential modifications to the IPHC harvest policy. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 177-200.

Stewart, I. J. and Martell, S. J. D. 2015. Assessment of the Pacific halibut stock at the end of 2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 161-180.

Stewart, I. J., Leaman, B. M., and Martell, S. J. D. 2015. Accounting for and managing all Pacific halibut removals. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 221-266.

Webster, R. A. and Stewart, I. J. 2014. Apportionment and regulatory area harvest calculations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 197-216.

Webster, R. A. and Stewart, I. J. 2015. Setline survey-based apportionment estimates. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 181-194.

Table 1. Results of survey-based apportionment calculations for 2015 (see Webster and Stewart, 2015 for details), target harvest rates and target TCEY distribution from the current harvest policy.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Apportionment	2.2%	14.8%	15.1%	33.5%	12.1%	6.7%	3.8%	11.9%	100.0%
Target harvest rate	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.6%
Target TCEY Distribution	2.4%	16.2%	16.5%	36.6%	9.9%	5.5%	3.1%	9.8%	100.0%

Table 2. Extended catch table projected for 2014 based on the adopted FCEYs. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.03	0.20	NA	NA	0.24	0.05	0.03	0.04	0.58
Bycatch	0.12	0.19	0.01	0.93	0.62	0.63	0.32	2.23	5.05
Sport (+ wastage)	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.15	0.79	1.31	2.63	0.90	0.71	0.35	2.29	9.13
O26 FCEY									
Comm. wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport (+wastage)	0.42	0.84	0.76	1.78	NA	NA	NA	NA	3.80
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.51	6.01	3.32	7.32	2.84	0.85	1.14	1.29	23.28
Total FCEY	0.96	6.85	4.16	9.43	2.84	0.85	1.14	1.29	27.52
TCEY	1.11	7.64	5.47	12.06	3.74	1.56	1.49	3.58	36.65
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.09
Bycatch	0.01	0.04	0.00	0.51	0.26	0.47	0.13	1.42	2.83
Total U26	0.01	0.04	0.01	0.52	0.30	0.48	0.14	1.42	2.92
Total Mortality	1.11	7.69	5.48	12.58	4.04	2.04	1.63	5.00	39.58

Table 3. Catch table estimated for 2014. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.24	NA	NA	0.29	0.03	0.05	0.05	0.67
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.09	0.86	1.55	2.88	1.10	0.59	0.40	3.14	10.61
O26 FCEY									
Comm. wastage	NA	NA	0.11	0.41	NA	NA	NA	NA	0.52
CSP Sport (+wastage)	0.41	0.95	0.87	2.18	NA	NA	NA	NA	4.41
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings*	0.54	5.88	3.44	7.63	2.93	0.90	1.12	1.26	23.69
Total FCEY	0.98	6.83	4.43	10.22	2.93	0.90	1.12	1.26	28.65
TCEY	1.06	7.69	5.98	13.10	4.03	1.49	1.51	4.40	39.26
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.01	0.10
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.50	0.51	0.40	0.06	1.75	3.25
Total Mortality	1.07	7.73	5.98	13.60	4.53	1.88	1.57	6.16	42.51

* Includes overage/underage and research catches.

Table 4. Extended catch table projected for 2015 Blue Line. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.17	NA	NA	0.24	0.05	0.03	0.01	0.52
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.08	0.80	1.55	2.88	1.06	0.60	0.38	3.11	10.46
O26 FCEY									
Comm. wastage	NA	NA	0.11	0.42	NA	NA	NA	NA	0.53
CSP Sport (+wastage)	0.31	0.69	0.79	1.89	NA	NA	NA	NA	3.68
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.41	4.27	3.40	7.81	2.46	1.35	0.72	0.37	20.78
Total FCEY	0.75	4.96	4.30	10.12	2.46	1.35	0.72	0.37	25.02
TCEY	0.84	5.75	5.85	13.00	3.51	1.95	1.10	3.48	35.48
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.50	0.50	0.40	0.06	1.75	3.24
Total Mortality	0.84	5.78	5.85	13.49	4.01	2.35	1.16	5.23	38.72

Table 5. Extended catch table based on the 2014 Blue Line. Results expanded from Webster and Stewart (2014). All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.14	NA	NA	0.24	0.05	0.02	0.02	0.49
Bycatch	0.12	0.19	0.01	0.93	0.62	0.63	0.32	2.23	5.05
Sport (+ wastage)	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.04
O26 FCEY									
Comm. wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport (+wastage)	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.38	4.37	3.32	7.32	2.84	0.85	0.82	0.64	20.53
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.44
TCEY	0.86	5.72	5.47	12.06	3.74	1.56	1.16	2.91	33.48
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.47	0.13	1.42	2.83
Total U26	0.01	0.04	0.01	0.52	0.30	0.48	0.14	1.42	2.92
Total Mortality	0.87	5.76	5.48	12.58	4.04	2.04	1.30	4.33	36.40

Table 6. Extended catch table projected for the *status quo* (2014) FCEY values set to the same values in 2015. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.24	NA	NA	0.28	0.03	0.05	0.05	0.66
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.09	0.86	1.55	2.88	1.09	0.58	0.40	3.15	10.60
O26 FCEY									
Comm. wastage	NA	NA	0.11	0.39	NA	NA	NA	NA	0.50
CSP Sport (+wastage)	0.40	0.95	0.76	1.78	NA	NA	NA	NA	3.90
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.53	5.90	3.29	7.26	2.84	0.85	1.14	1.29	23.10
Total FCEY	0.96	6.85	4.16	9.43	2.84	0.85	1.14	1.29	27.52
TCEY	1.05	7.71	5.71	12.31	3.93	1.43	1.54	4.44	38.12
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.01	0.09
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.49	0.50	0.40	0.06	1.75	3.25
Total Mortality	1.05	7.74	5.72	12.81	4.44	1.83	1.59	6.19	41.37

Table 7. Comparison of FCEY values (M lb).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
2014 Blue Line	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.44
Status quo (2014) FCEYs	0.96	6.85	4.16	9.43	2.84	0.85	1.14	1.29	27.52
2015 Blue Line	0.75	4.96	4.30	10.12	2.46	1.35	0.72	0.37	25.02

Table 8. Comparison of TCEY values (M lb).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
2014 Blue Line	0.86	5.72	5.47	12.06	3.74	1.56	1.16	2.91	33.48
Status quo (2014) FCEYs	1.05	7.71	5.71	12.31	3.93	1.43	1.54	4.44	38.12
2015 Blue Line	0.84	5.75	5.85	13.00	3.51	1.95	1.10	3.48	35.48

Table 9. Extended catch table projected based on achieving a 30 M lb total mortality in 2015. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.01	0.12	NA	NA	0.16	0.03	0.02	0.00	0.34
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.08	0.75	1.55	2.88	0.98	0.58	0.37	3.10	10.28
O26 FCEY									
Comm. wastage	NA	NA	0.07	0.28	NA	NA	NA	NA	0.35
CSP Sport (+wastage)	0.22	0.49	0.51	1.27	NA	NA	NA	NA	2.49
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.29	3.02	2.20	5.19	1.62	0.86	0.45	0.00	13.64
Total FCEY	0.54	3.51	2.78	6.74	1.62	0.86	0.45	0.00	16.51
TCEY	0.62	4.26	4.33	9.63	2.60	1.45	0.82	3.10	26.79
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.05
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.49	0.49	0.40	0.05	1.75	3.21
Total Mortality	0.62	4.29	4.33	10.11	3.09	1.84	0.87	4.85	30.00

Table 10. Extended catch table projected based on achieving a 50 M lb total mortality in 2015. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.23	NA	NA	0.34	0.07	0.05	0.05	0.76
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.09	0.86	1.55	2.88	1.16	0.62	0.39	3.15	10.70
O26 FCEY									
Comm. wastage	NA	NA	0.16	0.60	NA	NA	NA	NA	0.77
CSP Sport (+wastage)	0.42	0.93	0.98	2.49	NA	NA	NA	NA	4.83
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.56	5.78	5.01	11.14	3.47	1.95	1.06	1.43	30.41
Total FCEY	1.01	6.72	6.15	14.24	3.47	1.95	1.06	1.43	36.03
TCEY	1.10	7.57	7.70	17.12	4.63	2.57	1.45	4.58	46.73
U26									
Comm. wastage	0.00	0.01	0.01	0.04	0.05	0.01	0.00	0.01	0.12
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.51	0.51	0.40	0.06	1.75	3.28
Total Mortality	1.10	7.61	7.71	17.62	5.14	2.97	1.51	6.34	50.00

Table 11. Extended catch table projected by maintaining the same SPR realized in 2014. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.20	NA	NA	0.28	0.05	0.04	0.03	0.62
Bycatch	0.07	0.22	0.02	1.14	0.78	0.52	0.35	3.07	6.16
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.09	0.82	1.55	2.88	1.10	0.61	0.38	3.13	10.56
O26 FCEY									
Comm. wastage	NA	NA	0.13	0.50	NA	NA	NA	NA	0.63
CSP Sport (+wastage)	0.36	0.79	0.92	2.06	NA	NA	NA	NA	4.12
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.47	4.88	4.00	9.23	2.87	1.60	0.86	0.80	24.72
Total FCEY	0.86	5.67	5.05	11.79	2.87	1.60	0.86	0.80	29.50
TCEY	0.95	6.49	6.60	14.68	3.97	2.21	1.24	3.93	40.06
U26									
Comm. wastage	0.00	0.01	0.01	0.03	0.04	0.01	0.00	0.00	0.10
Bycatch	0.00	0.02	0.00	0.47	0.46	0.39	0.05	1.75	3.15
Total U26	0.00	0.03	0.01	0.50	0.51	0.40	0.06	1.75	3.25
Total Mortality	0.95	6.53	6.61	15.18	4.47	2.60	1.30	5.68	43.31

Table 12. Extended catch table based on the 2015 Blue Line including potential bycatch mortality increases in Alaska and British Columbia up to the full regulatory limits currently in place. All values reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O26 Non-FCEY									
Comm. wastage	0.02	0.15	NA	NA	0.22	0.04	0.03	0.00	0.45
Bycatch	0.07	0.90	0.02	1.50	1.03	0.62	0.41	3.66	8.20
Sport (+ wastage)	NA	NA	1.14	1.49	0.02	0.02	0.00	0.00	2.67
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.08	1.45	1.55	3.24	1.28	0.70	0.44	3.68	12.43
O26 FCEY									
Comm. wastage	NA	NA	0.11	0.40	NA	NA	NA	NA	0.51
CSP Sport (+wastage)	0.31	0.59	0.78	1.83	NA	NA	NA	NA	3.51
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Comm. Landings	0.41	3.67	3.37	7.45	2.21	1.24	0.65	0.00	19.00
Total FCEY	0.75	4.26	4.26	9.68	2.21	1.24	0.65	0.00	23.06
TCEY	0.83	5.72	5.81	12.92	3.49	1.94	1.10	3.68	35.48
U26									
Comm. wastage	0.00	0.01	0.01	0.02	0.03	0.00	0.00	0.00	0.08
Bycatch	0.00	0.10	0.00	0.62	0.61	0.47	0.06	2.08	3.94
Total U26	0.00	0.10	0.01	0.64	0.64	0.47	0.07	2.08	4.02
Total Mortality	0.83	5.82	5.82	13.56	4.13	2.41	1.16	5.76	39.50

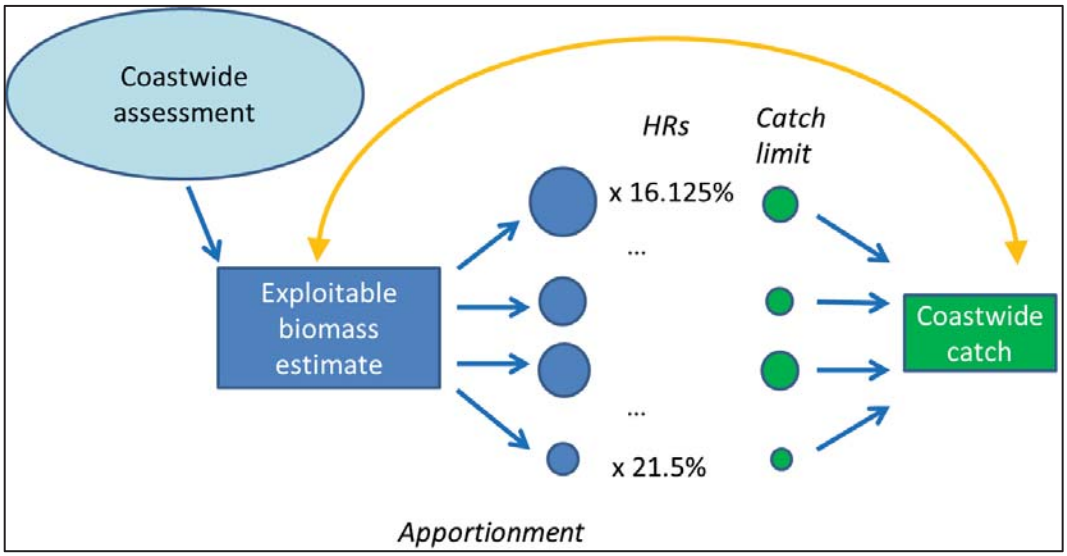


Figure 1. Illustration of the method for calculating the coastwide harvest rate target based on the IPHC's harvest policy.

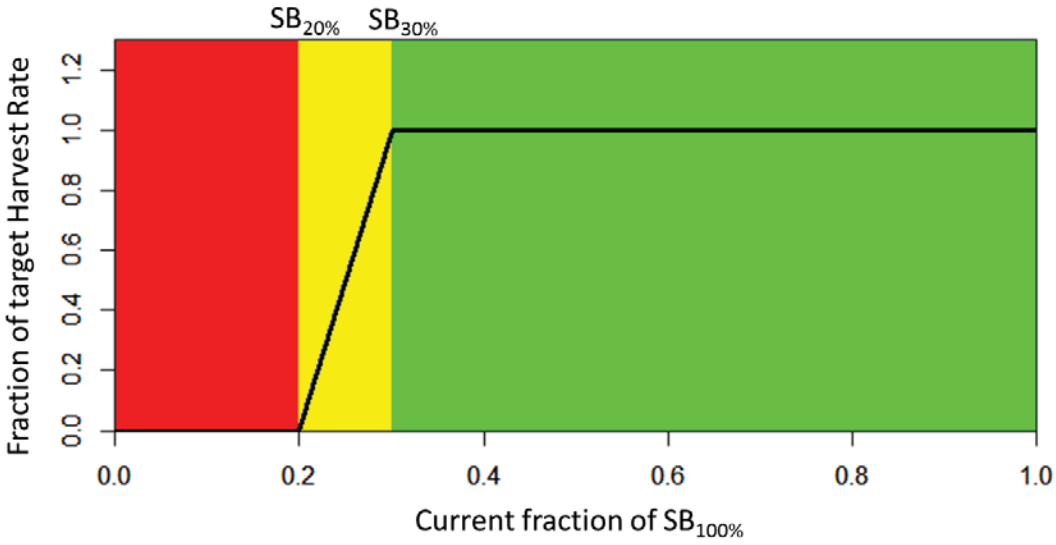


Figure 2. Current IPHC harvest control rule for determining the relative target harvest rate to apply in each Regulatory Area, as a function of the coastwide relative spawning biomass.

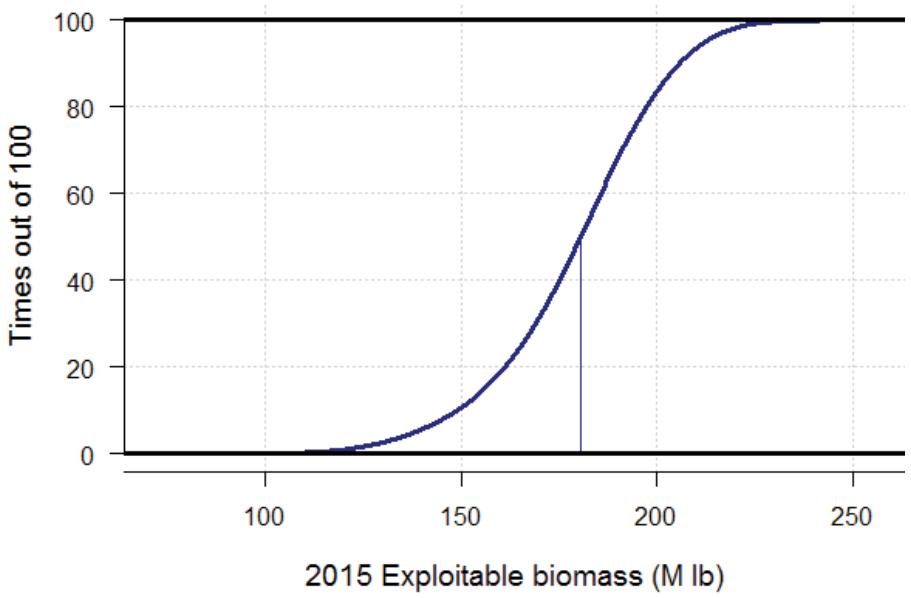


Figure 3. Cumulative distribution of 2015 exploitable biomass estimates including model and estimation uncertainty, but not uncertainty in the selectivity curve generating the calculation. Vertical line indicates the median value (181 million pounds).

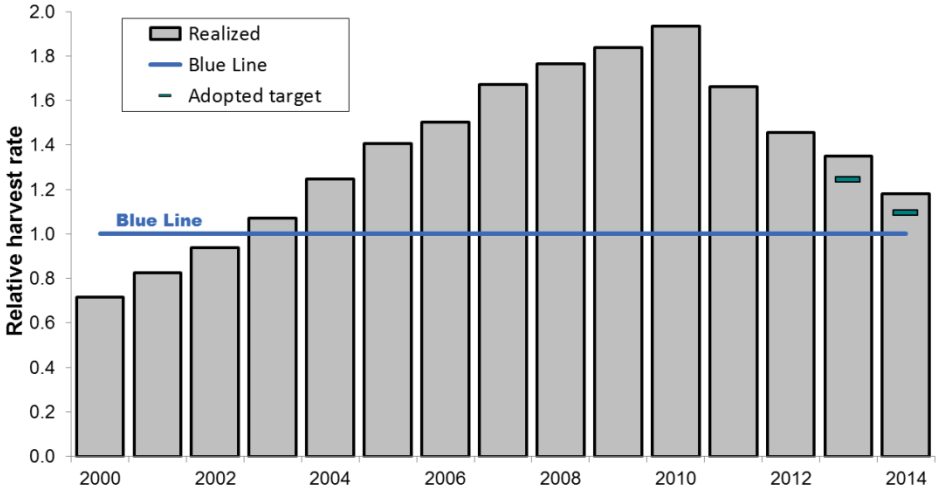


Figure 4. Time-series of estimated coastwide harvest rates (bars) relative to the annual harvest rate targets (line) from the current harvest policy. Values are hindcast based on the current ensemble estimates of exploitable biomass, not the estimates available each year. Dashes indicate the projected harvest rate from the 2013 and 2014 adopted catch limits.

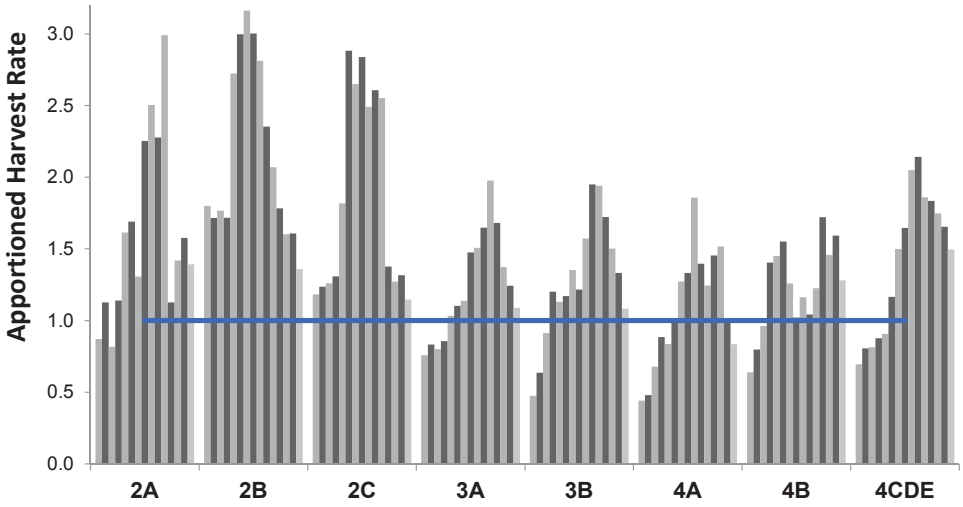


Figure 5. Estimated area-specific harvest rates from 2000 to 2014 (bars) relative to the annual harvest rate targets (line) from the current harvest policy. Values are hindcast based on the current ensemble estimates of coastwide exploitable biomass and apportionment results.

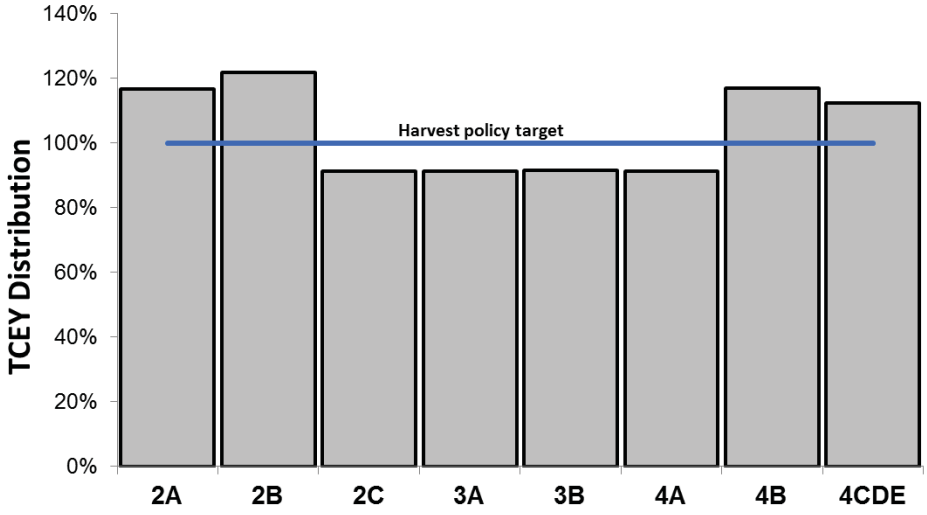


Figure 6. Projected distribution of the TCEY based on the adopted catch limits for 2014.

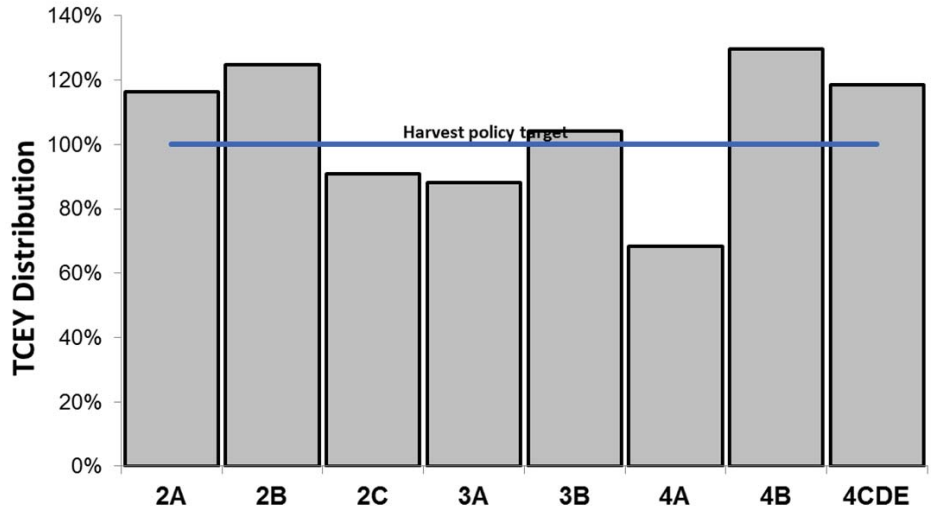


Figure 7. Projected distribution of the TCEY based on applying the status quo (2014 FCEYs) as the catch limits for 2015.

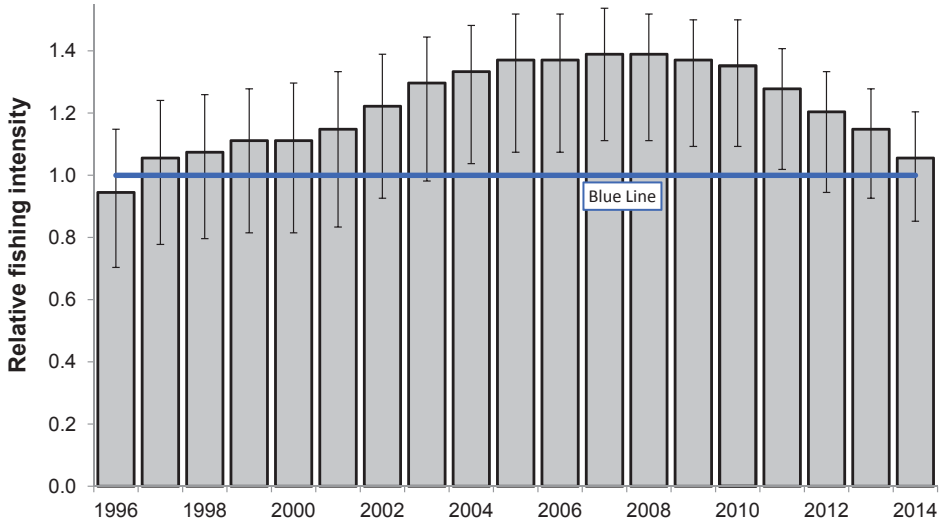


Figure 8. Time-series of estimated coastwide harvest rates (bars) relative to the target harvest rate for all sizes and sources of removals projected for the 2015 Blue Line (F46%). Values are hindcast based on the current ensemble estimates of Spawning Potential ratio.

Evaluation of commercial logbook records: 1991-2013

Cole C. Monnahan and Ian J. Stewart

Introduction

There has been considerable interest during recent years in evaluating the directed commercial halibut fishery catch-rates and comparing them with observations from the IPHC's annual setline survey. Further, it has been more than a decade since there has been a review of the IPHC's current method for standardizing annual fishery logbook observations for use in the stock assessment (Clark 2002). The standard method excludes snap-gear logbook records in all regulatory areas except 2A and 2B (where the proportion of snap-gear usage is high), all autoline records, and all records with hook-spacing less than four feet (Stewart 2015). There were a number of questions during recent annual meetings regarding how many data were being ignored, whether the spatial distribution of the records excluded could be important, and how robust the results of the standard method might be relative to the catch-rates observed by the entire halibut fleet. To address these concerns, in 2014 a detailed investigation of recent logbook records was initiated. This project had five primary goals:

1) Determine what fraction of the recent directed commercial fishing activity is represented in the IPHC's logbook records, and then delineate these records into those used in recent fishery catch-rate analyses, those that could potentially be used, and those that are not reliable due to mixed-species targeting or incomplete recording of the fishing information.
2) Compare the fishery catch-rates among fixed-hook, snap-gear, and autoline by regulatory area and year.
3) Investigate the hook-spacing correction used to standardize logbook records, and explore whether it might be modelled directly rather than treated as a correction to the raw data.
4) Compare model-based estimates of recent catch-rate trends with standard calculations used in stock assessment analyses.
5) Create a framework that would allow this type of analysis to be periodically repeated, and potentially extended to make the best possible use of the valuable information contained in fishery logbooks.

Data summary

For this part of the analysis, directed fishery logbook records from 1991 to 2013 were evaluated. This time period corresponds to a consistent data format in the IPHC database records, as well as a quantity of data small enough to process efficiently. This period is also most relevant to current analyses, trends, and fishery behavior. Data for each logbook record (set) included: retained weight of halibut, year, month, IPHC regulatory area, statistical area (Kong et al. 2004), gear-type, hook-size, depth, number of skates fished, target-species, and at least two of hook spacing, skate length, or number of hooks (to calculate the number of effective skates; see below). The IPHC annually reconciles each logbook record with fish-ticket information, pro-rating the retained catch for the entire fishing trip to each set made during that trip based on the recorded pounds per set in the logbook. The result of these calculations thus represents the best information about the

distribution of retained catch during the trip, as well as the magnitude of the entire catch for the trip as measured at the time of landing.

The weight of the catch for logbook records was first compared with the sum of all fish ticket records for each year and regulatory area. The difference in this calculation represents catch without a corresponding logbook record ("missing logs"). The remaining weight of the retained catch for logbook records was then categorized into records currently included in assessment analyses ("used"), those that had complete records, but corresponded to gears or gear configurations not included in the standard method ("usable"), and those records that were either lacking one or more required pieces of information (e.g., the quantity of gear deployed; "unusable"), or represented targeting of mixed or non-halibut species ("mixed"). By weight, 50% of the fishing activity during the period 1991-2013 was currently being included in the standardized catch-rate calculations (Table 1, Figs.1-2). An additional 22% of the landed weight was associated with fishing activity that could potentially be standardized and included in a more sophisticated method. Less than 1% of the overall landed weight was associated with incomplete logbook records. An aggregate of 23% of the fish ticket landings did not have a corresponding logbook record. Only 5% of the landed weight was associated with fishing targeting mixed-species. These results suggested that logbooks representing 72% of the landed catch could be potentially included in the standard calculations.

Within those aggregate values, there were significantly different patterns and temporal trends for individual regulatory areas (Table 1, Fig. 2). Some notable differences among areas included: a higher rate of missing logs in Area 2A than other areas, very high levels of logbooks used and usable in Area 2B (where snap-gear is already included in the standard analysis), and an increase in recent years of mixed-species fishing in Area 3A and particularly Area 2B. There has also been a gradual increase in proportion of usable logbook records over time for all areas, reflecting the IPHC's ongoing efforts to obtain as many logbooks as possible each year (Erikson and MacTavish 2015).

In order to investigate the relative prevalence of fixed-hook, snap-gear, and autoline fishing, the "usable" category was further partitioned into these three gear types by regulatory area and year. Based on the retained weight, the majority of the catch in Areas 2A and 2B has been removed with snap-gear (Fig. 3). In Areas 2C-4CDE, the majority of the catch weight is associated with fixed-hook operations, however there has been an increase in autoline gear in several regulatory areas (3A, and 3B in particular). Increases in autoline gear in the mid-2000s in Area 4 appear to have subsequently declined. Use of snap-gear has also increased gradually over time in most regulatory areas. When evaluated based on the number of trips, rather than the landed weight, a much larger fraction of the total fishing activity is associated with snap-gear (Fig. 4). This generally indicates a lower catch per trip for this gear type, and the pattern is most pronounced for Area 4CDE.

Catch rate comparisons

The current fishery catch-rate standardization method represents a simple summation of recorded landings divided by the sum of the effort for each regulatory area and year combination (see Stewart 2015). An important component of this calculation is the derivation of the effort metric, the number of effective skates (Hamley and Skud 1978). Effort for each gear deployment is standardized to an effective skate (*ES*) that is 1,800 feet long, with 100 hooks (and therefore an 18-foot average spacing), based on the number of skates fished (*S*), the average number of hooks fished per skate (N_h), and the hook-spacing (H_s; Fig. 5). This relationship is based on the

results from field experiments reported in Hamley and Skud (1978) and corroborated by those from Leaman et al. (2012):

$$ES = S \cdot \left(\frac{N_h}{100}\right) \cdot 1.52 \cdot (1 - e^{-0.06 \cdot H_s})$$

The effective skates calculation corrects for the decrease in catch per hook as the ratio of hook- to halibut-density increases. Despite the logical theoretical basis for this relationship (particularly the statistical certainty that as the hook spacing approaches zero, the catch per hook must approach zero), the relationship is assumed to be known without error. The effects of this assumption on logbook standardization are uncertain, and were therefore worth investigating.

A second important component of the current standardization is the correction applied to snap-gear catch-rates in Areas 2A and 2B. Due to the small number of fixed-hook sets in regulatory Areas 2A and 2B, snap gear is included in the calculation for these areas. The correction consists of dividing the snap gear effort (or equivalently multiplying the catch) by a factor of 1.35 (Clark 2002), and then analyzing these records along with fixed-hook records.

The broadest comparison of the catch-rates for fixed-hook and snap-gear can be made by simply aggregating the catch and effort (applying the hook-spacing correction, but not the catch-rate correction) data for each gear by regulatory area and year. This simple approach ignores differences in the dates and locations of fishing, and therefore assumes that average catch rates are homogenous for all fishing in that stratum. Visual inspection of this summary for fixed-hook vs. snap-gear reveals that for low to moderate catch-rates the correction of 1.35 appears to be reasonable (Fig. 6). However, there is a significant amount of variability about this relationship among areas and years, and for catch-rates above approximately 200 pounds-per-skate snap-gear appears to have a lower catch rate than implied by the correction factor of 1.35. Partitioning these data by regulatory area indicates that much of the divergence in catch-rates from the expected relationship occurs in Areas 3A, 3B, and 4CDE (Fig. 7). Area 2 generally lacks observations of higher catch rates entirely, and area 4A appears to have a consistent relationship, even at higher catch-rates.

The same approach was then applied to a comparison of logbook records from fixed-hook and autoline gear. The relationship by regulatory area and year is clearly much more variable, although the correction factor of 1.35 still appears to be a reasonable proxy for the central tendency of the relationship (Fig. 8). As for the snap-gear comparison, there were important differences in the relationship among regulatory areas (Fig. 9). Specifically, fewer areas showed a consistent relationship across the full range of observed catch-rates. The largest contrasts were among Area 3B, which seemed to closely track the correction factor applied to snap-gear, and Area 2C, where there appeared to be no clear relationship between fixed-hook and autoline catch-rates.

A considerable amount of visual analysis of the historical patterns in the geographic distribution of catch rates and gear deployed was undertaken in order to better understand the aggregate comparison of catch-rates among gears. Much of this work cannot be reported due to the confidential nature of specific fishing locations. However, some of the salient patterns can be summarized. For some regulatory areas, there were important geographic differences in the spatial distribution of fishing activity for each of the gear types. These differences became particularly pronounced in Alaskan waters before and after the adoption of the quota program, which converted the fishery from an increasingly shorter and shorter derby fishery to a much longer season. As

might be expected, the fishery adjusted by moving to a much broader spatial footprint after the quota system was put into place, and many of the areas into which this expansion was made were closer to shore and produced lower average catch-rats than some of the traditional offshore fishing areas that had produced the highest catch-rates during the derby fisheries. Much of the expansion into areas closer to shore represented snap-gear fishing. The pattern of relatively higher proportions of snap-gear fishing can be seen in the geographically binned proportion of gear deployments pooled among all years from 1991-2013 (Fig. 10). This type of spatial pattern means that the naïve comparisons of catch-rates within year and regulatory area are confounded with spatial differences in fishing, and therefore warrant further attention in both modelling and subsequent interpretation.

The next comparison among the gear types was a direct evaluation of the catch-rates observed from 1991-2013. Because fixed-hook and snap-gear represent the majority of the fishing activity both by weight and number of trips, these two were compared first. Catch-rates were standardized by applying the effective skate calculation (but not the catch correction of 1.35), and summarized by regulatory area and year. The results indicate similar trends across all regulatory areas (Fig. 11). Also evident are clear differences in scale between snap-gear catch-rates (lower) and fixed-hook catch rates (higher) for all areas. Somewhat shallower declines can be seen in some regulatory areas for the snap-gear catch-rates, for example in Area 3B, the catch-rates are similar at the end of the time-series, but fixed-hook rates are much higher at the beginning of the time-series. This may be a function of the different spatial distribution of fishing activity, as there is again no correction made for that factor.

Autoline gear was then summarized in the same manner and compared with snap-gear and fixed-hook catch-rates. It was quite evident, that the relatively small sample sizes available for autoline gear (and perhaps greater uncertainty in the standardization of the fishing effort) resulted in much higher interannual variability in catch-rates for that gear type (Fig. 12). Where sample sizes were larger, absolute catch rates as well as trends tended to track either the fixed-hook rates (Area 3A), the snap-gear rates (Area 3B), or an intermediate of the two.

When the catch correction of 1.35 is applied to both the snap-gear and autoline records, there is a small improvement in the consistency of the scale of the three sets of catch-rates, particularly for Area 3B (Fig. 13). However, the application of this correction for autoline records is not based on quantitative analysis of the data. Therefore, direct estimation of the corrections among the gear types by regulatory area was investigated further (see below).

Effective skate modelling

Although the logbook records do not represent a controlled experiment directly testing the effects of hook spacing (as was used to derive the currently assumed function) they can be used to explore this relationship. There are a range of different gear configurations that have been employed within the fishery, and for both fixed-hook and snap-gear a distribution of hook spacing within the gear type (Fig. 14). This contrast should provide the ability to estimate the hook spacing relationship directly in the context of catch rates calculated on a per-hook basis rather than per effective skate.

To perform this analysis without pre-specifying the shape of the hook spacing relationship a flexible parameterization is required. The approach was therefore implemented in the software package R, using the gamlss package which implements a General Additive Model (GAM) framework. This package provides a cubic spline (*cs*) smoother that was used to model the

relationship between hook-spacing (*hs*) and catch-per hook. Initial data exploration revealed that a catch per hook (*cph*) transformation of $y^{1/4}$ stabilized the variance in the data and provided better consistency with the assumed error distribution. Additional variables included: year (*y*), gear (*g*), statistical area (*sa*), month (*m*), hook size (*s*), and depth (*d*; also fit via a cubic spline smoother). The linear model was then fitted to data within each regulatory area sequentially in order to investigate the empirical relationship in the logbook data for a hook spacing effect and the shape of that relationship:

$$cph^{1/4} \sim y + g + sa + m + s + cs(d) + cs(hs)$$

In a statistical model of this sort the partial relationships for individual covariates do not have a meaningful scale, and can be confounded with other variables. However, the shape of the response based on the partial relationships estimated in the GAM model indicated a clear decline in catch per hook at lower values of hook spacing, as well as evidence for an asymptote (an upper limit to the catch rate per hook) at very large hook spacing in some regulatory areas (Fig. 15). These estimated relationships generally corroborate the shape of the curve derived by Hamley and Skud (1978). The partial relationship with depth was roughly linear (but small) in all regulatory areas, suggesting slightly higher catch-rates at deeper depths fished.

Further analysis was performed using the original hook-spacing experimental data (Hamley and Skud 1978), and it will be presented in a future document. Although not complete, the results of that analysis also generally indicated consistency with the existing assumed effective skate calculation.

Comparison of methods

The final modelling effort conducted as part of this analysis was aimed at comparing a fully integrated statistically standardized estimate of catch rate using all data possible with the results currently included in the stock assessment. Although the GAM models were useful for investigating the hook-spacing relationship they are likely not ideal for use in routine standardization of catch-rates. Therefore, based on the results from the hook spacing investigation, a simpler linear model was fit to the catch per unit effort (*cpue*; catch per effective skate, *es*) directly, also including effective skates as an explicit covariate. This model was also fit to the data from each regulatory area separately:

$$cpue^{1/4} \sim y + g + sa + m + s + d + es$$

After fitting, the model predictions were back-transformed and the covariates standardized to the first level of each categorical variable, to a fixed-hook prediction, and for a hook spacing of 18 feet. It is therefore expected that there would be some scale differences between these back-transformed predictions and the values used in standard stock assessment analyses, however the trends should be directly comparable.

The trends estimated by the linear model were similar to those calculated by traditional methods (Fig. 16). Differences in the absolute scale of the estimates in some regulatory areas are not meaningful for the stock assessment, where the catchability coefficient is estimated. This means that the relative trend is the salient result, and for all regulatory areas (as well as the geographically weighted total) the trends result in consistent inference about how recent catch rates have changed

over time. These results are encouraging, however further work could be done to better investigate the most robust method for model-based catch-rate standardization.

Discussion

Very few outliers and missing values were discovered in the exploration of the IPHC's logbook information. The completeness of the records is a testament to the meticulous care taken by the IPHC's port sampling staff in collecting logbooks, and to the considerable effort made by fishermen to fully and accurately document their fishing. This dataset represents a valuable resource linking the current fishery with historical time-periods (Stewart 2014, 2015) during which there was no comprehensive setline survey or other fishery-independent source of population trend information. As such, continued comprehensive data collection and processing on an annual basis should remain a priority.

This analysis represents only a preliminary investigation of the logbook data and potential methods that could ultimately produce a more comprehensive analysis. The tools developed can be easily updated to repeat this work in the future, thereby allowing for ongoing monitoring of trends in the fishery and catch-rates. Further work on mapping of aggregate catch-rate information such that confidential fishing information and locations are not compromised, but spatial patterns in the fishery can still be evaluated, can be done. Explicit modelling of smaller geographic areas than the current statistical areas may provide a better calibration among fixed-hook, snap-gear, and autoline catch-rates. This would also remove much of the confounding between gear type and catch-rates, which appear to be lower on average in the inshore waters. However, this would come at the expense of substantial modelling complexity, such that it may not be appropriate for routine standardization calculations.

Several other aspects of the data are relevant to recent discussions, and questions that have been raised during the IPHC's annual process. The magnitude of fishing activity and the spatial distribution of autoline gear does not currently suggest that its exclusion from standard calculations is problematic, but, this should be reevaluated in the future as its use in the fishery and among geographic areas may change over time. If trends in mixed-species fishing continue in Area 2B, it is possible that standardization of catch-rates could become problematic. Currently, two-thirds of the catch weight in Area 2B is included in the standard catch-rate approach; however, the proportion of mixed-species fishing has increased rapidly since the management integration of the line fisheries in that area. Periodic re-investigation of the fraction of trips included in catch-rate analysis should be considered for this area particularly.

The need to standardize fishery catch-rate data is widely understood, and methods have evolved substantially over the last several decades. However, there is a benefit to using simple summary statistics and methods, rather than complex statistical models, as the former may more closely respond to the direct observations made by participants in the fishery and may therefore be more easily interpreted. Ideally, both methods provide similar results, and identification of differences can be used as a tool to improve understanding of the underlying dynamics. In the case of Pacific halibut, both summary and model-based trends produced results that are similar in relative trend, and therefore likely to have a similar effect on the stock assessment and other analyses using this information. There are a number of additional analyses that could be conducted to further our understanding of these data and the halibut stock, and they are outlined below.

Future research

Although the results of this study suggest current inference about catch-rates is reasonable, the logbook records represent a valuable source of information that could be better analyzed and understood. There are several promising avenues for future research:

1) Development of models accounting for spatial differences in fishing activity by gear type that are confounded with observed differences in catch rates.
2) Further investigation into the contribution to trend and uncertainty estimates of the historical hook-spacing correction vs. the GAM approach to deriving the relationship directly from the logbook records themselves.
3) A reanalysis of the original Hamley and Skud (1978) data using modern statistical techniques, potentially including random effects to account for unbalanced and non-independent sampling. This work is ongoing by the authors.
4) Continued discussion and analysis of the relative benefits of using a simple approach to fishery catch-rate standardization vs. model-based approaches that may be harder to interpret in a management context.
5) Comparative investigation of snap-gear and fixed-hook catch rates, in small geographic and temporal strata as a supplement to future evaluation of snap-gear as a potential sampling gear for use in the IPHC's annual setline survey.

Acknowledgements

We thank the Pacific halibut fishery for the decades of meticulous logbook recording of fishing activity and the cooperation with IPHC port samplers in making this information available for analysis. The entire port sampling and data-entry program have contributed to the objectives and execution of this project, including many long discussions of the non-intuitive details in the data and processing. Heather Gilroy, Tom Kong, Kirsten MacTavish, Lara Erikson, and Afshin Taheri all contributed directly to this analysis.

References

Clark, W. G. 2002. Comparison of fixed-hook and snap-hook CPUE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001: 191-196.

Erikson, L. M. and MacTavish, K. A. 2015. Commercial catch sampling. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 65-78.

Hamley, J. M. and Skud, B. E. 1978. Factors affecting longline catch and effort: II Hook-spacing. Int. Pac. Halibut Comm. Sci. Rep. No. 62.

Kong, T. M., Gilroy, H. L., and Leickly, R. C. 2004. Definition of IPHC statistical areas. Int. Pac. Halibut Comm. Tech. Rep. No. 49.

Leaman, B. M., Kaimmer, S. M., and Webster, R. A. 2012. Circle hook size and spacing effects on the catch of Pacific halibut. Bull. Mar. Sci. 88:547-557.

Stewart, I. J. 2015. Overview of data sources for the Pacific halibut stock assessment and related analyses. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 87-160.

Table 1. Proportions of the total landed weight categorized by status: "used" represents logs used in the current calculation of fishery catch-rate, "usable" includes complete records representing gear types (autoline in all areas, snap in 3A-4CDE) or configurations (<4' spacing) not included in current calculations, "unusable" represents logs with one or more key pieces of information missing, "mixed" indicates log weight associated with sets of mixed-species targeting (i.e., not just halibut), and "missing logs" includes landed weight not associated with a logbook record currently in the IPHC's database.

	Regulatory area								
Status	2A	2B	2C	3A	3B	4A	4B	4CDE	All
Used	42%	83%	36%	42%	48%	48%	46%	48%	50%
Usable	0%	1%	24%	29%	28%	27%	17%	15%	22%
Unusable	2%	1%	0%	0%	0%	0%	0%	0%	0%
Mixed	2%	6%	3%	7%	2%	2%	5%	1%	5%
Missing	53%	8%	37%	21%	22%	22%	32%	37%	23%

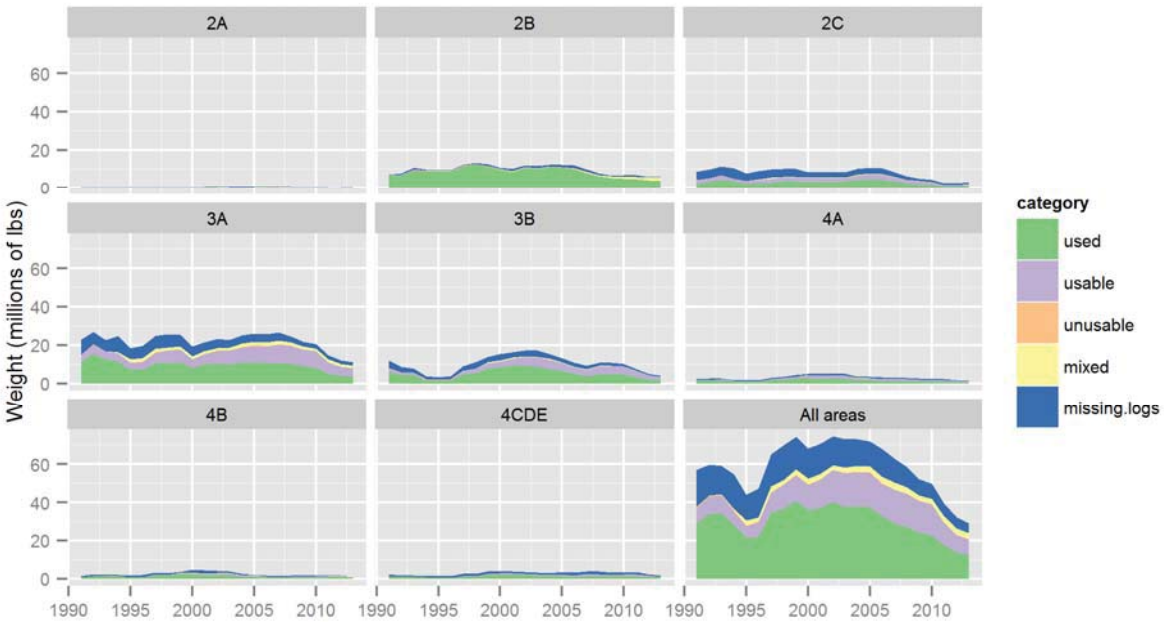


Figure 1. Total landed weight categorized by status: "used" represents logs used in the current calculation of fishery catch-rate, "usable" includes complete records representing gear types (autoline in all areas, snap in 3A-4CDE) or configurations (<4' spacing) not included in current calculations, "unusable" represents logs with one or more key pieces of information missing, "mixed" indicates log weight associated with sets of mixed-species targeting (i.e., not just halibut), and "missing logs" includes landed weight not associated with a logbook record currently in the IPHC's database.

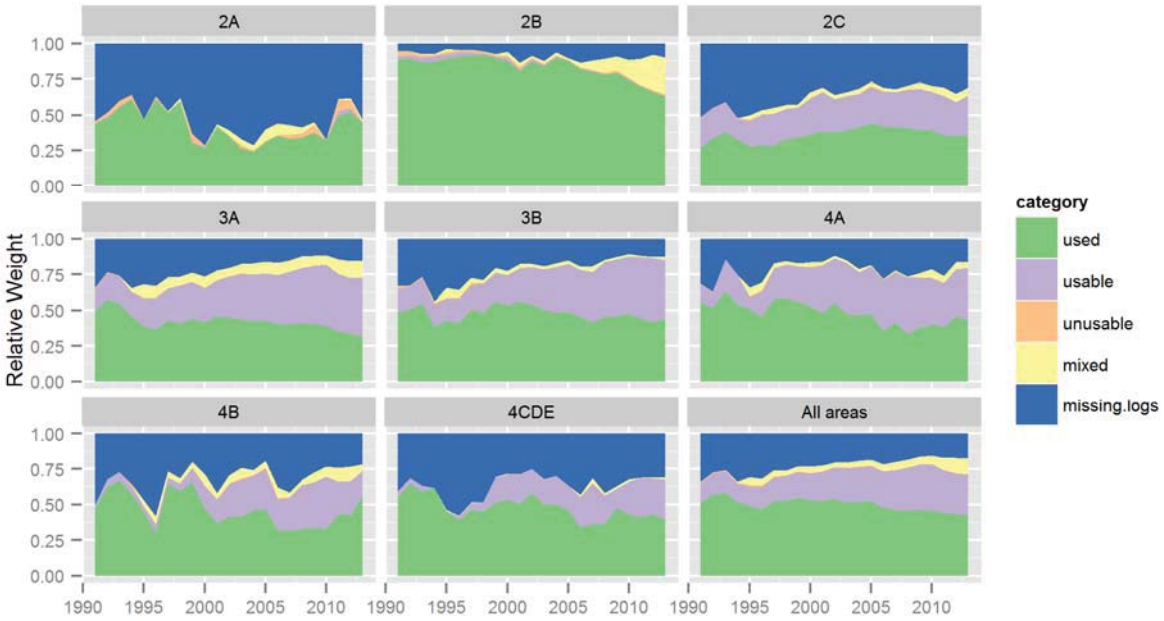


Figure 2. Proportions of the total landed weight categorized by status: "used" represents logs used in the current calculation of fishery catch-rate, "usable" includes complete records representing gear types (autoline in all areas, snap in 3A-4CDE) or configurations (<4' spacing) not included in current calculations, "unusable" represents logs with one or more key pieces of information missing, "mixed" indicates log weight associated with sets of mixed-species targeting (i.e., not just halibut), and "missing logs" includes landed weight not associated with a logbook record currently in the IPHC's database.

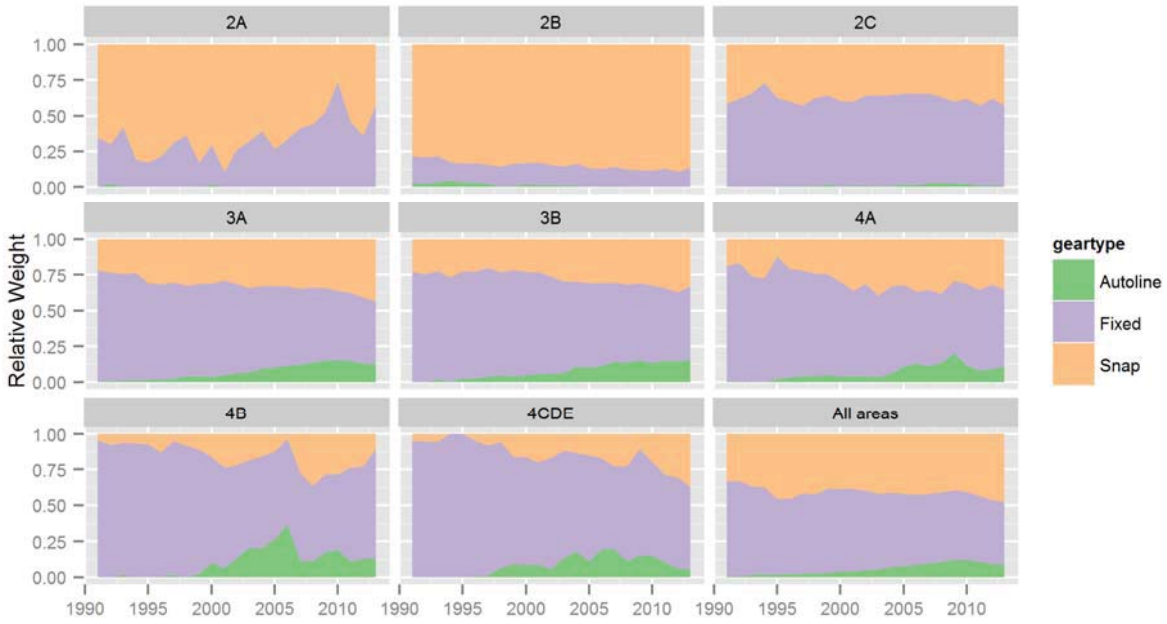


Figure 3. Proportions of the total landed weight associated with logbook records by gear type.

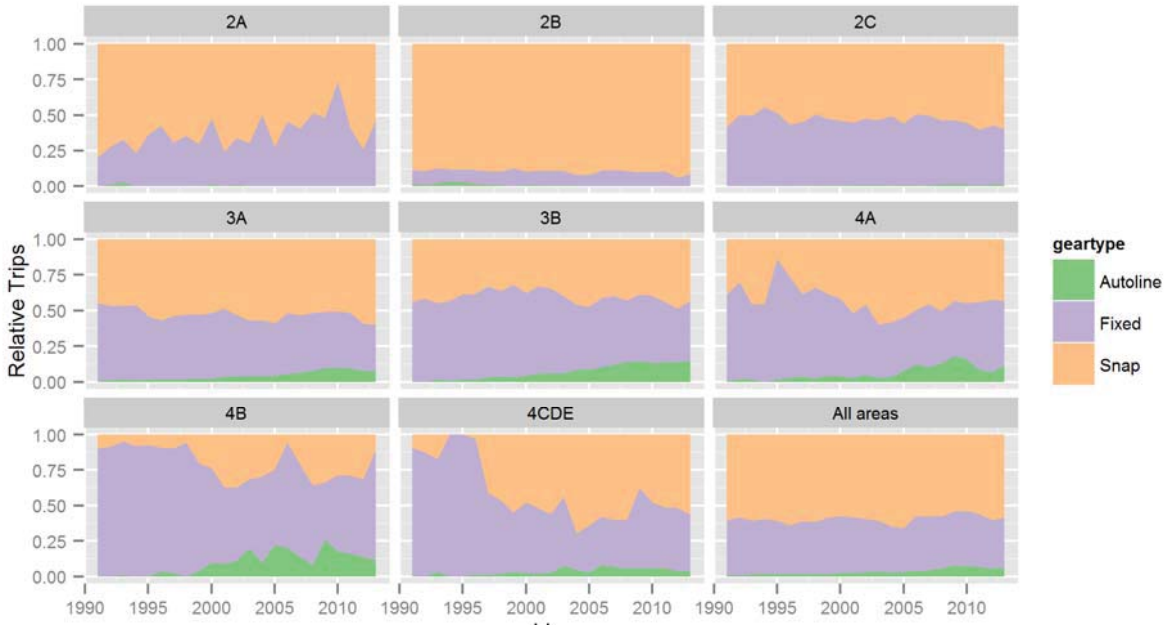


Figure 4. Proportions of the total number of halibut fishing trips associated with logbook records by gear type.

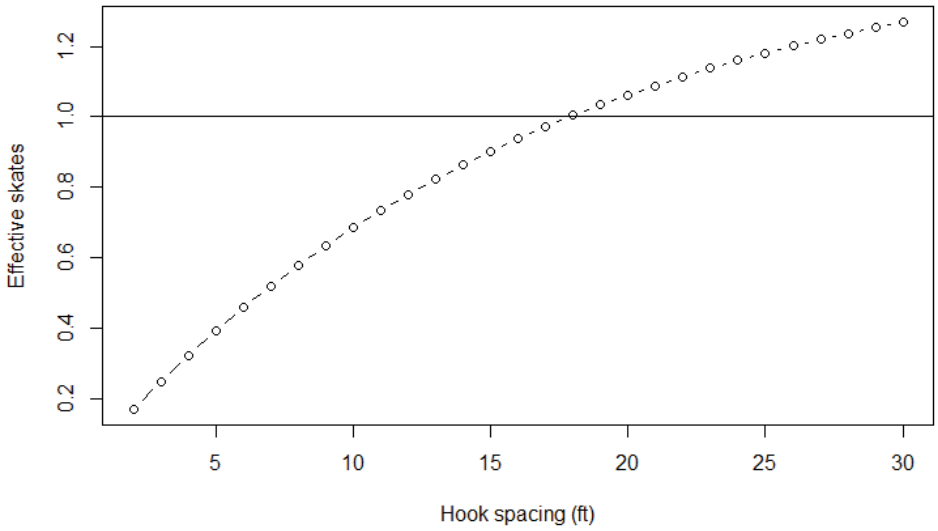


Figure 5. Relationship between hook spacing and the number of effective skates applied to both the setline survey and commercial fishery WPUE calculations (Stewart 2015, relationship originally from: Hamley and Skud 1978).

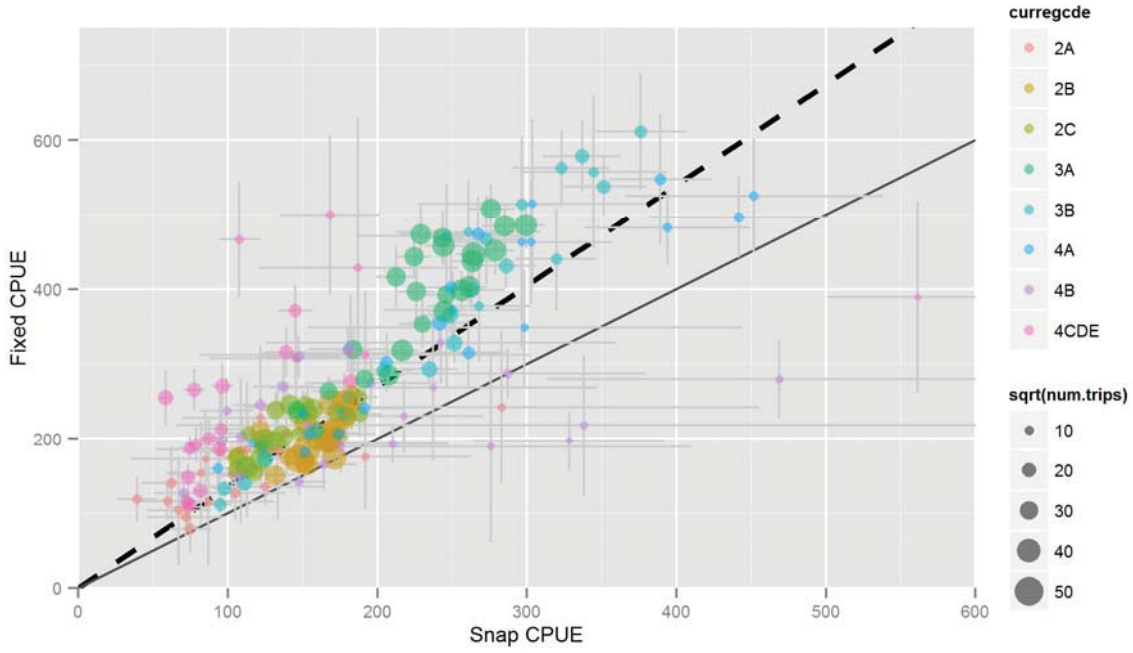


Figure 6. Scatterplot showing the relationship between fixed-hook and snap-gear catch-rates. Each point is a year/area combination. The thick dashed line denotes the current correction factor used in 2A and 2B, and the thin solid line the 1:1 line. Naive error bars are shown for both x and y-values.

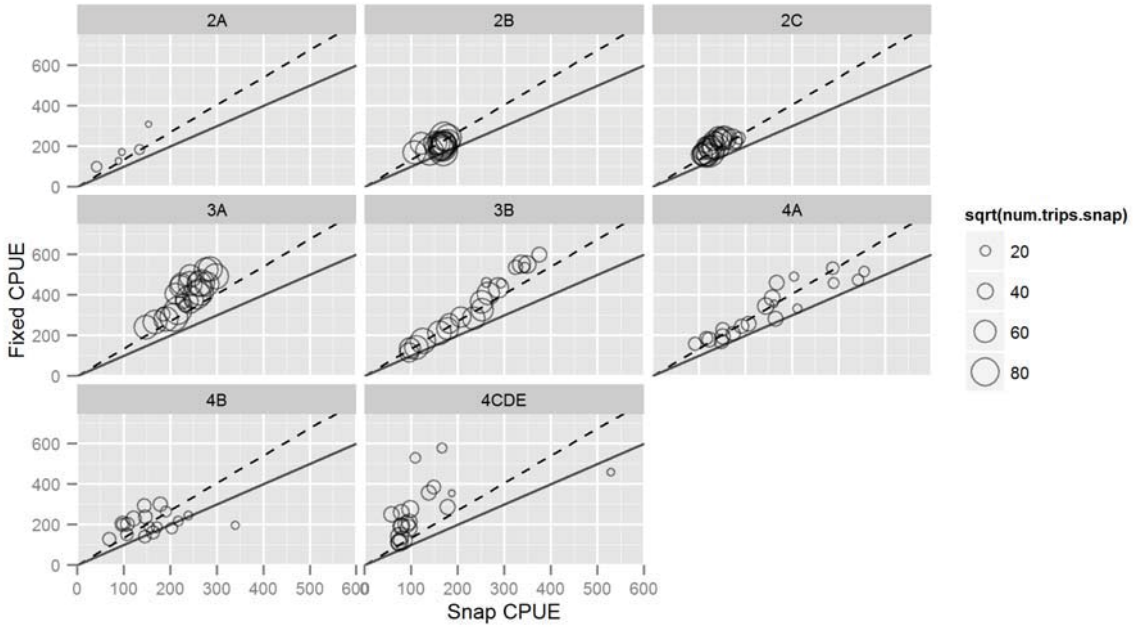


Figure 7. Scatterplot showing the relationship between fixed-hook and snap-gear catch-rates. Each point is a year/area combination. The thick dashed line denotes the current correction factor used in 2A and 2B, and the thin solid line the 1:1 line.

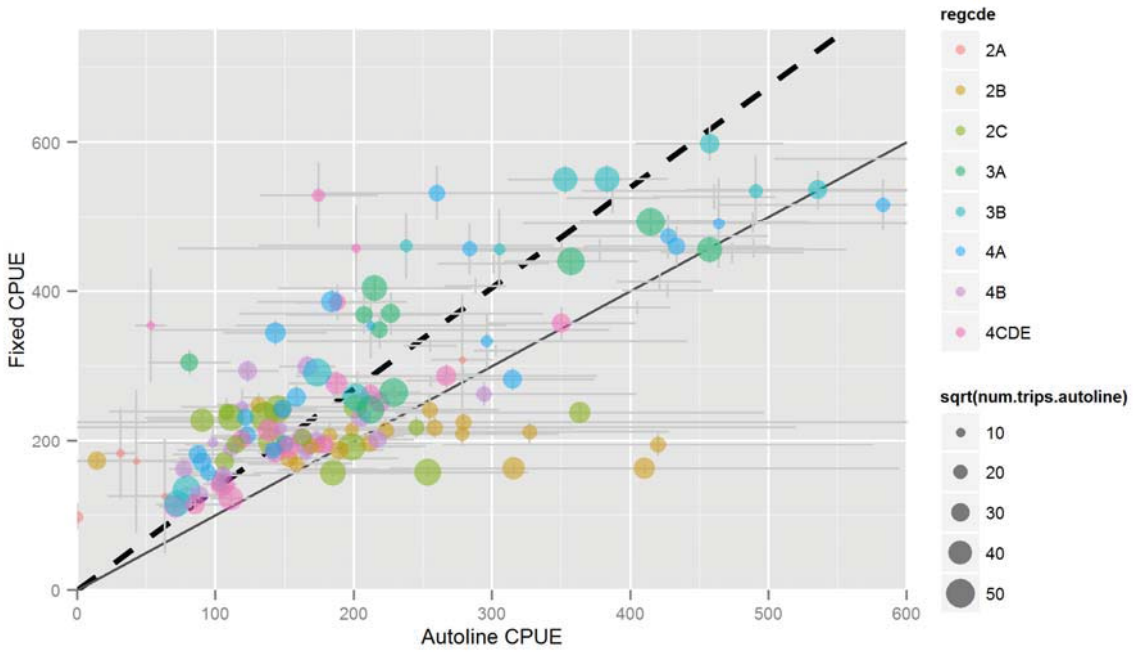


Figure 8. Scatterplot showing the relationship between fixed-hook and autoline catch-rates. Each point is a year/area combination. The thick dashed line denotes the snap-gear correction factor, and the thin solid line the 1:1 line. Naive error bars are shown for both x and y-values.

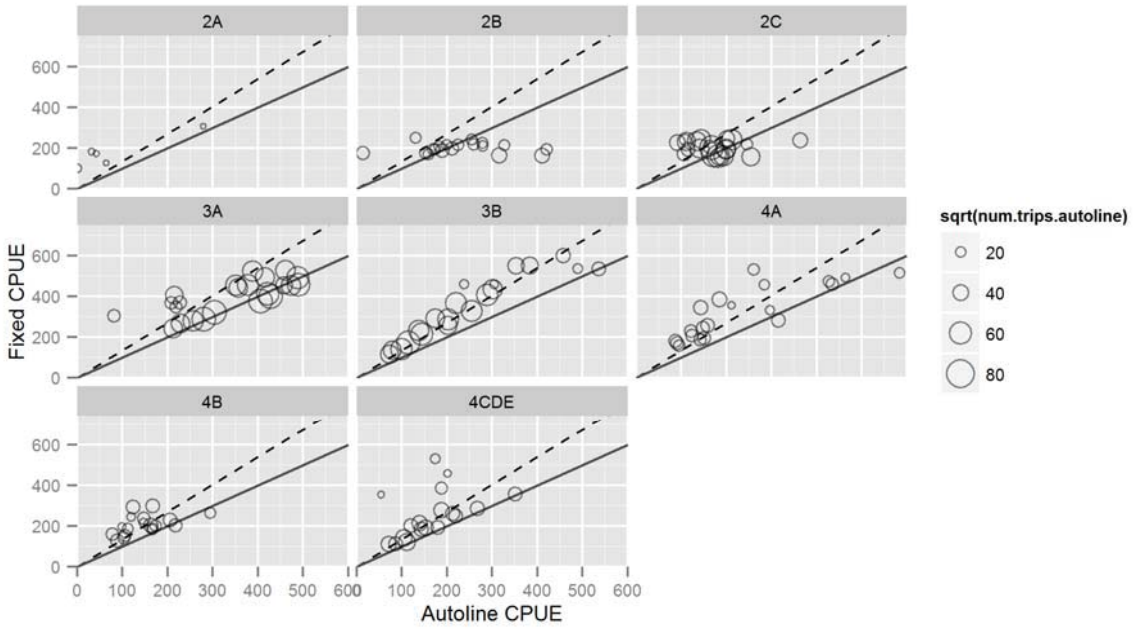


Figure 9. Scatterplot showing the relationship between fixed-hook and autoline catch-rates. Each point is a year/area combination. The thick dashed line denotes the snap-gear correction factor, and the thin solid line the 1:1 line. Naive error bars are shown for both x and y-values.

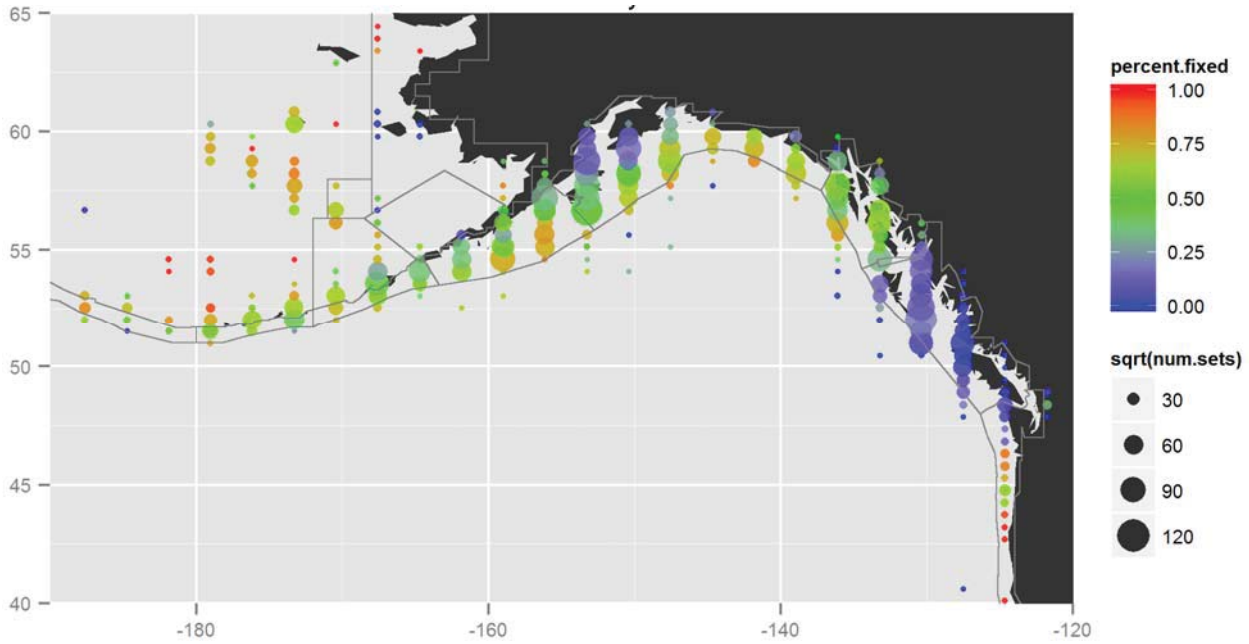


Figure 10. Map of the proportion of the catch weight represented by fixed-hook gear. Data have been geographically binned and aggregated over all years, so no specific fishing locations can be identified.

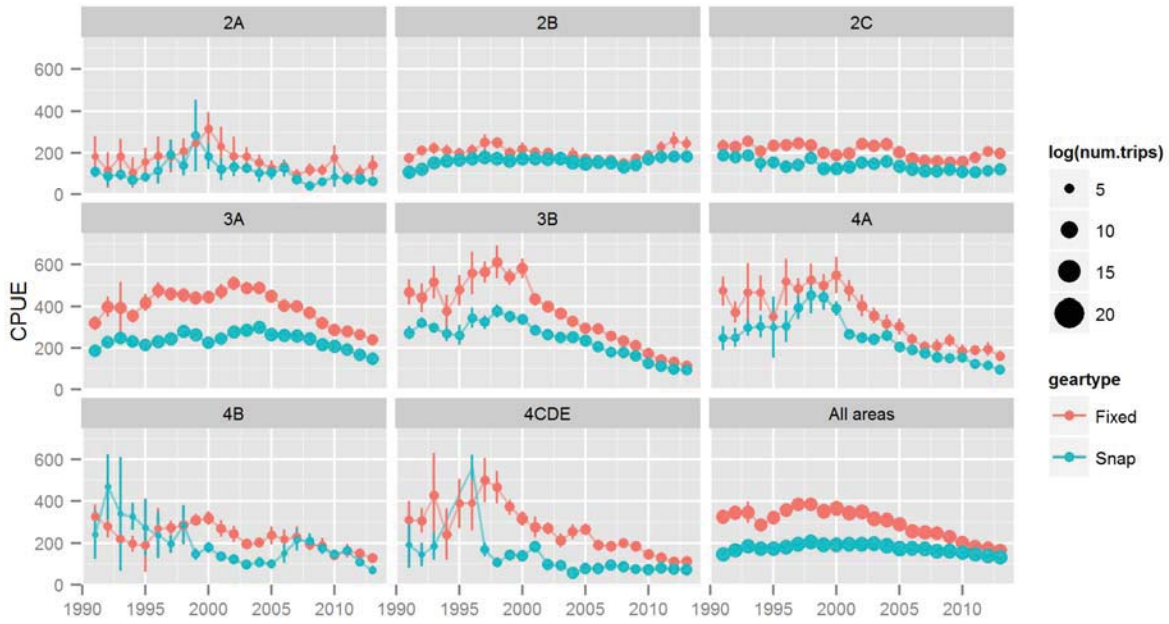


Figure 11. Comparison of raw catch-rate trends for fixed-hook and snap-gear by regulatory area.

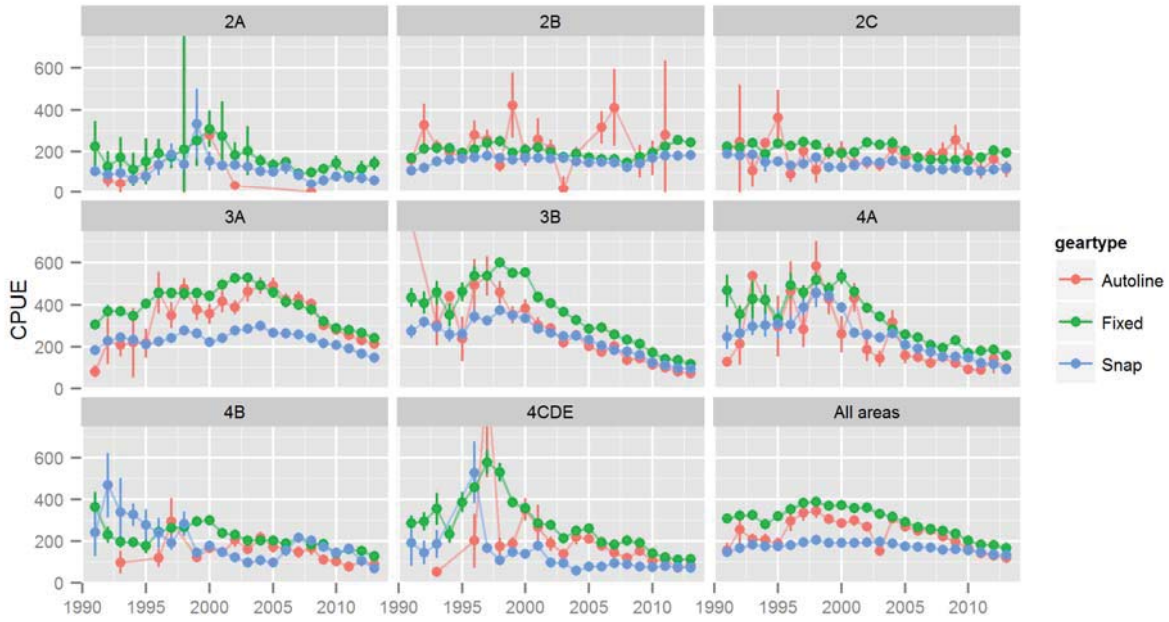


Figure 12. Comparison of raw catch-rate trends for fixed-hook, snap-gear, and autoline by regulatory area.

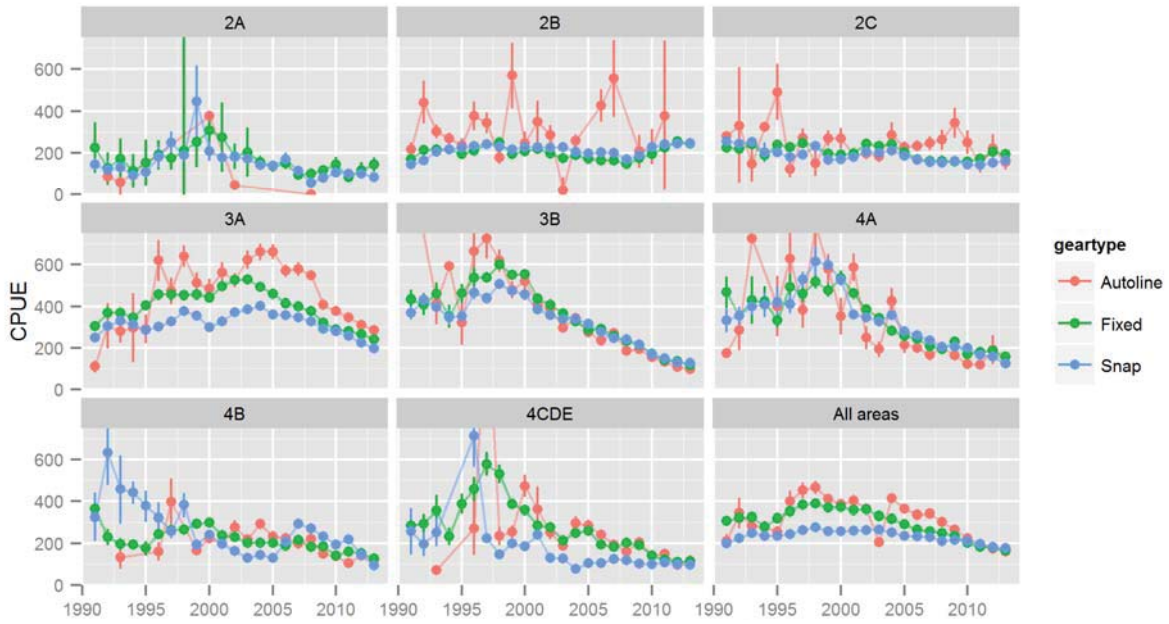


Figure 13. Comparison of catch-rate trends for fixed-hook, snap-gear, and autoline by regulatory area. Snap-gear and autoline series have been adjusted by 1.35.

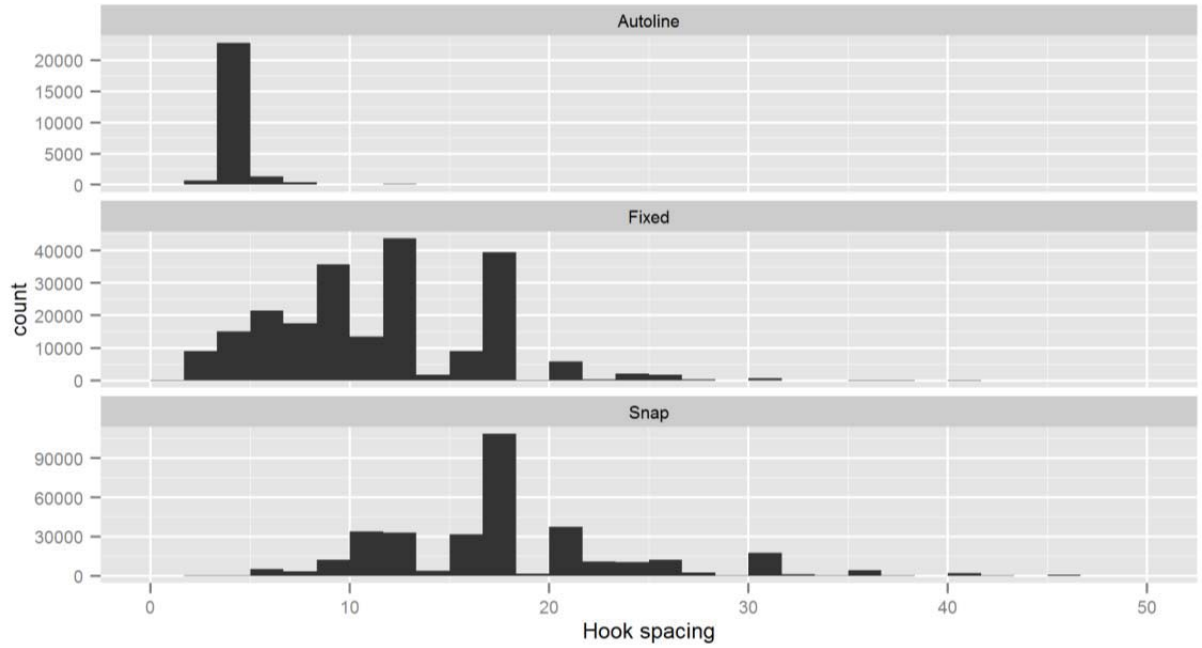


Figure 14. Distribution of hook spacing (feet) by gear type for all years combined.

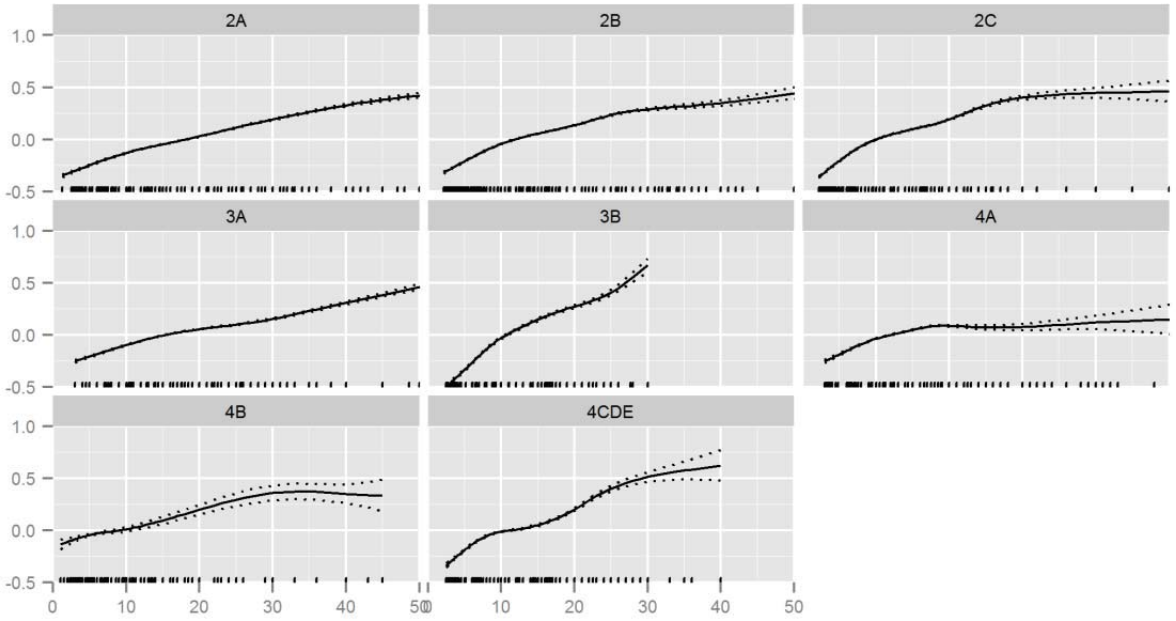


Figure 15. Partial predicted relationships (y-axis) estimated for hook spacing (x-axis, in feet) for the catch-rate model using catch-per-hook as the response variable.

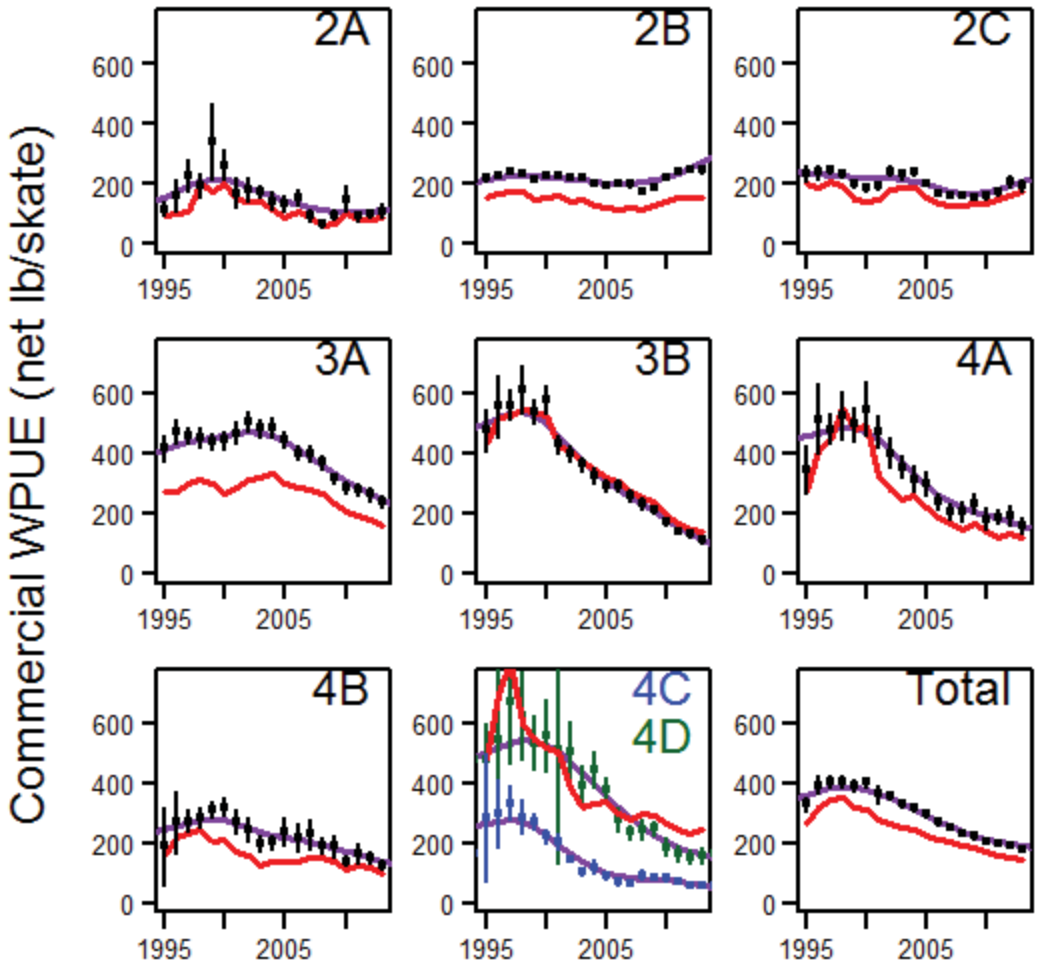


Figure 16. Comparison of catch-rate trends for the current catch-rate standardization method (points with error bars and a smoother for trend identification) and the model-based estimates using all three gear types, and hook-spacings (dark red line).

Accounting for and managing all Pacific halibut removals

Ian J. Stewart, Bruce M. Leaman, and Steven J. D. Martell

Abstract

The International Pacific Halibut Commission (IPHC or Commission) has the responsibility for conservation and yield from the Pacific halibut resource. In 2014, the Commission requested that the staff prepare a discussion paper on the biological and management issues involved with managing the removals of all sizes of Pacific halibut, particularly the explicit accounting for mortality of halibut less than 26 inches in length (U26). This report develops a conceptual extension to the current harvest policy which allows for direct evaluation of U26 mortality, and uses the 2013 results to compare harvest policy calculations with alternative distributions of removals among bycatch and the directed fishery.

Current harvest policy calculations do not respond to changes in projected annual U26 bycatch mortality; however, changes in bycatch removals (including both the O26 and U26 mortality) are found to have an approximate pound-for-pound effect on directed fishery yields when all other sources of mortality are considered. These effects are quantified and included in projection tables that summarize all sources and sizes of halibut mortality. This report outlines relevant management considerations, procedural constraints, and promising paths for future IPHC processes. Major sources of uncertainty relating to various components of these analyses are discussed, and potential data improvements that could reduce this uncertainty are also identified.

Introduction

The International Pacific Halibut Commission (IPHC or Commission) has the responsibility for conservation and yield from the Pacific halibut resource. All removals from the halibut resource are in the form of either directed (commercial, recreational, subsistence, ceremonial) or non-directed (bycatch mortality from releases of fish in non-target fisheries and incidental mortality of fish in directed fisheries that must be released by regulation, or wastage) fishing activities[1]. While mortality associated with the directed fisheries is under the management authority of the Commission, bycatch mortality is not. Rather, bycatch mortality is controlled by federal agencies of the two contracting parties (Canada and the United States).

Accounting for and managing all sizes of removals of Pacific halibut has been an increasingly important topic of discussion over the last decade, as directed fishery removals have been reduced, and non-directed removals have become relatively more important to both biological and fishery objectives. In recent years, mortality associated with bycatch in non-target fisheries as well as wastage in the commercial halibut fishery has comprised more than than 20% of the total removals (by weight) from the coastwide stock. In the Bering Sea and Aleutian Islands (BSAI), bycatch represents a much larger proportion: in Area 4CDE in 2013, 66% of the total removals were bycatch. The biological characteristics of these removals differ importantly from directed fishery

[1] This report uses the terms "removals" and "mortality" interchangeably to refer to dead fish. Further, all reference to bycatch and wastage indicates only the portion of those fish that subsequently die and, unless stated specifically, does not include fish that have been handled and subsequently survived.

landings: bycatch and wastage are predominantly comprised of fish less than 32 inches in length (U32) and, for bycatch, many are less than 26 inches in length (U26). This means that an equal weight of removals from bycatch or wastage will correspond to a much larger number of fish than in the directed commercial fishery. Commission staff have produced several analyses of the potential lost yield associated with mortality of U32 and U26 halibut, as well as the implications for equilibrium stock levels. However, previous analyses have not been framed in terms of application of the harvest policy and calculation of annual catch limits.

The IPHC's annual stock assessment, utilizing an ensemble of coastwide population dynamics models, includes complete accounting of estimated removals of all sizes of fish from the halibut stock. The results from the stock assessment have been summarized, since 2013, in a decision table evaluating the trade-off between potential benefits, in the form of fishery removals, and risks to the future stock and fisheries. An important reference component of the annual decision table is the Blue Line, or the mortality associated with the application of the IPHC's current harvest policy. The current harvest policy provides direct area-specific accounting for all removals of fish greater than 26 inches in length (O26). This has been the case since 2011, when the policy was extended from previous calculations that explicitly considered only O32 removals. In the current harvest policy mortality of U26 halibut is implicitly assumed to be present at a constant rate, which is included in the target harvest rates: the target harvest rates are lower than they would be in the absence of U26 mortality. However, U26 mortality is not included in the quantitative evaluation of annual catch limits and there has been no way to directly compare these removals with those of O26 fish. This means that the potential effects of changes in annual U26 mortality are not directly evaluated in the IPHC's annual process, and are only observed years later when they have been fully realized in the stock dynamics and are reflected in the assessment estimates of stock size and productivity. This system of accounting has not provided a clear understanding of the effects of U26 mortality to decision makers and resource users.

At its 2014 Annual Meeting, the Commission considered recent progress by its Halibut Bycatch Work Group. In particular, the Commission evaluated issues associated with levels of bycatch mortality and their impact on halibut population dynamics and yield, based on current understanding of the stock. As a result of its deliberations, the Commission requested that the staff prepare a discussion paper on the biological and management issues involved with managing the mortality of all sizes of Pacific halibut. The essence of this request is to bring the accounting for mortality of U26 fish into the same framework as that for mortality of O26 fish.

Subsequent to this direction to staff from the Commission, the North Pacific Fishery Management Council (NPFMC) began consideration of its management program for bycatch mortality of halibut in the Bering Sea/Aleutian Islands (BSAI) region. The NPFMC transmitted to the Commission a request for a summary of the status of the halibut stock and an estimate of the impacts of halibut bycatch mortality in the BSAI area on the halibut resource and its fisheries. IPHC staff had previously conducted similar analyses for the BSAI and the Gulf of Alaska (GOA) regions (Hare et al. 2012, Hare and Williams 2013). In particular, Hare et al. (2012) examined the issue of total mortality impacts on halibut stock management in a more restricted framework, involving maintenance of existing protections for stock spawning biomass afforded by the IPHC harvest policy.

The IPHC staff took the opportunity presented by the Commission request and the 2014 NPFMC request to begin development of a new total mortality accounting framework. This report extends the material prepared for the North Pacific Fishery Management Council (NPFMC or

Council), and presented at its June, 2014 meeting in Nome, Alaska (Stewart et al. 2014). That document considered specifically: 1) the status of the Pacific halibut (*Hippoglossus stenolepis*) resource in the Bering Sea and Aleutian Islands (BSAI), and 2) the impact of Prohibited Species Catch (PSC, or bycatch) in the BSAI trawl and fixed-gear groundfish fisheries on halibut stock biomass, reproductive potential, and the short- and long-term yields to the directed halibut fisheries.

This report develops a conceptual extension to the current harvest policy which allows for direct evaluation of U26 mortality impacts in the context of standard harvest policy results. It uses the 2013 results for comparison of alternative distributions of removals for bycatch and the directed fishery. It also outlines potential management considerations, procedural constraints, and promising paths for future IPHC processes. Major sources of uncertainty relating to various components of these analyses are discussed, and potential data improvements that could reduce this uncertainty are identified. Updated information following the framework presented here will be provided for the IPHC Commissioners and stakeholders consideration during the 2014 annual process.

History of IPHC management

The IPHC has managed the directed commercial halibut fishery since its inception in 1923. In the early decades, management focused on fishing gear and effort rather than total fishery removals. In 1940, a five pound minimum size limit (net weight) was instituted, and this was converted into a (nearly equivalent) 26-inch minimum size limit in 1944. In 1963, this size limit was extended to the Bering Sea. In 1973, a 32-inch minimum size limit was adopted for all existing commercial halibut fisheries, which included directed longline as well as an incidental troll fishery (Myre, 1973). This management action occurred at a time when size-at-age was very large, and therefore fish grew beyond the legal size limit much more rapidly than in either earlier or later periods. With the change in the minimum size limit came increased and appreciable fishery wastage, mortality associated with released fish that could not be legally landed.

Pacific halibut are caught in several directed fisheries including commercial longline, personal use and subsistence, and sport fisheries. Regulations of the IPHC prohibit United States fishermen from retaining halibut captured with gear other than hook and line. Similar IPHC and Canadian regulations apply in Canada with the exception that allows fishers licensed to catch sablefish in waters off British Columbia, using sablefish trap gear, to retain halibut under the quota share program up to bycatch limits as defined by Canadian regulations. The allowance of sablefish trap gear is part of an integrated groundfish fishery plan where most species are under individual quota shares and fishers are responsible for the mortality of these species, regardless of whether they are retained or discarded. Regulations in both countries are designed to prevent fisheries other than the directed halibut fishery, or those other hook and line fisheries permitted under regulation, from targeting fishing effort toward halibut. However, halibut are often caught incidentally in other fisheries, and released fish may not survive injuries received during capture. Thus, the incidental catch (bycatch) represents an important source of mortality, and resulting yield losses to the directed fisheries may be substantial.

The IPHC relies largely on information collected by other agencies as the source of bycatch amounts. The most reliable information on incidental catch is from on-board observers. However, observer programs are expensive to implement in a comprehensive manner. Observations on bycatch in BSAI fisheries are among the more extensive for fisheries in Alaska, but those in

the Gulf of Alaska (GOA), although improving, are among the least extensive. The trawl and hook-and-line fisheries in British Columbia operate under a fully integrated system using video monitoring, onboard observers, and port-based sampling to ensure that individual vessel quotas are effective. In Area 2A, the groundfish trawl fisheries have operated with 100% observer coverage and individual bycatch quotas since 2011.

Total halibut removals ranged from 64 to 85 million pounds net weight (Mlb; note that the IPHC uses net weight for all calculations, this dressed, head-off weight is approximately 75% of the round weight) during the 1960s, with bycatch mortality estimated to have ranged from a high of 21 Mlb in 1965 decreasing to a low of 15 Mlb in 1969. Total removals subsequently declined, primarily due to the reduced quotas allowed by IPHC, which was in response to a decline in the abundance of halibut. However, incidental mortality remained high due to a lack of regulation and became an increasingly larger share of the total removals through the 1970s.

Halibut abundance stabilized during the mid-1970s and total removals from the resource ranged from 34 to 43 Mlb during 1974 to 1982. Bycatch mortality declined to a low of 12 Mlb, but increased to 19 Mlb in 1980, partly as a result of increased foreign fishing effort. Bycatch mortality declined as foreign fisheries operating off Alaska were curtailed and were eliminated in the GOA in 1986. However, joint-venture fishing began in the late 1970s and expanded sharply in the early 1980s, as foreign fisheries were phased out. The joint-venture and subsequent domestic fisheries were not initially subject to the same bycatch restrictions as the foreign fisheries and bycatch mortality increased, peaking at 20 Mlb coastwide, and over 10 Mlb in the BSAI region in the early 1990s. Wastage in the directed commercial fishery, likely small prior to 1973, increased during the 1980s as the fisheries were restricted to shorter seasons, encouraging less efficient fishing practices and resulting in large quantities of lost gear.

Initial restrictions on bycatch mortality in the BSAI region were implemented under the auspices of the International North Pacific Fisheries Commission (INPFC) or bilateral arrangements between the U.S. and foreign fishing nations. The IPHC Bering Sea Closed Area was created by the Commission in 1967 to protect a nursery area for juvenile halibut, in response to severe declines in halibut abundance. The current Closed Area is slightly smaller than the original definition due to reductions that occurred when Area 4 was first partitioned into separate areas in 1983 (Hoag et al. 1993), and the exclusion of Bristol Bay in 1990 (Gilroy and Hoag, 1993). The Closed Area had historically accounted for a relatively small percentage (<10%) of the directed halibut landings in the Bering Sea but was a source of significant halibut mortality from foreign vessel bottom trawling. The Commission recommended the closure to both directed halibut fishing, which was under Commission jurisdiction, and to bottom trawling, which was not under Commission jurisdiction. However, through negotiations within the INPFC and bilateral agreements with foreign governments, the Closed Area was also closed to foreign bottom trawling. Throughout the late 1960s until the early 1970s, the Closed Area provided significant protection for juvenile halibut, with bycatch mortality dropping to an estimated low of 4.2 Mlb in 1985. Coincidentally, halibut abundance improved dramatically, fuelled in part by strong year classes of the mid-1970s.

As Americanization of the Bering Sea trawl fisheries occurred in the early 1980s, following promulgation of the U.S. Extended Economic Zone, the protection to juvenile halibut afforded by the Closed Area diminished as domestic fisheries were not excluded. The NPFMC implemented control measures for bycatch mortality by instituting gear and fishery-specific limits and closures within the BSAI including the Closed Area, throughout the 1980s. However, mortality on halibut in the BSAI again increased substantially in the 1985-1991 period, reaching a peak of 10.7 Mlb

in 1992. Bottom trawling within the Closed Area currently accounts for a significant proportion of the halibut mortality in the Bering Sea, and the area remains open to all fishing except directed halibut longline fishing.

As domestic groundfish fisheries developed and foreign fishing was phased out in the 1980s, federal regulations were implemented to limit bycatch of halibut so as to minimize impacts on the domestic halibut fisheries. Interception of juvenile halibut often occurs in trawl fisheries targeting other groundfish species such as rock sole, pollock, yellowfin sole, and Pacific cod. Incidental catch of halibut also occurs in groundfish hook and line and pot fisheries. Incidental 032 halibut within the longline sablefish fisheries can be retained if halibut quota share is held. In other groundfish hook and line or pot fisheries, regulations require that all halibut caught incidentally must be discarded, regardless of whether the fish is living or dead. Groundfish pot gear is exempted from halibut bycatch restrictions because the discard mortality rate and total mortality associated with this gear type is estimated to be relatively low, and existing pot gear restrictions are intended to further reduce halibut bycatch mortality. The IPHC does make estimates of this source of mortality, which are included in all analyses.

Regulations to control halibut bycatch in domestic groundfish fisheries were implemented initially as part of the BSAI groundfish Fisheries Management Plan (FMP) in 1982. These regulations reflected some of the time-area closures in effect for foreign trawl operations. Beginning in 1985, annual halibut PSC limits were implemented for the groundfish trawl fisheries, attainment of which triggered closures to bottom trawl gear. Seasonal allocations of halibut PSC limits also are authorized.

Other measures that have reduced halibut bycatch include seasonal and area allocations of groundfish quotas for selected target species, seasonal and year round area closures, gear restrictions, careful release requirements, public reporting of individual bycatch rates, and gear modifications. While the groundfish FMP's allow the NPFMC to set the season start dates to accommodate fishery interests, it has relied on the seasonal apportionments of halibut PSC limits to take advantage of seasonal differences in halibut and some groundfish fishery species distributions. Gear restrictions are specified to reduce bycatch or bycatch mortality of halibut. Restrictions include (a) requiring biodegradable panels on groundfish pots, (b) requiring halibut exclusion devices on groundfish pots, and (c) revised specifications for pelagic trawl gear that constrain the pelagic trawl fisheries for groundfish to a trawl gear configuration designed to enhance escapement of halibut.

PSC limits have been used to control the bycatch of halibut in the groundfish fisheries off Alaska since the initial groundfish FMPs were developed. PSC limits are intended to optimize total groundfish harvest, taking into consideration the anticipated amounts of incidental halibut catch in each directed fishery. They are apportioned by target fishery, gear type, and season. Essentially, these bycatch limits provide an incentive for specific fisheries to operate in times and areas where the highest volume or highest value target species may be harvested with minimal halibut bycatch. Directed fishing must stop when seasonal PSC limits are reached; all other fisheries remain unaffected. Reaching a PSC limit results in closure of an area or a groundfish directed fishery, even if some of the groundfish (particularly flatfish) total allowable catch (TAC) for that fishery remains available for harvest.

Current regulatory structure and jurisdictions

Each year the IPHC sets directed fishery catch limits (FCEYs) for each of eight major Regulatory Areas: 2A, 2B, 2C, 3A, 3B, 4A, 4B, and 4CDE. Included in those catch limits are

the directed commercial fishery landings in all regulatory areas. In Areas 2A, 2B, 2C and 3A, by Catch Sharing Plan (CSP) or regulatory authority (2B) some removals from the sport fishery, personal use and subsistence, and commercial fishery wastage are also included in the FCEY. Removals regulated independently of the IPHC's annual catch limits therefore include wastage in most areas, bycatch, non-CSP sport removals as well as all personal use and subsistence removals (except in Area 2A).

Halibut in the eastern Bering Sea, Area 4CDE (including the Closed Area), are considered to be a single unit in all IPHC analyses. However, management subareas 4C, 4D, and 4E were created to serve the needs of the NPFMC's Catch Sharing Plan (CSP). Annually, the Commission adopts the Council's CSP to determine the specific catch limits for these subareas. The percentage shares to these areas, as determined by the Council, are: Areas 4C and 4D each receive 46.43% of the Commission's adopted catch limit for Area 4CDE, and Area 4E receives 7.14%. If the total catch limit for Area 4CDE exceeds 1.6576 Mlb, Area 4E receives 0.08 Mlb off the top of the total catch limit before the percentages are applied. Within Area 4CDE, the annual available halibut yield is further allocated among CDQ and IFQ fishing within subareas. The amounts allocated to CDQ by area are: Area 4C 50%, Area 4D 30%, and Area 4E 100%. There are also provisions within the CSP allowing Area 4C CDQ and IFQ to be harvested in Area 4D, and for allowing Area 4D CDQ fish to be harvested in Area 4E. All of these allocations are outside of the Commission's jurisdiction and are governed by U.S. domestic agencies.

Incidental mortality of halibut occurs in directed halibut fisheries as a result of mortality to halibut required to be released if the fish are smaller than the IPHC minimum legal size limit (32 in). For the commercial fishery this mortality is estimated by the Commission annually. Release mortality in other directed fisheries (recreational and personal use) is estimated only for recreational fisheries in Regulatory Areas 2C and 3A. Mortality of halibut in non-target fisheries is estimated by federal regulatory agencies (the National Marine Fisheries Service, NMFS, and Fisheries and Oceans Canada, DFO) which regulate non-target bycatch mortality within the two nations. However, the regulatory structure for control of non-target bycatch mortality varies by regulatory area. Detailed presentation of the bycatch management framework in each area is contained in Karim et al. (2012) and we present only a brief synopsis of this framework here.

Regulatory Area 2A (Washington-Oregon-California)

For regulatory Area 2A, non-target bycatch mortality is under the jurisdiction of the NMFS but allocative and control measures are developed by the Pacific Fishery Management Council (PFMC). Mortality of halibut occurs in non-target trawl fisheries for groundfish, hook-and-line fisheries for groundfish and salmon, and pot fisheries for sablefish. Since 2011, the PFMC has instituted individual bycatch quotas for halibut mortality within the IFQ groundfish trawl fisheries, combined with 100% observer coverage of vessel trips. In 2013, the total mortality limit for the IFQ trawl groundfish fishery was set at 0.194 Mlb (net wt.), with over 90% of this total allocated to the groundfish trawl fishery north of 40°10' N. The actual halibut mortality in this trawl fishery has been decreasing since the imposition of individual bycatch quotas and for 2012 the mortality estimate was only 0.067 Mlb.

The hook and line fishery in Area 2A does not have 100% observer coverage and an assumed discard mortality rate (DMR) of 25% is applied to the estimated halibut releases in this fishery. For 2012, the estimated mortality in this fishery was 0.059 Mlb. There is no estimate for release mortality in the recreational fishery. Mortality in the groundfish pot fisheries is low and, using a

DMR of 18%, the estimated mortality of halibut in this fishery in 2012 was 0.001 Mlb. Halibut excluder devices have been required in all shrimp trawl fisheries since 2003 and halibut mortality has been assumed to be zero since 2012.

Regulatory Area 2B (British Columbia)

Halibut bycatch mortality in non-target fisheries in Area 2B is under the jurisdiction of the DFO, which is also responsible for allocative usage by different fishing sectors. Mortality of halibut in non-directed commercial fisheries occurs for groundfish trawl, shrimp trawl, crab pot, sablefish trap, and hook and line fisheries. Mortality of released fish also occurs in the recreational fishery, but no estimate of this mortality is available. Mortality of non-retained halibut is regulated in three ways: (i) direct monitoring of individual vessel bycatch limits in the groundfish trawl sector; (ii) direct monitoring and estimation of mortality in the hook and line (including directed halibut fishing) and sablefish trap sectors; and (iii) estimation of bycatch mortality in shrimp trawl and crab pot fisheries. Groundfish trawl, hook and line, and sablefish trap fishing is subject to 100% monitoring at sea, as well as 100% dockside monitoring.

Since 2006, the hook and line and trap sectors have been managed under a Commercial Groundfish Integration Program, wherein all vessels are responsible and accountable for their 032 halibut bycatch mortality. Vessels must obtain commercial halibut Individual Transferrable Vessel Quota (ITVQ) to cover both retained and discarded O32 halibut, and vessels are subject to trip limits and annual caps of halibut usage. The mortality of U32 fish associated with halibut landings is estimated from logbook discard records, and a 16% DMR; this mortality is covered under the commercial halibut ITVQ system through a pre-quota reduction. Mortality of U32 halibut for fishing activity that did not land halibut is currently unaccounted for.

Bycatch mortality in the Area 2B trawl sector is managed under a Halibut Bycatch Management Plan, as a component of the overall groundfish Integrated Fishery Management Plan. Provisions of the Bycatch Management Plan include: a total halibut mortality fleet limit of 1 Mlb; individual vessel mortality caps; and, the provision for bycatch ITQ transfer among vessels, subject to total vessel mortality caps. All vessels are subject 100% at sea monitoring and 100% dockside monitoring. Mortality is assessed from condition factors estimated by observers. Total estimated bycatch mortality in the Area 2B trawl sector for 2013 was 0.225 Mlb.

Bycatch mortality in the trawl fisheries for shrimp and pot fisheries for crab is based on only limited observer coverage and retention is prohibited in both fisheries. However, bycatch reduction devices have been mandatory in the shrimp trawl fishery since 2001/2002, and bycatch mortality is estimated to be zero, similar to Area 2A shrimp trawl fisheries. The characteristics of pots used in the Area 2B crab fishery provide limited opportunity for halibut bycatch. The target species is Dungeness crab (*Cancer magister*), a relatively small crab compared with king and tanner crabs targeted in Alaska, and the pots have small tunnels and mesh sizes which limit the capture of larger species. While direct observations of this fishery are limited, they indicate minimal occurrence of halibut over a decade-long record.

No estimates of total halibut discard mortality in recreational fisheries in Area 2B are available, although discards are known to occur in these fisheries. Discards within the ceremonial/subsistence fisheries by First Nations are assumed to be negligible.

Regulatory Areas 2C, 3, and 4 (Alaskan waters)

Non-target halibut bycatch mortality in IPHC Regulatory Areas 2C through 4 is under the jurisdiction of the NMFS but allocative and control measures are developed by the NPFMC. In addition, some monitoring and estimation processes are conducted by the Alaska Department of Fish and Game (ADF&G); however, the ADF&G does not have direct regulatory authority over halibut removals or allocation. Bycatch mortality of halibut in non-target fisheries occurs in groundfish trawl, groundfish fixed-gear, shrimp trawl, scallop dredge, and crab trap fisheries. Over 80% of the non-target halibut mortality occurs in the groundfish trawl fisheries; with fixed-gear groundfish fisheries creating approximately 10% of the halibut mortality.

Regulation of halibut bycatch mortality in non-target fisheries in Alaska is complex and is orchestrated by the NPFMC. The primary regulatory vehicle for halibut bycatch mortality control is through limits on Prohibited Species Catches (PSC). Subordinate to the PSC limits, are a host of regulatory processes that are designed to facilitate access to the maximum amount of available groundfish catches, while adhering to the PSC limits. These measures are detailed in Karim et al. (2012) and Williams (2014), and are only summarized here.

The BSAI halibut PSC limit is set in regulation and the GOA halibut PSC limit is set annually through the groundfish harvest specifications process; neither is tied to halibut abundance. Federal regulations also establish allocations of the BSAI halibut PSC limit between the community development quota (CDQ) and non-CDQ fisheries and a process for apportioning those limits among non-CDQ fisheries.

For 2013, the estimated bycatch mortality (in net weight) for halibut in Alaskan fisheries was: BSAI trawl 4.50 Mlb, BSAI fixed gear 0.71 Mlb, GOA trawl 1.82 Mlb, and GOA fixed gear 0.50 Mlb. These values, with the exception of GOA fixed gear were well below total PSC limits. The PSC mortality limits (in net weight) for halibut bycatch in 2013, were: 5.80 Mlb for BSAI trawl, 1.50 Mlb for BSAI fixed gear, 3.26 Mlb for GOA trawl, and 0.50 Mlb for GOA fixed gear. These PSC mortality limits are further subdivided into seasonal apportionments by species complexes and gears, in each area. The final subdivision of PSC bycatch mortality limits in Alaskan waters involves allocation by the NPFMC of specific halibut bycatch limits from the overall limits to fishery cooperatives that manage these allocations internally, to minimize bycatch and achieve maximum access to groundfish quotas. These include the Central Gulf of Alaska Rockfish Program, the Amendment 80 fishery cooperatives in the BSAI and GOA, the sideboard allocations to non-exempt American Fisheries Act vessels in the BSAI and GOA, and the 'other hook and line' allocations for fixed gear fisheries in the GOA. Groundfish pot and jig fisheries and sablefish IFQ fisheries are exempt from PSC limits. Mortality estimates from these fisheries are derived from observer estimates of discards paired with pre-season DMR estimates, which are updated every three years although data from observers are collected continuously.

Lastly, fisheries regulated by the State of Alaska in territorial waters are not subject to comprehensive monitoring of bycatch mortality. Fisheries within which bycatch occurs include: (i) beam trawling for shrimp and flounders in Area 2C; (ii) hook and line fisheries for sablefish in Area 2C; (iii) sablefish hook and line fisheries in Prince William Sound (Area 3A); and, (iv) king and tanner crab pot fisheries throughout the GOA and BSAI. Estimated bycatch in these fisheries had historically been estimated from research data but in 2012, the IPHC ceased using these out-of-date data and began to work with ADF&G to update estimates. Progress on this initiative has been limited and new estimates are not available for these fisheries.

Accounting and management in other fisheries

The IPHC's current harvest policy delineates between O26 removals, explicitly included in the annual catch limits, and U26 removals, not included in catch limit calculations (see full description of the harvest policy below). This approach is quite atypical in the context of similar fisheries in the North Pacific, and around the world. By the mid-1990s, fisheries reference points based on integrating all sources of mortality into estimates of Spawning Potential Ratio (SPR, described below) were in common use in the United States (Mace and Sissenwine 1993). Current catch limit calculations for the U.S. Pacific (http://www.pcouncil.org/) and North Pacific Council (http://www.npfmc.org/) processes generally include all sources of mortality and all sizes of fish. It is therefore often a prerequisite for calculation of directed fishery Optimal Yield (OY) or Total Allowable Catch (TAC) to make projections regarding other fisheries and the size structure of all removals (especially where it may differ from historical patterns). For example, TACs from the most recent Alaskan sablefish assessment (Hanselman et al. 2013) include all sizes of sablefish, both retained and discarded, from all of the long-line, trawl, and pot fisheries. Only research landings are excluded from the assessment analysis, and these represent less than 2% of the total. In this case, management of these removals includes separate NPFMC actions for the trawl fishery, the IFQ directed longline and pot fisheries, and the State managed fisheries.

Estimation of U26 Mortality

There are two components of U26 halibut mortality that are included in the stock assessment but not the standard harvest policy tables: directed fishery wastage and bycatch in non-target fisheries.

Wastage describes all mortality of halibut that occurs during the directed fishery, but that does not become part of the landed catch. There are three main sources of wastage: 1) fish that are estimated to have been captured by fishing gear that was subsequently lost during fishing operations, 2) fish that are discarded for regulatory reasons (e.g., the vessel's trip limit or harvester's IFQ limit have been exceeded), and 3) fish that are captured and discarded because they are below the legal size limit of 32 inches. Briefly, U26 (and all U32) halibut are assumed to be captured by the directed fishery at a rate equal to that observed by the IPHC's setline survey in each regulatory area. This rate provides an estimate of the number of halibut discarded by the fishery, to which a 16% DMR is applied for fisheries operating under a quota program, and a 25% DMR rate is applied to those operating under a derby system (currently only 2A). Lost gear is assumed to have encountered legal and sublegal halibut at the same rate as gear that was hauled in each regulatory area each year. For a full description of the methods used to estimate wastage see Gilroy and Stewart (2014).

Bycatch describes all halibut that have been captured and subsequently die during non-target fisheries (Williams 2014b). Bycatch includes trawl fisheries, hook-and-line fisheries other than halibut (e.g., Pacific cod, sablefish, rockfish), as well as pot fisheries. In order to estimate the mortality associated with these fisheries, the observer program first estimates the number of halibut discarded. For hook-and-line fisheries, a sample of the discarded fish is assessed based on the type of injury the fish have sustained due to hooking, and then these injuries are linked to estimates of discard mortality rate by injury type from previous analyses. For trawl fisheries a sample of the discarded halibut is assessed for condition, which is categorized and similarly assigned a DMR rate based on historical mark-recapture analysis. These values are then extrapolated to the discards

estimated for the entire fishery. Bycatch estimates also include halibut that are landed and, because they cannot legally be sold, are donated to food banks. This occurs primarily in Alaska through the SeaShare program (Williams 2014c), and in the shoreside hake fishery in 2A, which is required to have full retention of all catch.

Both wastage and bycatch have fluctuated over time (Stewart 2014); in recent years wastage has totaled from one to just over three Mlb (Fig. 1) with Areas 3A and 3B comprising the majority of this source of mortality. Over the same period, bycatch has totaled from just under 8 to just over 11 Mlb, with much of that total occurring in Area 4CDE (Fig. 2). To delineate this mortality (in weight) into the U26 and O26 components, length frequencies (in numbers) and the length-weight relationship are used. The fraction of the bycatch that is U26 is much higher in all regulatory areas than the fraction estimated for wastage. The highest proportion of U26 bycatch occurs in Area 4A (43%, Fig. 3) and wastage in 4CDE (11%; Fig. 4). In 2013 U26 bycatch was estimated to be 2.83 Mlb and U26 wastage was 0.12 Mlb (Webster and Stewart 2014).

These estimates of U26 and O26 wastage and bycatch are produced annually by the IPHC. They include significant uncertainty related to the data that are currently available (See section on uncertainty below). Further, recent restructured North Pacific Observer Program reports (2013 and 2014) have included different estimates of hook-and-line discards, which are difficult to compare to IPHC estimates for several reasons: 1) The IPHC reports all estimates of removals in pounds (generally millions); the observer program reports metric tons; 2) The IPHC uses net weight (head-off and gutted, approximately 75% of round weight); the observer program uses round weight; 3) The IPHC delineates discards in the directed halibut fishery (wastage) from those in non-target fisheries (bycatch); the observer program has combined these into a single hook-and-line estimate; 4) The IPHC reports both wastage and bycatch in estimated mortality; the observer program does not apply a discard mortality rate, but reports 100% of the estimated pounds discarded for all fisheries; and 5) There has been a known error in NMFS calculations where the average fish weight for the entire catch has been assigned to the number of discarded halibut (which creates a positive bias in the pounds discarded due to the minimum size limit; i.e., the discarded fish are systematically smaller than the retained fish).

Accounting

Stock distribution and apportionment

General understanding of Pacific halibut life history and distribution indicates that the bulk of the pelagic juvenile halibut occurs in the western GOA, Aleutian Islands, and southwestern Bering Sea. Densities of 1-4 year old halibut (not frequently encountered in setline surveys or the directed fishery) are typically also very high in these areas; this has been observed in trawl surveys (Sadorus and Lauth 2014, Sadorus et al. 2014, Sadorus and Palsson 2014, Sadorus and Palsson 2014b; Fig. 5), directed IPHC trawl investigations (Schmitt 1985), and in the length-frequencies of halibut captured as bycatch in various trawl fisheries operating in these areas. Although these observations allow for some insight into the average distribution of juvenile halibut (most U26 halibut are less than 6 years old), there is no single geographically comprehensive source of annual distribution information, as the GOA and Aleutian trawl surveys alternate biennially, and DFO surveys use different trawl gear and cover only two of four strata off the B.C. coast each year. In addition, juvenile halibut appear to be highly mobile, much more so than adults, so information regarding distribution would tend to be much less relevant for predictions.

The aggregate result of historical IPHC tagging programs indicates that the Bering Sea and the near Aleutian Islands are a net exporter of halibut of all sizes to all other regulatory areas. New analysis of historical tagging projects conducted by the IPHC in the BSAI is currently underway (Webster, In prep[2]). Some preliminary results of this analysis indicate that juvenile halibut tagged in the BSAI tend to remain near the area of tagging for the first year at large, but then distribute broadly to the Aleutian Islands, GOA (70-90%), and Area 2 (Fig. 6). This would imply that by the time they enter the directed fishery (and are fully selected by the setline survey) halibut spending their first few years of life in the Bering Sea could be in virtually any regulatory area. A very similar pattern of dispersal was observed for juvenile halibut tagged near Unalaska (Figs. 7, 8). At present it is not possible to correct for the spatial distribution of fishing effort in these data, which may lead to an overestimate of movement rates to areas (like the GOA) with more fishing activity.

Larger halibut are also estimated to move among regulatory areas, with the net result that regulatory Area 2 tends to benefit from immigration, while Area 4 has a net emigration (Valero and Webster 2012; Table 14, Webster et al. 2013). The observed distribution of the stock available to the directed fisheries in each year will reflect not only the historical fishing effort in each regulatory area, but also the interaction of recruitment distribution and movement rates over the 6-10 years that these fish have been alive.

Apportionment, a key input to the harvest policy and catch-limit calculations, uses the distribution of observed O32 halibut catch rates in the setline survey (Soderlund et al. 2012, Henry et al. 2014, Webster 2014) to infer the distribution of the stock. This process is similar to how survey estimates are used by other agencies in the north Pacific and around the world. Survey estimates reflect the relative catch rate in each area multiplied by the total available habitat occurring in depths of 0-400 fathoms. Apportionment calculations take into account the timing of fishery removals relative to the annual survey, as well as competition among halibut (of all sizes) and other species for the finite number of hooks deployed. These calculations are also smoothed, using the most recent three years to dampen the effects of sampling variability on stock distribution estimates (Webster and Stewart 2014).

Apportionment thus provides a 'snapshot' of how the halibut stock is distributed in each year, and this relative distribution has changed over time, with the Central and Western GOA (Areas 3A and 3B) representing less of the total stock over time, and Area 2 relatively more (Webster and Stewart, 2014). Calculations in 2013 resulted in roughly one-third of the stock estimated to be in Area 3A, 13-16% in each of areas 2B, 2C, and 3B, and smaller contributions from the other areas (Table 1). The estimate of current stock distribution (not including juveniles) is what allows for explicit consideration of area-specific removals in the harvest policy.

The current IPHC harvest policy

The IPHC's harvest policy has evolved through many levels of target harvest rate, spatial complexity, and implementation strategy. Briefly, early harvest policy implementations used higher target rates of exploitation, including values of 35%, 30%, and finally 20% in 1996 (Clark and Hare 2006). Clark and Hare (2004) provide a more detailed summary of the evolution of the IPHC's harvest policy through 2004. These early higher rates were reduced as subsequent analyses showed the stock to be less productive and the objectives of the harvest policy were

[2] Webster, R. A. *In prep*. Trawl tag releases of small halibut in the Bering Sea. Contact: Ray Webster, IPHC, 2320 W Commodore Way, Suite 300, Seattle, WA 98199, USA.

broadened from targeting Maximum Sustainable Yield (MSY), to also maintaining a reasonable stock size over a range of conditions.

The target harvest rate on which the current policy is based (20%) was generated via a simulation analysis that used data from the 'core' of the halibut stock including Areas 2B, 2C, and 3A. In order to account for lower productivity and greater uncertainty in Areas 3B and 4, target harvest rates were reduced in those areas (to 15%). During both the closed-area assessment period, and the coastwide assessment period (after 2006), these target harvest rates were used to generate regulatory area-specific Total Constant Exploitation Yield (TCEY) estimates.

The target rates have a number of important properties and assumptions embedded in them. Simulation analysis found that these rates would achieve a stock size that exceeds 30% of the equilibrium stock size in the absence of any fishing ($SB_{30\%}$) with at least an 80% probability over a sufficiently long time-horizon (Clark and Hare 2006). Fluctuations in size-at-age and variable recruitment regimes were included in the original analysis, and subsequent sensitivity analyses, and it was acknowledged that a fixed harvest rate policy in combination with natural fluctuations in recruitment would lead to similar fluctuations in the fishery removals (Hare and Clark 2002). In addition, the levels of bycatch and wastage occurring during the 1980s and 1990s contributed to the estimated productivity of the stock, and therefore the target rate of exploitation. In this way, an allowance for U32 (and later U26) mortality was built in to the original harvest rate targets.

In order to better understand what is being lost via U26 (and O26) mortality in the current approach, there have been several previous IPHC analyses investigating the effects of bycatch on the halibut stock using metrics of fishery yield and lifetime spawning biomass contribution (Hare et al. 2012, Hare and Williams 2013). These analyses were conducted separately from the annual stock assessment, using equilibrium calculations based on relatively simple assumptions about growth and mortality. Results indicated that there was a 1.0-1.14 pound loss of fishery yield per pound of bycatch (O26 and U26 combined). For each pound of bycatch, the potential lifetime contribution to female spawning biomass was found to be somewhat larger than the fishery yield.

Correspondence from the IPHC to the Council and internal reports indicate that in the late 1980s and early 1990s there was a considerable effort to define and quantify the "adult equivalents" associated with halibut bycatch, attempting to clarify and understand the exchange rate between mortality of different sizes of halibut. Yield equivalents for bycatch were estimated to be 1.4-1.6 pounds of fishery yield in the 1980s; however, recalculations based on spawning output led to a pound-for-pound deduction of O32 bycatch from the TCEY through the 1990s. This reduction was done for the coastwide total, and therefore distributed in proportion to the exploitable biomass (Hare and Clark, 2007).

Analyses conducted in 2010 (Hare 2011) used Spawning Biomass per Recruit (SBR) as a measure of total fishing intensity. The calculation of SBR in that analysis is consistent with that of SPR (described in detail below). Hare (2011) first found the SBR associated with the harvest policy at the time (20% and 15% harvest rates applied to O32 removals). He then solved for the TCEY values that would result in the same SBR if removals of O26 halibut were included directly in the TCEY. In this way, he applied an extended definition of removals, but used SBR to maintain the same level of fishing intensity. The harvest rates for O26 removals were higher (21.5%), but the sum of the TCEYs was slightly (0.84 Mlb) lower, indicating only a small divergence in the biological properties of all the removals since the original simulations. That analysis also calculated harvest rates that could be applied when all sizes of removals were included in the TCEY, and concluded there was no biological basis for area-specific deduction of these removals given the

highly migratory nature of juvenile halibut. A second option was presented, which distributed the U26 mortality in proportion to the exploitable biomass estimates by regulatory area. This is consistent with the logic of assuming that the effects of U26 mortality are realized equally across the O26 stock. The extended accounting for O26 halibut was adopted in 2011, and subsequent harvest policy calculations have relied on the 21.5 and 16.125% (15% scaled up by the same factor as 20% to 21.5%) rates. In aggregate, these changes brought a broader size-spectrum of mortality into the annual calculations, but retained a system of accounting that did not explicitly show U26 mortality in harvest policy tables and could not respond to future changes in U26 mortality.

Current IPHC harvest policy distributes the directed Fishery Constant Exploitation Yield (FCEY) limits for each regulatory area based on apportioned biomass estimates derived from survey catch rates, and application of fixed harvest rates (21.5% in Areas 2A-3A and 16.125% in Areas 3B-4CDE) to those estimates. The policy accounts for only O26 halibut removals from the directed and non-target fisheries in the calculation of exploitation rates and yield. Changes in O26 bycatch therefore directly translate into changes to directed fishery yields, as illustrated above, but changes in U26 mortality are not visited directly on calculations of available yield. Instead, the effects of changes in U26 mortality do not factor into the FCEY until those effects are realized through eventual changes in O26 biomass. To illustrate this gap in the current policy, it is useful to consider the hypothetical scenario where the total pounds of bycatch is increased by a million pounds, but the size distribution of that bycatch is shifted, such that all of the increase is realized on U26 halibut. It is clear that this would have an effect on the stock, as that increase in pounds would correspond to a very large number of fish. However, the application of the current harvest policy would yield identical TCEYs and FCEYs, despite the large increase in the total fishing intensity being applied to the stock. The converse would also occur: a million pound decrease in the bycatch of U26 halibut would also result in no change to the TCEYs or FCEYs. These results occur because the current harvest policy assumes a static level of U26 mortality.

Recent annual harvest policy tables (e.g., Webster and Stewart 2014) have been calculated in the following manner: 1) apportionment provides an estimate of the stock distribution, 2) the target harvest rates are applied, which generates a target distribution for the O26 harvest regardless of the scale of those removals (Table 1). The distribution of potential catch limits can then be compared to the target distribution. For example, the final adopted catch limits for 2014 resulted in TCEYs that exceeded the apportionment target in Areas 2A, 2B, 4B, and 4CDE, with the largest difference in 2B (Fig. 9). The scale of this relative distribution is then a function of the apportionment percentages applied to the coastwide total exploitable biomass (a definition created within the harvest policy reflecting a fixed selectivity schedule somewhat like the fishery at the time of the simulation analysis). The TCEY values therefore reflect the combination of stock distribution and target harvest rates by regulatory area (Table 2). In order to find the Fishery Constant Exploitation Yields (FCEYs) for each regulatory area, all O26 "other removals" are subtracted from the TCEYs. FCEY values thus represent what is 'leftover' after accounting for distribution and other sources of mortality.

To manage U26 mortality, harvest rates that account for changes in U26 removals must be dynamic, in order to maintain the same fishing intensity or protection for the spawning stock depending on annual changes in all sources and sizes of removals. A relevant metric to quantify all removals and their effect on the stock is the Spawning Potential Ratio.

Spawning Potential Ratio

It is common practice to consider fishing intensity in terms of fishing mortality: the catch as a fraction of the stock or as an instantaneous rate of mortality (per year/age). In both cases, there must be a clearly defined set of sizes or ages included in the calculations. Where multiple fisheries are present, and where these fisheries access differing size and age components of the stock, it is not possible to characterize a single fishing mortality rate for all fisheries simultaneously. In these cases, a metric that integrates the different fisheries (and therefore the mortality on different sizes of fish) is required.

Spawning Potential Ratio (SPR; Goodyear 1993) is a commonly used metric that summarizes the fishing intensity of all fisheries accessing different parts of the same population. SPR has two components: 1) the equilibrium spawning biomass in the absence of fishing and 2) the equilibrium spawning biomass given some distribution of fishing mortality at size or age. Without fishing, the spawning biomass produced by a fixed number of incoming recruits will be a simple function of individual growth, the maturity schedule, and the rate of natural mortality. Fishing just adds an additional source of mortality at each age. However, some of the fish that would have died of natural causes are caught first, such that natural and fishing mortality are not simply additive annual factors. The ratio of equilibrium spawning biomass with fishing to that without fishing is SPR. SPR can therefore range from 1.0 as fishing mortality approaches zero, to 0.0 as fishing mortality results in no fish surviving to reach maturity. SPR calculations are frequently summarized in units of one minus SPR, such that increasing fishing intensity equates to a larger value, similar to traditional metrics of fishing mortality.

This metric integrates fishing intensity across multiple sources, where selectivity may differ and traditional age-range dependent fishing mortality rate (F) or harvest fraction calculations can be misleading. Because the SPR metric includes all sources and sizes of mortality, it can be used to directly compare potential halibut fishery yield associated with different levels of total and U26 bycatch and can therefore be used to define a harvest target for the stock. This conceptual extension to the current harvest policy allows for quantification of the impacts of bycatch on the halibut stock via the yield estimates, rather than in terms of adult equivalents or equilibrium spawning biomass units. SPR is also a logical choice for defining fishing intensity for Management Strategy Evaluation (MSE) where trade-offs among fisheries and size-limits within fisheries need to be directly evaluated in a common framework.

Extended accounting for U26 mortality

SPR can be used to define the level of total fishing intensity that is consistent with current (2013) levels of mortality. This conceptual approach is identical to that used in Hare (2011), in order to include O26 mortality into the target harvest rates. The 2013 fishing intensity equates to a target SPR, which can then be used to set the scale of all removals under differing distributions of those removals among fisheries and sizes of halibut. The apportionment results and relative harvest rate targets by regulatory area still define the distribution of the TCEY. Both the target distribution of the TCEY among regulatory areas and the assumption that the effects of U26 mortality are distributed across the entire stock remain the same. This means that if there were no changes in U26 mortality, the extended accounting would produce the exact same results as the current accounting approach.

Two features of this extended accounting are important: 1) exploitable biomass is no longer necessary or relevant, as halibut mortality of all sizes is included in the calculation of SPR and,

2) the order in which the non-U26, O26 non-FCEY, and FCEY removals are calculated is no longer fixed. Specifically, the FCEY no longer represents only what is 'leftover' from the rest of the harvest policy calculations. The SPR-target and the relative distribution of TCEY from apportionment and relative target harvest rates by regulatory area can be achieved by solving for the fishery landings (and wastage) given any level of bycatch, or by solving for the bycatch given any level of fishery landings (and wastage). Changes to fishing practices that alter the projections of wastage for a given level of fishery landings can also be included. There are therefore dual entry points possible for management actions and trade-offs among fisheries can be directly evaluated.

Examples from the 2013 process

This analysis uses the 2013 stock assessment models (Stewart and Martell 2014), apportionment estimates, and current harvest policy calculations (Webster and Stewart 2014) to investigate how changes in U26 and O26 removals impact the annual TCEY and FCEY values. This is done via direct comparison with the results of the 2013 IPHC process; harvest policy calculations are repeated under different projected levels of coastwide and BSAI bycatch. For simplicity, this analysis focuses on the trade-offs between CEYs and bycatch. However, changes in wastage could be included in a similar manner. Due to the much smaller estimated magnitude of U26 wastage, the results would be very similar.

It is important to note that this analysis and annual calculations are based on the actual (2013) bycatch mortality estimates from all non-directed fishing in each regulatory area. As described above, recent bycatch levels in Alaska for both trawl and fixed-gear (except in the GOA) have been well below the PSC limits set by the NPFMC. Therefore changing the PSC limits in particular fisheries may or may not affect change in realized bycatch levels. Pacific halibut bycatch in non-target fisheries in recent years has represented a significant fraction of the total mortality of halibut due to fishing. In 2013, there was an estimated 7.9 Mlb of halibut bycatch coastwide, which represented 17% of the 46 Mlb of total fishing removals. The BSAI regulatory areas (4A, 4B, and 4CDE) contributed 5.2 Mlb, or 66% of the total.

This analysis starts from the results of apportionment and application of current harvest policy which generated the Blue Line FCEY values for 2014 (Table 2). This harvest policy table is first extended to show each of the individual components included in the TCEY, as well as all sizes of mortality by regulatory area (Table 3). Comprised predominantly of bycatch, the 2013 U26 mortality was estimated to be 2.92 Mlb, or 8% of the total 36.41 Mlb removals. In order to illustrate how changes in U26 and O26 mortality influence the TCEY and FCEY, values were recalculated using coastwide bycatch values that are 40, 20, and 10% above and below the estimates from 2013. This calculation integrates the changes in the distribution of halibut mortality among commercial, recreational, and subsistence catches, as well as estimates of wastage, associated with differing quantities of directed fishery landings.

With a 40% increase in bycatch (3.2 Mlb), the coastwide FCEY decreases from the 2013 value of 24.5 Mlb to 22.5 Mlb (Fig. 10). A 40% decrease in bycatch similarly produces a 1.9 Mlb increase in coastwide FCEY. Changes in bycatch of +/- 20% show an intermediate effect, but the results by specific regulatory area indicate that area 4CDE is the most sensitive (Tables 4-5). A 20% increase in bycatch results in the FCEY for 4CDE dropping from 0.64 (at the Blue Line) to 0.2 Mlb, and a decrease of 20% results in an increase in 4CDE to 1.07 (Tables 4-5). In Area 4CDE, for all values of estimated bycatch at least 30% greater than 2013, the FCEY would be 0

for the current harvest policy. Areas 4A and 4B are much less sensitive due to a much lower ratio of bycatch to directed fishery harvest.

For direct comparison, the same calculations are then repeated using the SPR target from the 2013 Blue Line, therefore including all the change in removals, both O26 and U26. When FCEYs are adjusted to maintain the same SPR target, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality: this is due to the effects of the U26 removals (Fig. 10). In this case, a 20% reduction in coastwide bycatch results in an FCEY of 26.0 Mlb (Table 6-7), compared to the Blue Line value of 24.5, while the reduction that did not account for U26 removals resulted in an FCEY of 25.4. These results are consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch.

The salient points of these comparisons are that the FCEY responds only to the change in O26 removals under the current harvest policy, and the TCEY does not respond to changes in coastwide bycatch, despite potentially large changes in total mortality (Table 8). By extending the accounting to maintain the same level of fishing intensity, an increase in coastwide bycatch results in a decrease in the FCEY, TCEY and total mortality (Table 8); the converse is true as well.

To investigate the BSAI areas specifically, where much of the coastwide bycatch occurs, the same relative changes are applied only to bycatch estimates from BSAI areas. Under the current harvest policy calculations, the results are identical for the BSAI areas (Tables 9-10). There are no changes to annual removals in Areas 2A-3B, despite the change in productivity that would be expected from immigration of some of those U26 fish over their lifetime. Applying the extended accounting for total fishing intensity, changes in BSAI bycatch correspond to changes in the FCEY and TCEY values across all regulatory areas (Tables 11-13). This is due to the distributed effects of U26 mortality. The current assumption is that U26 effects are distributed in proportion to the productivity of the stock as a whole, therefore changes in the TCEY among regulatory areas are most pronounced for areas that have larger apportioned biomass estimates. The largest change occurs in Area 3A, where the FCEY goes from 9.43 Mlb at the Blue Line (and for a 20% reduction in the BSAI bycatch when U26 mortality is not accounted for) to 9.59 when the same SPR is maintained. The clear difference in these calculations is that any response to changes in bycatch in the FCEY, up or down, is of greater magnitude when all sizes of mortality are accounted for. Ongoing research at the IPHC to evaluate size-limits, discard mortality rates in the directed fishery, and the interaction of bycatch with total fishing mortality is yielding very similar results.

The results of the full range of bycatch changes (+/- 40%, Fig. 10) show that the current harvest policy is much less sensitive to changes in bycatch than the extended accounting explicitly including U26 mortality. The results have been presented in the context of the change in FCEY as a function of changes in bycatch, consistent with recent harvest policy accounting. However, the same results can be considered in the opposite direction: How much would bycatch have to be reduced to achieve a given change in the FCEY? If a 6% increase in FCEY is desired, the bycatch would need to be reduced 30% given the current harvest policy, or 17% if all mortality is accounted for (Fig. 11). If the FCEY were reduced to accommodate slightly more anticipated bycatch, a 4% reduction in the FCEY would allow a 20% increase in bycatch under the current harvest policy, but only a 12% increase if the U26 component of bycatch mortality is accounted for via a constant SPR (Fig. 11). These results include changes in the ratios of commercial landings to wastage and recreational removals under the various CSPs, and therefore represent the fully realized tradeoffs necessary to achieve a desired change in the FCEY.

There are several results of this analysis that are particularly relevant to the BSAI regulatory areas. Current (2013) halibut bycatch in the BSAI represents 66% of the coastwide total from all non-target fisheries. This also represents a significant portion of the total mortality in BSAI areas, especially Area 4CDE. In Area 4CDE, based on 2013 estimates, application of the harvest policy would result in no directed fishery yield if the estimated O26 bycatch were to increase by at least 30%, the apportioned exploitable biomass were to decrease by the same amount, or any combination of these two adding up to at least 30%. When FCEYs are adjusted to maintain the same SPR target, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality, accounting also for the effects of the U26 removals. This result is consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch.

In 2012, the IPHC adopted a revised process for providing annual catch advice. To clearly delineate between risk assessment and management, the estimated risks associated with several alternative harvest levels have been presented to the Commission rather than just the results of the application of the current harvest policy. These results have been in the form of a decision table, including risk metrics associated with stock trend, as well as harvest policy based metrics of stock status and fishery status. Using the Blue Line results from 2013 (Table 11) as a direct comparison, the alternative distribution and magnitude of removals for the analyses reported above can be evaluated directly in the current decision-making framework. There is relatively little change in risk associated with changes in bycatch (+/- 20%), and between the two methods of accounting for that bycatch over the next three years (Table 12). This illustrates that the projections from the ensemble of assessment models are quite robust to changes in fishery removals, despite the fact that these changes have very large implications for current fisheries. Both the extended and current harvest policy calculations suggest a very similar recent history of exploitation: rates have been above target levels based on exploitable biomass (Fig. 12) and SPR (Fig. 13) targets over the last decade. Management actions have brought these rates down appreciably over the last five years, and by either metric the 2014 adopted catch limits were the closest to the current harvest policy in recent history.

Management

Adding full accounting to the IPHC's annual process

The easiest extension of current IPHC management is the explicit consideration of the harvest policy accounting system, and the results obtained in this report. The setting of annual catch limits has historically used information from the decision-table, apportionment, the current harvest policy and target exploitation rates, as well as survey and fishery trends and stakeholder perspectives. The SPR-based comparisons possible with this extension to the current harvest policy add another piece of potentially valuable information to the annual decision-making process. Perhaps most importantly, this information allows the direct evaluation of trade-offs, by source and area, for all halibut removals.

These calculations could be added to current harvest policy calculations in the short-term, and they could replace those calculations if the IPHC chose to adopt this extended accounting system, just as was done in 2011, when O26 mortality was added to the annual calculations. Benefits of the extended accounting include: no further need for the abstract and confusing concept of exploitable biomass, consistency in the target fishing intensity despite future changes in removals among

fisheries and/or changes in the size structure of removals within fisheries, a clear understanding of the direct tradeoffs between all directed and non-directed removals, and the use of SPR which provides a direct link to future output from MSE analyses.

Management of wastage

Direct management of wastage associated with the commercial fishery clearly falls under the purview of the IPHC and its annual regulations. Much of the current wastage (compared to the derby fisheries of the late 1980s and early 1990s, in Alaska) is a function of the 32 inch minimum size-limit. However, voluntary or regulatory reductions in this wastage may be possible without changes to that size limit. Fishermen may be able to avoid areas with high proportions of sub-legal fish, adjust hook- and bait-sizes to target larger halibut, and modify the timing of trips to correspond to periods when larger fish are relatively more available on the same fishing grounds. These changes in fishing behavior will require positive incentives, in contrast to current practices. Specifically, the IPHC's practice of indirect estimation of wastage (via the setline survey sub-legal catch rates applied to the directed commercial landings) provides no incentive for changes in wastage: fishermen opting to reduce wastage at their own expense in fishing efficiency (e.g., fuel to move among grounds or altering their catch rates) are faced with FCEYs the following year that are just as high as if they had not made any reductions to wastage. The only way to reverse this situation is to create a system of improved monitoring, such that the fishery itself can see and respond to changes in actual, and not estimated, wastage. This type of system is currently in place in Area 2B, where logbook records of wastage (validated with electronic monitoring) are used by the IPHC to estimate wastage directly. This means that fleet-wide changes in behavior will result in larger FCEYs in the future.

All areas currently lack vessel-specific accounting systems for wastage. If the accounting for wastage was conducted at an individual vessel level (e.g., wastage shares or limits associated with pounds of quota), then positive incentives could operate at the vessel level in addition to the fleet level. This would mean that each individual would benefit from reduced wastage directly in their own quota – a much stronger incentive than at the fleet-level. This would only be possible with 100% monitoring of all fishing activity to ensure accurate estimates of wastage.

A second avenue for reducing commercial wastage would be to decrease the realized DMR. The IPHC already mandates the careful release of all sub-legal halibut. However, as with wastage, the current static assumption that 16% of all discarded halibut subsequently die does not create an incentive to take additional time during each release to attempt to improve this rate; there is no feedback to subsequent estimates. Specifically, if DMRs were based on an observed distribution of injury rates, and/or release methods, then improvements in handling practices would translate into positive changes in the future FCEYs. This too would require extensive monitoring to provide accurate estimates of release categories.

Changes to the current 32 inch minimum size limit, and or slot or maximum size limits would all likely result in changes to the magnitude and size structure of wastage. Specifically, reduction in the minimum size limit, allowing retention of halibut smaller than 32 inches, would likely lead to less wastage overall, but might also allow the fishery to target relatively more smaller fish, which could offset some or all of any potential catch limit reduction. Changes to size-limits would also have very strong implications for the performance of the current harvest policy. In order to understand whether such changes would be beneficial to achieving fishery objectives, it would

be necessary to fully evaluate than in the context of harvest policy, and preferably a full MSE analysis. This effort is currently underway at the IPHC.

Bycatch control and reduction – collaboration among agencies

The Commission has no direct regulatory authority over the amount of halibut taken as bycatch or in the monitoring and estimation of bycatch. The Commission therefore relies on U.S. and Canadian agencies for the necessary bycatch information and management.

Bycatch is part of a national focus for the U.S. and Canada, based on specific requirements in federal legislation or policy. In the U.S., the Magnuson-Stevens Act (NMFS 2007) is the primary law for federal fisheries management. The MSA contains national standards for fishery conservation and management. National Standard 9 specifically addresses bycatch reduction, stating:

"Conservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch."

In addition, the NPFMC and PFMC have adopted regulations to manage halibut bycatch, including the designation of halibut as a "Prohibited Species" within groundfish fishery management. Other fishery restrictions include bycatch limits on the amount of halibut which can be taken by the groundfish fisheries (NPFMC 2010, 2012).

In April 2013, Canada adopted a Policy on Managing Bycatch as part of its Sustainable Fisheries Framework[3]. The policy is national and it applies to all commercial, recreational, and Aboriginal fisheries licensed and/or managed by DFO under the Fisheries Act. The policy has two objectives: 1) to ensure that Canadian fisheries are managed in a manner that supports the sustainable harvesting of aquatic species and that minimizes the risk of fisheries causing serious or irreversible harm to bycatch species; and 2) to account for total catch, including retained and non-retained bycatch.

Similar philosophies exist within these national policies. Both direct that the capture of bycatch species shall be minimized *to the extent practicable.* This implies that bycatch should be reduced to the point where it balances with other competing objectives. Both policies also contain language which addresses the status of the bycatch species following release. Objective 4 in DFO's policy states that the potential for survival should be maximized, whereas MSA National Standard 9 states that mortality should be minimized.

Since 1991, a succession of Commission-led work groups have been established to investigate various aspects of bycatch, including reviewing domestic bycatch management programs, identification of fisheries contributing to bycatch, optimal levels of bycatch, and options for reductions. The first initiative occurred in 1991, when the Commission established a Halibut Bycatch Work Group (HBWG I) to review the adequacy of management measures implemented by each country to control and reduce bycatch, examine potential measures to achieve reductions in bycatch, identify target levels of reduction, and to develop recommendations for additional Commission action (Salveson et al. 1992). The principal recommendations included the inclusion of all groundfish fisheries off Alaska into the bycatch limit management program, development of monitoring and estimation of bycatch off Washington and Oregon, a recommendation for a program to reduce bycatch limits off Alaska by a minimum of 10 percent per year, an expansion of the observer program off Canada to cover all bottom trawl fisheries, and that research should be conducted on the viability of trawl-caught halibut.

[3] http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/index-eng.htm

The Halibut Bycatch Work Group was re-established in 2010 (HBWG II) to review progress on reduction of halibut bycatch mortality, bycatch management programs, and to examine how best to incorporate halibut bycatch mortality into halibut assessment and management. Although the latter objective was subsequently dropped, the HBWG II compiled a comprehensive report on successful bycatch management programs and identified areas for improvement, accompanied by recommendations (Karim et al. 2012).

As a follow up, at the January 2012 IPHC Annual Meeting, the IPHC therefore approved a commissioner-led initiative focused on a better understanding of the implications of current levels of halibut bycatch and to explore possible actions to address these concerns. The Commission developed and approved the following specific objectives:

- To gain a better understanding of the amount of halibut bycatch occurring in each regulatory area;
- To gain a better understanding of the impact of bycatch on the conservation and allocation of the halibut resource and on the available harvest;
- To explore options for reducing the overall level of halibut bycatch; and
- To explore options for mitigating the impact of bycatch in one regulatory area on the available harvest in other regulatory areas.

The HBWG II is reporting on progress to the Commission in 2014. The report explores options for reducing the overall level of halibut bycatch in groundfish fisheries, and for mitigating the impacts of bycatch in one area on the available harvest in other areas. The Commission will consider this report at its 2015 Annual Meeting and develop an action plan for implementation of any adopted measures.

Independently of the HBWG II, the NPFMC initiated a review of PSC limits in the BSAI region in 2012 (NMFS 2012). At its June 2014 meeting the Council passed a multi-part motion to analyze reductions of these limits from 10-35%, individually by sector. A multi-agency work group, in which IPHC staff is participating, is developing an analysis of the benefits and costs of these options, for initial consideration by the Council in February 2015.

The IPHC has the opportunity to move forward with coordinated management of bycatch in non-halibut fisheries. This effort must entail evaluating what aspects of current and potential monitoring can provide positive incentives for the reduction in halibut mortality without unduly reducing the efficiency of those fisheries. Positive incentives for bycatch reduction, like wastage, can occur at the fleet-wide level, or more effectively at the vessel-level, where the benefits of bycatch reduction are conserved within the fishing operation itself via longer seasons, more quota for target species, or simply the avoidance of individual bycatch limits. Vessel-level incentives will require comprehensive monitoring of all fishing activities, in order to accurately estimate the absolute magnitude of bycatch. Given the financial and logistical constraints of many relevant fisheries, new approaches to estimation may be needed, approaches that require less direct measurement in favor of model-based estimators that can be periodically validated. These may include video monitoring of release methods, which are then linked to injury rates (or condition codes) and therefore DMRs, rather than direct enumeration of injury/condition via human observers onboard vessels. An important aspect of positive incentive structures seen in other fisheries is a focus on the goal (reducing bycatch), rather than the means (enforced changes in gear, areas or other methodological mandates): this allows harvesters to use their considerable creativity to find the most efficient means to success.

Uncertainty and future research

There are several very important sources of uncertainty in this analysis: some of these sources are inherent to the biology and management of Pacific halibut and are not easily addressed, while others could be substantially reduced through additional data collection and analysis.

The current harvest policy (and any extension to explicitly include all sizes of halibut mortality) makes the implicit assumption that the effects of U26 mortality are distributed across the entire stock, in proportion to the total productivity. If juveniles in some areas are less likely to disperse to other areas, or if these patterns change over time with environmental conditions or stock abundance, this assumption may not be a good one. Neither the directed fishery, nor the setline survey provides clear information on juvenile abundance distribution. Some information can be inferred from NMFS and DFO trawl survey observations, bycatch rates in non-target fisheries, and encounter rates in the directed fisheries; however, all of these are subject to incomplete spatial coverage as well as many other uncertainties. The design of a targeted survey of juvenile halibut abundance and distribution is likely to be both technically unfeasible and prohibitively expensive. An extensive tagging effort could provide a 'snap-shot' of migration rates (which might allow inference about the spatial distribution of recruitment), but these rates likely to vary with stock density, environmental conditions, and other unknown factors. Again, costs would likely be prohibitive due to the large number of tag releases required to compensate for low recovery rates caused by the extended time between tagging and recovery by the commercial fishery.

Juvenile natural mortality rates are highly uncertain, but are important to any evaluation of removals to population trend and productivity. The area of greatest uncertainty is for pre-recruit juveniles and may be highest for sizes of fish that are well below those first encountered by any survey gear. For this analysis, several alternative comparisons were made assuming juvenile natural mortality rates were 1.5 and 2 times the rates estimated for adults. The relative change in SPR was found to be similar across alternatives, but the relative importance of fishing mortality was slightly less with increased juvenile natural mortality. Natural mortality rates are notoriously difficult to estimate, even for well-sampled/observed age ranges for highly-studied species, and there are few avenues for experimental or data-collection based efforts to improve our understanding of juvenile halibut mortality. Indeed, the two-year releases of Passive Integrated Transponder (PIT) tags in the most recent tagging program were designed to directly estimate natural mortality, but produced a fairly broad and uninformative estimate, which included the currently used values.

The current distribution of the stock is estimated via apportionment. This analysis utilizes the catch-rates of legal-sized halibut observed in the setline survey. It is uncertain how inaccuracies in apportionment would affect long-term stock dynamics. They may be both direct effects through the annual distribution of removals, as well as indirect effects via their influence on weighting of area-specific indices for use in the stock assessment and therefore estimates of stock size and trend. Over the next five years, planned survey expansions (Webster et al. 2014) will allow the use of improved (more direct) estimators of stock abundance in deep waters (>275 fa), shallow waters (<20 fa) and for gaps in the current station grid. Further, calibration coefficients linking the IPHC's survey to auxiliary datasets (e.g., the NMFS Bering Sea Trawl survey) will be re-analyzed. Determining whether there are sufficient removals of O26 and U32 halibut to warrant using the survey catch-rate of U26 halibut as the basis for apportionment of these fish is a topic for further investigation, as harvest policy analysis continues.

The stock assessment and application of the harvest policy relies on accurate and precise estimation of the removals from all fishing sectors, including the directed fishery, recreational, and subsistence harvests, as well as discards from these fisheries and bycatch. There is a substantial amount of uncertainty in the current treatment of bycatch due to: the estimation framework (data collection), the summary of the estimates (data processing), the DMRs applied to these summaries, and the forecasting of bycatch and its biological properties from one year to the next.

The first of these relates to the current North Pacific Observer Program. While some fisheries in the BSAI region have observer coverage of 100% of fishing trips, other fisheries have much lower coverage (particularly in the GOA) or no coverage at all (small vessels). In these cases, observer data may not be representative of all fishing activity (observed and unobserved) and therefore there is no way to be certain that the estimates are unbiased, regardless of the statistical design. Indeed, evidence indicates that the existing estimates are biased by harvester behavior (Benoît and Allard 2009, Faunce and Barbeaux 2011). This situation can only be fully ameliorated via some type of monitoring (direct observer or electronic) on all fishing activity.

In addition to the magnitude of bycatch, the size-distribution (particularly the fraction U26) of these removals is important for harvest policy accounting. Currently, estimates of the total bycatch are obtained by the IPHC from the catch accounting system. There is uncertainty in assigning these summarized estimates to specific regulatory areas due to the imperfect alignment of IPHC and NMFS statistical reporting areas. This means that not all bycatch may be attributed to the correct regulatory area in each year. Additionally, the size information collected by the observer program is transmitted to the IPHC in an unprocessed form, which allows no easy method for weighting among fishing sectors within IPHC regulatory areas. Expansion of the raw length distributions is necessary to reflect differences in sampling rates among fisheries in each of the regulatory areas, and among vessels with different levels of observer coverage. This would require a substantial amount of integration between the observer data and catch accounting system. For this reason, bycatch length frequencies have not been updated annually for all Alaskan regulatory areas. Obtaining accurate size-, age-, and sex-specific estimates of the removals of halibut from all sectors via improved observation and reporting to the IPHC may be the most tractable avenue for improving our understanding of the role of bycatch in current stock trends and productivity.

The stock assessment and harvest policy calculations rely on an aggregate bycatch selectivity assumption. However, the size distribution of bycatch varies among regulatory areas, among fisheries and even annually within fisheries, in response to many extrinsic and intrinsic factors. Further, many of the tools proposed for bycatch reduction could have large effects on the potential size-distribution of future bycatch mortality through direct effects, or changes in the discard mortality estimates by fish size. These changes are difficult or impossible to predict, and therefore current practice is to use the values from the previous year for all calculations. This approach could introduce lags in response if clear trends occur. The sensitivity to some of these factors was investigated as part of this analysis: the proportions of young and old fish in the currently assumed curve were adjusted by 20% up and down and the results recalculated. This produced only modest changes in FCEYs, slightly smaller than those produced from a 10% change in the total magnitude of bycatch (~0.5 Mlb). These changes also illustrated the expected relationship between the size-distribution of the bycatch and the long-term implications for the stock productivity: if mortality is higher on small fish for the same total pounds removed (greater numbers), the harvest of larger fish would have to be reduced to offset the greater lifetime contribution of these fish that have yet to mature. More direct estimation of bycatch selectivity would require appropriately expanded

and weighted length-frequency observations not currently available and would likely have to be carried out with a more spatially disaggregated assessment approach.

In addition to bycatch, wastage in the directed commercial fishery is currently estimated indirectly, via catch-rates of U32 halibut observed on the IPHC's setline survey in each regulatory area and assumed discard mortality rates. The exception to this is Area 2B, where the number of U32 halibut discarded is taken directly from fishery logbooks. In this case, the average individual fish weight from the survey is used to convert the numbers of fish discarded into pounds of mortality. These direct estimates do compare well with the indirect estimates calculated in the traditional manner by the IPHC. Analysis of potential management actions that would influence wastage realized in the fishery (such as a change in the size-limit, regulated hook-sizes, or time-area closures) requires accurate estimates of that wastage. Current observer coverage in the Alaskan directed halibut fishery is very low, and therefore estimates of wastage are of unknown accuracy; however, improved monitoring via increased observer coverage and/or electronic monitoring offer potential for improvement in these estimates. In Area 2A, there is currently no at-sea monitoring of the directed halibut fishery. With increased monitoring, it may also be possible to improve discard mortality rates (currently assumed to be 16% for IFQ fisheries and 25% for 2A) through direct evaluation of hooking injuries, as is done for non-target hook-and-line fisheries in Alaska.

In all areas, the DMRs for both wastage and bycatch are an important source of uncertainty due to the relatively large quantity of halibut that are handled and released each year. Specifically, small changes in the realized DMR may correspond to large changes in mortality. Although there is no current evidence that the DMRs being currently applied are biased, use of direct annual observations would be required to track any changes in fishery behavior and handling. This is only possible for fully monitored fisheries.

Summary

Although the extended accounting developed in this analysis is a logical extension of the current harvest policy, it is not a re-analysis of the policy itself. Given changes in fishery selectivity, size-at-age, and other biological and anthropogenic factors, there remains a distinct need to re-evaluate the current harvest policy and determine whether it meets the current management objectives. This type of analysis is part of the MSE process. Development of a MSE at the IPHC has the potential to identify alternative management procedures that may be robust to many of the uncertainties described here, and serve as a vehicle to explore hypotheses regarding recruitment distribution, juvenile and adult migration, density dependence, spatial and temporal growth variability, and a multitude of other factors. The process is ongoing, as is the development of more spatially disaggregated assessment analyses that can also be used for future work on these topics.

SPR-based accounting provides a specific total mortality target for the entire halibut stock, consistent with the current harvest policy. This ensures the same level of protection for the stock in the future, despite changes in the relative magnitudes of target and non-target fisheries and changes within the fisheries themselves. Area-specific U26 mortality targets could be established by the IPHC; however, current understanding of juvenile distribution and migration does not support an apportionment-based approach that directly prescribes the levels of U26 removals in specific regulatory areas, as is the case for O26 mortality. Even if the distribution and migration rates for juvenile halibut were known perfectly, the mechanism for distributing this mortality would be completely conditional on fishery objectives rather than biological dynamics. However, the effects

of U26 mortality can now be directly evaluated in all regulatory areas, without waiting years for those effects to become obvious.

The extended accounting, using SPR in the context of the current harvest policy, provides additional information for the annual process of setting catch limits. Accounting for halibut removals of all sizes represents a conceptual extension of the current harvest policy, but not a change in the implicit logic of the approach. This analysis does broaden the scope of the policy, providing an analog in total mortality which avoids future changes in realized fishing intensity. Further, it allows for the explicit evaluation of trade-offs between removals of halibut associated with different fisheries and potential changes in the size structure of these removals in response to management actions. All sources of mortality are now 'on the table' for consideration in the same units. This analysis can therefore serve as the basis for direct comparisons within and among regulatory areas of the 'exchange rate' among fisheries in terms of both pounds of halibut removals and potential dollars earned via those removals or the removals of target species other than halibut. This approach should serve to elevate the discussion regarding such trade-offs; however, it does not presuppose any changes to current management by the U.S. Councils, DFO, or the IPHC.

Finally, the staff would like to thank the Commissioners for the opportunity to explore this topic in detail. A large amount of historical and recent analysis has addressed the harvest policy and specifically the treatment and management of various sources of mortality. The request from the 2014 Annual meeting has allowed us to perform a comprehensive review of the information available, the gaps in our current understanding of important processes, and the promising paths for future progress. The context provided here will be helpful as the Commission moves forward with annual decision making as well as ongoing long-term harvest policy and management strategy evaluation.

References

Benoît, H.P. and Allard, J. 2009. Can the dat from at-sea observer surveys be used to make general inferences about catch composition and discards. Can. J. Fish. Aquat. Sci. 66: 2025-2039.

Clark, W. G., and Hare, S. R. 2004. A Conditional Constant Catch Policy for Managing the Pacific Halibut Fishery. N. Am. J. Fish. Man. 24: 106-113.

Clark, W. G., and Hare, S. R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. No. 83. 104 p.

Faunce, C. H. and Barbeaux, S. J. 2011. The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer. ICES J. Mar. Sci. 68: 1757-1763.Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Can. Spec. Pub. Fish. Aquat. Sci. 120:67-81.

Gilroy, H. L. and Hoag, S. H. 1993. The 1987 Bristol Bay survey and the Bristol Bay halibut fishery, 1990-1992. Int. Pac. Halibut Comm. Tech. Rep. 28. 18 p.

Hanselman, D. H., Lunsford, C. R., and Rodgveller, C. J. 2013. 3. Assessment of the sablefish stock in Alaska. NPFMC Bering Sea, Aleutian Islands and Gulf of Alaska SAFE. p. 267-376.

Hare, S. R. 2011. Potential modifications to the IPHC harvest policy. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010. p. 177-200.

Hare, S. R., and Clark, W. G. 2002. Evaluation of the Pacific halibut harvest policy and medium term harvest projections. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001. p. 147-167.

Hare, S. R., and Clark, W. G. 2007. Discussion paper on “regularizing” of bycatch, sport and subsistence catch. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2006. p. 191-196.

Hare, S. R., Williams, G. H., Valero, J. L., and Leaman, B. M. 2012. Potential yield and female spawning biomass gains from proposed Pacific halibut prohibited species catch limit reductions in Gulf of Alaska groundfish fisheries. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011. p. 233-254.

Hare, S. R., and Williams, G. H. 2013. Coastwide estimates of lost CEY and FSBio from the bycatch of halibut in non-directed fisheries. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012. p. 355-372.

Henry, E., Soderlund, E., Dyksytra, C. L., Geernaert, T., and Ranta, A. M. 2014. 2013 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 379-414.

Hoag, S. H., Peltonen, G. J., and Sadorus, L. L. 1993. Regulations of the Pacific halibut fishery, 1977-1992. Int. Pac. Halibut Comm. Tech. Rep. 27. 54 p.

Karim, T., Keizer, A., Busch, S., DiCosimo, J., Gasper, J., Mondragon, J., Culver, M., and Williams, G. 2012. Report of the 2010 halibut bycatch work group. Int. Pac. Halibut Comm. Tech. Rep. 57. 64 p.

Mace, P. M., and Sissenwine, M. P. 1993. How much Spawning per Recruit is Enough? *In* Smith, S. J. Hunt, J. J., and Rivard, D. Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120. p. 101-118.

McCaughran, D. A. and Hoag, S. H. 1992. The 1979 Protocol to the Convention and related legislation. Int. Pac. Halibut Comm., Tech. Rep. 26. 32 p.

Myhre, R. J. 1973. Setting the new halibut size limit. Western Fisheries. February, 1973. 2 p.

NMFS. 2007. Magnuson-Stevens Fishery Conservation and Management Act. Public Law 94-265 As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479). http://www.nmfs.noaa.gov/msa2007/docs/act_draft.pdf

NPFMC. 2010. Gulf of Alaska halibut prohibited species catch limit. Discussion Paper. June, 2010. 58p. http://www.alaskafisheries.noaa.gov/npfmc/PDFdocuments/bycatch/HalibutPSC_510.pdf

NPFMC. 2011. Discussion paper on individual bycatch allowances: Gulf of Alaska trawl groundfish fisheries. North Pacific Fishery Management Council, Anchorage, AK. 5 p.

NPFMC. 2012. Halibut prohibited species in the Bering Sea groundfish FMP and regulations. Discussion Paper. May 2012. 35p. http://www.alaskafisheries.noaa.gov/npfmc/PDFdocuments/halibut/BSAIPSC_discpaper512.pdf

NPFMC. 2012. Measures to address Gulf bycatch. North Pacific Fishery Management Council, Anchorage, AK. 21 p.

Sadorus, L. L., and Lauth, R. R. 2014. Cruise report for the 2013 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 457-462.

Sadorus, L. L. Lauth, R. R., and Ranta, A. 2014. Size and age composition of Pacific halibut in NMFS Bering Sea shelf trawl surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 463-470.

Sadorus, L. L. and Palsson, W. A. 2014. Abundance and age composition of Pacific halibut as estimated by the NOAA Fisheries Service Gulf of Alaska bottom trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 479-486.

Sadorus, L. L. and Palsson, W. A. 2014b. Results from the Gulf of Alaska NOAA Fisheries Service bottom trawl survey in 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 471-478.

Sadorus, L. L., Stewart, I. J. and Kong. T. 2015. Juvenile halibut distribution and abundance in the Bering Sea and Gulf of Alaska. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 367-404.

Salveson, S., Leaman, B. M., Low, L-L., and Rice, J. C. 1992. Report of the halibut bycatch working group. Int. Pac. Halibut Comm. Tech. Rpt. 25. 29 p.

Schmitt, C. C. 1985. Review of a trawl survey program for juvenile Pacific halibut, M.S. Thesis. University of Washington. 182 p.

Soderlund, E., Randolph, D. L., and Dykstra, C. 2012. IPHC Setline Charters 1963 through 2003. Int. Pac. Halibut Comm. Tech. Rep. No. 58. 264 p.

Stewart, I. J. 2014. Overview of the data sources for the Pacific halibut stock assessment and related analyses. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 95-168.

Stewart, I. J., and Martell, S. 2014. Assessment of the Pacific halibut stock at the end of 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 169-196.

Stewart, I. J., Martell, S. J. D., Leaman, B. M., Webster, R. A., and Sadorus, L. L. 2014. Report to the North Pacific Fishery Management Council on the status of Pacific halibut in the Bering Sea and Aleutian Islands and the impacts of Prohibited Species Catch. June, 2014. 39 p.

Valero, J. L., and Webster, R. A. 2012. Current understanding of Pacific halibut migration patterns. Int. Pac. Halibut Comm. Report of assessment and research activities 2011. p. 341-380.

Webster, R. A. 2014. Construction of a density index for Area 4CDE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 261-288.

Webster, R. A., and Stewart, I. J. 2014. Apportionment and regulatory area harvest calculations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 197-216.

Webster, R. A., Clark, W. G., Leaman, B. M., and Forsberg, J. E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Can. J. Fish. Aquat. Sci. 70(4):642-653.

Webster, R. A., Dykstra, C. L., Soderlund, E., and Kong, T. 2014. Depth and range expansion of the setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 451-456.

Williams, G. H. 2014. Halibut bycatch limits in the 2013 Alaska groundfish fishery. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 311-320.

Williams, G. H. 2014b. Incidental catch and mortality of Pacific halibut, 1962-2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 289-310.

Williams, G. H. 2014c. The Alaska groundfish trawl fishery Prohibited Species Donation Program: Results from 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013. p. 321-324.

Table 1. 2013 IPHC setline survey legal-size biomass distribution (apportionment), area-specific harvest rate targets based on the current harvest policy, and the resulting target TCEY distribution.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Apportionment	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
HR targets	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Target TCEY Dist.	2.6%	17.1%	16.3%	36.0%	11.1%	4.7%	3.5%	8.7%	100.0%

Table 2. Apportionment and harvest policy table from 2013 based on the Blue Line (current IPHC harvest policy). All biomass values are reported in millions of net pounds (From: Webster and Stewart 2014).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.73	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Other removals (O26) 26)	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.04
Fishery CEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.45

Table 3. Projected 2014 removals (millions net pounds) based on the Blue Line (current IPHC harvest policy) from 2013.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.47	0.13	1.42	2.83
Total U26	0.01	0.04	0.01	0.52	0.30	0.48	0.14	1.42	2.92
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.05	0.02	0.02	0.49
Bycatch	0.12	0.19	0.01	0.93	0.62	0.63	0.32	2.23	5.05
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.05
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.32	2.84	0.85	0.82	0.64	20.54
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.45
TCEY	0.87	5.72	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Total Mortality	0.87	5.77	5.48	12.58	4.04	2.04	1.30	4.33	36.41

Table 4. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in coastwide bycatch.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.61	0.31	0.57	0.16	1.70	3.40
Total U26	0.01	0.05	0.01	0.63	0.35	0.57	0.16	1.70	3.48
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.23	0.04	0.02	0.01	0.46
Bycatch	0.14	0.23	0.01	1.12	0.74	0.76	0.38	2.68	6.06
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.16	0.78	1.31	2.81	1.01	0.83	0.41	2.71	10.02
O26 FCEY									
Wastage	NA	NA	0.08	0.32	NA	NA	NA	NA	0.40
CSP Sport	0.31	0.61	0.76	1.75	NA	NA	NA	NA	3.42
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.37	4.34	3.32	7.17	2.72	0.73	0.76	0.20	19.61
Total FCEY	0.71	4.95	4.16	9.24	2.72	0.73	0.76	0.20	23.46
TCEY	0.87	5.72	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Total Mortality	0.88	5.77	5.48	12.68	4.08	2.13	1.33	4.61	36.97

Table 5. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in coastwide bycatch.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.09
Bycatch	0.00	0.03	0.00	0.40	0.21	0.38	0.11	1.13	2.27
Total U26	0.00	0.03	0.01	0.42	0.25	0.38	0.11	1.14	2.35
O26 Non-FCEY									
Wastage	0.02	0.15	NA	NA	0.25	0.05	0.02	0.03	0.53
Bycatch	0.10	0.15	0.01	0.74	0.50	0.50	0.26	1.78	4.04
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.12	0.70	1.31	2.44	0.78	0.59	0.28	1.84	8.07
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.32	0.62	0.76	1.82	NA	NA	NA	NA	3.52
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.39	4.40	3.32	7.47	2.95	0.97	0.88	1.07	21.45
Total FCEY	0.75	5.02	4.16	9.61	2.95	0.97	0.88	1.07	25.42
TCEY	0.87	5.72	5.47	12.06	3.73	1.56	1.16	2.91	33.49
Total Mortality	0.87	5.76	5.48	12.48	3.98	1.95	1.27	4.05	35.84

Table 6. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in coastwide bycatch accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.61	0.31	0.57	0.16	1.70	3.40
Total U26	0.01	0.05	0.01	0.62	0.35	0.57	0.16	1.70	3.48
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.22	0.04	0.02	0.00	0.45
Bycatch	0.14	0.23	0.01	1.12	0.74	0.76	0.38	2.68	6.06
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.16	0.77	1.31	2.81	1.00	0.83	0.41	2.71	10.01
O26 FCEY									
Wastage	NA	NA	0.08	0.31	NA	NA	NA	NA	0.39
CSP Sport	0.30	0.59	0.74	1.70	NA	NA	NA	NA	3.33
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.36	4.24	3.23	6.99	2.65	0.70	0.74	0.15	19.06
Total FCEY	0.69	4.83	4.05	9.00	2.65	0.70	0.74	0.15	22.82
TCEY	0.85	5.61	5.36	11.82	3.65	1.53	1.15	2.86	32.83
Total Mortality	0.86	5.66	5.37	12.44	4.01	2.10	1.31	4.56	36.30

Table 7. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in coastwide bycatch accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.09
Bycatch	0.00	0.03	0.00	0.40	0.21	0.38	0.11	1.13	2.27
Total U26	0.00	0.03	0.01	0.42	0.25	0.38	0.11	1.14	2.36
O26 Non-FCEY									
Wastage	0.02	0.15	NA	NA	0.25	0.06	0.02	0.03	0.54
Bycatch	0.10	0.15	0.01	0.74	0.50	0.50	0.26	1.78	4.04
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.12	0.71	1.31	2.44	0.79	0.59	0.28	1.84	8.08
O26 FCEY									
Wastage	NA	NA	0.08	0.34	NA	NA	NA	NA	0.42
CSP Sport	0.33	0.63	0.78	1.86	NA	NA	NA	NA	3.60
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.40	4.49	3.40	7.63	3.01	1.00	0.90	1.12	21.96
Total FCEY	0.77	5.13	4.26	9.83	3.01	1.00	0.90	1.12	26.01
TCEY	0.89	5.83	5.57	12.27	3.80	1.59	1.18	2.96	34.09
Total Mortality	0.89	5.86	5.58	12.69	4.05	1.98	1.29	4.10	36.45

Table 8. Comparison of coastwide projected 2014 removals (millions net pounds) based the Blue Line, alternate levels of bycatch, and current vs. extended accounting via SPR. Target TCEY distribution, based on apportionment, is maintained in all projections (Detailed results in Tables 3-7).

	Total U26	Total O26 Non-FCEY	Total FCEY	Total TCEY	Total Mortality
Blue Line	2.92	9.05	24.45	33.49	36.41
Current accounting					
Bycatch (+20%)	3.48	10.02	23.46	33.49	36.97
Bycatch (-20%)	2.35	8.07	25.42	33.49	35.84
Extended accounting					
Bycatch (+20%)	3.48	10.01	22.82	32.83	36.30
Bycatch (-20%)	2.36	8.08	26.01	34.09	36.45

Table 9. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in bycatch in Areas 4A, 4B, 4CDE.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.57	0.16	1.70	3.24
Total U26	0.01	0.04	0.01	0.52	0.30	0.57	0.16	1.70	3.32
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.04	0.02	0.01	0.47
Bycatch	0.12	0.19	0.01	0.93	0.62	0.76	0.38	2.68	5.69
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.83	0.41	2.71	9.66
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.33	2.84	0.73	0.76	0.20	19.92
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.73	0.76	0.20	23.83
TCEY	0.87	5.72	5.47	12.06	3.73	1.56	1.17	2.91	33.49
Total Mortality	0.87	5.76	5.48	12.59	4.04	2.13	1.33	4.61	36.80

Table 10. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in bycatch in Areas 4A, 4B, 4CDE.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.38	0.11	1.13	2.43
Total U26	0.01	0.04	0.01	0.52	0.30	0.38	0.11	1.14	2.51
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.05	0.02	0.03	0.52
Bycatch	0.12	0.19	0.01	0.93	0.62	0.50	0.26	1.78	4.41
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.43
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.33	2.84	0.97	0.88	1.07	21.15
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.97	0.88	1.07	25.06
TCEY	0.87	5.72	5.47	12.06	3.73	1.56	1.16	2.91	33.49
Total Mortality	0.87	5.76	5.48	12.59	4.04	1.95	1.27	4.05	36.00

Table 11. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in bycatch in Areas 4A, 4B, 4CDE accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.57	0.16	1.70	3.24
Total U26	0.01	0.04	0.01	0.52	0.30	0.57	0.16	1.70	3.32
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.04	0.02	0.00	0.46
Bycatch	0.12	0.19	0.01	0.93	0.62	0.76	0.38	2.68	5.69
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.89	0.83	0.41	2.71	9.65
O26 FCEY									
Wastage	NA	NA	0.08	0.32	NA	NA	NA	NA	0.40
CSP Sport	0.31	0.60	0.75	1.75	NA	NA	NA	NA	3.41
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.37	4.31	3.26	7.20	2.79	0.71	0.75	0.16	19.55
Total FCEY	0.71	4.92	4.09	9.27	2.79	0.71	0.75	0.16	23.40
TCEY	0.85	5.65	5.40	11.90	3.68	1.54	1.16	2.87	33.05
Total Mortality	0.86	5.69	5.41	12.42	3.98	2.11	1.32	4.57	36.36

Table 12. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in bycatch in Areas 4A, 4B, 4CDE accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.09
Bycatch	0.01	0.04	0.00	0.51	0.26	0.38	0.11	1.13	2.43
Total U26	0.01	0.04	0.01	0.53	0.30	0.38	0.11	1.14	2.52
O26 Non-FCEY									
Wastage	0.02	0.15	NA	NA	0.24	0.06	0.02	0.03	0.52
Bycatch	0.12	0.19	0.01	0.93	0.62	0.50	0.26	1.78	4.41
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.44
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.32	0.62	0.78	1.81	NA	NA	NA	NA	3.53
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.39	4.44	3.38	7.45	2.88	0.99	0.90	1.11	21.53
Total FCEY	0.73	5.06	4.24	9.59	2.88	0.99	0.90	1.11	25.50
TCEY	0.88	5.80	5.55	12.22	3.78	1.58	1.18	2.95	33.94
Total Mortality	0.88	5.84	5.56	12.74	4.08	1.97	1.29	4.09	36.46

Table 13. Comparison of coastwide projected 2014 removals (millions net pounds) based the Blue Line, alternate levels of bycatch in the BSAI (Areas 4A, 4B, 4CDE), and current vs. extended accounting via SPR. Target TCEY distribution, based on apportionment, is maintained in all projections (Detailed results in Tables 3, 9-13).

Alternative:	Total U26	Total O26 Non-FCEY 2A-3B	Total O26 Non-FCEY BSAI	Total FCEY 2A-3B	Total FCEY BSAI	Total TCEY 2A-3B	Total TCEY BSAI	Total Mortality
Blue Line	2.92	5.72	3.32	22.13	2.31	27.84	5.64	36.41
Current accounting								
BSAI Bycatch (+20%)	3.32	5.72	3.95	22.13	1.69	27.84	5.64	36.80
BSAI Bycatch (-20%)	2.51	5.72	2.71	22.13	2.92	27.84	5.64	36.00
Extended accounting								
BSAI Bycatch (+20%)	3.32	5.71	3.95	21.78	1.62	27.48	5.57	36.36
BSAI Bycatch (-20%)	2.52	5.72	2.71	22.50	3.00	28.23	5.71	36.46

Table 14. Final 2013 decision table results.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2015		in 2017		in 2015		in 2017		in 2015		in 2017		in 2014
2014 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Harvest rate	is less than 2014	is 5% less than 2014	is less than 2014	is 5% less than 2014	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2014	is 10% less than 2014	is less than 2014	is 10% less than 2014	is above target
No removals	0.0	0.0	0.0%	5/100	<1/100	23/100	4/100	3/100	<1/100	1/100	<1/100	0/100	0/100	0/100	0/100	0/100
FCEY = 0	11.4	0.0	5.0%	31/100	<1/100	32/100	18/100	3/100	<1/100	2/100	<1/100	0/100	0/100	0/100	0/100	<1/100
	20.0	8.5	10.1%	33/100	<1/100	37/100	24/100	4/100	<1/100	3/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	30.0	18.2	15.9%	39/100	<1/100	66/100	41/100	4/100	<1/100	5/100	<1/100	5/100	2/100	8/100	4/100	7/100
Blue Line	36.4	24.5	19.7%	56/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	43/100	20/100	74/100	47/100	50/100
Final adopted	39.6	27.5	21.5%	67/100	1/100	87/100	72/100	5/100	<1/100	8/100	1/100	80/100	46/100	95/100	81/100	89/100
	40.0	28.0	21.8%	68/100	1/100	87/100	73/100	5/100	<1/100	8/100	1/100	85/100	52/100	96/100	84/100	92/100
	45.0	32.8	24.7%	82/100	4/100	93/100	83/100	6/100	1/100	10/100	1/100	>99/100	95/100	>99/100	99/100	>99/100
status quo	48.5	36.1	26.7%	88/100	8/100	95/100	87/100	6/100	1/100	13/100	1/100	>99/100	>99/100	>99/100	>99/100	>99/100
	55.0	42.6	30.5%	95/100	23/100	98/100	94/100	6/100	1/100	19/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
	60.0	47.5	33.5%	98/100	38/100	99/100	97/100	7/100	1/100	26/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
				a	b	c	d	e	f	g	h	i	j	k	l	m

Table 15. Comparison of alternative 2013 decision table results based on changes in bycatch and U26 mortality accounting: row a) 2013 Blue Line, b) 20% reduction in coastwide bycatch in 2014, c) 20% reduction in coastwide bycatch in 2014 maintaining target SPR, d) 20% reduction in 2014 bycatch in areas 4A, 4B, and 4CDE, and e) 20% reduction in 2014 bycatch in areas 4A, 4B, and 4CDE maintaining target SPR. Rows correspond to apportionment and harvest policy tables above and are ordered by increasing total mortality.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2015		in 2017		in 2015		in 2017		in 2015		in 2017		in 2014
2014 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Harvest rate	is less than 2014	is 5% less than 2014	is less than 2014	is 5% less than 2014	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2014	is 10% less than 2014	is less than 2014	is 10% less than 2014	is above target
b	35.8	25.4	19.7%	55/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	55/100	26/100	81/100	57/100	49/100
d	36.0	25.1	19.7%	55/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	50/100	23/100	78/100	53/100	49/100
a	36.4	24.5	19.7%	56/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	43/100	20/100	74/100	47/100	50/100
e	36.5	25.5	19.9%	57/100	1/100	83/100	64/100	5/100	<1/100	6/100	1/100	52/100	24/100	80/100	55/100	51/100
c	36.5	26.0	20.0%	58/100	1/100	83/100	65/100	5/100	<1/100	6/100	1/100	57/100	27/100	83/100	59/100	50/100

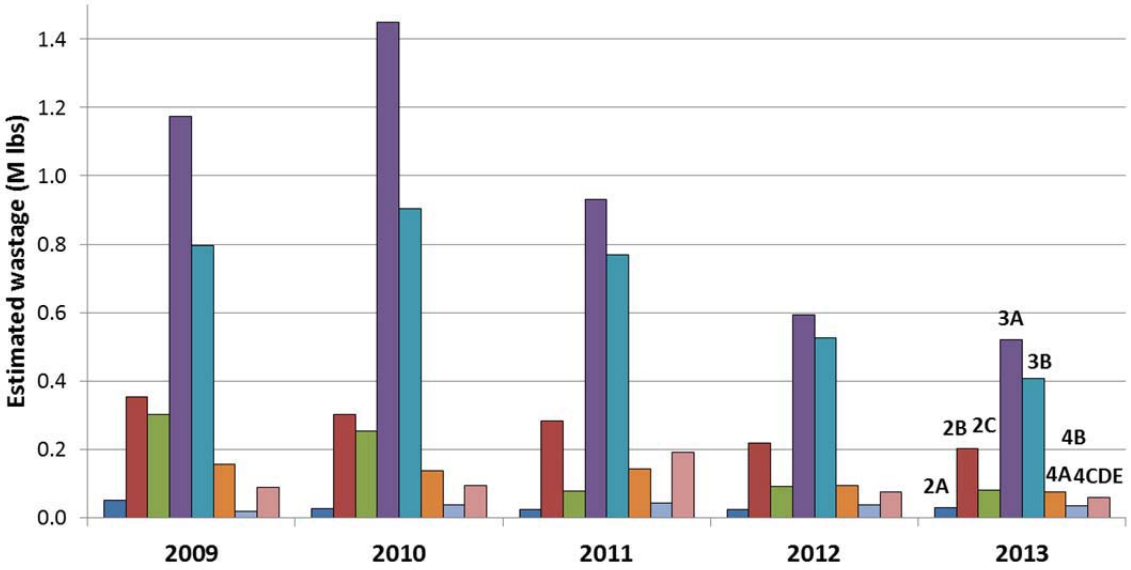


Figure 1. Wastage estimates by IPHC regulatory area over the period 2009-2013.

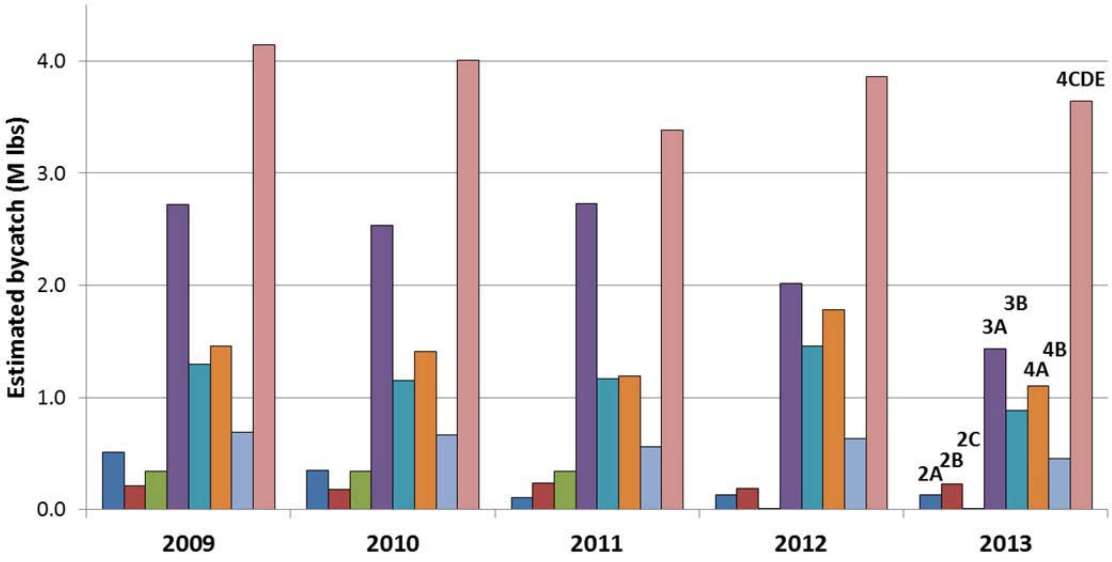


Figure 2. Bycatch estimates by IPHC regulatory area over the period 2009-2013.

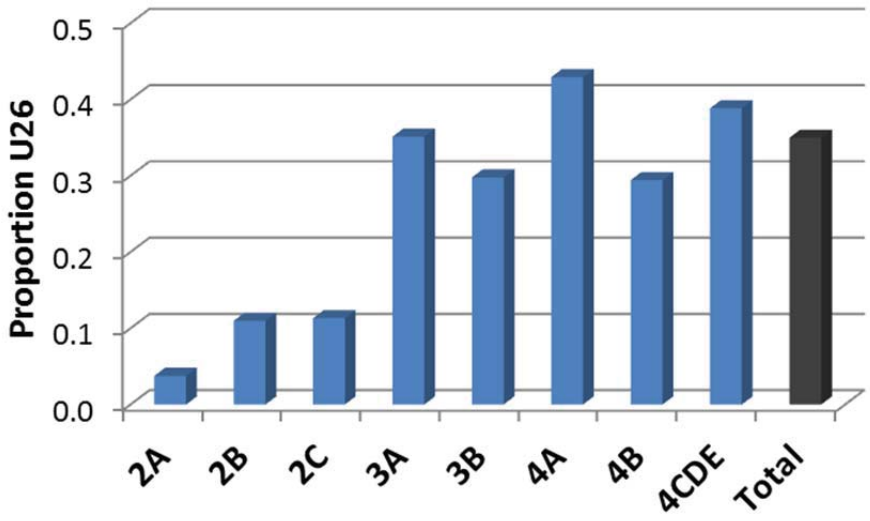


Figure 3. Estimated proportion of U26 halibut bycatch by regulatory area averaged over the period 2009-2013.

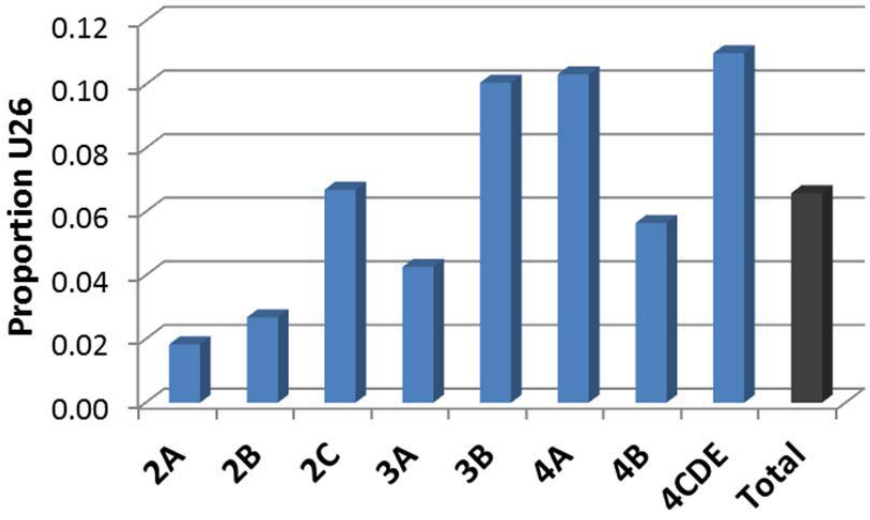


Figure 4. Estimated proportion of U26 halibut wastage by regulatory area averaged over the period 2009-2013.

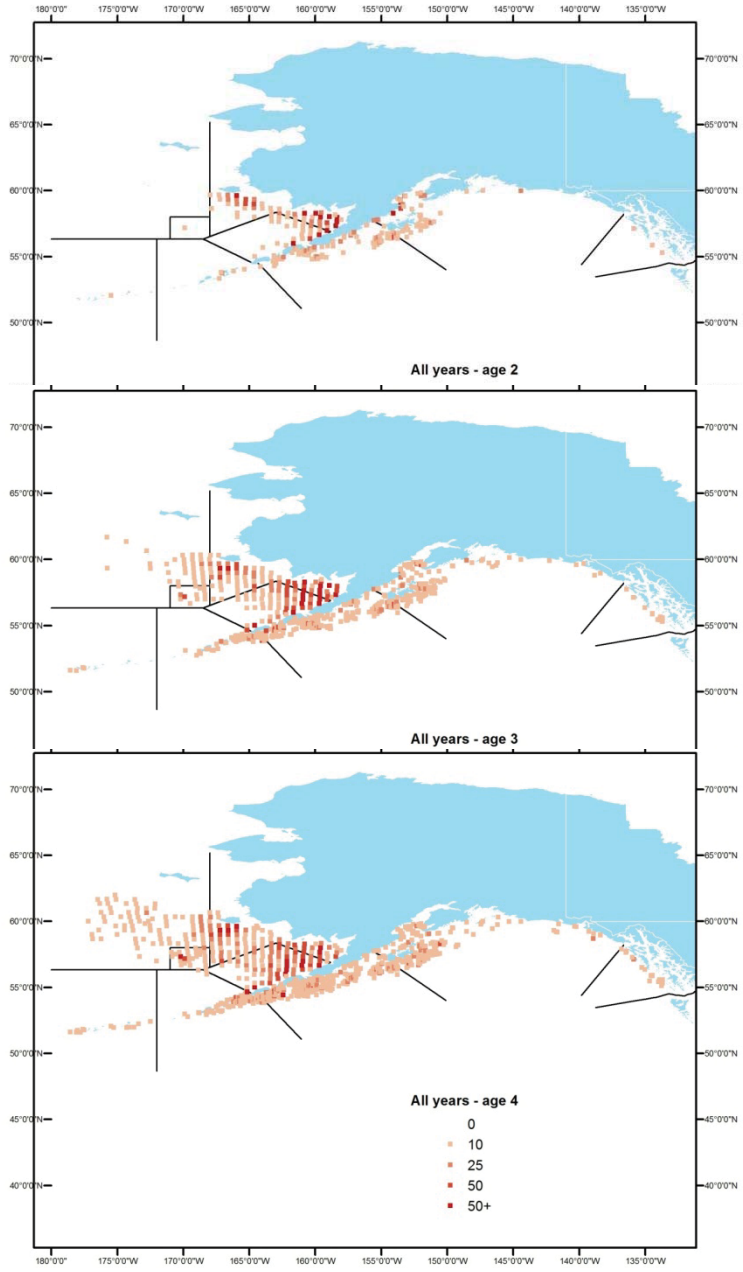


Figure 5. Distribution of aggregate halibut catch for age 2 (top panel), age 3 (middle panel), and age 4 (lower panel) from all available NMFS Bering Sea, Aleutian Islands, and Gulf of Alaska trawl surveys (Sadorus et al. 2015).

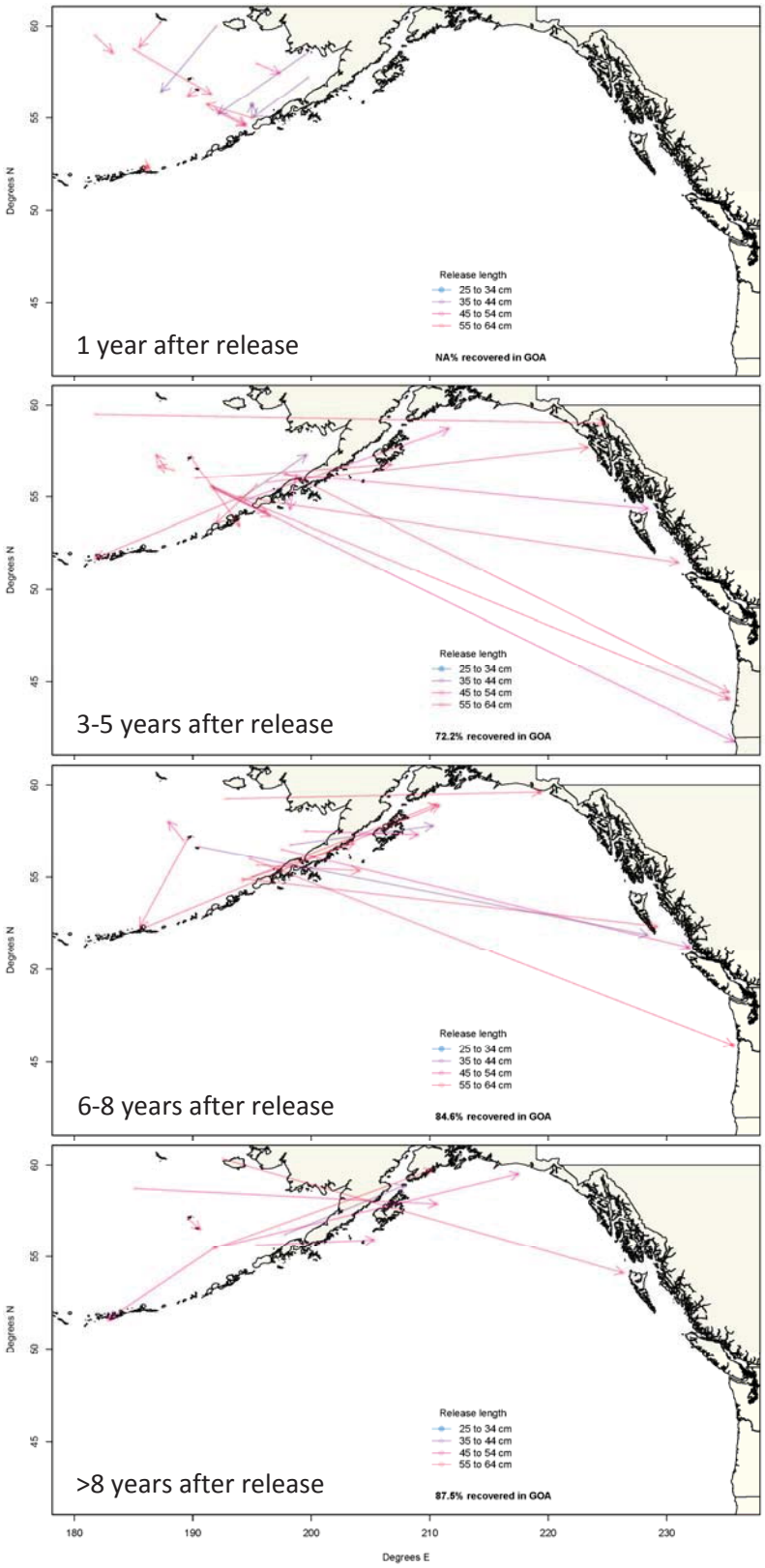


Figure 6. Release and recovery locations for juvenile halibut tagged in the Bering Sea, grouped by time at large (From: Webster, in prep.)

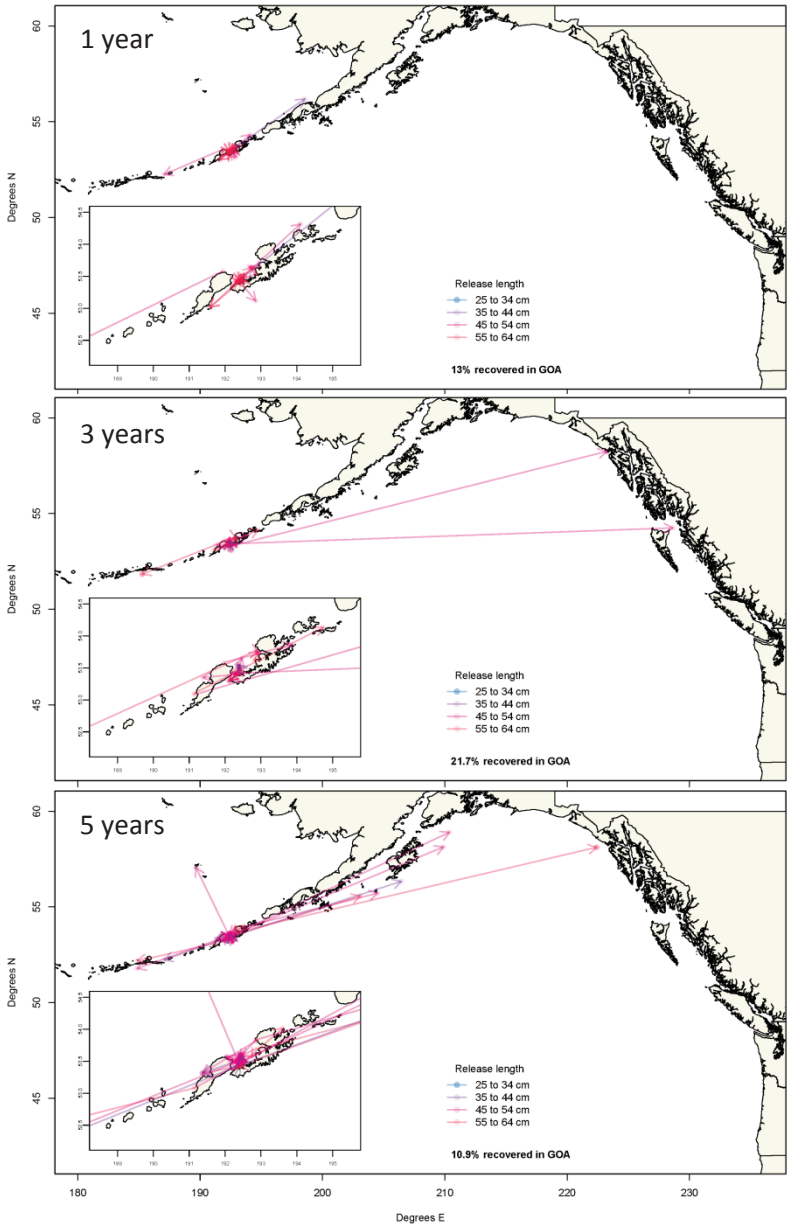


Figure 7. Release and recovery locations for juvenile halibut tagged near Unalaska, grouped by time at large (also see next figure; From: Webster, in prep.).

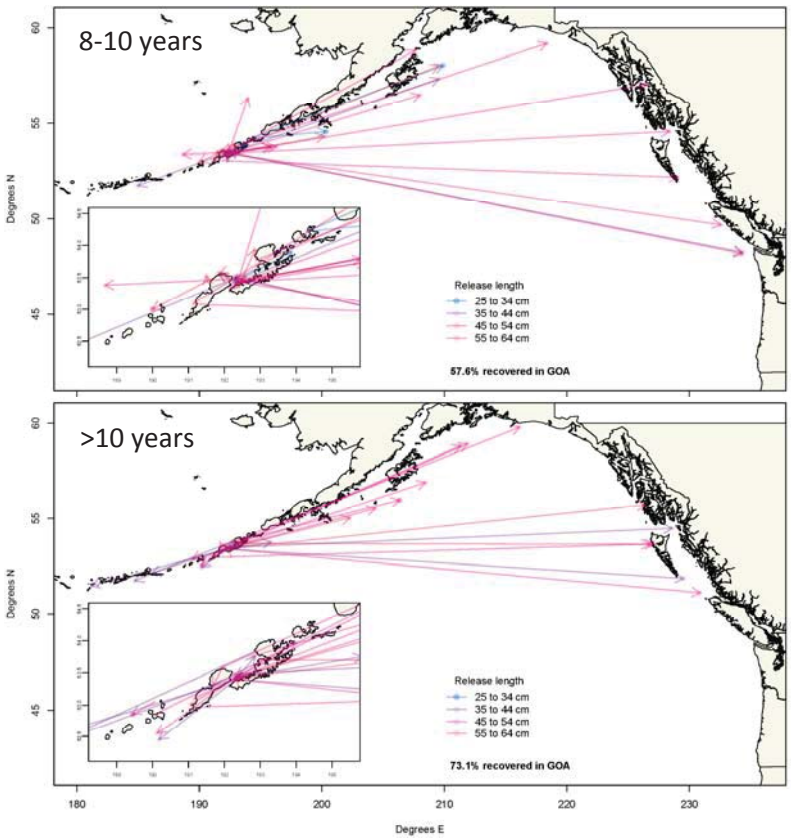


Figure 8. Release and recovery locations for juvenile halibut tagged near Unalaska, grouped by time at large (also see previous figure; From: Webster, in prep.).

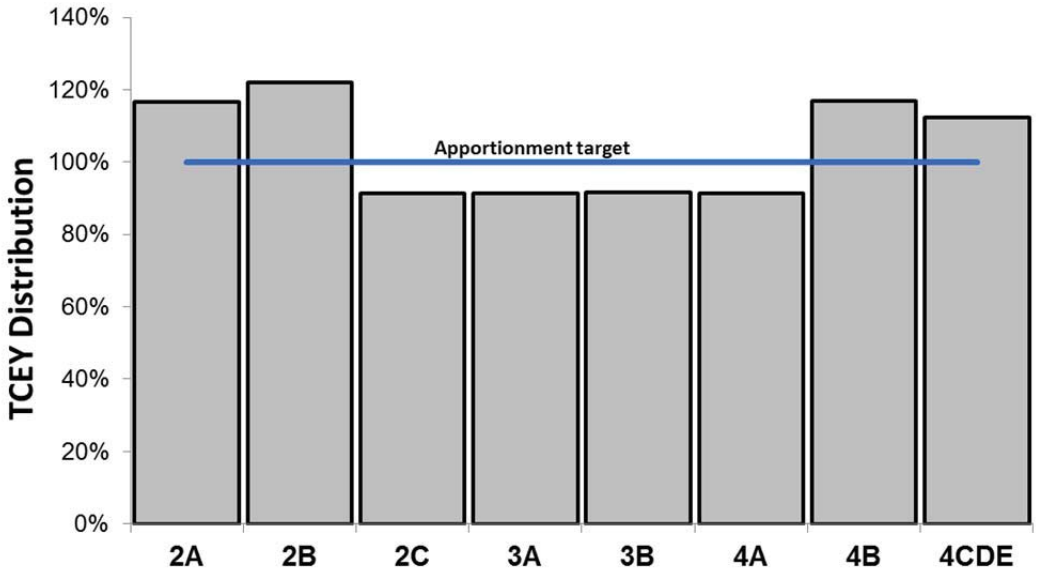


Figure 9. Relative distribution of the TCEY from the 2014 adopted catch limits.

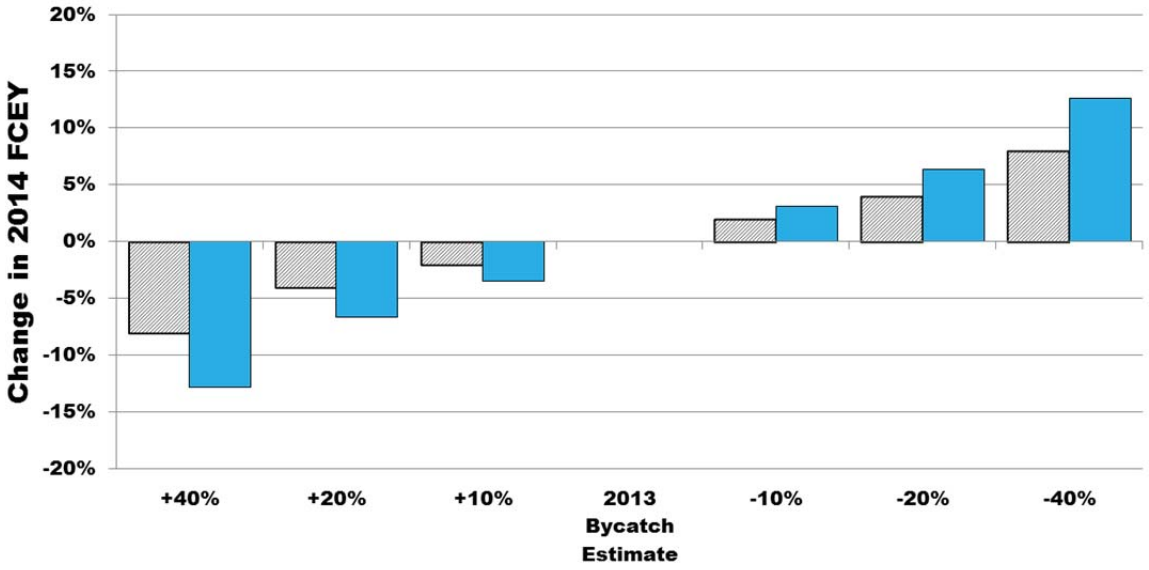


Figure 10. Change in projected coastwide 2014 FCEY in response to changes in coastwide halibut bycatch. Gray bars (left) indicate the application of current harvest policy directly accounting for only O26 mortality, darker blue bars (right) indicate an extension of this policy explicitly accounting for all mortality by maintaining the same level of fishing intensity (SPR) for all scenarios.

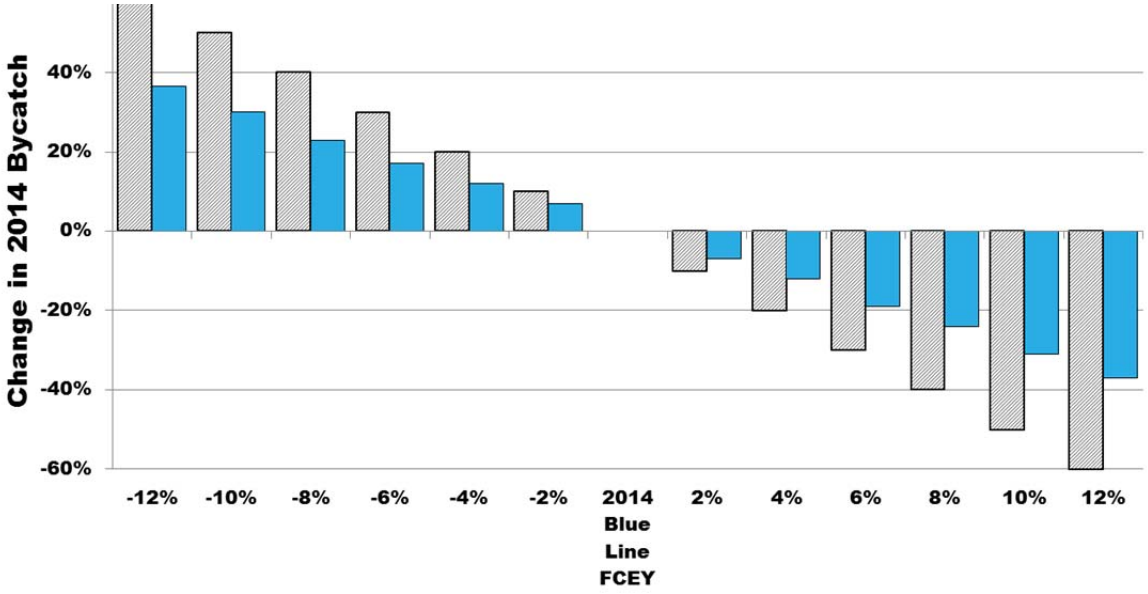


Figure 11. Change in projected coastwide 2014 Bycatch in response to different coastwide halibut FCEYs. Gray bars (indicate the application of current harvest policy directly accounting for only O26 mortality, darker blue bars indicate an extension of this policy explicitly accounting for all mortality by maintaining the same level of fishing intensity (SPR) for all scenarios.

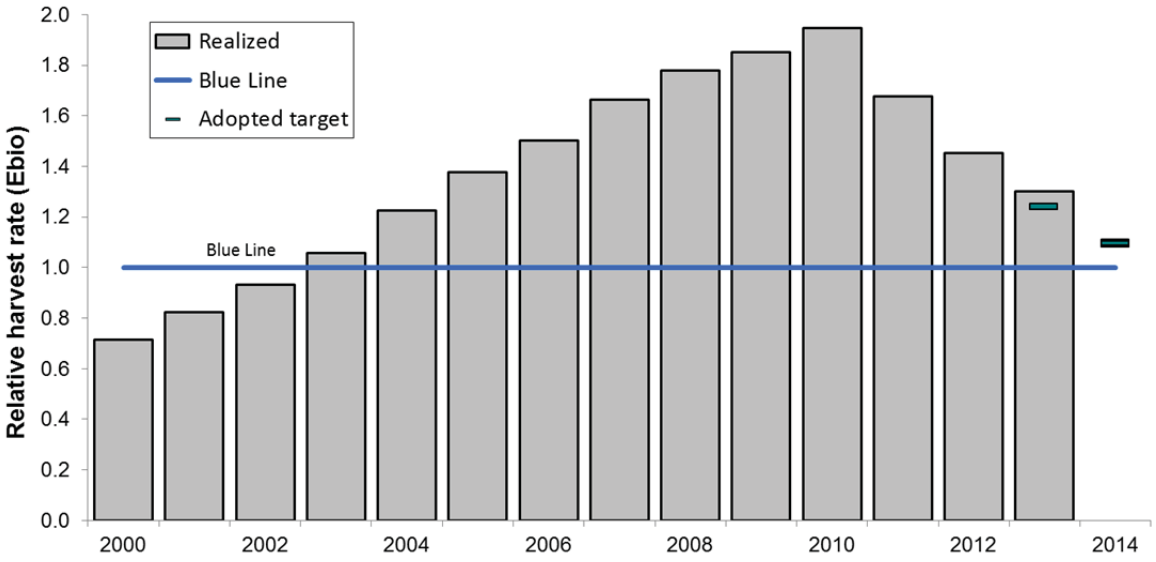


Figure 12. Recent relative harvest rate trends estimated via O26 removals and exploitable biomass.

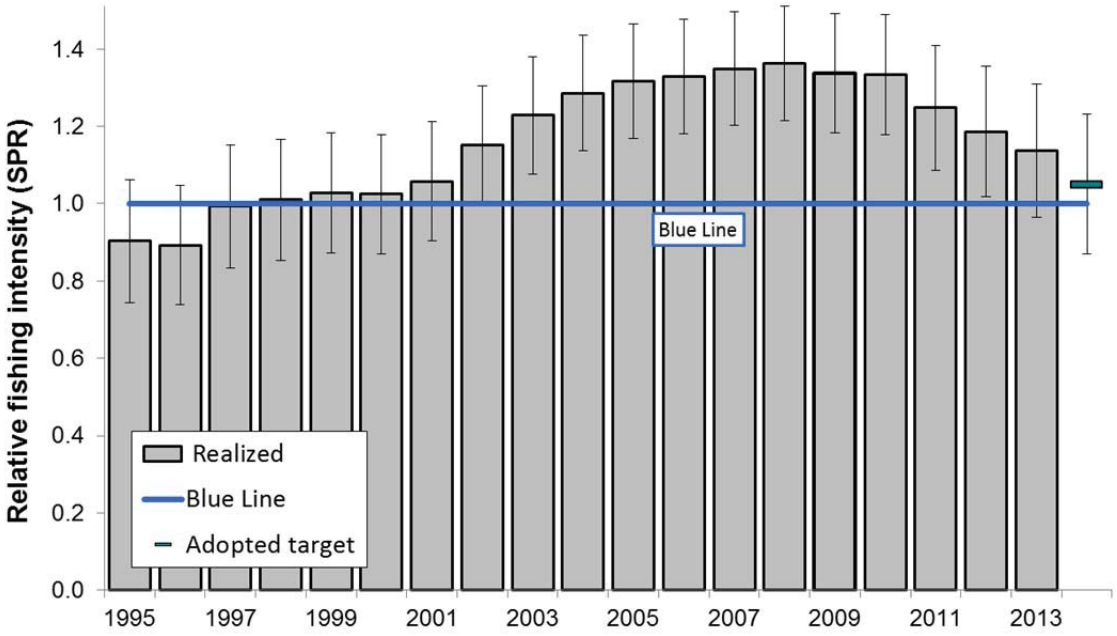


Figure 13. Recent relative harvest rate trends estimated via SPR calculated using the long-; time series model from the 2013 stock assessment ensemble.

Reports of the IPHC Scientific Review Board, 2014

Sean P. Cox, Chair
Simon Fraser University, Burnaby BC, Canada

James Ianelli
National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle WA, USA

Marc Mangel
University of California, Santa Cruz CA, USA

Introduction

In 2013, the International Pacific Halibut Commission (IPHC) formed a Scientific Review Board (SRB). The purpose of the SRB is to provide scientific review of Commission science products and programs, support and strengthen the use of a credible, effective stock assessment process. In the near term, this is expected to focus on a review of the annual stock assessment model and harvest policy prepared by IPHC staff. Over time, this emphasis will shift to broader review scientific programs, as well as of the annual stock assessment results and advice. The SRB will also conduct other key reviews, as determined by the Commission, which may include: the Five-Year Research Plan, updates and changes to survey methodology, white papers on selected critical issues, etc.

This report contains the results of two reviews conducted by the SRB during 2014: a review of the Commission stock assessment, management strategy evaluation, and long-term research plans held in June; and, a review of progress on stock assessment issues, held in October. The results of the two meetings are presented separately in this report.

IPHC Scientific Review Board Meeting

June 2014

Dr Sean P. Cox, Associate Professor, School of Resource and Environmental Management, Simon Fraser University, 8888 University Dr., Burnaby, B.C., Canada V5A 1S6

Dr James Ianelli, Research Scientist, National Marine Fisheries Service-NOAA, 7600 Sand Pt Way NE, Seattle, WA, USA 98115

Dr Marc Mangel, Distinguished Research Professor and Director, Center for Stock Assessment Research, University of California, Santa Cruz, CA 95064

Overview

We met for a whole day on June 23, 2014. IPHC staff reviewed their current research on Halibut stock assessment, management strategy evaluation, long-term research plans. This brief report is meant to provide a summary of the status and progress on key IPHC research topics.

5-year Research Plan

The long-term research plan is guided by Article III of the Halibut Convention which states:

> *"The Commission shall make such investigations as are necessary into the life history of the Halibut and may conduct or authorize fishing operations to carry out such investigations...for the purpose of developing the stocks of Halibut of the North Pacific Ocean and Bering Sea to levels which will permit the optimum yield from that fishery, and of maintaining the stocks at those levels..."*

While we understand the need for broad policy statements like this to provide general guidance on research, the mandate seems too broad to be useful in guiding a 5-year research plan aimed at improving Halibut fishery management.

Applied fisheries research needs to have a clearer and more concrete mandate that is achievable within the 5-year timeframe. One way to improve the clarity and focus of the plan is to substitute unfocussed statements such as: ""it is important that this [stock] structure be correctly understood..." with more achievable goals like: "identify and assign relative plausibility to least two alternative hypotheses for stock structure and mixing to be used in operating model scenarios." The latter form is consistent with the Management Strategy Evaluation (MSE) approach that IPHC is actively pursuing and will naturally lead to some very specific research challenges and objectives that could be accomplished within 5 years.

A 5-year research plan is very similar to large academic grant writing, so we encourage IPHC staff to consult that literature for specific strategies that would work best in this context.

Bycatch management

Research on the downstream biological effects of Halibut bycatch is an ongoing scientific challenge mainly because of uncertain processes determining movement of juvenile fish. However, even if the biological details were known well enough to warrant management action, institutional barriers currently limit IPHC ability to impose new regulations.

We suggest adding a policy research component to the Research Plan.

Stock Assessment

IPHC staff presented research progress and ideas on three general topic areas – Data Processing, Stock Assessment, and the Harvest Policy.

The main research progress in stock assessment was investigating the so-called "fleets-as-areas" (FAS) approach that we recommended after the October 2013 SRB meeting. The FAS approach could potentially improve the assessment model quality, as well as general utility by representing some of the spatial aspects of the Halibut fishery within the coastwide stock assessment model. Separating the IPHC survey data into spatial areas is relatively straightforward and, at our meeting, IPHC staff presented some preliminary results examining area-specific trends within the CPUE and age-composition data. The most notable Data Processing challenge at the moment is determining area-specific U26 Halibut weight-at-age

The spatial approximation provided by the FAS approach could help in preliminary evaluations of the downstream effects of bycatch. However, IPHC staff noted challenges posed by gaps in understanding Halibut pre-recruit biomass trends, spatial distribution, and movement. Although this is clearly an interesting question that could be relevant to the overall IPHC mandate, it is likely a type of question that is more appropriately addressed within the MSE research because it integrates over multiple spatial processes in the Halibut population and fisheries. Furthermore, it is not clear how information about sub-legal Halibut abundance or trends would be used within the current decision-making framework. Regardless of the context within which sub-legal Halibut bycatch is examined, there will be serious data challenges because of limited size frequency coverage in observer samples and unknown sampling rates mainly in the GOA.

IPHC staff are investigating more effective ways of communicating with decision-makers. One approach is to incorporate U26 mortality into the harvest policy information to make it clearer how O26 catch limits affect mortality over all sub-sets of the stock.

We note that decision-makers operating in different institutional contexts (e.g. NPFMC vs IPHC vs DFO) may respond better to familiar information. For instance, adopting an approach based on Spawning Potential Ratio (SPR)[1] would be more consistent with information provided to NPFMC. Although we encourage research into more effective communications, the SPR approach presented at our meeting generated some confusion and probably warrants further investigation and review before it is formally used in decision-making context.

In 2013, IPHC used an ensemble modeling approach in which multiple stock assessment models were fitted to data and then combined to generate harvest advice and decision tables. Models are being investigated for inclusion in this year's ensemble. Notable options include (i) a virtual population analysis, which is an age-structured approach that doesn't require assumptions about fishery selectivity (note, however, that VPA and a statistical catch-age approach will give nearly identical solutions if selectivity is allowed to vary over time in the latter) and (ii) using iSCAM (see MSE comments) to establish a connection with the assessment approach used in the MSE simulations.

---

[1] SPR is the ratio of Spawning Biomass Per Recruit of a fished population to that of the unfished population. When not otherwise annotated, SPR is calculated at the rate of fishing mortality that gives Maximum Sustainable Yield. A brief review of SPR can be found in Mangel et. al. 2013. A perspective on steepness, reference points, and stock assessment. Canadian Journal of Fisheries and Aquatic Sciences 70:930-940

We encourage further analysis of BSAI and GOA length frequencies in an attempt to estimate the apparent mortality rate of fish in those areas because apparent mortality could be an indication of movement/emigration.

Management Strategy Evaluation

IPHC staff noted that stakeholder uptake of MSE has been slow and that the process continues to require a large education component. Slow uptake of MSE is not uncommon where it has been attempted and it is also not surprising given the biological and political complexity of Halibut fishery management.

IPHC staff is making good progress in developing state-of-the-art stock assessment modeling and simulation tools needed to support the MSE process.

Similar to the 5-year research plan (described above), the Halibut MSE process faces challenges in establishing a clear and concise set of goals and objectives.

Some possible questions and issues that could be investigated:

- What differences do stakeholders see between MSE and the annual stock assessment? There are some instances where MSE-type questions are raised in stock assessment research (e.g., downstream effects of bycatch) and this may create the perception that MSE is redundant to stock assessment. Similarly, the stock assessment seems to investigate harvest policy issues independent of MSE context.
-
- What are the key challenges facing each fishery that the annual stock assessment does not address? Which of these are controllable and which are uncontrollable? This exercise could help stakeholders understand how MSE can help improve outcomes in the presence of the uncontrollable factors.
-

Finally, we are concerned that the names and visual images of the models (iSCAM, a cow, and a chocolate bar) may tend to cause some stakeholders to dismiss the work. We suggest considering Halibut or fishery related names for the assessment and operating models, to add gravitas, and increase the likelihood of buy-in by stakeholders.

IPHC Scientific Review Board Meeting

October 2014

Dr Sean P. Cox, Associate Professor, School of Resource and Environmental Management, Simon Fraser University, 8888 University Dr., Burnaby, B.C., Canada V5A 1S6
Dr James Ianelli, Research Scientist, National Marine Fisheries Service-NOAA, 7600 Sand Pt Way NE, Seattle, WA, USA 98115
Dr Marc Mangel, Distinguished Research Professor and Director, Center for Stock Assessment Research, University of California, Santa Cruz, CA 95064

18 November 2014

Overview

We were asked to comment on both

- 2013-14 progress on SRB Oct 2013 recommendations

and

- 2014 progress on SRB June 2014 recommendations.

General comments

Although we feel reasonably well informed about the stock assessment data and models, our future contributions to IPHC science and stock assessment research will require detailed mathematical specifications of the models in the assessment ensemble, as well as dynamic pool and operating models used for the MSE. Specifically, we will need formal descriptions of the models, including the equations and explanations of how parameters are determined. We are cognizant of the time requirements of IPHC staff, so this material can be reported to us as the methods section of a putative paper.

Additionally, providing the key input files (e.g., for 2014 SS3 model runs) might help in future to pick up on details that are difficult to portray in a presentation. This would allow the SRB to learn more about the configuration, assumptions, and overall results by running the model and looking at specific outputs.

It is clear that the fishery has been dominated by the 1987 year-class, which was exceptional, and for that reason management has been buffered in a way that we cannot expect in the foreseeable future. We encourage the IPHC staff to start thinking now about the potential scientific and management implications of those issues.

Response to specific IPHC questions

1. How should alternative models and sources of uncertainty be best incorporated into the 2014 ensemble and decision table results?

We recommend adopting the expanded catch table, but with revisions as discussed for presentation, namely to present table sub-sections in any PPT presentations and the full table in assessment documents.

1a. Candidate stock assessment models for the 2014 ensemble

Comments on the candidate models for the 2014 ensemble

VPA-ADAPT is based on the tenuous assumption that age-specific survey trends and observation errors are independent. We note differences in scale, but similar trends between this model and other candidates for the ensemble and the terminal spawning biomass estimates were very similar to the coastwide model. The ***VPA-ADAPT*** retrospective pattern is not very good, which seems to be typical of this approach.

The ***Areas As Fleets (AAF)*** model is based on assumptions that are similar to the coastwide assessment model, but takes better account of spatial differences in fishery selectivity. We suggest a review of the female and male selectivity-at-age functions because there appears to be some constraint in how much these can vary between fleets (or over time?). Consistent appearance of males at older ages in this model should be investigated.

In the ***AAF-Long*** model, area-specific weight-at-age is difficult to obtain outside the short period. We consider it worth investigating how area-specific weight-at-age assumptions affect differences between the ***AAF-Short*** and ***AAF-Long*** models over a comparable period (i.e., the short period).

We note that the ***AAF-Long*** model fit shows odd residuals at the extra 20-year-old plus group, as well as some other areas, and we suggest closer investigation of these patterns.

In the ***Coastwide-Short***, model the plus group was over-estimated for the period 1997-2001 and there was a large plus-group residual at age-20 that should be investigated. The retrospective pattern is slightly worse than the ***AAF-Short*** model.

For the ***Coastwide-Long*** model, we encourage IPHC staff to investigate why higher natural mortality (M) leads to higher biomass and lower M implies lower biomass (this is possibly caused by linear growth). This is a puzzle worth solving.

Recommendations

We recommend the following models for the 2014 ensemble: ***Coastwide-Short***, ***Coastwide-Long***, ***AAF-Short***, and ***AAF-Long***.

1b. What aspects of data analysis and stock assessment model development should be prioritized for 2015?

We suggest that IPHC staff consider adding a spatial model component to the ensemble by fitting area-specific models with halibut movement/exchange among areas. For example, one could explore a multi-stock delay-difference approach. In addition, a model in which movement propensities were fit (called a gravity model by the UBC crowd) to generate Markov movement probabilities could be explored.

It appears to us that uncertainty in the Bering Sea indices is under-estimated since, as far as we can tell, only the point estimates are used in the calibration. We recommend investigating methods for propagating trawl survey measurement errors through the trawl-longline survey calibration model.

Sensitivity to the AAF models' assumed weight-at-age by fleet should be conducted and where possible, regional estimates should be developed (or defended if data are limited).

More study on halibut abundances in the EBS should be pursued, particularly if resources become available for another calibration survey. Also, it may be possible to more explicitly evaluate the EBS model (see Appendix) compared to the coastwide model to provide a better accounting for U26 fish. Also the comment about assumed observation errors in the EBS setline index being small also would apply to this analysis.

An evaluation of models using discard mortality parameters within the model (with a prior) should be pursued.

The SPR image is effective at communicating what is probably non-intuitive to most Commissioners and stakeholders. The approach presented to us is one possibility, but we recommend trying some variations. For instance, one could use a single halibut, chopped into various pieces. If SPR is going to be a major tool, we suggest that the Commission invest in a design and communications specialist to develop the most informative communications tool. In addition, F_{SPR} implied by F_{MSY} should be explored. Finally, we note that SPR calculations in the assessment and in the catch tables are different.

A communications consultant could also help in a developing a graphical explanation of replacement yield and surplus production based on existing stock assessment models.

2. Is the coastwide operating model structure appropriate for use by the MSAB and Commission?

We note the progress made over the past year on the coastwide halibut operating model. There has been considerable progress in two directions. First, IPHC staff developed a steady state analytical framework for addressing interrelationships among halibut biology, size and slot limits, discard mortality rates, and catch composition among fleets. The web-based platform and interface are critically important for the future MSE process for halibut, because it provides a vehicle to engage stakeholders (and commissioners) in the analytical process. Stakeholder ownership is the single most important factor in establishing a productive MSE process and the web-based interface represents a way for stakeholders to get involved and stay informed.

Our recommendations are these:

a. IPHC staff should continue developing the web-based interface as well as an efficient mechanism for training stakeholders. In particular, (i) add a "Biology" tab to the interface to summarize biological assumptions and data, (ii) include a long-term projection from one of the current assessment models to demonstrate what is meant by "equilibrium" and how it relates to the current assessment.

b. Rapid feedback will probably be important for non-IPHC users of the web-based model. Considerably faster response times may be achieved using simulation methods applied in other contexts (e.g., climate models, cosmology, complex systems); see Lee (2004), Kaufman et al. (2011), Wolters and Bingham (2011), and Gramacy and Lian (2012). Briefly, these methods pre-compute simulation model outputs over a high-dimensional grid of control inputs and then fit statistical models to the outputs. Treating the output like a spatial model, for example, allows one to apply powerful tools such as Bayesian spatial hierarchical models in which the outputs at unsampled points can be modeled via GLMs for the deterministic part and conditional auto-regressive spatial effects for the random parts. Output from these models would be nearly instantaneous to compute and therefore useful for rapid feedback as well as for designing simulation experiments. Cox and Mangel have colleagues who work exactly in this area and will gladly provide introductions for IPHC staff.

   It may be worthwhile exploring the possibility of a statistics graduate student supported at UCSC or SFU to do this work.

c. It is highly likely that the Commission will continue to rely on statistical catch-at-age (SCAA) modeling for annual assessments. Therefore, we recommend investigating a fast and efficient SCAA model (e.g., short coastwide) for use in preliminary MSE simulations. Some research will be needed on the structure of age-composition errors and biases if the simulations are to be representative of future SCAA model performance.

d. Investigate methods to characterize historical TAC decision-making behaviour well enough to be captured in quantitative models. MSE simulations will need to be "believable" to stakeholders in the sense that decision outputs from the simulations should be consistent with historical decisions under similar circumstances.

References

R.B. Gramacy, H. Lian. 2012. Gaussian process single-index models as emulators for computer experiments. *Technometrics*, 54: 30-41

Kaufman, C., Bingham, D., Habib, S., Heitman, K. and Friedman, J. 2011, "Efficient Emulators of Computer Experiments Using Compactly Supported Correlation Functions with an Application to Cosmology", *Annals of Applied Statistics*, 5, 2470-2492. □

Lee. H.K.H. 2004. Bayesian Nonparametrics via Neural Networks. ASA-SIAM Series in Statistics and Applied Probability, SIAM, Philadelphia, PA

Wolters, M.A. and Bingham, D. 2011. Simulated Annealing Model Search for Subset Selection in Screening Experiments. *Technometrics*, 53: 225-237.

Appendix: Eastern Bering Sea (EBS) Model of Juvenile Halibut Population Dynamics

The EBS model was developed to investigate patterns in apparent mortality rates of small halibut occupying this region and captured in EBS trawl surveys. Trawl survey catch rates in EBS indicate an increase in abundance around 2006 followed by decline. There is no directed halibut fishing in this region, so inter-annual variation in estimated mortality rates should arise from some combination of (i) natural mortality; (ii) emigration from the region; (iii) bycatch mortality in non-halibut fisheries; and (iv) survey catchability, which could change with environmental factors (e.g., temperature) similar to other flatfishes in the region.

The EBS model is an interesting initial exploration into the possible linkages between halibut in the EBS and the Gulf of Alaska. We therefore recommend continuing investigations with this model. For instance, the model could be used to compute a net export of halibut from the EBS to compare with expected juvenile input the GOA. Trawl survey estimates averaging approximately 330 million pounds of mainly small (juvenile) halibut are much larger than the estimated juvenile halibut bycatch in the region, which is approximately 4 million pounds. It would be useful to determine whether the apparent bycatch mortality derived from this model (e.g., 100% x (4/330) = 1.2%) is on the appropriate scale.

Developments in Management Strategy Evaluation/ Management Strategy Advisory Board

Steve J.D. Martell, Bruce M. Leaman, Stephen W. Keith, and Ian J. Stewart

The Commission's Management Strategy Evaluation process is a formal process in which to evaluate the performance of alternative management procedures for the Pacific halibut stock against a range of scenarios that encompass observation and process uncertainty in stock assessments, alternative hypotheses about stock dynamics and structural assumptions. This process is commonly referred to as Management Strategy Evaluation (MSE) in fisheries science.

To assist and help guide this process the Commission formed a Management Strategy Advisory Board (MSAB) comprised of harvesters (commercial, sport, and subsistence), fisheries managers (DFO and NMFS), processors, IPHC staff and IPHC commissioners. The MSAB works interactively with analysts on the Commission staff to initially define clear measurable objectives for this fishery, define candidate management procedures (MP) for testing within the MSE framework, and define the performance measures to evaluate alternative MPs. A management procedure constitutes the entire decision making process starting with what data to be used in stock assessment, a stock assessment method to interpret the data, a harvest control rule in which to compute yield options and a projection model in which evaluate impacts of alternative yield options on the stock. A series of quantitative measures must be defined in which to evaluate how well each MP performs relative to perfect information. The central role of the MSAB is to define fishery objectives, articulate management procedures, and defining performance measures.

The MSAB held two meetings in 2014 and the summary minutes and agenda for these meetings follow.

MSAB Meeting III – Summary Minutes

May 5-6, 2014. IPHC offices, Seattle WA

Attending: John Woodruff, Scott Meyer, Scott Mazzone, Michelle Culver, Gary Robinson, Jim Lane, Loh-Lee Low, Brad Mireau, Paul Ryall, Ted Assu, Ryan Littleton, Jeff Kauffman, Dan Hull, Bruce Gabrys, Peggy Parker, Tom Marking, Greg Elwood (Day 1), Per Odegaard, Adam Keizer, Robyn Forrest

By Phone: Chris Sporer

IPHC staff: Steve Keith, Bruce Leaman, Steve Martell, Ian Stewart, Jay Walker, Catarina Wor (UBC graduate student)

Absent: Jim Balsiger, Rachel Baker, Rob Kronlund, Shane Halverson

NOTE: The May meeting of the MSAB was webcast and recorded. These summary minutes therefore note highlights and salient points of discussion but do not attribute points to individual speakers. The detailed discussions from the meeting are available in recordings here: https://www.youtube.com/watch?v=dxtK8kkOlkk (Day 1); https://www.youtube.com/watch?v=Iy23JjEtp0I (Day 2); unfortunately, technical issues on Day 2 resulted in only the afternoon session being recorded.

Meeting Objectives (Agenda for the meeting is in Appendix 1)

At its October 2013 meeting the MSAB scheduled its next major meeting for October 20-21, 2014 but also elected to hold a meeting in April/May 2014 to update the Board on progress. Specifically, the May 5-6, 2014 meeting was intended to:

- Receive feedback on objectives based on:
  - Use of the Shiny simulation tool
  - Dialogue with other stakeholders
- Modify candidate procedures based on feedback
- Report on progress in development of coastwide operating model for halibut
- Demonstrate integrated coastwide modelling framework with bycatch and size limit examples, if progress is sufficient; and
- Outline expectations and purpose for October 20-21, 2014 meeting.

Feedback on objectives based on Board members use of tools and dialogue with colleagues

Using the MSE simulation tool

A majority of the Board had spent some time using the simulation tool developed by Dr. Martell. Most found it to be helpful in orienting them to how simulations can be used in the

MSE context. In particular, users appreciated how tradeoffs among objectives were exposed with the tool and how pre-conceived notions on the effects of some procedures or scenarios were overturned. Using the tool highlighted the need for joint consideration of all performance metrics, because procedures did not produce universal or consistent effects on all metrics. However, the exercise left many pining for the next version which would have real halibut data to provide relevance, and to subsequent versions with area-specific features.

Dialogue with other stakeholders

Members reported that their discussions with colleagues elicited a wide range of responses. Some harvesters are taking a 'wait-and-see' attitude to the MSAB process, while others are critically interested in both the objectives and the modelling framework for investigating the scenarios and candidate procedures. The integration of management by the different bodies involved in governing halibut removals (Councils, DFO, IPHC) was a topic of interest to many stakeholders. For harvesters who had not looked in detail at the process, concern was expressed about not 'falling in love with the models' and ensuring that output from the exercises can be validated with real-world observations, to the extent that will be possible. Additionally, some stakeholders want to be reassured that the operating model and scenarios are as realistic as possible and that we don't overestimate our capabilities to understand the true effects of management procedures. Lastly, there is still some confusion by stakeholders about the role of the MSAB and MSE in the decision-making process of the IPHC.

Review and refinement of candidate objectives, procedures, and performance metrics

Members stressed that conservation remains the priority objective of management. There was also a broad commitment to the overarching objectives identified at previous meetings:

- Biological sustainability – identify stock conservation objectives
- Fishery (all directed fisheries) sustainability and stability – identify harvest minimum and acceptable variability
- Assurance of access – minimize probability of fishery closures
- Minimize bycatch mortality
- Serve consumer needs

However, members did spend some time re-visiting the candidate management objectives from previous meetings (Appendix II). It is recognized that the working objectives will evolve as we undertake the process of evaluating them against various scenarios and procedures, and that we are still developing the tools with which to conduct these evaluations. Most felt that it was important to keep all objectives on the table until that process is underway and that we should not be self-censoring objectives or procedures at this stage, although several members noted both the redundancy and conflict included in the draft objectives.

The issue of area-specific vs. coastwide objectives garnered much discussion, with members frequently expressing a desire for area-specific objectives over the long term but recognizing that we will start with coastwide objectives, and that area-specific objectives may not be possible without either very precise knowledge of migration probabilities or strong assumptions about them. Members also felt that it was important to understand the tradeoffs between trying to achieve area-specific objectives simultaneously with coastwide objectives. Regarding the

objectives that specify particular results (e.g., spawning stock levels or specific probabilities), it was recognized that the specific values require evaluation and should not be regarded as ultimate targets until such evaluation occurs. The objective of minimizing bycatch continued to attract the majority of attention and comment, with members desiring to understand both area-specific and coastwide impacts of bycatch mortality. From the perspective of procedures to be investigated, exploring the impacts of variable harvest rates among areas and changing the minimum size limit were high on the list of desirables.

Lastly, Dr. Martell reminded the meeting of some broad principles for the investigations: what objectives and results do we want to achieve, how are we measuring that achievement, over what time interval do we wish to achieve the results, and how badly to we want to achieve them? Casting the investigations in this context should help us prioritize the objectives and results. This process was followed in developing the modified objectives presented later in this report.

Progress and details on development of the coastwide operating model

Dr. Martell and Catarina Wor reviewed the progress on development of the coastwide operating model (OM). The presentation of this material is included on the MSAB website here: MSE OM Presentation May 2014.

Much of the presentation and discussion concerned technical aspects of the model construction and how it handles data inputs from various sources. The general features of the OM are:

- Inherits data structures from any estimation model.
- Stock dynamics: explicit rules for sex, area, stock/group, recruitment, advection-migration.
- Fishery dynamics: explicit rules for fleets, areas, selectivity/availability, size-limits.
- Scientific data: sex-specific data on catch, age composition, size composition, weight-at-age sampling.
- Stochastic variability: recruitment deviations, size/age sampling, relative abundance indices, implementation error.

Most of the details of these features are not yet complete and there is much work still to be done on the OM. Each of the features is described in greater detail in the presentation. However, the first feature of the OM is an extremely important development because the OM will not need to be recoded when the assessment model (which produces the original data series to condition the OM) changes. This important feature resulted from extensive web-based collaboration on the model development by a number of experts from around the world.

The OM will be conditioned on output from the two stock assessment model data periods (1888-2013 and 1988-2013), corresponding to the periods of different data availability (e.g., comprehensive fishery-independent surveys). These two conditioning periods will allow the evaluation of the different data streams to decision making. While the model is still in the development stage, the staff plans to have the operational version reviewed by the IPHC's Scientific Review Board.

Dr. Martell then used the current version of the OM to illustrate its usage with a simple example involving two scenarios (random/independent recruitment vs. environmentally-driven recruitment) and several procedures (no size limit, 82 cm size limit, 82-108 cm size limit, and combination of these limits, with either fixed harvest rates or a 30:20 F_{MSY} control rule harvest).

The demonstration showed both predictable and surprising results. Harvesting at a fixed harvest rate (similar to the current harvest rate) resulted in continuous declines in spawning biomass under either scenario; addition of a minimum size limit reduced the magnitude of the decline and resulted in higher spawning biomass and higher catch. However, it requires more fishing effort for the same catch when a size limit is in place, compared with no size limit. In the case of a management procedure with an 82-108 cm slot limit, the results showed a decrease in spawning biomass compared with a fixed 82 cm limit because both large and small fish had to be discarded, with attendant mortality on some discards. Like the fixed 82 cm size limit, more fishing effort is required for the same weight of catch under the slot size limit. A new term, fishing efficiency, was introduced for consideration as a performance metric. Efficiency refers to the ratio of landed weight (or numbers) to the total weight of landed and discarded fish handled during the catching process.

The Board provided feedback to Dr. Martell on elaboration of performance metrics to be considered for the fishery, including average size of fish in the catch, discard ratio by area, effect of PSC limits on the directed fishery, etc. Dr. Stewart outlined the framework of total mortality accounting that will be presented to the Commission for its consideration at a September work meeting. In this approach, all mortality is presented as part of the yield tables. In comparison, the accounting for U26 mortality is currently embedded within the target harvest rate and not directly visible in the yield tables. This framework will be reviewed by the Commission and the SRB. The eventual product of these reviews will then be brought forward for broader discussion, likely to occur first at the Commission's Interim Meeting in December, 2014.

There is much work on the OM still to be done. The key elements are to implement the model with Pacific halibut data and parameters, determine an appropriate method for seeding recruitment into the population, modify MSY-based reference points to account for size limits and bycatch limits, evaluate current management procedures vs. perfect information, explore alternative harvest control rules and management procedures, develop data structures for spatially resolved modelling, develop frameworks for migration by size, age, and sex, and develop and relate performance measures to stated objectives. The Board expressed a concern that the project remain focused on some achievable goals for 2014 and not get buried in trying to do everything at once. Dr. Martell concurred and explained that an evaluation structure needs to be adequate for eliminating unusable management procedures at an early stage. Not all procedures need to be investigated individually if general patterns are included. A major concern is the non-stationarity of the resource (not all regulatory areas have the same exploitation history or local characteristics). While this cannot be controlled, the OM needs to accommodate it.

The second day of the meeting was largely occupied with further discussions on the performance metrics to be considered and refinement of the candidate objectives. The Board discussed economic performance of the fishery at length, but most felt it was beyond the current scope of the project and that the performance metrics of catch rate, total catch, and biological characteristics of the catch could function as economic proxies for the current investigations. Dr. Leaman reviewed the expectations for the MSE process in 2014, noting that no spatially explicit results are expected, but the goal is to have a fully-functioning coastwide halibut OM for the fall MSAB meeting. He also noted that some of the questions the Board wished to investigate would be addressed only partially in the coastwide model, while others would await the development of a spatially explicit OM. The latter is not anticipated until sometime in 2015.

The Board held a broader discussion on the performance metrics as they pertain to the decision table used at the annual meeting to determine catch limits. There was a diversity of opinions on the utility of the decision table with most believing that the explicit treatment of risk was valuable for decision-making as well as accountability. However, others regretted the loss of direct staff recommendations on a specific catch limit. Staff explained that the entire table represented staff recommendations and that the Blue Line was the anchor point to previous/existing harvest policies, although it did not represent a uniquely acceptable option. Staff also noted that the existing harvest policy needs to be updated – a part of which involves the MSE process. Board members noted that fishing mortality had been reduced over the past several years and was moving in an appropriate direction. It is necessary to do a thorough evaluation of any new harvest policy before replacing the current policy. The Board suggested receiving input on the development of the management procedure process in the Pacific hake and herring fisheries.

The Board spent considerable time refining the candidate objectives and a small working group produced a new table of candidate goals and objectives, with accompanying performance metrics, probabilities, and suggested time frames (Table 1). This table is an attempt to bring some operational clarity and specificity to the five overarching goals identified in previous meetings. The Board's discussion concerned the management procedures to be investigated, as well as the performance metrics. The management procedures included:

- Total mortality: Direct accounting by area for all sources of mortality in that area, including sublegals.
- Size limits: No size limit, current minimum size limit, 26 inches instead of 32, slot limits.
- Harvest strategies: 30:20 control rule, reference removal rate 21.5%/16.125%, coastwide and by area.
- National shares: catch limits by areas would be allocated rather than based on apportionment.
- Bycatch mitigation: Compensation among areas for bycatch in a particular area.

Dr. Martell commented that while the procedures were somewhat general, there were many nuances to them and we need to be careful about the combinatorics that arise from these nuances. It will not be possible to address all of these combinatorics. Dr. Stewart also pointed out that the current apportionment process applies to the O26 biomass and there is no current analogue for allocating U26 biomass.

An extensive discussion on bycatch impacts identified the issue that two separate agencies (IPHC, NPFMC/PFMC) are attempting to control the mortality of halibut. The separate jurisdictions and authorities of the two agencies indicate a need for coordinated management of the entire mortality spectrum, and the Board suggested that something like a joint protocol committee between the agencies would be basic to such coordinated management.

The Board invited staff comments on the table elements and these are included in the table. It was noted that several elements are missing from the table, including procedures involving management of bycatch mortality in non-directed fisheries. Board members noted the need to be aware of unstated objectives which may be embedded within broader objectives. For example, while recreational and commercial fisheries may share broadly similar yield objectives, recreational fisheries may desire larger average size of fish than may be acceptable within a commercial fishery. In addition, the table generally specifies objectives but not the management procedures intended to achieve the objectives.

Future Steps

The Board requested that the staff supply a ranking of objectives, scenarios, and procedures to be evaluated, based on the Board's discussions [see below]. Dr. Martell will make his presentation on the OM available on the MSAB website and inform the Board of availability of simulation tools as they become available. The next meeting of the Board is scheduled for October 20-21, 2014 in Seattle.

Lastly, Dr. Leaman presented a request to have the Board select a Chair or Co-Chairs at its October meeting and to have these individuals report on the MSAB process to the Commission at its Interim Meeting in December. The Board agreed to this process.

Staff ranking of objectives, scenarios, and procedures

The staff's ranking of Objectives for evaluation is the same as that the Board developed in Table 1. That is, conservation being the paramount objective followed by fishery performance issues, and assessing the impacts of other sources of mortality.

In terms of Scenarios, the staff believes that maintaining the two alternative scenarios of environmentally-driven recruitment and variable stationary production is an important and realistic framework for investigation. In addition, the scenarios of variable vs. constant mortality with size/age are a second-tier for examination. The former can incorporate elements of bycatch mortality.

Lastly, the staff believes that, for the coastwide evaluation, target harvest rates, harvest control rules, and minimum size limits are the priority Procedures for investigation. The more involved investigation of migration impacts will require spatially explicit operating and assessment models, which are still some time in the future.

Table 1. Candidate goals and objectives for MSE process – May 2014

Goal	Objective	Performance Metric	Probability	Time frame	IPHC Staff Comments
Biological sustainability	Limit - the level of biomass below which no fishing can occur	1) Maintain a minimum of number of mature female halibut coast-wide (e.g., one million)	0.99	Each year	Number of females and spawning biomass can be equivalent, however this objective could also be evaluated with respect to average female size
		2) Maintain a minimum spawning stock biomass of 20% of the unfished biomass	0.95	Each year	Part of current harvest policy. The probability should be evaluated relative to recruitment variability and yield
Biological sustainability	Threshold - the level of biomass below which the harvest rate should decline	3) Maintain a minimum spawning stock biomass of 30% of the unfished biomass	0.75	Each year	See above.
Fishery sustainability and stability Assurance of access Serve consumer needs	Target Harvest Rate - harvest rate applied when biomass is above threshold level - Maintain median catch within ±10% of 1993-2012 average - Maintain average catch at >70% of	4) Maintain directed fishing opportunity	0.95	Each year	Evaluate probability relative to recruitment variability and minimum annual variation in catch desired by industry. This needs a quantifiable unit in order to calculate a probability, e.g., maintain directed fishing opportunity of xx million pounds each year.

Goal	Objective	Performance Metric	Probability	Time frame	IPHC Staff Comments
	historical 1993-2012 average	5) Maximize yield in each regulatory area	0.5	Each year	* See above. This performance metric is actually an objective and requires a specific value for calculating a probability.
			?	Within 5 years of implementation	* See above.
			0.9	Each year	* The absolute quantities for catch will be difficult to achieve. For example you may never be able to achieve 70% of the average catch in 90 out of 100 cases. In terms of assurance of access in 90 out of 100 cases, adjusting the % of the average catch may be necessary.
Fishery sustainability and stability	Harvest efficiency	Wastage in the longline fishery <10% of annual catch limit	0.75	Over a 5 year period	* The performance metric might be best expressed as the ratio of discards to retained, or sublegal:legal. Wastage is difficult to quantify due to assumptions about discard mortality rate and biases in the observer programs with partial coverage.
Fishery sustainability and	Limit catch variability	6) Limit annual changes in TAC,	1	Each year	* This might be better described as a harvest control

Goal	Objective	Performance Metric	Probability	Time frame	IPHC Staff Comments
stability Assurance of access Serve consumer needs		coastwide and/or by Regulatory Area, to less than 15%			rule or procedure (akin to slow up fast down). The performance metric would be the average annual variability in catch. In this case the AAV <= 0.15 with a probability of 1 each year.
Biological sustainability	Risk tolerance and assessment uncertainty	When Limit < estimated biomass < Threshold, limit the probability of declines	0.05 – 0.5, depending on estimated stock status	10 years	* The performance metric here might better be expressed as the frequency that Blimit < estimated biomass <= threshold, and the desired probability of being in this window is on the order of 0.05-0.5 over a 10 year window.

* Many of the performance metrics are likely to interact with both conservation targets and harvest rate objectives, and their probabilities will be dependent on recruitment variation and desirable/acceptable economic standards of participants. Finding the balance of these competing objectives is the primary purpose of the MSE process.

Appendix I – Agenda

Monday May 5, 2014

12:30 PM:	Welcome, introductions and format for meeting
12:45 PM:	Meeting objectives and questions
1:00 PM:	Review and refinement of candidate fishery objectives and performance metrics for investigation, based on feedback since last meeting
2:00 PM:	Experience of the MSAB with existing simulation tool
2:30 PM:	Break
2:50 PM	Introduction of coastwide operating model and features
3:30 PM:	Demonstration of application of coastwide model with bycatch scenario
4:30 PM:	Discussion of alterative procedures to investigate, e.g., size limit changes
5:00 PM:	Adjourn

Tuesday May 6, 2014

8:00 AM:	Coffee and pastries
8:30 AM:	Recap of first day
9:00 AM	Refinement of evaluation framework for management procedures and further investigation of candidates
10:00 AM:	Break
10:30 AM:	Implications of 2013 stock assessment results to MSE outline
12:00 PM:	Lunch
1:00 PM:	Tasks for staff and MSAB for the next meeting (October 20-21, 2014)
2:30 PM:	Discussion, feedback, & closing remarks
3:15 PM:	Adjourn

Appendix II – Working objectives and performance metrics

The working fishery objectives from the previous MSAB meetings:

1. Maintain a minimum of number of mature female halibut coast-wide (e.g., one million) in each year with a probability of 0.99.
2. Maintain a minimum spawning stock biomass of 20% of the unfished biomass in each year with a probability of 0.95 (spawning biomass limit).
3. Maintain the spawning stock biomass above 30% of the unfished biomass in each year with a probability of 0.75 (spawning biomass threshold).
4. Maintain directed fishing opportunity each year, conditional on satisfying objectives 1 and 2, with a probability of 0.95 (i.e., cannot afford to close the directed fishery for a single year).
5. Maximize yield in each regulatory area each year without exceeding the target harvest rate in a given area 50% of the time.
6. Limit annual changes in TAC, coastwide and/or by Regulatory Area, to less than 15% per year, conditional on satisfying objectives 1 and 2.
7. Maintain median catch within ±10% of 1993-2012 average within five years of implementing the procedure.
8. Maintain average catch at >70% of historical 1993-2012 average, 90% of the time.
9. Reduce bycatch mortality to within 5% of total catch limits/minimize bycatch to the extent practicable.

The working performance metrics from the previous MSAB meetings:

1. Absolute number of sexually mature female halibut (re: objective 1).
2. Ratio of current SSB relative to unfished SSB_0 (where SSB_0 is based on current size-at-age (re: objectives 1 & 2).
3. Total catch and directed catch from each regulatory area (re: objectives 4, 5, 6, 7, & 8).
4. Legal biomass in each regulatory area in each year (re: objective 5).
5. Bycatch from each regulatory area in each year (re: objective 9).

MSAB Meeting IV – Summary Minutes

October 20-21, 2014. IPHC offices, Seattle WA

Attending: John Woodruff, Scott Meyer, Scott Mazzone, Michelle Culver, Gary Robinson, Jim Lane, Brad Mireau, Paul Ryall, Jeff Kauffman, Dan Hull, Bruce Gabrys, Peggy Parker, Tom Marking, Greg Elwood, Per Odegaard, Chris Sporer, Bob Alverson, Jim Balsiger, Rachel Baker

Visiting: Allan Hicks (Northwest Fisheries Science Center)

Absent: Shane Halverson, Loh-Lee Low, Ryan Littleton, Adam Keizer, Robyn Forrest

IPHC staff: Steve Keith, Tom Kong, Bruce Leaman, Steve Martell, Ian Stewart, Jay Walker, Catarina Wor (UBC graduate student)

NOTES:
This meeting of the MSAB was webcast and recorded. These summary minutes therefore note highlights and salient points of discussion but do not attribute points to individual speakers. The detailed discussions from the meeting are available in recordings here:

Day 1 (currently unavailable)
Day 2

The agenda and presentations from this meeting are also posted on the MSAB webpage:

Agenda
MSAB IV
Table 1
Pacific Hake MSE Process

The IPHC MSE Tool, which is used to review equilibrium simulation results from the operating model, is found at:

https://iphc.shinyapps.io/MSAB/

Meeting Objectives

The objectives for the October 2014 MSAB meeting were:

- Update on the status of the MSE objectives.
- Current status of the coast-wide Operating Model.
- A new tool for exploring alternative policy options.
- Compare notes with the Pacific hake MSE process.
- Set research priorities.
- Selection of chairs and co-chairs, and develop procedures for reporting to the Commission

The agenda for the meeting is included in the Appendix.

Summary Review from MSAB Meeting III, May 2014

The meeting opened with a brief review of the previous MSAB meeting. (Summary minutes of the May 2014 meeting are posted here: http://www.iphc.info/MSAB%20Documents/MSABMay2014SummaryMinutes.pdf)

Dr. Leaman presented the staff comments on the table of candidate MSE goals and objectives developed during the May meeting (Table 1). There was a brief discussion of the term "compensation" regarding bycatch mitigation in the list of candidate management procedures. In this instance, it refers to compensation in the biological sense, rather than in terms of fishery yield or regulations, and the group's focus is on mitigation of impacts. The Board made no changes to the table at this point, noting that further refinement of the table will take place during the MSE process.

Dr. Martell reviewed the size-limit case study from the May meeting as an example of using an evaluation tool with the Operating Model to test candidate management procedures with different scenarios.

A review of highlights from the May meeting led to a discussion of the MSE process and its place in the IPHC decision-making framework, including whether the MSAB would displace other IPHC advisory bodies. Dr. Leaman noted that the MSE process is designed to fit into and inform the IPHC decision-making structure, and that this was a good reason to discuss the MSE governance process later in this meeting. Regarding bycatch impacts in particular, coordinated management of total mortality among the agencies involved will be desirable, and MSE will provide inputs to both assessment and harvest management decisions. Dr. Martell noted that we have likely reached a good plateau in the refinement of management objectives and procedures, and the task now is to proceed with developing the operating model and conduct detailed evaluations.

Conditioning the Operating Model

Dr. Martell presented the current status of the MSE Operating Model, which is now conditioned with halibut data. It is still in the developmental stage regarding the structures of the assessment ensemble models. The Operating Model currently operates at a coastwide level;

spatial data for a four-area model is now ready, and incorporating it to model downstream effects will be the subject of continued work in the coming year.

The Operating Model will be used to model a range of scenarios in three overlapping areas: biological (including such variables as stock recruitment, natural mortality, environmental effects, growth, and migration), management (variables such as data and assessment, harvest policy, allocation, control rules, and agency action), and fishing effort dynamics (variables such as the directed fishery, bycatch fisheries, other fisheries, selectivity, and the setline survey).

Dr. Martell reviewed the differences between procedures – things we can manage – and scenarios – things we cannot manage – both of which include a wide range of uncertainty (see illustration below).

PROCEDURES SCENARIOS

	Things we can manage	Things we cannot manage
Things were certain about	•Size limits •Catch limits •Rate of TAC change •Allocation among sectors •...	•PDO - recruitment variation •Changes in size-at-age •Migration, dispersal •...
Things were uncertain about	•Bycatch •Wastage •Discard mortality rates •...	•Natural mortality •Recent recruitment trends •Range contraction •...

Creating Alternative Scenarios

Dr. Martell explained that scenarios for the Operating Model should bracket the range of hypothesized uncertainty. In contrast to assessment modeling, which aims to fit the available data, the Operating Model should encompass a variety of scenarios that result in divergent policy prescriptions. In response to the question of how to determine if a particular model is a good choice, Dr. Stewart and Dr. Martell discussed the ensemble of three models currently used for assessment, including their assumptions and the differences among them. Stock assessment modeling is focused on portraying the current state of the stock and historical trends. The Operating Model can be used to examine the range of possible outcomes going forward from the current state of the stock. They emphasized the need to limit the Operating Model scenarios to a manageable number, focusing on the largest sources of uncertainty and the greatest impact on harvest policy.

Dr. Stewart presented two examples of sensitivity in assessment modeling to illustrate the concept of focusing on factors with the greatest impact on harvest policy. He noted that a 10% change up or down in the sex ratio of the commercial catch translates into a 50-million-pound range of spawning biomass estimates. Thus the assessment, and by extension, the harvest policy, is very sensitive to variability in the sex ratio. In contrast, spawning biomass estimates are relatively insensitive to the doubling of wastage in the directed commercial fishery. Although greater wastage doesn't change the current state of the stock, it means the stock appears to be less productive from the perspective of directed yield, which leads to reduced optimal harvest rates. Thus, changes in wastage have a large impact on harvest policy even if they don't affect the assessment to a similar degree.

Because of these often counter-intuitive contrasts between sensitivity in the model and sensitivity in the policy, the challenge for MSE scenario modeling is to choose scenarios that fit the data equally well but which encompass alternative assumptions in the resulting policy prescription going forward. Dr. Martell noted that it is useful to focus on the sensitivity of the underlying production function (such as natural mortality, recruitment, and growth) and global scaling (such as B_{100} [unfished spawning biomass]) when considering possible scenarios.

Creating Alternative Procedures

In choosing alternative management procedures to examine, Dr. Martell noted that there are an infinite number of possible combinations of regulations, data, assumptions, and models, quoting Rob Kronlund of DFO: "The combinatorics will kill you." The key is to define a manageably small number of hierarchical objectives in advance, which can be used to screen candidate management procedures. The focus should be on what can be managed, and to pick a range of possibilities robust to changes in things we cannot control (the scenarios).

Dr. Martell introduced the IPHC MSE Tool, a web-based application that uses an equilibrium model to exploring candidate procedures using the MSE Operating Model: https://iphc.shinyapps.io/MSAB/ (nicknamed "Shiny"). The objective of the equilibrium model interface is to better understand the relationship and tradeoffs between policy variables (such as fishing mortality, size limits, and discard mortality rates) and response variables (such as yield, discards, and wastage in the directed fishery) by reviewing simulation results from the Operating Model. It compares alternative procedures developed using the six different harvest variables that can be adjusted:

- Fisheries selectivity,
- Minimum and maximum size limits,
- Discard mortality rate (DMR) for the directed fishery,
- Average selectivity in bycatch fisheries,
- Bycatch mortality from all other fleets, and
- Price per pound for four different size grades.

The model output consists of graphical and tabular results that summarize the biological sustainability objectives, fisheries sustainability objectives, and economic metrics. The harvest policy variables can be set independently for the alternative scenarios and the resulting differences can be compared using the graphical or tabular outputs.

Dr. Martell explained that the IPHC MSE Tool is an equilibrium model, which predicts a steady-state equilibrium outcome given a particular set of input values that are held constant over a range of alternative fishing mortality rates in the directed fishery. It assumes static (or

stationary) underlying processes, but this relative simplicity makes it good for rapid response and analysis within this limitation. In contrast, a dynamic model that can account for processes (such as recruitment variation) or procedures (such as harvest control rules that are functions of stock status) that vary over time is much more complex both to develop and to use in a practical meeting. The process will be to use the equilibrium tools to better understand the long-term consequences of alternative policies, then filter candidate management procedures and further evaluate using a dynamic operating model (which is more computationally expensive than the simple equilibrium model).

The Board explored a series of examples using the tool, including changing selectivities and size limits. This allowed the Board to see the tool in action and better understand how to use it. The accompanying wide-ranging discussion encompassed topics as varied as size at age, the proportion of males in the catch, female fecundity and maternal effects, fishing behavior, wastage, economic incentives, and effects on future spawning biomass. Interactions among these variables were explored, noting which parameters are modeled and which are not, as well as what can be managed and what cannot.

Dr. Martell emphasized that the current tool is a good early realization, but not to over-interpret the results, as time-varying parameters and more detailed economic behaviors or incentives are not modeled. He noted the value of using the tool with an open and organic discussion like this, where the staff can respond directly to questions and the Board can investigate scenarios in real time without having to wait weeks or months to explore model results. He also noted that an equilibrium spatial model is in development, which will further enhance the value of the tool in analyzing candidate management procedures with respect to impacts of migration on harvest policy.

Research Priorities

Dr. Martell opened the discussion of research priorities by noting that MSE is being identified as the vehicle for solving a large number of questions, not all of which are realistic at this time. With so many possibilities to pursue, research priorities need to be listed and ranked.

There are a huge number of moving parts to reconcile in modeling and managing halibut. The "Shiny" equilibrium tool can be used to help construct and evaluate procedures to run later in the dynamic Operating Model. The tool currently models only two fisheries, directed commercial and bycatch, but will eventually include other fisheries relevant to halibut. The four-area model in development will offer an area-specific equilibrium approach where parameters such as migration and DMR can be modeled on an area-specific basis. In the future it will be desirable to consider control rules against a more dynamic background, but in the meantime alternative scenarios in the equilibrium model can be chosen to approximate the range of dynamic inputs. This process can help uncover gaps in knowledge and identify needed research.

The Board engaged in a wide-ranging discussion of research questions, including the following points:

- Some parameters are more important than others. Perhaps sideboards could be developed to focus on the more promising areas. The Board asked for staff advice on key sensitivities and the staff asked for Board feedback from using the tool.
- Suggested possible scenarios included missing fish (under-reporting of catch), variations in migration, change in size at age, and minimum size limits.

- The precision of modeling is limited by the precision of data. In order to avoid false comfort from model results, management procedures need to be robust to the underlying data being wrong. A priority is to capture the big errors well and avoid chasing minor issues. The question of whether a larger, healthier stock should be used in modeling led to a discussion of the derivation of the current harvest control rules, which were based on modeling of both good and poor recruitment. The Board discussed the derivation of the current harvest policy limit and threshold points, as well as the different harvest rates used in the IPHC regulatory areas. [The background to the current harvest policy was presented at the October 2013 MSAB meeting: http://www.iphc.int/documents/MSAB/201310/IPHC_HP_MSAB_Oct13_v2.pdf]
- DMR was discussed in detail, including its significance to determining yield and its influence on harvest policy. Sources of discard rates and DMR information were reviewed, as well as gaps, assumptions, and biases associated with these data. The challenges and benefits of improving these data sources and the resulting DMR estimates were discussed. Efforts to reduce DMR in different sectors were noted.
- The critical importance of data collection to test any change in management procedures was emphasized. Absence of data means an absence of any ability to evaluate the impacts of procedures.
- Despite the gaps in current knowledge, developments on the status quo can nevertheless be more productive than waiting for perfect information.

The MSE Process for Pacific Hake (Whiting)

The Board heard an informative presentation by Dr. Allan Hicks on the MSE process for Pacific hake (whiting). The hake experience provides a useful comparison and reference for the halibut MSE process. The hake process has a great many similarities to what the halibut MSE is doing. Dr. Hicks indicated that the hake MSE process would also benefit from this interchange.

MSE Priorities and Objectives

With the five overarching objectives in mind, the Board discussed the priorities for investigating candidate management procedures, beginning with the five management procedures from the previous meeting.

The Five Overarching Objectives

- Biological sustainability.
- Fishery sustainability and stability.
- Assurance of access.
- Minimize bycatch mortality.
- Serve consumer needs.

The Five Management Procedures

- Accounting for total mortality from all sources, by area.

- Size limits.
- Harvest strategies: the 30:20 control rule and the reference removal rates (21.5% and 16.125%), coastwide and by area.
- National shares by allocation rather than apportionment.
- Bycatch mitigation.

Regarding this list of procedures and how they might be developed, the discussion highlighted the following points:

- These management procedures are very broad, and some are more tractable than others. All can be tuned in order to achieve management objectives. For example, various size limits or removal rates can be considered and adjusted such that the biological objectives are met.
- The first item on this list is about accounting for total mortality, and is not necessarily a specific management action.
- It will be helpful to include what operational steps would be required to implement a particular management measure – how to get from here to there. The transition from status quo to a new management procedure could involve a series of small changes over a number of years. Multiple management entities may be involved, as well as monitoring and enforcement outside the IPHC.
- The effects, benefits, and trade-offs among the procedures and how they affect different sectors and areas should be considered. Some may have positive or negative relationships with others, and unintended consequences should be avoided.
- It would be valuable to have the Shiny tool incorporate how well various procedures address the stated objectives. It was recognized that this would be a useful output but that it will take some time to develop.
- In considering how to investigate national shares and bycatch mitigation with coastwide tools, it was noted that national shares could be negotiated among the Parties to the Convention. Bycatch analysis will depend on a spatial structure to measure, so it will remain on the wish list until the future Operating Model can support it.

The Board discussed particular aspects of bycatch, including what mitigation means, the impact of bycatch, how bycatch can be reduced, and the trade-offs involved. The example of the Canadian integrated fisheries and other efforts to reduce bycatch were considered.

Returning to a previous discussion, the Board considered how DMR fits into the MSE evaluation. Is it a scenario or a procedure? Dr. Martell demonstrated an example of changing management procedures and testing the sensitivity of the results to DMR. The Board discussed ways to minimize excess handling and maximize efficiency in the fishery, as well as how to measure the value of these measures to the stock and the fishery.

Size limits were discussed as a way to leaving more older fish in the water and not to get more quota, and what this would represent in terms of trade-offs for future yield.

The Board considered whether any procedures needed to be added to the current list. Procedures relating to the recreational sector are desirable, but will need to wait until area-specific analysis is available.

It was stressed that the Shiny tool is for identification and screening of promising procedures, and not the final tool to choose procedures. It can be used by all the Board members, in real time, as they map the rough contours and trade-offs of candidate procedures, which can then be further refined in spatial and eventually dynamic testing. The task for Board members is to go forth and work with colleagues to explore the possibilities. In the meantime, the staff will be working on building the spatial and dynamic models, as well as developing a feedback process for Board members' experiences with evaluations using the MSE tool.

MSE Governance

The Board discussed governance of the MSE process in order to best serve the process and the Commission.

Initial discussion focused on the upcoming IPHC meeting cycle and how the work of the MSAB would be reported to the Commission, the other advisory bodies, and the public. This progressed to the larger topic of who should lead MSAB meetings and how they should be run. Noting that MSE should be a stakeholder-driven process, both Board and staff members acknowledged that it is awkward for staff members to present stakeholder views. This is more than a reporting issue; a successful MSE process requires buy-in among stakeholders, and the Commissioners and other stakeholders want to hear directly from the Board members. In addition, having staff members lead the meetings as they do now limits their personal participation in the process.

Various possible leadership options were presented and discussed, including a single chair, co-chairs, a panel, a chair and a rapporteur, and a chair or facilitator who is not a stakeholder. Aside from running meetings and reporting out, the leader(s) could also provide more coordination between meetings to move the process along and reduce the time spent at meetings catching up. If the chair or facilitator were not a stakeholder, it would be preferable to have someone with MSE experience.

Returning to the immediate future, the Board agreed that it would go one more round with staff reporting at the coming Interim and Annual Meetings, backed up by MSAB members in attendance. As the MSAB is still in a learning phase, there may not be much to report now, but in the future it will be much more important for the Board to clearly communicate its policy analyses and recommendations.

At the 2014 Interim Meeting, the staff will give the technical presentation and the Commissioners in attendance at this MSAB meeting will comment. The Commissioners will discuss options for MSAB leadership, and recommendations for MSAB facilitators should be forwarded to the lead Commissioners.

At the 2015 Annual Meeting, the staff will give the technical presentation and the MSAB members from the Conference Board and the Processor Advisory Group will report to those bodies. An outreach memo will be prepared by the staff to support complete and consistent reporting. The Board considered whether to convene a short MSAB meeting during the Annual Meeting, but decided against it.

The MSAB's next meeting is tentatively set for May 2015.

Appendix – Agenda

Monday October 20, 2014

12:30 PM: Welcome, introductions, meeting objectives and questions.
1:00 PM: Summary review from MSAB Meeting 3 (May 5-6, 2014).
1:30 PM: Conditioning the coast wide operating model with Pacific halibut data.
2:30 PM: BREAK
2:45 PM: Process of creating alternative scenarios.
3:30 PM: Process of creating alternative management procedures.
4:30 PM: Discussion about research priorities & the list of questions to address.
5:00 PM: ADJOURN

Tuesday October 21, 2014

8:00 AM: COFFEE & PASTRIES
8:30 AM: Recap from previous day, questions & discussion.
9:00 AM: Long-term vs short-term objectives (equilibrium vs. dynamic models).
10:00 AM: BREAK
10:15 AM: Developments on status quo versus perfect information.
11:00 AM: Allan Hicks on MSE process for Pacific hake.
12:00 PM: LUNCH
1:00 PM: MSE laundry list (priorities and objectives for the MSE process).
2:00 PM: Selection of MSAB Chairs and Co-chairs & procedures for reporting to the Commission at Interim and Annual meetings.
2:30 PM: Discussion & feedback, and closing remarks.
3:15 PM: ADJOURN

Recent developments in the IPHC Management Strategy Evaluation process and size-limit implications

Steven Martell, Bruce Leaman, and Ian Stewart

Abstract

At the 2013 Annual meeting, the IPHC Commission approved the formation of the Management Strategy Advisory Board, or MSAB. Since its inception the MSAB has had biannual meetings, with the latest meeting occurring this past October, 2014. In this report we update recent developments in the Management Strategy Evaluation Process. In 2014, IPHC staff developed a new web-based application for exploring alternative harvest procedures on the long-term impacts on the halibut resource. Size-at-age in the Gulf of Alaska is low relative to the past several decades and there is strong interest in understanding how a reduction in the minimum size limit would impact the overall total mortality. In short, reducing the minimum size-limit in the directed commercial fishery would likely result in an overall reduction in the wastage mortality assuming no change in fisheries selectivity or catch limits. Greater savings in total mortality can be achieved by avoiding areas with small halibut, targeting large halibut, and reducing the number of sublegal fish handled. The most sensitive inputs with respect to long-term impacts on the halibut resource are bycatch mortality and assumed discard mortality rates in all fisheries sectors.

Introduction

The overarching objective of the Management Strategy Evaluation (MSE) is to develop a formal process in which to evaluate the performance of alternative management procedures for the Pacific halibut fishery. The current harvest policy for Pacific halibut was developed in 2005 (Clark and Hare, 2006). Since this time there have been a considerable number of changes in the biology and distribution of Pacific halibut, changes to the assessment, and changes in how risk is communicated to the Commissioners; therefore, it is necessary to update the current harvest policy. The Management Strategy Advisory Board (formed in 2013) is comprised of fishermen, processors, fisheries managers, IPHC staff, and IPHC commissioners. The role of this board is to develop objectives for the Pacific halibut fishery (in consultation with stakeholders), propose alternative management procedures, evaluate the performance of each management procedure, and communicate the findings to stakeholders and the Commission.

To summarize the MSE process, a set of objectives for the fishery are established *a priori*, a simulation model is then used to compute performance metrics for the management procedure, the management procedures are then tuned (if possible) to achieve these objectives, and the procedure that is most robust to uncertainties in processes that cannot be controlled is then implemented for a period of time. This process is continually updated and re-evaluated to ensure the fisheries objectives are being met; a time period of 3-5 years is typical for updating the MSE simulations. As more information is gathered over time, and as we learn more about how the stock and fishery responds to changes in policy, the MSE process is then re-evaluated.

In this paper we report on the recent developments in the IPHCs' MSE process. Specifically we report on the development of a new equilibrium tool for exploring the long-term consequences of

alternative management procedures on the estimates of optimal exploitation rates, total mortality, FCEY, spawning biomass threshold, discards and wastage, bycatch, and the potential savings associated with alternative size-limits in the directed commercial fishery. The model is conditioned on size-at-age data from the 2014 setline survey, and output from the 2014 stock assessment. The objective of this paper is to develop a clear understanding of how policy variables (i.e., size-limits, selectivity, bycatch) affect components of the harvest policy (i.e., target exploitation rate, stock and catch levels).

Equilibrium model

To explore alternative management procedures, an age-size-sex structured equilibrium model was developed to estimate the long-term population responses over a range of fishing mortality rates in the directed fishery. The equilibrium model has two explicit fisheries: (1) a directed fishery, which includes the commercial long-line fishery, recreational, subsistence and personal use, and (2) a non-directed fishery, which include all bycatch fisheries (i.e., trawl and other fixed gear). The full mathematical model is specified in (Martell et al., in press), and is based on the model constructed originally by (Pine et al., 2008). Key features of this model that are important for Pacific halibut include: size-selective effects of fishing on the mean size-at-age, sex-specific growth parameters, natural mortality rates, and fisheries selectivity. Capture and retention of halibut are modelled as a joint probability distribution; this allows for two forms of fishing mortality: (1) retention in the directed fishery for captured fish greater than the minimum size limit, and (2) discard mortality for captured fish that are smaller than the minimum size limit.

For the bycatch fisheries, the model assumes the full bycatch cap is utilized, and the user can directly specify the total bycatch mortality as well as the size-selectivity of the bycatch. In reality, bycatch rates are most likely a function of stock size, and total bycatch would decline as the bycatch stock size declines or the target species of the bycatch fishery increases. However for the purposes of examining reference points that would be utilized in the decision making process, it is appropriate to conduct these simulations assuming the full bycatch is utilized. If the realized bycatch is lower than projected then the resulting harvest policy would err on the conservative side.

Equilibrium models, or equilibrium concepts such as spawning potential ratio (SPR) and yield per recruit (YPR) are the basis for establishing fisheries reference points. There are two general analytical approaches for developing equilibrium models: deterministic model and stochastic models. Deterministic models represent the average population response to a range of alternative harvest policies. Stochastic models are constructed from the same deterministic model and random variation in one or more biological processes is incorporated. Monte Carlo simulations are then used to compute the average and distribution of the population response to alternative harvest policies, allowing probabilistic statements about potential outcomes. The output from an equilibrium model represents the long-term average response to specific policy options. The advantage of using an equilibrium model to predict stock responses to changes in harvest policy is that the model calculations are very efficient and take fractions of a second to compute.

In contrast, a dynamic population model can also capture the transitional changes in abundance, fishing mortality rates, etc. in response to harvest policy changes. Dynamic population models are necessary in Management Strategy Evaluation, and importantly better characterize the transition of populations from the current status quo levels to new levels based on application of alternative

harvest policies. These transitions are perhaps more important in screening alternative harvest policies with respect to changing from a status quo harvest policy to a new policy. For example, the equilibrium model described herein, cannot be used to evaluate the short-term gains or losses associated with changing from the status quo. Of disadvantage, however, is the time required to construct, test, and run a dynamic operating model. For example, the dynamic operating model that is currently being tested in the Pacific hake fisheries off the west coast of North America, takes a couple of weeks to evaluate only a few alternative policies (Allan Hicks, pers. comm., Northwest Fisheries Science Center, NOAA).

The equilibrium model is implemented in a web-based application that is accessible to the general public (https://iphc.shinyapps.io/MSAB/). The application continues to evolve as more elements are developed in response to feedback from the MSAB, the Scientific Review Board (SRB), and IPHC staff.

It is essential to understand two distinct overfishing definitions when interpreting the results of this equilibrium model. The first is "recruitment overfishing", which is defined as the fishing intensity that reduces the abundance to a point where recruitment is limited by the available spawning stock biomass. The second definition is "growth overfishing", which is defined as harvesting fish at a size such that the yield per recruit is less than the yield that could be obtained if the fish were allowed to grow larger. The yield per recruit and growth overfishing is mostly affected by size-at-first-capture and minimum size limits. Whereas, recruitment overfishing is mostly affected by fishing intensity. Therefore it is possible to be both growth overfishing and recruitment overfishing. The general objective of a harvest policy is to both maximize the yield per recruit and maximize the total yield in a risk averse manner.

To explore the effects of changing the minimum size limit in the directed fishery, we use the equilibrium model to compute long-term estimates of yield, spawning biomass, recruitment, and a number of other outputs of interest, over a range of fishing mortality rates in the directed fishery. For example, one of the model outputs is the equilibrium yield versus fishing mortality rate, and as fishing mortality rates increase, so too does the equilibrium yield. However, as the fishing mortality rates increase the yield per unit of fishing effort begins to decline. The point at which the yield is maximized is referred to as the Maximum Sustainable Yield (or MSY). This level of fishing mortality is also used to compute MSY-based reference points, which define target fishing mortality rates and threshold spawning biomass.

Reducing the minimum size limit from 32 inches

Reducing the minimum legal size limit from 32 inches to 30 inches results in a small increase in total mortality due to the increase in FCEY associated with reductions in fisheries wastage (Fig. 1). The increase in total mortality from the 32 to the 30 inch minimum size limit is 0.49 million pounds, the increase in FCEY is 1.24 million pounds, and the reduction in fisheries wastage is 0.76 million pounds (Table 1). As a consequence of reducing the minimum size limit, the optimal fishing mortality rate that maximizes long-term yield is also reduced.

Assuming a landed price of $2.50 per pound for halibut in the 5-10 pound size category, and $5.00 per pound for all other size categories, the expected landed value would increase by $1.16 million at a 30 inch minimum size limit (Table 1). Lowering the minimum size limit below 30 inches to 28 or 26 inches is expected to result in a loss of $0.17 million and $0.91 million, respectively.

At the MSY-based fishing mortality rates, total mortality increases with greater reductions in the minimum size limit (0.81 million pounds at a 26-inch size limit), but the FCEY increases are much greater (2.02 million pounds at a 26-inch size limit, Table 1). This implies adjustments to the harvest policy could be made such that there is an increase in FCEY, but no corresponding increase in total mortality rates relative to the 32 inch size limit. Such an adjustment would be even more conservative than the MSY-based fishing mortality rates. For example, changing the minimum size limit from 32 inches to 30 inches results in a decrease in fisheries wastage of 0.76 million pounds. This savings could be added directly to the FCEY, and would not result in an increase in total mortality. The aforementioned example assumes that fisheries selectivity remains the same, and does not change as a result of changes to the minimum legal size limit.

One consequence of reducing the minimum size limit is that the average weight of fish in the directed fishery decreases when retaining fish below 32 inches. Reducing the minimum size limit also introduces some minor conservation concerns; the equilibrium spawning stock biomass declines with increasing mortality of fish below the minimum legal size limit. This is why it is necessary to decrease the target exploitation rate to ensure recruitment over-fishing does not occur.

We strongly note that these results are conditional on having no change in commercial selectivity and that even greater conservation benefits to the halibut resource would accrue if selectivity shifts towards catching larger halibut. Moreover, if there is change in the growth rates that results in changes to the average size-at-age, then total mortality would decrease if halibut grew faster due to less wastage, and vice versa.

Sensitivity to size-at-age and changes in selectivity

One of the major concerns about reducing the minimum size limit, is that the directed commercial fishery would change its behavior and target smaller fish (i.e., increased selectivity on fish less than 32 inches, Fig. 2). If the length-at-50% selectivity were to also decline by 2-inches, then the potential benefits of reducing the minimum size limit are negligible with respect to the overall directed fisheries yield and total mortality (Figure 3). Further reductions in the target fishing mortality rate would also accompany changes in selectivity that result in a high fraction of smaller fish being captured. Increases in the capture rate of smaller fish would also result in increased probabilities of spawning biomass decline in the decision table calculation as well. As a consequence of the shift in selectivity towards smaller fish, the optimal MSY-based fishing mortality rate is reduced by roughly 5% in comparison to the status quo.

Based on the assumed coastwide selectivity and size-at-age data, for every 100 halibut captured in the directed fishery, roughly 28 would be less than 32 inches in total length. Reducing the size limit to 30 inches has the potential to reduce this rate to 14 fish in 100. However, if selectivity were to shift, then discard rates would increase to 35 fish in 100 captured. There is no commercial size composition data to inform commercial selectivity estimates below 32 inches in the directed halibut fishery; only landed fish are sample for size. The IPHC currently assumes the selectivity below the legal size-limit is the same as it is in the commercial setline survey. The ratio of U32:O32 fish by weight in the setline survey has been increasing, and in any given area the number of sub legal fish per 100 captured could be much higher. The worst of these areas would be Areas 3A and 3B where trends in size-at-age continue to decline (Fig. 4). Based on the size-at-age data from areas 3A and 3B, roughly 39 in 100 captured fish are below the legal 32-inch minimum size limit, and this would be reduced to 21 in 100 under a 30 inch minimum size limit.

Spatial variation in size-at-age

Size at age in Pacific halibut continues to decline for many of the regulatory areas based on length-age data collected in the set line survey (Fig. 5). These continued declines in size-at-age, especially the small sizes-at-age in Regulatory Area 3, result in increases in the assumed wastage in the directed fishery under the current assumed coastwide fisheries selectivity and the 32-inch minimum size limit. Reductions in the minimum size limit would alter the fraction of legal size fish in each of the regulatory areas due to the higher fractions of sub-32 inch fish in the Gulf of Alaska. As a result, apportionment based on legal size halibut would also change, with larger fractions of the biomass being apportioned to areas with higher proportions of 30-32 inch fish. These are also the same areas that would potentially have large reductions in wastage (assuming no changes in fisheries selectivity) and overall reductions in total mortality rates.

Changes in the minimum size limit would also have area-specific impacts with respect to the average size of landed fish. Based on the size-at-age data from the 2014 setline survey, the average size of landed fish in Area 2 would be greater than the coast wide average, well below average in Area 3 (Table 2).

Bycatch in non-directed fisheries

Representation of bycatch in the equilibrium model assumes a single coastwide bycatch fishery with size-based selectivity. This differs from the coastwide assessment, which currently uses age-based selectivity. At the MSY-based reference points, an increase in bycatch from 8 million pounds to 9 million pounds (all sizes including U26) roughly translates into a loss of 0.88 million pounds of fisheries yield (FCEY) assuming the coastwide mean size-at-age. In other words, 1 pound of bycatch is roughly equivalent to 0.88 pounds of lost fisheries yield. Based on mean size-at-age data from Area 4CDE this same increase in bycatch roughly translates into a loss of 0.94 million pounds of lost yield per pound of bycatch. Again, these differences are based on all sizes of bycatch. The loss in FCEY for each pound of bycatch is fairly robust to alternative minimum size limits. Decreases in coastwide bycatch translate directly into increased yield in the directed fishery.

Reducing the minimum size-limit translates into increased yield in the directed fishery, and reduced density of halibut. In order to obtain the bycatch cap, bycatch fisheries actually have to fish harder to reach the cap. In theory, if the same level of fishing effort was used in the bycatch fisheries, and these same fisheries were not previously constrained by the cap, then it is possible that a reduction in the minimum size limit would also lead to reduced bycatch. For example, in the IPHC setline survey the fraction of U32 fish in area 3 is greater than 60% by number. Some of these fish could be retained in the directed fishery, and the encounter rate in bycatch fisheries would be reduced.

Discussion

The objective of Management Strategy Evaluation (MSE) is to formalize a process in which to evaluate the performance of alternative management procedures. This process requires a detailed operating model that is capable of generating the existing data, as well as, any future data we wish to evaluation using this MSE process. The development of such a model is underway at the IPHC. Existing examples of operating models for detailed fisheries policy analysis suffer from long run-

times (hours to weeks). These long run-times preclude rapid evaluation of alternative management procedures during the course of a meeting. The objective of this effort was to develop a model that could be deployed on virtually any computing platform and could be used to rapidly evaluate alternative harvest procedures during discussions with stakeholders and decision makers. The age-, size-, and sex-structured equilibrium model developed in this paper takes only fractions of a second to compute long-term equilibrium outputs. More importantly, stakeholders can actually run the model on the web-based interface to gain a more thorough understanding of how policy variables (i.e., selectivity, or size limits) impact the halibut resource (i.e., spawning stock biomass) and affect fishing opportunities. Moreover, this work is consistent with how long-term harvest policies are developed using many of the generic stock assessment platforms that are currently in use.

We note several times throughout this document that the equilibrium model represents the long-term view. The model should not be used to predict how the current stock status will respond in the short-term to changes in harvest policy. This type of analysis should be conducted using a dynamic model that is consistent with current estimates of stock status and productivity. Another note of caution, is that this particular equilibrium model does not capture the spatial variability in many of the management processes. For example, reducing bycatch in one regulatory area may have much more of an effect in comparison to reductions in another area due to the spatial differences in size-at-age, or availability of the fish. In the example using size-at-age data from different regulatory areas, we stress how changes in size-limits would either result in an increase or decrease in the average-size of the landings relative to the coast wide average. A dynamic, spatially explicit model would be preferred to examine the transition from the current harvest policy to a new procedure. Simply put, the equilibrium model assumes that any change in fishing practices would occur coast wide, and are not restricted to a single area.

Some of the major assumptions when examining stock responses to changes in the size limits include, no change in fisheries selectivity, size-at-age remains at its current 2014 levels, and a stock-recruitment relationship. Previous efforts on developing harvest policies using stochastic models were based on average recruitment (from positive and negative PDO regimes), density-dependent growth, and a higher value of bycatch, to name just a few differences (Clark and Hare, 2006). Density-dependent growth could be included in this equilibrium model; but recent data suggest the opposite density-dependent relationship than what was assumed by Clark and Hare (2006). This model, however, does include the effects of size-selective fishing. Although the results are not shown here, the net effect is that the average weight-at-age declines with increasing size-selective fishing mortality.

Given the aforementioned assumptions, reducing the minimum size limit would likely result in reduced total mortality in the halibut fisheries. This also assumes a worst case scenario, that the bycatch fisheries would fish right to the cap, regardless of what the size-limit is in the directed fishery. In reducing the minimum size limit the savings in wastage mortality translates directly into increased yield in the directed fishery, and requires less fishing effort to obtain the FCEY due to increased overall densities of Pacific halibut. The tradeoff, however, is that there is an increased risk of growth overfishing, and recruitment overfishing when harvesting smaller sizes. As a consequence, the target harvest mortality rate (e.g., 21.5% and 16.125% that is currently used in the harvest policy) would have to be lower to reduce the risk of recruitment and growth overfishing.

It may seem counterintuitive from a stock conservation perspective to reduce the minimum size-limit at time when the stocks are declining, and the average size-at-age also continues to decline. The results here suggest that the directed fishery, in the long-term, would benefit with more yield, requiring less effort to obtain that yield, and the overall total mortality could be less owning if there is no increase in bycatch. The major issue at play here is that the current estimated selectivity in the directed fishery results in the capture of a large fraction of individual fish that are below the legal size limit. Based on the setline survey data, as much as 70% by numbers consists of fish less than the minimum legal size of 32 inches in Area 3. Even if the discard mortality rate in the directed fishery were zero (i.e., all sublegal fish survive) there would still be a net savings in total mortality due to reduced densities of small fish that would otherwise die in bycatch fisheries if the bycatch fisheries weren't fully subscribed.

There is always concern of growth overfishing when reducing or eliminating minimum size limits. Minimum size limits help guard against growth overfishing and are intended to maximize the yield per recruit. This logic, however, assumes constant natural mortality and constant size-at-age (Beverton and Holt 1957). Pacific halibut have undergone large changes in the size-at-age, and the IPHC assumes that natural mortality has remained relatively constant. As a consequence, retaining the minimum size limit at a fixed value increases the risk of growth overfishing during periods of constant natural mortality and declining size-at-age (Beverton and Holt 1957), especially if discard mortality rates greater than 0.

Size-at-first-capture, discard mortality rates, and minimum size-limits are all very important from a harvest policy perspective. Changing a minimum size-limit is strictly a policy decision. Adjustments to the harvest policy (e.g., reducing the target exploitation rate with decreases in size-at-first capture) have to be addressed on a frequent basis even if the minimum size limit remains constant. If there are changes in fisheries selectivity, and discard mortality rates are not zero, then adjustments to the target harvest rates have to be made to maintain the same desired spawning stock biomass targets. This highlights the importance of collecting size composition data for all fish captured, not just fish that are landed. If estimates of fisheries selectivity are relatively stable over time, and growth is stable, then it is probably not necessary to change the target harvest rates. If, however, there is a change in the minimum size limit, then a corresponding change in the target harvest rate must be made if the desire is to maintain the same risk of growth and recruitment overfishing. In general, if the minimum size-limit decreases, then the target harvest rate would also decrease.

References

Beverton, R. J. H. and Holt, S. J. 1957. On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries and Food Series 2, Fyshery investigations 19.

Clark, W. and Hare, S. 2006. Assessment and management of pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. 83.

Martell, S. Stewart, I., and Sullivan, J. In press. Implications of bycatch, discards, and size-limits on reference points in the Pacific halibut fishery. [In] Proceedings of the 29th Lowell Wakefield Fisheries Symposium. Fisheries Bycatch: Global Issues and Creative Solutions. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, AK USA.

Pine, W., Martell, S., Jensen, O., Walters, C., and Kitchell, J. 2008. Catch-and-release and size limit regulations for blue, white, and striped marlin: the role of post-release survival in effective policy design. Can. J. of Fish. and Aquat. Sci. 65(5):975–988.

Table 1. Maximum sustainable yield (MSY) based estimates of fishing mortality, total mortality (TCEY), directed fisheries mortality (FCEY), directed fishery waste, spawning stock biomass (SSB), average net weight of the commercial catch, and landed value versus a range of minimum size limits (MSL) in the directed fishery. All scenarios assume bycatch mortality of 8 million net pounds.

Procedure	FMSY	Total Mortality (M lb)	FCEY (M lb)	Waste (M lb)	SSB (M lb)	Average net weight (lb)	Landed value ($ Millions)	Number of sub-legal halibut per 100 captured
32” MSL	0.28	46.1	36.81	1.3	116.9	16.79	182.86	28
30” MSL	0.27	46.59	38.05	0.54	113.57	15.73	184.02	14
28” MSL	0.26	46.82	38.62	0.2	113.98	15.14	182.69	6
26” MSL	0.26	46.91	38.83	0.07	112.47	14.74	181.95	2
Difference								
30” MSL	-0.01	0.49	1.24	-0.76	-3.33	-1.06	1.16	-14
28” MSL	-0.02	0.72	1.81	-1.1	-2.92	-1.65	-0.17	-22
26” MSL	-0.02	0.81	2.02	-1.23	-4.43	-2.05	-0.91	-26
Percent								
30” MSL	-3.57%	1.06%	3.37%	-	-	-6.31%	0.63%	-50.00%
28” MSL	-7.14%	1.56%	4.92%	-	-	-9.83%	-0.09%	-78.57%
26” MSL	-7.14%	1.76%	5.49%	-	-	-12.21%	-0.50%	-92.86%

Table 2. Change in average net weight (lbs) of the catch based on size-at-age data from each regulatory area relative to the coastwide average, versus minimum size limit (inches).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
32” MSL	12%	9%	20%	-10%	-11%	-2%	22%	-2%	16.79
30” MSL	19%	9%	23%	-11%	-12%	-1%	24%	-1%	15.73
28” MSL	14%	9%	21%	-12%	-14%	-2%	25%	-2%	15.14
26” MSL	15%	10%	23%	-12%	-13%	-1%	27%	0%	14.74

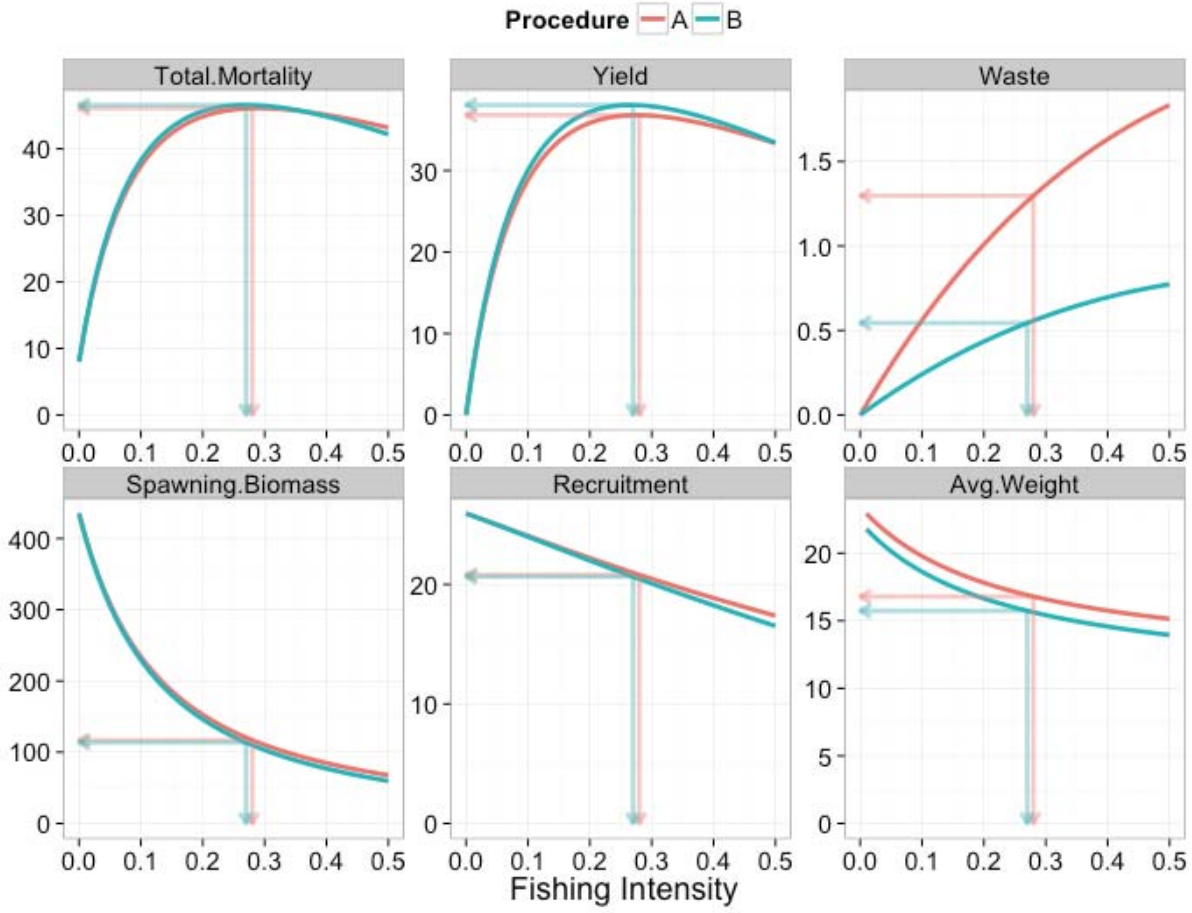


Figure 1. Equilibrium values of total mortality, yield in the directed fishery, wastage in the directed fishery, spawning biomass, recruitment and average weight in the directed fishery catch versus fishing intensity for a minimum size limit of 32 inches (Procedure A) and 30 inches (Procedure B). The vertical and horizontal arrows reference the maximum sustainable yield values in the directed fishery.

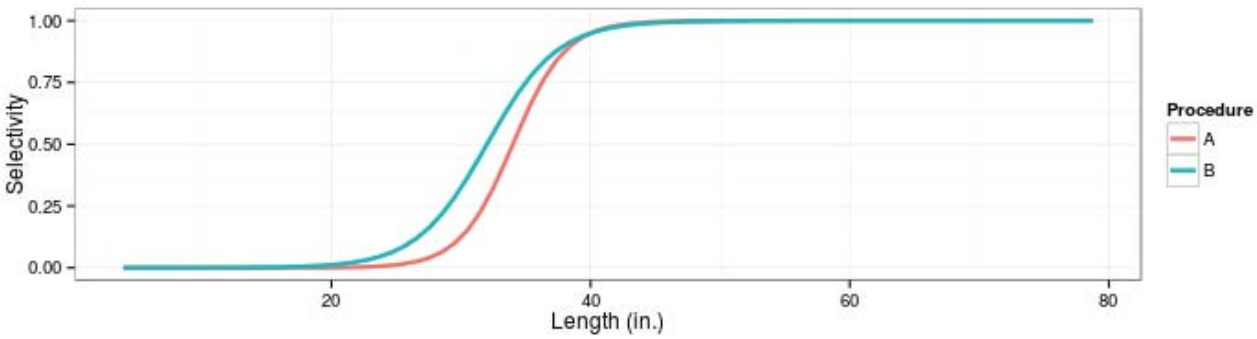


Figure 2. Hypothetical change in the directed fisheries selectivity, where the length-at-50% vulnerability decreases by 2 cm in the directed commercial longline fishery.

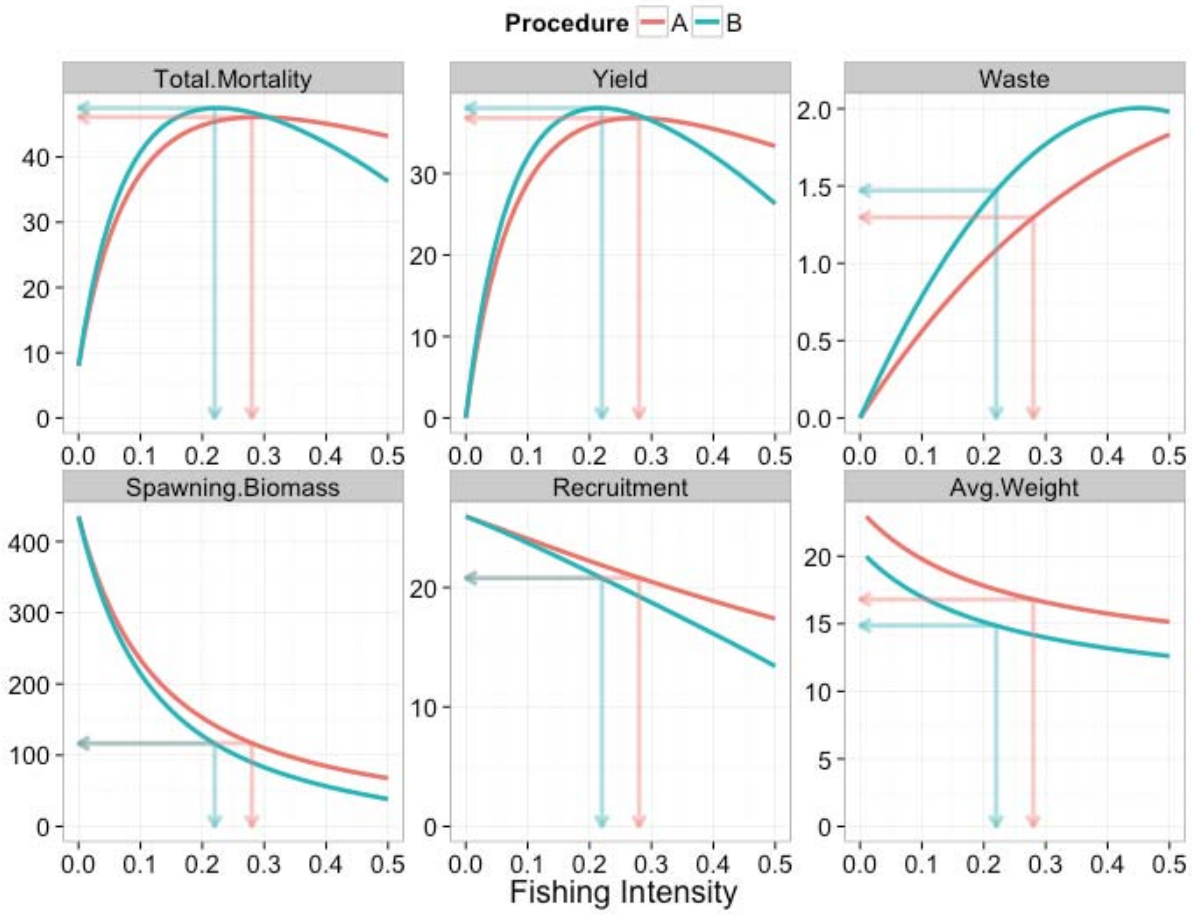


Figure 3. Equilibrium values of total mortality, yield in the directed fishery, wastage in the directed fishery, spawning biomass, recruitment and average weight in the directed fishery catch versus fishing intensity for a minimum size limit of 32 inches (Procedure A) and 30 inches with a 2-inch shift in selectivity of Fig. 2 (Procedure B). The vertical and horizontal arrows reference the maximum sustainable yield values in the directed fishery.

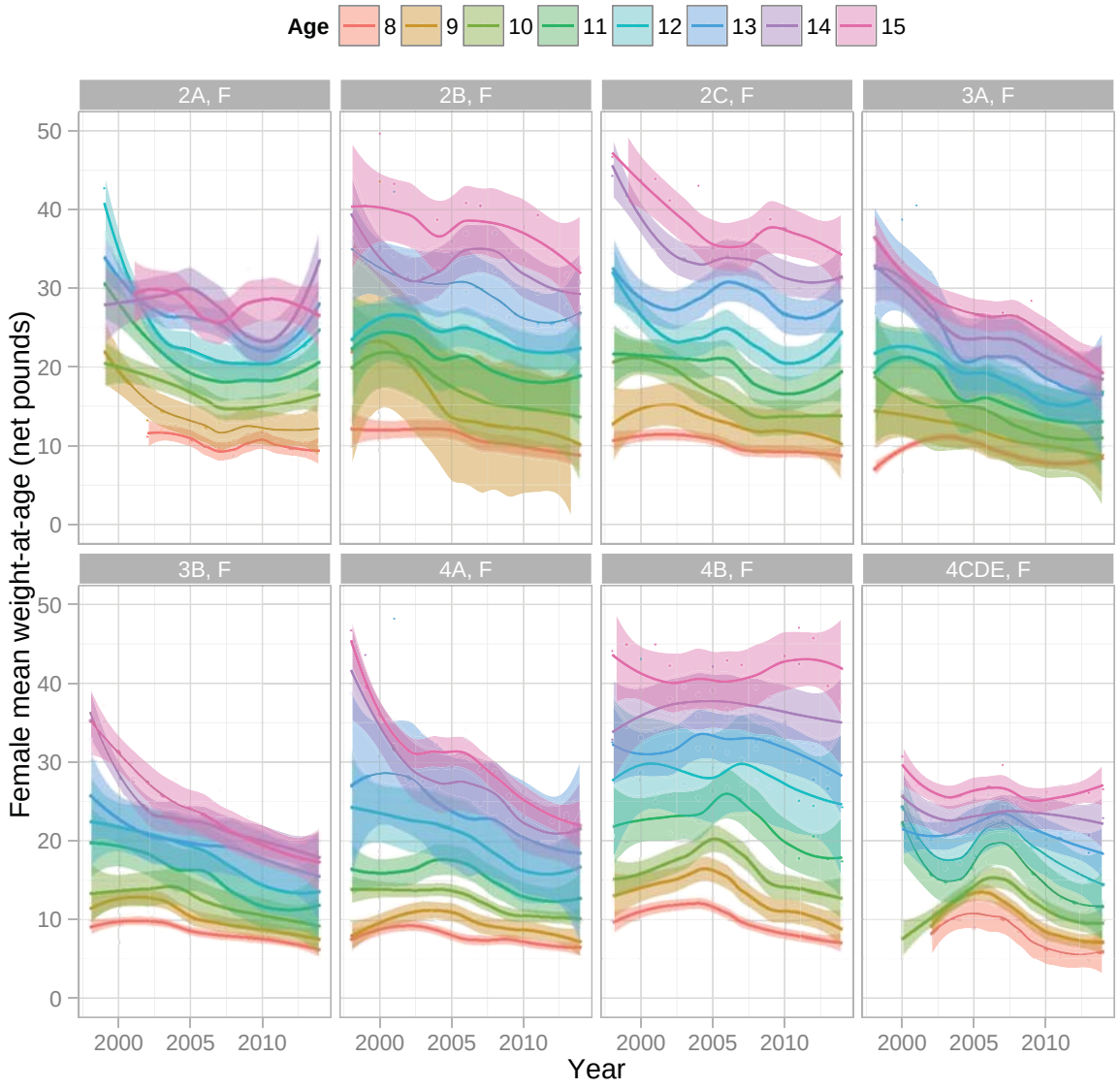


Figure 4. Setline survey female mean weight-at-age for ages 8-15 for each regulatory area.

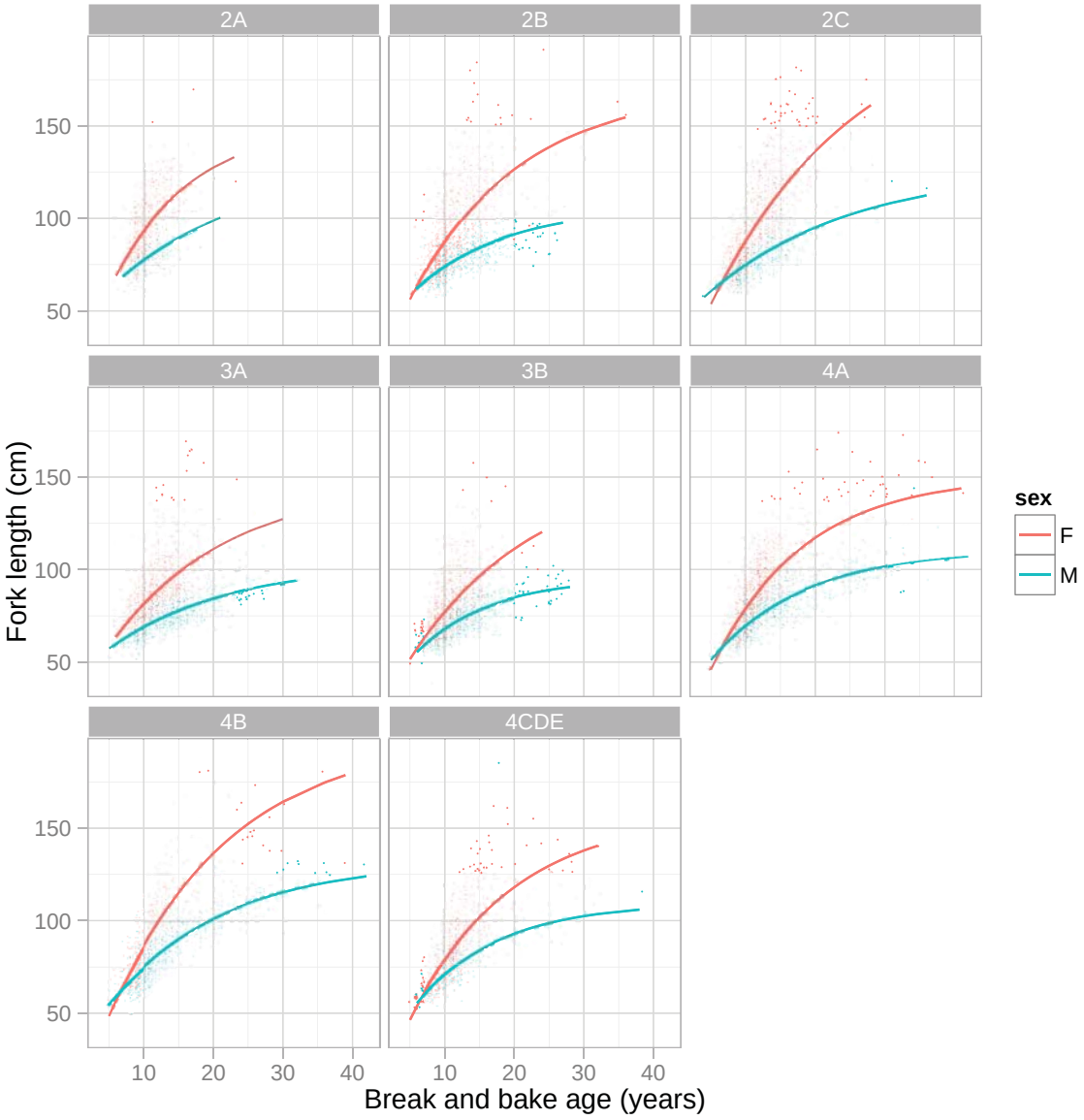


Figure 5. Size-at-age data by regulatory area and sex for Pacific halibut captured in the 2014 setline survey. Fitted lines represent the average mean size-at-age and the scatter plots are jittered to better represent samples sizes.

Incidental catch and mortality of Pacific halibut, 1962-2014

Gregg H. Williams

Abstract

Estimates of the bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) in 2014 totaled 9.3 million pounds (net weight), representing an increase of 5% from 2013. Bycatch increased in all areas, with the largest increases occurring in Area 3 (12%). In Area 2A, bycatch mortality continued to be low, mainly as a result of an individual quota program in the groundfish trawl fishery. Bycatch in the area dropped by almost 50% from 2012 to 2013, the latest year for which data are available. Bycatch in Area 2B also remained low in 2014, at about the same level reported for the past 10 years, 0.2 Mlbs. In Alaskan areas, bycatch increased in 2014, with the largest increase (27%) occurring in Area 3B, going from 0.98 Mlbs in 2013 to 1.25 Mlbs in 2014. Analyses to update estimates of bycatch taken by fishing within state waters of Alaska or those managed by the State of Alaska were provided by the Alaska Department of Fish and Game. Their new estimates for crab pot fisheries in southeast Alaska are included in this year's report but were not available in time for the halibut assessment.

Introduction

Fisheries targeting on other fish and shellfish inadvertently catch Pacific halibut (*Hippoglossus stenolepis*). Information collected by at-sea observers has indicated the incidental catch, or bycatch, is substantial. U.S. and Canadian domestic regulations require that halibut be returned to the sea with no additional injury, but some fish die from being caught and handled. This document provides an overview of the estimated halibut bycatch mortality in 2014 by International Pacific Halibut Commission (IPHC) regulatory area.

Sources of information

IPHC relies upon information supplied by observer programs run by domestic agencies for bycatch estimates in most fisheries. Research survey information is used to generate estimates of bycatch in the few cases where fishery observations are unavailable. The U.S. National Marine Fisheries Service (NMFS) operates observer programs off Alaska and the U.S. west coast, which monitor the major groundfish fisheries. Data collected by those programs are used to estimate bycatch. Trawl fisheries off British Columbia are comprehensively monitored and bycatch information is provided to IPHC by Fisheries and Oceans Canada (DFO).

Estimates of bycatch off Alaska for 2014 were based on bycatch reported by NMFS from fishing conducted through October 25 from the NMFS Alaska Region website (http://alaskafisheries.noaa.gov/2014/car240_psc_halibut.csv) and projected through the remainder of the year. Groundfish fishery management is conducted according to NMFS management areas, which are not exactly the same as IPHC regulatory areas. The NMFS areas were recoded to IPHC areas according to the schedule shown in Table 1. In addition, weight units were converted from metric tons to pounds, net weight. The projections for 2014 were made by applying the proportions taken by a similar

date during 2011-2013 to the 2014 partial year data. Fishery monitoring was conducted with at-sea observers.

The amount of information varies for fisheries conducted off British Columbia. For the trawl fishery, bycatch is managed with an individual bycatch quota program implemented by DFO in 1996. Fishery observers sample the catch on each bottom trawler, collecting data to estimate bycatch and discard mortality. Bycatch in other fisheries, such as the shrimp trawl, sablefish pot, and rockfish hook-and-line fisheries, was largely unknown until the inception of the Integrated Groundfish Management Program in 2006. The program has requirements for full accounting and accountability of all bycatch, and includes 100% at-sea monitoring, either by human observers or electronic monitoring (McElderry et al. 2003).

Off the U.S. west coast, an individual quota (IQ) program was implemented in 2011 for the domestic groundfish trawl fisheries. The program is quite similar to the program for the B.C. trawl fishery, in that it contains an individual bycatch quota component for managing and reducing halibut bycatch mortality. Fishery monitoring is required at 100% coverage levels, so all vessels carry an observer to record the vessel's catch. Bycatch estimates for the shrimp trawl fishery have been provided by Oregon Department of Fish and Wildlife (ODFW) staff from examinations of halibut bycatch during gear experiments. Updated estimates were provided by ODFW in 2011.

In 2014, ADF&G provided IPHC with estimates of the bycatch mortality in crab pots for southeast Alaska. The catch estimates are based on fishery data collected by on-board observers, and the results are reported in this report and were available for the 2014 assessment. Additional work is underway to evaluate bycatch in crab pot fisheries in other regions, and in the scallop fishery. The results of this latter work will be available for the 2015 assessment.

Discard mortality rates and assumptions

Discard mortality rates (DMRs), used to determine the fraction of the estimated bycatch that dies, vary by fishery and area. Where observers are used for fishery monitoring, DMRs are calculated from data collected on the release viability or injury of halibut. For areas without observers, assumed DMRs are used, which are based on the similarity of fisheries to those in other areas where data are available. The mortality models used to calculate these rates have been presented by Clark et al. (1993) and Williams (1997).

Observer data are used to calculate DMRs in fisheries in three major areas. NMFS manages the groundfish fisheries off Alaska according to a schedule of DMRs recommended by IPHC (Table 2, Williams 2013). In Areas 2A and 2B, observers deployed on the bottom trawl vessels examine each halibut to determine release viability. The bycatch mortality reported to IPHC incorporates these release mortality observations.

Data to determine DMRs for other fisheries are not available. Therefore, assumptions are made on likely DMRs based on similar fisheries with known DMRs. For the sablefish hook-and-line fishery off the U.S. west coast, NMFS uses a DMR of 16%, based on an analysis of the observer data from the sablefish fishery off Alaska prior to the implementation of individual fishing quotas (IFQ) in 1995. The DMR for pot fisheries is assumed to be 18%. Bycatch mortality in the catcher/processor midwater fishery for Pacific hake is based on a 100% DMR.

Fishery monitoring in Alaska groundfish fisheries in 2014

This was the second year of a new method by which vessels in federal fisheries off Alaska were chosen for monitoring. The previous plan, in place from 1990 to 2012, placed the responsibility for deciding when to take an observer on the vessel operator, creating the potential for a lack of representative fishery sampling and resulting bias in the data collected by observers. The new deployment plan introduced in 2013 creates a science-driven process for vessel selection to reduce bias, and also included for the first time the directed halibut fishery for monitoring.

It is important to note that the vessels covered by the new plan include those vessels not participating in specific management programs with a mandatory 100% coverage requirement. The NPFMC has developed several fishery programs with this requirement, including the Gulf of Alaska (GOA) Rockfish Program, the Bering Sea and Aleutian Islands (BSAI) Community Development Quota fisheries, the American Fisheries Act (AFA) pollock cooperative, and the BSAI Amendment 80 fishery cooperative. The new deployment plan therefore applies to vessels not involved in these programs, and also to those in the directed halibut IFQ fishery. This group of vessels is termed the 'partial coverage' category, and the amount of coverage varies by certain criteria:

- No selection: Vessels less than 40 ft in length overall (LOA) or fishing with jig gear (which includes handline, jig, troll, and dinglebar troll gear) are in the "no selection" pool. These vessels were not selected for observer coverage in 2014.
- Vessel selection: Vessels fishing hook-and-line or pot gear, and are greater than or equal to 40 ft but less than 57.5 ft LOA, are in the vessel selection pool. NMFS randomly selected vessels in the vessel selection pool for mandatory observer coverage. Selected vessels were required to carry an observer for all trips taken within a selected 2-month period.
- Trip selection: This stratum is comprised of two classes of vessels: (1) all vessels fishing trawl gear and (2) vessels fishing hook-and-line or pot gear that are also greater than or equal to 57.5 ft LOA. NMFS developed a system to facilitate the random assignment of observers to trips.

The new deployment plan is funded, in large part, by a fee assessed by NMFS on the ex-vessel value of the landings. Currently this is set at 1.25%, and is evenly split between the vessel and the processor. The processor is required to collect and forward the fees to NMFS on a regular basis.

For 2014, NMFS estimated a deployment rate of 13.7% for the trip selection vessels, and 10.2% for the vessel selection group. These levels of deployment are slightly lower than in 2013 (14-15% for trip selection, and 11% in vessel selection) due to an anticipated increase in effort from 2013 to 2014.

Bycatch mortality by regulatory area

Halibut bycatch mortality was relatively low until the 1960s, when it increased rapidly due to the sudden development of the foreign trawl fisheries off the North American coast. Total estimated bycatch mortality (excluding the Japanese directed fishery in the eastern and western Bering Sea) peaked in 1965 at about 21 Mlbs (Fig. 1). Bycatch mortality declined during the late 1960s, but increased to about 20 Mlbs in the early 1970s. During the late 1970s and early 1980s, it dropped to roughly 13 Mlbs, as foreign fishing off Alaska came under increasing control and restrictions. By 1985, bycatch mortality had declined to 7.2 Mlbs, the lowest level since the IPHC began its

monitoring nearly 25 years earlier. Bycatch mortality increased in the late 1980s due to the growth of the U.S. groundfish fishery off Alaska, which had few bycatch restrictions, peaking at 20.3 Mlbs in 1992. Estimated bycatch mortality has since declined. Preliminary estimates for 2014 total 9.3 Mlbs, representing a 4.7% increase from 2013. Estimated bycatch mortality ranged between 12-14 Mlbs from the mid-90s to 2007 and has been below 11 Mlbs since 2009.

Estimates of bycatch mortality by fishery and major IPHC regulatory area for 2005 through 2014 are shown in Table 3 and discussed in the following sections. Tables 4 through 6 provide bycatch mortality estimates by various area groupings. Tables 7 and 8 provide estimates of bycatch mortality in the Alaskan groundfish fisheries operating in U.S. federal waters.

Area 2A – U.S. West Coast

Bycatch reporting for this area lags by one year, so what is presented here is for 2013. The final estimate of bycatch mortality in Area 2A for 2013 is 0.07 Mlbs (Fig. 2; Table 3; Jannot et al. 2014). This estimate is one of the lowest since bycatch estimation began for this area in 1998 and an 81% decrease from 0.35 Mlbs in 2010, the final year of the open access fishery. This drop was due to the reductions achieved in part by the IQ program for the bottom trawl fishery and significant reductions by the hook-and-line fisheries seeking other species. Estimates for 2014 were not available, so the 2013 estimate was used as the preliminary total for 2014, and will be updated when final estimates become available. As the fishery continues to adapt to IQ management and reporting becomes timelier, it is expected that year-end projections will be available.

The Pacific Fishery Management Council (PFMC) set the 2014 total halibut IQ mortality limit for the groundfish trawl fishery at 194,033 net pounds (258,710 round pounds). This coastwide total was divided into 177,495 net pounds (236,660 round pounds) designated for trawl fisheries north of 40°10' N. (NMFS 2013) and 16,538 net pounds (22,050 round pounds) for fisheries south of that latitude. This reflects the Council's plan that the area south of 40°10' N. is allocated 10 t (22,050 round pounds), with the remainder allocated to the northern area.

Bycatch in the 2013 hook-and-line fishery was estimated at 9,000 pounds, which was a substantial drop from the 2012 estimate of 59,000 pounds. The decrease was most noticeable in the limited entry sablefish and open access fishery sectors. The decrease was driven in part by a reduction in fishery effort but also by an increase in the amount of halibut retained by sablefish fishers relative to the target catch. The observer coverage in this sector is much less than 100%, and an assumed DMR of 16% is applied, as previously noted. Mortality in the pot fishery for sablefish was quite small, estimated at less than 1,000 net pounds (Table 3), based on an assumed DMR of 18% (Jannot et al. 2014).

Finally, as noted in previous reports, bycatch in shrimp trawls has been revised to zero (Williams 2012). Fish excluders have been required in shrimp trawls since 2003 (R. Hannah, ODFW, 2040 S.E. Marine Science Drive, Newport OR, 97365, personal communication). An excluder directs fish out of the net, so fish bycatch is believed to be essentially nonexistent.

Area 2B – British Columbia

Bycatch mortality in the 2014 B.C. bottom trawl fishery was estimated at 0.24 Mlbs, which is relatively unchanged from the final 2013 estimate of 0.23 Mlbs (Table 3). Bycatch continued to be greatest during summer months (Fig. 3), although bycatch during January-March was the highest it has been since 2007. Typically the amount observed in January-March has been less than 0.04

Mlbs, but approached 0.07 Mlbs in 2014. Less than 10% of the annual amount is taken during the final three months of the year.

Estimates were provided by DFO staff at the Pacific Biological Station, based on data collected by observers (K. Rutherford, DFO/PBS, 3190 Hammond Bay Road, Nanaimo, B.C. V9T 6N7, personal communication). Monthly estimates of mortality were supplied for 2013 and 2014, with the 2014 data complete through August. Projections for the full calendar year 2014 were made by extrapolating to the full 12 months based on the mean proportion of bycatch (0.843) taken through the same time period, e.g., January-August, during 2009-2013.

A general note on bycatch in state-water and state-managed fisheries in Alaska

Across Alaska, halibut bycatch has been attributed to a few fisheries conducted in state waters and/or under state management. These include (1) beam trawling for shrimp and flounders in the inside waters of Area 2C, (2) hook-and-line fisheries for sablefish in Chatham and Clarence Straits of Area 2C, (3) sablefish fisheries in Prince William Sound, (4) king/tanner crab and shrimp fisheries throughout the Gulf of Alaska and Bering Sea, and (5) scallop fisheries throughout Alaska. The lack of comprehensive observer coverage to provide bycatch data for most of these fisheries led IPHC to estimate bycatch for the crab and shrimp fisheries based on capture rates on ADF&G research surveys (Williams et al. 1989). The estimations were originally done in the late 1980s, but have not been updated in a number of years.

In 2014, ADF&G supplied IPHC with estimates for crab fisheries conducted in southeast Alaska, and shrimp fisheries in Prince William Sound, which are reviewed in the following sections. Estimates for other fisheries are also under development in collaboration with ADF&G staff, with the goal of providing new estimates for fall 2015. Some of this information was made available in late 2014 but it was not able to be included in this document. Until this work is completed, bycatch estimates for these fisheries will be noted as 'n/a', i.e., not available, in Table 3.

Area 2C – Southeast Alaska

For the federal waters of Area 2C in 2014, only bycatch by hook-and-line vessels fishing in the outside waters has been reported by NMFS. These vessels are primarily targeting Pacific cod (*Gadus macrocephalus*) and rockfish (*Sebastes* spp.). In the aggregate, these fisheries result in roughly 12,000 pounds of bycatch mortality in 2014. There is also a minor amount of bycatch by vessels fishing in the federal sablefish IFQ fishery which do not have halibut QS to enable bycatch retention.

State water fisheries which take halibut as bycatch in this area include pot fisheries for red (*Paralithodes camtschatica*) and golden (*Lithodes aequispinus*) king crab, and tanner crab (*Chionoecetes bairdi*). In 2014, ADF&G estimated halibut bycatch in these fisheries (*Estimates of halibut bycatch (not mortality) in Southeast Alaska commercial king and Tanner crab pot and shrimp trawl fisheries – Draft 10/24/14*, ADF&G staff, personal communication). Estimates of the number of halibut caught by these fisheries are derived using halibut catch rates from ADF&G annual research assessment surveys, which are then applied to fishery effort (pot lifts). The weight of the bycatch was then estimated using an average weight of 11.2 pounds, based on information reported by Williams et al. (1989). Mortality was then based on a DMR of 100%. The results provided by ADF&G are shown in Table 9, along with the mortality estimates. In general, most of the mortality from pot fisheries occurs in the tanner crab fishery; it accounts for the majority of the bycatch since 1997, often 90% or more of the total. However, since 2011 its share has dropped

to 57-65% due to the growth of the red king crab fishery. Since 1995, annual estimates have been less than 35,000 pounds, and frequently lower than 21,000 pounds, especially since 2004. Only in 1997 did the estimate exceed 100,000 pounds, due to a spike in the survey catch rate of halibut and a relatively high level of effort in the fishery that year.

Area 3 – Eastern, Central, and Western Gulf of Alaska

Bycatch mortality in Area 3 in 2014 was estimated at 2.86 Mlbs, an increase of 12% from 2013 (Table 3; Fig. 4). Despite the increase, this level is the second lowest amount seen since 2005. Bycatch is estimated to have increased in both Area 3A and 3B, with 3B increasing the greatest. Notably, bycatch increased in the trawl fisheries occurring in 3A and 3B, and the hook-and-line fishery in 3B. Only the hook-and-line fishery in 3A was lower in 2014. The total for Area 3 is below the 10-year average of 3.79 Mlbs.

Trawl fishery bycatch was 81% of the total bycatch in the area (Fig. 5), estimated at 2.3 Mlbs. Area 3A accounted for 1.4 Mlbs of this total. Target fisheries for arrowtooth flounder (*Atheresthes stomias*) and shallow water flatfish (primarily rock sole (*Lepidopsetta* spp.) and yellowfin sole (*Limanda aspera*)), accounted for over half of the trawl bycatch in Area 3 (Fig. 6). Roughly 75% of this mortality was taken in Area 3A.

Bycatch mortality in hook-and-line fisheries primarily occurs in target fisheries for Pacific cod (*Gadus macrocephalus*). Since 2006, slightly more than half of the annual bycatch mortality from this fishery has usually been taken in Area 3B. The cod fishery occurs in January-March, when halibut tend to be in deeper water for spawning and cod are schooling in shallow water. This keeps bycatch lower than would otherwise occur. However, many of the boats fishing cod are < 57.5 ft LOA, with low observer coverage, so the reliability of these estimates is poor.

The Central Gulf of Alaska Rockfish Program (CGOARP), which began in 2012, permits harvesters to form voluntary cooperatives ("co-ops") and receive exclusive harvest privileges for certain rockfish species. Co-op participants are assigned rockfish quota shares based on their catch history, which are then aggregated to the co-op and fished collectively by its members. Two co-ops have been formed, one composed of catcher/processors and one of catcher vessels. The co-ops operate with limits to their halibut bycatch mortality and have a 100% observer requirement. The co-op bycatch mortality limits are a portion of the overall trawl bycatch mortality limits for the Gulf of Alaska and were set at 191.4 t (0.32 Mlbs) for all co-op fishing in 2014, although only 164 t (0.27 Mlbs) could be used before fishing ceased. Through November 28, only 77 t (0.13 Mlbs, or 47% of the 164 t bycatch allocation) had been taken, while 92% of the CGOARP groundfish allocation of 21,155 t had been harvested.

Area 3 remains the area where bycatch mortality is estimated most poorly. Observer coverage for most fisheries is relatively low, as noted earlier, and the extrapolation of bycatch rates from a small set of observed vessels to a much larger unobserved fleet renders the estimates provided here uncertain.

Area 4 – Bering Sea and Aleutian Islands

Bycatch mortality in Area 4 was estimated at 6.1 Mlbs, an increase of 5% from 2013 (Table 3; Fig. 7). Since 2000, bycatch mortality in this area has been as high as 7.7 Mlbs (2005), but the estimate for 2014 is the third lowest during this time period (Table 4). The estimate was below the 2005-2014 mean of 6.5 Mlbs. An increase in trawl fishery bycatch of 3.3% was partially offset by a 7.4% decrease in hook-and-line bycatch.

Trawl fishery bycatch was estimated at 5.3 Mlbs. More than 60% of the trawl fishery bycatch mortality is taken by flatfish fisheries; specifically those targeting rock sole and yellowfin sole (Fig. 8). As recently as 2006, the cod fishery was the major source of halibut bycatch. However, bycatch in the 2014 cod trawl fishery declined to just 12% of the total trawl sector mortality.

Hook-and-line fishery bycatch in 2014 was estimated at 0.80 Mlbs, a slight decrease from the 0.86 Mlbs estimated for 2013. Pacific cod is the major bycatch fishery, which is conducted in the late winter/early spring and late summer. Almost all of the vessels are required to have 100% observer coverage because of the vessel size and requirements of their fishery cooperative; very few small vessels fish cod in this area. Because of this high level of observer coverage, bycatch estimates for Area 4 fisheries are believed to be reliable.

Pots are also used to fish for cod and sablefish (*Anoplopoma fimbria*) and fish very cleanly. Bycatch rates are quite low and survival is relatively high. Annual bycatch mortality is typically less than 10,000 pounds, and was estimated at 5,000 pounds for 2014.

In the past few years, bycatch in Community Development Quota (CDQ) fishing has been tracked separately and reports have been posted online by NMFS to make this possible. Since 2009, data for these fisheries have been included in the separate gear totals for Area 4.

References

Clark, W. G., Hoag, S. H., Trumble, R. J., and Williams, G. H. 1993. Re-estimation of survival for trawl caught halibut released in different condition factors. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1992: 197-206.

Jannot, J. E., Somers, K., Riley, N. B., and McVeigh, J. 2014. Pacific halibut bycatch in the U.S. west coast fisheries (2002-2013). NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112. 75 p.

McElderry, H., Schrader, J., and Illingworth, J. 2003. The efficacy of video-based electronic monitoring for the halibut longline fishery. Canadian Science Advisory Secretariat, Research Document 2003/042. 80 p.

NMFS. 2013. Interim 2013 shorebased trawl vessel limits. NMFS Public Notice NMFS-SEA-13-07, issued April 11, 2013. (http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/groundfish/public_notices/nmfs-sea-13-07.pdf)

Williams, G. H. 1997. Pacific halibut discard mortality rates in the 1990-1995 Alaskan groundfish fisheries, with recommendations for monitoring in 1997. Int. Pac. Halibut Comm. Rep. Of Assess. and Res. Activ. 1997: 211-227.

Williams, G. H. 2012. Incidental catch and mortality of Pacific halibut, 1962-2011. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011:381-398.

Williams, G. H. 2013. Recommendations for Pacific halibut discard mortality rates in the 2013-2015 groundfish fisheries off Alaska. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012:337-354.

Williams, G. H., Schmitt, C. C., Hoag, S. H., and Berger, J. D. 1989. Incidental catch and mortality of Pacific halibut, 1962-1986. Int. Pac. Halibut Comm., Tech. Rep. No. 23.

Table 1. Area reassignments used to aggregate groundfish and halibut statistics to IPHC regulatory areas.

NMFS Areas	IPHC Area	Region
650+	2C	GOA
630,640,649	3A	
610, 620	3B	
517, 518, 519	4A	BSA
541,542,543	4B	
513,514,521,523, 524	4CDE	
508, 509, 512,516	CL	

Table 2. Preseason assumed discard mortality rates used by NMFS for monitoring halibut bycatch mortality for 2013-2015 in the Alaskan groundfish fisheries. From Williams (2013).

I. **Non-CDQ Fisheries**

Bering Sea/Aleutians		Gulf of Alaska		
Gear/Target	**Used in 2013-2015**	**Gear/Target**		**Used in 2013-2015**
Trawl		***Trawl***		
Atka mack	77	Bottom poll		60
Bottom poll	77	Pacific cod		62
Pacific cod	71	Dpwtr flats		43
Other Flats	71	Shallwtr flats		67
Rockfish	79	Rockfish		66
Flathead sole	73	Flathead sole		65
Midwtr poll	88	Midwtr poll		71
Rock sole	85	Sablefish		71
Sablefish	75	Arr. flndr		73
Turbot	64	Rex sole		69
Arr. flndr	76			
YF sole	83			
Pot		***Pot***		
Pacific cod	8	Pacific cod	17	17
Longline		***Longline***		
Pacific cod	9	Pacific cod	12	11
Rockfish	4	Rockfish	9	9
Turbot	13			

II. **Bering Sea/Aleutian Islands Community Development Quota Fisheries**

Gear/Target	**Used in 2013-2015**
Trawl	
Atka mackerel	86
Bottom pollock	83
Pacific cod	90
Rockfish	80
Flathead sole	79
Midwtr pollock	90
Rock sole	88
Turbot	89
Yellowfin sole	86
Pot	
Sablefish	34
Longline	
Pacific cod	10
Turbot	4

Table 3. Estimates (thousands of pounds, net weight) of bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) by year, area, and fishery, for 2005 through 2014. Estimates for 2014 are preliminary and subject to change as new information becomes available.

Region and Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
AREA 2A										
Groundfish Trawl	475	402	346	345	416	300	-	-	-	-
IFQ bottom trawl	-	-	-	-	-	-	52	67	54	54
Other gfish trawl	-	-	-	-	-	-	2	2	4	4
Groundfish Pot	-	-	-	-	-	-	1	1	0	0
Hook & Line	-	-	-	-	-	-	52	59	9	9
Fixed gear	61	178	41	78	93	46				
Total	536	580	387	423	509	346	108	129	67	67
AREA 2B										
Groundfish Bottom Trawl	346	294	320	143	213	181	232	189	225	244
Total	346	294	320	143	213	181	232	189	225	244
AREA 2C										
King/Tanner Crab Pot	13	15	23	19	7	18	10	21	13	1
Hook & Line (non-IFQ)	1	2	3	7	5	4	3	7	7	12
Hook & Line (IFQ)	3	3	3	3	3	3	3	3	3	3
Chatham Str. Sablefish	8	8	8	8	8	8	8	n/a	n/a	n/a
Clarence Str. Sablefish	25	25	25	25	25	25	25	n/a	n/a	n/a
Total	50	53	62	62	48	58	49	31	23	16
AREA 2 Subtotal	**932**	**927**	**769**	**628**	**770**	**585**	**389**	**349**	**315**	**327**
AREA 3A										
Crab Pot/Shrimp Trawl	250	250	250	250	250	250	250	n/a	n/a	n/a
Groundfish Trawl	2,664	2,339	2,347	2,381	2,141	2,030	2,232	1,649	1,275	1,364
Hook & Line (non-IFQ)	149	239	102	293	197	111	92	218	179	122
Hook & Line (IFQ)	119	119	119	119	119	119	119	119	119	119
Groundfish Pot	28	18	15	13	5	12	23	34	6	5
Pr Wm Sd Sablefish	10	10	10	10	10	10	10	n/a	n/a	n/a
Total	3,220	2,975	2,843	3,066	2,722	2,532	2,726	2,020	1,579	1,610
AREA 3B										
Crab Pot/Shrimp Trawl	50	50	50	50	50	50	50	n/a	n/a	n/a
Groundfish Trawl	862	926	795	979	865	676	806	1,192	752	957
Hook & Line (non-IFQ)	69	299	136	190	256	269	172	116	92	156
Hook & Line (IFQ)	116	116	116	116	116	116	116	116	116	116
Groundfish Pot	29	9	18	18	7	36	21	36	19	18
Total	1,126	1,400	1,115	1,353	1,294	1,147	1,165	1,460	978	1,247
AREA 3 Subtotal	**4,346**	**4,375**	**3,958**	**4,419**	**4,015**	**3,679**	**3,891**	**3,480**	**2,558**	**2,857**
AREA 4										
Crab Pot/Shrimp Trawl	300	300	300	300	300	300	300	n/a	n/a	n/a
Groundfish Trawl	6,454	6,269	5,841	4,897	4,774	4,668	4,185	5,148	5,098	5,268
Hook & Line (non-IFQ)	666	593	659	936	1,160	1,045	820	1,018	862	798
Hook & Line (IFQ)	60	60	60	60	60	60	60	60	60	60
Groundfish Pot	2	8	7	7	3	9	17	10	7	5
CDQ Trawl	128	187	309	223						
CDQ Hook & Line	82	74	86	131						
CDQ Pot	0	0	0	1						
AREA 4 Subtotal	**7,692**	**7,491**	**7,262**	**6,555**	**6,297**	**6,082**	**5,382**	**6,236**	**6,027**	**6,131**
GRAND TOTAL	**12,970**	**12,793**	**11,989**	**11,602**	**11,082**	**10,346**	**9,661**	**10,065**	**8,900**	**9,315**

Table 4. Estimates (thousands of pounds, net weight and metric tons, round weight) of the bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) from all sources by IPHC regulatory area, since 1962. Estimates for 2014 are preliminary and subject to change as new information becomes available.

	Thousands of Pounds, net weight				*Metric Tons, round weight*			
Year	**Area 2**	**Area 3**	**Area 4**	**Total**	**Area 2**	**Area 3**	**Area 4**	**Total**
1962	1,383	3,083	4,143	8,609	834	1,860	2,499	5,192
1963	1,283	6,102	2,038	9,423	774	3,681	1,229	5,683
1964	1,310	11,639	2,965	15,914	790	7,020	1,788	9,599
1965	1,640	16,539	3,182	21,361	989	9,976	1,919	12,884
1966	1,879	12,495	3,400	17,774	1,133	7,537	2,051	10,721
1967	2,091	9,528	4,718	16,337	1,261	5,747	2,846	9,854
1968	2,478	7,053	5,685	15,216	1,495	4,254	3,429	9,178
1969	2,651	4,980	7,599	15,230	1,599	3,004	4,584	9,186
1970	2,032	6,230	8,028	16,290	1,225	3,758	4,842	9,825
1971	2,284	4,341	13,095	19,720	1,377	2,618	7,899	11,894
1972	2,506	7,099	9,675	19,280	1,512	4,282	5,836	11,629
1973	2,357	7,147	8,029	17,533	1,422	4,311	4,843	10,575
1974	2,738	8,667	7,620	19,025	1,651	5,228	4,596	11,475
1975	3,025	5,231	3,650	11,906	1,825	3,155	2,202	7,181
1976	3,249	5,938	4,564	13,751	1,960	3,582	2,753	8,294
1977	2,874	5,988	2,914	11,776	1,733	3,612	1,758	7,103
1978	2,325	4,895	5,023	12,242	1,402	2,952	3,029	7,384
1979	3,149	6,715	5,419	15,282	1,899	4,050	3,269	9,218
1980	2,368	7,099	9,235	18,702	1,428	4,282	5,570	11,280
1981	2,169	6,282	6,408	14,859	1,308	3,789	3,865	8,963
1982	1,644	5,972	4,756	12,373	992	3,602	2,869	7,463
1983	1,723	4,892	4,269	10,883	1,039	2,951	2,575	6,564
1984	1,851	3,647	4,692	10,189	1,116	2,199	2,830	6,146
1985	1,915	1,578	4,207	7,700	1,155	952	2,538	4,644
1986	1,940	1,246	5,576	8,762	1,170	752	3,363	5,285
1987	2,428	3,113	5,738	11,279	1,465	1,878	3,461	6,803
1988	2,389	3,415	8,858	14,662	1,441	2,060	5,343	8,844
1989	2,278	4,085	7,282	13,646	1,374	2,464	4,393	8,231
1990	2,943	6,159	8,580	17,682	1,775	3,715	5,175	10,665
1991	3,133	6,514	10,022	19,669	1,890	3,929	6,045	11,864
1992	2,925	6,650	10,718	20,293	1,764	4,011	6,465	12,240
1993	2,847	5,353	7,764	15,964	1,717	3,229	4,683	9,629
1994	2,191	5,294	9,466	16,951	1,322	3,193	5,710	10,224
1995	2,484	4,723	8,726	15,933	1,498	2,849	5,263	9,610
1996	1,258	4,700	8,507	14,465	759	2,835	5,131	8,725
1997	1,226	4,408	7,880	13,514	739	2,659	4,753	8,151
1998	1,656	4,051	7,725	13,432	999	2,443	4,660	8,102
1999	1,538	4,622	7,684	13,844	928	2,788	4,635	8,350
2000	1,447	4,402	7,441	13,290	873	2,655	4,488	8,016
2001	1,355	4,684	7,120	13,159	817	2,825	4,295	7,937
2002	1,219	4,118	7,273	12,610	735	2,484	4,387	7,606
2003	845	4,914	6,822	12,581	510	2,964	4,115	7,589
2004	609	4,945	6,735	12,289	367	2,983	4,062	7,412
2005	932	4,346	7,692	12,970	562	2,621	4,640	7,823
2006	927	4,375	7,491	12,793	559	2,639	4,518	7,716
2007	769	3,958	7,262	11,989	464	2,387	4,380	7,232
2008	628	4,419	6,555	11,602	379	2,665	3,954	6,998
2009	770	4,015	6,297	11,082	464	2,422	3,798	6,684
2010	585	3,679	6,082	10,346	353	2,219	3,669	6,240
2011	389	3,891	5,382	9,661	235	2,347	3,246	5,828
2012	349	3,480	6,236	10,065	211	2,099	3,761	6,071
2013	315	2,558	6,027	8,900	190	1,543	3,635	5,368
2014	327	2,857	6,131	9,315	197	1,723	3,698	5,618

Table 5. Estimates (thousands of pounds, net weight and metric tons, round weight) of the bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) from all sources by IPHC regulatory area, since 1962. Estimates for 2014 are preliminary and subject to change as new information becomes available.

	Thousands of pounds, net weight							*Metric tons, round weight*						
Year	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4	TOTAL	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4	TOTAL
1962	-	1,176	207	1,919	1,164	4,143	8,609	-	709	125	1,157	702	2,499	5,192
1963	-	1,077	206	3,314	2,788	2,038	9,423	-	649	124	1,999	1,682	1,229	5,683
1964	-	1,105	205	9,370	2,269	2,965	15,914	-	667	124	5,652	1,369	1,788	9,599
1965	-	1,435	205	6,097	10,442	3,182	21,361	-	866	124	3,678	6,298	1,919	12,884
1966	-	1,666	213	4,513	7,982	3,400	17,774	-	1,005	128	2,722	4,815	2,051	10,721
1967	-	1,652	439	4,633	4,895	4,718	16,337	-	996	265	2,795	2,953	2,846	9,854
1968	-	1,963	515	5,476	1,577	5,685	15,216	-	1,184	311	3,303	951	3,429	9,178
1969	-	2,183	468	3,806	1,174	7,599	15,230	-	1,317	282	2,296	708	4,584	9,186
1970	-	1,470	562	3,389	2,841	8,028	16,290	-	886	339	2,044	1,714	4,842	9,825
1971	-	1,745	539	2,974	1,367	13,095	19,720	-	1,052	325	1,794	825	7,899	11,894
1972	-	1,750	756	5,406	1,693	9,675	19,280	-	1,056	456	3,261	1,021	5,836	11,629
1973	-	1,509	848	4,452	2,695	8,029	17,533	-	910	511	2,685	1,626	4,843	10,575
1974	477	1,729	532	5,247	3,420	7,620	19,025	288	1,043	321	3,165	2,063	4,596	11,475
1975	477	1,909	639	3,158	2,073	3,650	11,906	288	1,151	385	1,905	1,250	2,202	7,181
1976	477	2,064	708	3,495	2,443	4,564	13,751	288	1,245	427	2,108	1,474	2,753	8,294
1977	477	1,817	580	4,094	1,894	2,914	11,776	288	1,096	350	2,469	1,142	1,758	7,103
1978	477	1,471	377	3,055	1,840	5,023	12,242	288	887	227	1,843	1,110	3,029	7,384
1979	476	1,852	821	5,780	935	5,419	15,282	287	1,117	495	3,486	564	3,269	9,218
1980	476	1,372	520	5,852	1,246	9,235	18,702	287	828	314	3,530	752	5,570	11,280
1981	475	1,188	507	4,720	1,563	6,408	14,859	287	716	306	2,847	942	3,865	8,963
1982	475	867	302	3,797	2,175	4,756	12,373	287	523	182	2,290	1,312	2,869	7,463
1983	476	943	304	2,957	1,935	4,269	10,883	287	568	183	1,784	1,167	2,575	6,564
1984	475	1,074	302	2,140	1,507	4,692	10,189	287	648	182	1,290	909	2,830	6,146
1985	475	1,139	301	1,001	577	4,207	7,700	287	687	182	604	348	2,538	4,644
1986	476	1,161	303	836	410	5,576	8,762	287	700	183	504	247	3,363	5,285
1987	476	1,649	303	2,240	873	5,738	11,279	287	995	183	1,351	527	3,461	6,803
1988	477	1,609	303	3,365	50	8,858	14,662	288	971	183	2,030	30	5,343	8,844
1989	477	1,498	303	3,267	818	7,282	13,646	288	904	183	1,971	494	4,393	8,231
1990	408	1,679	856	4,114	2,045	8,580	17,682	246	1,013	516	2,481	1,233	5,175	10,665
1991	408	1,992	733	4,843	1,671	10,022	19,669	246	1,202	442	2,921	1,008	6,045	11,864
1992	444	1,745	736	4,668	1,982	10,718	20,293	268	1,053	444	2,816	1,195	6,465	12,240
1993	444	1,661	742	4,291	1,062	7,764	15,964	268	1,002	448	2,588	641	4,683	9,629
1994	444	1,219	528	3,907	1,387	9,466	16,951	268	735	318	2,357	837	5,710	10,224
1995	614	1,522	348	2,963	1,760	8,726	15,933	370	918	210	1,787	1,062	5,263	9,610
1996	614	299	345	2,743	1,957	8,507	14,465	370	180	208	1,655	1,180	5,131	8,725
1997	614	215	397	2,965	1,443	7,880	13,514	370	130	239	1,788	870	4,753	8,151
1998	1,082	213	361	2,662	1,389	7,725	13,432	653	128	218	1,606	838	4,660	8,102
1999	987	193	358	2,885	1,737	7,684	13,844	595	116	216	1,740	1,048	4,635	8,350
2000	822	230	395	2,892	1,510	7,441	13,290	496	139	238	1,744	911	4,488	8,016
2001	837	177	341	3,009	1,675	7,120	13,159	505	107	206	1,815	1,010	4,295	7,937
2002	635	244	340	2,194	1,924	7,273	12,610	383	147	205	1,323	1,161	4,387	7,606
2003	260	244	341	3,180	1,734	6,822	12,581	157	147	206	1,918	1,046	4,115	7,589
2004	288	251	70	3,671	1,274	6,735	12,289	174	151	42	2,214	768	4,062	7,412
2005	536	346	50	3,220	1,126	7,692	12,970	323	209	30	1,942	679	4,640	7,823
2006	580	294	53	2,975	1,400	7,491	12,793	350	177	32	1,794	844	4,518	7,716
2007	387	320	62	2,843	1,115	7,262	11,989	233	193	37	1,715	673	4,380	7,232
2008	423	143	62	3,066	1,353	6,555	11,602	255	86	37	1,849	816	3,954	6,998
2009	509	213	48	2,722	1,294	6,297	11,082	307	128	29	1,642	780	3,798	6,684
2010	346	181	58	2,532	1,147	6,082	10,346	209	109	35	1,527	692	3,669	6,240
2011	108	232	49	2,726	1,165	5,382	9,661	65	140	30	1,644	703	3,246	5,828
2012	129	189	31	2,020	1,460	6,236	10,065	78	114	19	1,218	881	3,761	6,071
2013	67	225	23	1,579	978	6,027	8,900	40	136	14	953	590	3,635	5,368
2014	67	244	16	1,610	1,247	6,131	9,315	40	147	9	971	752	3,698	5,618

Table 6. Estimates (thousands of pounds, net weight and metric tons, round weight) of the bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) from all sources by geographic region of the coast, since 1962. Estimates for 2014 are preliminary and subject to change as new information becomes available.

	Thousands of Pounds, net weight					*Metric Tons, round weight*				
Year	WOC	B.C.	Gulf of Alaska	B Sea & Aleut.	Total	WOC	B.C.	Gulf of Alaska	B Sea & Aleut.	Total
1962	-	1,176	3,290	4,143	8,609	-	709	1,984	2,499	5,192
1963	-	1,077	6,308	2,038	9,423	-	649	3,805	1,229	5,683
1964	-	1,105	11,844	2,965	15,914	-	667	7,144	1,788	9,599
1965	-	1,435	16,744	3,182	21,361	-	866	10,100	1,919	12,884
1966	-	1,666	12,708	3,400	17,774	-	1,005	7,665	2,051	10,721
1967	-	1,652	9,967	4,718	16,337	-	996	6,012	2,846	9,854
1968	-	1,963	7,568	5,685	15,216	-	1,184	4,565	3,429	9,178
1969	-	2,183	5,448	7,599	15,230	-	1,317	3,286	4,584	9,186
1970	-	1,470	6,792	8,028	16,290	-	886	4,097	4,842	9,825
1971	-	1,745	4,880	13,095	19,720	-	1,052	2,943	7,899	11,894
1972	-	1,750	7,855	9,675	19,280	-	1,056	4,738	5,836	11,629
1973	-	1,509	7,995	8,029	17,533	-	910	4,822	4,843	10,575
1974	477	1,729	9,199	7,620	19,025	288	1,043	5,549	4,596	11,475
1975	477	1,909	5,870	3,650	11,906	288	1,151	3,541	2,202	7,181
1976	477	2,064	6,646	4,564	13,751	288	1,245	4,009	2,753	8,294
1977	477	1,817	6,568	2,914	11,776	288	1,096	3,962	1,758	7,103
1978	477	1,471	5,272	5,023	12,242	288	887	3,180	3,029	7,384
1979	476	1,852	7,536	5,419	15,282	287	1,117	4,545	3,269	9,218
1980	476	1,372	7,619	9,235	18,702	287	828	4,595	5,570	11,280
1981	475	1,188	6,789	6,408	14,859	287	716	4,095	3,865	8,963
1982	475	867	6,274	4,756	12,373	287	523	3,784	2,869	7,463
1983	476	943	5,196	4,269	10,883	287	568	3,134	2,575	6,564
1984	475	1,074	3,949	4,692	10,189	287	648	2,382	2,830	6,146
1985	475	1,139	1,879	4,207	7,700	287	687	1,133	2,538	4,644
1986	476	1,161	1,549	5,576	8,762	287	700	934	3,363	5,285
1987	476	1,649	3,416	5,738	11,279	287	995	2,060	3,461	6,803
1988	477	1,609	3,718	8,858	14,662	288	971	2,243	5,343	8,844
1989	477	1,498	4,388	7,282	13,646	288	904	2,647	4,393	8,231
1990	408	1,679	7,015	8,580	17,682	246	1,013	4,231	5,175	10,665
1991	408	1,992	7,247	10,022	19,669	246	1,202	4,371	6,045	11,864
1992	444	1,745	7,386	10,718	20,293	268	1,053	4,455	6,465	12,240
1993	444	1,661	6,095	7,764	15,964	268	1,002	3,676	4,683	9,629
1994	444	1,219	5,822	9,466	16,951	268	735	3,512	5,710	10,224
1995	614	1,522	5,071	8,726	15,933	370	918	3,059	5,263	9,610
1996	614	299	5,045	8,507	14,465	370	180	3,043	5,131	8,725
1997	614	215	4,805	7,880	13,514	370	130	2,898	4,753	8,151
1998	1,082	213	4,412	7,725	13,432	653	128	2,661	4,660	8,102
1999	987	193	4,980	7,684	13,844	595	116	3,004	4,635	8,350
2000	822	230	4,797	7,441	13,290	496	139	2,893	4,488	8,016
2001	837	177	5,025	7,120	13,159	505	107	3,031	4,295	7,937
2002	635	244	4,458	7,273	12,610	383	147	2,689	4,387	7,606
2003	260	244	5,255	6,822	12,581	157	147	3,170	4,115	7,589
2004	288	251	5,015	6,735	12,289	174	151	3,025	4,062	7,412
2005	536	346	4,396	7,692	12,970	323	209	2,652	4,640	7,823
2006	580	294	4,428	7,491	12,793	350	177	2,671	4,518	7,716
2007	387	320	4,020	7,262	11,989	233	193	2,425	4,380	7,232
2008	423	143	4,481	6,555	11,602	255	86	2,703	3,954	6,998
2009	509	213	4,063	6,297	11,082	307	128	2,451	3,798	6,684
2010	346	181	3,737	6,082	10,346	209	109	2,254	3,669	6,240
2011	108	232	3,940	5,382	9,661	65	140	2,376	3,246	5,828
2012	129	189	3,511	6,236	10,065	78	114	2,118	3,761	6,071
2013	67	225	2,581	6,027	8,900	40	136	1,557	3,635	5,368
2014	67	244	2,873	6,131	9,315	40	147	1,733	3,698	5,618

Table 7. Estimates (thousands of pounds, net weight and metric tons, round weight) of the bycatch mortality of Pacific halibut (*Hippoglossus stenolepis*) from the Alaskan groundfish fishery since 1990. Estimates for 2014 are preliminary and subject to change as new information becomes available. All federally managed fisheries are represented, including the Individual Fisheries Quota sablefish fishery and Community Development Quota fisheries. However, fisheries operating within State of Alaska jurisdiction, e.g., Chatham Strait sablefish fishery, are excluded.

	Gulf of Alaska							
	Thousands of Pounds, net weight				*Metric Tons, round weight*			
Year	**Trawls**	**H&L**	**Pot**	**Total**	**Trawls**	**H&L**	**Pot**	**Total**
1990	4,331	2,012	52	6,395	2,612	1,214	31	3,857
1991	4,538	2,081	7	6,626	2,737	1,255	4	3,997
1992	4,060	2,684	26	6,770	2,449	1,619	16	4,083
1993	3,548	1,900	19	5,467	2,140	1,146	19	3,305
1994	3,619	1,512	23	5,154	2,183	912	14	3,109
1995	3,745	645	35	4,425	2,259	389	21	2,669
1996	3,890	498	11	4,399	2,346	300	7	2,653
1997	3,291	855	13	4,159	1,985	516	8	2,509
1998	3,042	705	19	3,766	1,835	425	11	2,272
1999	3,333	854	147	4,334	2,010	515	89	2,614
2000	3,416	718	17	4,151	2,060	433	10	2,504
2001	3,724	614	41	4,379	2,246	370	25	2,641
2002	3,193	615	4	3,812	1,926	371	2	2,299
2003	3,748	827	34	4,609	2,261	499	21	2,780
2004	3,899	710	52	4,661	2,352	428	31	2,811
2005	3,526	457	57	4,040	2,127	276	34	2,437
2006	3,265	778	27	4,070	1,969	469	16	2,455
2007	3,142	479	33	3,654	1,895	289	20	2,204
2008	3,360	728	31	4,119	2,027	439	19	2,484
2009	3,006	622	11	3,639	1,813	375	7	2,195
2010	2,706	622	48	3,376	1,632	375	29	2,036
2011	3,038	505	44	3,587	1,832	304	27	2,163
2012	2,841	579	70	3,490	1,714	349	42	2,105
2013	2,027	516	25	2,568	1,223	311	15	1,549
2014	2,321	528	23	2,872	1,400	318	14	1,732

….cont'd

Table 7. Continued)

	Bering Sea/Aleutians							
	Thousands of Pounds, net weight				*Metric Tons, round weight*			
Year	**Trawls**	**H&L**	**Pot**	**Total**	**Trawls**	**H&L**	**Pot**	**Total**
1990	6,309	627	4	6,940	3,805	378	2	4,186
1991	8,254	1,464	4	9,722	4,979	883	2	5,864
1992	7,622	2,775	21	10,418	4,597	1,674	13	6,284
1993	6,603	861	tr	7,464	3,983	519	tr	4,502
1994	7,199	1,944	9	9,152	4,342	1,173	5	5,520
1995	6,610	1,731	25	8,366	3,987	1,044	15	5,046
1996	6,582	1,535	30	8,147	3,970	926	18	4,914
1997	5,947	1,564	9	7,520	3,587	943	5	4,536
1998	5,945	1,409	11	7,365	3,586	850	7	4,442
1999	6,159	1,214	11	7,384	3,715	732	7	4,454
2000	5,443	1,674	24	7,141	3,283	1,010	14	4,307
2001	5,379	1,428	13	6,820	3,244	861	8	4,114
2002	5,722	1,234	17	6,973	3,451	744	10	4,206
2003	5,776	718	28	6,522	3,484	433	17	3,934
2004	5,675	754	6	6,435	3,423	455	4	3,881
2005	6,582	808	2	7,392	3,970	487	1	4,459
2006	6,456	727	8	7,191	3,894	439	5	4,337
2007	6,150	805	7	6,962	3,710	486	4	4,199
2008	5,120	1,127	7	6,254	3,088	680	4	3,772
2009	4,774	1,220	3	5,997	2,880	736	2	3,617
2010	4,668	1,105	9	5,782	2,816	667	5	3,488
2011	4,185	880	17	5,082	2,524	531	10	3,065
2012	5,148	1,078	10	6,236	3,105	650	6	3,761
2013	5,098	922	7	6,027	3,075	556	4	3,635
2014	5,268	858	5	6,131	3,178	518	3	3,698

…cont'd

Table 7. (Concluded)

	TOTAL ALASKA							
	Thousands of Pounds, net weight				*Metric Tons, round weight*			
Year	**Trawls**	**H&L**	**Pot**	**Total**	**Trawls**	**H&L**	**Pot**	**Total**
1990	10,640	2,639	56	13,335	6,418	1,592	34	8,043
1991	12,792	3,545	11	16,348	7,716	2,138	7	9,861
1992	11,682	5,459	47	17,188	7,046	3,293	28	10,367
1993	10,151	2,761	19	12,931	6,123	1,665	19	7,807
1994	10,818	3,456	32	14,306	6,525	2,085	19	8,629
1995	10,355	2,376	60	12,791	6,246	1,433	36	7,715
1996	10,472	2,033	41	12,546	6,316	1,226	25	7,567
1997	9,238	2,419	22	11,679	5,572	1,459	13	7,044
1998	8,987	2,114	30	11,131	5,421	1,275	18	6,714
1999	9,492	2,068	158	11,718	5,725	1,247	95	7,068
2000	8,859	2,392	41	11,292	5,344	1,443	25	6,811
2001	9,103	2,042	54	11,199	5,491	1,232	33	6,755
2002	8,915	1,849	21	10,785	5,377	1,115	13	6,505
2003	9,524	1,545	62	11,131	5,745	932	37	6,714
2004	9,574	1,464	58	11,096	5,775	883	35	6,693
2005	10,108	1,265	59	11,432	6,097	763	36	6,895
2006	9,721	1,505	35	11,261	5,863	908	21	6,792
2007	9,292	1,284	40	10,616	5,605	774	24	6,403
2008	8,480	1,855	38	10,373	5,115	1,119	23	6,257
2009	7,780	1,842	14	9,636	4,693	1,111	8	5,812
2010	7,374	1,727	57	9,158	4,448	1,042	34	5,524
2011	7,223	1,385	61	8,669	4,357	835	37	5,229
2012	7,989	1,657	80	9,726	4,819	999	48	5,866
2013	7,125	1,438	32	8,595	4,298	867	19	5,184
2014	7,589	1,386	28	9,003	4,577	836	17	5,430

Table 8. Estimates of 2014 groundfish catch (mt) and Pacific halibut bycatch mortality (thousands of pounds, net weight) by region, gear, and target fishery in the groundfish fisheries off Alaska. Does not include Individual Fishing Quota fisheries. Data represent fishing through October 25, 2014. Catches less than 500 lbs or 0.5 t noted by "tr", i.e., trace.

	Hook & Line/Jig		Pot		Trawl	
Region & Target fishery	**Groundfish Catch (mt)**	**Hbt Byc Mort (Klbs)**	**Groundfish Catch (mt)**	**Hbt Byc Mort (Klbs)**	**Groundfish Catch (mt)**	**Hbt Byc Mort (Klbs)**
Bering Sea						
Alaska Plaice					tr	1
Arrowtooth Flounder					4,456	315
Atka Mackerel					15,617	138
Bottom Pollock					41,084	127
Flathead Sole					15,029	199
Greenland Turbot	598	2			tr	tr
Kamchatka Flounder					1,041	24
Midwater Pollock					1,124,747	197
Other Flatfish					tr	tr
Other Species	tr	tr	tr	tr		
Pacific Cod	117,695	557	29,918	4	39,592	545
Rock Sole					70,912	1,113
Rockfish	tr	tr			13,396	115
Sablefish			tr	1	tr	1
Yellowfin sole					170,029	1,675
Total	**118,293**	**559**	**29,918**	**4**	**1,495,903**	**4,449**
Gulf of Alaska						
Arrowtooth Flounder					19,984	1,145
Bottom Pollock	tr	tr			23,028	158
Deep Water Flats					tr	tr
Flathead Sole					tr	4
Midwater Pollock	tr	tr			115,122	tr
Other Species			tr	tr		
Pacific Cod	13,880	235	37,159	22	19,480	367
Rex Sole					305	91
Rockfish	73	1			17,569	129
Sablefish	tr	tr	tr	tr	tr	2
Shallow Water Flats					1,615	259
Total	**13,953**	**236**	**37,159**	**22**	**197,103**	**2,155**

Table 9. Estimates of halibut bycatch in crab fisheries in Southeast Alaska (numbers of halibut caught), based on data supplied by the Alaska Department of Fish and Game. The estimated weight is based on an average weight of 11.2 pounds from Williams et al. (1989).

Year	Golden King Crab	Red King Crab	Tanner crab	Total Number	Estimated weight (lbs, net)
1995		357		357	3,998
1996		1,027		1,027	11,502
1997		235	9,858	10,093	113,042
1998			2,710	2,710	30,352
1999		571	550	1,121	12,555
2000			3,112	3,112	34,854
2001		422	1,394	1,816	20,339
2002		189	1,791	1,980	22,176
2003		174	2,517	2,691	30,139
2004			946	946	10,595
2005		390	778	1,168	13,082
2006			1,325	1,325	14,840
2007	26		2,037	2,063	23,106
2008	74		1,603	1,677	18,782
2009	0		624	624	6,989
2010	83		1,480	1,563	17,506
2011	142	242	523	907	10,158
2012	795		1,109	1,904	21,325
2013	404		757	1,161	13,003
2014	31			31	347

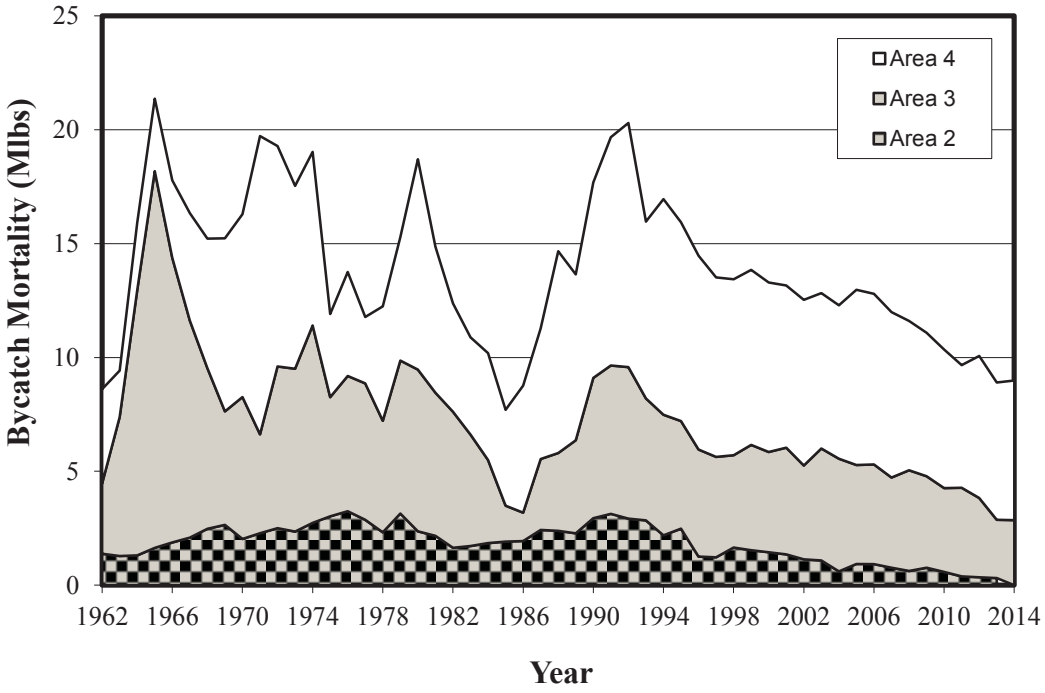


Figure 1. Bycatch mortality of Pacific halibut by IPHC regulatory area (millions of pounds, net weight), 1962-2014.

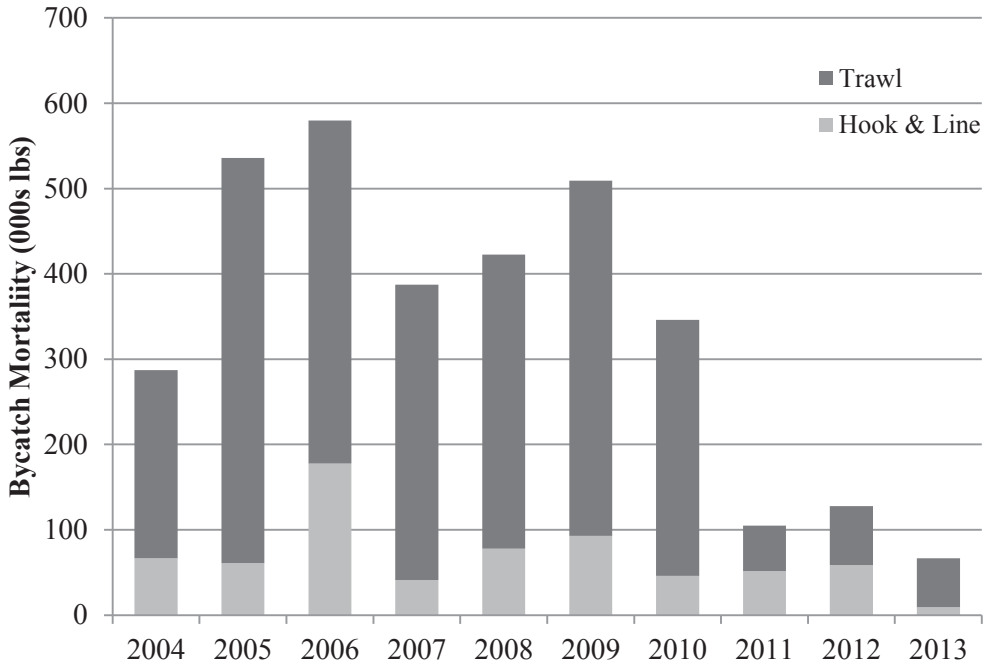


Figure 2. Pacific halibut bycatch mortality (thousands of pounds, net weight) in the trawl and hook-&-line groundfish fisheries in IPHC Area 2A during 2004-2014. Data from Jannot et al. (2014).

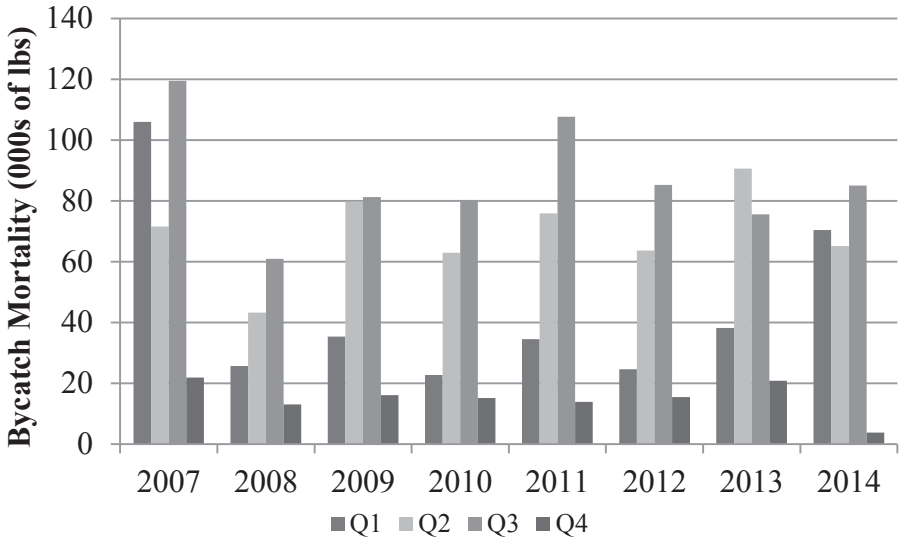


Figure 3. Pacific halibut bycatch mortality (thousands of pounds, net weight) by calendar quarter in the 2007-2014 Area 2B (B.C.) bottom trawl groundfish fishery.

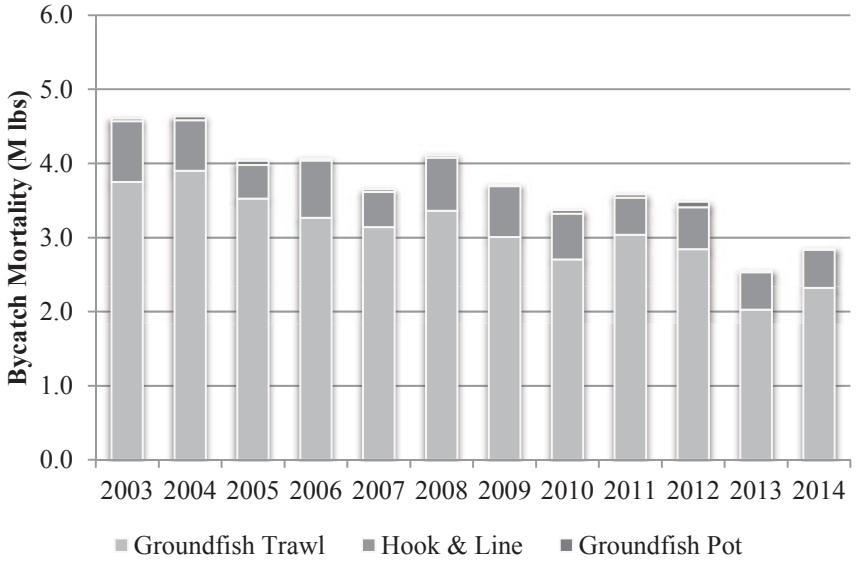


Figure 4. Bycatch mortality (millions of pounds, net weight) in Area 3 during 2005-2014 by gear.

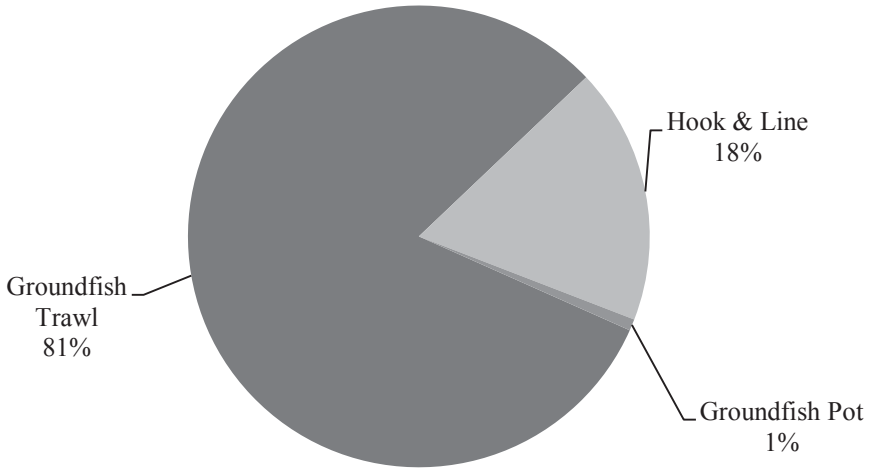


Figure 5. Proportion of 2014 bycatch mortality in Areas 3A/3B by gear type.

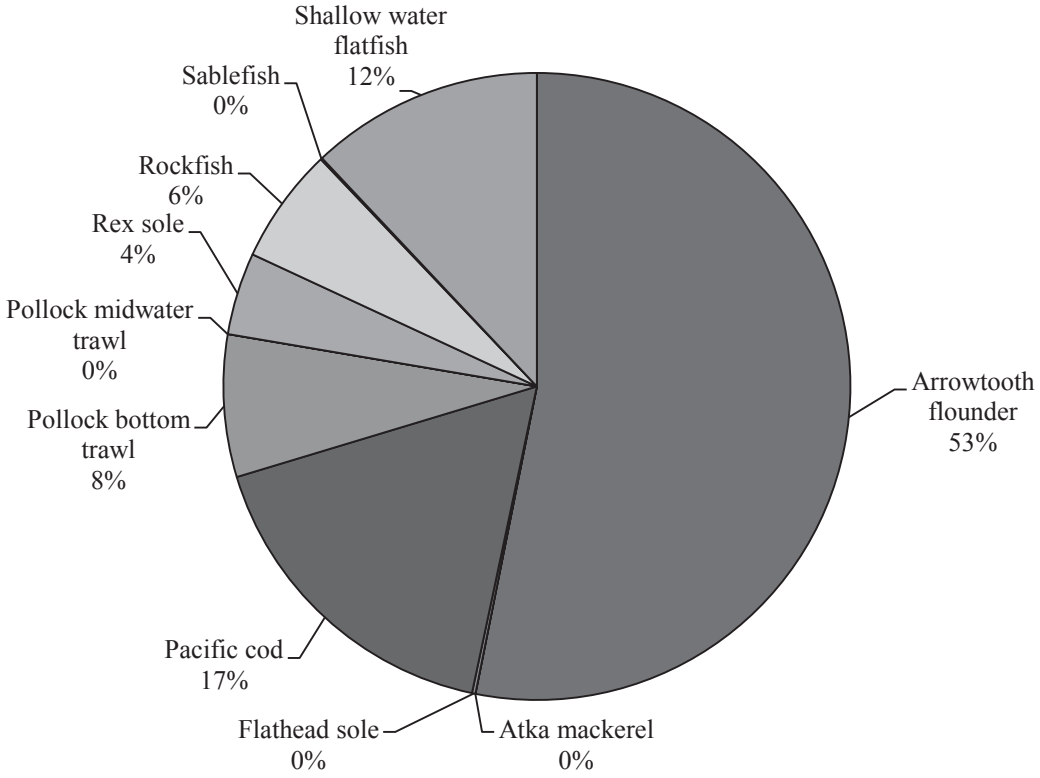


Figure 6. Breakdown of 2014 trawl bycatch mortality by target fishery in Areas 3A/3B.

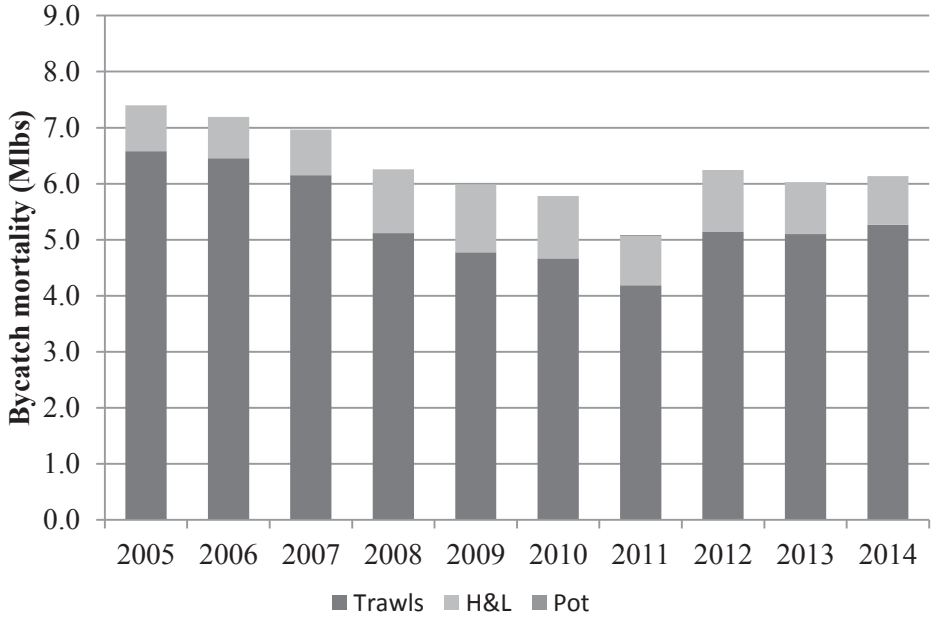


Figure 7. Bycatch mortality (millions of pounds, net weight) in Area 4 by gear type during 2005-2014.

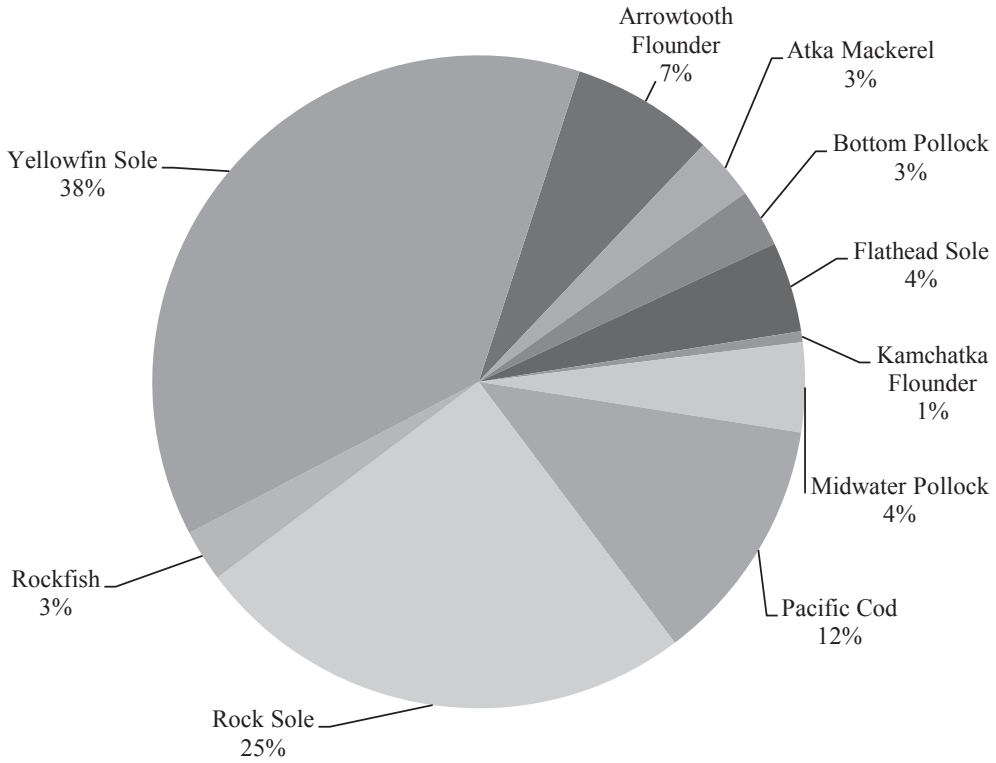


Figure 8. Proportion of the 2014 Bering Sea/Aleutian Islands region trawl fishery bycatch by target fishery. The flatfish category is primarily yellowfin sole and rock sole.

Halibut bycatch limits in the 2014 Alaska groundfish fishery

Gregg H. Williams

Abstract

Bycatch of Pacific halibut in the groundfish fisheries off Alaska is managed with Prohibited Species Catch limits. The limits, first established by the North Pacific Fishery Management Council in the early 1990s, are subdivided by gear type, target fishery, and time period, and among several management programs. Halibut limits are set as mortality rather than total catch. In 2014, the limits totaled 2,127 t (3.52 million pounds) in the Gulf of Alaska and 4,425 t (7.30 million pounds) in the Bering Sea. However, under Fishery Management Plan Amendment 80 for the Bering Sea trawl fishery, only 3,525 t of the fishery's 3,675 t limit was allocated in 2014, similar to previous years.

Introduction

This document summarizes the management of halibut bycatch in the 2014 groundfish fisheries off Alaska. These fisheries are managed by the National Marine Fisheries Service (NMFS), following advice and recommendations developed by the North Pacific Fishery Management Council (Council). The Council sets limits to the amount of halibut bycatch mortality which is allowed to occur annually in the groundfish fisheries. If a fishery's limit is reached, the fishery is closed and no further directed fishing is allowed. Certain gear types, e.g., pots or jigs, are exempted from closures due to their low bycatch properties and to encourage their use.

2014 halibut bycatch limits and fishery closures

The Council adopts halibut bycatch mortality limits for the Alaskan groundfish fisheries during its annual specification process in the fall of each year. Currently, the limits are set by management area (Figs. 1 and 2). The limits are fixed in regulation[1] and can only be changed through a formal amendment. For both regions, regulations allow the Council to apportion the trawl and fixed gear limits into seasonal amounts and by fishery, to enable the groundfish fisheries to maximize their groundfish catch within the specified limits. A complete history of the halibut bycatch limits is in Table 1.

Gulf of Alaska

This was the first year of a three-year phase-in of a 15% reduction for the GOA bycatch limits. The reduction is being implemented with a 7% reduction in 2014, 5% in 2015 (to 12%), and 3% in 2016 (totaling 15%). The proposed reduction for the catcher/processor (CP) hook-and-line gear would be 7%, which was implemented in one step in 2014. Thus, the reductions result in a new cap of 1,848 t in 2014, 1,759 t in 2015, and 1,705 t in 2016 and later years for the trawl sector. The Council used the 2013 bycatch limit of 1,973 t as the baseline for its proposed trawl PSC limit reduction. For the hook-and-line sector, the reduction differs between vessel types. The hook-

[1]Prior to 2014, the bycatch limits in the GOA were frameworked, allowing annual changes. In 2013, the NPFMC decided to change that process by putting the limits in regulation, similar to the BSAI bycatch limits. 2014 was the first year of the new process.

and-line CP sector would fish under a 109 t bycatch limit, based on 2012 Pacific cod TACs in the Western and Central GOA, but will vary annually. For example, in 2014 the limit was 115 t. The hook-and-line catcher vessel (CV) sector limit was 153 t in 2014, but is expected to be 152 t in 2015, and 147 t in 2016 and beyond.

Consequently, the 2014 trawl fishery limit was 1,848 t (3.06 million pounds[2]; Table 2). The trawl limit was divided by season for shallow water and deep water fisheries, as has been the practice since 1991. However, the fifth seasonal apportionment (October 1 through December 31) was not divided between the complexes.

Bycatch management in the GOA fixed gear fisheries in 2014 was similar to previous years in that limits were assigned to specific fisheries. The bycatch limit was set at 279 t (0.46 million pounds; Table 2) for all fixed gear fisheries, a slight reduction from 2013. The fixed gear fisheries targeted primarily Pacific cod in the central and western GOA during the winter and rockfish in the eastern GOA in the spring. The fixed gear limit is divided between the CV and CP sectors; the sector limits are further divided seasonally (Table 3, part A). All pot and jig gear fisheries, as well as the sablefish Individual Fishing Quota (IFQ) fishery, were exempted from mortality limits.

Several programs exist in the GOA for which the Council has allocated specific halibut bycatch limits from the overall limit. The Central GOA Rockfish Program (CGOARP) began in 2012 and isolates fishing for certain rockfish species from other fisheries within the fishery management system. Fishery cooperatives ("co-ops") are formed under the program, and a portion of the overall rockfish quotas and halibut bycatch limit are specified for the program. The CGOARP bycatch limit is divided between the trawl catcher/processor and catcher vessel sectors, and longline vessels designated as entry level (Table 3, part B). The limits are designed to keep bycatch from increasing above historic levels. In 2014, all vessels participated in co-ops.

Another program for halibut bycatch management in the Gulf of Alaska applies to vessels that participate in the fishery co-ops in the BSAI. Briefly, BSAI Plan Amendment 80 (A80) permits vessels to form fishery co-ops, which allows for a more efficient prosecution of their fisheries. Although A80 does not require vessels to join a co-op, in 2014 all eligible A80 vessels belonged to the only co-op in operation. The A80 co-op trawl vessels which do not fish in the CGOARP are excluded from directed fishing for Pacific ocean perch, pelagic shelf rockfish, and northern rockfish in the GOA. The exclusion is put into place through limitations on their catch of other groundfish species and the associated halibut bycatch. These limitations were adopted to protect the interests of GOA trawl fishers who are not in an A80 co-op from expansion by A80 co-op vessels into their GOA fisheries. To limit the catches by the A80 co-op vessels in the GOA, the Council created limits, or sideboards, on their catches. The halibut bycatch mortality sideboard limits for A80 vessels (Table 3, part C) are based on historic use of halibut bycatch by those vessels in the shallow-water and deep-water fisheries from 1998-2004.

The final apportionment of halibut bycatch in the GOA is a result of the 1998 American Fisheries Act (AFA). The AFA specified that certain trawl catcher/processors fishing for pollock in the BSAI were prohibited from fishing for certain other groundfish species in the GOA. The AFA also specified limits on the amounts of other non-pollock groundfish species those vessels were allowed to catch; these limits are also termed sideboards. To support directed fishing for the groundfish sideboard species, the Council set halibut bycatch limits. These limits (Table 3, part D)

[2]Throughout this report, weights in net pounds (head off, eviscerated) will be provided which are equivalent to the metric tons round weight (head on, not eviscerated).

are based on the proportion of the total groundfish catch caught by the AFA catcher vessels from 1995-1997.

Bering Sea/Aleutian Islands

The halibut bycatch mortality limits for the 2014 BSAI trawl and fixed gear fisheries totaled 4,575 t (7.4 million pounds, Table 4), unchanged since 1999. However, not all of the limits were assigned to fisheries, so a portion of the trawl limit remained unallocated.

As in past years, the BSAI fixed gear fisheries were allocated a total bycatch limit of 900 t (1.49 million pounds), but 7.5% (68 t; 0.11 million pounds) was reassigned to Community Development Quota (CDQ) fisheries, leaving 832 t (1.38 million pounds). This was divided between the hook-and-line fishery for Pacific cod and all other fixed gear fisheries. The cod fishery limit was further divided between CPs and CVs (Table 5). All pot and jig fisheries were exempted from halibut mortality closures. The sablefish IFQ hook-and-line fishery was also exempted from the bycatch limit.

The 2014 trawl fishery bycatch mortality limit was 3,675 t (6.0 million pounds; Table 4). By regulation, a fixed amount of 326 t (0.5 million pounds) is reallocated to CDQ fisheries (gear nonspecific), leaving 3,350 t (5.5 million pounds) for all remaining trawl fisheries. However, only 3,200 t (5.3 million pounds) was allocated among fisheries. A80 also separated the trawl fleet into an A80 sector and a Limited Access sector. The latter group includes the pollock co-ops created by the AFA. Within the A80 fleet, the bycatch limit was assigned to the Alaska Seafood Cooperative. Halibut bycatch limits for these co-ops and sectors are shown in Table 4.

In addition, the Council created bycatch limit sideboards for the AFA vessels which apply to these vessels when they fish in non-AFA fisheries (Table 6), i.e., any target species other than pollock. These bycatch limit sideboards were created to ensure that this sector would not enter other fisheries and adversely affect vessels operating in those other fisheries.

The CDQ program operated throughout the year and 10% of the pollock total allowable catch (TAC) and 7.5% of all other groundfish TACs were allocated to the six CDQ programs. A fixed amount of the trawl bycatch limit (326 t; 0.54 million pounds) and 7.5% of the hook-and-line bycatch limit (68 t; 0.11 million pounds) (Table 4) was allocated to the CDQ program, which was then subdivided among the six CDQ programs in proportion to their groundfish allocations.

Table 1. Halibut bycatch limits in the Alaska groundfish fishery since 1990.

A. **Metric tons, round weight**

Gulf of Alaska			Bering Sea/Aleutians Islands		
Time Period	**Trawl**	**Fixed Gears**	**Time Period**	**Trawl**	**Fixed Gears**
1990-1994	2,000	750	1991	5,333[a]	None
1995-2012	2,000	300	1992	5,033[a]	750
2013	1,973	300	1993	3,775	750
2014	1,848	279	1994-1998	3,775	900
2015	1,759	270	1999-2008	3,675	900
			2009	3,625[b]	900
			2010	3,625[b]	900
			2011	3,575[b]	900
			2012-15	3,525[b]	900

[a] Limit is in terms of catch for 1991-1992, and mortality in subsequent years.

[b] Values shown indicate the actual amount allocated by NMFS; overall limit specified in regulations was 3,675 t.

B. **Millions of pounds, net weight**

Gulf of Alaska			Bering Sea/Aleutians Islands		
Time Period	**Trawl**	**Fixed Gears**	**Time Period**	**Trawl**	**Fixed Gears**
1990-1994	3.30	1.20	1991	8.80[a]	none
1995-2012	3.30	0.50	1992	6.60[a]	1.20
2013	3.26	0.50	1993	6.26	1.20
2014	3.06	0.46	1994-1998	6.26	1.50
2015	2.91	0.45	1999-2008	6.10	1.50
			2009	6.00	1.50
			2010	6.00	1.50
			2011	5.90	1.50
			2012-15	5.80	1.50

[a] Limit is in terms of catch for 1991-1992, and mortality in subsequent years.

Table 2. Halibut bycatch mortality limits (t, round weight) for the 2014 Gulf of Alaska groundfish fisheries. Exempted fisheries include groundfish pots, jigs, and the Individual Fishing Quota hook-&-line fishery for sablefish. ***Note that some totals may not sum precisely due to rounding.***

Gear/Time Period	Bycatch Limit (t)
Trawl	**1,848**
Shallow water complex[1]	
January 20 – April 1	168
April 1 – July 1	47
July 1 – September 1	185
September 1 – October 1	138
Deep water complex[2]	
January 20 – April 1	35
April 1 - June 30	627
July 1 – September 1[3]	370
September 1 – October 1	Any remainder
October 1 - December 31 (available to either complex)	277
Hook-&-Line	**279**
All species except demersal shelf rockfish	
January 1 – June 10	233
June 10 – September 1	5
September 1 – December 31	32
Demersal shelf rockfish (Southeast only)	9
Groundfish Pots & Jigs	**Exempt**
GRAND TOTAL	**2,127**

[1] Shallow water complex: pollock, Pacific cod, shallow water flatfish, flathead sole, Atka mackerel, and other species.
[2] Deep water complex: rockfish, sablefish, deep water flatfish, and arrowtooth flounder.
[3] Vessels participating in the Central Gulf of Alaska Rockfish Program fish under a limit of 191 mt of the third season deep-water complex PSC limit.

Table 3. Apportionments of the 2014 trawl and fixed gear halibut bycatch limits (t) in Gulf of Alaska programs. ***Note that some totals may not sum precisely due to rounding.***

A. Apportionments of the "Other hook-and-line" halibut bycatch mortality limits (t) between hook-and-line catcher vessel and catcher/processor sectors.

Season	Catcher vessels	Catcher/Processors
January 1 – June 10	132	99
June 10 – September 1	3	2
September 1 – December 31	18	14
Total	**154**	**115**

B. Central Gulf of Alaska Rockfish Program halibut bycatch mortality limits (t) by sector.

	Shallow-water complex		Deep-water complex		Complex
Program Sector	**Total**	**Sideboard[1]**	**Total**	**Sideboard[1]**	**Total[1]**
Catcher/processors	11	2	80	46	91
Catcher vessels	0	--	0	--	0
Total	**11**	**2**	**80**	**46**	**91**

[1] Sideboard amounts are a portion of the total.

C. Halibut bycatch mortality sideboard limits (t) for Amendment 80 vessels.

Season	Shallow-water target fisheries	Deep-water target fisheries
January 20 – April 1	9	21
April 1 – July 1	35	198
July 1 – September 1	27	96
September 1 – October 1	14	3
October 1 – December 31	42	69
Total	**127**	**387**

D. Halibut bycatch mortality sideboard limits (t) for non-exempt American Fisheries Act trawl catcher vessels.

Season	Shallow-water targets	Deep-water targets
January 20 – April 1	141	6
April 1 – July 1	31	19
July 1 – September 1	63	26
September 1 – October 1	47	0
October 1 – December 31	57 (all targets)	
Total	**390**	

Table 4. Halibut bycatch mortality limits (t, round weight) for the 2014 and 2015 Bering Sea/ Aleutian Islands groundfish fisheries. Exempted fisheries include those fishing pots or jigs for groundfish, and the Individual Fishing Quota hook-&-line fishery for sablefish. *Note that some totals may not sum precisely due to rounding.*

Gear sector	Bycatch Mortality Limits (t)
A. Fixed Gear fisheries	**900**
1) CDQ Allocation	68
2) Fixed gear sector total	832
a. Pacific cod H&L sector	775
1. Catcher/processors	760
2. Catcher vessels	15
b. All other targets sector	58
B. Trawl fisheries	**3,675**
1) CDQ allocation	326
2) Trawl fishery limit	3,349
3) Amount allocated[1]	3,200
a. Amendment 80 sector	2,325
AK Seafood Cooperative	1,602
(unallocated)	723
b. Limited access sector	875

[1] According to the reduction schedule for the trawl bycatch limit, only 3,200 t of the 3,350t limit was allocated.

Table 5. Breakdown of 2014 and 2015 Bering Sea/Aleutian Islands region fixed gear limited access sector halibut bycatch mortality limits (t).

Fixed Gear	Catcher/processors	Catcher vessels
Hook-&-line Pacific cod	**760**	**15**
January 1 – June 10	455	10
June 10 – August 15	190	3
August 15 – December 31	115	2
Other hook-&-line (all vessels)	**58**	
May 1 – December 31	58	
Groundfish Pot & Jig	**exempt**	
Sablefish IFQ (hook-&-line)	**exempt**	
Total Fixed Gear Mortality Limit	**833**	

Table 6. Seasonal and fishery breakdown of 2014 and 2015 trawl fishery bycatch mortality sideboard limits (t) for Limited Access and AFA sectors.

Trawl Limited Access sector	Bycatch Limit (t)	
Target fishery	**2014**	**2015**
Yellowfin sole	227	167
Rock sole/flathead sole/other flatfish	0	0
Turbot/sablefish/arrowtooth flounder	0	0
Rockfish	5	5
Pacific cod	393	453
Pollock/Atka mackerel/other species	250	250
Total	**875**	**875**

AFA sector: Sideboards for non-AFA fisheries	2014 and 2015
Catcher vessels	**1,225**
Pacific cod trawl	887
Pacific cod hook-&-line or pot	2
Yellowfin sole total	101
Rock sole/flathead sole/other flatfish	228
Turbot/sablefish/arrowtooth flounder	0
Rockfish	2
Pollock/Atka mackerel/other species	5
Catcher/processors	**286**

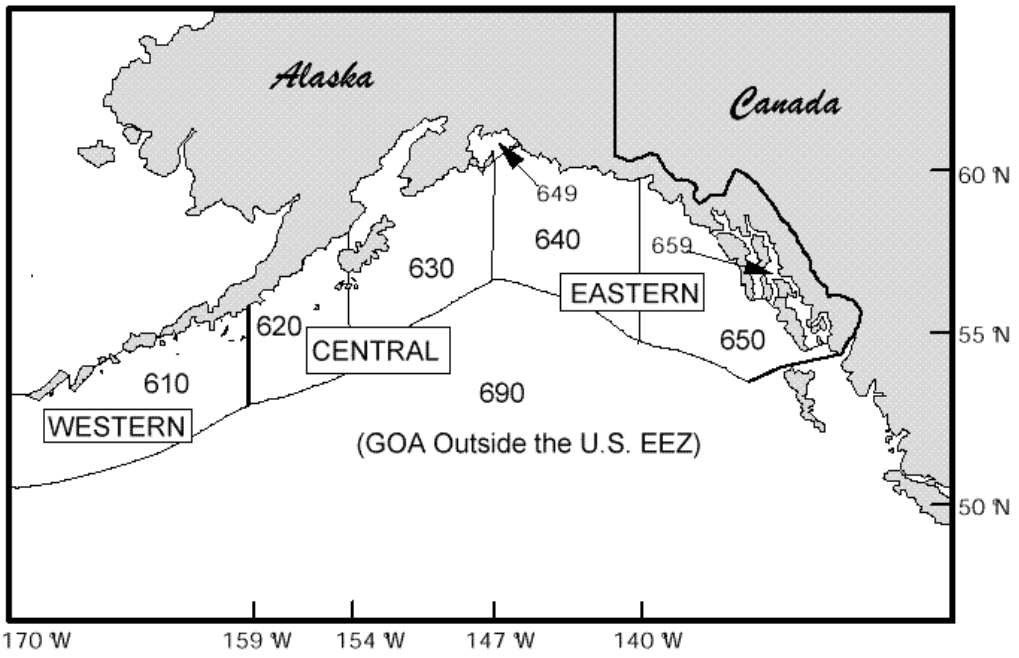


Figure 1. NMFS statistical and management areas for the Gulf of Alaska.

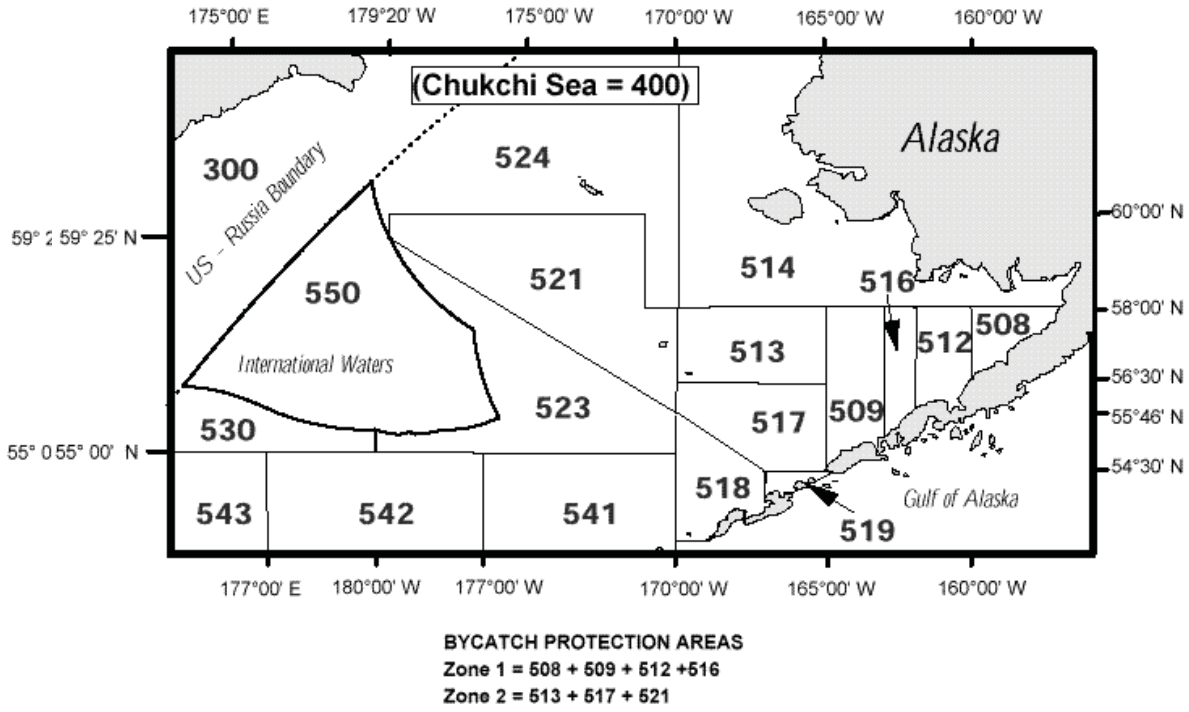


Figure 2. NMFS statistical and management areas for the Bering Sea/Aleutian Islands.

The Alaska groundfish trawl fishery Prohibited Species Donation program: Preliminary results for 2014

Gregg H. Williams

Abstract

The amount of halibut bycatch landed by vessels fishing groundfish off Alaska in 2014 through September 30 totaled 31,838 pounds (net weight). This was split between 10,190 pounds delivered to processors in Bering Sea ports and 21,648 pounds to processors in Gulf of Alaska ports. Since the program began in 1998, these donations have been handled by SeaShare, Inc. under a permit granted by the National Marine Fisheries Service, and SeaShare has provided annual reports to IPHC on the quantity handled. The fish is processed into steaks and distributed to food banks. The amount of landed halibut bycatch handled in the program has totaled 442,837 pounds (net weight) since program inception.

Introduction

Since 1998, SeaShare, Inc., of Bainbridge Island, Washington has operated a program which acquires unintentionally-landed halibut bycatch and other species from Alaskan fisheries for donation to hunger relief programs. SeaShare acquires halibut, salmon, and many other species from numerous sources, which are then distributed. The Prohibited Species Donation (PSD) program is one of its sources for seafood. The PSD program was adopted by the National Marine Fisheries Service (NMFS) and the North Pacific Fishery Management Council (NPFMC) following several years of development and, ultimately, approval by the International Pacific Halibut Commission (IPHC). This report provides a summary of the quantity processed through the PSD through 2014.

Program history

The initial program adopted by the NPFMC in 1998 expired on December 31, 2000. NMFS and IPHC staff conducted a review of the program during 2000 for the purpose of examining the appropriateness of an extension. The review was discussed with the NPFMC at its June 2000 meeting and led to an extension of the program. The extension contains no sunset provision but does require a review every three years. The PSD was initially limited to shore-based trawl catcher vessels that landed in Dutch Harbor, but was expanded into Gulf of Alaska ports in 2011. The PSD program has no limitations on the amount that can be donated, nor any requirement that the halibut bycatch originates from specific fisheries.

SeaShare has been providing annual reports to IPHC since the program began. Those reports have noted the weight of donated halibut based on dock tallies of dressed (eviscerated) fish from the Dutch Harbor processors. Since 2008, SeaShare has reported the amount of final processed product, i.e., steaks or headed/gutted. IPHC staff has used a product recovery rate of 0.79 to convert the steak weights back to headed and gutted form for continuity in reporting, based on recovery rates reported by Crapo et al. (1993). Headed/gutted weights are used as provided.

Final 2013 results

The total amount of halibut collected by SeaShare in 2013 was 49,814 pounds, with 9,684 pounds (19%) coming from Bering Sea ports and 40,130 pounds (81%) from Gulf of Alaska ports (Table 1). Processing and inspection was conducted by SeaFreeze (Seattle), as in previous years.

Preliminary 2014 results

The amount of halibut processed in 2014 through September 30 was 31,838 pounds (net weight) (Table 1). Bycatch amounts came from both Bering Sea and Gulf of Alaska ports. The preliminary figures showed a continuation in 2014 of the majority (68%) of the halibut coming from Gulf of Alaska processors.

Handling of fish was similar to past years. Shipping to Seattle was donated by Coastal Transportation and AML. The U.S. Coast Guard also flew fish to Kotzebue. The fish was weighed, inspected, steaked, and repacked at Seafreeze Cold Storage, City Ice Cold Storage, E&E Foods, and SPC. Headed/gutted fish of good quality were sorted and distributed to food banks. Receiving food banks for this period were Kodiak Food Bank (Baptist Mission), Brother Francis Shelter (Kodiak), St. Herman's Seminary (Kodiak), Food Bank of Alaska (Anchorage), NANA Corp. (Kotzebue), the Qawalangin Tribe (Unalaska), Oregon Food Bank (Oregon), and San Francisco Food Bank (California). The total pounds for 2013-2014 represent 294,832 meals distributed, with additional meals to be provided following the receipt and processing of the final delivery from Alaska.

References

Crapo, C., Paust, B., and Babbit, J. 1993. Recoveries and yields from Pacific fish and shellfish. AK Sea Grant, Mar. Adv. Prog. Bull. No. 37. np.

Table 1. Amount of halibut (pounds, net weight) received and distributed by SeaShare acquired through the NMFS Prohibited Species Donation program. Through 2007, the amount is based on dock-side tallies of fish weight. Beginning in 2008, the amount is based on finished product (steak) and a recovery rate of 0.79, based on guidelines reported by Crapo et al. (1993). Data for 2014 are preliminary through September 30.

	Bering Sea/Aleutians				Gulf of Alaska				
Year	Dutch Harbor	Akutan	Beaver Inlet	Total	Kodiak	King Cove	Sand Pt.	Total	Overall Total
1998	21,196	0	0	21,196	0	0	0	0	21,196
1999	4,476	0	0	4,476	0	0	0	0	4,476
2000	18,269	0	0	18,269	0	0	0	0	18,269
2001	43,579	0	0	43,579	0	0	0	0	43,579
2002	33,974	0	0	33,974	0	0	0	0	33,974
2003	18,406	0	0	18,406	0	0	0	0	18,406
2004	15,890	0	0	15,890	0	0	0	0	15,890
2005	29,286	0	0	29,286	0	0	0	0	29,286
2006	10,762	0	0	10,762	0	0	0	0	10,762
2007	34,619	0	0	34,619	0	0	0	0	34,619
2008	43,375	0	0	43,375	0	0	0	0	43,375
2009	14,258	0	0	14,258	0	0	0	0	14,258
2010	11,739	0	1,375	13,114	0	0	0	0	13,114
2011	6,914	0	2,233	9,147	13,908	775	0	14,683	23,830
2012	--	--	--	5,502	--	--	--	30,649	36,151
2013	3,557	6,127	0	9,684	38,353	141	1,636	40,130	49,814
2014	0	10,190	0	10,190	14,848	1,203	5,597	21,648	31,838
Total	**310,300**	**16,316**	**3,608**	**335,727**	**67,110**	**2,118**	**7,234**	**107,110**	**442,837**

IPHC oceanographic monitoring program 2014

Lauri L. Sadorus and Jay Walker

Abstract

This was the sixth consecutive year that the International Pacific Halibut Commission's (IPHC) profiler project collected oceanographic data from southern Oregon northward to British Columbia, into the Gulf of Alaska, Bering Sea, and Aleutian Islands, during the IPHC stock assessment survey. In addition to the standard setline survey stations, 133 survey stations were added in IPHC Areas 2A and 4A in order to expand the survey's depth range. The profilers were deployed at the shallow and standard stations, but not in waters below 500 m due to instrument limitations. Additionally, the northern California expansion that was initiated in 2013 continued this year, resulting in 27 stations fished there, and 14 stations were fished in the Salish Sea, Washington. The IPHC has been operating profilers since 2000 on a limited basis and coastwide since 2009. A total of 1,267 successful casts were made this year out of a possible 1,394.

Background

Since the expansion of its survey in 1997, the International Pacific Halibut Commission (IPHC) has annually conducted fishing operations at more than 1,000 stations ranging geographically from off the Oregon coast to the Bering Sea. Periodically, additional stations are added in areas not normally surveyed because of a particular question or concern. For example, in 2011, the Puget Sound region (southern Salish Sea) was surveyed to ground-truth predicted density of halibut in the area relative to that observed on the outer coast of Area 2A, and that was repeated in 2014. Last year, 15 stations were added in northern California due to a recently-developed halibut sport fishery in the area and the subsequent need to assess the halibut density there. It was unclear if the southern terminus of the commercially exploitable halibut biomass had been located so another 12 stations were added, extending further south, in 2014. All survey stations are located on the continental shelf and are arranged on an equidistant 10-nmi grid. As such, the IPHC operates the largest consistent sampling program of any research agency in the north Pacific (see Henry et al. (2015) for detailed survey information)

Fundamental changes in the physical and chemical makeup of the ocean waters affect the health and distributions of organisms. This area of investigation has gained momentum in recent years as scientists and stakeholders try to understand the direct and indirect effects on fisheries.

Coupling oceanographic observations with catch estimates from the IPHC setline survey over time is a necessary next step to understanding the impacts of these changing conditions on the halibut resource. In the late 1990s, the IPHC began considering the feasibility of collecting environmental data alongside halibut catch data on the setline survey. In 2000, a Sea-Bird™[1] Seacat SBE-19 water column profiler equipped with sensors to measure depth, temperature, and salinity was purchased by the IPHC and deployed aboard a longline vessel chartered for the annual setline survey. The profiler was then deployed on different vessels and in different areas successfully for

[1] Sea-bird Electronics Inc. 13431 NE 20th Street. Bellevue, Washington, USA.

several years. In 2005, a dissolved oxygen (DO) sensor was added to the profiler and proved well-suited for the project's purposes. In 2007, the IPHC received a grant from the Oregon Department of Fish and Wildlife Restoration and Enhancement Program to purchase a second Sea-Bird™ Seacat SBE-19*plus* (an updated version of the SBE-19) dedicated to the IPHC survey stations off the Oregon coast. This new profiler was equipped with additional sensors to measure dissolved oxygen (SBE-43), pH (SBE-18), and chlorophyll *a* concentration (WET Labs[2] ECO-FLRTD).

The successful deployment of these two profilers aboard multiple vessels over multiple years and areas provided proof of concept that these oceanographic data could be collected with minimal disruption to the core survey operations. To that end, the IPHC received a grant from the National Oceanic and Atmospheric Administration (NOAA) in late 2008. The grant allowed for the purchase of 14 Sea-Bird™ Seacat SBE19*plus* V2 water column profilers, laptop computers for each, as well as annual maintenance and data processing costs for four years. The grant expired in September 2012 and ongoing maintenance costs are currently borne by the IPHC.

Methods

Instruments

The Seacat profilers are equipped with a titanium housing which is rated for depths to 7,000 m. The sensors have maximum depth ratings ranging from 1,000-7,000 m, which is sufficient for all standard IPHC survey stations. Part of the 2014 survey expansion included stations with an estimated average depth as deep as 730 m (from 500 m traditionally). To err on the side of caution, the profilers were deployed at standard survey stations, and expansion stations up to 500 m depth only. The units weigh approximately 25 kg in air and 14 kg in water. The profiler is protected by a stainless steel cage, 96 cm tall and specially designed for each unit. Software for downloading and displaying the data is provided by the manufacturer. Communication between the profiler and the laptop computer is accomplished via USB ports.

To adapt the profiler for deployment from a halibut fishing vessel, a system was designed using weights and floats that permits the profiler to descend rapidly enough through the water column to collect valid data and also ensures that the unit will not crash into or become permanently attached to the ocean bottom (Hare 2001). A sustained descent rate of 1-2 m/s is the target, and the weight of the assembly in the water is sufficient that, if the unit is allowed to free fall, the target descent rate is achieved.

A 15-meter anchor line is attached to the bottom of the profiler cage using a section of gangion line as a weak link (in case the anchor cannot be freed from the bottom). A 40-pound longline anchor is attached to the end of the 15-meter line. To the top of the cage, two floats are attached that effectively offset the weight of the anchor in water. The floats are attached to standard halibut buoy line which is almost neutrally buoyant.

Deployment

A profiler unit was deployed at each eligible survey station, just prior to hauling the fishing gear. To deploy the unit, the anchor was lowered into the water followed by the profiler and cage, and then the buoy line and buoys. After a minimum 90-second acclimation period at the surface, the line was released, and the full setup allowed to free fall to the bottom. Each profiler took measurements from the surface to depth at a rate of four per second and a pump ensured consistent

[2] WET Labs, 620 Applegate Street, Philomath, Oregon, USA.

water flow past the sensors. Once the anchor had hit the bottom, the remainder of the unit ceased descent shortly afterward, due to the strong positive buoyancy of the floats. On board the vessel, it was usually evident when the anchor hit bottom because of a noticeable slackening of the line. At that time, the vessel's gurdy was engaged and the profiler was immediately hauled back aboard. Once on deck, a series of protocols were executed to clean the sensors and store the unit until the next deployment, as outlined in IPHC (Unpub.).

Data capture

Each profiler was equipped with a dedicated laptop computer that accompanied it into the field. Approximately once per day, the profiler was connected to the computer, data were uploaded, and the profiler unit was then reset for the next day's casts. The data were sent remotely or via data storage cards back to the Seattle office after each trip. To facilitate quicker retrieval and processing of the data, beginning in 2013, a *cloud* storage service was used to transmit the data more efficiently to the IPHC office. Specifically, when the vessels arrived in port after each trip, the samplers (whenever possible) connected the laptops to the internet in order to synchronize the collected data to a secured storage location in the *cloud*. The IPHC office staff was then notified that the data were available for download.

Results

Data collection

In 2014, a total of 11 fishing vessels were chartered to complete the IPHC setline survey (Henry et al. 2015) and each vessel was outfitted with a Seacat19*plus* V2 profiling unit, a laptop computer, and accessory gear. Out of a possible 1,394 stations coastwide, 1,267 useable casts of environmental data were collected (Table 1), resulting in a 91% success rate.

Occasionally, data collection was unsuccessful or not attempted, and there were several reasons for this. The vessel captain and lead biologist together decided whether it was prudent to launch the profiler, given the conditions at each station. Poor weather and strong tides were the most common reasons given for aborted casts. On stations where tides were strong but the station was otherwise deemed viable, the samplers were allowed to incorporate an additional 10-20 pound weight to the bottom of the assembly to achieve a more vertical descent. In 2013, there were several reports of profilers having shut down mid-cast, and in some cases they had to be replaced with new units mid-season. In 2014, this problem appeared to have been mostly solved by updating connection caps and taking measures to keep water out of the interior of the units' connectors. Most other problems were dealt with in the field and resulted in little or no loss of data. Two profilers were lost in previous years, but none have been lost since 2011.

The laptop computers, most purchased in 2008, have already exceeded their expected lifespan, due largely to the careful handling of these units by the field staff. However, in 2014 several unit malfunctions caused delays in data transfers, and troubleshooting with the office or replacement with another unit ultimately resulted in no data loss. The goal is to eventually switch the data capture system to environmentally-protected field tablets that are now in the beta-testing phase, but implementation is still at least two years away.

Environmental conditions

The sampled area encompassed a wide range of environmental conditions. The highest chlorophyll concentrations appeared to be in the Aleutian Islands and the U.S. west coast with less intense blooms elsewhere. For the first time since collecting coastwide environmental data, the IPHC instruments did not detect hypoxia in the bottom waters off the west coast of Oregon and Washington. There were some hypoxic waters detected in the western Aleutians, which is not unusual especially at deeper stations, but there were no other areas of note coastwide. Average bottom temperatures continued to show an increase coastwide from an average of 5.6°C (Sadorus and Walker 2014) in 2013 to almost 6°C (preliminary) this year. Other environmental monitoring programs detected an unusually warm water mass in the Gulf of Alaska that persisted through most of the summer. Data collected by IPHC have not yet been analyzed, but isosurface plots in Appendix II give some indication that higher temperatures were detected at a larger number of GOA inshore stations than in 2013. The coldest station is routinely found off of St. Matthew Island in the Bering Sea and often has temperatures below 0° C. This year, that area continued to have the coldest bottom temperatures coastwide, but none were below 0°C. A complete set of figures displaying surface plots for each environmental variable collected can be viewed in the online appendices.

Based on the first six years of this project, general environmental differences among the major areas of the coast can be identified. Relative to the other sampled areas, near-bottom conditions along the U.S. west coast and B.C. are characterized by low DO, low pH (more acidic water), warmer temperatures, and moderate amounts of primary production. Gulf shelf waters differ between east and west, with the western Gulf, especially around Kodiak Island and Cook Inlet, tending towards warmer temperatures, higher DO, and less acidic water than the eastern and central Gulf. The Bering Sea and Aleutian Islands are characterized by cooler temperatures, higher DO except at very deep stations, moderate primary production, and a variety of pH conditions. The Appendices (available online only) provide a closer look at the conditions in each of these areas.

Data processing and availability

A primary goal of this project is to make the survey profiler data available to scientists worldwide. The IPHC is working with the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) at the University of Washington and NOAA's Pacific Marine Environmental Laboratory to process the oceanographic data and make them publicly accessible. The complete set of 2009 - 2012 data is now available at:

http://www.ecofoci.noaa.gov/projects/IPHC/efoci_IPHCData.shtml

Processing of the 2013 and 2014 datasets is in progress.

Acknowledgments

The success of the profiler project depends on the efforts and cooperation of many people. We would like to acknowledge the IPHC survey program staff for competently incorporating the profiler project into the survey protocols, Bruce Biffard for making sure the gear was ready for the field, IPHC sea samplers for their hard work and attention to detail in collecting the data, the survey vessel captains and crews for making sure the Seacats were safely retrieved after every cast, and Peggy Sullivan at NOAA/JISAO for her tireless work on the data and website.

References

Hare, S. H. 2001. Deployment of a water column profiler from a halibut longliner during IPHC survey operations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000: 257-264.

Henry, E., Dykstra, C. L., Geernaert, T. O., Soderlund, E., Ranta, A. M., and Kong, T. 2015. 2014 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014. 531-568.

International Pacific Halibut Commission. Unpub. Oceanographic sampling on IPHC setline surveys, Seacat manual 2014. Operation manual. International Pacific Halibut Commission. 56 p.

Sadorus, L. L. and Walker, J. 2014. IPHC oceanographic monitoring program 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 325-334.

Table 1. Number of profiler casts completed during the 2014 standardized stock assessment survey, by survey region and vessel. Note that the expansion stations in 2014 resulted in station depths from 18-700 m, but the profilers were not set at stations deeper than 500 m due to instrument limitations. "Stations possible" in this table reflect only those stations at depths ≤ 500 m.

	Stations		
Survey region	**Profiled**	**Possible**	**Vessel name(s)**
N. California	16	23	Pacific Surveyor
Oregon	35	51	Pacific Surveyor
Washington	57	64	Pacific Surveyor
Puget Sound	12	14	Pacific Surveyor
Vancouver	36	41	Pender Isle
Goose Island	37	43	Pender Isle
St. James	38	42	Star Wars II
Charlotte	44	44	Star Wars II
Ketchikan	34	41	Pender Isle
Ommaney	37	40	Bold Pursuit
Sitka	41	42	Bold Pursuit
Fairweather	42	49	Bold Pursuit
Yakutat	40	51	Waterfall &Free to Wander
Prince William Sound	45	45	Waterfall
Seward	48	48	Waterfall
Gore Point	44	45	Clyde
Portlock	43	46	Clyde
Albatross	45	45	Free to Wander
Shelikof	44	45	Clyde
Trinity	30	47	Van Isle
Semidi	44	47	Van Isle
Chignik	43	45	Van Isle
Shumagin	43	44	Seymour
Sanak	48	48	Free to Wander
Unimak east	32	32	Free to Wander
Unimak west	25	27	Kema Sue
Four Mountains east	24	26	Kema Sue
Four Mountains west	8	16	Norcoaster
4A Edge south	41	41	Free to Wander
4A Edge north	43	45	Kema Sue
4D Edge	66	68	Kema Sue
Adak	42	45	Norcoaster
Attu	40	44	Norcoaster
Total regions: 33	**1,267**	**1,394**	**Total vessels: 11**

Appendices (for website/full color viewing)

Accessible through the IPHC webpage is a series of plots produced using Ocean Data View (Schlitzer 2010) software illustrating oceanographic conditions in summer 2014 as measured by Sea-Bird profilers during the IPHC standardized setline survey. Appendix 1 contains information for the west coast, Appendix 2 for the Gulf of Alaska, and Appendix 3 for the Bering Sea and Aleutian Islands. Temperature, salinity, dissolved oxygen, and pH are calculated using the deepest measurements at each station - typically 5-10 m off bottom. Chlorophyll *a* concentration is calculated using measurements at 25-m depth. The data are illustrated as iso-surface plots, which are continuous surfaces that use the observed point values to interpolate values at locations between those observations. Survey stations (i.e., where measurements were actually taken) are denoted as black dots. Note that these data are preliminary.

Appendix 1: U.S. West Coast and British Columbia

Appendix 2: Gulf of Alaska

Appendix 3: Bering Sea and Aleutian Islands

To view the complete document including the full color maps, please visit the IPHC website: http://www.iphc.int/library/raras.html

Reference

Schlitzer, R., 2010. Ocean Data View, http://odv.awi.de.

Estimating hooking success for large halibut on circle hooks

Stephen M. Kaimmer

Abstract

A GoPro camera was used to observe hook attacks on a single baited hook off Afognak Island near Alaska's Kodiak Island. We hoped to observe attacks by 50 halibut, each over 40 pounds, and to create a hooking success point estimate for these larger halibut. We did not observe enough large halibut to generate this parameter but did observe numbers of smaller halibut which confirmed our earlier estimates of hooking success for halibut 60 to 100 cm fork length and validated the technique for estimating hooking parameters.

Introduction

The study attempted to observe hook attacks by halibut in the 110 to 150+ cm fork length (FL) range to estimate hooking success. These are 40 to 80+ pound fish. Previous camera studies (Kaimmer 1998) demonstrated an increasing hooking success with increasing size for halibut ranging from about 70 to 110 cm. Our Didson[1] studies in 2006 and 2007 (Kaimmer and Wischniowski 2008 and 2009) used a much larger pool of observations to refine this curve. Although these investigations estimated an increasing relationship between hooking success and fish size, which would be indicative of an asymptotic cure, neither had enough observations of large fish (over 100 cm) to estimate whether this relationship might be dome shaped with a decreasing hooking success for very large fish. It is expected that observing an additional 50 attacks from halibut spread throughout the 110 to 150+ cm range would allow the estimation of the form of the relationship between hooking success and fish length for these larger fish. The form of this curve has very important implications for stock assessment assumptions (Clark and Kaimmer 2006).

Methods

The 63-foot *F/V Venturess* was chartered to deploy a drop camera to observe hook attacks of large halibut. All hook attacks were monitored and recorded. A light aluminum frame holding a GoPro Hero2[2] camera was focused on a single baited hook (Fig. 1). This was the same frame and system which was used in the 2012 Hook Modification Study; full details of the gear design can be found in Kaimmer and Wischniowski (2013). Images were viewed in real time and were also recorded by the GoPro camera for later review. Captured rockfish were repressurized using a SeaQualizer™[3] pressure-activated release mechanism set to release the fish at 100 feet depth. Fork lengths of captured halibut were measured to the nearest centimeter. The length of fish not captured was estimated from the video recording. This estimation was aided by the fact that most halibut spent at least some part of their time on or very near the bottom and thus length could be compared with length of known items in the video recording. The gangion was marked at 20 cm intervals, and in most cases this was the best comparable item of known length.

[1] *www.soundmetrics.com/products/didson-sonars*

[2] www.GoPro.com

[3] SeaQualizer LLC, Miami, Florida, United States: theseaqualizer.com

Results

Fifty-nine gear deployments were completed, with durations of time on bottom ranging from 9 to 147 minutes with a total of 61 hours and 31 minutes recorded (see Fig. 2 for a chart of fishing locations). The gear was deployed in depths ranging from 20 to 65 fathoms. We observed 152 hook attacks by halibut, 64 resulting in captures, for an overall hooking success rate of 42% (Table 1). Length of halibut captured ranged from 66 to 138 cm, while length of halibut not captured ranged from 58 to 114 cm. We observed hook attacks by eleven halibut 110 cm or longer in length. Ten of these eleven attacks resulted in hooked fish.

Analysis

There were too few hook attacks by large fish to create a point estimate for the hooking success of this size group. However, the hooking success data for the smaller size fish lends itself to comparison with the more extensive hooking success data from the earlier Didson scanning sonar work (Kaimmer, unpublished). Combining the current observations with the original Didson data allows us to test for evidence of a difference in the relationships for 16/0 hooks between data gathered in 2009 and 2014. Fitting a simple logistic model, we find no evidence (Table 1) for differences in rates of hooking success between years (test of "year" effect) or of a year effect on the relationship of hooking success and fork length (test of "fork length:year"). Based on this analysis, the Didson and GoPro data sets could be combined into a single data set for 16/0 hooks. As in the earlier study, there is evidence for a relationship (test of fork length) and for a hook size effect (hook size); and, as before, no evidence that the steepness of the slope depends on hook size (hook size:fork length).

Discussion

While too few large halibut were encountered for determination of the hooking success for larger halibut, the hooking success results for smaller fish, and the close agreement of those results with results gathered earlier using scanning sonar, give a validation of the current technique for determining hooking success.

Acknowledgements

We would like to thank Tor A. Bjorklund, an oceanographic equipment fabricator at the University of Washington, for his innovative design help in constructing our deployment frame, and Captain Travis Larson of the *F/V Venturess* for sharing his knowledge of fish behavior and distribution during the field portion of our project.

References

Clark, W. G. and Kaimmer, S. M. 2006 Estimates of commercial longline selectivity for Pacific halibut (*Hippoglossus stenolepis*) from multiple marking experiments. Fish. Bull. 104:465-468.

Kaimmer, S. M. 1998. Direct observations on the hooking behavior of Pacific halibut, *Hippoglossus stenolepis*. Fish. Bull. 97:873-883.

Kaimmer, S. M. and Wishniowski, S. 2008. Estimating halibut hooking success using DIDSON sonar. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2007:335-346.

Kaimmer, S. M. and Wishniowski, S. 2013. Hook modification study to reduce rockfish bycatch on circle hooks. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012:487-498.

Table 1. Hooking success for halibut with standard error during the 2014 experiment.

Forklength (cm)	Number of hook attacks	Number caught	Hooking success
55-64	**7**	0	0.00
65-74	**32**	**7**	0.22
75-84	**48**	**11**	0.23
85-94	**37**	**21**	0.57
95-104	**15**	**13**	0.87
105-114	**8**	**7**	0.88
115-124	**3**	**3**	1.00
>124	**2**	**2**	1.00
Total	**152**	**64**	0.42

Table 2. Analysis of deviance table comparing current GoPro results with earlier Didson results for 16/0 hooks. Terms are added sequentially first to last. Significant relationships are noted with an asterisk.

	Df	Deviance residual	DF residual	Dev	Probability
			558	760.06	
Hook size	1	12.826	557	747.23	0.0034*
Fork length	1	123.485	556	623.75	<0.001*
Year	1	0.948	555	622.80	0.3302
Hook size:fork length	1	0.646	554	622.15	0.4215
Fork length:year	1	2.163	553	649.19	0.1413

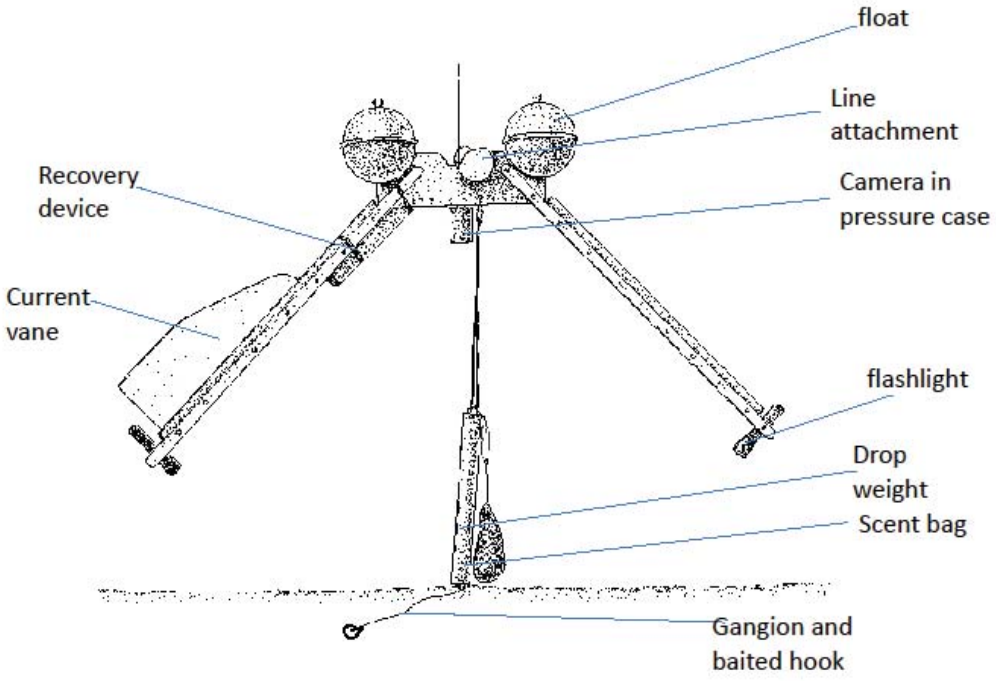


Figure 1. GoPro deployment frame used in 2014 Hooking Success experiment.

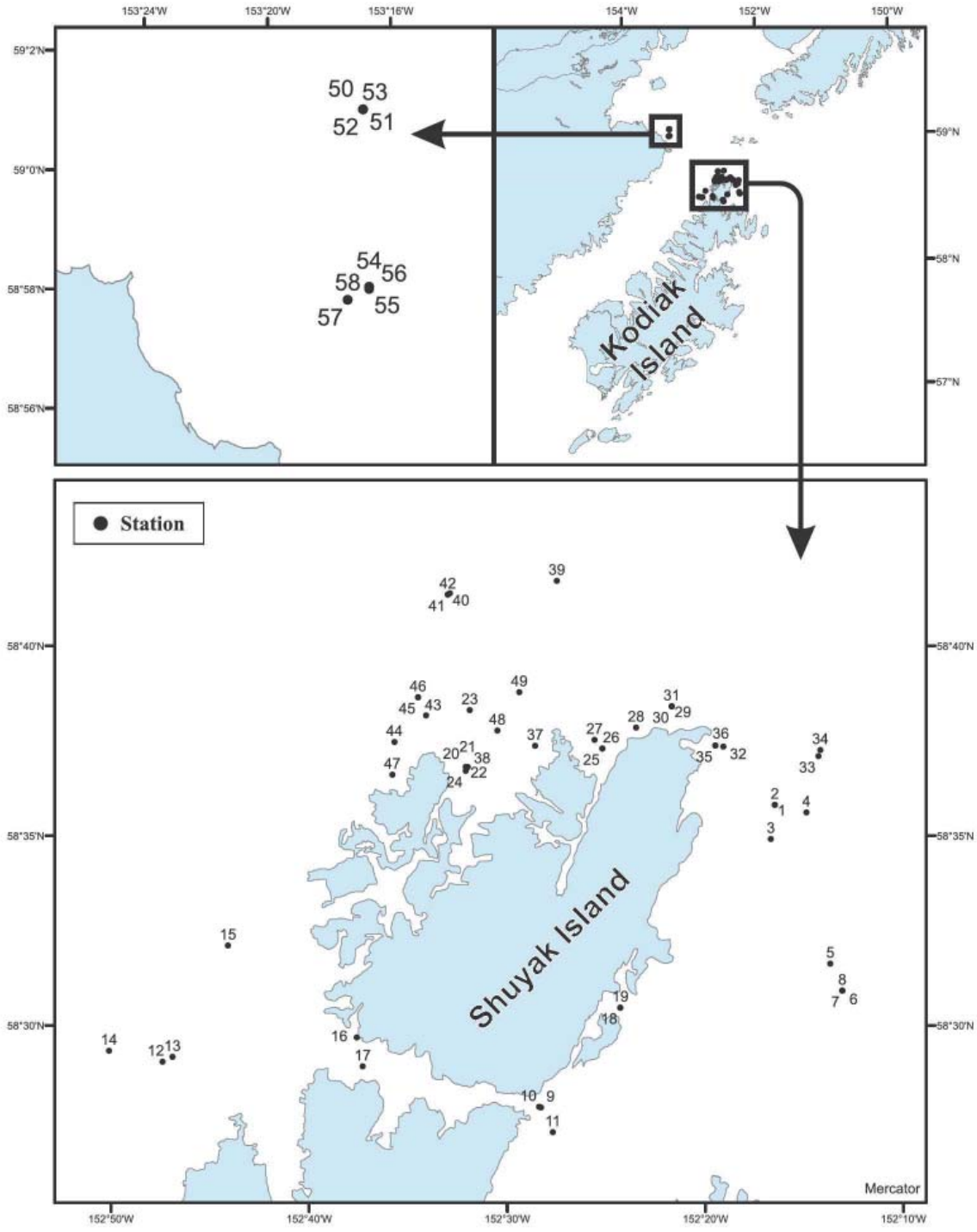


Figure 2. Fishing locations during the 2014 Hooking Success experiment.

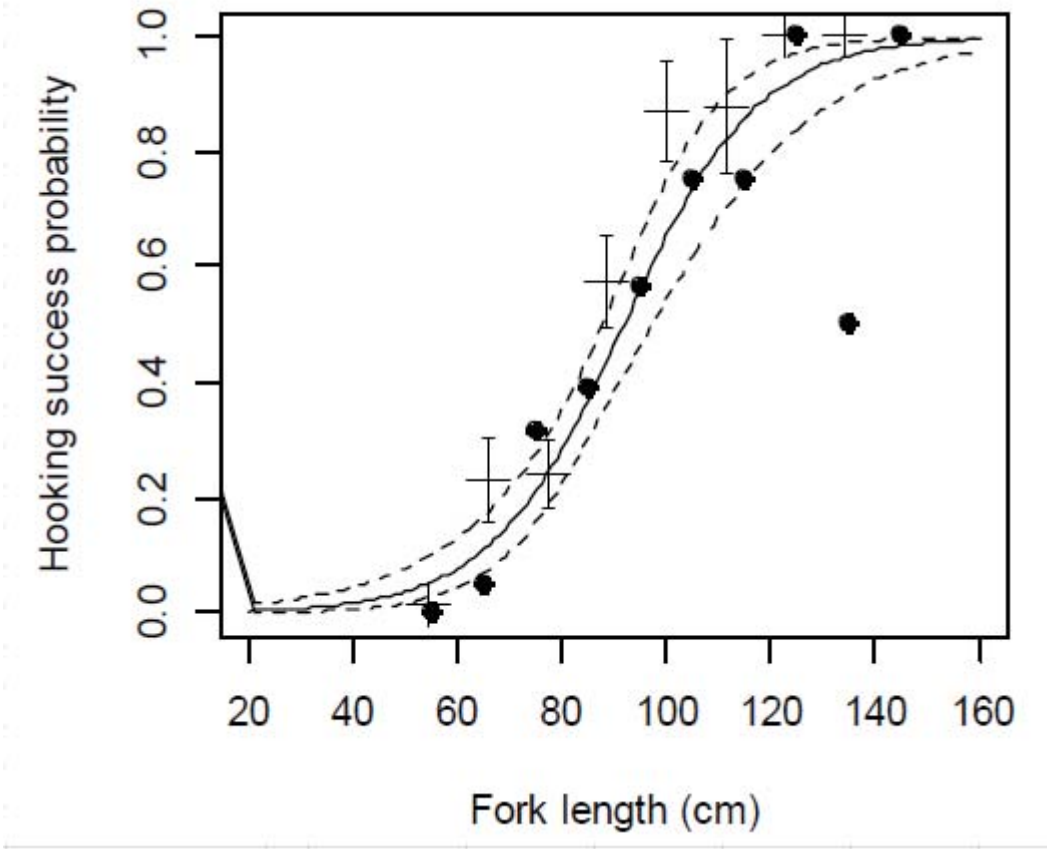


Figure 3. Hooking success from the 2014 experiment compared to the results from the 2007-8 Didson experiment. Didson results are shown by the solid circles with solid line showing the fitted curve and dotted line showing 95% confidence intervals. Crosses indicate data from the current 2014 experiment with vertical bars indicating plus or minus 1 standard error.

Juvenile halibut distribution and abundance in the Bering Sea and Gulf of Alaska

Lauri L. Sadorus, Ian J. Stewart, and Thomas Kong

Abstract

Juvenile Pacific halibut (*Hippoglossus stenolepis*) are highly migratory, first dependent on oceanic currents as larvae to carry them to suitable nursery habitat, and second as relatively small, but fully-formed fish that counter-migrate against the currents to disperse coastwide. Larval halibut have been detected in ichthyoplankton surveys coastwide to as far south as British Columbia. As 1- and 2-year olds, they are concentrated in the southeastern Bering Sea and western Gulf of Alaska around Kodiak Island in shallow nursery habitats. Over the next several years of their lives, halibut disperse north, south, and west in the Bering Sea, and north, east, and south in the Gulf of Alaska and eventually to deeper depths. A principal component analysis showed that while there was ample variability, larger year classes tended to correspond to years of warmer temperatures and calmer oceanic conditions, and smaller year classes corresponded to years with colder temperatures and stormier weather. Diet data were examined, but were largely inconclusive in determining halibut recruitment to the commercial fishery.

Introduction

The occurrence of adult Pacific halibut (*Hippoglossus stenolepis*) is widespread, spanning the continental shelf waters off of northern California northward into the Gulf of Alaska and Bering Sea. The resource has been managed by the International Pacific Halibut Commission (IPHC) since 1923 in U.S. and Canadian territorial waters. Monitoring of the population is aimed primarily at adults in order to estimate spawning biomass and the amount of yield available for the directed fisheries (Stewart and Martell 2014). Halibut in the commercial fishery cannot be harvested until they are at least 82 cm in length; however there are many sources of mortality for fish smaller than this size. Over the past 50 years, bycatch removals of halibut in non-target fisheries has ranged from under 8 Mlb to over 21 Mlb annually (Williams 2014), and a large proportion of that catch is young fish (defined here as U32 or < 82 cm, fork length) (Stewart et al. 2015). Additional removals of juveniles occur during the recreational and personal use fisheries, as well as during the commercial fishery when halibut below the minimum size limit are caught and released.

The adult population is monitored closely through IPHC programs such as port sampling (Erikson and MacTavish 2014) and a comprehensive coastwide survey (Henry et al. 2014). Data on the abundance of the juvenile population are available from the National Marine Fisheries Service (NMFS) trawl surveys and icthyoplankton surveys. However, not all of these surveys are annual, nor do they cover the full extent of the geographical distribution of juvenile halibut.

Larval halibut are detected during the ichthyoplankton surveys, allowing a look at distribution within the survey area. However, abundance estimation is neither possible, nor relevant at this life stage because mortality is extremely high and variable, and the catch rates of juvenile halibut during the planktonic stage are very low. The first measure of year-class abundance therefore comes from the NMFS bottom trawl surveys when the fish are 2 years old. The temporal gap between

that first glimpse of the population at 2 years old and recruitment into the commercial fishery (and setline survey indices of abundance) is generally 6-10 years. Both year-class abundance and distribution can change substantially during that time. Young halibut face a number of challenges to survival beginning with where and when they are spawned and whether or not the currents deliver them to favorable nursery grounds. Varying food supply, favorable or unfavorable environmental conditions, predation, and disease may all contribute to aspects of a juvenile halibut's chance to move, survive, and thrive. This report is a summary of what is currently known about juvenile halibut distribution and abundance in the Gulf of Alaska (GOA) and Bering Sea.

Ocean basins

The GOA has numerous currents and features which facilitate transport of nutrients and larvae. The GOA is the recipient of North Pacific Current water that travels eastward across the northern Pacific Ocean and flows counterclockwise into the GOA (Fig. 1) forming the Alaska Current. The Alaska Current becomes the Alaska Stream, a fast moving boundary current, as it flows westward. The Alaska Coastal Current flowing from the north central GOA westward is driven by winds and freshwater runoff and is a major contributor to water transport along the shelf (Stabeno et al. 1995). The coastline of the GOA experiences both upwelling and downwelling which transports water and nutrients vertically through the water column, although upwelling tends to be less intense in the GOA than further south along the west coast of North America. The formation of intermittent mesoscale eddy features result in significant water exchange between the continental shelf and slope (Ladd et al. 2009) and are thought to influence larval assemblages (Atwood et al. 2010).

Oceanographic characteristics of continental shelf waters in the GOA differ between the east and the west. Although year-to-year values are highly variable, in the east, waters are generally cooler, more acidic (lower pH), and have a lower dissolved oxygen (DO) content. In the west, waters are warmer, less acidic, and have higher DO. Primary production (i.e., phytoplankton blooms) is found coastwide in varying concentrations (Sadorus and Walker 2014).

The Bering Sea receives water from the western-most part of the Alaskan Stream in the Pacific Ocean. The water flows northward through the passes among the Aleutian Islands to form the Aleutian North Slope Current along the islands, and the Bering Slope Current along the continental shelf edge (Fig. 2). The bathymetry in the area north of the Bering Slope Current is relatively flat and shallow and serves as a nursery ground for many species of fish. Over the shelf are several current fronts that aid in the transport of larvae northward into Bristol Bay. The area south of the current is deep and is home to many pelagic species. The western boundary current in the Bering Sea is the Anadyr Current to the north and the Kamchatka Current further south. Water is transported out of the Bering Sea northward into the Chukchi Sea and southward via the western boundary currents and the passes among the Aleutian Islands (Stabeno and Reed 1994).

In winter, the Bering Sea experiences sea ice cover. The extent of the ice cover and its persistence into spring and summer are variable, and this variability can influence both survival and the level of predation on larvae (Hunt et al. 2011). Overall, the Bering Sea shelf is characterized by relatively low temperatures, variable pH, high dissolved oxygen (DO) except at deeper depths, and moderate primary production (Sadorus and Walker 2014).

Juvenile halibut distribution

Adult halibut migrate to the continental shelf edge in winter (November through March) to spawn. Spawning halibut have been found as far south as northern Washington and throughout the GOA and Bering Sea (St-Pierre 1984), but major spawning grounds are thought to be concentrated in the central and western GOA and the southern Bering Sea shelf edge (Fig. 3). Eggs are laid in deep water along the slope and are then left to drift in the ocean currents as they mature through the hatching and larval phases.

Eggs and larvae

It takes an estimated six months for a halibut to move from the egg phase to settlement in shallow coastal nursery areas where they take on the adult form (IPHC 2014). During those first six months, a larval halibut is highly vulnerable to predation, and is dependent on favorable environmental conditions and current strength, as well as availability of prey once the yolk sac has been fully absorbed. Over a period of several years in the late 1920s to early 1930s, the IPHC (then known as the International Fisheries Commission) surveyed the GOA and found that halibut eggs occurred in large numbers in the central and western GOA, in moderate numbers off Haida Gwaii (Queen Charlotte Islands), and in very small numbers in the eastern GOA (Thompson and Van Cleve 1936). Larval halibut were found in decreasing numbers as they passed through the various larval and post-larval stages, suggesting wide-spread mortality and dispersal (Fig. 4) as the larvae matured.

More recently, egg and larval occurrence data have been collected by NMFS during ichthyoplankton surveys (NOAA 2014a). These surveys span the area off the U.S. west coast, the GOA, and the Bering Sea/Aleutian Islands, but do not include B.C. waters. Eggs have been found off the U.S. west coast and in the western GOA. Larval halibut (all stages) have been found primarily in the central and western GOA, and southern Bering Sea edge, and to a lesser extent, further north and west in the Bering Sea (Fig. 5).

The prevailing currents generally transport the eggs and larvae from the spawning grounds westward in the GOA and northward in the Bering Sea. Larvae also depend on currents to transport them to areas of plankton production where they are able to feed on zooplankton, and eventually inshore for settlement to the bottom in shallow nursery areas. Halibut begin migrating from the nursery areas within a year or two of settlement and begin dispersing to greater depths, as well as eastward in the GOA and both westward and southward in the Bering Sea, in a counter-migration pattern. As adults, the population is widespread (Fig. 6).

Distribution of 1-6 year olds

Halibut become vulnerable to the NMFS groundfish shelf trawl surveys when they are 15-20 cm fork length or 1-2 years old. The Bering Sea shelf survey has been conducted annually since 1982. The GOA and Aleutian Islands surveys were conducted triennially beginning in 1984 and then biennially since 1999. In addition to length data, age data are collected during these surveys that can then be used to map distributions of halibut as they age and disperse. These surveys frequently encounter halibut to age 6, but catch rates of older and larger fish decline rapidly (much more so than abundance), likely because catchability of larger halibut is lower for the trawl gear and methods employed in these surveys.

Figures 7 through 11 illustrate the occurrence of juvenile halibut from ages 1 to 6 as seen in the NMFS groundfish trawl surveys. These figures map the data for all years of the survey in aggregate. Trawl surveys in British Columbia also indicate a small number of age 1-2 halibut off the northeastern corner of Haida Gwaii, although these values are not included in figures 7-11. The major halibut nursery areas can be clearly seen in Bristol Bay, around Kodiak Island, and between Kodiak Island and the eastern Aleutian Islands. While the largest numbers of juvenile halibut continue to be detected on or near nursery grounds for several years, it is clear that a portion begin to disperse at ages as young as 2 years old. Three-year-olds are found in small numbers in the central Gulf and southern Bristol Bay, and 4-year olds are found Gulf-wide and into the Aleutian Islands. Five- and 6-year-olds are found in greater numbers coastwide and at greater depths, throughout the known range for Pacific halibut. Survey data are inherently variable and no clear year-to-year patterns have yet emerged that link dispersal patterns to other factors such as environment or year class strength..

Juvenile halibut abundance

Juvenile halibut abundance estimates are derived using the number of halibut caught related to the area swept by the trawl gear during the NMFS groundfish trawl surveys (described in Clark et al. 1997), and extrapolating that information across the surveyed area. Ages collected from a subsample of halibut caught were used to build an abundance-based age composition for the Bering Sea (Fig. 12). In this format, relative year-class size can be tracked from one year to the next. For example, the particularly large 1987 year class, which is marked on Figure 12, can be clearly followed from year to year as the fish grow and eventually fade from the trawl catches due to reduced selectivity. As expected, as year classes decrease in number in the trawl survey, they begin to appear in greater numbers in the commercial fishery and setline survey (Stewart and Martell 2014). In more recent years, the 2004 and 2005 year classes were captured in very large numbers in the trawl survey, but have failed, as of yet, to appear in commercial or setline survey samples as anything but average-size year classes. This suggests that either year-class strength of very young juveniles in the Bering Sea may not always be a reliable indicator of recruitment into the coastwide commercial fishery, juvenile halibut were particularly vulnerable to the Bering Sea survey design in those years, or that these fish have experienced lower growth rates or higher mortality rates than other recent cohorts. During their younger years, juvenile halibut are subject to a variety of conditions that can lead to variable survival rates. These include environmental conditions, food supply, predation, and competition for resources such as food and preferred habitat. These factors are discussed in the following sections. Similar juvenile year-class trends may also be present in the GOA, but it is difficult to follow cohorts annually there due to the biennial schedule of that trawl survey.

Environmental effects

Environment has been shown to play a critical role in the population variability of many marine species. Bakun (2010) described three classes of environmental conditions that combine to yield favorable habitat for reproduction and juvenile survival including: enrichment processes such as upwelling and mixing; concentration processes such as convergence, frontal formation, and water column stability; and processes favoring retention within or drift toward favorable habitat. In an effort to describe and monitor various environmental scenarios, researchers have

developed environmental indices, with each one including a unique set of parameters to describe particular climatic regimes or conditions. Table 1 describes a number of indices that involve the north Pacific and Bering Sea. Although many have been developed only in recent years, some have already shown correlation with recruitment of various species. For example, Bailey and Picquelle (2002) found that the El Nino Southern Oscillation (ENSO) was linked to positive recruitment of halibut in the GOA, possibly due to enhanced onshore advection to nursery grounds and increased larval numbers in warm ENSO years. Clark and Hare (2002) linked recruitment of halibut to the Pacific Decadal Oscillation (PDO); i.e., PDO "warm" years correspond with higher recruitment. Wilderbuer et al. (2013a) found that the Arctic Oscillation (AOI), which is related to sea ice cover and therefore sea surface temperature, was an indicator of arrowtooth flounder (*Atheresthes stomias*) productivity. Individual environmental features such as temperature, dissolved oxygen, and pH have also been studied recently. Mathis et al. (2014) reported that although there is little research showing direct effects of ocean acidification related to fishes in the north Pacific, there is a strong effect in the production of marine calcifiers, which are a key component in the food chain. Sadorus et al. (2014) found distribution pattern changes with particularly low dissolved oxygen off the U.S. west coast and British Columbia. Both dissolved oxygen concentration and the degree of ocean acidification are related to upwelling in oceanic waters.

The IPHC currently operates a coastwide environmental data collection program (Sadorus and Walker 2014) in tandem with its setline surveys (Henry et al. 2014). These data enable researchers to directly study environmental effects in relation to adult and sub-adult halibut. However, linking environmental conditions to juvenile recruitment and survival is especially complex due to the fact that the fish must survive through several life stages where they are particularly vulnerable. In addition, there are very few direct observations of environmental conditions that match the spatial and temporal scope of young halibut.

Methods

A principal component analysis (PCA) using singular value decomposition (Golub and Reinsch 1970) was performed on environmental indices relevant to the region being studied, to examine whether these indices correlate to relative observed year-class strength of halibut. Year-class strength was determined using NMFS trawl survey abundance estimates and estimations of age-0 halibut from the long time-series model (Stewart and Martell 2014). The PCA allows variables to be correlated with one another and in fact, many of the indices share inputs and are highly correlated. The Bering Sea and GOA were analyzed separately, each with a unique combination of inputs. See Table 1 for a description of each index (including acronyms) and the source of the data. The indices chosen for each area were:

<u>Gulf of Alaska</u>
AOI, NPI, MVENSO, PDO, Upwelling

<u>Bering Sea</u>
PDO, ONI, ICI, SST_May, Bottom temperature, BSPIw, AOI

Indices were chosen based on geographic relevance and availability of data. An effort was made to choose a variety of indices that included unique factors, e.g., sea level pressure, bottom temperature, surface temperature, and air pressure. The annual anomalies were used instead of the

index values themselves. All anomalies were of similar scale, so there was no need to standardize/transform the data further. Bering Sea data spanned 1982-2013 and GOA data spanned 1984-2013. Figures 13 and 14 illustrate the positive and negative anomaly years for each index and in relation to one another.

Results

The PCAs for the Bering Sea and GOA revealed both similarities and differences. For both areas, all but one of the inputs was significant on the first principal component (PC) which explained 43% and 51% of the variance for the GOA and Bering Sea, respectively. For both regions, it took four PCs to explain at least 90% of the variance (Tables 2 and 3) illustrating that defining the conditions in any given year is not a straightforward process. However, looking at the primary characteristics of the first two PCs in relation to year provides some context for conditions in that particular year. Coupling this information with what is known of relative year-class strength of particularly large and small year classes of Pacific halibut, can provide a fresh look at how environment and recruitment may be related.

In the Bering Sea (Fig. 15), the PCs have noticeable differences with primarily temperature-related indices on PC1 and pressure-related indices on PC2. Pressure can indicate temperature variations, but also advection and mixing processes. The placement on the biplot of those years that also produced large observations of juvenile halibut (e.g., 1987, 2004, and 2005) shows that they were all years of positive temperature-related anomalies, or warmer years. Many of the most recent years are far to the left in the plot, corresponding to increased ice cover and lower temperatures, and these are also years for which preliminary estimates show there is low recruitment of halibut. Other years for which juvenile abundance has been observed to be poor, e.g., 1991, 1992, and 1993, are placed neutral or slightly positive on PC1, and positive on PC2. Positive pressure indices (PC2) in this case indicate low pressure phases in Alaska, or more simply put, stormy, wet weather in Alaskan waters. Stormy weather means increased mixing in the water column, which likely interferes with transport of larvae to the surface and inshore. Inshore transport is necessary for upright larval halibut so that as they metamorphose to the adult, flatfish form, they can settle to the bottom in shallow nursery habitats.

As in the Bering Sea, the first PC in the GOA analysis (Fig. 16) also tends toward temperature-related indices, with positive, or warmer, temperatures to the right and cooler temperatures to the left. The second PC, dominated by upwelling/downwelling and the AOI, encompasses indices related to sea level pressure and therefore transport processes. Negative placement on the second PC relates to low atmospheric pressure and stormy weather in the GOA. It is important to note that the factors on the first and second PCs are not mutually exclusive. For example, Bailey and Picquelle (2002) reported that ENSO events, prominent in both the Bering Sea and GOA on the first PC as ONI and MVENSO, respectively, aid in larval fish recruitment due both to warmer temperatures and enhanced onshore flow to coastal nursery areas.

Analysis of the GOA components and resulting year placements shows that 1987 is clearly a year of strong, warm-phase PDO and ONI conditions and is also a year when a very large year class of halibut was produced. Other years producing large observations of juvenile halibut in the Bering Sea are either neutral or slightly positive on the first PC and neutral (2004) or positive (2005) on the second PC in the GOA. In fact, there is little corroboration in the GOA data for similarly large year-class strengths of the 2004 and 2005 cohorts, however, the signal is less clear due to the biennial nature of the survey. The placement of years for which halibut year classes were

known to be smaller according to abundance and biomass estimates (e.g., 1991, 1992, and 1993) is neutral or slightly positive on PC1 and negative on PC2, suggesting poor recruitment during stronger upwelling and positive phase AOI years (stormy weather in the GOA). Many of the more recent years are negative on the first component and neutral on the second. Negative on the first component corresponds to the NPI, which generally runs opposite the PDO in cold vs. warm phases. These results are similar to those found in the Bering Sea.

This analysis suggests that not surprisingly, both temperature and transport processes may be important to juvenile recruitment and abundance. Both processes likely have the largest impact during the larval phase when halibut are particularly vulnerable to, and completely dependent on the elements, as opposed to juvenile halibut that have made it past the larval stage and settled to the bottom. Still, while years that produced particularly large or small observations of halibut year classes corresponded relatively well to environmental indices in this analysis, there are many years where the correspondence signal was ambiguous, Likewise, there were years that according to the environmental analysis alone, should have yielded larger or smaller year classes of halibut, but appear to have not. Therefore, it is clear that while temperature and transport processes play a role in defining particularly large or small year classes, most likely at the larval phases, recruitment to the commercial fishery (which does not occur until 8-10 years of age) is a complex process involving a variety of factors over time.

Population fluctuations compared with similar species

Pacific halibut share life history characteristics with a number of other fishes in the north Pacific and Bering Sea. Stachura et al. (2014) grouped arrowtooth flounder and Greenland turbot (*Reinhardtius hippoglossoides*) together with Pacific halibut based on processes important to recruitment for all three species, most notably in this case, cross-shelf transport. The idea is that factors affecting recruitment of one species may also be evident in correlated fluctuations of biomass/abundance in similar species. Yellowfin sole (*Limanda aspera*) was also considered for this analysis given its close geographic proximity to halibut during surveys (Wilderbuer et al. 2013b).

A general comparison of the four species (age-2 abundance estimates of halibut and arrowtooth flounder (Spies and Turnock 2013), age-1 estimates of turbot offset by one year (+1 year), and age 3 estimates of yellowfin sole (-1 year)) in the Bering Sea (Fig. 17) shows some weak similarities. Extreme values appear somewhat similar, especially between halibut and turbot, but most average values do not. In 1986, all but yellowfin sole show an increase in abundance simultaneously. In other years, such as 1989 and 2006, 2-year-old halibut recruitment appears to increase substantially. Turbot recruitment also increases but in the years following, not in the same year as halibut. Both yellowfin sole and halibut show a dramatic increase in the mid-2000s, although not in the same year. A Pearson product correlation test was performed in an attempt to quantify the relationship among the four species (Table 4). The correlation coefficients indicated a low positive correlation between yellowfin sole and halibut abundance, and yellowfin sole and arrowtooth flounder abundance.

In the GOA, age-specific data for juvenile fish was available only for halibut. Overall biomass estimates for arrowtooth flounder (Spies and Turnock 2013) were available, but not for Greenland turbot since it is managed as part of a flatfish complex and biomass estimates are calculated for the grouping, not for each species. Therefore, the comparison was performed between halibut abundance and arrowtooth flounder biomass of all sizes. Walleye pollock (*Gadus chalcogrammus*)

biomass estimates for age 3+ fish (Dorn et al. 2013) were added because pollock occupies much of the same adult habitat as halibut (Fig. 18). In the figure, trend lines were added for each species to better illustrate the trajectory, and in fact highlight similar population trends for halibut and arrowtooth flounder, as well as an opposite trend for pollock. The Pearson product correlation test (Table 5) revealed that trajectories over time for the halibut/arrowtooth and arrowtooth/turbot combinations were moderately correlated, positive and negative, respectively. The halibut/turbot combination had a low negative correlation.

Overall, it's clear that while each of these species occupies similar habitat and may have similar life histories, each experiences a wide range of unique factors affecting its survival and catchability. It does appear as though halibut and arrowtooth flounder experience similar fluctuations in overall abundance, and it is reasonable to assume that environmental factors affecting one in the early life history stages will also affect the other. However, because of the mismatches over time, more questions remain about possible drivers.

Pacific halibut diet

The fact that young halibut were seen in large numbers in the Bering Sea trawl surveys in 2006 and 2007, but have not recruited as expected to the commercial fishery, suggests that factors beyond transport and temperature during early life history may play a role in survival. Young of the year are only a few centimeters in length, making them highly vulnerable to predation after they have settled into the nursery areas. A halibut that is successful in finding food can grow 10 cm in length per year on average, and the larger the halibut, the less vulnerable to predation it becomes. A halibut that is less successful will experience slower growth, making it vulnerable to predation longer than its more successful counterparts. Additionally, poor nutrition likely leads to increased risk for disease.

Halibut of all ages are opportunistic feeders and will consume a variety of prey depending on what is available, including other fish, crabs, shellfish, and various other invertebrates (IPHC 2014). A very small halibut, once it has passed the larval phases and settled to the bottom, will generally target prey smaller than itself including shrimp, gastropods, and fish.

The diet data from halibut used here are routinely gathered from stomach samples collected during the NMFS trawl surveys (NOAA 2014b). Note that stomach analysis data used here are for all halibut sampled, including both juvenile and adult fish. Stomach samples have been collected in three main survey subareas (Bering Sea, GOA, and Aleutian Islands) and each subarea included a large number of total species, many of which overlap with other areas. Overall, 89 unique categories were used to describe the stomach contents of halibut, some of which were identified to species, and others that were identified to genus or family groupings (Table 6).

Although there were a large number of species identified, over 50 percent of the total weight of material in the stomachs collected over a given year was made up of just the top four species. Figures 19 and 20 list the top four species consumed each year in each area. Pollock and crabs were top food choices in all areas. In the Bering Sea, the other top choices were highly variable and included a number of different item categories. Sculpins and Atka mackerel were common food choices in the Aleutian Islands, as were cephalopods. In terms of dietary changes, in the GOA, pollock was a top food choice for all years until the most recent sample collected in 2009 when it did not appear in the top four.

Analysis

There are missing or incomplete stock assessments for many of the prey species, making it difficult to statistically compare halibut abundance trends with food item biomass trends. However, there are pollock catch-at-age estimates based on observer data both for the Bering Sea (Ianelli et al. 2013) and the GOA (Dorn et al. 2013). The forage fish complex biomass has been estimated in the Bering Sea since 2003 using bycatch data and contains known prey items for halibut (Table 7; Ormseth 2013). In the Bering Sea, there were juvenile halibut abundance estimates for all years (1982-2013). Figures 21 and 22 show the trends of juvenile halibut (< 80 cm forklength) and juvenile pollock (1-2 year olds) abundance for the Bering Sea and GOA, respectively. Also plotted for the Bering Sea is the forage fish complex.

To look more closely at the similarities, a linear regression was performed to test whether the relationships were significant. For the GOA, juvenile pollock abundance was used as the only explanatory variable. One major limitation to the GOA analysis was the fact that there were only 13 Pacific halibut abundance estimates using real data spanning 30 years. In order to perform the regression, the non-estimated years were given incremental values based on the next data point so that all years had a value. Estimates based on real data may have yielded different results.

Results

In the GOA, juvenile pollock abundance was not significant (p-value 0.6348) as a descriptor for juvenile halibut abundance and in fact, the R^2adj = 0. Bering Sea results were slightly more positive than the GOA. Juvenile pollock alone was not significant (p-value 0.2166 and the R^2adj was 0.0478) but pollock and forage fish together explained 30.5% of the variability. Still, the p-values were not significant for either descriptor (p-value for pollock and forage fish being 0.2166 and 0.0958, respectively). Since the forage fish complex has only been estimated since 2003 and pollock estimated through 2012, the time series used spanned 2003-2012. The pollock/forage fish model shows some promise, but the limitation of only a decade's worth of data is significant. It may take several more years of data before this relationship can be fully described.

Data were limited for analysis of halibut related to prey and results were inconclusive. In both cases, adding additional prey species and/or years to the regression models may improve results.

Discussion

Juvenile halibut experience a wide range of environmental and habitat conditions during larval transport, settlement, and migration away from nursery areas. It is likely that environment plays a role in survival of larval and post-larval fish with temperature and transport processes being primary drivers. Aspects of changing ocean chemistry such as ocean acidification and decreasing DO (both of which have been detected in the north Pacific), may become larger factors in survival as they intensify and expand into spawning grounds and nursery areas in the future. Major prey items include crabs and gastropods, both of which depend on ocean water saturated with aragonite and calcium to form shells. Acidification lowers the saturation depth, making it more difficult for shell-forming organisms to function efficiently and thrive. Acidification also has a potential detrimental effect on phytoplankton, which would impact the entire food web.

While there are fairly detailed diet data for halibut, the stock assessments for the prey species are lacking. In many cases, exploited prey species are pooled into complexes for management purposes, and many other species important to halibut such as gastropods, are not commercially exploited and therefore have no assessments. Into the future, as data become available, looking

at links between the abundance of certain types of zooplankton serving as prey and survival of pelagic post larvae may be significant in explaining recruitment trends (Doyle et al., Unpublished data[1]). Energetics models for halibut, and monitoring stomach content changes over time to detect higher calorie (primary) prey versus lower calorie (secondary) prey in juvenile fish, may also provide some further insight into challenges related to food availability.

It is clear that juvenile halibut face ample challenges to survival in the first few years of life. Warmer water, calmer weather, and favorable food supply all contribute to a positive outcome for larvae and young of the year. Diet data for settled fish show that halibut have a diverse palate and supports previous findings that they are capable of opportunistic feeding. This trait likely buffers them against fluctuations in the population size of any one prey item. However, if there are major decreases in several prey species at once, it follows that growth and survival may be affected over the long term.

This paper addresses factors affecting distribution and observed abundance of juvenile halibut in general, but more specifically, the results may help to form hypotheses around a recent anomaly in juvenile halibut recruitment to the commercial fishery. The 2004 and 2005 halibut year classes, which showed very strongly in the Bering Sea trawl survey for several years as young fish, have as of yet failed to recruit in large numbers to the commercial fishery as expected. Possible explanations include: increased trawl survey catchability for those year classes; average or below-average year-class size in the GOA coupled with strong emigration to the GOA where the fish then dispersed widely and are therefore not detected in large numbers; slower than normal growth; and higher than normal mortality due to environmental factors, bycatch mortality, or diet.

In fact, the answer may be a combination of these things. First, addressing what the reasons are unlikely to be, it is unlikely that the observed recruitment anomalies are the result of variability in the trawl survey observations since the year classes in question were present in large numbers in several consecutive years in the Bering Sea survey. This persistence in the survey also suggests that halibut from the 2004/2005 year classes successfully settled to nursery areas, so transport and environmental factors were favorable in the larval and young-of-the-year phases. The threat of predation also decreases as the fish grow and age so increased predation is not likely.

That leaves environment, emigration, availability of prey, growth, and survey catchability as plausible explanations. The principal component analysis showed that many of the most recent years were environmentally unfavorable to larval halibut recruitment, so it may follow that those same favorable conditions needed for halibut recruitment are also needed for recruitment of prey species. The analysis here showed little or no relationship between selected prey species and juvenile halibut abundance, but a halibut's diet is highly varied and the analysis here was vastly limited due to lack of stock assessments for many of the major prey species. If a large proportion of the juvenile halibut from the Bering Sea have emigrated to the GOA and dispersed, and the same year classes were only average there, the overall result may be just an average-size year class coastwide. It is also possible that the 2004 and 2005 year classes have been less available to the subsequent surveys and fisheries and their abundance in these sources is currently underestimated. This explanation becomes less likely with each additional year of observation.

[1] Doyle, M. J., Coyle, K. O, and Strom, S. L. Unpublished data. Early life history phenology among Gulf of Alaska fish species: ecological implications for recruitment processes. Contact: Miriam Doyle, JISAO, 7600 Sand Point Way NE, Seattle, WA 98115.

References

Atwood, E., Duffy-Anderson, J. T., Horne, J. K., and Ladd, C. 2010. Influence of mesoscale eddies on ichthyoplankton assemblages in the Gulf of Alaska. Fish. Oceangr. 19(6): 493-507.

Bakun, A. 2010. Linking climate to population variability in marine ecosystems characterized by non-simple dynamics: Conceptual templates and schematic constructs. J. Mar. Sci. 79: 361-373.

Bailey, K. M. and Picquelle, S. J. 2002. Larval distribution of offshore spawning flatfish in the Gulf of Alaska: potential transport pathways and enhanced onshore transport during ENSO events. Mar. Ecol. Prog. Ser. Vol. 236: 205-217.

Clark, W. G. and Hare, S. R. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. N. Amer. J. Fish. Man. 22: 852-862.

Clark, W. G., St-Pierre, G., and Brown, E. S. 1997. Estimates of halibut abundance from NMFS trawl surveys. Int. Pac. Halibut Comm. Tech. Rep. 37.

Dorn, M., Aydin, K., Jones, D., Palsson, W., and Spalinger, K. 2013. Chapter 1: Assessment of the Walleye Pollock stock in the Gulf of Alaska. NPFMC Gulf of Alaska SAFE: 53-158.

Erikson, L. M. and MacTavish, K. A. 2014. Commercial catch sampling. Int. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 67-80.

Golub, G. H. and Reinsch, C. 1970. Singular value deomposition and least squares solutions. Numerische Mathematik 14(5): 403-420.

Henry, E., Soderlund, E., Dykstra, C. L., Geernaert, T., and Ranta, A. M. 2014. 2013 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 379-414.

Hunt, G. L., Coyle, K. O., Eisner, L. B., Farley, E. V., Heintz, R. A., Mueter, F., Napp, J. M., Overland, J. E., Ressler, P. H., Salo, S., and Stabeno, P. J. 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. ICES J. of Mar. Sci 68(6): 1230-1243.

Ianelli, J. N., Honkalehto, T., Barbeaux, S., Kotwicki, S., Aydin, K., and Williamson, N. 2013. Assessment of the walleye pollock stock in the Eastern Bering Sea. NPFMC Bering Sea and Aleutian Islands SAFE: 53-152.

International Pacific Halibut Commission (IPHC). 2014. The Pacific halibut: biology, fishery, and management. Int. Pac. Halibut Comm. Tech Rep. 59.

Ladd, C., Crawford, W. R., Harpold, C. E., Johnson, W. K., Kachel, N. B., Stabeno, P. J., and Whitney, F. 2009. A synoptic survey of young mesoscale eddies in the eastern Gulf of Alaska. Deep-Sea Res. Part II 56: 2460-2473.

Mathis, J.T., Cooley, S.R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., Hauri, C., Evans, W., Cross, J.N., Feely, R.A. 2014. Ocean Acidification Risk Assessment for Alaska's Fishery Sector, Progress in Oceanography. doi: j.pocean.2014.07.001

National Oceanic and Atmospheric Administration (NOAA). 2014a. Ichthyoplankton data retrieved 29August 2014. http://access.afsc.noaa.gov/ichthyo/pdf/genus/Hippoglossus.pdf

NOAA. 2014b. Resource Ecology and Ecosystem Modeling, Groundfish Diet Composition: Pacific halibut. Retrieved 8 July 2014. http://access.afsc.noaa.gov/REEM/WebDietData/DietTableSpeciesList.php?NODC=8857041901

NOAA. 2014c. Resource Ecology and Ecosystem Modeling, forage fish data. Accessed Retrieved 15 October 2014. http://www.afsc.noaa.gov/REFM/Docs/2013/BSAIforage.pdf

Ormseth, O. A. 2013. BSAI Forage Fishes: Appendix 2. Preliminary assessment of forage species in the Bering Sea Aleutian Islands. NPFMC Bering Sea and Aleutian Islands SAFE: 1029-1064.

Sadorus, L. L., Mantua, N. J., Essington, T., Hickey, B., and Hare, S. 2014. Distribution patterns of Pacific halibut (Hippoglossus stenolepis) in relation to environmental variables along the continental shelf waters of the US West Coast and southern British Columbia. Fish. Oceangr. 23(3): 225-241.

Sadorus, L. L. and Walker, J. 2014. IPHC oceangraphic monitoring prgram 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 325-334.

Skud, B. E. 1977. Drift, migration, and intermingling of Pacific halibut stocks. Int. Pac. Halibut Comm. Sci. Rep. 63.

Spies, I. and Turnock, B. J. 2013. Assessment of the arrowtooth flounder stock in the Gulf of Alaska [In] NPFMC Gulf of Alaska SAFE. Alaska Fisheries Science Center: 541-610.

Stabeno, P. J. and Reed, R. K. 1994. Circulation in the Bering Sea basin by satellite tracked drifters. J. Phys. Ocean. 24: 848-854.

Stabeno, P. J., Reed, R. K., and Schumacker, J. D.. 1995. The Alaska Coastal Current: continuity of transport and forcing. J. Geophysical Res. 100: 2477-2485.

Stachura, M. M., Essington, T. E., Mantua, N. J., Hollowed, A. B., Haltuch, M. A., Spencer, P. D., Branch, T. A., and Doyle, M. J. 2014. Linking Northeast Pacific recruitment synchrony to environmental variability. Fish Oceangr. doi:10.1111/fog.12066

Stewart, I. J. and Martell, S. 2014. Assessment of the Pacific halibut stock at the end of 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 169-196.

Stewart, I. J., Leaman, B. M., and Martell, S. J. D. 2015. Accounting for and managing all Pacific halibut removals. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 221-266.

St-Pierre, G. 1984. Spawning locations and season for Pacific halibut. Int. Pac. Halibut Comm. Sci. Rep. 70.

Thompson, W. F. and Van Cleve, R. 1936. Life history of the Pacific halibut – Distribution and early life history. Int. Fish. Comm. Rep. 9.

Wilderbuer, T., Stockhausen, W., and Bond, N. 2013a. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. Deep-Sea Res. II 94: 157-164.

Wilderbuer, T. K., Nichol, D. G., Ianelli, J. 2013b. Assessment of the yellowfin sole stock in the Bering Sea and Aleutian Islands. NPFMC Bering Sea and Aleutian Islands SAFE: 619-708.

Williams, G. 2014. Incidental catch and mortality of Pacific halibut, 1962-2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 289-310.

Table 1. Description of the environmental indices produced for the north Pacific and Bering Sea that are used in the PCA analysis.

Index	Acronym	Description	Source
Pacific Decadal Oscillation	PDO	The average life span for a PDO regime is 2-3 decades. In its warm phase, sea surface temperature (SST) anomalies are negative from the coast of Japan eastward with the strongest signal in the east-central North Pacific, and positive along the North American coast, extending to the south-eastern Bering Sea. For the cold PDO phase the distribution of SST anomalies is the opposite.	http://www.beringclimate.noaa.gov/data/BCresult.php
North Pacific Index	NPI	A descriptor for atmospheric circulation over the central and western GOA and Bering Sea. Negative values of the NPI correspond to periods of lower pressure and a tendency for stormy weather. Years with positive values of the NPI tend to correspond to years with positive summer SST anomalies. There was a shift toward more years with positive values of the index after the late 1980s, which implies reduced cloud cover and increased solar radiation at the sea surface.	http://www.beringclimate.noaa.gov/data/BCresult.php https://climatedataguide.ucar.edu/climate-data/north-pacific-np-index-trenberth-and-hurrell-monthly-and-winter
Multivariate El Nino Southern Oscillation	MVENSO	Bering Sea variability is significantly related to the Aleutian Low, which, in turn, responds, among other factors, to ENSO events in the equatorial Pacific. During warm ENSO events the Aleutian Low tends to become stronger and move southeastward of its normal position.	http://www.beringclimate.noaa.gov/data/BCresult.php
Oceanic Nino Index	ONI	One of several indices describing the effects of El Nino.	http://www.esrl.noaa.gov/psd/data/climateindices/list/
Arctic Oscillation	AOI	The Arctic Oscillation is the dominant pattern of non-seasonal sea-level pressure (SLP) variations north of 20°N. It has been described as a see-saw pattern in which atmospheric pressure at polar and middle latitudes fluctuates between positive and negative phases. When the AOI is positive, surface pressure north of about 45°N latitude is low, resulting in colder temperatures and is the reverse in the negative phase.	http://www.beringclimate.noaa.gov/data/BCresult.php
Bering Sea pressure index	BSPIw	A measure of cyclonic activity in the region and is closely linked with the strength of the Aleutian low. When the BSPIw is positive (anticyclonic regime) surface air temperatures tend to be colder than normal in the Gulf of Alaska and the eastern Bering Sea. The opposite is true when the index is negative (cyclonic regime).	http://www.beringclimate.noaa.gov/data/BCresult.php
Ice cover index	ICI	The extent of the sea ice cover of the Bering Sea has a profound influence on the physical and biological ocean environment. The Bering Sea is free of ice from late June to late October, with the greatest coverage in February-March. In its most extensive years, sea ice arrives in January and remains to May. Maximum extent years tend to coincide with negative values of the PDO.	http://www.beringclimate.noaa.gov/data/BCresult.php

Table 1. continued

BS Sea surface temperature	SST_May	The temperature in spring affects the metabolic rate of zooplankton and fish, i.e. warmer temperatures increase the rates of metabolic processes. Sea surface temperatures in May, when ice has retreated from the south-eastern Bering Sea, are, to a large extent, a product of climatic processes operating during the previous winter.	http://www.beringclimate.noaa.gov/data/BCresult.php
BS bottom temperature	BT	As surface waters are warmed and diluted in spring, the water column in the middle domain of the shelf is deep enough to become stratified into two layers. This stratification traps the residual water formed in winter below the pycnocline and creates a "cold pool" that persists through the summer. The cold pool can affect recruitment of fishes, distribution, and egg maturation rates.	http://www.beringclimate.noaa.gov/data/BCresult.php
Upwelling index	Upwelling	Upwelled water originates from depths of 100 m or more, is cooler and saltier than the original surface water, and typically has much greater concentrations of nutrients that are necessary to sustaining biological production. Variations in upwelling over seasonal to interannual periods, due to large-scale shifts in wind patterns and atmospheric systems, are linked to variability in fish populations and other biological components. Upwelling values used here are from 60°N and 149°W.	http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html

Table 2. Results of the Principal Component Analysis for the Gulf of Alaska.

	PC1	PC2	PC3	PC4	PC5
Standard deviation	1.4671	1.1003	0.9843	0.6659	0.4741
Proportion of variance	0.4305	0.2421	0.1938	0.0887	0.0450
Cumulative proportion	0.4305	0.6726	0.8664	0.9551	1
Coefficients	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
AOI	-0.27321	-0.50336	0.67742	-0.42827	-0.17227
NPI	-0.54746	-0.34355	0.02525	0.60752	0.46102
MVENSO	0.50933	-0.45035	0.10275	0.55516	-0.46798
PDO	0.60402	-0.19771	0.19941	-0.13275	0.73395
Upwelling	-0.03730	-0.62185	-0.70011	-0.34881	-0.00969
Structural correlations	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
AOI	-0.401	-0.554	0.667		
NPI	-0.803	0.405			
MVENSO	0.747	-0.496			
PDO	0.886				
Upwelling	-0.684	-0.689			

Table 3. Results of the Principal Component Analysis for the Bering Sea.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Standard deviation	1.891	1.0905	0.9605	0.81507	0.56925	0.49061	0.28885
Proportion of variance	0.5108	0.1699	0.1318	0.09491	0.04629	0.03439	0.01192
Cumulative proportion	0.5108	0.6807	0.8125	0.9074	0.9537	0.98808	1
Coefficients	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
PDO	0.42108	-0.08153	-0.26384	0.39368	0.76341	0.09200	-0.01370
ONI	0.31877	0.03950	-0.74039	0.22433	-0.54221	0.00179	0.06578
ICI	-0.45763	-0.07178	-0.18997	0.34189	0.08238	-0.71179	-0.34497
SST_May	0.48548	0.20478	0.20621	-0.10992	-0.12459	-0.06489	-0.80501
Bottom_temp	0.46762	0.11387	0.12662	-0.29207	0.03971	-0.69142	0.43289
BSPIw	-0.23500	0.54277	-0.47663	-0.56340	0.30720	0.03663	-0.09931
AOI	-0.04539	0.79821	0.24575	0.51283	-0.07038	0.03568	0.17663
Structural correlations	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
PDO	0.796	0.435					
ONI	0.603	-0.711					
ICI	-0.865						
SST_May	0.918						
Bottom_temp	0.884						
BSPIw	-0.444	0.592	-0.458	-0.459			
AOI	0.870	0.418					

Table 4. Pearson product moment correlation matrix for Bering Sea species (yo=years old).

	Halibut 2 yo	Turbot 1 yo (t+1)	Arrowtooth 2 yo (000s)	Yellowfin (M of 3 yo (t-1))
Halibut 2 yo	1			
Turbot 1 yo (t+1)	-0.03293	1		
Arrowtooth 2 yo (000s)	-0.00319	-0.02496	1	
Yellowfin (M of 3 yo (t-1)	0.183943	-0.07595	0.214551	1

Table 5. Pearson product moment correlation matrix for Gulf of Alaska species.

	Halibut abundance	Arrowtooth biomass (t)	Pollock age 3+ biomass (t)
Halibut abundance	1		
ATF Biomass (t)	0.4714361	1	
Pollock age 3+ biomass (t)	-0.254965	-0.500825	1

Table 6. Items identified in stomach samples collected from Pacific halibut in the Bering Sea (1984-2008), Gulf of Alaska (1990-2009), and Aleutian Islands (1991-2006).

Stomach sample items identified		
Alaska Plaice	Miscellaneous Crab	Unidentified Chionoecetes
Alaska Skate	Miscellaneous Crustacean	Unidentified Clupeids
Algae	Miscellaneous Flatfish	Unidentified Crab
Anemones	Miscellaneous Worms	Unidentified Crustacea
Arrowtooth Flounder	Myctophidae	Unidentified Echinoderm
Atka	Mysid	Unidentified Fish
Bathylagidae	Non-pelagic Shrimp	Unidentified Flatfish
Benthic Amph	Northern Rock Sole	Unidentified Gadid
Benthic Urochordata	Northern Rockfish	Unidentified Mollusc
Bering Skate	Octopus	Unidentified Particulate
Big Skate	Offal	Unidentified pelagic smelt
Birds	Pacific Halibut	Unidentified Rajidae
Brittle Star	Pacific Ocean Perch	Unidentified Rock Sole
Capelin	Pacific. Cod	Unidentified Rockfish
Chionocetes opilio	Pandalidae	Unidentified Sebastes
Chionoecetes bairdi	Pelagic Amphipod	Unidentified Smelt
Clam	Pelagic Gelatanous Filter Feeder	Unidentified Thornyhead
Copepod	Polychaete	Walleye Pollock
Dover Sole	Prickle squish deep	Yellowfin Sole
Dungeness	Prickle squish round	
Eelpout	Rex sole	
Eulachon	Sablefish	
Euphausiid	Salmon	
Fish Eggs	Sandlance	
Flathead Sole	Sculpin	
Glopp	Scyphozoid Jellies	
Greenlings	Sea Star	
Hake	Sea Urchins, Sand Dollars, Sea Cucumbers	
Hermit Crab	Shortspine Thornyhead	
Herring	Snail	
Kamchatka flounder	Southern Rock Sole	
King Crab	Sponge	
Large Sculpin	Squid	
Macrouridae	Unidentified Bathyraja	
Managed Forage	Unidentified Cephalopod	

Table 7. Listing of species groupings included in the forage fish complex category. These groupings represent approximately 50 species.

Forage fish complex categories
Eulachon
Other osmerids
Myctophidae
Capelin
Stichaeidae
Surf smelt
Sand lance
Bathylagidae
Pholidae

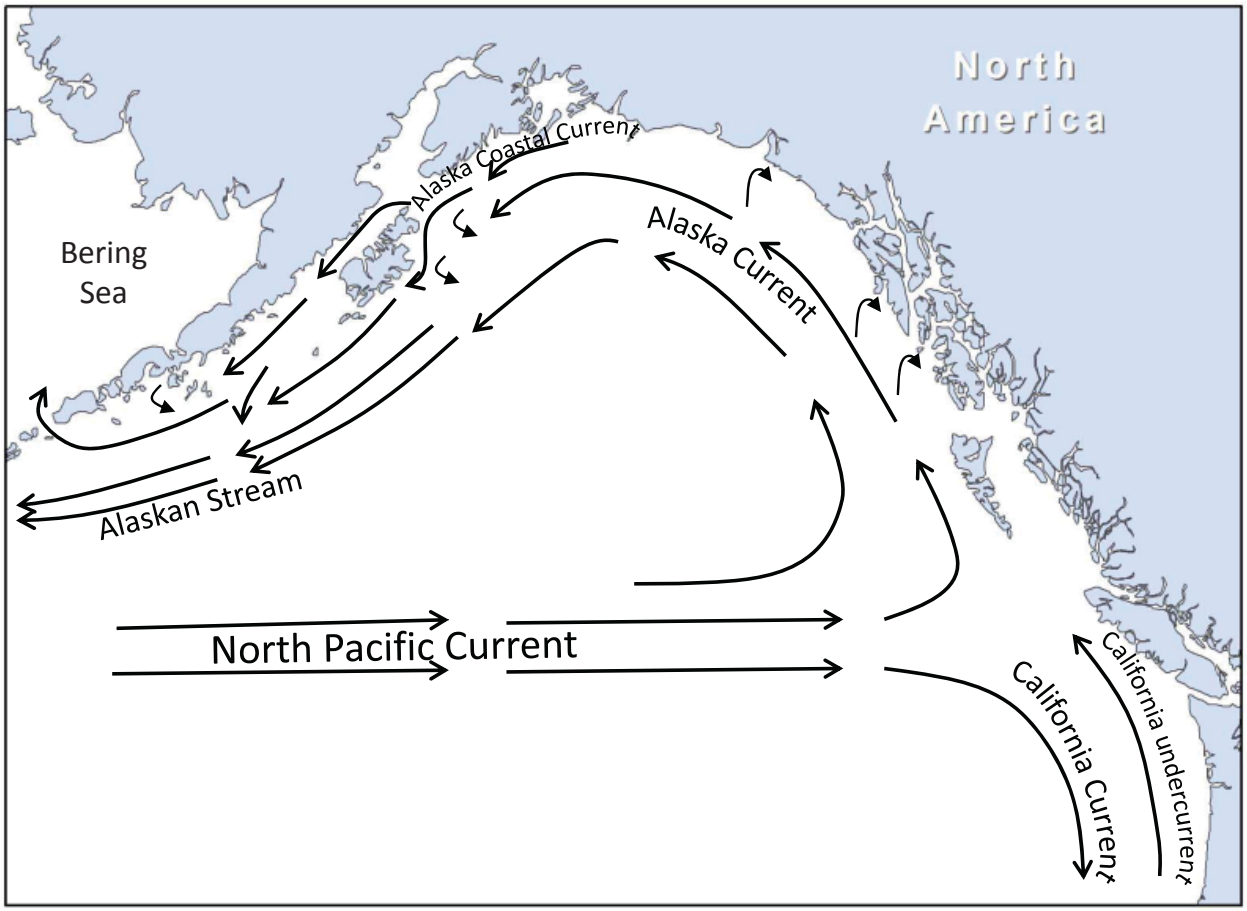


Figure 1. Major oceanic currents in the Gulf of Alaska

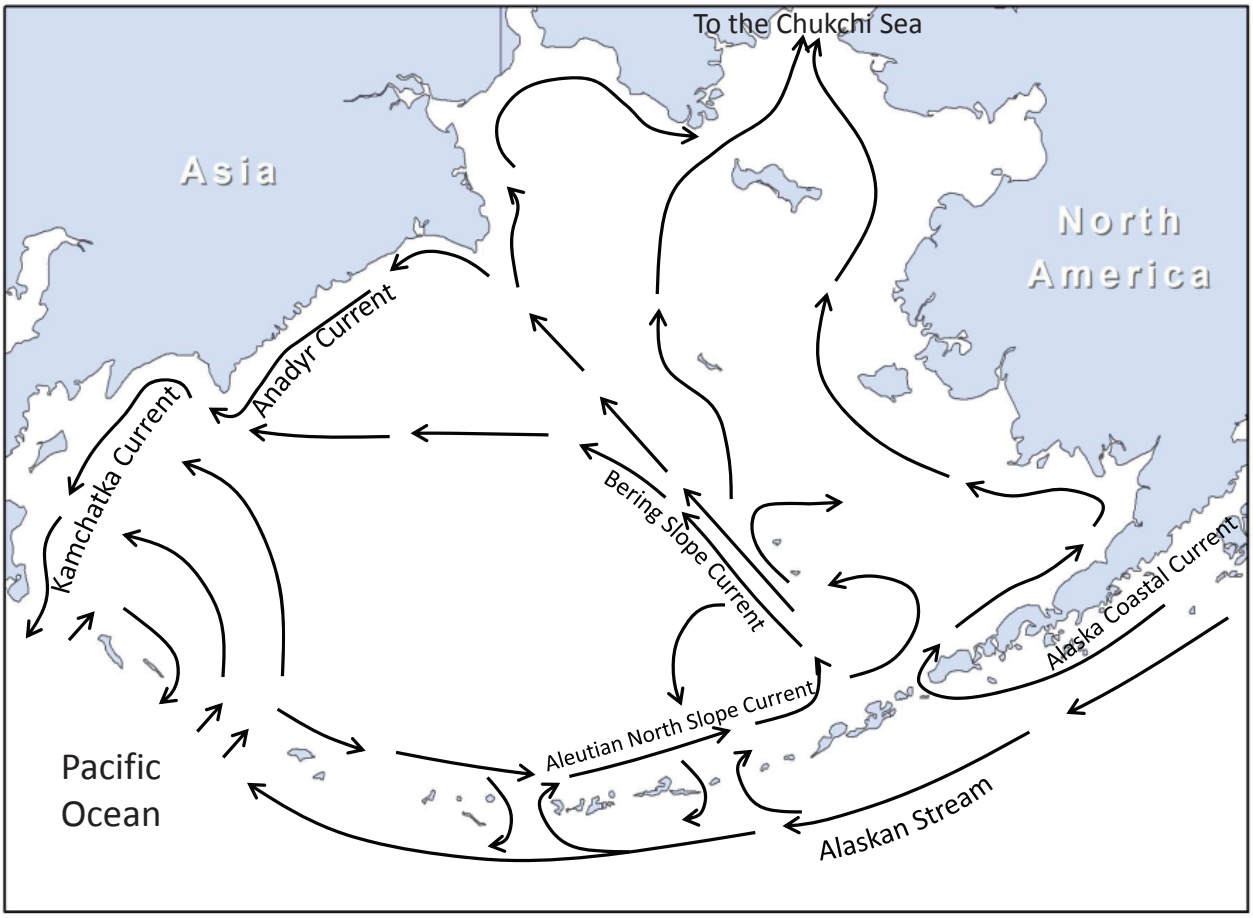


Figure 2. Major oceanic currents in the Bering Sea.

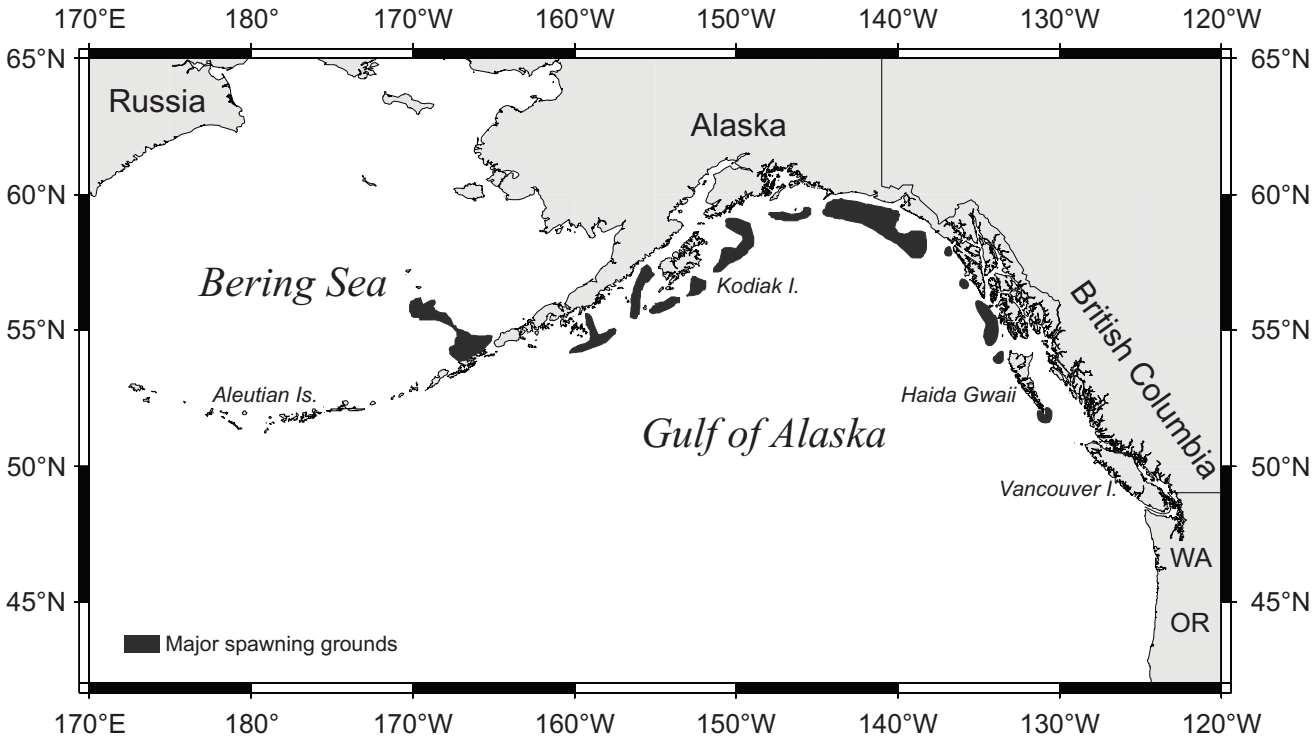


Figure 3. Major known spawning grounds for Pacific halibut (figure from IPHC 2014).

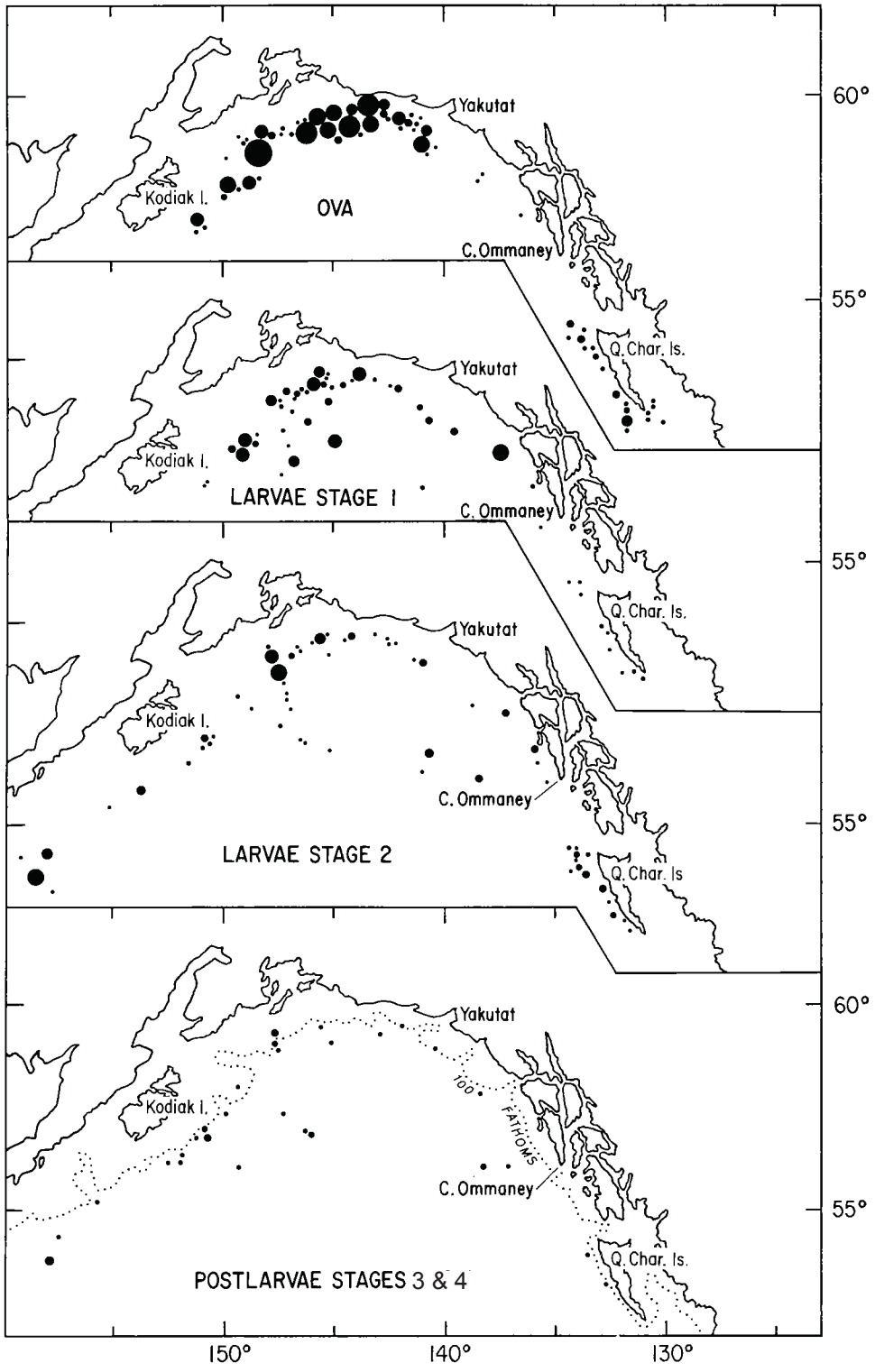


Figure 4. Distribution of halibut eggs and larvae as reported in Thompson and Van Cleve 1936 and reproduced in Skud (1977).

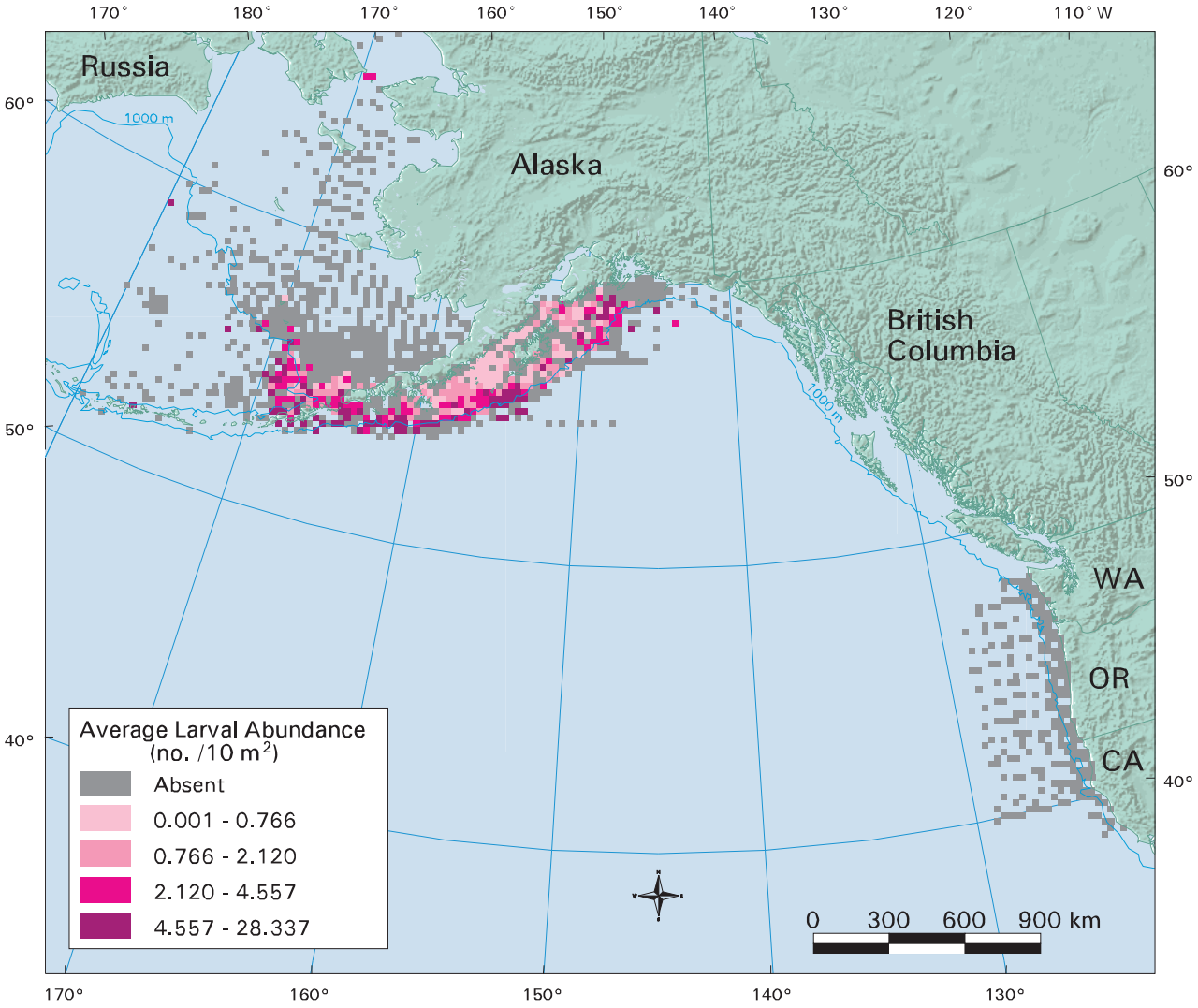


Figure 5. Distribution of larval Pacific halibut for all years combined through 2013 as detected during the NOAA ichthyoplankton surveys. Source: NOAA (2014a). Figure reproduced for this report with permission from Debbie Blood, NOAA, Seattle, WA.

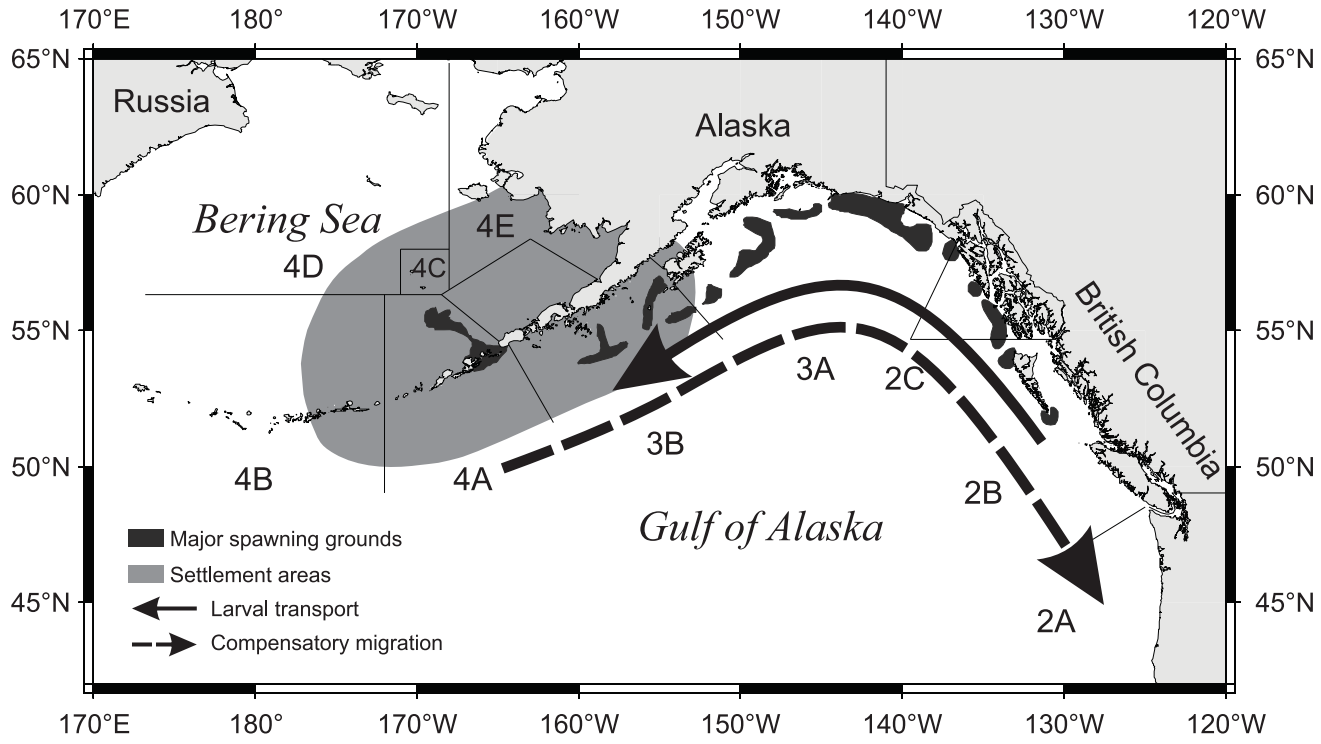


Figure 6. Drift and countermigration routes of young Pacific halibut.

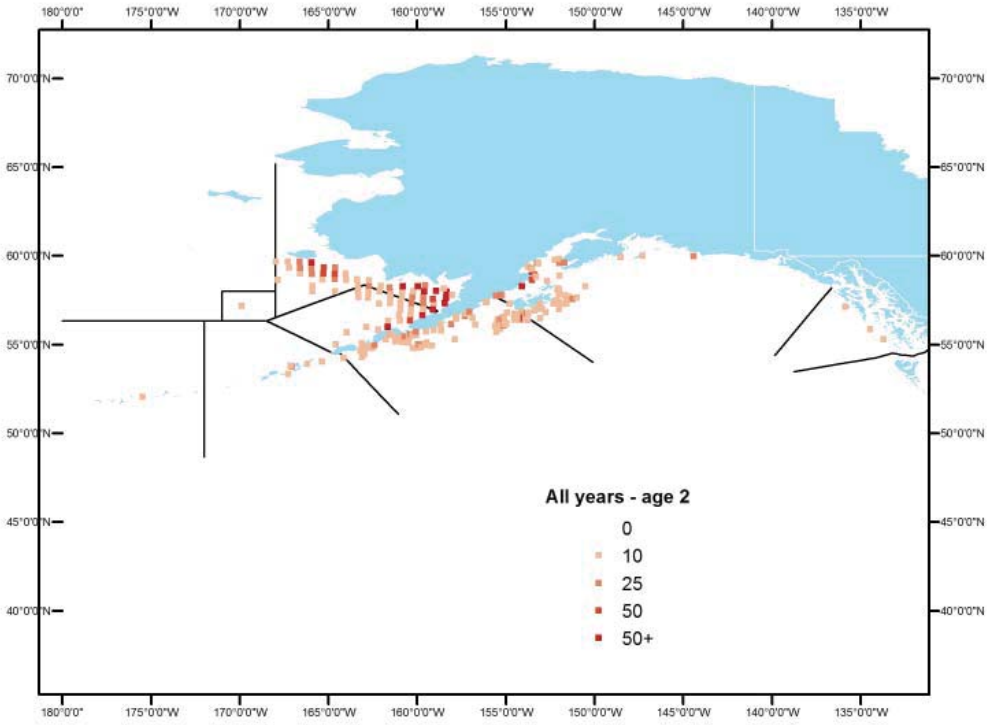


Figure 7. Distribution of age-2 halibut caught aboard the NMFS groundfish trawl surveys for all years combined. This figure is intended to be viewed in color - see online version.

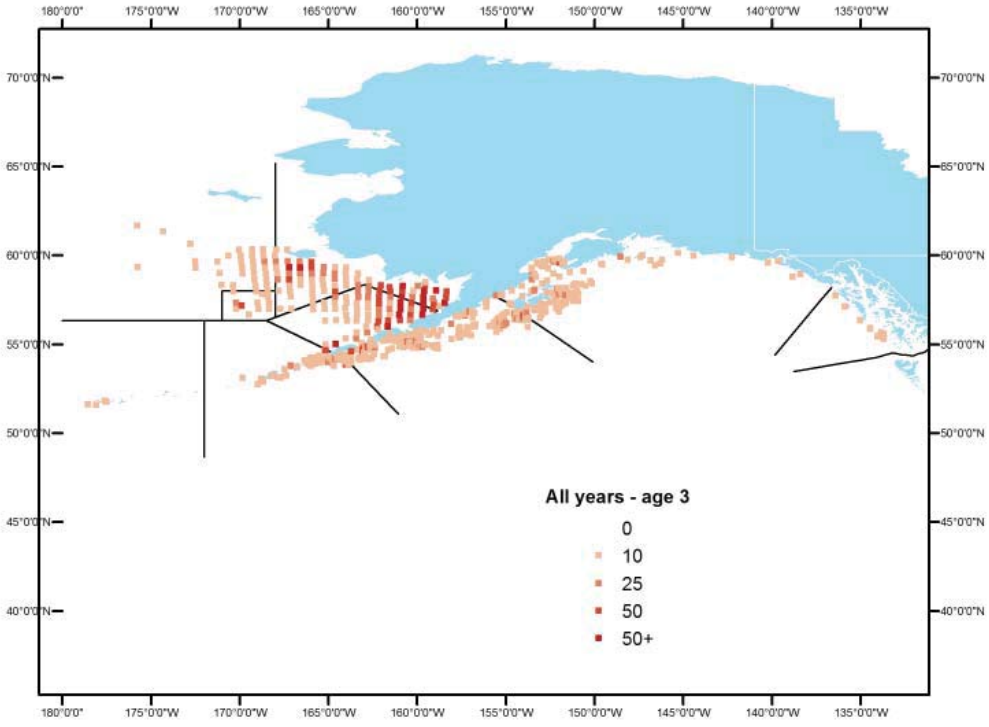


Figure 8. Distribution of age-3 halibut caught aboard the NMFS groundfish trawl surveysfor all years combined. This figure is intended to be viewed in color - see online version.

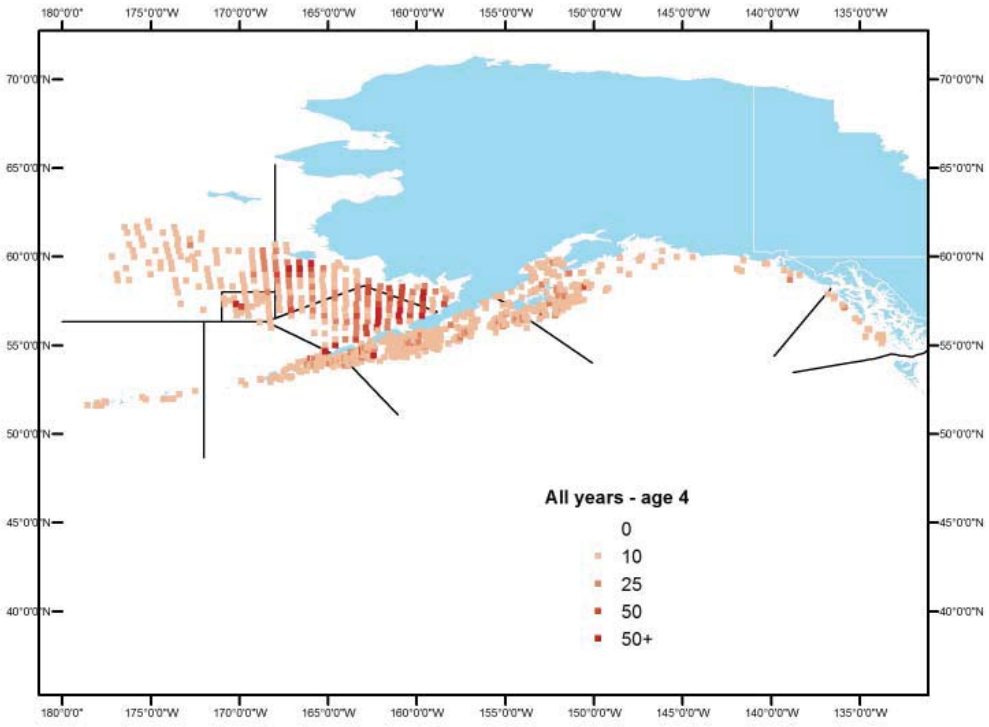


Figure 9. Distribution of age-4 halibut caught aboard the NMFS groundfish trawl surveysfor all years combined. This figure is intended to be viewed in color - see online version.

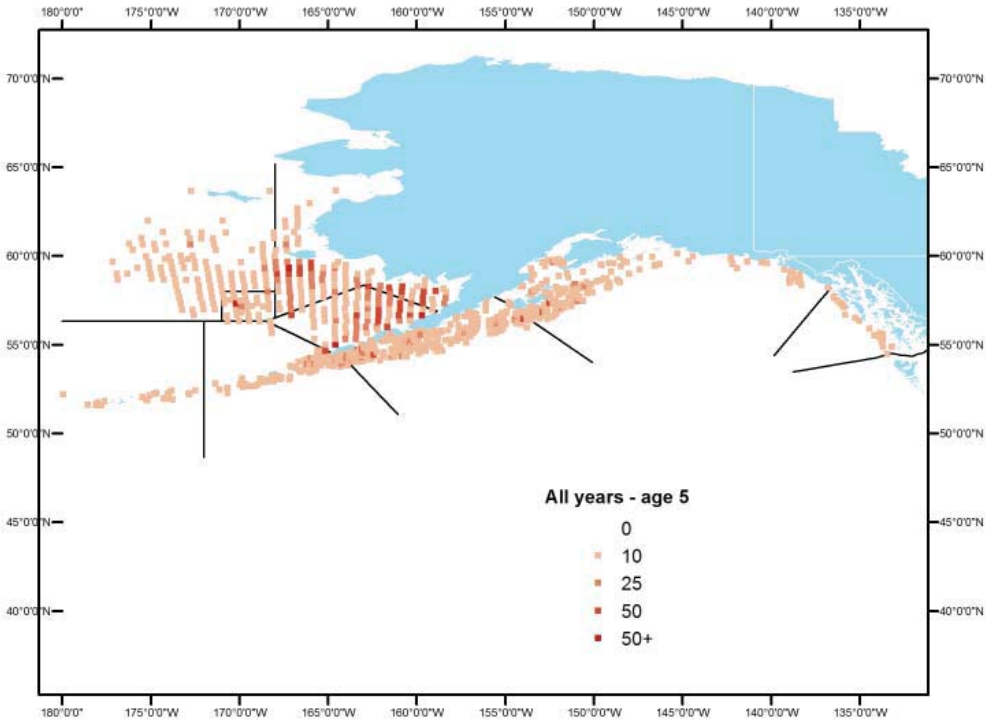


Figure 10. Distribution of age-5 halibut caught aboard the NMFS groundfish trawl surveysfor all years combined. This figure is intended to be viewed in color - see online version.

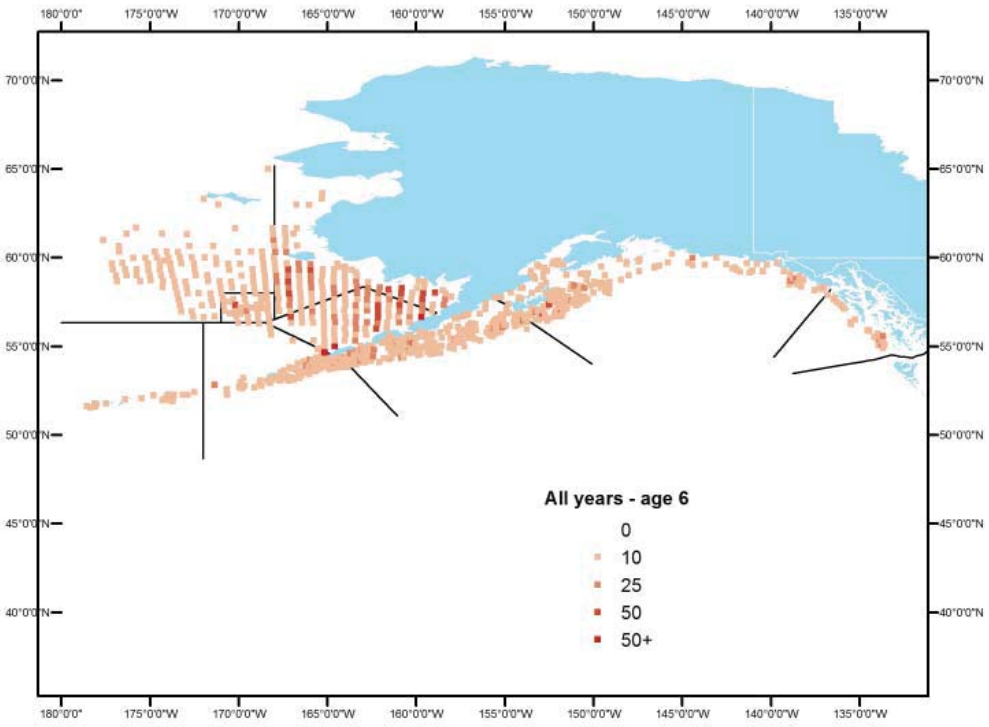


Figure 11. Distribution of age-6 halibut caught aboard the NMFS groundfish trawl surveysfor all years combined. This figure is intended to be viewed in color - see online version.

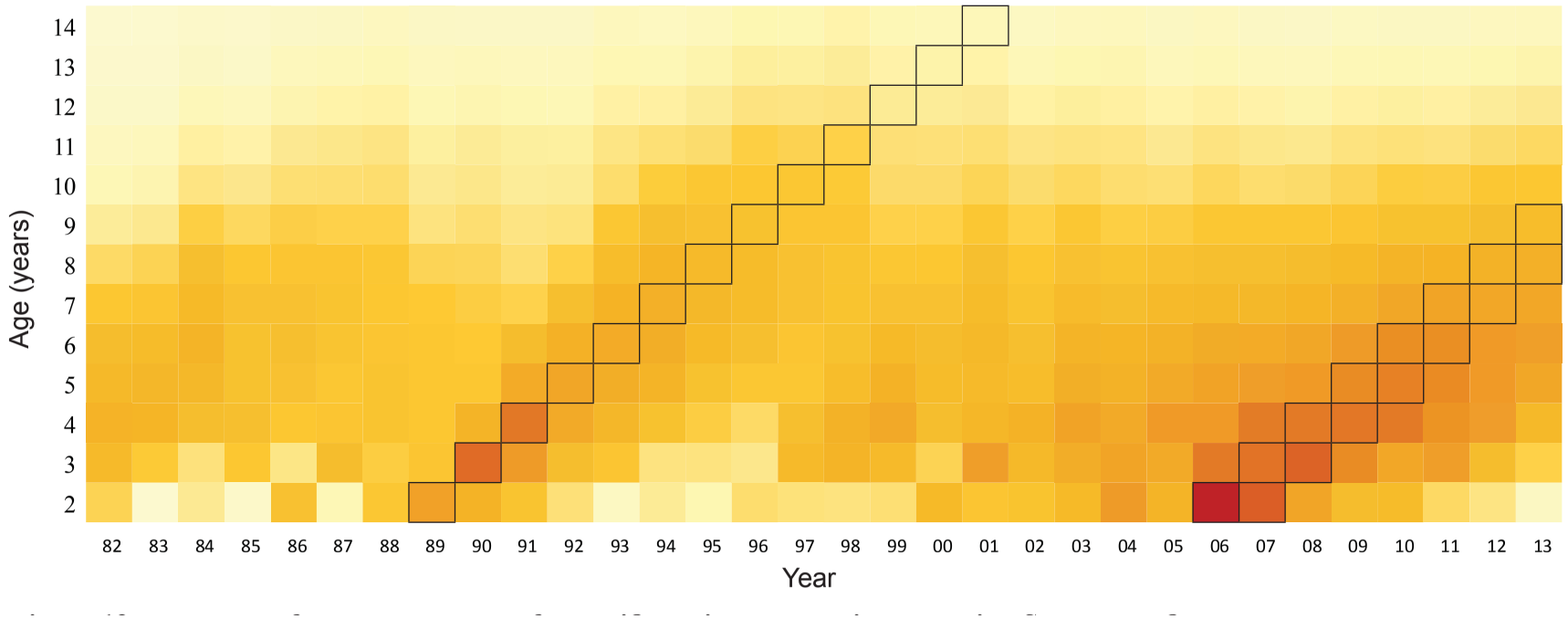


Figure 12. Heat map of abundance at age for Pacifi c halibut caught in the Bering Sea groundfish bottom trawl survey. The 1987, 2004, and 2005 year classes are highlighted.

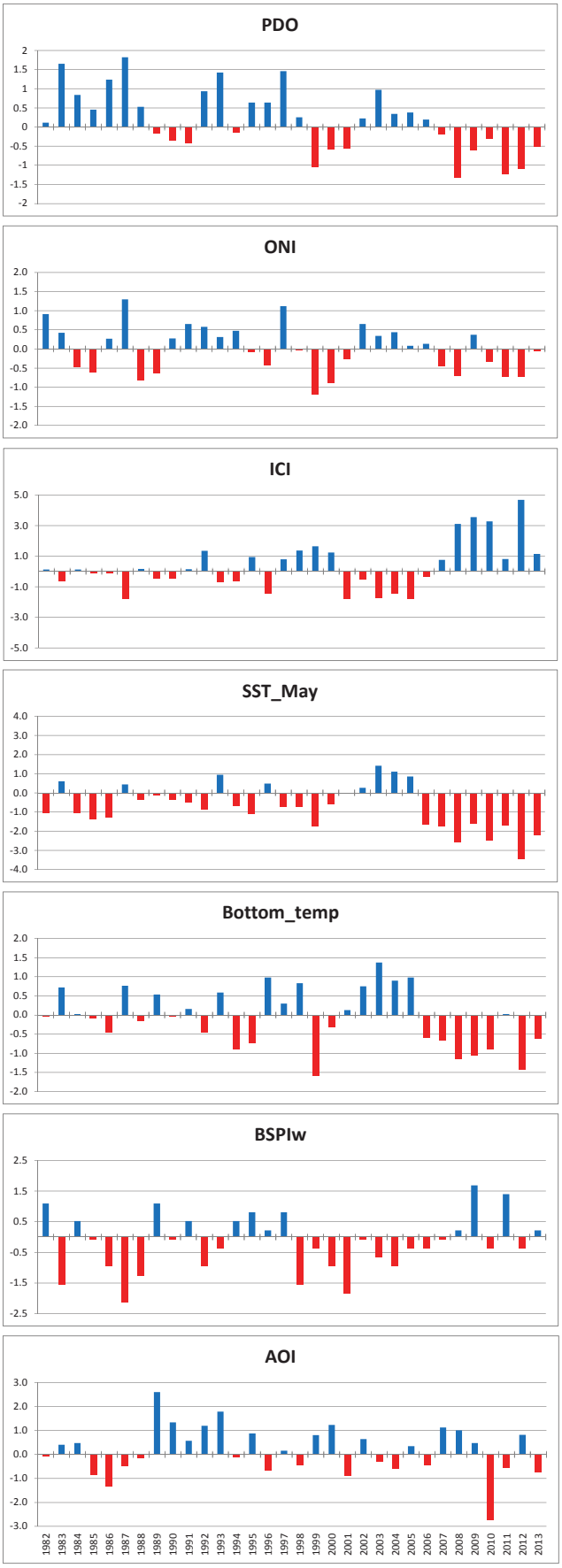


Figure 13. Environmental index anomolies used in the Bering Sea PCA analysis.

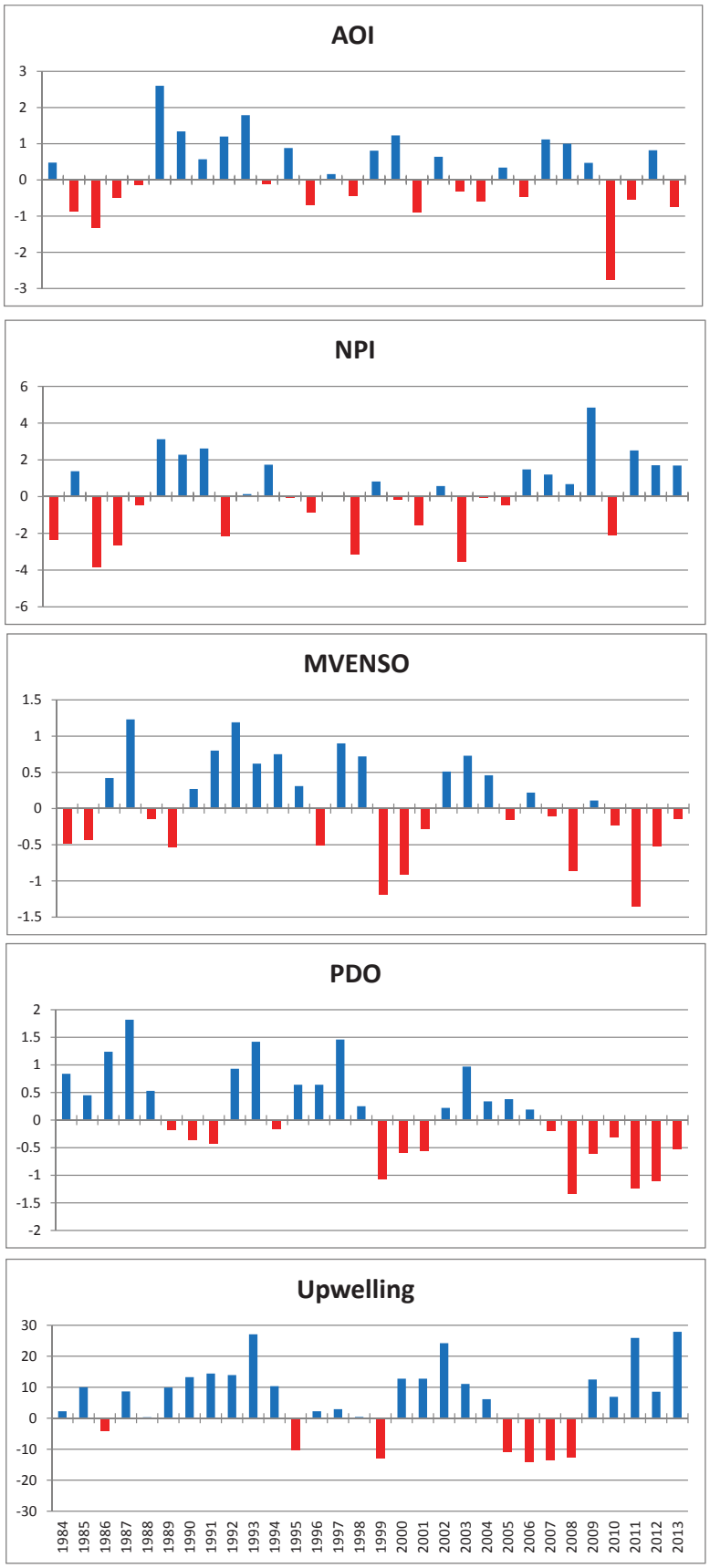


Figure 14. Environmental index anomolies used in the Gulf of Alaska PCA analysis.

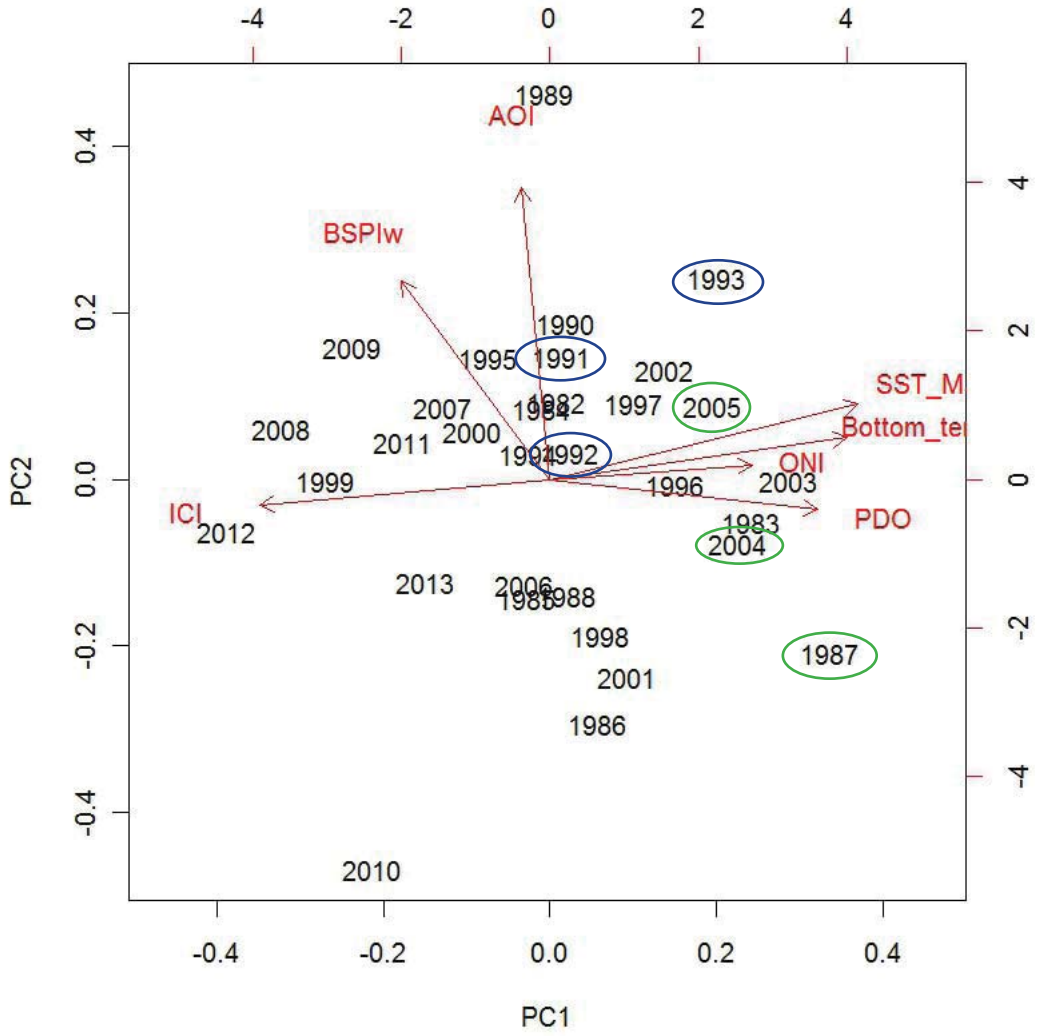


Figure 15. Biplot of the first two principal components of the Bering Sea principal component analysis. Years where abundance estimates of juvenile halibut appeared particularly high are circled in green and examples of years where estimates were particularly low are circled in blue.

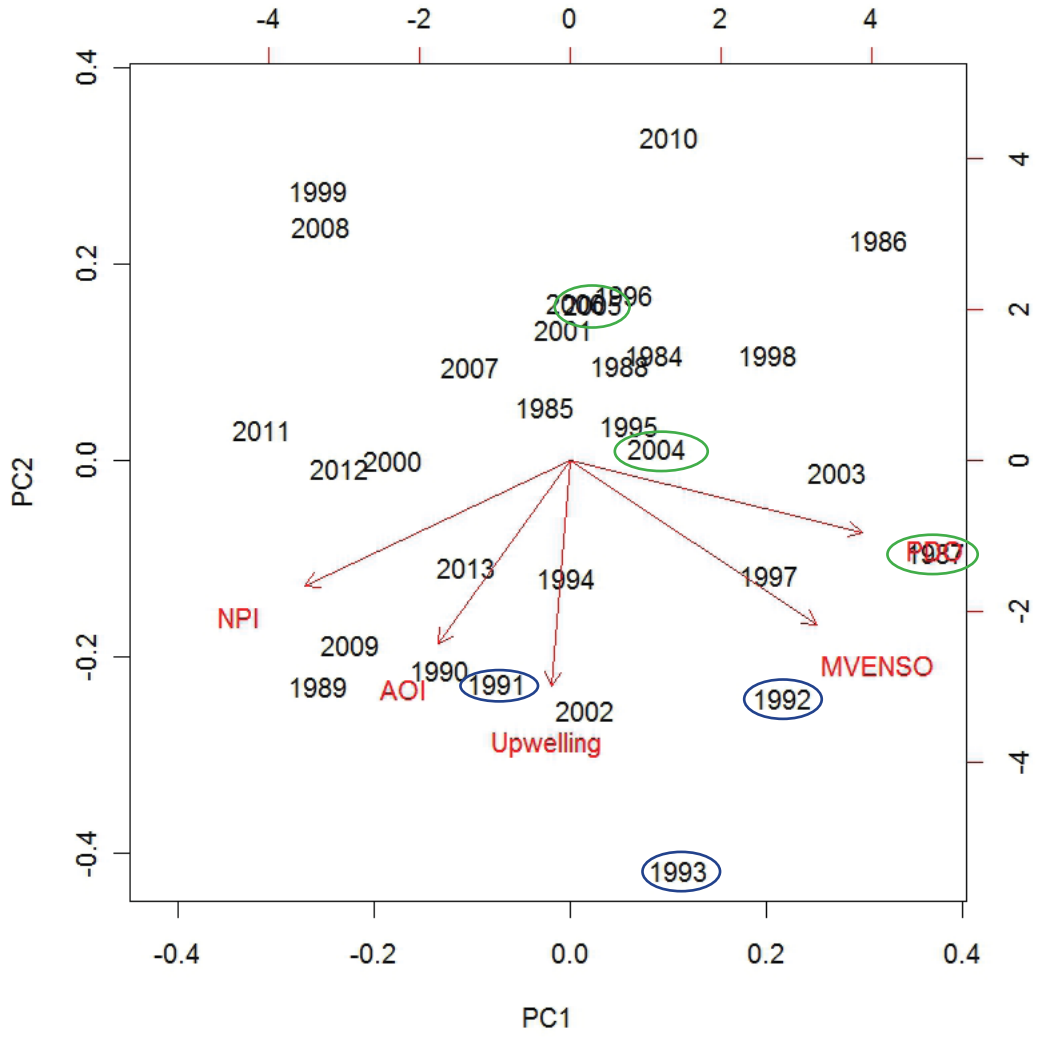


Figure 16. Biplot of the first two principal components of the GOA principal component analysis. Years where abundance estimates of juvenile halibut appeared particularly high (1987 in both the Bering Sea and GOA; 2004 and 2005 in the Bering Sea but inconclusive in the GOA) are circled in green and examples of years where estimates were particularly low are circled in blue.

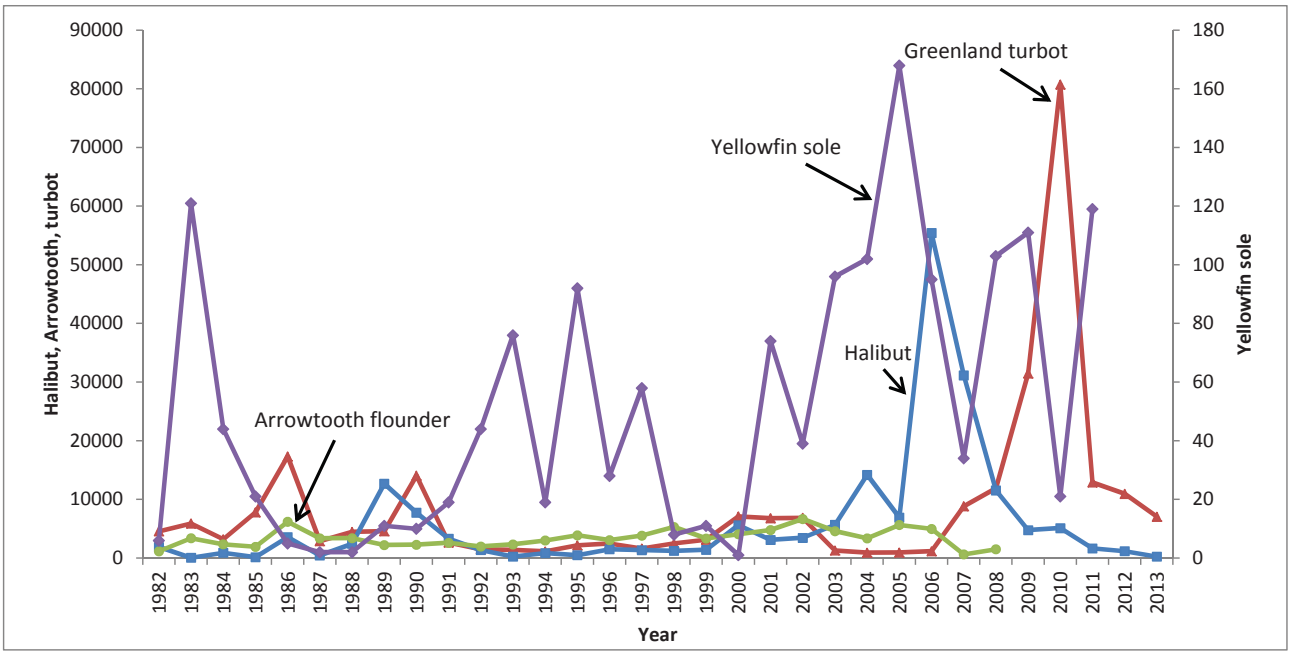


Figure 17. Abundance estimates over time of Pacific halibut and four other flatfish species in the Bering Sea. Note that abundance scales differ among species in order to allow for comparisons. Units are as follows: halibut in thousands of fish, arrowtooth flounder in thousands of fish, turbot in numbers, and yellowfin sole in millions of fish.

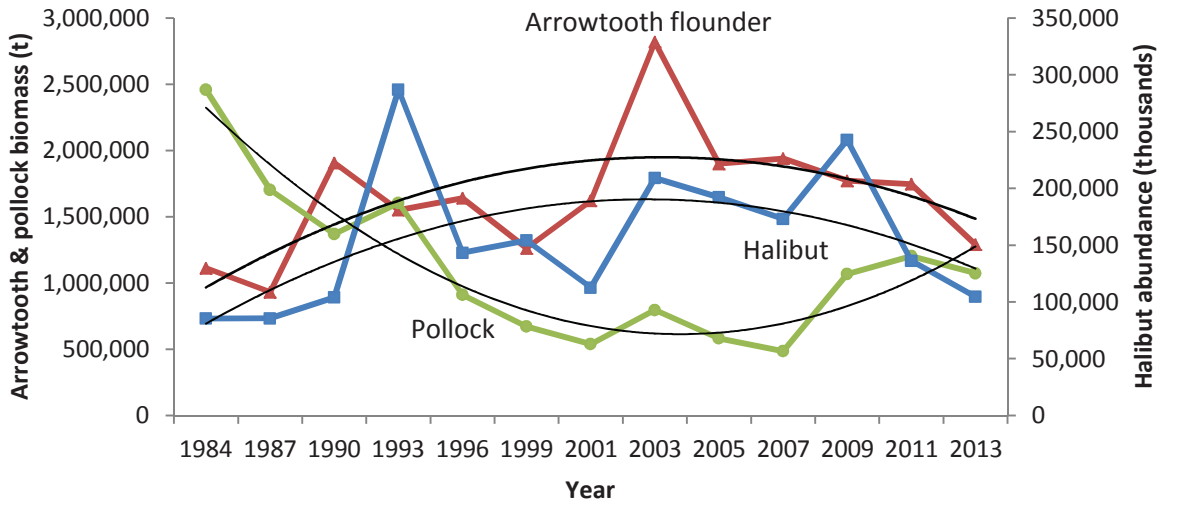
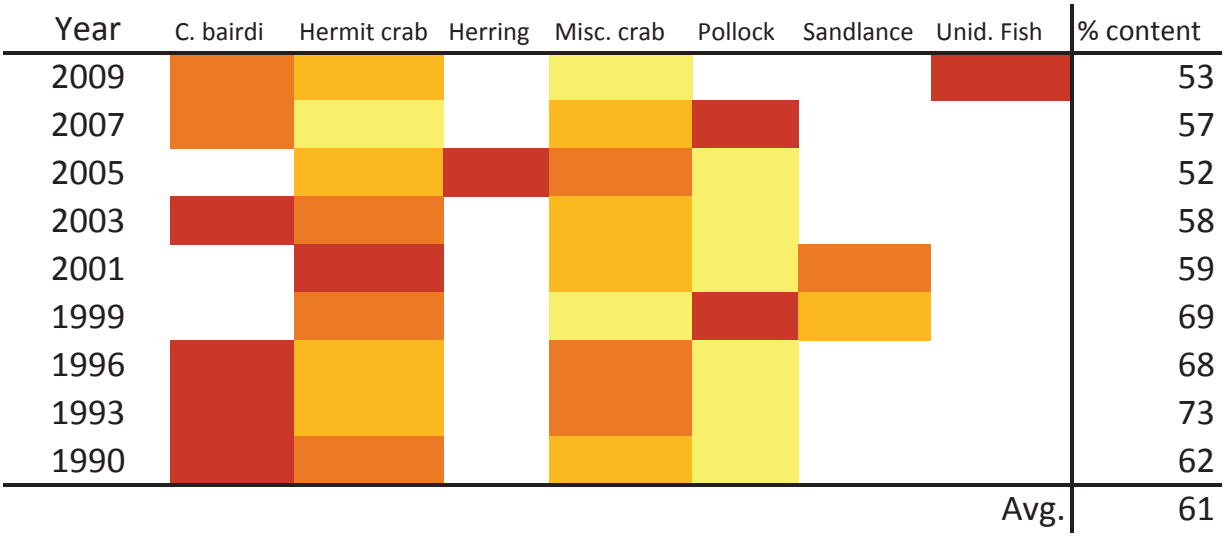


Figure 18. Abundance estimates of Pacific halibut and arrowtooth flounder over time in relation to pollock.



Definitions: C. bairdi = Chionoecetes bairdi; Pollock = Walleye pollock

Figure 19. Top four halibut prey items by year in the Gulf of Alaska as determined by stomach content analysis. Percentage of total is depicted from dark to light with the darkest being the most common. Note that these data reflect the results from all halibut sampled which included both juveniles and adults. Source: NOAA (2014b).

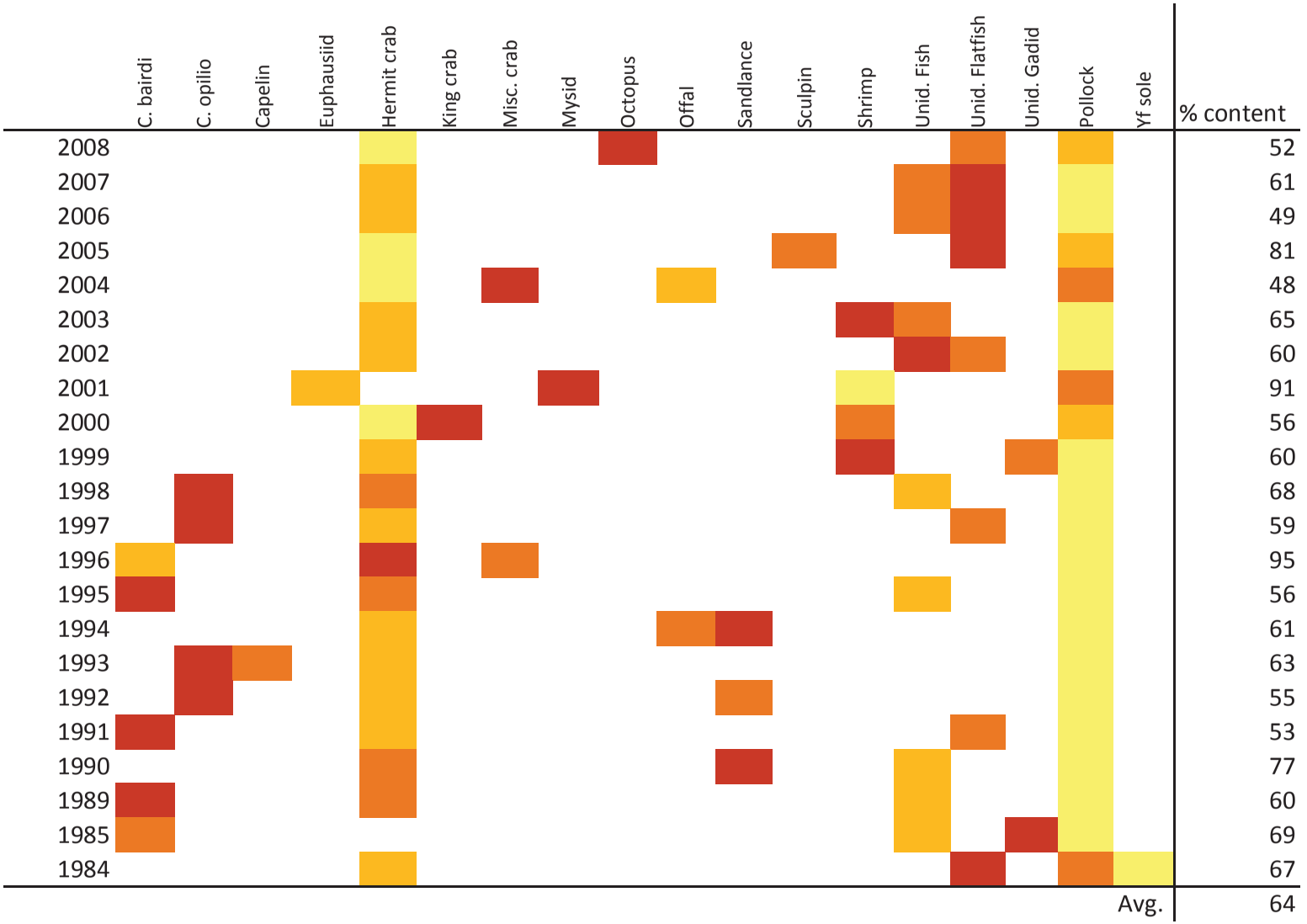


Figure 20. Top four halibut prey items by year in the Bering Sea as determined by stomach content analysis. Percentage of total is depicted from dark to light with the darkest being the most common. Note that these data reflect the results from all halibut sampled which included both juveniles and adults. Source: NOAA (2014b).

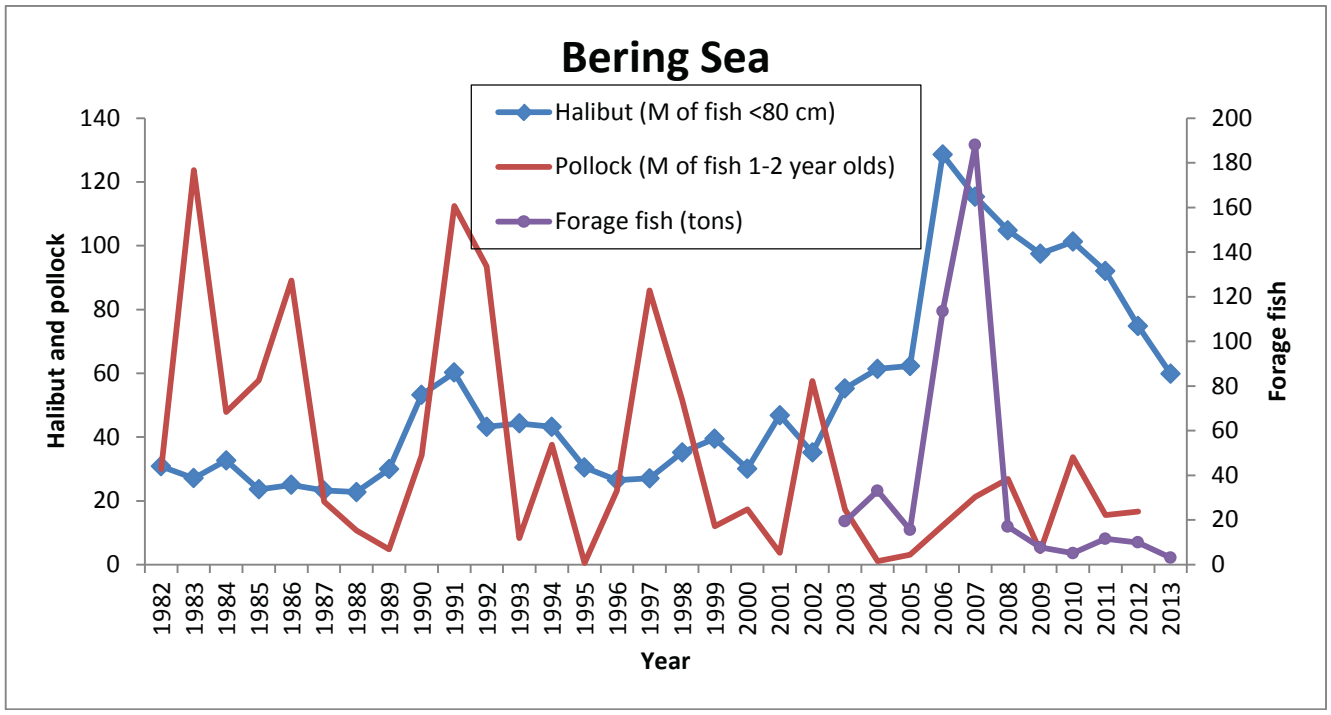


Figure 21. Abundance of juvenile Pacific halibut along with estimates for juvenile pollock and the forage fish complex in the Bering Sea.

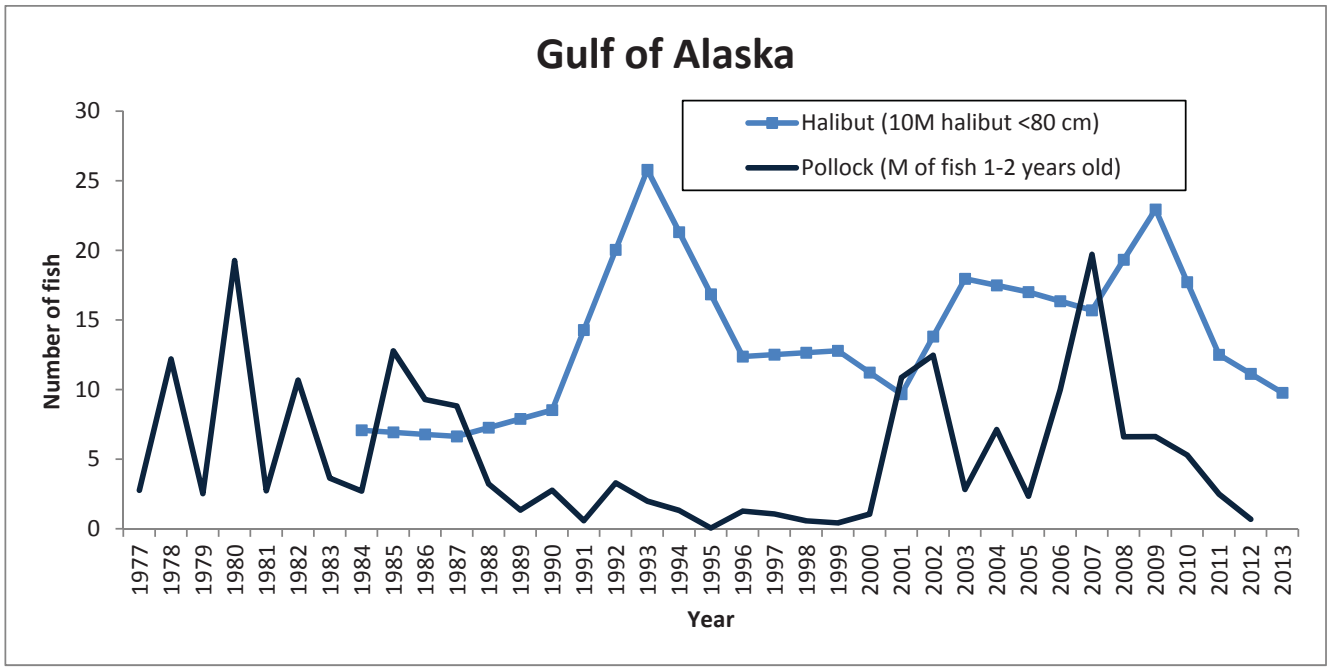


Figure 22. Abundance of juvenile halibut along with estimates for juvenile pollock in the Gulf of Alaska.

Re-ageing of archived otoliths from the 1920s to the 1990s

Joan E. Forsberg and Ian J. Stewart

Abstract

The International Pacific Halibut Commission has collected otoliths for age determination since 1925. After otoliths are aged, they are stored and archived. The Commission's otolith collection contains samples from over 1.6 million halibut. Age determination techniques used for halibut have changed over time; prior to 1992, all otoliths were surface aged. Beginning in 1992, otoliths that met certain criteria (high surface age, difficult pattern, etc.) were also aged by break-and-burn or break-and-bake method in addition to surface aging. The break-and-burn/bake method was determined to provide more accurate ages. Therefore beginning in 2002, all otoliths collected from setline surveys or the commercial catch were aged by break-and-bake. To provide information on the bias and imprecision of historical surface ages relative to age data from the 1990s onward, subsets of otoliths from each decade from the 1920s to the 1980s were re-aged by both the surface and break-and-bake technique and original surface ages were compared to the ages made in 2014. Additionally, otoliths collected in 1992 and 1993 that were to be used in another project were re-aged by break-and-bake, and a systematic subsample of otoliths from the 1998 survey, re-aged in 2013, were also included in this analysis. Results indicated that historical samples contained very few fish aged older than 15 years by either method. Based on simultaneous estimation of bias and imprecision for up to four unique ages per otolith, the properties of historical surface ageing methods were found to be very similar to current methods, becoming increasingly biased and imprecise beyond 15 years.

Introduction

The International Pacific Halibut Commission (IPHC) has collected otoliths for age determination since 1925. All otoliths that have been examined for age determination are kept in storage after they have been aged. The IPHC's otolith collection contains samples from over 1.6 million halibut, spanning a collection period of 89 years. Age determination techniques utilized by the IPHC have changed over time. Prior to 1992, halibut were aged using the surface method exclusively. With the surface method, the whole otolith is immersed in water against a dark background and winter growth zones are counted to give the age estimate in years. Beginning in 1992, otoliths that met certain criteria (high surface age, difficult pattern, etc.) were also aged by break-and-burn or break-and-bake method (Forsberg 2001). Since deposition on the various surfaces of the otolith changes as the fish grows older, some annuli are not visible from the surface. Viewing the otolith in cross-section allows viewing of such "hidden" annuli. Burning or baking increases the contrast between the summer and winter zones; the summer zones turn light brown while the winter zones, due to their higher concentration of protein, turn dark brown when heated (Forsberg 2001). Validation of the break-and-burn/bake method relative to actual age was performed via analysis of radiocarbon levels observed in known-age otoliths (Piner and Wischniowski 2004) and since 2002, all otoliths collected from setline surveys or the commercial catch have been aged by break-and-bake. A study in 1999 demonstrated no difference between ages determined from baked versus burned halibut otolith sections (Barto 2000) with baking having the advantage of

greater efficiency (multiple otoliths can be baked at a time) and reduced potential for damage to the otolith due to over-burning. Although the baked section is used to obtain the annulus count, viewing the otolith surface can still provide useful information on overall growth patterns and location of the first year. The anterior end of the otolith is preferred for surface reading; baking the posterior end allows the reader to also age the otolith surface (Fig. 1). Readers usually look at both halves of the otolith when making an age determination.

Otoliths have been cleared in glycerin solution (50% glycerin/50% water) to increase readability of the growth patterns since the 1920s. Otoliths are also stored in glycerin solution after reading. Prior to 2002, otoliths were kept in open trays with individual cells while they were being aged. After otoliths were aged, they were stored in vials that held around 25 otoliths, stacked one on top of the other, with numbered paper labels between to separate and identify individual otoliths. The vials were then filled with glycerin solution to completely cover the otoliths. After the transition to the break-and-bake method for all otoliths, stacking in vials was no longer a suitable storage method because the otolith halves could become separated. Baked and aged otoliths are now stored in plastic trays that have individual cells to keep otoliths separate and lids that fit over the trays. The cells of the plastic trays are filled with enough glycerin solution to cover the otoliths. Vials from the historical collection were topped up with glycerin solution periodically; most recently in the early 1980s and again in 2010. Until the late 1980s, glass vials with cork stoppers were used for otolith storage. The corks did not provide an airtight seal so water evaporated from the glycerin solution over time. Thymol (an antifungal agent) has been added to the glycerin solution used for clearing and storing otoliths at IPHC for many years, but it is not clear when it began to be added routinely. The oldest samples in the IPHC's archives (collected in 1925) have been in glycerin solution for almost 90 years.

Study goals

The main goal of the re-ageing project was to generate additional age data (new surface readings as well as break-and-bake readings) so that comparisons could be made between historical and modern surface ages as well as surface/break-and-bake age comparisons. Datasets from three different periods were generated: from 1998 and 1992/93 subsamples which were re-aged by break-and-bake; and subsamples from the 1920s through the 1980s ("decadal" samples) which were re-aged by both surface and break-and-bake methods. Historical estimates of the imprecision of 'break-and-bake' ageing showed that the method was very precise (Clark 2004a, b, Clark and Hare 2006). Previous analyses of the properties of surface ages were based on comparison of an extensive data set of duplicate surface and break-and-bake ages (each otolith read at least twice) that had been collected opportunistically (Clark 2004a, Clark and Hare 2006). Specifically, as readers found otoliths that were difficult to surface age, they had the option to break-and-bake them, thus the comparisons represented a nonrandom sample biased toward the most difficult ages to read. That work found a modest amount of bias for the surface ageing method for ages less than 13-15, but rapidly increasing bias and imprecision with further increases in age.

Observed size-at-age (SAA) of Pacific halibut has changed substantially over time and the reasons behind changes in halibut SAA are not well understood. Prior to this study, the potential contribution of changes in ageing methods to observed SAA was uncertain. Comparisons of new and historical surface ages would demonstrate whether a differing degree of bias is present in surface ages made in earlier decades relative to those made today due to factors such as changes in surface age assignment protocol over time or quality of microscopes used. For example, in an

unpublished IPHC document from the 1940s, the author noted that the practice in the 1930s was to count only "distinct" zones on otoliths that were difficult to interpret, which could potentially result in lower age estimates for some otoliths aged in earlier decades (Forsberg 2001).

Re-ageing otoliths from the archives also directly provided additional size-at age data from break-and-bake ages that is more precise and unbiased relative to historical surface ages. Additionally, retrieval of otoliths from long-term storage in glycerin and subsequent re-ageing facilitated observations on the condition of otoliths in the IPHC's archived collection.

Sample selection and ageing protocol

All samples used in this study were drawn from the setline survey collection rather than the commercial catch samples. Survey samples have additional associated data such as sex and maturity that commercial catch samples do not.

Additionally, all otoliths in the study were stored in vials so it was necessary to remove the otoliths from vials and transfer them to trays with individual cells. Staff paid careful attention to ensure that each otolith was associated with the correct label after removal from the vial. Each otolith label was examined during transfer to confirm that the otoliths were in order. For some samples, the writing on the labels was too faded to read. Also, otoliths occasionally were found to have become separated from their labels during storage in or removal from the vial; this was usually observed with adjacent otoliths. In cases where otoliths were separated from their labels or labels were illegible, they were matched to the correct sample numbers by comparing their ages to the ages in the database for those samples, and if necessary (i.e., if two mixed otoliths were the same age), by matching otolith size to fish size from the database. Removing otoliths from vials and transferring to trays is a slow, labor-intensive process; at the most, several hundred otoliths per day can be transferred. The datasets used for this analysis are described below.

"Decadal" samples (1920s-1980s)

The target subsample size was set at 500 otoliths per IPHC regulatory area from one year out of each decade from the 1920s through the 1980s. Re-ageing samples from the historical collections were restricted to surveys conducted between May and early September, comparable to current setline surveys. The composition of the halibut population differs with time of year due to spawning migration; halibut may inhabit grounds in one regulatory area during the summer and move to a different regulatory area to spawn in the winter. Summer surveys were not conducted every year nor in every regulatory area in all decades. Otoliths were collected in Area 2B in every decade from the 1920s onward and in Area 3A from the 1950s onward. Otoliths were collected in Area 3B in 1929 and from Area 4A in 1930, 1965, and 1976. In some of the years selected for re-ageing, multiple vessels fished in the targeted regulatory areas. Length frequencies for all samples combined from each target year and regulatory area were compared with length frequencies for individual vessels and trips. In order to reduce the amount of effort and time to extract the otoliths, a single vessel or trip was used to provide the subsample as long as the vessel/trip length frequency was not significantly different from that of all samples combined for that year and regulatory area. Depending on the number of otoliths collected by a selected vessel or trip, further subsampling was required to achieve the 500 per year/area target. Rather than transferring the otoliths a second time, the readers systematically skipped otoliths. For example, if a trip contained 1,500 otoliths, the reader would be instructed to age one of every three otoliths (Table 1). One exception to the

systematic subsampling was the set from the 1926 *F/V Scandia*. Not all otoliths from this trip had been aged originally, so a subset of 500 previously-aged otoliths was assembled and provided to the readers.

Samples from 1992-1993

Otoliths collected in 1992 and 1993 were already being removed from storage for another project, so subsets of 1,000 otoliths per regulatory area from these years that were previously only surface-aged were also re-aged by break-and-bake. Single vessels conducted the surveys in 1992 and 1993. All regulatory areas were surveyed over the two years except for Areas 2A and 2C. Otoliths that had already been aged by break-and-burn were not re-aged for this study. Subsampling by regulatory area to achieve the 1,000 otolith/area target was necessary for some areas and was accomplished by systematically skipping otoliths (Table 1).

Samples from 1998

A subset of the 1998 survey otoliths was re-aged by break-and-bake in 2013 (Stewart 2014). About 10% of these otoliths had already been aged by break-and-burn or break-and-bake in 1998. The subset of otoliths to be re-aged by break-and-bake was determined as follows: a target was set at 600 otoliths previously only surface aged per regulatory area. Since the collection totals were not equal among regulatory areas, different subsampling rates were set by area to achieve the 600 otolith/area target. Subsampling was accomplished by the readers systematically skipping otoliths. For Areas 3A, 3B, and 4A, every 3rd otolith was re-aged; for Area 2C, 3 of 5 were re-aged; for Area 4B, all were re-aged; and for Area 2B, 3 of every 4 were re-aged.

Some of the previously broken and burned/baked otoliths were re-aged in 2013. Readers did not bake the unburned half but looked at the previously burned/baked section. Readers discovered that the patterns for most of the otoliths burned/baked in 1998 had faded, so that age determinations made in 2013 on these otoliths were less reliable than those made in 1998. For this reason, otoliths previously broken and burned in the 1992-93 samples were not re-aged.

Ageing protocol

Age readers followed the standard IPHC protocol for otolith preparation, age determination, and edge type description described in Forsberg (2001). All readers participating in this study were experienced readers, with between 12 and 30 years of experience reading Pacific halibut otoliths. Readers made surface readings (recording age and edge type) from whole otoliths for decadal samples from the 1920s through the 1980s. Surface readings were not repeated for the 1992-1993 or 1998 samples because surface ageing protocol and microscope equipment have remained the same since the 1990s. For the break-and-bake reading, readers baked the posterior half of the otolith when possible. Otoliths were baked at 500°F for 20-25 minutes in a toaster oven. Break-and-bake age and edge type were recorded. Readers had access to their previously recorded surface age when they made their break-and-bake age assignment. They also looked at the surface of the unbaked half at the same time they looked at the baked otolith section.

Analysis

The combined dataset from the samples available included otoliths read by various combinations of the two ageing methods (Fig. 2). In some cases only the original surface age and new surface age were available for comparison, but in others, one or more break-and-bake ages were also

available for individual otoliths. These data require a relatively complex analysis, because each method (and possibly time-period) may differ in the degree of bias and imprecision. Simultaneous estimation of parameters defining both relationships for each method is required in order to account for the probability that even ages that are identical may be inaccurate. A widely available software program was used for this purpose. The program has been simulation tested (Punt et al. 2008) and applied as part of many Pacific coast groundfish stock assessments. Briefly, the program estimates a latent age structure in the sample, and estimates the degree of bias and imprecision (requiring the assumption that at least one method is unbiased) for each ageing method via the joint probability of possible combinations of individual age reads. There are several functional forms for bias and imprecision available in the software ranging from a simple linear relationship to a Hollings-type curvilinear form that can increase or decrease with age. Equations for these curves are given in Punt et al. (2008).

For this analysis, a series of models were fitted to the available data, each assuming that the break-and-bake method was unbiased, but with unknown and estimated imprecision. Due to memory constraints, the full design of nine separate methods (each of the decadal periods), with unique bias and imprecision was unable to be analyzed. Separate relationships for both bias and imprecision of the surface ageing method for each of the decadal periods were therefore estimated in a stepwise manner, both forward and backward, then in blocks of two decades, then for the entire historical period vs. recent surface ages (1990s).

Results

Decadal samples (1920s-1980s)

Over 17,000 otoliths from 18 different year/regulatory area combinations spanning seven decades were retrieved from vials. Of these, 8,036 were re-aged by both surface and break-and-bake methods; in 31 cases, an otolith that was re-aged by surface was not aged by break-and-bake because the otolith had broken into too many pieces, was crystallized in the region where the break-and-bake reading would be made, or had a surface age less than five years. IPHC readers still use the surface method for otoliths from halibut four years old or younger; the growth patterns appear less distinct in a baked or burnt section than they do on the otolith surface for very young halibut. Because of their small size, it can also be challenging to break otoliths from young fish in the correct spot. Additionally, studies conducted in 1995 and 1999 did not indicate a difference between surface and break-and-burn ages for surface ages of seven years or younger (Forsberg et al. 2002). Subsampling rates for ageing and number aged by year and regulatory area are reported in Table 1.

Samples from 1992-1993

Over 9,600 otoliths from the 1992 and 1993 survey collection were retrieved from vials. A total of 5,932 otoliths were re-aged by break-and-bake in 2014. An additional 1,340 otoliths collected in Area 4B in 1992 had been aged by break-and-burn at that time for a surface/burn age comparison (Blood 2003). The break-and-burn ages for Area 4B that were assigned in 1992 were used in this analysis (Table 1).

Samples from 1998

Around 8,800 otoliths from the 1998 survey collection were transferred from vials. Of those, 3,450 were re-aged by break-and-bake in 2013 (Table 2, Stewart 2014).

Quality control results

Replicate break-and-bake readings were made by two different readers on 1,646 otoliths from the decadal and 1992/1993 re-ageing samples as part of IPHC's standard quality control procedure. Agreement within one year was 87.1%, with coefficient of variation (CV) of 3.9 and average percent error (APE) of 2.8 which is within the acceptable statistical range for halibut ages (Forsberg 2001).

Replicate break-and-bake readings were also made in 2013 on 10% of the re-aged otoliths from 1998 (376 otoliths). Agreement within one year for the 1998 sample was much higher than usual for survey otoliths; 97% with CV of 1.6 and APE of 1.1.

Age comparisons among techniques

Comparison of the age frequency distributions for the original surface ages vs. break-and-bake ages revealed that the bias expected in surface ages from recent comparisons was also present in the historical samples, although at varying degrees. A slightly greater proportion of ages beyond age 12-15 was observed for the break-and-bake method for each of the decadal periods (Figs. 3-10) with the exception of the 1950s, where the original surface ages assigned more fish to ages 14-16 (Fig. 6b).

Estimated imprecision parameters for the break-and-bake method corroborated earlier results but indicated a slightly broader level of imprecision than the previous (2004) relationship (Table 3, Fig. 11) especially beyond age 20; however, this may be just an artifact of the small sample size for halibut older than 20 in the historical samples. There were no clear patterns of increasing or decreasing surface ageing bias or imprecision across the individual decadal samples. When pooled into groups, all periods showed a relatively consistent and small degree of bias increasing from around age 10, such that it was 2-3 years by age 20 (Fig. 12). The sample from the 1950s was slightly positively biased, which could represent a difference in how the edge was assigned relative to the time of year of the sample. Despite small differences among periods, when all historical surface ages were pooled and compared with recent surface ages, a very similar degree of bias and imprecision was estimated for both (Table 3, Fig. 13).

Discussion

In aggregate, the results from analysis of the decadal and early 1990s re-aged samples corroborate those obtained from the 2013 re-ageing of a large random sample of the 1998 survey otoliths: 1) break-and-bake ages are quite precise relative to surface ages (and those for other groundfish species), and 2) the sample analyzed by Clark (2004a) overestimated the degree of bias in the surface ages, likely because the break-and-bake ages in that sample represented the older and more difficult otoliths in a given year's sample, rather than a random subsample. For use in the stock assessment, the small differences in bias and imprecision among time-periods are negligible, because they do not show a clear increasing or decreasing trend. The similarities between current and historical surface ages suggest that both sources of information can be treated as representative of the historical age-structure of the stock, given the increasing bias from around age 15 and the much greater degree of imprecision relative to break-and-bake ages.

This study reconciles two important questions for assessment and related analyses attempting to reconstruct the historical abundance and biological trends for Pacific halibut. These results support the conclusion that increasing trends in size-at-age observed from the 1930s through

the late 1970s were not an artifact of changes in ageing methods, but represent a real biological phenomenon, for which probable mechanisms are currently being investigated. Second, there does not appear to be a need for extensive further re-ageing of historical samples. The truncated age structure of most historical samples suggests that little information will be lost if ages are aggregated beyond age 20 (as has been done in most analyses) and both the bias and imprecision of the surface method are included in any analysis.

In addition to clarifying precision of ageing methods, the re-ageing of archived otoliths also provided an excellent opportunity to observe the condition of otoliths stored in glycerin solution for up to 88 years. Most of the otoliths examined were in good condition. Some of the otoliths from the 1920s and 1930s had a chalky coating that obscured surface growth patterns but most were still readable when broken and baked. The chalky coating may be partially dissolved otolith material, mold growth, or a combination of both. In one vial from the 1926 *F/V Scandia*, the otoliths appeared to have decalcified and consolidated into small, round lumps. There was also mold growth in the vial. When retrieved for a study in the early 2000s, otoliths from halibut aged at 0 to 2 years that had been stored in glycerin solution for up to 40 years were found to be decalcified. To stop further sample deterioration, the IPHC's small fish otolith collection was consequently transitioned from storage in glycerin solution to dry storage. Although otoliths from juvenile halibut showed evidence of damage from long term storage in glycerin solution, the condition of otoliths from larger halibut stored in glycerin for similar periods of time did not appear to be degraded, so the otoliths from setline-caught halibut in the IPHC's collection were left in glycerin solution. Clearing in glycerin solution is necessary for surface ageing and since readers still rely on the surface to assist with interpretation of baked patterns, storage in glycerin solution is necessary at least until otoliths have been aged. Baked sections of cleared otoliths also have better contrast between growth zones than baked sections made from dry otoliths.

The results of quality control break-and-bake readings on the decadal and 1992/1993 otolith samples were similar to those of recent years for the setline survey. Results might have been expected to show lower agreement and higher CV due to poor quality of some otoliths and the potential for undetected mixing of otoliths. (Otoliths could have been put in the vials out of order as well as getting mixed during retrieval from vials). The between-reader agreement of quality control break-and-bake readings from the 1998 sample was higher than usual; however the replicate readings were made only for otoliths broken and baked in 2013, which were otoliths that were relatively easy to read; the older and more difficult otoliths having already been broken and burned or baked in 1998. When replicate break-and-burn/bake ages assigned in 1998 are included, the percent agreement drops to 85.3% with CV of 3.2 and APE of 2.2 for this group.

References

Barto, T. J. 2000. Comparison of break-and-burn and break-and-bake aging techniques on halibut otoliths. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1999: 281-290.

Blood, C. L. 2003. I. Age validation of Pacific Halibut. II. Comparison of surface and break-and-burn otolith methods of ageing Pacific halibut. Int. Pac. Halibut Comm. Tech. Rep. 47.

Clark, W. G. 2004a. Statistical distribution of IPHC age readings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: 99-110.

Clark, W. G. 2004b. Nonparametric estimates of age misclassification from paired readings. Can. J. Fish. Aquat. Sci. 61:1881-1889.

Clark, W. G. and Hare, S. R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. 83.

Forsberg, J. E. 2001. Aging manual for Pacific halibut: procedures and methods used at the International Pacific Halibut Commission. Int. Pac. Halibut Comm. Tech. Rep. 46.

Forsberg, J. E., Chen, D., and Kong, T. M. 2002. Variance comparison for surface and break-and-burn ages. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001: 263-270.

Piner, K. R. and Wischniowski, S.G. 2004. Pacific halibut chronology of bomb radiocarbon in otoliths from 1944 to 1981 and a validation of ageing methods. J. Fish. Bio. 64:1060-1071.

Punt, A. E., Smith, D. C., Krusic-Golub, K., and Robertson, S. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Can. J. Fish. Aquat. Sci. 65:1991-2005.

Stewart, I. J. 2014. Overview of data sources for the Pacific halibut stock assessment and related analyses. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 95-168.

Table 1. Number of otoliths retrieved from vials and re-aged from samples collected in the 1920s through the early 1990s.

Year	Reg. Area	Vessel	Trip	Number retrieved	Number aged	Subsampling rate
1926	2B	Scandia	1-3	3,771	567	1 of 7
1929	3B	Dorothy	7	514	489	all
1930	4A	Dorothy	2	518	454	all
1936	2B	Hoover	1	1,032	471	1 of 2
1947	2B	Santa Maria	1-2	1,820	562	1 of 3
1951	2B	Eclipse	4-6	2,337	863	1 of 2
1951	3A	Eclipse	1	512	457	all
1964	3A	Eclipse	4	847	558	2 of 3
1965	2B	Christian S	1-4	1,724	527	1 of 2
1965	4A	Chelsea	2-3	542	510	all
1976	2B	Seymour	1-2	198	181	all
1976	4A	Polaris	1	703	555	4 of 5
1977	2B	Chelsea	1	146	135	all
1977	2B	Evening Star	1	66	64	all
1977	3A	Polaris	1	392	305	4 of 5
1977	3A	Resolute	1	418	311	4 of 5
1985	2B	Star Wars II	1-2	891	562	2 of 3
1985	3A	Chelsea	1-2	1,074	499	1 of 2
1992	3A	Kaare	6-7	1,165	1,139	all
1992	3B	Kaare	6	913	893	all
1992	4A	Kaare	1	1,516	1,003	2 of 3
1992	4B	Kaare	4-5	2,099	*1,340	*n/a
1992	4C	Kaare	3	908	846	all
1992	4D	Kaare	2-3	1,109	1,093	all
1993	2B	Kristiana	1-4	1,913	958	1 of 2

*break-and-burn ages made in 1992

Table 2. Ageing totals for samples from 1998. The first two columns display numbers of ages made in 1998; the third column shows numbers of break-and-bake ages made in 2013, and the last column lists numbers of 2013 and 1998 break-and-bake/burn (BB) ages combined that were used in the analysis.

Reg Area	Total surface aged	Baked or burned in 1998	Baked in 2013	Total BB
2B	1,058	90	654	744
2C	1,155	132	607	739
3A	1,923	208	537	745
3B	2,012	211	591	802
4A	2,081	181	630	811
4B	521	90	431	521
Total	**8,750**	**912**	**3,450**	**4,362**

Table 3. Estimated bias and imprecision for the break-and-bake method, recent surface and historical surface ageing.

	Break-and-bake		Recent surface		Historical surface	
Predicted Age	Average observed age	Standard deviation of observed age	Average observed age	Standard deviation of observed age	Average observed age	Standard deviation of observed age
1	1	0.06	0.40	0.12	0.51	0.06
2	2	0.12	1.55	0.19	1.72	0.12
3	3	0.18	2.68	0.26	2.89	0.19
4	4	0.24	3.78	0.33	4.03	0.26
5	5	0.30	4.85	0.41	5.13	0.33
6	6	0.36	5.90	0.49	6.21	0.41
7	7	0.41	6.92	0.57	7.25	0.49
8	8	0.47	7.92	0.65	8.27	0.57
9	9	0.53	8.90	0.74	9.25	0.65
10	10	0.59	9.86	0.84	10.21	0.74
11	11	0.65	10.79	0.93	11.14	0.84
12	12	0.71	11.70	1.04	12.05	0.93
13	13	0.77	12.59	1.14	12.92	1.04
14	14	0.83	13.46	1.25	13.78	1.14
15	15	0.89	14.32	1.37	14.61	1.25
16	16	0.95	15.15	1.49	15.41	1.37
17	17	1.01	15.96	1.61	16.19	1.49
18	18	1.07	16.76	1.74	16.95	1.61
19	19	1.13	17.53	1.88	17.69	1.74
20	20	1.18	18.29	2.02	18.41	1.88
21	21	1.24	19.03	2.17	19.11	2.02
22	22	1.30	19.76	2.32	19.79	2.17
23	23	1.36	20.46	2.48	20.44	2.32
24	24	1.42	21.15	2.65	21.08	2.48
25	25	1.48	21.83	2.83	21.70	2.65

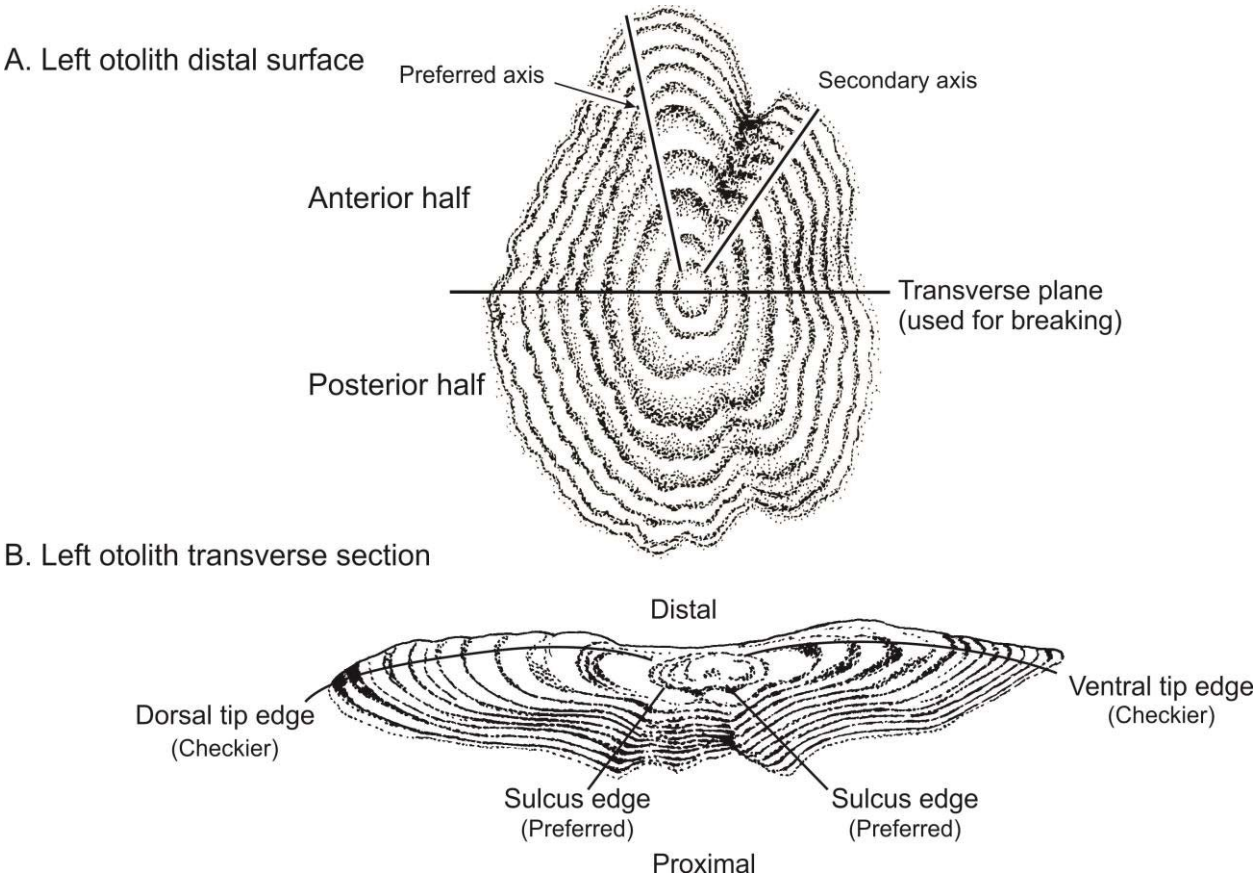


Figure 1. Drawing of halibut otolith showing preferred reading axes for surface ageing on anterior end of surface (A) and on baked section (B).

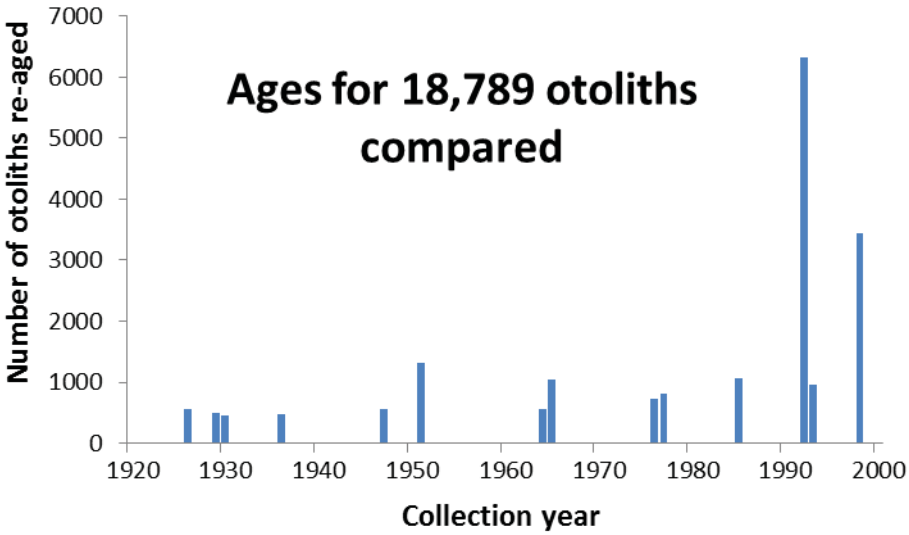


Figure 2. Number of historical otoliths included in the re-ageing analysis.

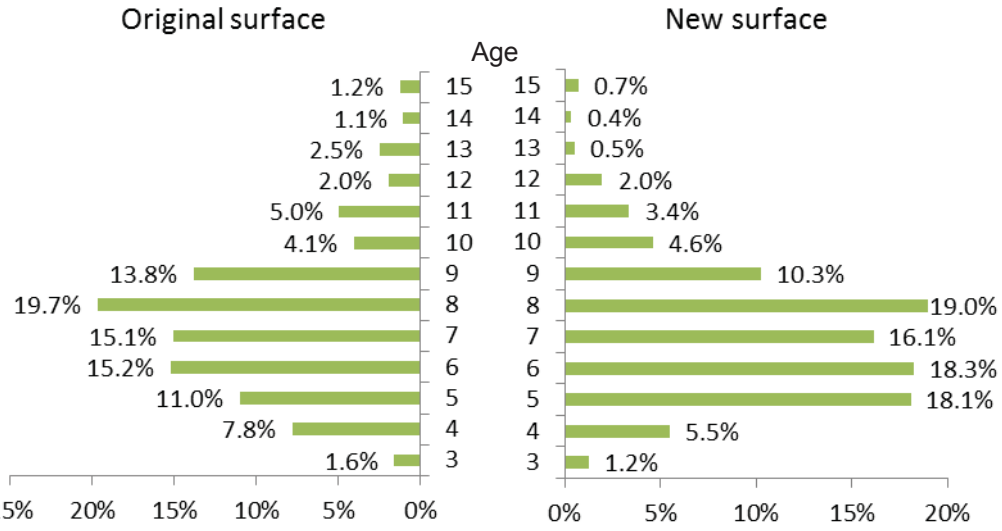


Figure 3a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1926 (n=564).

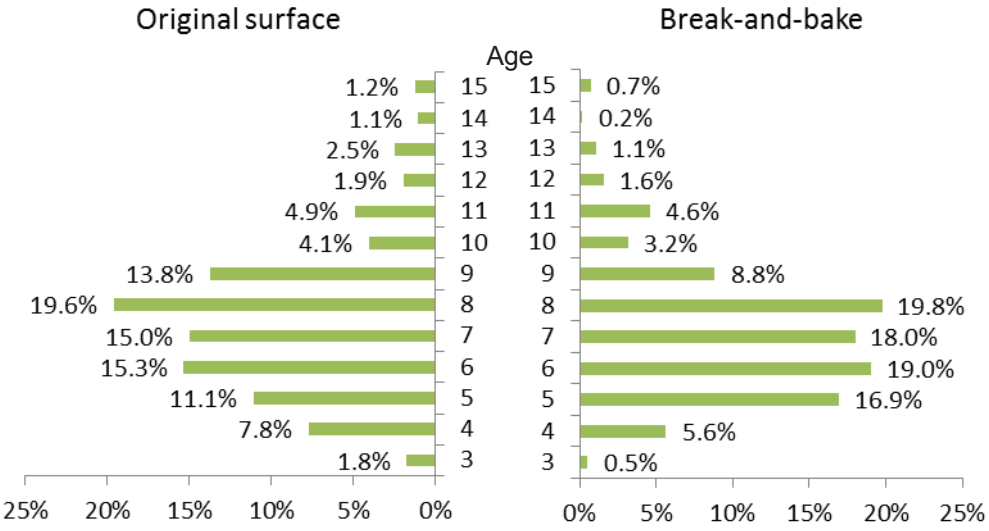


Figure 3b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1926 (n=567).

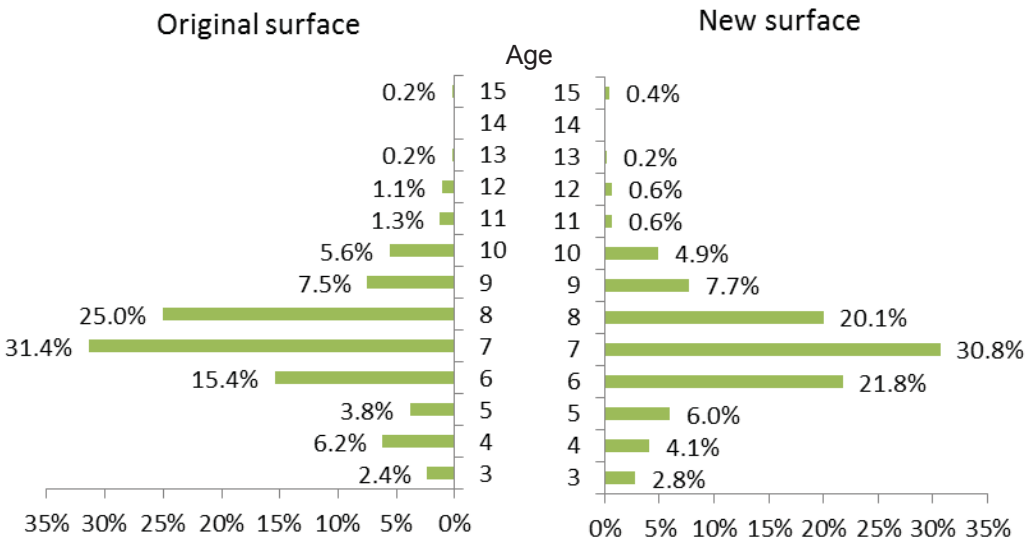


Figure 4a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1936 (n=468).

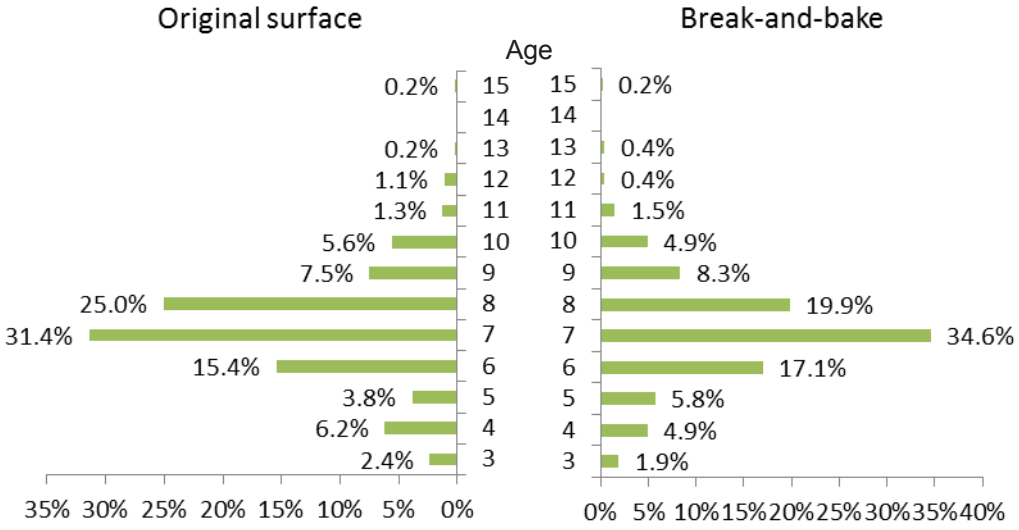


Figure 4b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1936 (n=468).

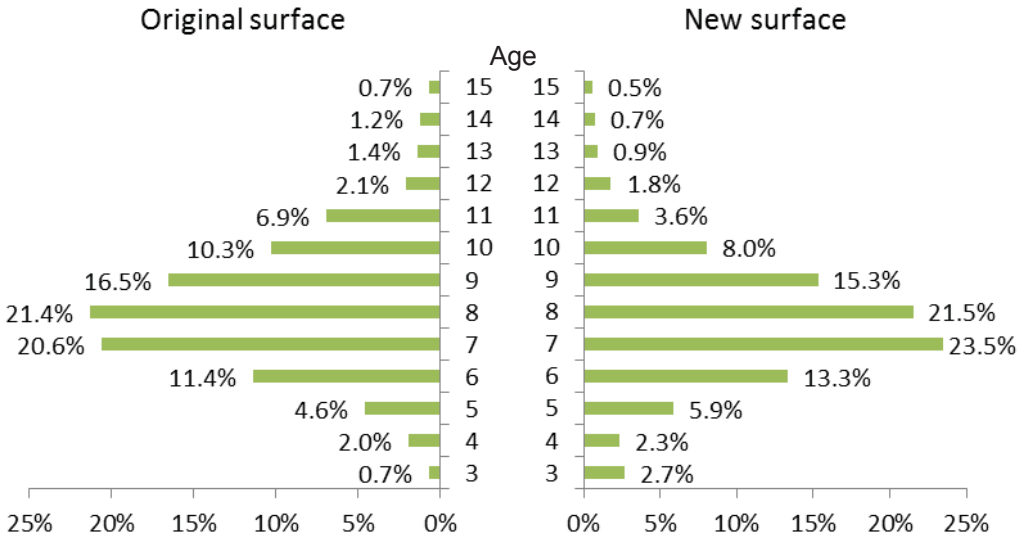


Figure 5a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1947 (n=562).

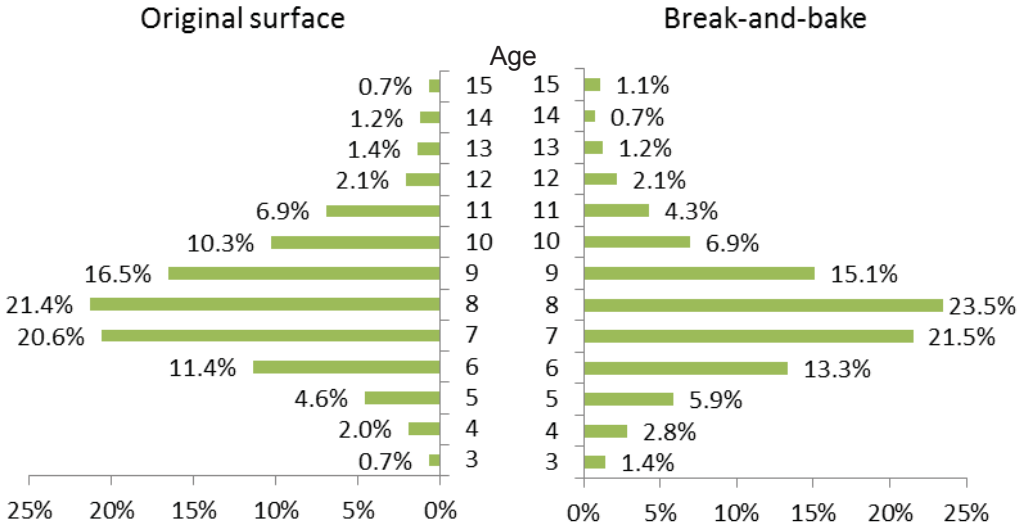


Figure 5b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1947 (n=562).

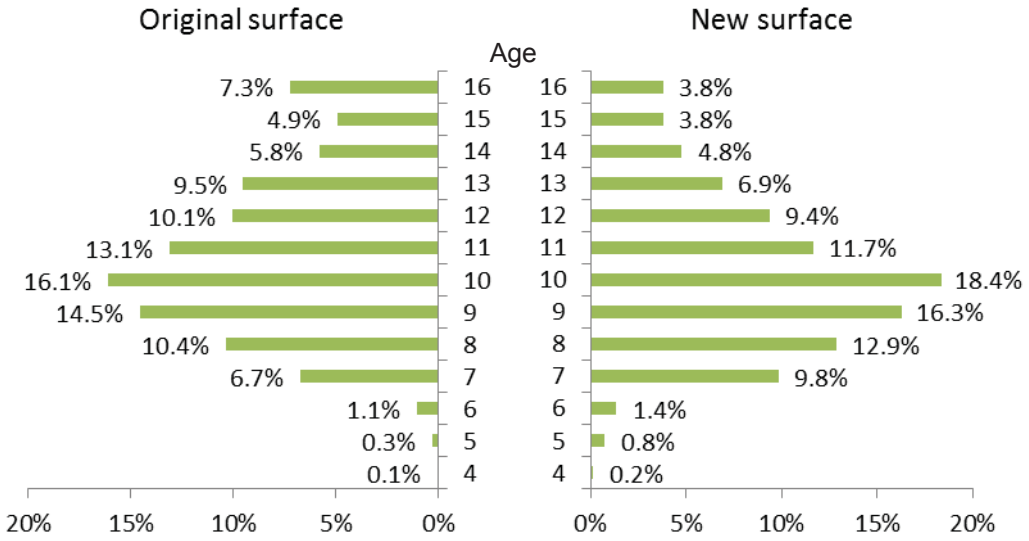


Figure 6a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1951 (n=1,320).

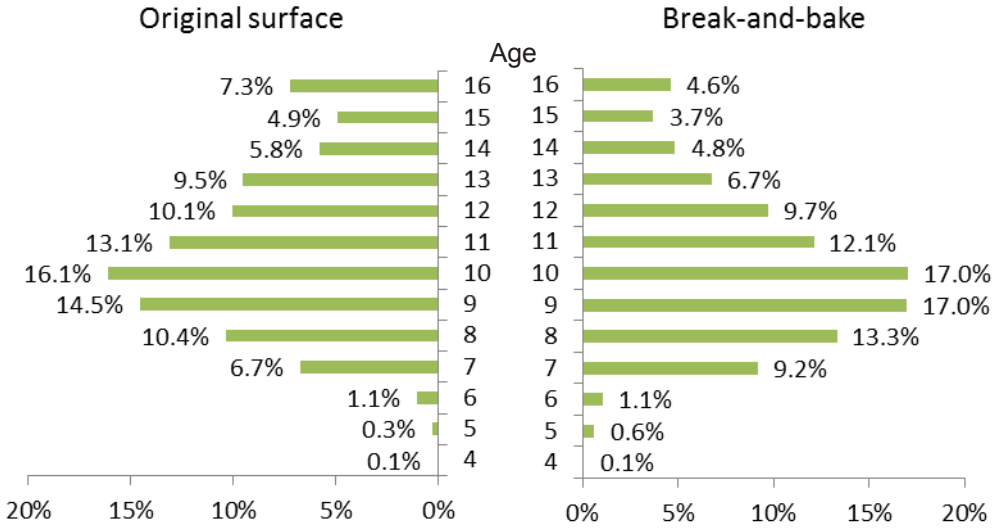


Figure 6b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1951 (n=1,320).

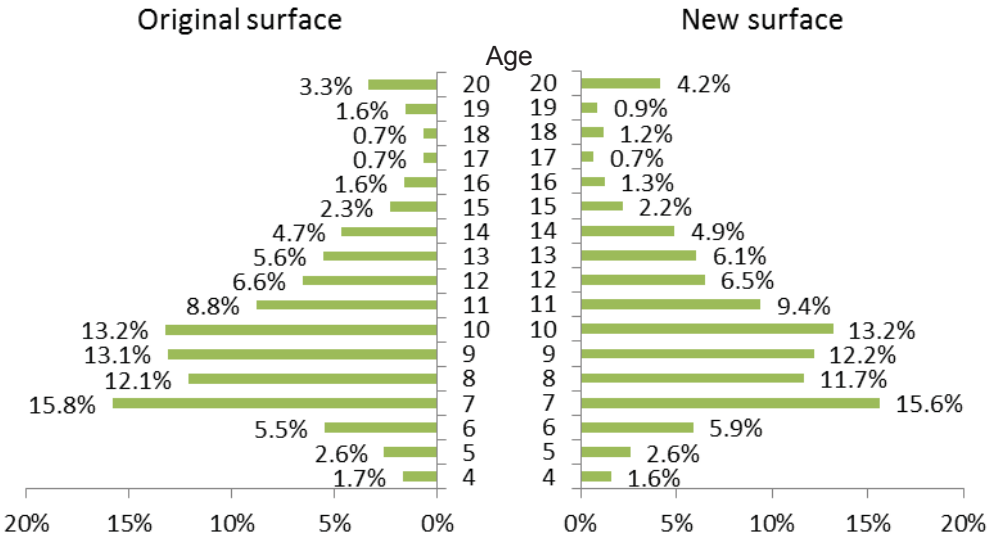


Figure 7a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1964-1965 (n=1,585).

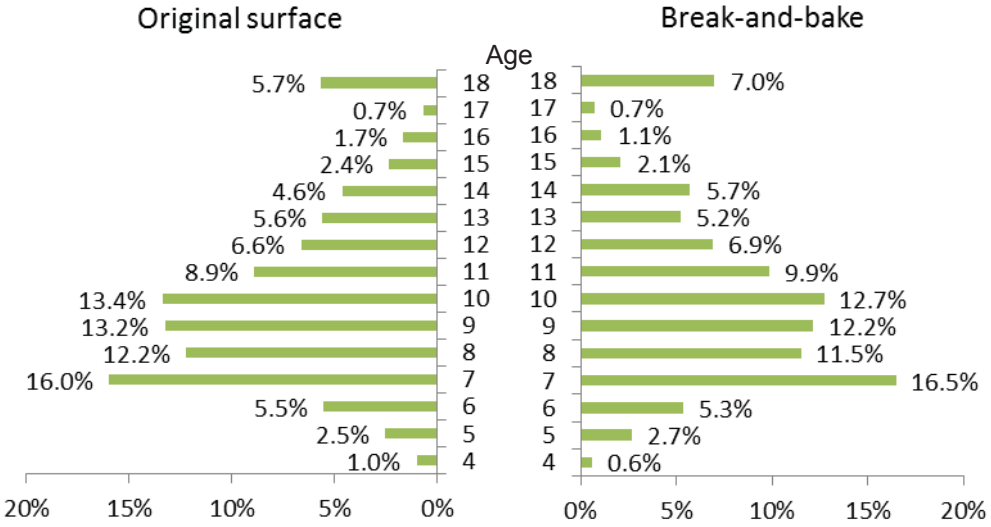


Figure 7b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1964-1965 (n=1,572).

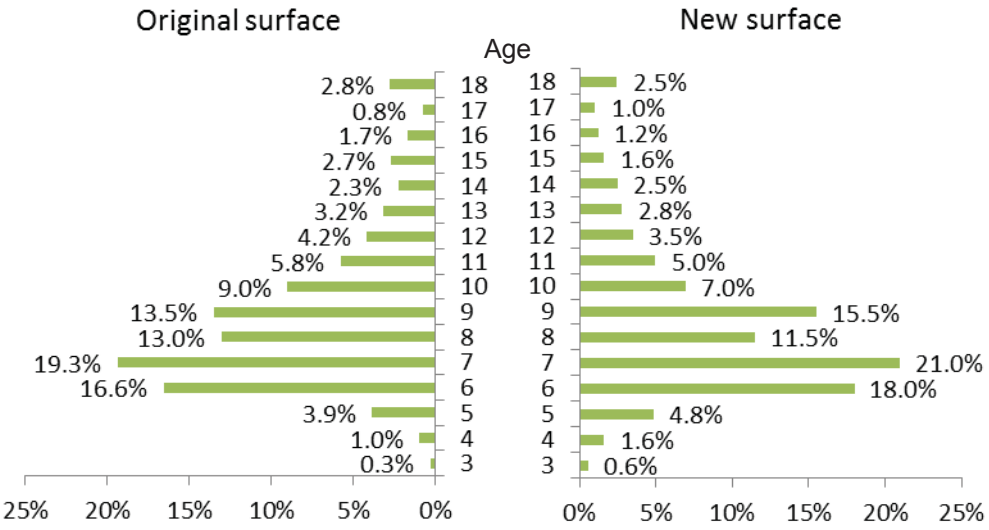


Figure 8a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1976-77 (n=1,551).

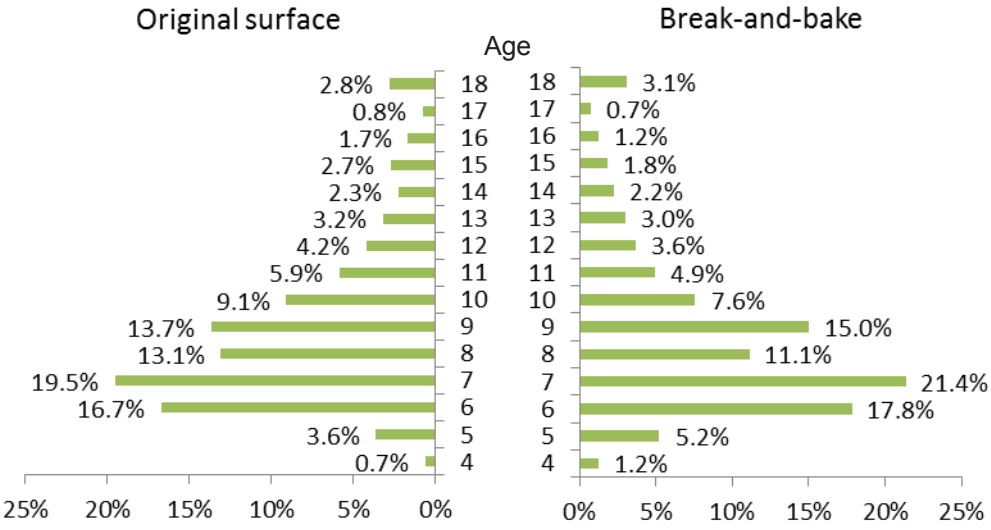


Figure 8b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1976-77 (n=1,536).

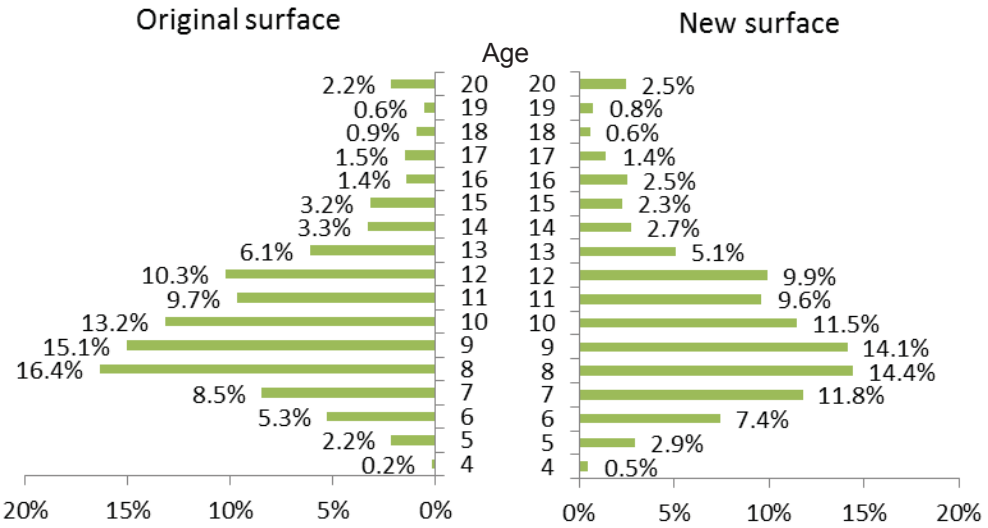


Figure 9a. Comparison of age frequency distributions for original and new surface readings for otoliths from 1985 (n=1,061).

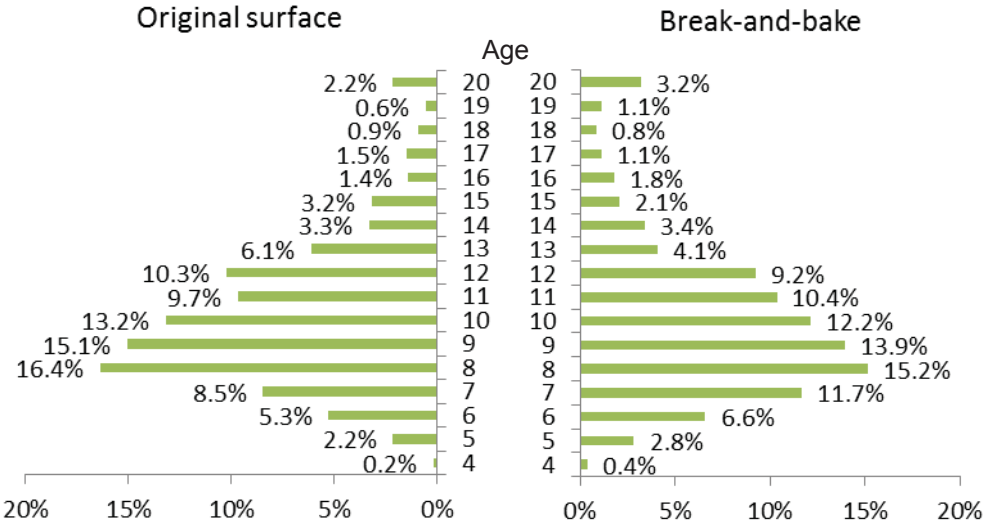


Figure 9b. Comparison of age frequency distributions for original surface ages and new break-and-bake ages for otoliths from 1985 (n=1,061).

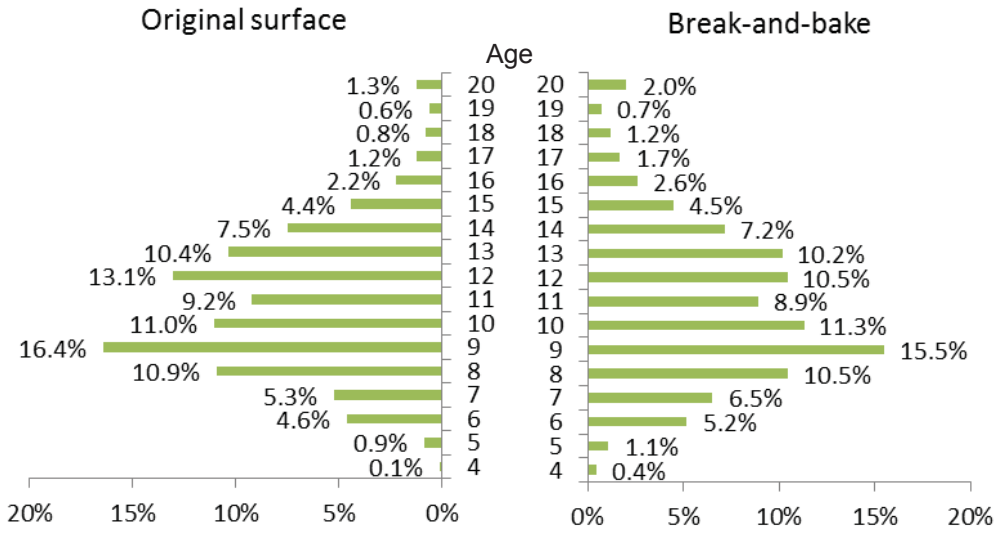


Figure 10. Comparison of age frequency distributions for original surface and new break and bake readings of otoliths from 1992-93 (n=7,272).

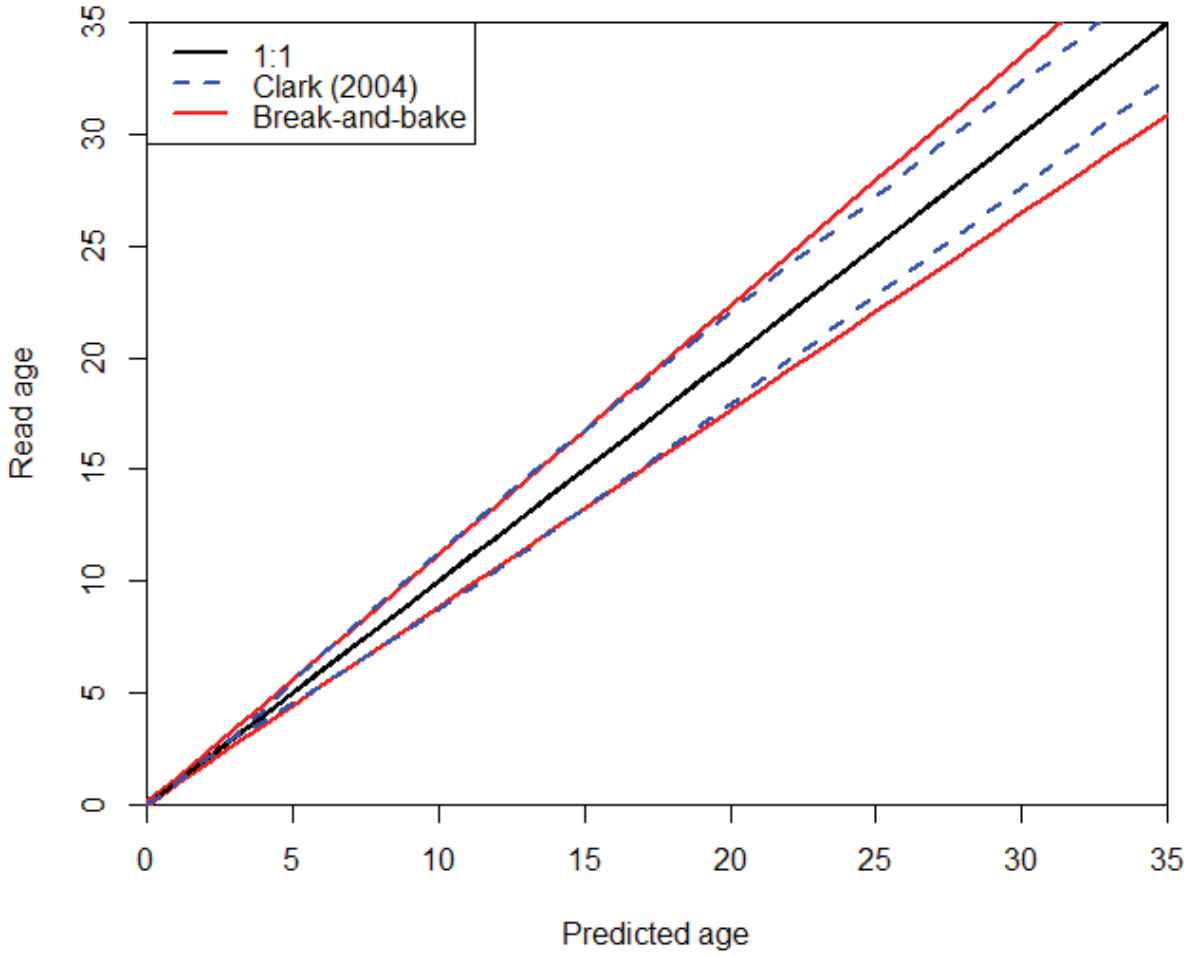


Figure 11. Comparison of imprecision (95% confidence intervals) in the break-and-bake ageing method estimated by Clark (2004; dashed lines) and re-estimated simultaeously.

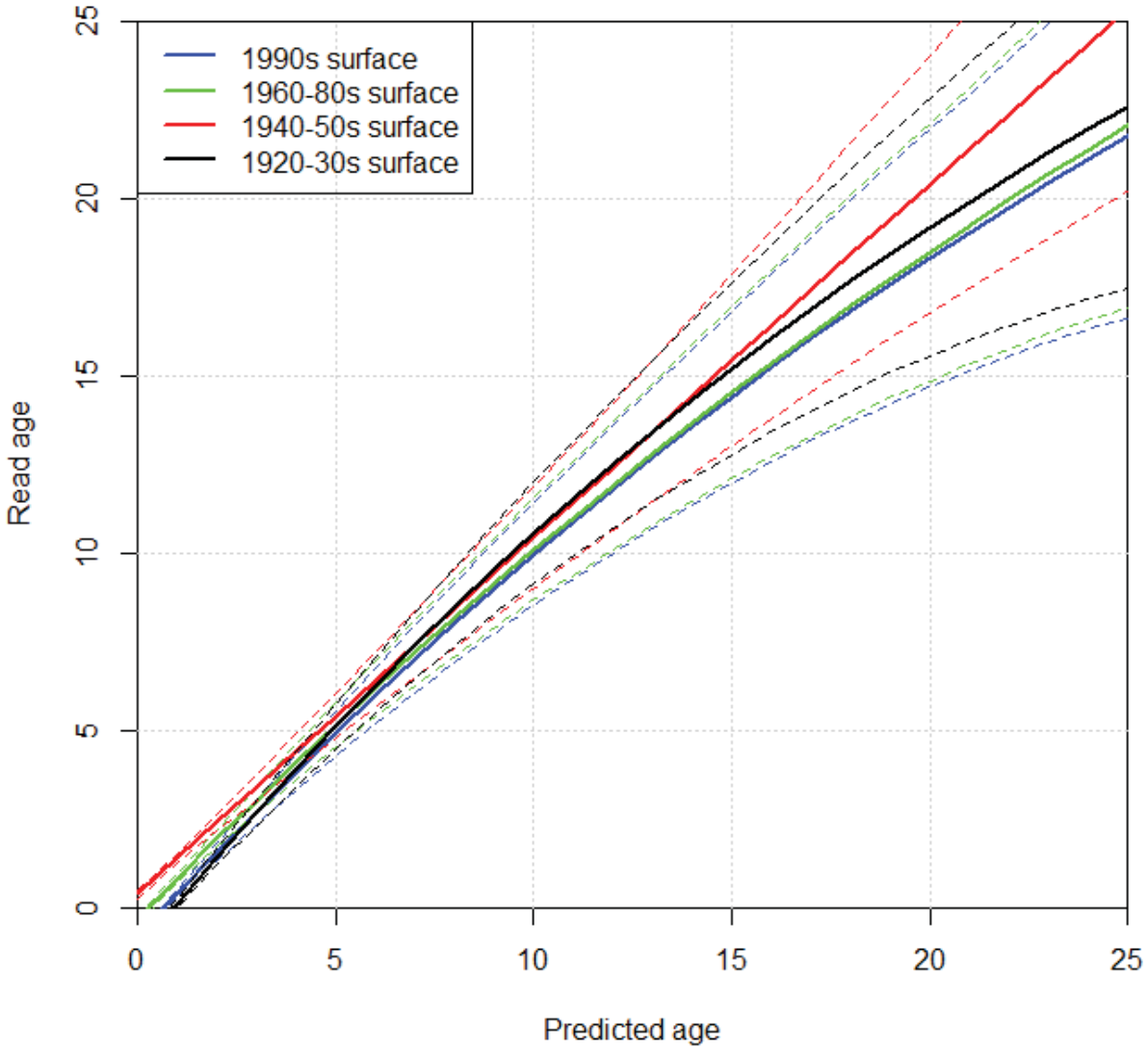


Figure 12. Comparison of bias (solid lines) and imprecision (dashed lines) estimates for surface ages read during the 1990s, 1960s-1980s, 1940s-1950s and 1920s-1930s.

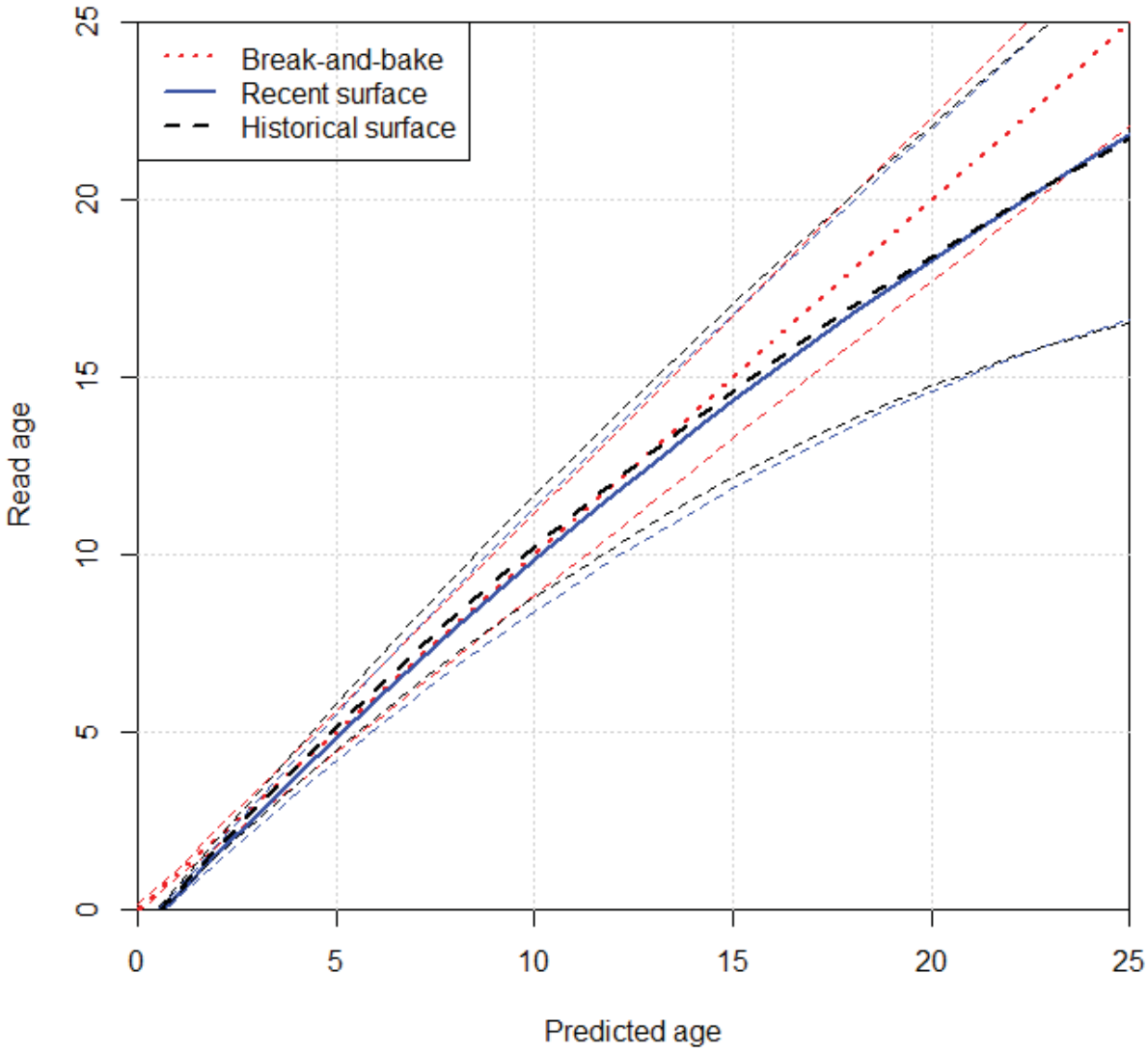


Figure 13. Comparison of bias and imprecision for break-and-bake, recent (1998+) and pooled historical (1926-1993) surface ages.

Clean otolith archive collection

Robert S. Tobin and Joan E. Forsberg

Abstract

Recent trends in otolith research include analysis of trace element constituents of the otolith. Samples used in these types of analyses need to be free of contaminants, such as glycerin. The International Pacific Halibut Commission's otolith archive has primarily been comprised of otoliths collected for age determination, which have been stored in a glycerin/thymol solution to increase readability. A new collection of otoliths was started in 2010 in addition to the routine otolith collection for stock assessment. This new collection is for use in future elemental studies, and these samples are stored dry.

Background

Recently, with the advent of new technologies, fisheries researchers have the ability to study the elemental constituents incorporated in the microstructure of the otolith. The otolith is essentially a recorder of not only time, but the elemental environment in which the fish live. The most commonly measured elements are those that fall under the alkali, alkaline earth, and transition metals categories of the periodic table, which include, but are not limited to, beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and manganese (Mn). It is possible to detect and measure extremely small concentrations of these elements in otoliths, however any contaminants in the sample, such as glycerin (propane-1,2,3-triol), can make these measurements difficult to interpret.

The International Pacific Halibut Commission (IPHC) otolith archive has, by and large, been created from samples collected for age determination for input into the annual stock assessment. These structures have been stored in a glycerin/thymol (2-isopropyl-5-methylphenol) solution that allows for increased readability. As useful as it has been, the existing IPHC otolith archive has limitations for other research purposes. In recent years, otolith-based research has seen a shift from age and growth studies to isotopic and elemental analyses of otoliths (Campana 2005). Oxygen isotope analysis can be used to reconstruct temperature history, and stable isotope analysis (carbon and nitrogen) can provide information on a fish's diet history. Trace elements in the otoliths can be used in conjunction with other sampling to identify nursery origin by analyzing the trace element composition of the core. Analyzing trace element composition over time within an otolith (by sampling material from sequential annuli along a transect of a sectioned otolith) can provide information useful to understanding migration (Campana and Thorrold 2001, Gao and Noakes 2012). A glycerin/thymol solution maintains readability in stored otoliths, enabling age determination; however, it renders these structures unusable for research involving some isotopic and all elemental analyses. While methodological problems with measurement of otolith trace elements remain (Geffen et al. 2013), it is likely that studies involving otolith elemental and isotopic analyses will become more useful as the technologies that underlie these studies become more reliable. To make structures available for future chemical analyses, a clean otolith archive collection (COAC) program was initiated in 2010.

Collections.

The COAC is composed of structures sampled from all IPHC otolith collection programs and other research opportunities, including: the Standardized Stock Assessment survey (SSA), Commercial Port Sampling Program (PSP), National Marine Fisheries Service (NMFS) Trawl Survey, and any special charters that sacrifice halibut for research. These otoliths are collected along with any associated data, such as capture location and fork length (FL), following the established collection procedures of that particular program. Otoliths from the COAC are not used for age determination, but are cleaned, dried, and stored whole in climate-controlled conditions for future analysis.

There are separate annual COAC sampling goals for halibut caught on setline gear and for halibut caught on trawl gear. For setline-caught halibut, the annual COAC sampling goal is to collect a random sample of 100 otolith pairs from each of IPHC Regulatory Areas 2A through 4B, and 100 pairs from Areas 4C and 4D combined (4CD). Ideally these otoliths would come from the SSA, because sex and exact capture location are available. However, in areas of lower catch, the SSA otolith sampling rate may already be 100% to achieve the stock assessment otolith target. For areas that cannot be sampled on the SSA, COAC otoliths are collected from commercial deliveries. For the NMFS survey, annual COAC sampling goals range between 210 and 250 otolith pairs, depending on the survey regions for a given year. Parts of the NMFS survey cover IPHC regulatory areas not surveyed by the SSA; in addition, the trawl survey encounters small halibut that are not caught on setline gear. The total COAC collections for 2014 consisted of 1,096 otolith pairs.

Standardized Stock Assessment Survey

Clean otolith collections on the SSA survey began in 2010. To achieve a per-area target of 100 otolith pairs for the COAC, survey otolith sampling rates were increased by approximately 5% for each regulatory area, excluding those areas that required a 100% sampling rate to meet the stock assessment otolith target. Otoliths were not collected for the clean otolith archive from Areas 2A and 4CD in 2014 because those areas were sampled at 100% for the stock assessment collection. Selection of fish to be sampled for the COAC, as well as for the stock assessment collection, was determined from a random number table. COAC otoliths were placed in black Tray Bien™ storage trays to prevent confusion with the standard blue Tray Biens™ utilized for the SSA. Totals for the SSA portion of the COAC were 629 otolith pairs. Numbers collected by vessel are listed in Table 1 by vessel code as defined in the 2014 IPHC survey manual (IPHC 2014a).

Port Sampling Program

Collection of clean otoliths from the commercial fishery began in 2011. These otoliths are only collected from deliveries of halibut caught in regulatory areas where COAC sampling cannot be fully conducted on the SSA. The number of otoliths targeted from commercial deliveries varies from year to year and depends on the availability of otoliths from the SSA survey in a given regulatory area. In 2014, clean otolith samples from the commercial fishery were requested from Areas 2A, 4B, and 4CD and 99, 105, and 124 otolith pairs were collected from Areas 2A, 4B, and 4CD, respectively (Table 1). These COAC otoliths were collected by samplers in Bellingham, WA and Newport, OR (2A); Kodiak, AK (4B); Dutch Harbor, AK (4A, 4B, and 4D); and St. Paul, AK (4C). Sampling protocol and rates were established by port and regulatory area prior to the start of sampling in those ports (IPHC 2014b). Portside collection of COAC otoliths from

Area 4A was not requested in 2014, however one 4A delivery into Dutch Harbor was sampled. Portside COAC sampling was conducted for Area 4B in 2014 even though sampling for 4B also took place on the survey; this is because the 2014 sampling rates for the SSA were not available when the port sampling protocol was developed, so the 2013 areas and rates were carried over. In Bellingham, Newport, Kodiak, and Dutch Harbor, most of the COAC samples were taken from the same deliveries sampled for age and length data to be used in the stock assessment, but a few came from deliveries not sampled for the assessment. In St. Paul, the sampler collected COAC otoliths on days when commercial samples for the assessment were not being collected.

NMFS trawl survey

The NMFS conducts an annual trawl survey in the Eastern Bering Sea (EBS) and biennial surveys on alternate years in the Gulf of Alaska (GOA) and Aleutian Islands (AI). Due to the nature of the trawl survey, a large portion of the catch consists of small halibut that are not represented in the SSA or PSP collections. All halibut ≤ 25cm FL selected for COAC sampling on NMFS trawl vessels are measured and sexed, then bagged, tagged, frozen, and shipped whole to the IPHC in Seattle. Because COAC otoliths might be used for elemental analysis, it is important to minimize contamination from all sources. Otoliths from fish two years old or less are often analyzed whole, so extracting and handling small otoliths with standard metal sampling tools could introduce metal contaminants. To eliminate any possible contamination via an at-sea removal, otoliths from specimens ≤ 25 cm FL are extracted with ceramic tools in the clean and metal-free environment of the IPHC otolith wet lab. Use of metal sampling tools on otoliths from larger halibut is not an issue because analyses are conducted on the internal structure of the otolith, which would not be affected by surface contamination.

In 2014, samples for the clean otolith archive were requested from the NMFS EBS and AI trawl surveys. The 2014 trawl surveys were conducted by four vessels: two in the AI and two in the EBS. An IPHC sampler was deployed on one of the AI survey vessels. On the EBS survey, IPHC sampling took place on both vessels but on sequential trips (trip one of the *F/V Vesteraalen* and trips two and three on the *F/V Alaska Knight*). For the EBS survey, the sampling rate was set at six fish per station, with a maximum total goal of 110 fish (50 from Bristol Bay, 30 from the Pribilof Islands, and 30 from St. Matthew Island). The IPHC samplers deployed on the NMFS EBS trawl survey was instructed to collect otoliths from halibut > 25 cm FL, and to retain and freeze whole halibut ≤ 25cm FL. In 2014, a total of 123 otolith pairs were collected at sea on the NMFS EBS survey from halibut > 25 cm FL and 10 whole halibut ≤ 25cm FL were frozen and shipped to Seattle. Of the 123 otolith pairs collected at sea on the EBS survey, 74 pairs were discarded in the office after the tray containing samples collected on the *Alaska Knight* spilled prior to shipping and otoliths were mixed up.

For the AI trawl survey, a maximum of 100 whole halibut ≤ 25cm FL were requested to be collected: 40 from the collection region between Unimak Pass and Amukta Pass, 30 from the collection region between Amukta Pass and Amchitka Pass, and 30 fish from the collection region westward of Amchitka Pass. In 2014, no halibut ≤ 25cm FL were caught in these regions.

Reference

Campana, S. E., 2005. Otolith science entering the 21st century. Mar. Freshw. Res. 56: 485-495.

Campana, S. E., Thorrold, S. R., 2001. Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? Can. J. Fish Aquat. Sci. 58(1): 30-38.

Geffen, J.G., Morales-Nin, B., Perez-Mayol, S., Canterero-Roldan, A.M., Skadal, J., and Tovar-Sanchez, A. 2013. Chemical analysis of otoliths: cross validation between techniques and laboratories. Fish. Res. 143:67-80.

Gao, Y., and Noakes, D. L. G. 2012. Chemical signatures of otoliths and application in fisheries. Environ. Biol. Fishes. 95: 415–418.

International Pacific Halibut Commission (IPHC). 2014a. 2014 Stock Assessment Survey Manual. Int. Pac. Halibut Comm., Seattle, WA.

IPHC. 2014b. 2014 Port Sampler Handbook. Int. Pac. Halibut Comm., Seattle, WA.

Table 1. Total number of COAC otoliths collected by regulatory area in 2014.

		Regulatory Area											
Vessel	**Type**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	**AI**	**BS**	**Total**
STW	SSA		64										
KSU	SSA						45						
NCR	SSA						24	74					
BDP	SSA			73	11								
PEN	SSA		52	29									
WFL	SSA				22								
VNI	SSA					61							
FTW	SSA				21	24	64						
CLD	SSA				48								
SEY	SSA					17							
	PSP	99					6	105	120	4			
AKN	NMFS											74	
VST	NMFS											59	
AKP	NMFS										0		
		99	116	102	102	102	139	179	120	4	0	133	1,096

Development of a method for marking Pacific halibut by sex onboard commercial fishing vessels

Orion McCarthy[1]

Abstract

Pacific halibut (*Hippoglossus stenolepis*) are characterized by sexually dimorphic growth patterns and a female-skewed sex ratio among O32 fish. Examination of gonads is required to definitively sex halibut, but gonads are not present upon arrival at port because halibut are dressed at sea. Thus, no method exists for port samplers to assess the sex ratio of commercial halibut landings. This study aims to develop a marking technique that can be carried out by fishers and used by port samplers to identify commercially-landed halibut by sex. Successful marks must be cost effective, easily executed, identifiable, and not damaging to the fish. Distinct male and female knife cuts were developed, the female cut consisting of two incisions in the dorsal fin and the male cut consisting of an incision in the gill plate. To test the effectiveness of the marking technique, the accuracy of fishers marking halibut by sex was monitored aboard an IPHC survey vessel, and the accuracy of port samplers subsequently identifying those marks was monitored. Differences in marking accuracy between sexes were analyzed, and crew member accuracy was examined by individual. Fork length, maturity stage, date fished, and haul size were also investigated for relationships with fisher accuracy. The majority of halibut were marked correctly, the most common error being unmarked fish. Opposite sex errors were significantly more common among male fish. Haul size impacted fisher accuracy, and fisher accuracy was observed to increase over time. The majority of port sampler errors were due to port sampler oversight rather than fisher inaccuracy, and a low instance of false identification from applied marks was observed. The sex ratio of the catch marked by fishers and assessed by the port sampler did not differ significantly from the true biological sex ratio of the catch, indicating the marking method may be useful to represent the sex ratio of halibut stocks. Fisher participation is crucial if the IPHC truly wishes to gauge the sex ratio of commercial halibut stocks, and it is recommended a voluntary program be established before regulations are implemented. Future research should address the limitations of the current study, namely the small size of the offload, lack of repetition, limited geographical scope, and port sampler limitations.

Introduction

Every summer the IPHC carries out an annual stock assessment survey, which is used in conjunction with other data sets such as the commercial catch data to estimate the size of the Pacific halibut (*Hippoglossus stenolepis*) population. The stock assessment's setline survey monitors halibut across their North American range in the eastern Pacific and Bering Sea. The survey area is divided into 10 regulatory areas stretching along the continental shelf of Alaska, British Columbia, Washington, Oregon, and northern California (Henry 2013). Since 2003, the IPHC has conducted

[1] The IPHC provides training opportunities for undergraduate student interns and encourages them to prepare reports of their projects conducted at the IPHC. Reports by interns are included here with only minor editing.

separate stock assessments for male and female halibut due to the sexually dimorphic growth patterns of the species (Clark 2004). Female halibut exhibit a faster growth rate than males and reach a larger adult size, meaning they constitute a greater proportion of legally harvestable halibut (fish over 81 cm (32 inches) in length or O32). Halibut caught during the IPHC setline survey are sexed directly through gonad examination and the sex composition of the survey catch is used to estimate the sex ratio of commercial halibut landings. Thus, no method is currently in place for directly measuring the sex ratio of the commercial catch. Females have a high reproductive value to the population and there has been a recent push by the IPHC to expand sex ratio monitoring to the commercial fishery, to improve overall population assessments of the halibut stock.

While male and female Pacific halibut are characterized by sexually dimorphic growth rates, significant overlap precludes using fork length measurement as a proxy for sex. The sexes are not characterized by any reliable external identifying features, and the sex of individual halibut may only be identified definitively upon examination of the internal gonads (IPHC 2013). Since the process of catching, dressing, and storing halibut necessitates evisceration of the fish at sea, the gonads required for sex identification are not present when commercially caught halibut reach port for inspection. As such, no reliable method exists for portside samplers to directly assess the sex ratio of commercial halibut landings (IPHC 2013). Recent genetic experiments carried out by the IPHC identified several alleles that demonstrate moderate female sex linkage, but the low accuracy and high expense of identifying these alleles precludes this method from being adopted on a large scale for fishery-wide sex ratio determination (Woods 2011).

Currently, the sex ratio of the survey catch is determined by examination of the gonads of individual fish as they are harvested and cleaned onboard survey vessels. Until now these ratios, by size and age, have been extrapolated to estimate the sex ratio of the commercial halibut catch, either by comparing the mean size at age with survey data or through incorporation into models estimating the selectivity of the commercial halibut fishery (Stewart 2013). This is problematic because certain aspects of the commercial fishery, such as the area fished by the commercial fleet, the time of year over which fishing occurs, and the exact fishing methods may differ from those employed by IPHC survey vessels, creating a potential source of error for the stock assessment. An IPHC study comparing the mean length at age between commercial and survey landings illustrates the issues with estimating commercial sex ratios from survey data (Clark 2004). Spatial and temporal variability in the fishery is high, and the comparison of survey and commercial data returned similar sex ratio predictions for Areas 2 and 3A but not for Areas 3B and 4 where the commercial mean size at age is larger, indicating a higher take of females by the commercial fishery in these charter areas. A recent sensitivity analysis carried out by the IPHC found that variability in sex ratio estimates of 10% corresponded to a 50 million pound range in spawning biomass of the species (Stewart 2013). Given that the entire annual biomass harvested by the commercial fishery has ranged from 34 to 100 million pounds over the past century (Stewart 2013), uncertainty of up to 50 million pounds constitutes a substantial source of potential error in the annual stock assessment.

The commercial fleet is ultimately affected by stock assessment accuracy through the estimation of catch limits. The commercial catch represents a large potential dataset for sex ratio determination if a practical method of marking fish for portside identification can be developed. This study's goal was to develop a marking technique that can be used by fishers at sea so that port samplers can definitively identify commercially-caught halibut by sex. A successful mark must

be cost effective, quick and easy for fishers to execute, easily identifiable by port samplers, and unobtrusive to the product so as not to decrease the sale value of the fish

Methods

The research conducted for this study took place in three distinct phases: a portside trial and error phase where exploratory marks were tested, a controlled experimental phase aboard an IPHC survey vessel where fishers were instructed to mark fish, and a portside controlled experimental phase where an IPHC port sampler estimated the sex ratio of a survey offload by examining the marked catch.

The first phase of the study was conducted in the ports of Homer, AK and Dutch Harbor, AK with the goal of developing an ideal male and female mark in collaboration with IPHC port samplers, before boarding the IPHC vessel. Before heading into the field, a consensus was reached that the ideal strategy for marking halibut would involve the use of a knife to make an identifying cut. This method was selected over other options, such as tagging fish, using identifying rubber bands or zip-ties, or hole-punching fins, because of its inherent ease, use of normal on-board vessel tools, and cost effectiveness.

In Homer, halibut from a 1,300 lb. commercial delivery were marked with experimental knife cuts to test the effectiveness of potential marks. The skipper and local buyer were both interested in the marking methodology and expressed a willingness to participate. During two subsequent offloads in Homer and Dutch Harbor, the most promising three marks (two cuts in the dorsal fin, a triangular cut in the gill flap, and a cut along the pectoral fin) were applied to a subsample of halibut and sampled by the port sampler. A single tote of halibut was set aside at each offload, and individual fish were marked with one of the three marks or left unmarked. After the port sampler completed their regular sampling duties, the marked halibut were transferred from the full tote to the measuring table, where the port sampler examined the fish and communicated the observed mark. The accuracy of the port samplers and their opinion on the ease of identifying each mark were recorded and used to select two knife cuts for use aboard the survey vessel.

The second research phase took place on board the *F/V Kema Sue* during survey fishing in the Unimak West and Four Mountains East survey regions in Area 4A (Henry 2015). Fifteen stations were fished during the study between July 26 and July 31, 2014, with an average of 2.5 stations fished per day (Fig. 1). Two cuts in the dorsal fin (Fig. 2) and a triangular cut in the gill plate were initially chosen as marks, the former for female and the latter for male. The crew was given a demonstration of how to mark halibut using these knife cuts with the first few fish caught at the first station on the first day of the trip. The female cut was made by inserting the knife into the base of the dorsal fin where it meets the body and cutting outwards, while the male cut was made by gripping the gill plate in one hand and making two angled cuts with the knife in the other. All subsequent O32 halibut were dressed and marked by the crew, although some fish were missed and left unmarked. Four of the six fishers on board and both of the sea samplers took part in dressing and marking halibut. Once O32 halibut were cleaned, marked, and sampled by the sea samplers, they were inspected for the knife cut and its presence or absence was recorded. The fish were recorded as either marked (Y), marked as the incorrect sex (N1), marked as the correct sex but with an ineffective or improper mark (N2), or mistakenly unmarked (U) (Fig. 3). In addition to the mark success code, the fork length, maturity stage, skate number, station, and date caught were recorded for each fish. Once the information was recorded, a tag made of twine was looped

through a cut made in the lower jaw, and the fish were dropped in the hold where each was iced and stored white side up. The tags attached to the twine were made of clear packing tape sealed over a duct tape square with a fish identity number written in waterproof ink and were a square inch in size. These unique numbers were matched with the data for each individual fish and used to keep a record of each fish's true sex and sex marking, as well as which crew member dressed the fish and where each fish was caught, including the station and skate number.

After the first day onboard the *F/V Kema Sue*, the male mark was changed due to logistical problems with carrying out the original knife cut, and was replaced with a single incision down the gill flap, creating a hanging flap (Fig. 2). The cut, developed jointly by fishers and researchers, was created by inserting the knife in the upper middle region of the gill plate on the white side and cutting down. This mark became the new male cut and was carried out in conjunction with the dorsal fin cut for females by the crew for the remaining days and stations. Fish marked with the initial male mark as well as fish used for demonstrations to the crew were recorded as test fish and excluded from the calculation of port sampler and fisher accuracy.

The third and final research phase took place during the *F/V Kema Sue* offload in Dutch Harbor on August 1, 2014. All 4,800 lbs. of halibut caught during the trip were offloaded into 4.5 totes. Fork lengths had already been recorded and the otoliths already removed by onboard biologists, so the port sampler did not need to perform normal sampling duties. Instead, she was asked to treat the fish as if it was a normal commercial offload and inspect the fish for markings. Halibut were positioned white side up and the port sampler called out "boy" or "girl" depending on her interpretation of the mark. The tag number as well as the port sampler's assessment of the fish's sex were recorded.

Every fish from the offload was examined by the port sampler, totaling 254 pieces, and the port sampler's sex assessment was cross referenced with the true sex of the fish using the tag identity number. The true sex ratio of the catch was calculated, as well as the sex ratio of the catch as marked by the crew and as assessed by the port sampler. Test fish and unmarked fish were excluded from the calculation of the latter two ratios. The sex ratio of the catch was also examined based on size classes of fish to explore the relationship between length and sex. The accuracy of crewmember marks was examined by error type (N1, N2, U), and port sampler accuracy was determined based on a comparison of port sampler sex assessment and mark type. The individualized tags for each fish made it possible to examine the accuracy of each crewmember individually. In addition, the relationships between crewmember accuracy and experience, time since the trip began, and haul size were examined.

The tagging method developed in this study has potential usefulness in future research projects unrelated to sex ratio determination. Tagging fish individually allowed biological factors, such as fork length and maturity stage, and spatial factors, such as time and location, to be cross referenced with the mark success of fishers as well as port sampler accuracy down to the level of each individual fish. Composed of durable twine, packaging tape, and improvised labels drawn on duct tape, the tags were made as needed and attached by cutting a hole beneath the jawbone, threading the twine through and tying a knot. During the offload the tags were cut off with a knife and read by the port sampler. The tags were made of cheap materials and were quickly and easily attached, legible, and stayed on 97% of the fish. One recommendation for increased legibility would be using typed labels on waterproof paper or plastic inside the packaging tape instead of duct tape inscribed at sea.

Results

Choosing a mark

A simple knife cut was selected as the ideal marking method in the early stages of planning due to the inherent ease and cost effectiveness of using a knife. Unlike zip-ties, rubber bands, and other tagging methods initially considered, using knife cuts required no additional tools or materials to be purchased, and since fishers already had a knife in hand while dressing the fish, the mark for sex identification became an easy additional step. The biggest challenge to using a knife cut was avoiding an obtrusive cut with the potential to damage the fish and decrease its value for sale, known as a No. 2 fish. The best knife cuts were designed to be convenient for fishers dressing halibut to execute, specifically cuts near the head on the white side of the fish. Marking halibut on the white side was desirable since right handed fishers and all port samplers handle halibut white side up.

Marking halibut based on sex necessitated designing two different knife cuts; one for male and one for female fish. If fishers were to mark only one sex, the port sampler assessment of the sex ratio would be skewed by every fish that was missed or fisher that did not mark their catch. To avoid this issue, two visually distinct marks were required. Due to the variable and uncertain conditions aboard the vessel and in port, ten marks in total were considered or attempted in the trial and error phase before deciding on the final set of marks. The complete list of marks ranked by feasibility is outlined in Table 1 and illustrated in Figure 4. It quickly became apparent that any knife cut would have some potential for false identification due to natural or fishing related injuries, and that many parts of the halibut are difficult to cut. Any cuts that involved removing the pelvic or pectoral fins were quickly abandoned, as these fins were relatively tiny and difficult to grasp or cut. Any marks to the tail region of the fish were ruled out due to the inconvenient reach required by fishers, and cuts to the gill arch were abandoned due to the difficulty of cutting a notch out of bone.

Ultimately, three potential cuts were selected for a trial port sampling assessment: the dorsal fin cut, the triangular cut in the gill flap, and a pectoral fin cut (Fig. 2, Fig. 4, Fig. 5). While the results of preliminary trials illustrated a high instance of correct mark identification by port samplers (Table 2), each mark had unique issues that need to be addressed. The pectoral fin mark was difficult to create and resulted in a worksite injury, and was no longer pursued after that point. The triangular cut in the gill plate was time consuming to create and was missed by the port sampler most frequently due to the frequency of damaged halibut gill plates. These problems were mostly ameliorated by altering the mark to a long incision in the gill plate, which was more identifiable and quicker to execute. This mark was eventually adopted as the male mark, although there remains a remote possibility that the mark could interfere with port sampler otolith collection by damaging the skull.

The selected female mark, two cuts to the dorsal fin, was chosen due to the ease of execution and identification. Two cuts were selected as opposed to one to avoid false identification with natural injuries to the dorsal fin. The mark was identified by port samplers most often as the easiest to identify, and fishers preferred the mark slightly over the male knife cut. For successful program implementation, it is important to reserve the easiest knife cut for female fish due to the high prevalence of females among O32 halibut. Fishers will be more likely to participate in the marking process if the mark they have to execute most often is convenient. One issue with the dorsal cut is its potential to be obscured by sand flea damage, although this issue could potentially be mitigated

by instructing port samplers to disregard any halibut obviously infested with sand fleas from their sex ratio assessment, although further studies would be required to test the efficacy of this method.

The selection of two visually and spatially distinct knife cuts was an intentional measure to avoid the potential confusion of similar marks. While considering a potential alternative to the original male mark, three dorsal fin cuts or two cuts to the lower ventral fin were considered as alternative cuts. However, the *F/V Kema Sue* skipper expressed concern that fishers may cut the dorsal fin more than two times to ensure the mark has been made, a practice that would confound the sex ratio assessment. Furthermore, cutting the mirror image of any fin, such as the lower ventral fin instead of the dorsal fin, would create a high potential for error among left handed fishers who clean halibut dark side up. Thus, to avoid a high prevalence of N1 errors, the gill plate cut for male fish was selected.

The trial and error marking period in Homer and Dutch Harbor was a successful exercise that allowed the best possible marks to be established. The majority of the O32 halibut caught aboard the *F/V Kema Sue* were marked with either two dorsal fin cuts or a single gill plate cut so the sex ratio of the catch could be assessed during the offload in Dutch Harbor.

Crew member accuracy

While aboard the *F/V Kema Sue*, the true biological sex of each fish and the mark each fish received were recorded and cross referenced, allowing the accuracy of crew members to be assessed. Differences in marking accuracy between both sexes of halibut were analyzed, and crew member accuracy was investigated by individual fisher or sea sampler performance as well as by experience. Biological factors such as fork length and maturity stage as well as spatial factors such as date, location, and haul size were also investigated for relationships with crew member performance.

The prevalence of each type of unsuccessful mark has implications for the overall success of the marking program and the accuracy of the final sex ratio. The least desirable type of unsuccessful mark is the N1 mark because it decreases the perceived number of one sex while raising the perceived number of the other, altering both aspects of the sex ratio. An N2 error skews sex ratio calculations less because mismarked fish may be confused as unmarked fish by port samplers, only altering the perceived number of one sex. The least skewing error is leaving a fish unmarked, since those fish will presumably be disregarded during port sampler examination of the sex ratio.

Measurements of crew member accuracy aboard the *F/V Kema Sue* showed that nearly 80% of fish were marked successfully, while 15.1% of fish were marked as either N1, N2, or U (Fig. 6). The vast majority of unsuccessfully marked fish were U marks, while N1 and N2 fish accounted for only 34.4% of unsuccessfully marked fish, not including test fish. This suggests that crew members were capable of identifying halibut correctly by sex and able to execute the appropriate mark in most cases, and that the primary source of erroneous marks stemmed from failure to mark the fish at all. General observations of crew members revealed that simply forgetting to mark the fish was the primary cause of U errors rather than purposefully leaving fish unmarked, a promising trend that suggests potential for improvement over time as fishers integrate the knife cut into their cleaning routine.

As long as fish from both sexes are unmarked or mismarked at equally random rates, the skewing effects on the sex ratio calculations should be minimized. Comparing the accuracy of crew members by the sex of the halibut cleaned revealed that N1 errors are significantly more common ($p=5.410 \times 10^{-7}$) among male fish than female fish, while the frequency of other error

types or correctly marked fish revealed no significant difference between the sexes (N2 p=0.935, U p=0.356, Y p=0.481) (Fig. 7). The high prevalence of N1 errors among male fish is to be expected, as males are the less common sex among O32 halibut which could cause them to be passed over more often, marked as the female default by fishers focused on dressing fish quickly. Furthermore, the prevalence of N1 errors shown by this data is more representative of a single station with a more even sex ratio compared than the majority of stations, which were skewed towards females. No N1 errors were observed across 13 of 15 stations, with all but one N1 error occurring at station 6046 (Fig. 1). While the average O32 sex ratio across all stations was 81.75% females , the sex ratio of station 6046 was 51.61% females . The higher than average number of males caused more male fish to be mismarked than at stations with a more typical female skewed sex ratio. While the prevalence of N1 errors may not be representative of fishing areas with skewed sex composition, it suggests that the probability of N1 errors increases when sex ratios approach a 1:1 male-female ratio. This potential for N1 errors among male fish highlights the importance of inspecting gonads visually, rather than feeling around inside the body cavity and identifying gonads without visual confirmation.

Recording information for individual fish allowed several other metrics to be analyzed, including individual crew member accuracy and the effect of experience and occupation on marking accuracy. Analyzing the likelihood of erroneously marking fish (N1, N2, or U) by individual crew member revealed considerable variability in crew member accuracy, which ranged from 92.1% correctly marked to only 38.9% correctly marked (Fig. 8). In general, most crew members marked fish with an accuracy rate above 75%, with an average accuracy rate of 77.5% across all crew members. No significant difference in accuracy was observed between fishers and sea samplers that could not be attributed to a difference in experience.

The level of prior experience cleaning fish exhibited a trend in both accuracy rate and error type. Experienced crew members demonstrated a high accuracy rate of 88.7% but committed 75% of all N1 errors and 100% of all N2 errors, while amateur and novice crew members demonstrated lower accuracy rates of 84.7% and 38.9% respectively, with much higher numbers of U errors, which made up 55.5% of all novice crew member marks (Fig. 9). This indicates that experienced crew members have a higher accuracy rate marking fish and are less likely to leave halibut unmarked compared to newer crew members, but are more likely to mismark fish with N1 or N2 errors. This suggests that crew members still learning to clean fish struggle with integrating new steps into their routine and are more likely to forget the extra step of marking fish, while a higher level of experience facilitates the easy adoption of extra steps, although the speed and efficiency with which experienced fishers work may compromise accuracy.

The effects of biological factors such as fork length and maturity stage on crew member marking accuracy were explored as well. All N1 errors where found among small (82-89 cm) and medium (90-99 cm) O32 halibut, which would be expected due to the higher number of males in smaller size classes (Fig. 10). Aside from the obvious difference in N1 prevalence, no obviously meaningful patterns in crew member accuracy were apparent across size classes, although the extra-large size class (fish over 110 cm) exhibited only 3.1% unmarked fish compared to an average of 13.3% across the other size classes (Fig. 10). The effects of maturity stage on crew member accuracy were examined to explore the possibility of gonad identification errors associated with immature female (stage one) gonads. All N2 marking errors were found to have occurred in stage one females, although this suggests crew members were still able to correctly identify the sex of the fish from the gonads (Fig. 11). The high number of N2 errors among stage

one females is likely due to the large proportion of the catch made up by this group rather than any significant relationship. All but one of the N1 errors were associated with mature males, but this may be attributable to the higher error rate associated with identifying the less common sex, not maturity stage.

Any effects the number of halibut caught per skate of gear (haul size) may have on crew member accuracy are important to consider, especially since catch rates aboard survey vessels such as the *F/V Kema Sue* are lower than commercial rates (IPHC 2013). The 100 skates fished were divided into low haul (1-4 fish caught per skate), medium haul (5-9 fish caught per skate), and high haul (10-22 fish caught per skate) and compared with crew member accuracy (Fig. 12). While all haul types exhibited error rates of 20% or lower, the type of errors differed between low and high haul skates, with 51.9% of U errors occurring at low haul skates and 62.5% of N1 and 80.0% of N2 errors occurring at high haul skates (Fig. 12). This suggests that crew members are more likely to forget marking fish when hauling is slow. When marking a steady stream of fish, crew members include the extra marking step as part of the cleaning process but are more likely to mismark fish. These N1 or N2 errors are likely due to decreased time and available effort fishers can expend on individual fish, and the increased prevalence of N1 and N2 errors in high hauls should be considered for busier fishing areas.

Remembering to mark fish was the biggest learning curve experienced by crew members, and an investigation of the number of fish left unmarked over time revealed a decrease in unmarked fish over the course of the trip. Out of all unmarked fish, 45.9% occurred on the first fishing day over the course of two stations, and the second half of the trip only saw 16.2% of all unmarked fish (Fig. 13, Fig. 14). Examining the number of marked and unmarked fish by station reveals a decrease in unmarked fish over time at both busy and relatively empty stations, while an examination of the same factor by date reveals a steady decline in unmarked fish throughout the week (Fig. 14). This promising trend suggests crew member accuracy has the potential to increase substantially over time following the period of introduction, and that mark accuracy statistics from this study may underrepresent the true potential accuracy of fishers trained to mark fish by sex.

Port sampler accuracy

Measuring the accuracy with which the port sampler recorded male and female marks during the *F/V Kema Sue* offload was the final step in gauging the effectiveness of marking halibut with specific knife cuts at sea. The accuracy rate of the port sampler was determined by comparing the port sampler assessment of sex to the knife cut given by the crew, not to the true biological sex of the fish. Out of the 247 fish identified by the port sampler, only 22 were incorrectly assigned the distinction "male", "female", or "unmarked" based on the knife cut given by the *F/V Kema Sue* crew. Of these 22 errors, 68.2% were from fish with either Y or N1 marks, indicating the port sampler was responsible for the error since the marks executed were identifiable, while 9.1% of the port sampler errors were from fish with N2 marks, indicating the crew was responsible for failing to create legible marks (Fig. 15). The other 22.7% of errors were the result of test mark fish, which are not included in assessments of port sampler accuracy as they are not representative of mark application in practice. This indicates that the majority of port sampler misidentifications are due to port sampler oversight rather than crew member negligence, and suggests proper mark execution is less of a problem than mark identification. In addition, no mistakenly unmarked fish were misidentified as marked fish, although one fish that was unmarked intentionally was

misidentified. Still, this suggests a low potential for prior natural or fishing related injuries to be confused with sexing marks.

To reveal the effectiveness of each sexing mark, halibut were divided into three categories, those marked as males or females, and those left unmarked by the crew. The accuracy of the port sampler for each category was calculated, excluding test fish. The port sampler correctly identified all male marks, with 93.8% of the misidentified fish possessing the female knife cut (Fig. 16). Of these misidentified female-marked fish, 33.3% were identified as males by the port sampler and 66.6% were mistakenly identified as unmarked, indicating that mark misidentification by the port sampler is present but that passing over the mark completely is more prevalent (Fig 16). While these factors are worth noting, the trends were not significant (female $p=0.286$, male $p=0.092$), precluding the conclusion that the female mark is less optimal for port sampler recognition and correct identification than the male mark. It is more likely that the large number of female fish led to increased port sampler error, while the small sample size of male fish allowed none to be missed. In addition, the port sampler commented that both marks were easy to spot and identify but that the female dorsal cut was optimal over the male gill plate cut.

The offload also offered a chance to test the likelihood of marked halibut receiving a No. 2 distinction. Out of 4,800 lbs. offloaded, 78 lbs received a No. 2 distinction, or 1.63%, a rate lower than the average 4.03% of the *F/V Kema Sue* catch typically graded No. 2 in the same charter regions. The cause for the No. 2 distinction was not revealed, but 42.1 lbs of fish were observed with lamprey induced lesions at the time of hauling and were likely No. 2. However, a single instance of a dorsal fin female cut damaging the body was observed, and is the possible origin for 17.1 lbs of the No. 2 catch.

Sex ratio

With a record of crew member and port sampler accuracy as well as a record of the true biological sex of each fish, it is possible to calculate the biological "true" sex ratio, the "marked" sex ratio with crew member marks as a proxy for sex, and the sex ratio of the fish as assessed by the port sampler during the offload. The true sex ratio was investigated by fork length and size class to corroborate the assertion that female halibut exhibit a faster growth rate than males, leading to greater female representation among larger halibut size classes. Indeed, prior findings on sex-specific halibut growth differences were applicable to the *F/V Kema Sue* catch, as shown in Figure 17. The small size class (halibut 82-88 cm) had the sex ratio with the highest number of males while the extra-large size class (halibut over 109 cm) had no males at all, the largest male caught being 109 cm (Fig. 17). The true sex ratio of the entire catch was found to be 81.75% females to 18.25% males.

The overall success of the marking methodology is dependent on how representative the marked and port sampler sex ratios are of the true biological sex ratio. The accuracy of the marked sex ratio compared to the true sex ratio indicates the success of the knife cut design in implementation as well as the capability of fishers to mark by sex. To ensure the accuracy of fishers was correctly measured, fish purposely given N1 marks under specific researcher instruction were omitted from sex ratio calculations (Table 3). To gauge the accuracy of the port sampler sex assessment for this study, the difference in the port sampler sex ratio was compared to the marked sex ratio only, not to the true sex ratio of the catch. This was done because port sampler assessment can only be based on visible marks on the fish, and biological sex is unapparent without the gonads present. The

accuracy of the port sampler sex ratio compared to the marked sex ratio indicates the success of the knife cut design in detectability and its propensity for false identification.

Excluding test fish, the marked sex ratio was 85.02% females to 14.98% males, exhibiting a greater skew towards females than the true sex ratio (Fig. 18). While this difference suggests a tendency for fishers to under-mark male fish, the difference between the marked and true sex ratios was not significant (p=0.2221). The port sampler sex ratio was 78.61% females to 21.39% males, exhibiting a greater skew towards males than either the marked or true sex ratio (Fig. 18). This difference suggests a tendency exists for the port sampler to incorrectly identify a higher proportion of female marks compared to male marks, a pattern shown in Figure 16. However, the difference in the marked and port sampler sex ratios was not significant (p=0.2938) when the purposefully marked excluded from the marked sex ratio were included in the port sampler sex ratio.

Despite a substantial number of crew member and port sampler errors, neither the marked nor the port sampler sex ratio differed significantly from the true sex ratio, suggesting the marking technique was successful at accurately representing the sex ratio of the catch. One potential explanation for why these errors haven't altered the sex ratio significantly is that the majority of crew member errors involved leaving O32 halibut unmarked. Figure 19 shows the similarity of the sex ratio of U fish and the true sex ratio, which are not significantly different (p=0.4656). As long as both sexes experience U errors at an equivalent rate, there should be no effect on the marked and port sampler sex ratio beyond a reduced sample size of males and females.

Discussion

Project reception and implementation recommendations

The development of convenient and effective male and female marks is irrelevant without proper implementation in the commercial halibut fishing community. Fisher participation is crucial if the IPHC truly wishes to gauge the sex ratio of commercial halibut stocks. The opinions of the key participants in the commercial halibut industry, namely fishers, processors, and port samplers, are outlined below, as are a number of recommendations to ensure that implementation proceeds as smoothly as possible.

There are many factors affecting the potential success of a sex-based marking program, including the size of halibut offloads, the number of fish caught per skate, and the ability of fishers to recognize gonads. Above all, the program's success hinges on the willingness of fishers to participate in the marking process and the willingness of processors and buyers to accept marked halibut at an equivalent cost. To gauge receptiveness, fishers and processors in Homer and Dutch Harbor were informed of the goals and research plan behind the project and casually surveyed about their willingness to participate. All fishers and processors were understanding and seemed to display a willingness to consider participation, although their commitment was muted somewhat by the lack of a confirmed marking method, which was developed after the interviews. Fishers were eager to suggest potential marks, and while a few found the science behind the project particularly interesting, most fishers simply accepted the desire by the IPHC to obtain data for the stock assessment as in their best interest. The few processors that were interviewed, suggested fin or gill plate cuts would not result in a No. 2 designation, and were comfortable with test mark application to purchased fish.

The interviews with fishers highlighted the practice of marking both males and females as a potential problem for fisher accuracy. Most of the questions regarding the project came from

fishers asking why both male and female fish needed to be marked. Most fishers believed that marking one sex of halibut would be sufficient and wanted to know why a methodology requiring more work was being developed. Without proper education or outreach to fishers regarding this issue, the IPHC runs the risk of accepting sex ratio data skewed by uninformed fishers taking shortcuts while marking fish. As stated before, most fishers seemed receptive to participating in the project, and it is likely this issue could be mitigated through education.

Despite a generally cooperative reception among fishers, the biggest issue faced by implementation will likely be participation. Instead of quickly rolling out new regulations, it is recommended a voluntary program be established across charter regions where receptive vessels mark their catch by sex. A question for skippers concerning whether or not the catch was marked by sex should be included as part of protocol when port samplers gather log book information so that time is not wasted inspecting unmarked offloads. After a few years of the voluntary program paired with follow-up IPHC studies on mark success, sex ratio accuracy, and fisher participation, regulations can be implemented requiring halibut be marked by sex.

Limitations

Due to several uncontrolled aspects of the study, there are several limitations that deserve discussion and consideration. The halibut fishing grounds in regulatory Area 4 are substantially less productive than areas in the Gulf of Alaska and Southeast Alaska, specifically Areas 3A and 2B (IPHC 2013). The average daily catch aboard the *F/V Kema Sue* was 800 lbs., catch rates less than half the average of some regions in Area 3A and 2C, which can reach up to 2,800 lbs. per day (Henry 2013). Several fishers asserted that taking the time necessary to sex fish during 2,000 lb. or greater hauls would be difficult, which could lead to either a large number of unmarked fish or a large number of fish marked as females to avoid the extra work of checking gonads in busy charter regions.

An additional consideration is the ability of the average fisher to determine the sex of halibut from the gonads. The fishers aboard the *F/V Kema Sue* demonstrated a high rate of accuracy determining the sex of their catch, but survey vessels operate differently from commercial vessels. Fishers aboard the survey vessels are required to separate the gonads from the rest of the innards, an extra step that requires additional knowledge of halibut anatomy which could potentially result in an above average rate of marking success. Both of these issues are present regardless of the marking method used and are pervasive factors that need addressing if implementation is to be successful.

The accuracy with which the port sampler identifies halibut is a key feature of eventual implementation, so it is worth noting the port sampler used for the majority of the assessments in this study was new to the job, her first offload occurring a week before the *F/V Kema Sue* offloaded. She was familiar with halibut and still identified the majority of the marks correctly, but it is still recommended that the experience level of the port sampler and the effect of additional mark identification training be tested in the future. Error could have also arisen from reading the tags attached to each halibut, which were used to reference the port sampler assessment with the biological sex determined on the boat. All but 3% of the tags survived the offload and appeared to be legible, but reading and cutting them off the fish was an additional step not typically taken when port sampling and could be considered a potential source of error. While the port sampler was taking the extra step of cutting off and reading fish tags, she was not removing otoliths and taking fork length measurements, which decreases the applicability of the findings of this study as well.

A final limitation with these marks and any type of knife cut is the potential for false identification due to confusion of the mark with natural injuries. Care was taken to select regions of the fish that were not subject to high fishing related injuries such as prior hook injuries (PHI) or gaffing injuries, and no fish were observed to have natural markings that could be mistaken for either the male or female mark. Still, multiple fish were observed with a single cut in the dorsal fin or damage to the gill plate, which could complicate port sampler identification. Nonetheless, these marks are strongly believed to be the best possible option moving forward and were subject to low levels of false identification by the port sampler.

Future studies

This study highlighted several areas where further research would be beneficial to gauge the effectiveness of marking halibut aboard commercial vessels for sex ratio determination. Future research should address the limitations of the current study, namely the small size of the halibut offload, lack of repetition, limited geographical scope, and port sampler limitations. These studies should use multiple vessels so that a greater sample size and the effect of variation in haul size across charter regions can be analyzed. An added benefit of a larger sample size across multiple ports is testing the accuracy of multiple port samplers. Testing multiple port samplers across a range of skill levels is imperative moving forward since port sampler experience was not accounted for. It is recommended that the 2015 IPHC setline survey integrate the marking method as standard procedure on all survey vessels so that a large number of vessels and port samplers can be tested. Sea samplers would be able to monitor fisher compliance, allowing such a study to test the representativeness of the marking method compared to the actual sex ratio under ideal participation conditions. Once the 2015 setline survey is complete and further implementation commences, a comparative study should be conducted on fisher compliance and the effectiveness of marking for sex across regions. Such a study should specifically investigate if increased haul size effects fisher compliance or accuracy, as a decrease in the latter was exhibited for larger hauls in this study.

Another area of future research should focus on the efficacy of marks for the sex they were designed for. Since more O32 females are caught than males, an ideal program would entail that the female mark to be easier to create and spot than the male mark. This study showed similar ease among fishers creating both marks, although testimonials slightly favored the female mark for ease. While both port samplers preferred the female mark in their testimonials, halibut marked as females were most commonly missed by the port sampler while no males were missed. Since the final knife cuts were not tested representing the opposite sex, it is unknown whether the current female mark, two cuts in the dorsal fin, would be more successful as the male mark. This could be easily tested during the 2015 IPHC setline survey as well, with fish destined for a specific port receiving opposite marks and a single port sampler instructed accordingly.

References

Cited references

Clark, W. G. 2004. A method of estimating the sex composition of commercial landings from setline survey data. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: 111-162.

Henry, E., Soderlund, E., Dykstra, C. L., Geernaert, T., and Ranta, A. M. 2013. 2013 Standardized stocks assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 379-414.

International Pacific Halibut Commission. 2013. Annual Report 2012.

Stewart, I. J., and Martell, S. 2013. Assessment of the Pacific halibut stock at the end of 2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 169-196.

Woods, M., and Loher, T. 2011. Sampling of Pacific halibut aboard commercial vessels for comparison of genetic analysis and sex-at-length methods for segregating commercial catch by sex. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 331-336.

Additional references

Erikson, L. M., and MacTavish, K. A. 2013. Commercial catch sampling. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 67-80.

Loher, T., and Hobden, J. C. 2012. Length and sex effects on the spatial structure of catches of Pacific halibut (Hippoglossus stenolepis) on longline gear. Fish. Bull. 110(1):46-51.

Loher, T., Woods, M., Jimenez, I., and Lorenz, H. 2012. Comparison of survey-derived length-at-age-based sexual probabilities and microsatellite-based genetic techniques for estimating sex composition of Pacific halibut catch samples. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012: 415-436.

Table 1. A list of all the knife cuts either conceptualized or performed during the project ranked by the feasibility of their execution, along with the pros and cons of each cut and any unique factors to take note of. For a visual diagram of each cut, see the corresponding number next to each cut in Figure 2.

Female	Dorsal fin cut (x2)	The eventual female knife cut, it was easy and quick to create. Two cuts must be made to avoid confusion with pre-existing injuries to the dorsal fin, and only the top fin can be used to prevent confusion with left handed fishers marking the inverse. The cut must be made from the body edge outwards to avoid cutting the flesh. There is a possibility of the cut being obscured by sand flea damage.
Male	Gill flap straight cut	The eventual male knife cut, it was decided on after the gill flap triangular cut did not work. Easy and quick to create, the cut could possibly be obscured by serious prior head injuries. The potential of cutting the flap completely off exists, which could complicate identification and a remote potential for otolith damage exists as well.
1	Gill flap triangular cut	A Triangular cut out of the gill flap about one square inch in size which results in a piece missing from the fish. The gill flap is flimsy, with the first cut easy to make but a more difficult second cut. Two knife cuts are required to avoid confusion with prior injuries, as the region of the fish is susceptible to fishing related injuries. It was a time consuming cut to make and not liked by fishers.
2	Lower ventral fin cut (x2)	Entirely possible knife cut and easy as a dorsal fin alternative, but should not be carried out in conjunction with dorsal fin cut as a male alternative because it is too similar and subject to N1 errors by left handed fishers.
3	Pectoral fin cut	A lengthwise cut up the pectoral fin, this cut was dangerous to make since the fin is relatively small and slippery and there is a possibility of cutting into the flesh if the knife misses. Overall, not an easy cut to make.
4	Tail cut	Would be made in a similar fashion to the dorsal cut but in the middle of the tail and would probably necessitate two knife cuts to avoid confusion with prior injuries. However, the tail is too far from the head, making it an inconvenient cut for fishers cleaning halibut.
5	Notch in gill arch	A small, triangular notch cut into the bone of the gill arch, this mark would have to be felt by the port sampler rather than seen. The cut is also difficult to make, requiring a sawing motion with the knife. Overall the mark is time consuming to cut and identify.
6	Chop off pelvic fin	The pelvic fins are too tiny and difficult to grasp or cut, although prior injury in this region of the fish was not observed, making it a good potential marking are in theory.
7	Cut corner off of tail	The tail was to flimsy and bony to cut just the corner.
8	Chop off pectoral fin	The pectoral fin was too big to chop off and the act of doing so would have been time consuming. It was a difficult and impractical cut with a high potential to No. 2 the fish.

Table 2. The number of fish in Homer and Dutch Harbor offloads with experimental markings applied as well as the perceived number as assessed by the port sampler.

HOMER*	Gill Flap (Triangular Cut)	Dorsal Fin (2 cuts)	Pectoral Fin (1 cut)	Unmarked
Actual Marks	9	11	14	10
Port Sampler Assessment	9	11	14	8

DUTCH HARBOR	Gill Flap (Triangular Cut)	Dorsal Fin (2 cuts)	Pectoral Fin (1 cut)	Unmarked
Actual Marks	12	12	11	8
Port Sampler Assessment	9	12	11	11

* The initial count of fish and the port sampler count didn't add up, indicating an error was made by one

Table 3. The numerical data used to calculate p values for the marked and port sampler sex ratios, with the top table showing fish included in those calculations and the bottom table showing fish excluded from those calculations. Test fish refers to all fish with experimental markings that were not representative of correct marks, while test fish* refers to fish that were purposefully marked as the wrong sex. The p value for the marked sex ratio was calculated using marked (no test or test*) as observed values and true (all fish) as expected values, while the p value for the port sampler sex ratio used port sampler (no test) as observed values and marked (no test) as expected values.

Included in Calculation	True (All Fish)	Marked (All Fish)	Marked (No Test)	Marked (No Test or Test*)	Port Sampler (All Fish)	Port Sampler (No Test)
Female	206	176	176	176	163	158
Male	46	40	39	31	44	42
Unmarked	2	38	31	31	40	39

Excluded from Calculation	True (All Fish)	Marked (All Fish)	Marked (No Test)	Marked (No Test or Test*)	Port Sampler (All Fish)	Port Sampler (No Test)
Test Fish	0	0	8	8	0	8
Test Fish*	0	0	0	8	0	0
Fish missing tags	0	0	0	0	7	7

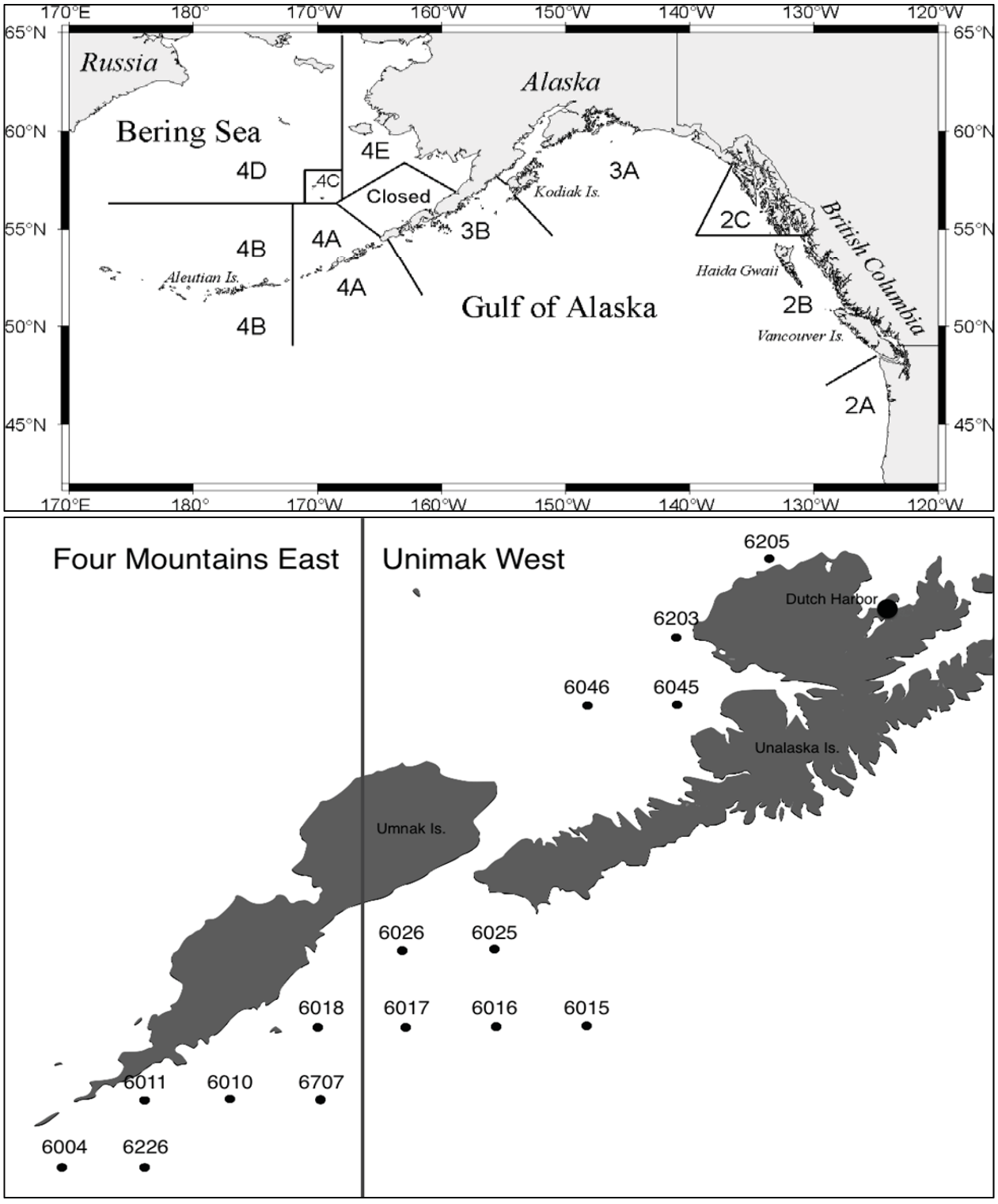


Figure 1. A map of the IPHC regulatory areas (top) and a map of Unimak West and Four Mountains East charter regions in Area 4A (bottom) including the stations the *F/V Kema Sue* fished from July 26 to July 31, 2014.

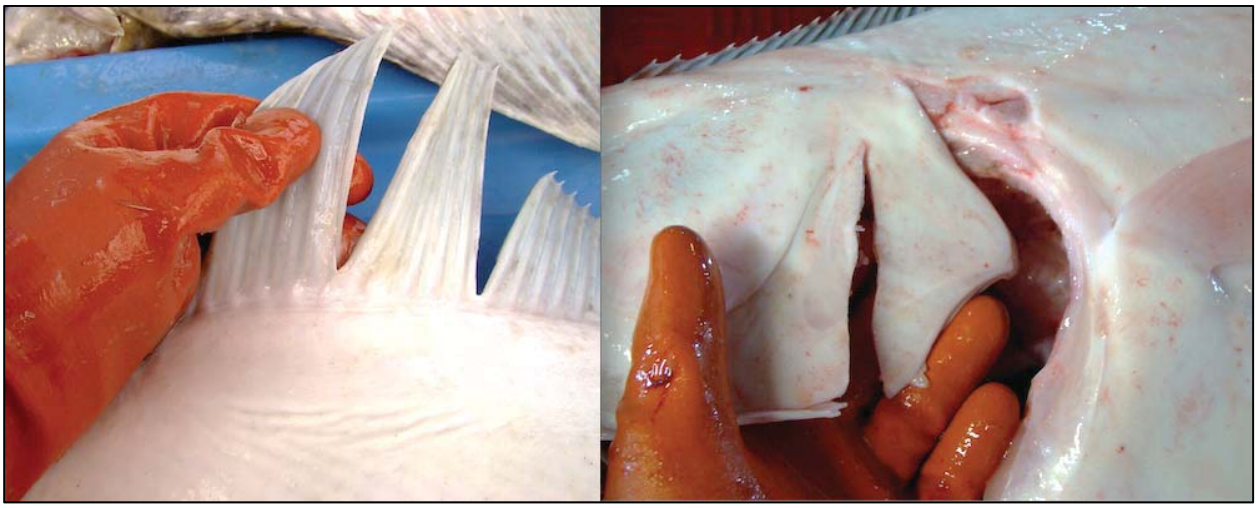


Figure 2. The final knife cuts used in the project, with the female cut on the left and the male cut on the right. The female cut consists of two knife cuts in the dorsal fin, starting close to the body and cutting outwards. The male cut consists of a single knife cut in the gill plate, starting in the top region of the flap and cutting down until the bottom of the flap becomes severed from the rest of gill flap.

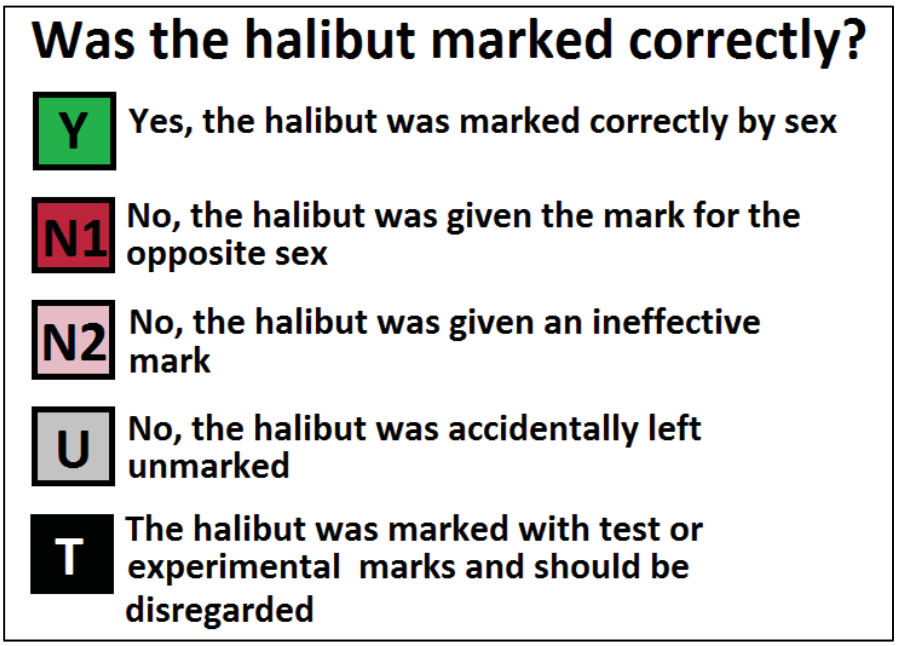


Figure 3. The key containing the accuracy codes used to assess crew member marking accuracy when dressing halibut.

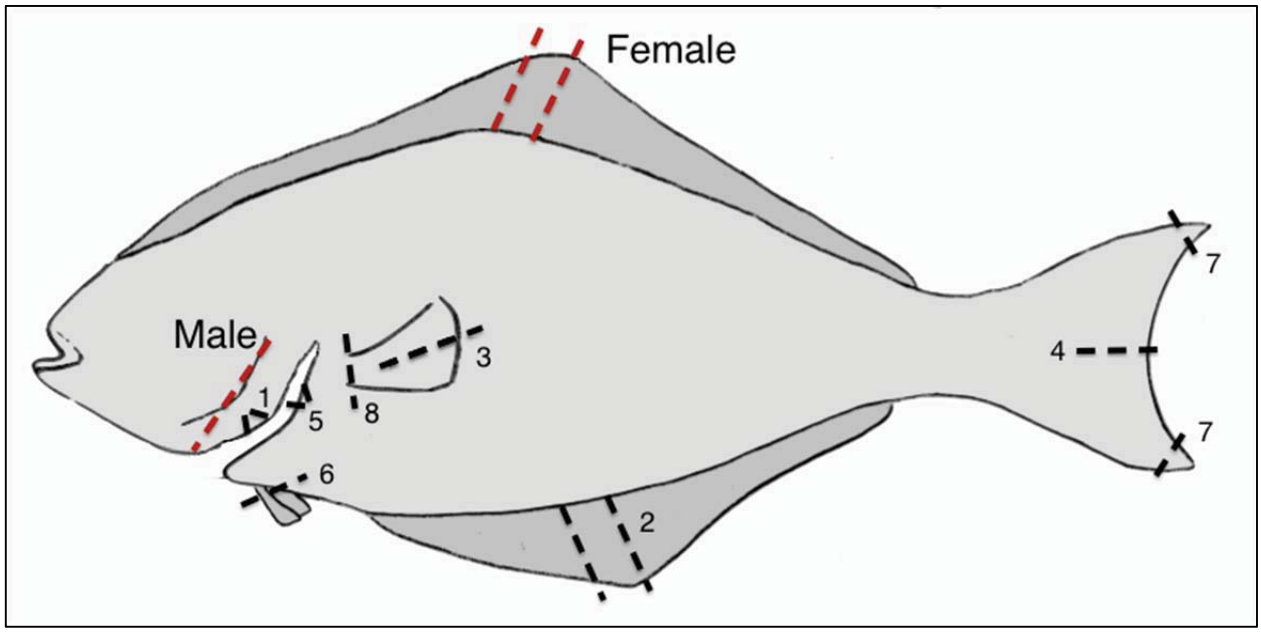


Figure 4. Diagram of all attempted knife cuts numbered by their feasibility, with one being the most feasible and eight being the least. The final male and female knife cuts are shown as well. The descriptions accompanying each number are outlined in Table 1.



Figure 5. Experimental knife cuts used in Homer, AK and Dutch Harbor, AK before being passed over for marks in Figure 2. The triangular gill cut mark (left) was initially used onboard the F/V Kema Sue to mark males before switching to the gill plate cut (Fig. 2). The pectoral fin cut (right) was abandoned due to difficulty making the cut, as well as a worksite injury it resulted in.

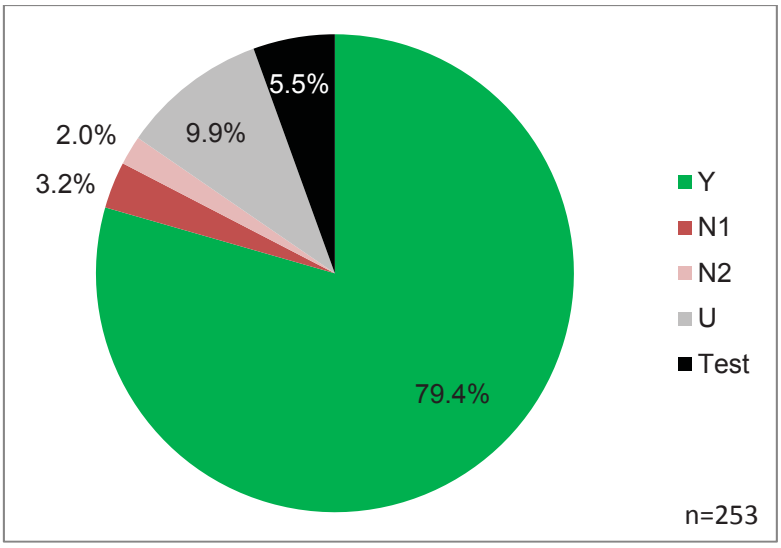


Figure 6. The percentage of fish that were marked successfully (Y), that were given the opposite sex mark (N1), that were mark with an ineffective mark (N2), accidentally unmarked (U), or given test or trial markings (Test) by the crew aboard the *F/V Kema Sue*.

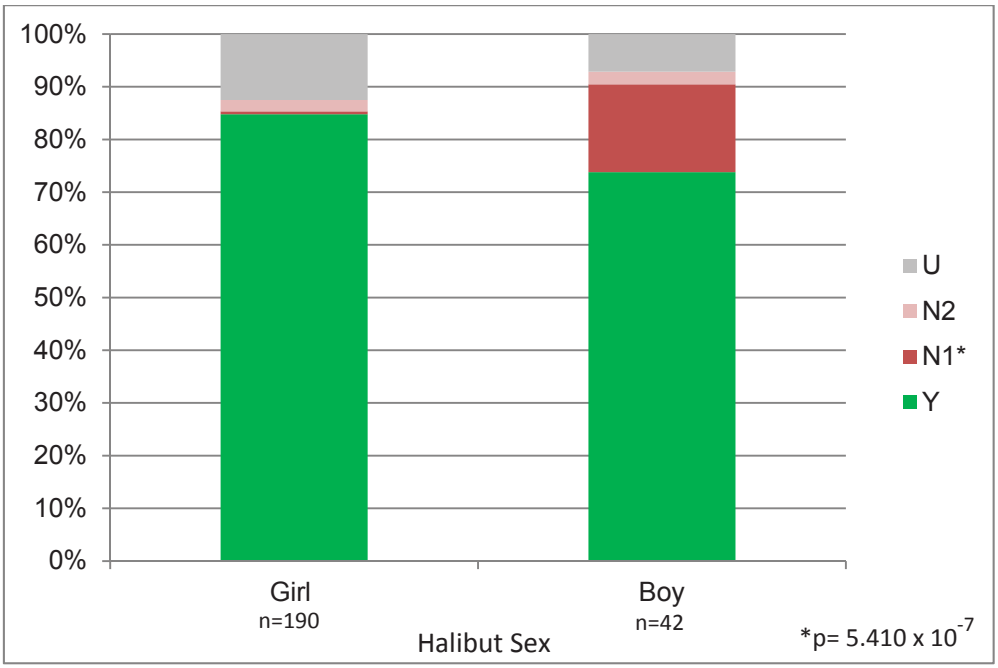


Figure 7. The marking accuracy of crew members aboard the *F/V Kema Sue* for male and female halibut. A significant difference in the prevalence of a marking error between sexes is denoted, and p values for significant differences are included.

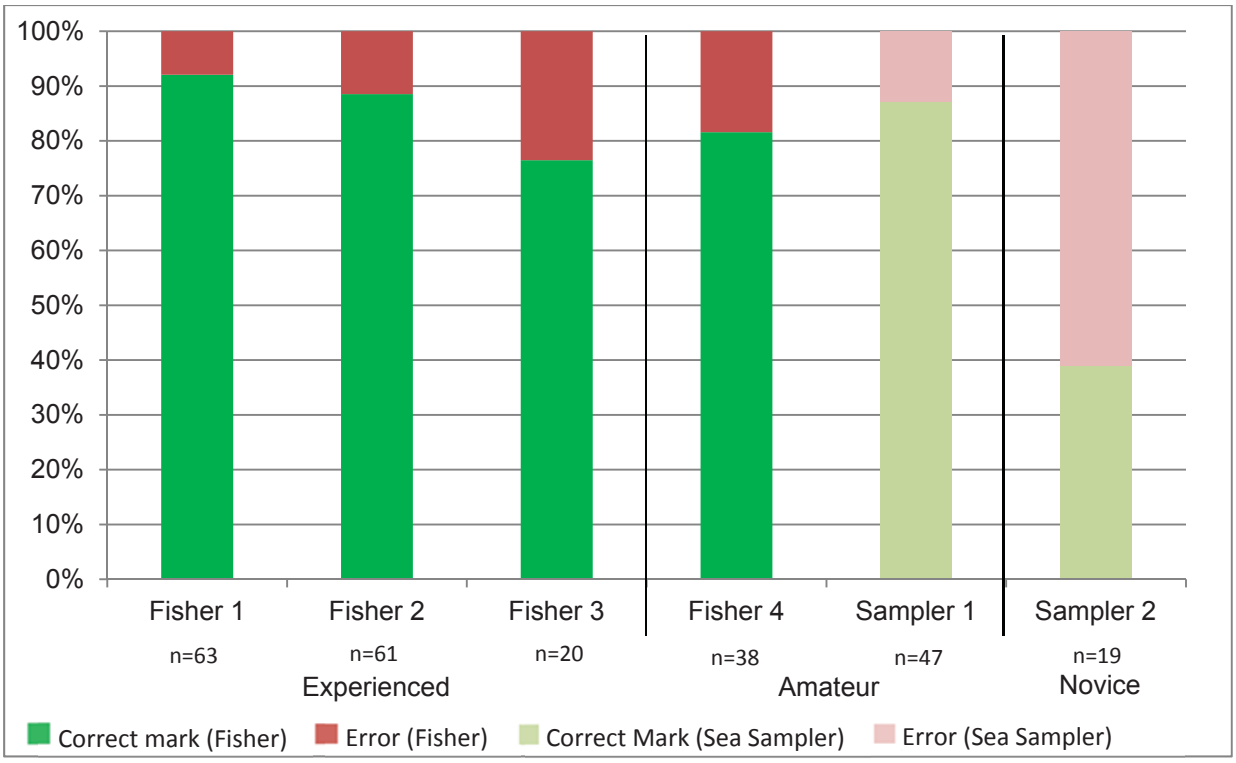


Figure 8. The accuracy of individual crew members aboard the *F/V Kema Sue* denoting the proportion of fish marked correctly and the proportion of fish either unmarked or mistakenly marked (N1, N2, or U). Crew members are broken down by experience level and occupation (fisher or sea sampler). Crew members were considered experienced if they had dressed halibut for multiple seasons, amateur if they had learned this season, and novice if they learned during the week long survey trip. Test fish were not included.

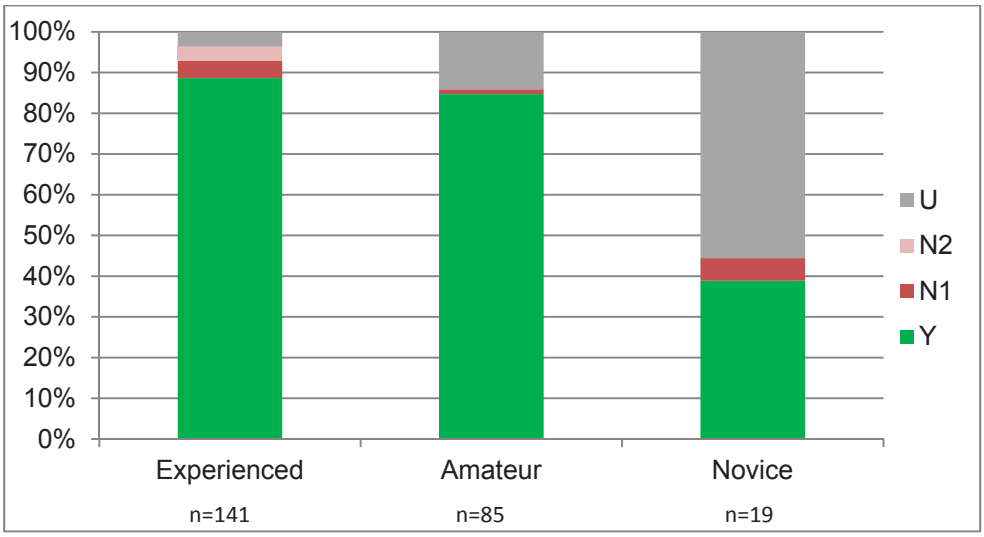


Figure 9. The accuracy of crew members aboard the *F/V Kema Sue* grouped by experience level denoting the proportion of fish marked correctly and the proportion of fish either unmarked or mistakenly marked, separated by error type.

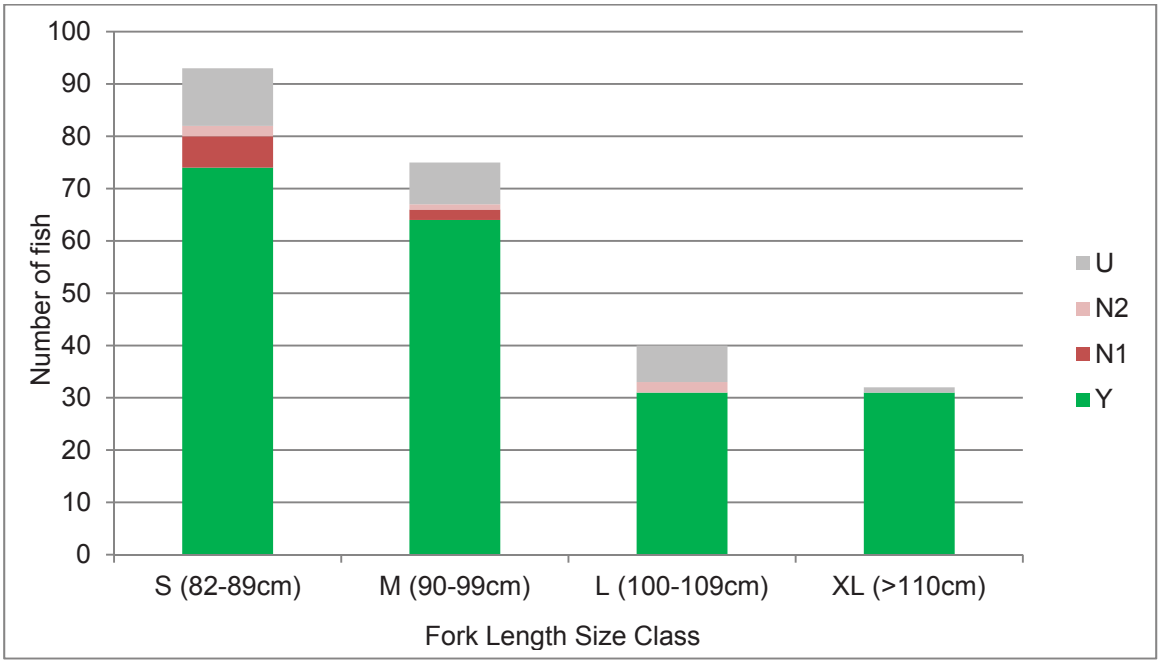


Figure 10. The accuracy of marks made by crew members aboard the *F/V Kema Sue* grouped by size class, denoting the proportion of fish marked correctly and the proportion of fish either unmarked or mistakenly marked, separated by error type. Test fish were not included.

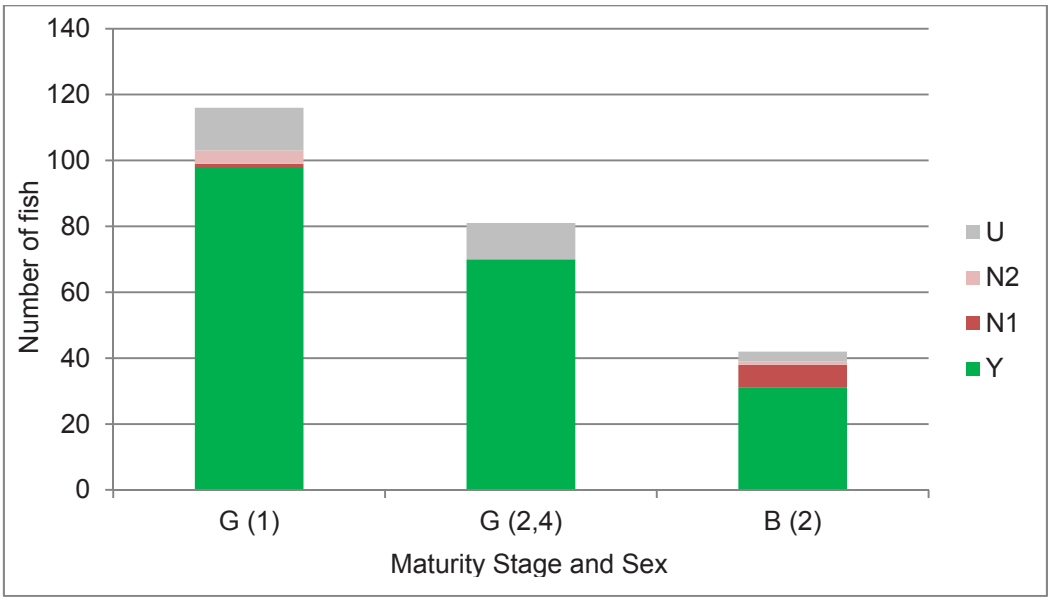


Figure 11. The accuracy of marks made by crew members aboard the *F/V Kema Sue* grouped by maturity stage (as discerned from halibut gonads by sea samplers), denoting the proportion of fish marked correctly and the proportion of fish either unmarked or mistakenly marked, separated by error type. G(1) refers to immature females, G(2,4) refer to developing or developed females, and B(2) refers to developed males. Test fish were not included.

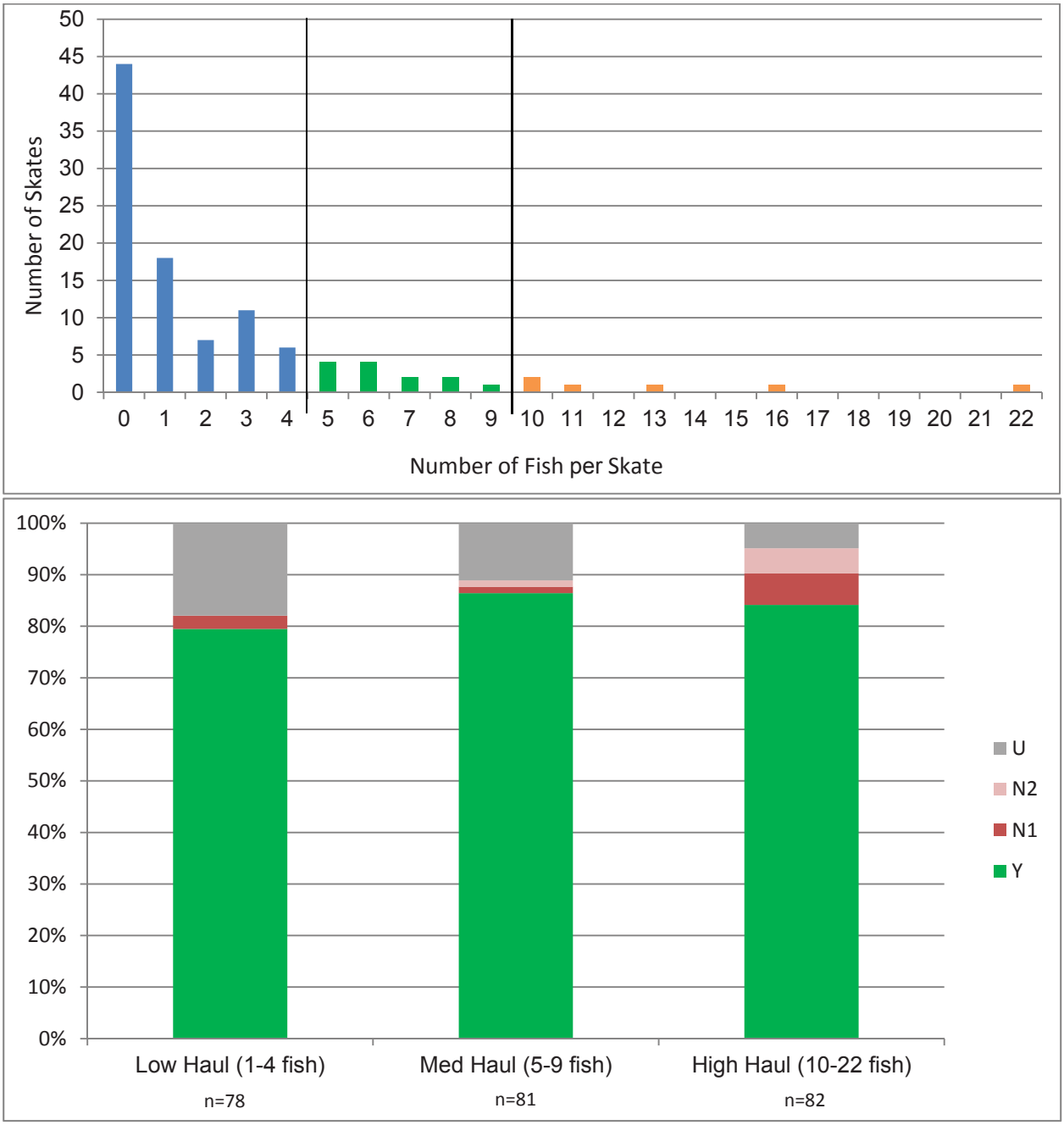


Figure 12. The top figure shows the distribution of skates by the number of fish caught on each skate (haul size), as well as the divisions of low haul, medium haul, and high haul used in the bottom figure. The bottom figure shows the accuracy of crew member marks based on the haul size of each skate.

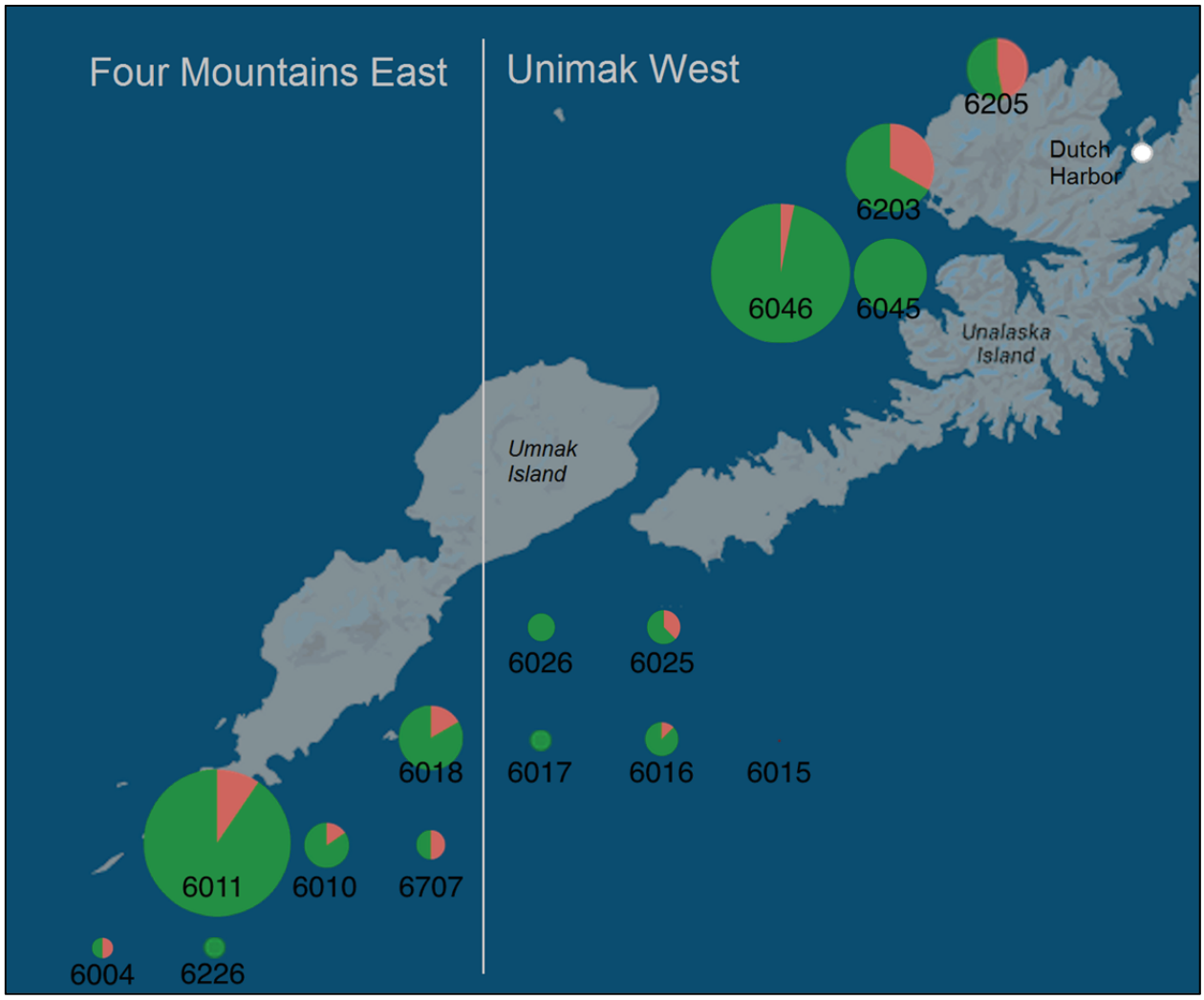


Figure 13. The stations fished by the F/V Kema Sue represented graphically by the proportion of catch left unmarked by the crew (red) or marked by the crew (green). The size of the station is directly related to the number of fish caught at that station, with the most fish being caught at station 6011 (n=63) and the least at station 6015 (n=0).

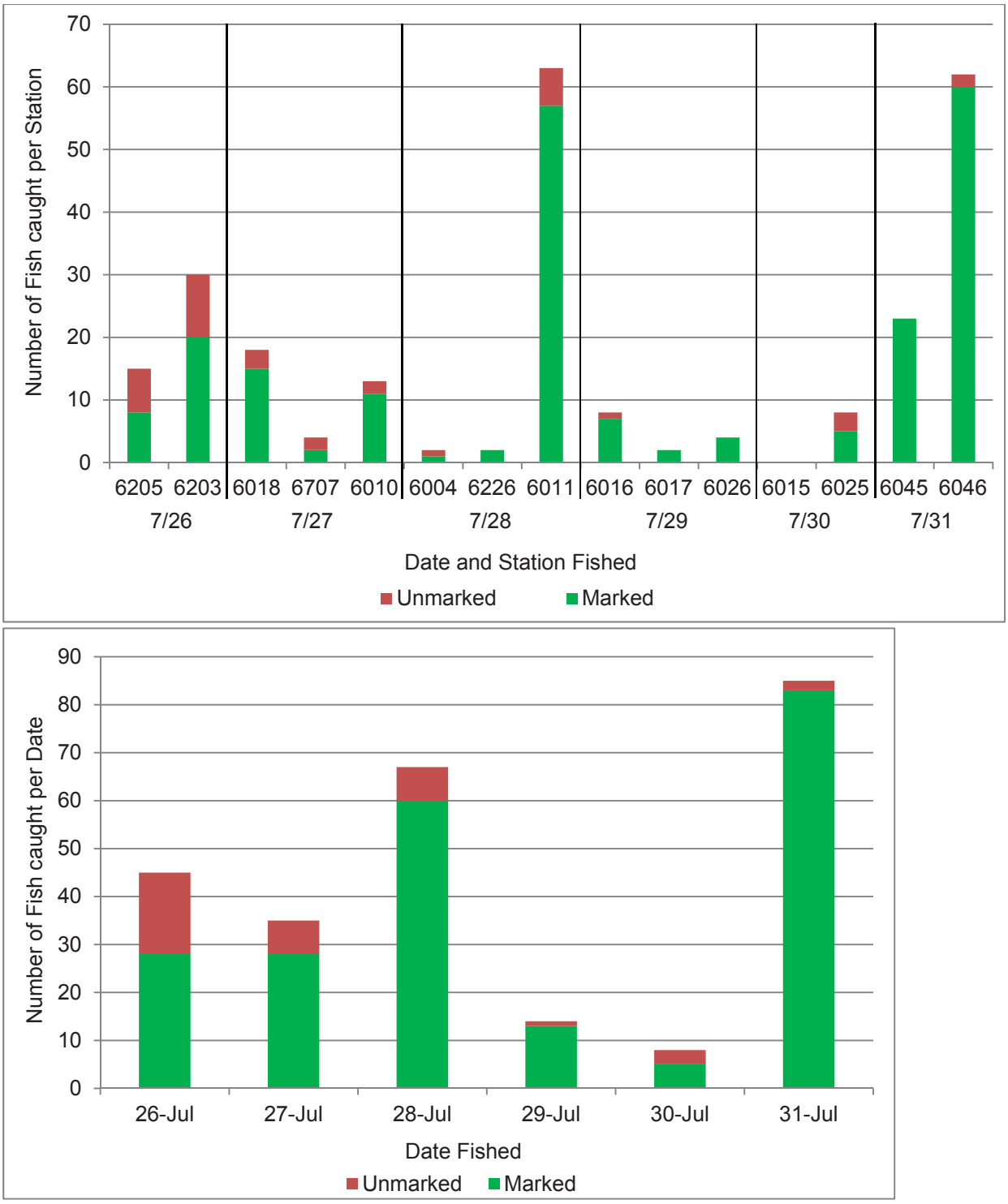


Figure 14. The above figure illustrates the changes in marking frequency over time, showing the number of marked and unmarked fish per station (top) and the number of marked and unmarked fish per day (bottom). Test fish are not included.

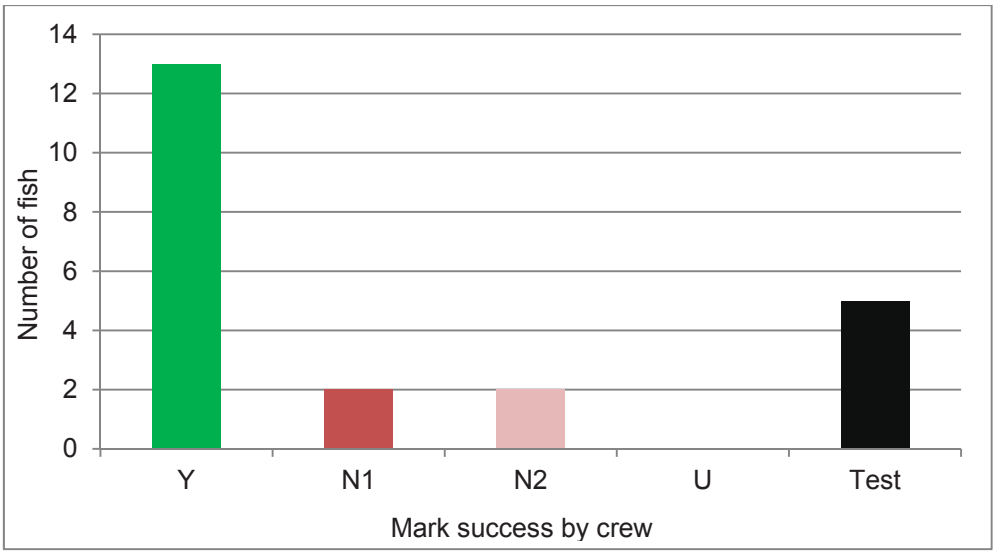


Figure 15. The success of original crew marks for all fish mistakenly identified by the port sampler.

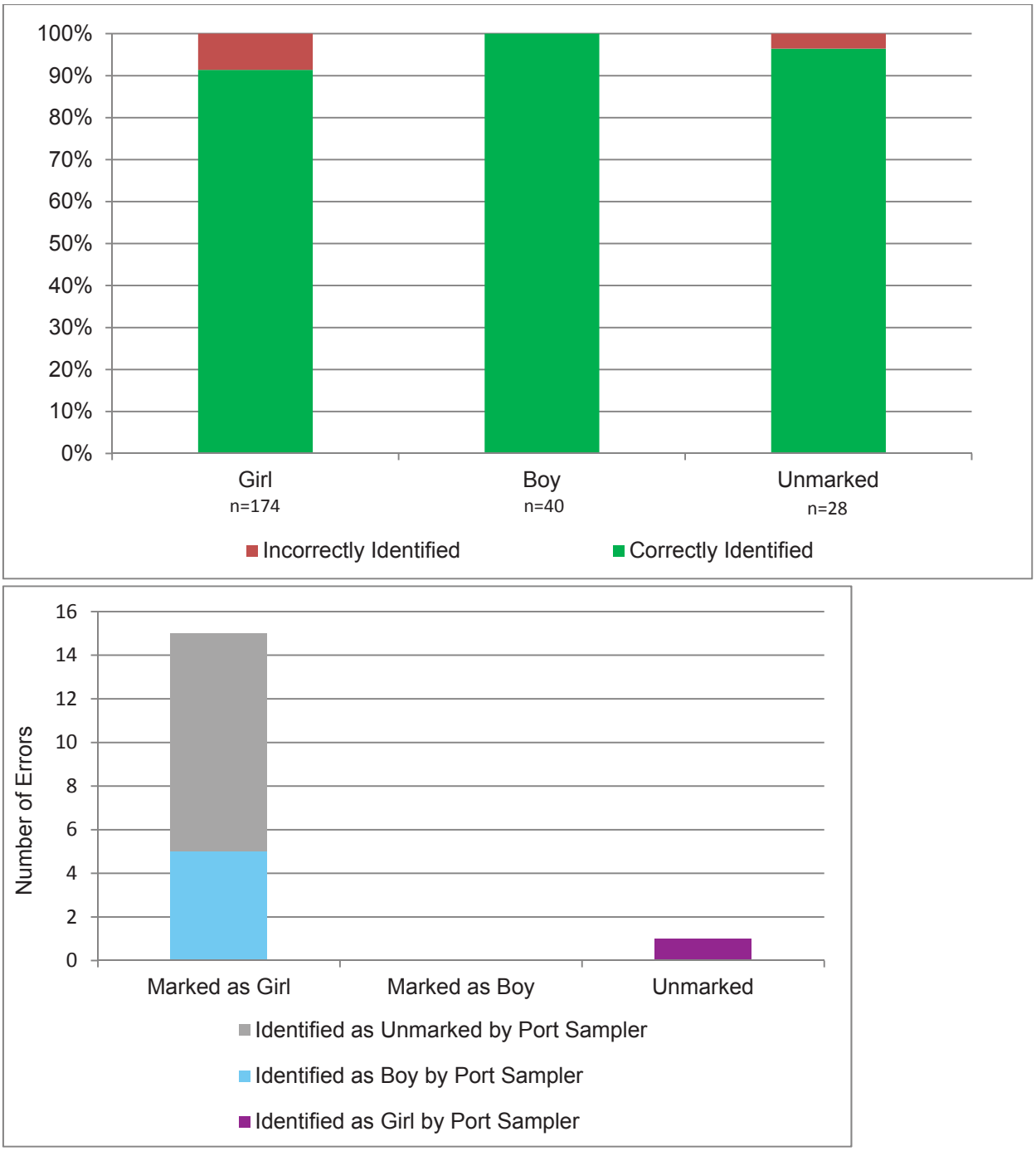


Figure 16. The accuracy of port sampler sex assessment based on crew member marks, not the actual sex of the fish, for fish marked as girls, boys, and unmarked fish (top). The port sampler assessment errors are shown in the bottom figure, grouped by the original crew member mark and subdivided by the erroneous port sampler assessment.

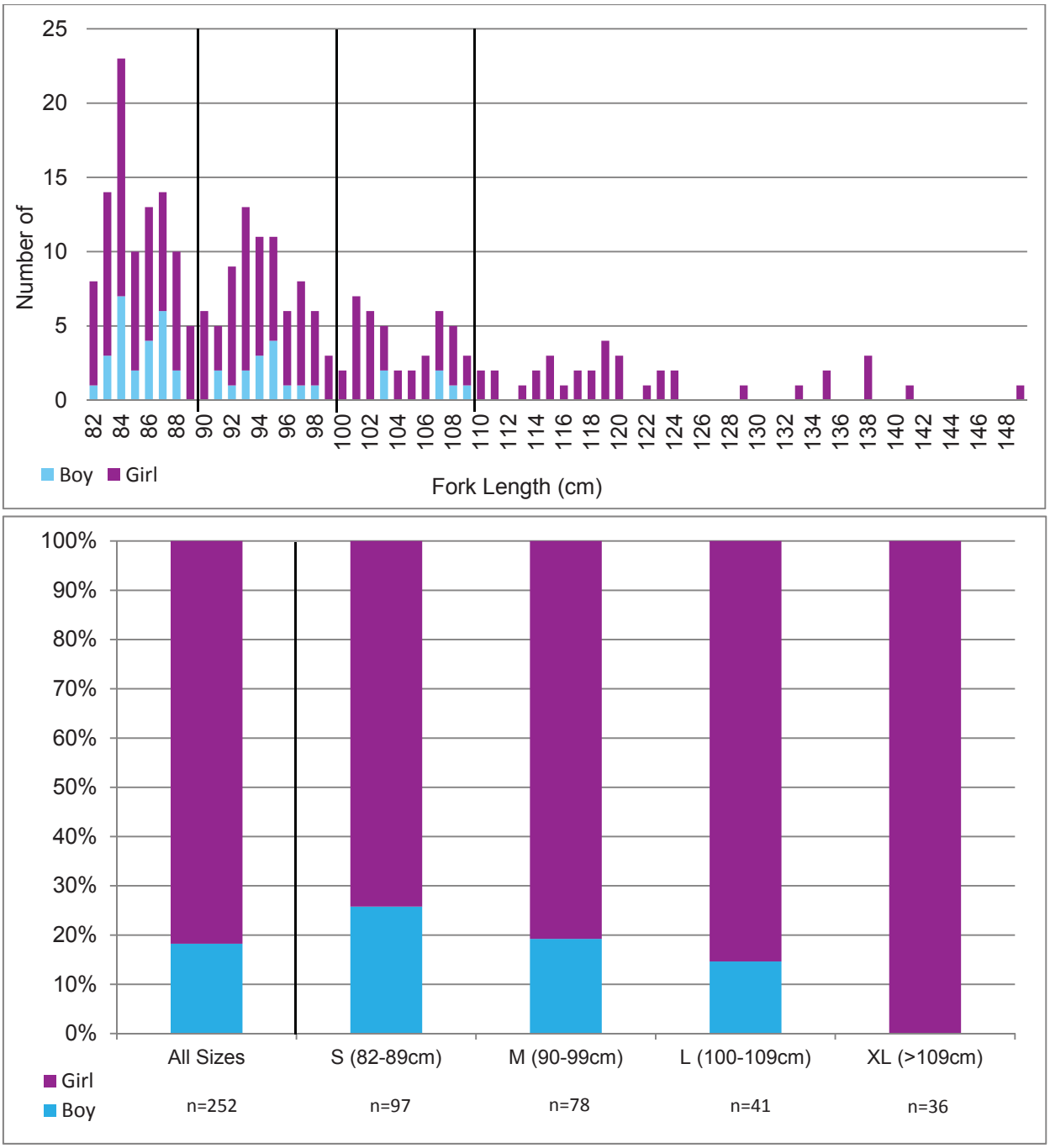


Figure 17. The sex ratio of the *F/V Kema Sue* O32 catch by fork length (top) and size class (bottom), as well as the sex ratio across all O32 fish caught (bottom). All sex ratios were determined from assessment of fish gonads.

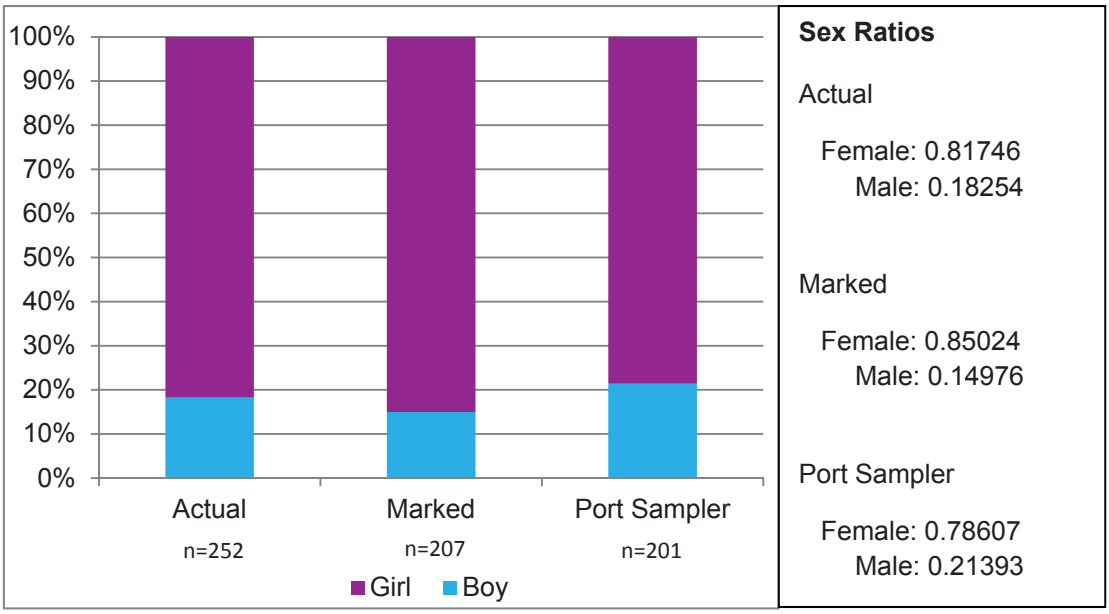


Figure 18. The sex ratio of the O32 halibut caught while aboard the *F/V Kema Sue*. The "Actual" sex ratio was determined from the gonads of the fish caught, which is the current method of sexing fish used by IPHC sea samplers. The "Marked" sex ratio was determined by the using the knife cuts given to the halibut by crew members as a proxy for sex. The "Port Sampler" sex ratio was obtained from the port sampler's assessment of the offload, using marks created by crew members as a proxy for sex. The numerical sex ratios are shown on the right. Marked and Port Sampler sex ratios were calculated excluding fish with trial marks, designated as "test fish".

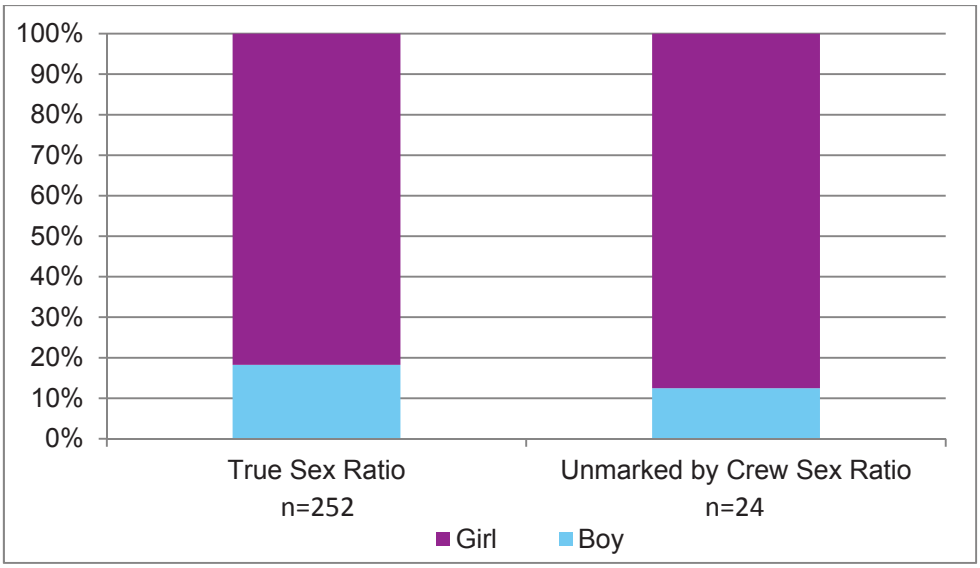


Figure 19. The "True sex ratio" refers to the biological sex ratio of all O32 halibut caught while aboard the *F/V Kema Sue*. The "Unmarked by crew" sex ratio was determined from only fish that were accidently left unmarked by the crew. Sex ratios were determined by looking at the gonads of the fish.

Tagging studies

Joan E. Forsberg

Abstract

Since the International Pacific Halibut Commission (IPHC) began tagging halibut in 1925, over 450,000 tagged halibut have been released and more than 50,000 of these releases have been recovered. Halibut are tagged to study migration, utilization, age, growth, and mortality. The IPHC conducted one tagging experiment in 2014 in which 12 halibut were tagged and released. Forty-four tagged halibut, representing recoveries from several different IPHC experiments and sport tag releases, were recaptured in 2014. Tags from an additional two fish were recovered in 2013 and reported to IPHC in 2014.

Introduction

Since the International Pacific Halibut Commission (IPHC) began tagging in 1925, over 450,000 tagged halibut have been released. To date, more than 50,000 of these releases have been recovered. Halibut are tagged to study migration, utilization, age, growth, and mortality.

Tag releases

The IPHC tagged and released 12 halibut with pop-up satellite transmitting archival (PAT) tags in 2014. These releases, which took place in Area 2A, are discussed in detail in Loher (2015).

Tag recoveries

Tag recoveries from a total of 34 halibut from various IPHC tagging experiments were reported in 2014, as well as 12 tags from sport tagging programs. Recoveries by experiment or tag type are discussed in the next section. Total release and recovery numbers for the most recent major IPHC tagging experiments are presented in Table 1. Current-year recoveries of tagged halibut from sport tagging programs are presented in Table 2.

Recoveries from experiments using wire tags only

In 2014, three tags from the 2010 Aleutian wire tagging study (Loher 2011) were returned. Two tags were from fish captured in 2014; the third tag was from a fish captured in 2013.

Recoveries from archival and dummy archival tag experiments

One tag from the 2011 geomagnetic-sensing archival release in Area 2C (Loher and Nielsen 2012) was recovered in 2014; this fish had one tag type attached externally to the dorsal musculature and the other type implanted internally within the coelomic cavity and both tag types were recovered. Tags from 30 fish from the 2013 dummy archival tag experiment in Regulatory Area 3A (Loher and Geernaert 2014) were returned in 2014 (29 recovered in 2014, one recovered in 2013). Twenty-four of these fish had been tagged with both a dummy archival dart tag and a plastic-coated wire cheek tag, and six had been tagged with only an external dummy archival tag attached to the operculum.

Sport tag recoveries

The IPHC continued to provide tags on a cost-recovery basis for several sport fishing derbies in 2014. The Homer Jackpot Halibut Derby released 115 tags in 2014 and eight of those tags were recovered. Additionally, three tags from previous Homer Derby releases were recovered in 2014: two from the 2011 derby and one from the 2013 derby. All of the Homer Derby tags recovered in 2014 were recovered by sport fishers during the derby.

In its third year, the Seward Halibut Tournament released 15 tags in 2014, one of which was recovered during the tournament.

The IPHC provided tags for a sport fishing derby in Coffman Cove in southeast Alaska for the second year: the Coffman Cove Derby released another five tags in 2014 and there have been no recoveries from either year's releases to date.

Other

One halibut bearing a pop-up satellite transmitting archival (PAT) tag was processed by the IPHC port sampler in Juneau. The PAT tag was not part of an IPHC release. It was from a 2013 experiment conducted in Glacier Bay by researchers at the University of Alaska Fairbanks Juneau (Seitz and Nielsen 2013). In addition, one "rogue" tag was recovered from a commercially-caught halibut landed in Port Hardy: over the last 15 or so years there have been instances of unauthorized tagging and releasing of halibut in areas of Alaska and northern Washington. These unauthorized or "rogue" tags generally have the name of the individuals or group doing the tagging imprinted on the tags. The IPHC and staff from Alaska Department of Fish and Game and National Oceanographic and Atmospheric Administration Fisheries enforcement have contacted these groups to request that they discontinue tagging of halibut and most have complied.

References

Loher, T. 2011. Wire tagging in the Aleutian Islands region as a means to identify future electronic archival tagging sites. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 369-375.

Loher, T. 2015. Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal dispersal of Pacific halibut in the southern Salish Sea. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 523-530.

Loher, T. and Geernaert, T. O. 2014. Captive holding to study halibut migration and behaviour: captive holding to develop long-term tagging protocols, and deployment of external dummy tags in IPHC Regulatory Area 3A. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 369-378.

Loher, T. and Nielsen, J. K. 2012. Test deployment of geomagnetic-sensing electronic archival tags in IPHC Regulatory Areas 2C and 3A. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 483-490.

Seitz, A. and Nielsen, J. 2013. Using pop-up satellite transmitting tags to understand Pacific halibut. Research Highlights Fall 2013. Glacier Bay National Park and Preserve. Retrieved 25 November 2014. http://www.nps.gov/glba/naturescience/upload/Seitz-2013-Highlight-FINAL-web.pdf

Table 1. Total recovery rates for the most recent major tagging experiments.

Experiment	Reg. Area of release	Release year(s)	Number released	Number recovered to date	Num. reported in 2014	Recov. rate
Glacier Bay local movement	2C	1992-96	1,592	207	0	13%
Longline mortality	3A, 3B	1993-94	13,096	1,123	0	9%
Trawl mortality	3A	1995	4,852	178	0	4%
Wire/PIT double-tagging (3A)	3A	2001	281	30	0	11%
Wire/PIT double-tagging (2B)	2B	2003	2,661	731	0	27%
PIT tagging (coastwide)	2A through 4D	2003	43,999	2,266	0	5%
PIT tagging (2B and 3A)	2B, 3A	2004	23,437	1,179	0	5%
PAT tagging Gulf spawning	2B, 2C, 3A, 3B	2002	12	0*	0	0%
PAT tagging Bering Sea spawning	4C, 4D	2002	11	0*	0	0%
PAT tagging Bering Sea spawning	4B	2004	25	1*	0	4%
PAT tagging Gulf migration timing	2B, 2C, 3A, 3B	2005	49	15*	0	31%
PAT tagging Bering Sea spawning	4A, 4D	2006	24	2*	0	8%
PAT tagging Area 2 dispersal	2A, 2B	2006	78	12*	0	15%
PAT tagging Bering Sea dispersal	4A, 4B, 4C, 4D	2008	115	5*	0	4%
PAT tagging Bering Sea dispersal	4A, 4C, 4D	2009	17	1*	0	6%
Archival tagging (2B)	2B	2008	166	22	0	13%
Wire/dummy archival double-tagging	3A	2009	200	39	0	20%
Aleutian wire tagging	4B	2010	773	41	3	5%
Geomagnetic-sensing archival	2C, 3A	2011	30	2	1	7%
External dummy archival attachment	3A	2013	901	12	30	5%

* refers to physical recovery of tagged fish, not pop-up data broadcast to satellite

Table 2. Sport tag recoveries in 2014.

Release source	Number recovered in 2014
Homer Jackpot Halibut Derby	11
Seward Halibut Tournament	1

Captive holding to develop long-term archival tagging protocols in Pacific halibut

Timothy Loher and Tracee O. Geernaert

Abstract

In 2006, the International Pacific Halibut Commission began investigating the use of fishery-recaptured archival tags in order to extend its electronic tagging program to study multi-year behavior of individual halibut and behavior of fish that have traditionally been considered too small to carry pop-up archival transmitting tags. The program began with a captive holding experiment designed to develop surgical techniques for internal tag implantation and, in 2009, a second holding experiment was initiated to investigate external tag-mounting protocols and compare them to internal tag implantation results. A total of 30 halibut, in captivity at the Oregon Coast Aquarium (Newport, Oregon), were tagged with inactive, "dummy" archival tags using a variety of experimental treatments that included through-body dorsal attachment, opercular attachment initially oriented either perpendicularly or parallel to the main axis of the fish, three external dart-and-tether configurations, two intramuscular dart-and-tether configurations, and a treatment of intracoelomic implantation that will allow external tagging results to be directly compared to the effectiveness of surgical methods. This report provides a brief summary of the ongoing holding experiment.

Introduction

In 2002, the International Pacific Halibut Commission (IPHC) began an electronic archival tagging program with the intention of investigating seasonal movements of halibut. This program has five main goals: 1) quantify migration distances between summer and winter grounds; 2) identify winter spawning areas in poorly-studied regions such as the Bering Sea; 3) examine basin-specific differences in interannual site fidelity; 4) define seasonal migration periods and seasonal depth-specific habitat use, representing the stock's transition between shallow-water summer distribution and deep-water winter distribution; and 5) define active spawning periods on a regional basis as evidenced by short-period vertical migratory behavior.

Electronic archival tags have been proven an effective tool for studying behavior and environmental conditions experienced by a variety of marine fish species, including plaice (*Pleuronectes platessa*; Hunter et al. 2003, Solmundsson et al. 2003), bluefin tuna (*Thunnus thynnus*; Block et al. 2001, Kitagawa et al. 2004, Teo et al. 2004), bigeye tuna (*Thunnus obesus*; Schaefer and Fuller 2005) and school sharks (*Galeorhinus galeus*; West and Stevens 2001). To date, studies on Pacific halibut have primarily employed pop-up archival transmitting (PAT) tags that allow accumulated data to be retrieved without the need to recapture the fish (Loher and Seitz 2006, Loher 2008, Loher and Blood 2009, Loher and Clark 2010, Seitz et al. 2011). However, while PAT tags have proven valuable for studying a variety of processes, deployments of more than one year are inadvisable due to tag loss and battery-life limitations. Additionally, the relatively large size of PAT tags means that only the behavior of relatively large halibut can be studied. In order to fully understand halibut movement, behavior, and population structure, the IPHC's

electronic tagging program must expand to include smaller fish and longer periods of observation of individual fish.

Electronic archival tags are continually becoming smaller, the types of data that they are able to collect are continually expanding, and battery life and memory capacity have advanced to such a degree that archival tags now have the capacity to record high-resolution data for periods in excess of five years. These advancements provide an opportunity to monitor behavior for periods that span the juvenile-to-adult transition in long-lived species such as halibut. However, the ability of modern archival tags to record data for such long periods of time challenges previous definitions of "long-term" tag retention and holding studies. Rather than being limited by tag life, modern behavioral studies may be constrained to a greater degree by the ability to secure tags to fish and recover unbiased data after periods that may well approach a decade. The current study was designed to investigate methods for affixing tags to halibut for periods of five years or more, and compares retention and apparent physiological and behavioral impacts of external tagging methods to those already developed for internal implantation (*sensu* Loher and Rensmeyer 2011).

Summary of tagging

In total, ten tagging treatments have been employed in this study. The configurations are:

1. Intracoelomic implantation of a cylindrical tag (Lotek model LAT 1800cl).
2. External to the dorsal musculature using a cylindrical tag (Lotek model LTD 2310) mounted on a polyvinylchloride (PVC) cradle.
3. External to the dorsal musculature using a flattened ("flat pack") tag (model LAT 1800fp) resting directly on the fish.
4. Attachment to the operculum (LAT 1800fp), oriented perpendicular to the fish's main axis.
5. Attachment to the operculum (LAT 1800fp), oriented parallel (longitudinal) to the fish's main axis.
6. External to the dorsal musculature via dart-and-tether (LAT 1800fp), using a flat titanium dart.
7. External to the dorsal musculature via dart-and-tether (LAT 1800fp), using a flat stainless steel dart.
8. External to the dorsal musculature via dart-and-tether (LAT 1800fp), using a cylindrical PVC dart.
9. Embedded in the dorsal musculature via dart-and-tether (LAT 1800cl), using a flat stainless steel dart.
10. Embedded in the dorsal musculature via dart-and-tether (LAT 1800cl), using a cylindrical PVC dart.

Treatments 1-4 and 6 were initiated at the beginning of the experiment, during November 2009, and are fully detailed in Loher and Geernaert (2010, 2011). Treatment 5 was initiated on March 24, 2011, and Treatments 7-10 on May 20, 2011; these treatments are fully detailed in Loher and Geernaert (2012).

Results to date

Physical examination and behavioral observation of tagged fish has occurred at 0, 2, 5, 13, 22, 32, 44, 54, 69, 77, 86, 106, 115, 126, 146, 167, 179, 203, 223, and 248 weeks following initial tagging. Treatments 1-4 and 6 were initiated at week 0; Treatment 5 was initiated at week 69; and Treatments 7-10 were initiated at week 77. The holding period is expected to be terminated in mid-December of 2014, at which time the remaining tags will be removed from all fish in order to allow them to recover, in preparation for their potential use in other investigation(s).

Nine mortalities have occurred since the beginning of the post-tagging period. The first mortality was an internally implanted (Treatment 1) fish that died during week 6; it had experienced complete suture failure shortly after implantation as a result of considerable abdominal distension associated with heavy feeding. This caused the fish's intestines to sometimes extrude through the incision when fully fed. It bears noting that this fish's incision had been closed using only three stitches, a procedure now deemed unacceptable, given that no suture loss has been observed in any individual where four or five stitches were used. The second and third mortalities were an untagged control fish that died during week 48 and an externally titanium-darted (Treatment 6) fish that died during week 100; the cause(s) of mortality of these fish were not apparent. The fourth and fifth fish were lost in spring and summer of 2013 due to ovarian septicaemia; i.e., these fish achieved spawning condition during the winter of 2012-2013, were unable to either fully extrude or re-absorb their eggs, and developed critical internal infections as a result. One of these fish had been 'through-body' tagged with an external flat pack (Treatment 3; died in April, during week 175) and the other had been tagged using a stainless steel dart-and-tether (Treatment 7; died in July, during week 188. During May 2013 (week 182), the sixth fish, with a tag that had been internally-implanted (Treatment 1), died after having been notably thin and weak for at least 8 months and having become apparently blind in one eye earlier that spring. Following its death, this fish was dissected and inspected for physiological tag interactions, including intestinal adhesions and blockages; none were found, and its ultimate cause of death remains unknown. Three additional fish were lost during the autumn of 2013: one control-group individual, one fish from Treatment 5, and one from Treatment 10. The proximate cause of death of the control fish appeared to be starvation, after becoming blind in both eyes. The other two fish died from complications associated with ovarian septicaemia.

Persistent irritation and open tagging wounds have been observed for all through-body dorsal (Treatments 1 & 2) and opercular (Treatments 3 & 4) attachment configurations. Tag shedding has been observed for both of the through-body dorsal methods (i.e., with a cradle and direct-to-body) and for both opercular attachment methods. Given that the cradle-mounted configuration represented one that was not expected to be employed again *in situ*, Treatment 2 was terminated at week 77 and the tags were removed from those individuals that still bore them (n = 2). Rapid (i.e., within 10 weeks) extrusion of the intramuscular tags (Treatments 9 and 10) was observed; however, none of these tags had been shed after more than three years of observation. Rather, the darts have remained embedded in the fish while the tag bodies have become external. Dissection of the individual that died on November 17, 2013, confirmed that the tagging dart was still locked "beneath" (i.e., resting on the blind side of) the pterygiophores, as originally inserted. The tag-body had migrated to the surface by "rising" to a position directly above the tagging dart. That is, the tag had not "backed out" of the original insertion channel; rather, it had migrated through the flesh to emerge from a new location located more anteriorly than where it had been inserted.

No obvious behavioral differences have been noted among treatment groups. Behavioral data will be statistically analyzed at the end of the experiment.

References

Block, B. A., Dewar, H., Blackwell, S., Williams, T. D., Prince, E. D., Farwell, C. J., Boustany, A., Teo, S. L. H., Seitz, A., Walli, A., and Fudge, D. 2001. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. Science 293:1310-1314.

Hunter, E., Metcalfe, J. D., and Reynolds, J. D. 2003. Migration route and spawning area fidelity by North Sea plaice. Proc. Royal Soc. London 270:2097-2103.

Kitagawa, T., Kimura, S., Nakata, H., and Yamada, H. 2004. Diving behavior of immature, feeding Pacific bluefin tuna (*Thunnus thynnus orientalis*) in relation to season and area: the east China Sea and the Kuroshio-Oyashio transition region. Fish. Oceanogr. 13:161-180.

Loher, T. 2008. Homing and summer feeding site fidelity of Pacific halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska, established using satellite-transmitting archival tags. Fish. Res. 92:63-69.

Loher, T. and Blood, C. 2009. Seasonal dispersion of Pacific halibut (*Hippoglossus stenolepis*) summering off British Columbia and the US Pacific Northwest evaluated via satellite archival tagging. Can. J. Fish. Aquat. Sci. 66:1409-1422.

Loher, T. and Clark, W. G. 2010. Deployment of pop-up archival transmitting (PAT) tags to study interannual dispersal and seasonal migration timing in IPHC Regulatory Area 4. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009: 537-551.

Loher, T. and Geernaert, T. O. 2010. Archival tagging to study halibut migration and behavior: captive holding to develop external tagging protocols, and deployment of internal and external dummy tags off Kodiak Island. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009: 345-351.

Loher, T. and Geernaert, T. O. 2011. Archival tagging to study halibut migration and behavior: captive holding to develop external tagging protocols, and deployment of internal and external dummy tags off Kodiak Island. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 521-535.

Loher, T. and Geernaert, T. O. 2012. Captive holding to develop external archival tagging protocols for pacific halibut, and comparison to internal implantation. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 475-482.

Loher, T. and Rensmeyer, R. 2011. Physiological responses by Pacific halibut, *Hippoglossus stenolepis*, to intracoelomic implantation of archival tags, with a review of tag implantation techniques employed in flatfishes. Rev. Fish Biol. Fish. 21:97-115.

Loher, T. and Seitz, A. 2006. Seasonal migration and environmental conditions experienced by Pacific halibut *Hippoglossus stenolepis*, elucidated from pop-up archival transmitting (PAT) tags. Mar. Ecol. Prog. Ser. 317:259-271.

Schaefer, K. M. and Fuller, D. W. 2005. Behavior of bigeye tuna (*Thunnus obesus*) and skipjack (*Katsuwonus pelamis*) tunas within aggregations associated with floating objects in the equatorial eastern Pacific. Mar. Biol. 146:781-792.

Seitz. A., Loher, T., Norcross, B. L., and Nielsen, J. L. 2011. Dispersal and behavior of Pacific halibut *Hippoglossus stenolepis* in the Bering Sea and Aleutian Islands region. Aquat. Biol. 12:225-239.

Solmundsson, J., Karlsson, H., and Palsson, J. 2003. Sexual differences in spawning behavior and catchability of plaice (*Pleuronectes platessa*) west of Iceland. Fish. Res. 61:57-71.

Teo, S. L. H., Boustany, A., Blackwell, S., Walli, A., Weng, C., and Block, B. 2004. Validation of geolocation estimates based on light level and sea surface temperature from electronic tags. Mar. Ecol. Prog. Ser. 283:81-98.

West, G. J. and Stevens, J. D. 2001. Archival tagging of school shark, *Galeorhinus galeus*, in Australia: initial results. Env. Biol. Fish. 60:283-298.

Trawl tag releases of small halibut in the Bering Sea

Raymond A. Webster

Abstract

A re-examination of historical tagging data from small (fork length less than 65 cm) halibut released into the Bering Sea show high rates of movement into the Gulf of Alaska over the course of several years following release. We conclude that a combination of low recovery rates from the most representative releases, unrepresentativeness of releases with higher recovery rates, and the lack of consistent simultaneous tagging programs in the Gulf likely preclude the estimations of reliable, unbiased migration rates from the Bering Sea into the Gulf of Alaska from these data. Future tagging studies that aim to estimate such rates should be based on tags that can be recovered independent of halibut fisheries, but at present, it is unclear whether the newest generation of pop-up tags would be appropriate for use on any but the largest of the fish under 65 cm in length.

Introduction

Beginning with a pilot in 1963, the International Pacific Halibut Commission (IPHC) initiated a tagging program on trawl surveys for the purpose of studying the migration and recruitment of small fish. This Trawl Recruitment Series (TRS) release program continued with some interruptions until 1986, and included extensive tagging of small (<65 cm, designated "juvenile" at the time) halibut in the Bering Sea (BS). Bering Sea tags were released from 1963-1971, and from 1976-1986, with peak releases of small halibut occurring in 1970-1971 (over 2000 tags per year), 1981 (3128 tags) and 1985 (4320 tags) according to IPHC database records (Table 1). Kaimmer (2000) also describes Bering Sea releases in 1983 and 1984, but no such releases appear in the database. It is likely there is an error in that report, and instead, the author was referring to Area 4A releases in the Gulf of Alaska (GOA).

Other, generally smaller, releases of small tagged fish have occurred in the Bering Sea since 1930 as part of other research studies (Table 2). Database records are incomplete or missing for the early studies, and only data from recovered tagged fish have been entered into the database. No recoveries of releases under 65 cm in length are recorded from the 1947-1959 releases.

The IPHC databases have records on 21,637 halibut under 65 cm in length tagged and released in the Bering Sea. Of these, 557 have at least the year of recovery recorded, and 529, of these, have either a recovery position or recovery statistical area recorded, allowing us to examine movement patterns of recovered halibut.

TRS study designs

The basic survey design for the Bering Sea TRS was a grid of stations within and nearby Bristol Bay. This standard grid was expanded to the west and north in some years, and augmented with shallower inshore stations in most years. The location of stations that conform to the grid alignment (and at which tags were released) are clearly distinguishable from any supplementary stations that were not aligned to the grid on Figures 1a to 1c. Information on tag release locations

is found in the IPHC database. Reports describing TRS tag releases provide some information on how fish were selected for tagging:

- Tagging was undertaken on selected summer survey hauls, with a few days of tagging scheduled when catch numbers were adequate (Best 1974, 1977).
- On completion of sampling for ages, all viable halibut remaining in a vessel's live tank were tagged, with different protocols for small (< 65 cm) and large halibut (Best 1969 a, b).
- In some years, additional hauls were undertaken at high-density locations in order to increase the sample sizes of tagged fish (Best 1974).

In most documents, hauls on which tagging took place are not identified, making it impossible to distinguish stations which were targeted for tagging, but on which no fish were released because no viable halibut were available, from those on which no tagging took place. This makes it more difficult to evaluate the representativeness of the released fish with respect to the underlying population.

Best (1970) reviewed the earliest TRS surveys from 1963, 1965, and 1966. The former two took place on the Bering Sea flats, almost as far west as the Pribilof Islands, and south of Nunivak island. The 1966 survey extended as far north as Nunivak and almost as far west as St Matthew Island, although small tagged halibut were not released that far west. In 1967, the survey was expanded almost as far north as St Lawrence Island (Best 1969a) and tagged fish were released at 62 °N. Figure 1a shows the extent of the 1960s releases.

Best (1974) describes the Bering Sea trawl surveys of 1970-72. Tagged fish were released as part of the TRS only in 1970 and 1971 on selected hauls on the standard Bering Sea grid. Additional fishing was concentrated around the northeastern part of Unimak Island in order to obtain larger sample sizes for tagging. Database records show that the fish caught through these efforts comprise the bulk of fish tagged in 1970-71 (over 2000 fish per year), and the reason for much higher tag releases in those years compared to earlier TRS surveys.

The distribution of tag releases was much more limited in 1976 when tagging on the TRS surveys resumed in the Bering Sea, with tagged fish concentrated in the vicinity of Unimak and Akutan Islands. This was due to cold bottom temperatures resulting in hauls with zero halibut on grid stations to the northeast (Best 1982). The geographic range of releases increased in 1977-80, although the extent of the survey continued to be less than in the 1960s (Best 1982). Database records show that additional inshore stations around Unimak Island were fished from 1979 to 1982. Release totals for the 1970s are shown in Figure 1b.

There are no documents for the TRS surveys from 1981-1986 corresponding to those cited above, and inference on the nature of these surveys comes from the tagging database records alone (Figure 1c). The surveys in 1981 and 1982 sampled from the same set of stations used on previous surveys, with the addition of inshore stations around Unimak Island noted above. In 1981, more inshore stations were fished near Unimak Island, with high release numbers in that region leading to the largest annual TRS release count up to that time. The original station grid was not used for the 1985 releases, which were all in the vicinity of Unalaska and Umnak Islands, almost all of them close to shore. The few releases in 1986 appear to have been made on a sample of standard grid stations north and northeast of Unimak Island.

Release totals of small fish from other tagging studies, by decade from 1960 onwards, are shown in Figures 2a to 2d. Other tagging releases (Table 2) of small fish from 1960-1981 were very localised and small in number, although the 1961 releases were in the same region as the core

grid stations used for subsequent TRS releases. The releases in 1983 and 1984 followed a new grid, generally aligned along lines of longitude and latitude. Different regions were targeted each year: the 1983 grid sampled the western Bering Sea flats, from the Pribilof Islands north, while the 1984 releases occurred largely in the eastern Bering Sea, similar to the grid followed in earlier years of TRS surveys. Both years included releases along the Bering Sea shelf edge that were not aligned with the grid. Releases on the eastern Aleutian Islands were part of the 1983 program only, while the 1984 program instead included releases on the northern shelf edge and inshore releases around the Pribilof Islands. A small subset of stations, mainly north of Unimak Island, had releases in 1985, while the range of releases in 1987 spanned almost the entire Bering Sea flats. As previously mentioned with other releases, it is unclear whether gaps in coverage in that year were due to a lack of viable fish at sampled stations, or an absence of sampling.

Table 3 presents a break-down of releases by region, length class, and gear type, combined over all release years. The size distribution of releases differed considerably among the three release regions discussed above. The majority of Unimak releases were in the 25-34 cm range, while most Unalaska/Umnak releases were over 45 cm in length. Releases elsewhere in the Bering Sea were more evenly spread across the five size groups, with the largest count in the 35-44 cm range.

Recoveries

There were very few recoveries from any of 1960s releases, with recovery rates of less than 0.5% for all TRS releases (Table 1). Recovery rates were somewhat higher in the 1970s and 1980s. The highest TRS recovery rate was for the anomalous releases of 1985, which unlike previous TRS releases, were concentrated around Unalaska and Umnak Islands. Otherwise, the greatest number of TRS recoveries came from releases which were supplemented with a large number of additional tags near Unimak Island (1970, 1971, and 1981) and thus most information on movement patterns comes from releases that are only representative of a very small part of the Bering Sea halibut population.

To help visualise movement patterns of recovered halibut from the 1961-2003 release programs, we created figures showing release and recovery locations by release size class and the number of years elapsed since release (Figs. 3-5). Separate figures were created for the Bering Sea flats and edge releases, and for the more localised releases around the Aleutian Islands described above. Otherwise, data were aggregated across all release years and tagging programs (TRS and other).

Recoveries of Unimak releases (defined as releases in IPHC statistical areas 543163, 543164, 550162, 550163, and 550164) are shown in Figures 3a to 3e. In the year following release, all halibut were recovered in the vicinity of their release location. Only one fish technically crossed into the Gulf of Alaska by moving into a three-digit statistical area, although it was recovered very close to Unimak Island. Recovery patterns were generally similar two years following release, although three fish were recovered further from the release sites, two to locations south of the Pribilof Islands, and one near the Shumagin Islands in Area 3B. Data for more than two years following release were aggregated because of lower sample sizes. Nevertheless, there was a large change in the pattern of recoveries following the second year. Half of the tagged fish recovered 3-5 years following release had moved into the Gulf of Alaska, while two fish had dispersed west along the Aleutian chain, and another halibut was recovered on the Area 4D Edge, southwest of

St Matthew Island. A similar pattern of recoveries was apparent for 6-8 years following release, although for these fish, around 93% were recovered in the Gulf of Alaska. Fewer fish were recovered more than eight years following release, but the recovery locations were consistent with those from 3-8 years. Unalaska/Umnak releases were defined to be those in statistical areas 523168, 523169, 530167, 530168, 530169, 533166, 533167, 533168, 540165, and 540166. The recovery pattern of Unalaska/Umnak releases differed from the Unimak releases, although this may be in part due to the different size distribution at release of these fish (far larger proportions in the top two size groups, Table 3). In particular, the recovery data (Figures 4a to 4i) imply that dispersal of halibut into the Gulf of Alaska was generally a slower process, with the proportion recovered in the Gulf only reaching 50% at 8-10 years following release, compared with 3-5 years for Unimak releases.

The remaining recoveries, from releases on the Bering Sea flats, Edge, and elsewhere on the northern side of the Aleutians, showed movement patterns that were generally more similar to the Unimak releases than the Unalaska/Umnak releases (Figures 5a to 5e). Proportions recovered in the Gulf of Alaska increased quickly with the number of years following release, from 0% after one year, to 44% after two years, and over 70% after more than two years. One important difference with the Unimak halibut was that very few fish were recovered close to their release locations: even halibut that remained in the Bering Sea had generally moved some distance, including those recovered just one or two years after release.

We further examine the patterns of recoveries in Table 4, where recoveries are categorised by release region and length class, the ocean region of recovery (BS or GOA) and recovery gear type. Recovery gear is divided into trawl and "other", although the latter is overwhelmingly longline gear. While GOA recoveries were predominately captured with non-trawl gear for all size classes of released halibut, the gear type for tagged fish recovered in the Bering Sea depended greatly on release region. Unimak releases, which occurred in the area closed to longline fishing for halibut, were almost entirely recovered by the trawl fleet. This would also be due to their generally smaller size making them less selectable to non-trawl gear until several years after release, even if they moved outside of the Closed Area. Conversely, the Unalaska/Umnak recoveries were largely captured with non-trawl gear. The fact that many recoveries occurred close to the release locations (particularly within the first two years following release) may be a reflection of the predominant type of fishing undertaken near Unalaska and Umnak islands around the time of the 1985 releases, along with the generally larger size of these fish, making them more selectable to longline gear than fish released elsewhere in the Bering Sea. Recovered fish released on the Bering Sea flats, Edge, and other Aleutian Island regions were more evenly divided between recovery gear types.

Potential for statistical modelling

At present, there are no formal estimates of migration rates of juvenile halibut from the Bering Sea into the Gulf of Alaska. For statistical modelling of the available tag-recovery data to produce unbiased estimates, the tag releases should be representative of the population of interest, that is, juvenile halibut in the Bering Sea. It is conceivable that the core TRS grid survey did tag halibut in approximate proportion to catch, although more information is required to fully assess the representativeness of releases within the core stations (such as distinguishing tagging hauls with no viable fish for release from those not targeted for tagging). However, the core survey only covered part of the southern eastern Bering Sea (EBS) in most years: other parts of the EBS were

covered sporadically. Therefore, it does not seem possible to create a representative release data set for the entire BS stock from these data. Further, relatively few recoveries were made of fish released on the core grid stations (Table 1), and inclusion of data from high-count local releases would lead to biased estimates of movement rates.

To estimate movement rates from the BS to GOA, we also require information on recovery probabilities in the GOA, yet releases of juveniles there were even more localised than the BS trawl survey releases (Valero and Webster 2012). We would need to determine if we could subset the GOA releases to something close to a representative sample. The best coverage appears to be in the 1960s, but data from the same time frame as the Bering Sea releases is required, and the lack of recoveries from 1960s Bering Sea releases makes reliable estimation of migration rates, from data during this period, difficult.

Discussion

Data from the Bering Sea tagging programs show that halibut under 65 cm in length have historically had high rates of movement into the Gulf of Alaska: depending on the release area, 70-90% of tagged halibut were recovered in the Gulf after eight or more years following release. While the general pattern was for a south and eastward movement across the Gulf, there was also some migration of small halibut to the west, towards Area 4B for all release regions (Figs 3-5). Studies tagging larger fish have found much less movement into or out of Area 4B than other regulatory areas (Valero and Webster 2012), but these data provide evidence that the population in Area 4B is connected with that in the eastern Bering Sea through the westward movement of juvenile fish.

While the raw data provide evidence that juvenile halibut tagged in the Bering Sea have, over a period of several years, high rates of migration into the Gulf of Alaska, the juvenile tagging studies were never designed with the goal of producing statistically sound estimates of migration rates. Low recovery rates for the most consistent grid design, high recovery rates resulting from unrepresentative sampling, and the lack of a consistent, contemporaneous tagging program in the Gulf of Alaska make these data unsuitable for formal statistical modelling. The data do show that a few years after release, a majority of the recovered tagged halibut is in the GOA. That being said, it is also likely that a greater intensity of longline fishing in the Gulf of Alaska than in the Bering Sea means tagged fish that move to the Gulf of Alaska are more likely to be recovered than those that remain within the Bering Sea. Raw out-of-region recovery rates, therefore, imply a higher annualised movement rate than is likely to have been occurring. Even if we overlook the shortcomings of the design, an estimate of annual movement rates cannot be derived without additional information on the relative probabilities of tag recovery in the Bering Sea and Gulf of Alaska.

With low selectivity to longline gear until years after release, and high movement rates out of areas with high-trawl density, any future tagging program for small halibut would ideally rely on fishery-independent recoveries of tagged fish. At present, we are confident that Wildlife computers mini-PAT (pop-up archival transmitting) tags, or Microwave Telemetry X-tags, could be used on fish as small as 60 cm in length. It is possible that they might also be used on smaller fish. However, it would be wise to first conduct holding experiments specifically aimed at establishing lower size thresholds for the use of these tags; no such work has been conducted to-date. With such tags, migration rates out of the Bering Sea could be estimated, without the need for simultaneous

releases in the Gulf of Alaska, as would be required with conventional tags. At a cost of $4000 per tag including data retrieval, large scale releases of miniPATS throughout the Bering Sea would require a substantial investment. Alternative, pop-up tags such as the Wildlife Computers mrPAT, that produce simple endpoint data while providing *in situ* movement (acceleration) analysis without recording full archival environmental data, might be employed for migration estimation at about 25% of the cost of standard miniPATs. These tags are also somewhat smaller (~2 cm diameter by 11 cm in length) than miniPATs, and would presumably be appropriate for even smaller fish. Still, the studies described herein tagged fish as small as 25 cm in length, and we are currently unaware of any tags available for fish that small that would allow for fishery-independent tag-recovery.

References

Best. E. A. 1969a. Recruitment investigations: trawl catch records in Bering Sea, 1967. Int. Pac. Halibut Comm. Tech. Rep. 1.

Best. E. A. 1969b. Recruitment investigations: trawl catch records eastern Bering Sea, 1968 and 1969. Int. Pac. Halibut Comm. Tech. Rep. 3.

Best. E. A. 1970. Recruitment investigations: trawl catch records eastern Bering Sea, 1963, 1965 and 1966. Int. Pac. Halibut Comm. Tech. Rep. 7.

Best. E. A. 1974. Juvenile halibut in the eastern Bering Sea: trawl surveys, 1970-72. Int. Pac. Halibut Comm. Tech. Rep. 11.

Best, E. A. 1977. Distribution and abundance of juvenile halibut in the southeastern Bering Sea. Int. Pac. Halibut Comm., Sci. Rep. 62.

Best. E. A. and Hardman, W. H. 1982. Juvenile halibut surveys, 1973-80. Int. Pac. Halibut Comm. Tech. Rep. 20.

Kaimmer, S. M. 2000. Pacific halibut tag release programs and tag release and recovery data, 1925 through 1998. Int. Pac. Halibut Comm. Tech. Rep. 41.

Valero, J. L. and Webster, R. A. 2012. Current understanding of Pacific halibut migration patterns. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 341-379.

Table 1. TRS releases of tagged fish under 65 cm in length in the Bering Sea (IPHC statistical area code >1000). Unless otherwise indicated, tag releases were entirely or predominately on standard TRS grid stations.

Experiment #s	Year	Tags released	Tags recovered	% recovered	% of recoveries in GOA
294-298 (TRS pilot)	1963	977	1	0.1	0.0
380-383	1965	866	2	0.2	0.0
395	1966	1,501	1	0.1	100.0
414	1967	719	1	0.1	0.0
430	1968	257	0	0.0	-
449	1969	267	1	0.4	0.0
472*	1970	2,595	40	1.5	0.0
480*	1971	2,395	56	2.3	1.8
502¶	1976	489	7	1.4	85.7
516	1977	191	1	0.5	100.0
528	1978	307	6	2.0	66.7
547†	1979	130	1	0.8	0.0
579†	1980	341	4	1.2	75.0
624*	1981	3,128	35	1.1	54.8
678†	1982	571	5	0.9	80.0
793§	1985	4,320	332	7.7	21.1
804*	1986	53	0	0.0	-

* Most tag releases around Unimak Island and not on TRS grid stations.
¶ Most tag releases around Unimak and Akutan Islands and not on TRS grid stations.
† TRS grid stations releaseas supplemented with inshore releases around Unimak Island.
§ All tag releases around Unalaska and Umnak Islands and not on TRS grid stations.

Table 2. IPHC releases of tagged fish under 65 cm in length in the Bering Sea, non-TRS studies. 'M' indicates data are missing from the IPHC database.

Experiments	Purpose/gear	Year	Tags released	Tags recovered	% recovered	% of recoveries in GOA
27	Banks tagging	1930	M	2	M	100.0
55		1947	M	0	M	-
100		1952	M	0	M	-
122		1954	M	0	M	-
146,147,149-152		1956	M	0	M	-
171-179		1959	M	0	M	-
216	US Cooperative Research	1961	80	1	1.3	100.0
311	Coastwide marking program	1963	1	0	0.0	-
337,338	Banks tagging	1964	85	0	0.0	-
389, 391	Coastwide marking program	1965	48	0	0.0	-
416-423, 429	Banks tagging/FH	1967	60	3	5.0	33.3
464	Foreign trawl catch comparison	1970	86	1	1.2	0.0
481	Foreign trawl catch comparison	1971	65	0	0.0	-
488	Hook spacing	1972	1	0	0.0	-
501	USSR cooperative research	1975	23	0	0.0	-
511, 512	Banks tagging	1976	91	3	3.3	100.0
603	US cooperative research	1981	158	1	0.6	0.0
707,728-730	Japan/US cooperative research	1983	760	26	3.4	54.5
751,752,770	Japan/US cooperative research; Banks tagging	1984	702	19	2.7	50.0
801	US cooperative research	1985	166	5	3.0	60.0
835,837	US cooperative research; Banks tagging	1987	150	2	1.3	100.0
872	Coastwide PIT tag release	2003	42	1	2.4	100.0

Table 3. Release totals over all years, by release region, gear type, and length class.

Release length (cm)	Bering flats/Edge			Unimak			Unalaska/Umnak		
	Trawl	Longline	Total	Trawl	Longline	Total	Trawl	Longline	Total
15-24	288	0	288	53	0	53	0	0	0
25-34	1585	0	1585	5729	0	5729	309	0	309
35-44	2532	14	2546	2676	8	2684	1133	0	1133
45-54	1782	85	1867	390	13	403	2190	2	2192
55-64	1232	339	1571	149	63	212	1045	20	1065
Total	7419	438	7857	8997	84	9081	4677	22	4699

Table 4. Recovery totals over all years, by release region and length class, and recovery gear type and ocean region (Bering Sea or Gulf of Alaska).

Bering Sea recoveries									
Release length (cm)	Bering flats/Edge			Unimak			Unalaska/Umnak		
	Trawl	Other	Total	Trawl	Other	Total	Trawl	Other	Total
25-34	1	0	1	87	0	87	1	1	2
35-44	7	0	7	18	2	20	8	31	39
45-54	3	3	6	2	0	2	7	105	112
55-64	7	9	16	0	0	0	5	92	97
Total	18	12	30	107	2	109	21	229	250
Gulf of Alaska recoveries									
Release length (cm)	Bering flats/Edge			Unimak			Unalaska/Umnak		
	Trawl	Other	Total	Trawl	Other	Total	Trawl	Other	Total
25-34	0	0	0	0	7	7	0	3	3
35-44	0	3	3	1	10	11	1	12	13
45-54	1	10	11	0	6	6	4	32	36
55-64	5	16	21	0	4	4	0	22	22
Total	6	29	35	1	27	28	5	69	74

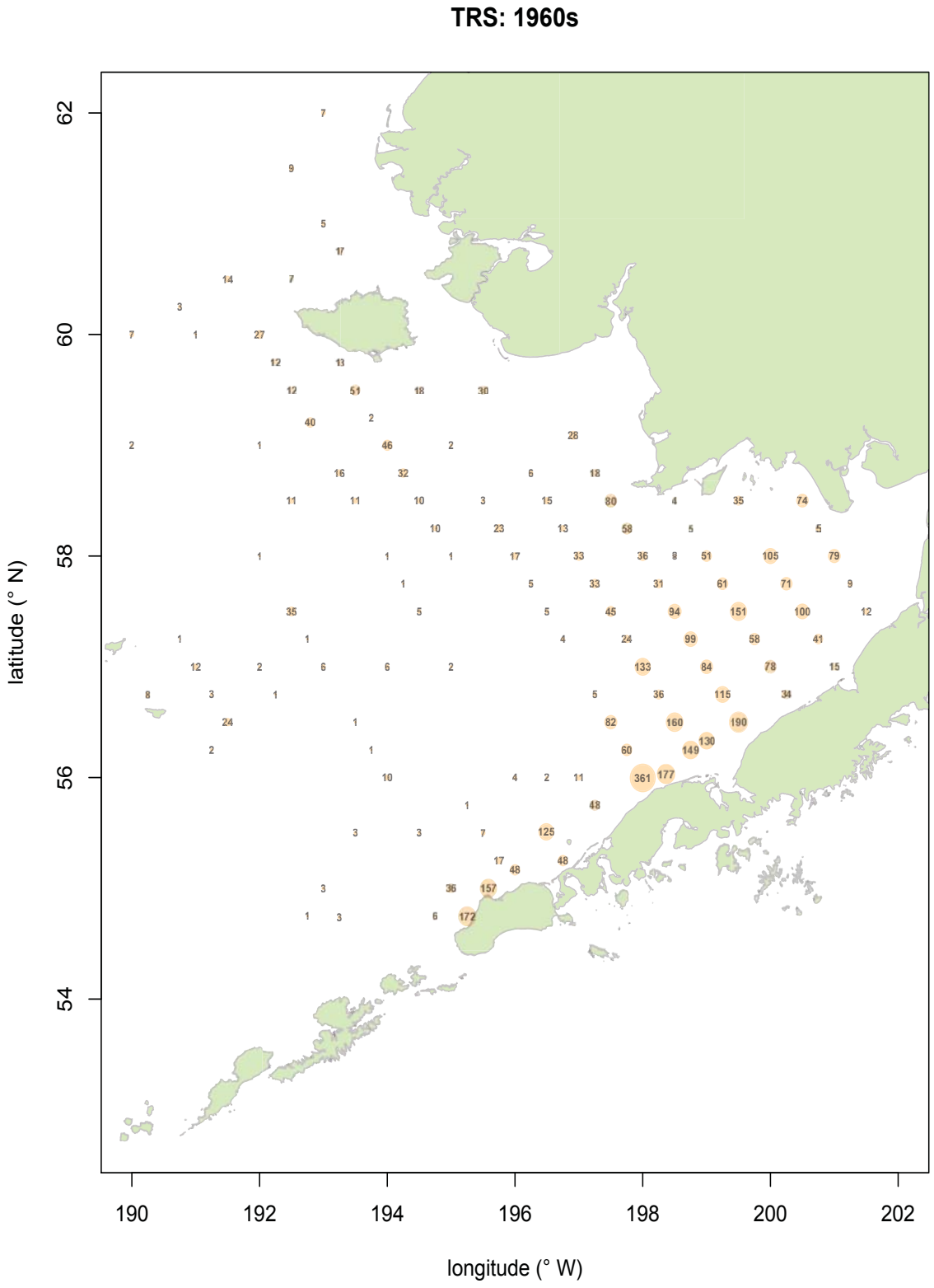


Figure 1a. Counts of TRS releases in the 1960s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

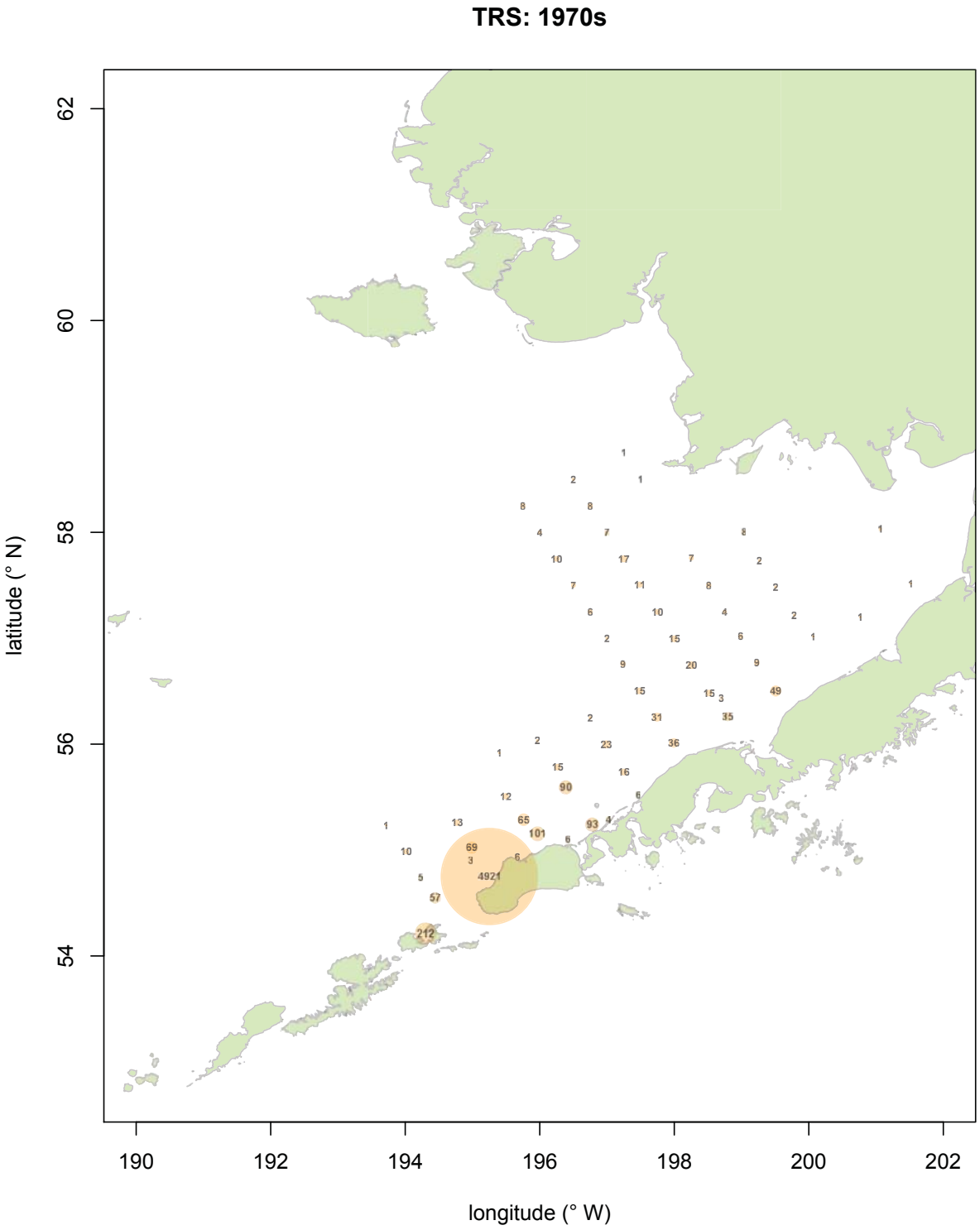


Figure 1b. Counts of TRS releases in the 1970s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

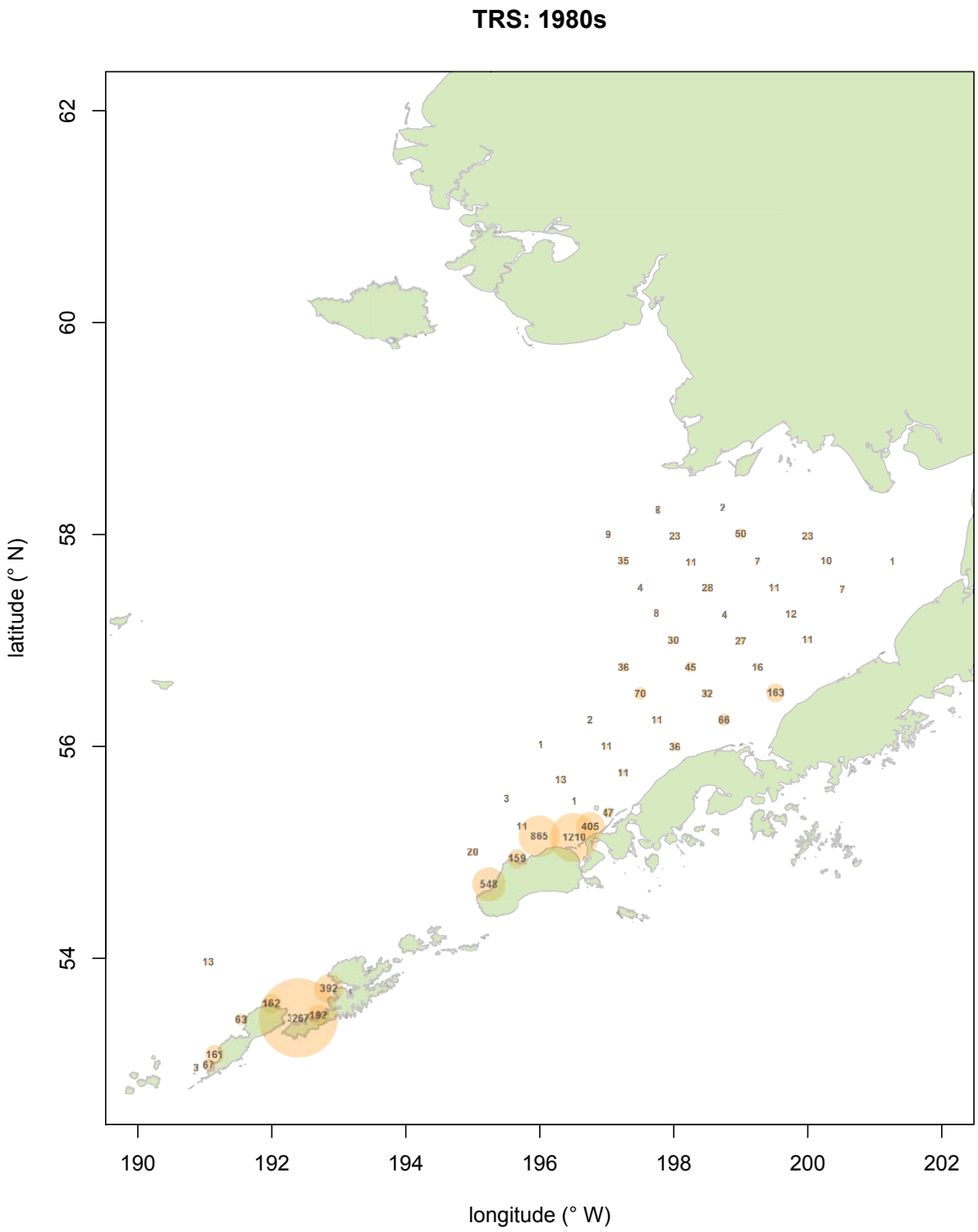


Figure 1c. Counts of TRS releases in the 1980s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

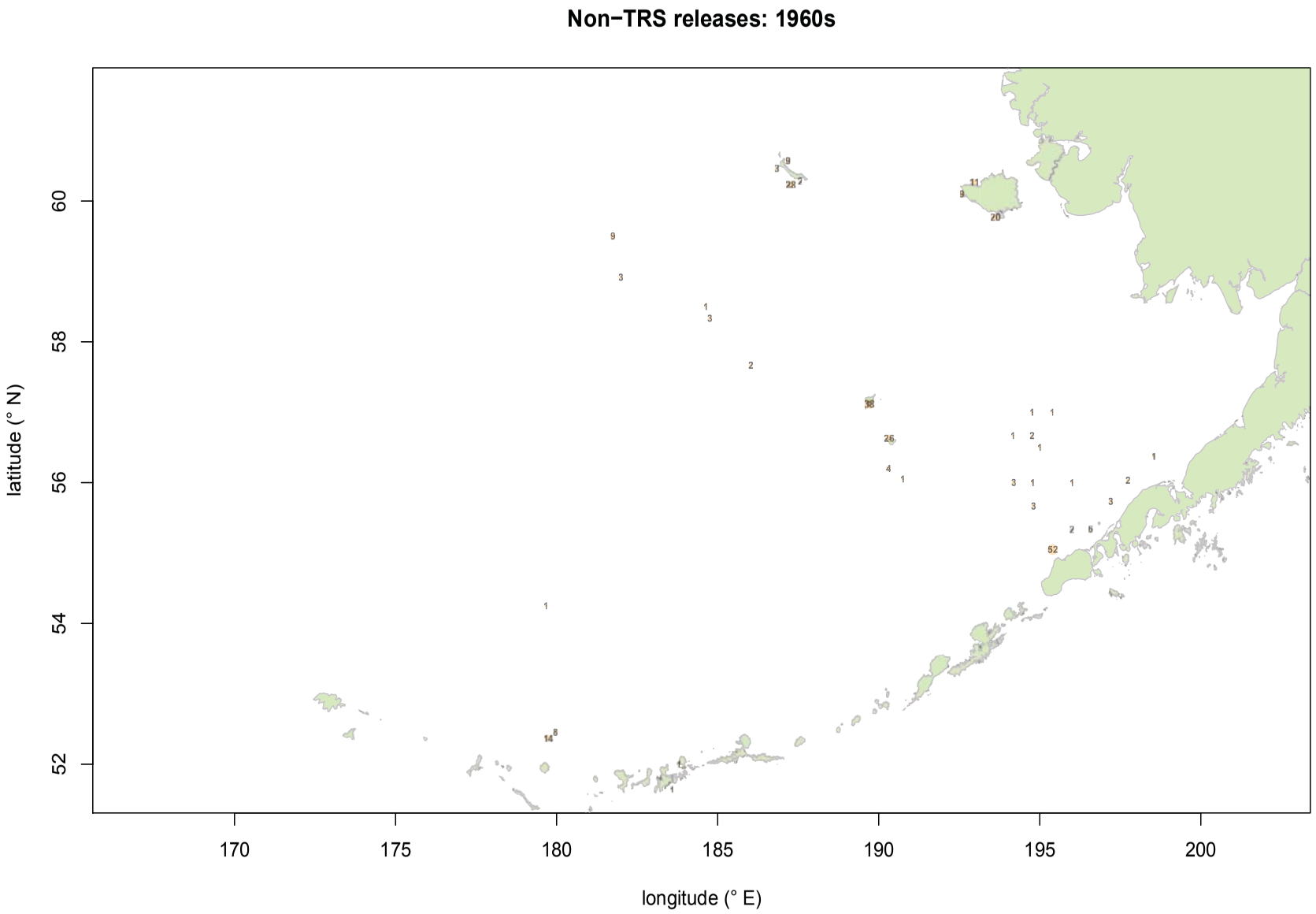


Figure 2a. Counts of non-TRS releases in the 1960s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

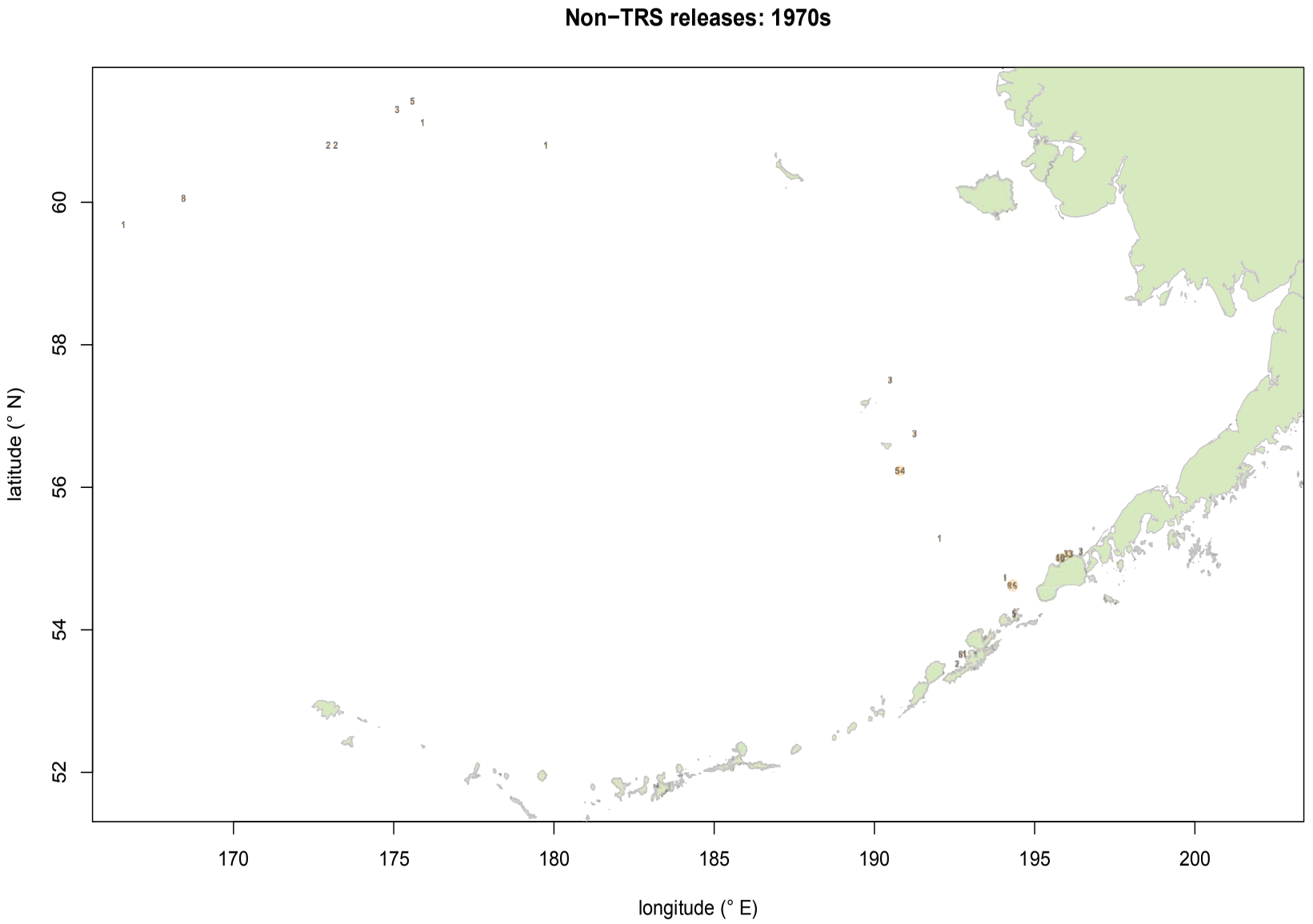


Figure 2b. Counts of non-TRS releases in the 1970s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

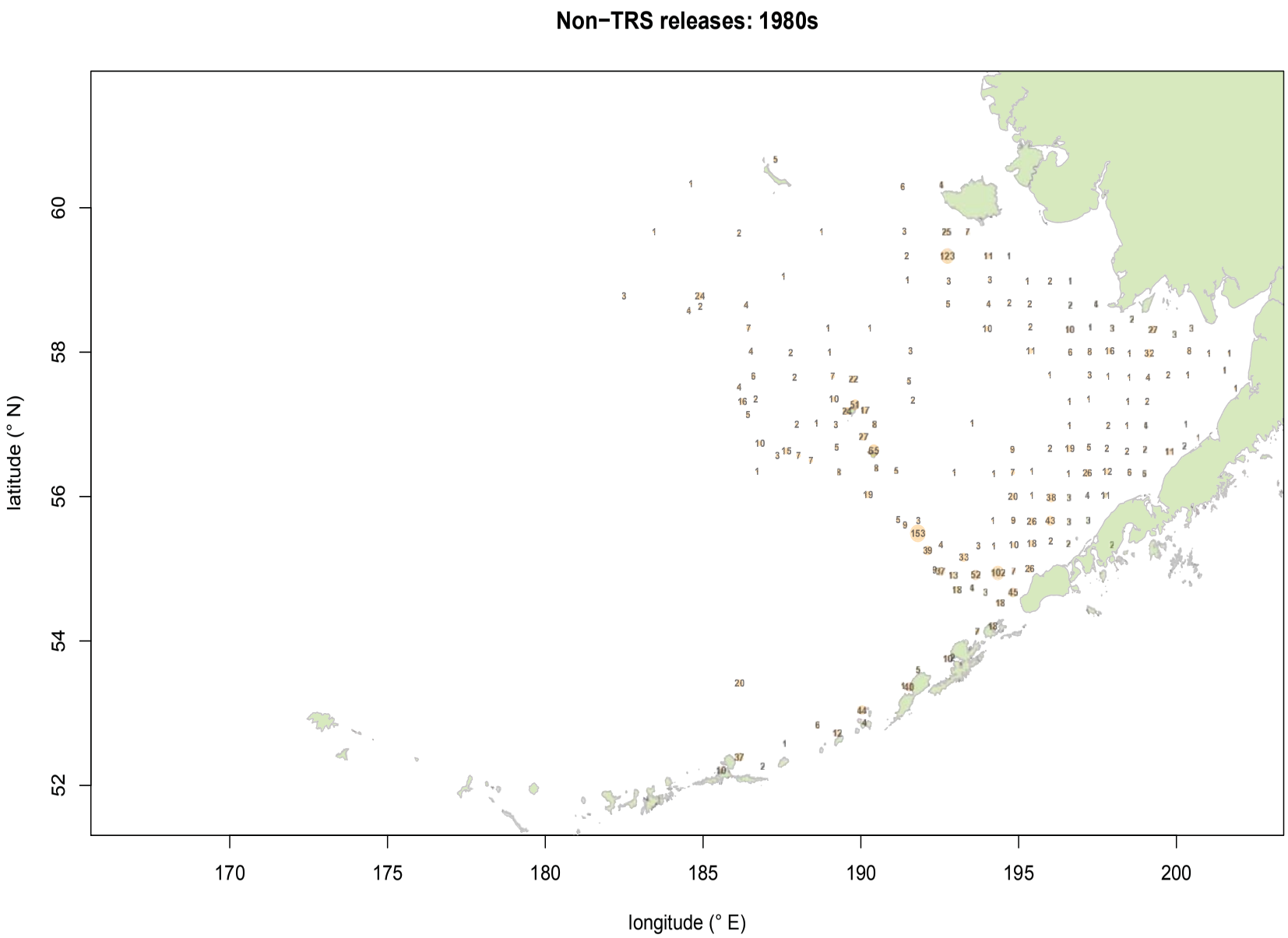


Figure 2c. Counts of non-TRS releases in the 1980s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

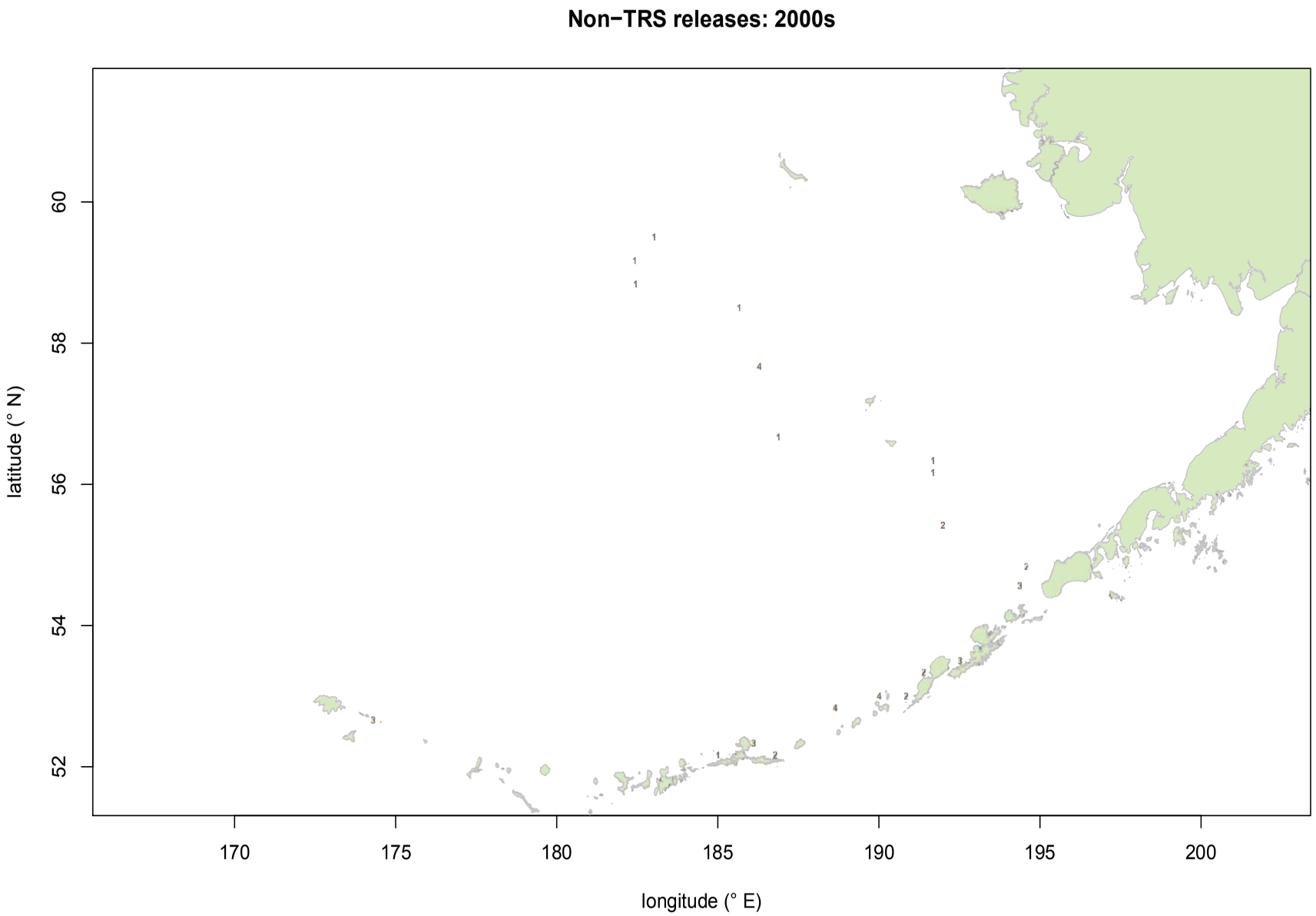


Figure 2d. Counts of non-TRS releases in the 2000s by release location. Releases at locations that are close in space have been combined to improve clarity of the figure.

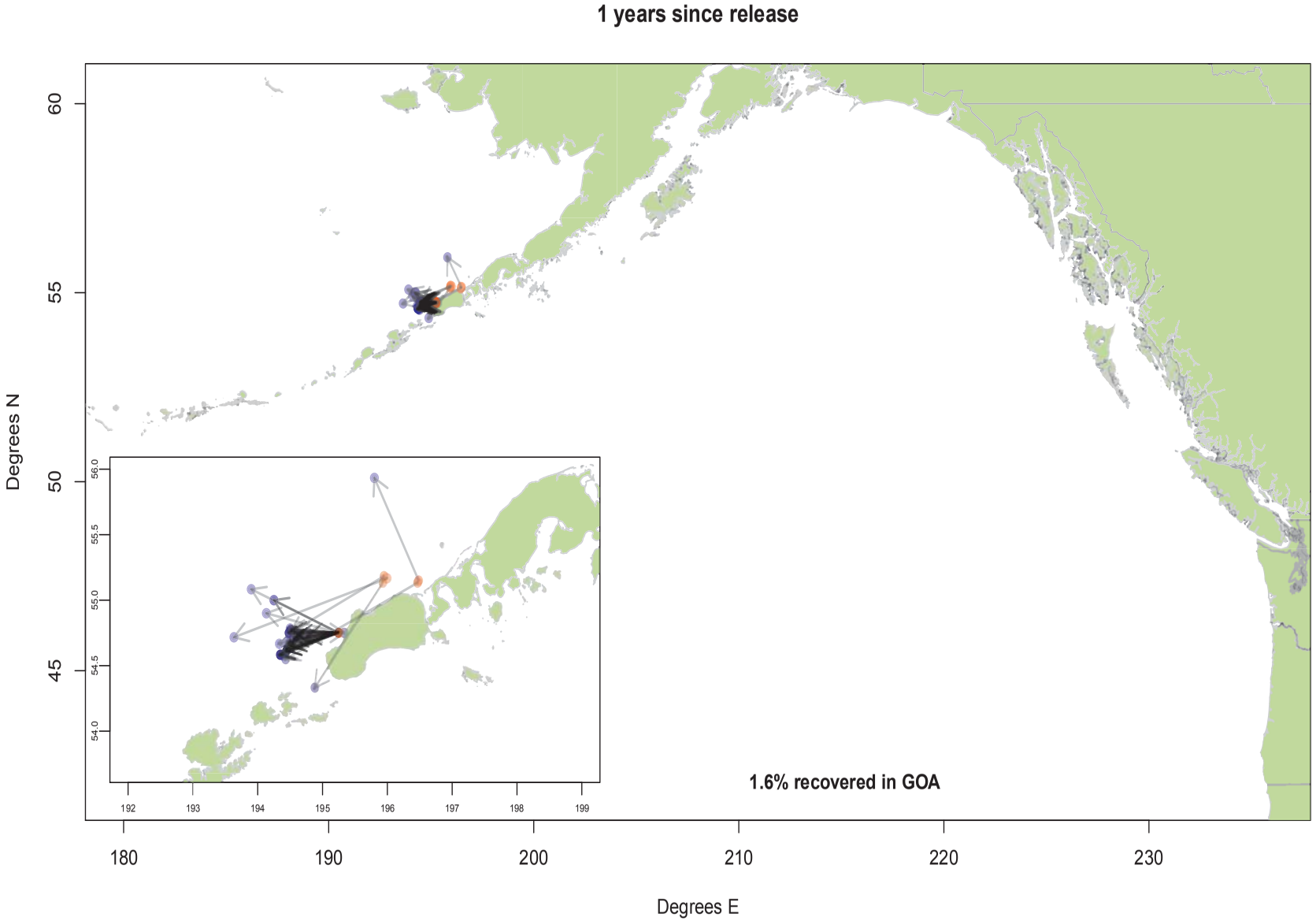


Figure 3a. Release and recovery locations of halibut tagged near Unimak Island one year following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

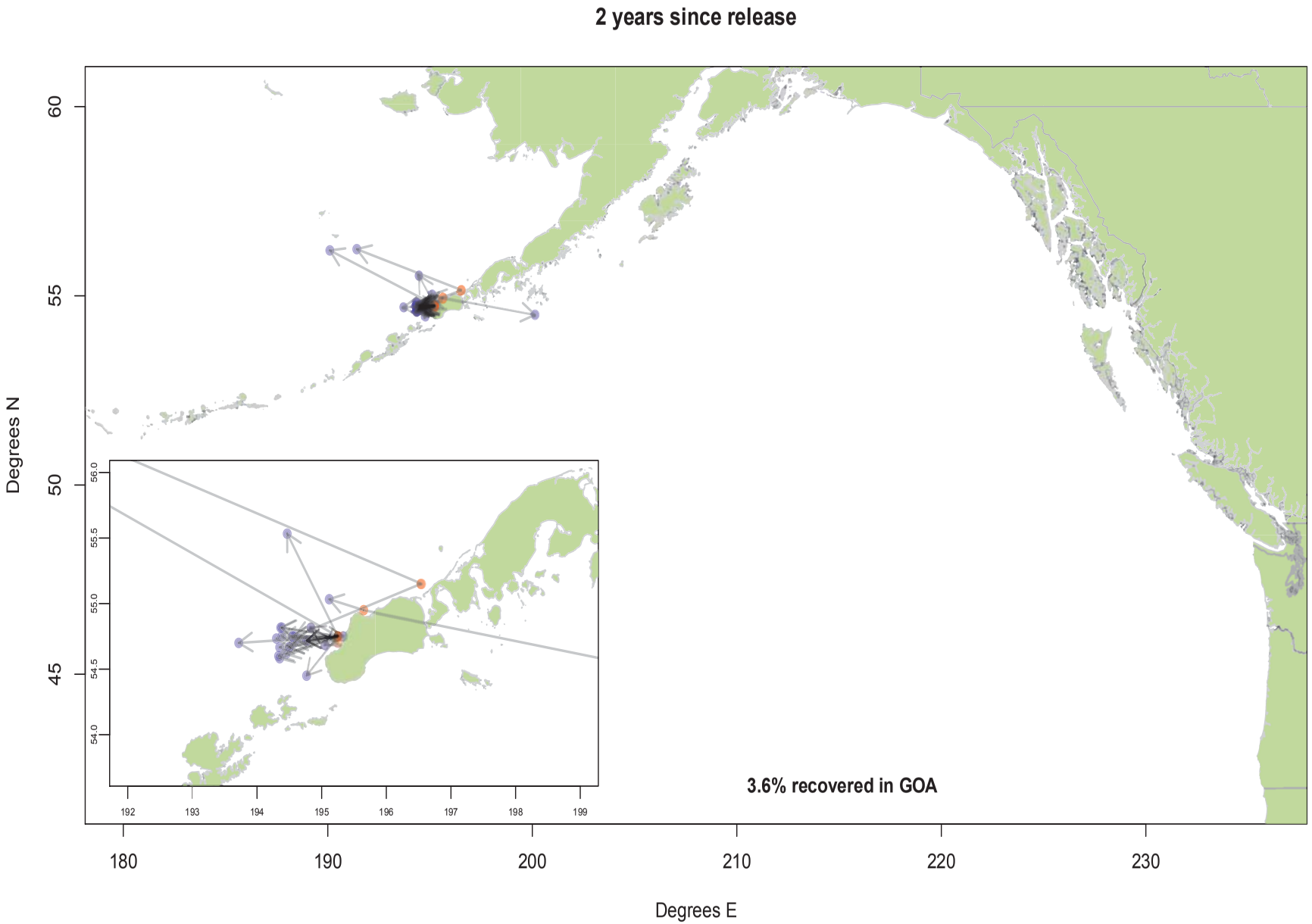


Figure 3b. Release and recovery locations of halibut tagged near Unimak Island two years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

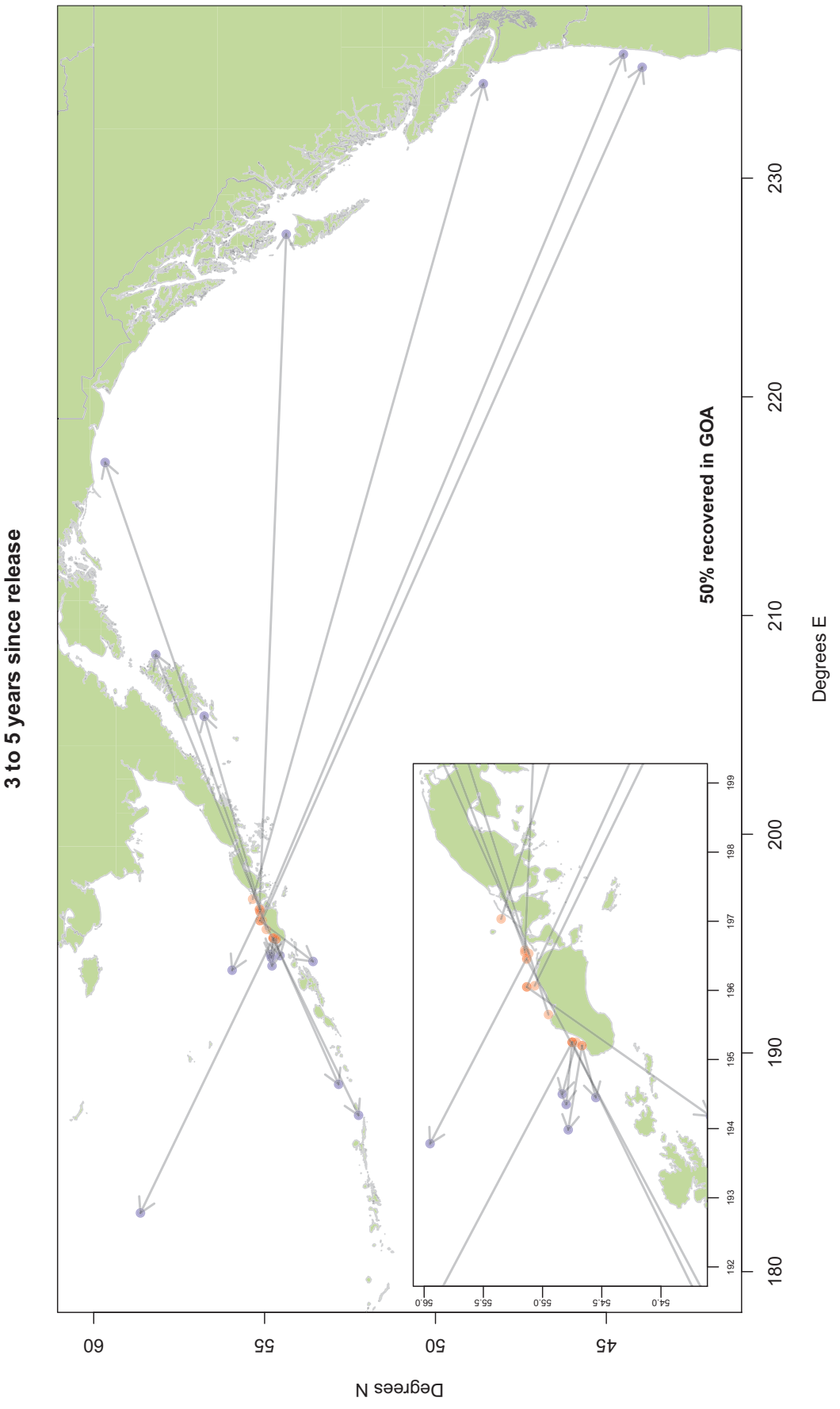


Figure 3c. Release and recovery locations of halibut tagged near Unimak Island 3-5 years following release, combined over TRS and non-TRS releases and all release yearsArrows indicate direction of movement between release and recovery locations.

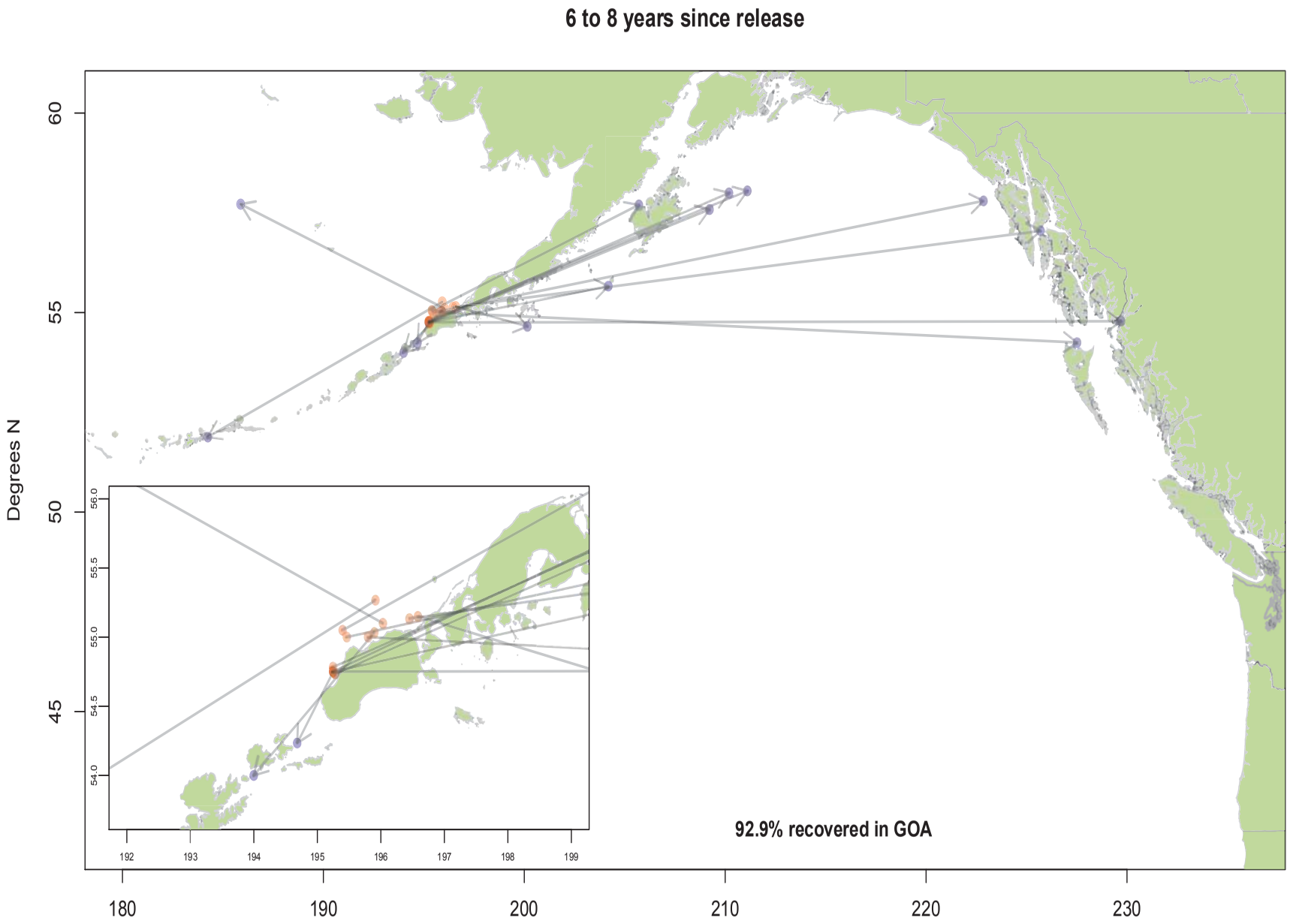


Figure 3d. Release and recovery locations of halibut tagged near Unimak Island 6-8 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

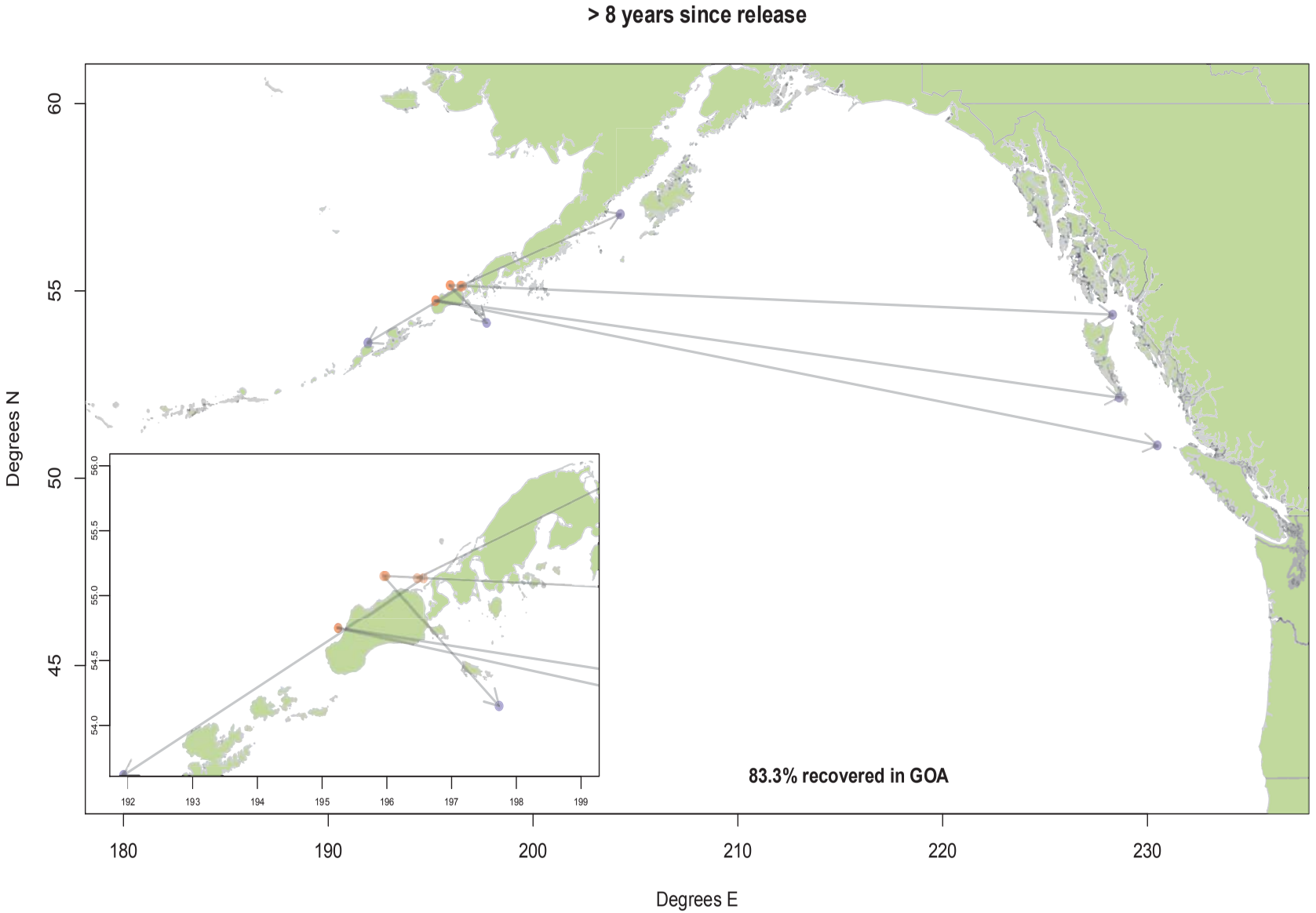


Figure 3e. Release and recovery locations of halibut tagged near Unimak Island over 8 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

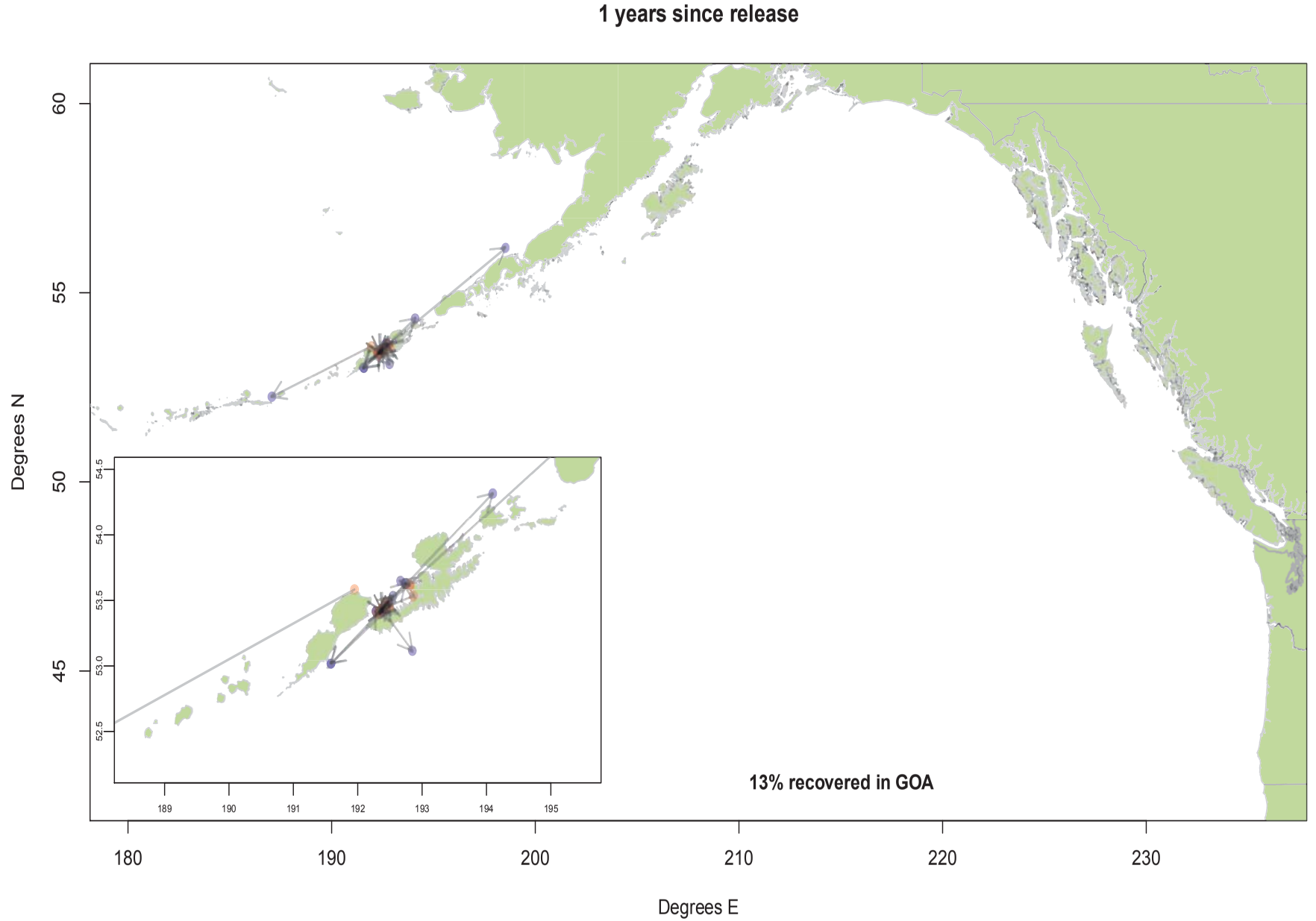


Figure 4a. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands one year following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

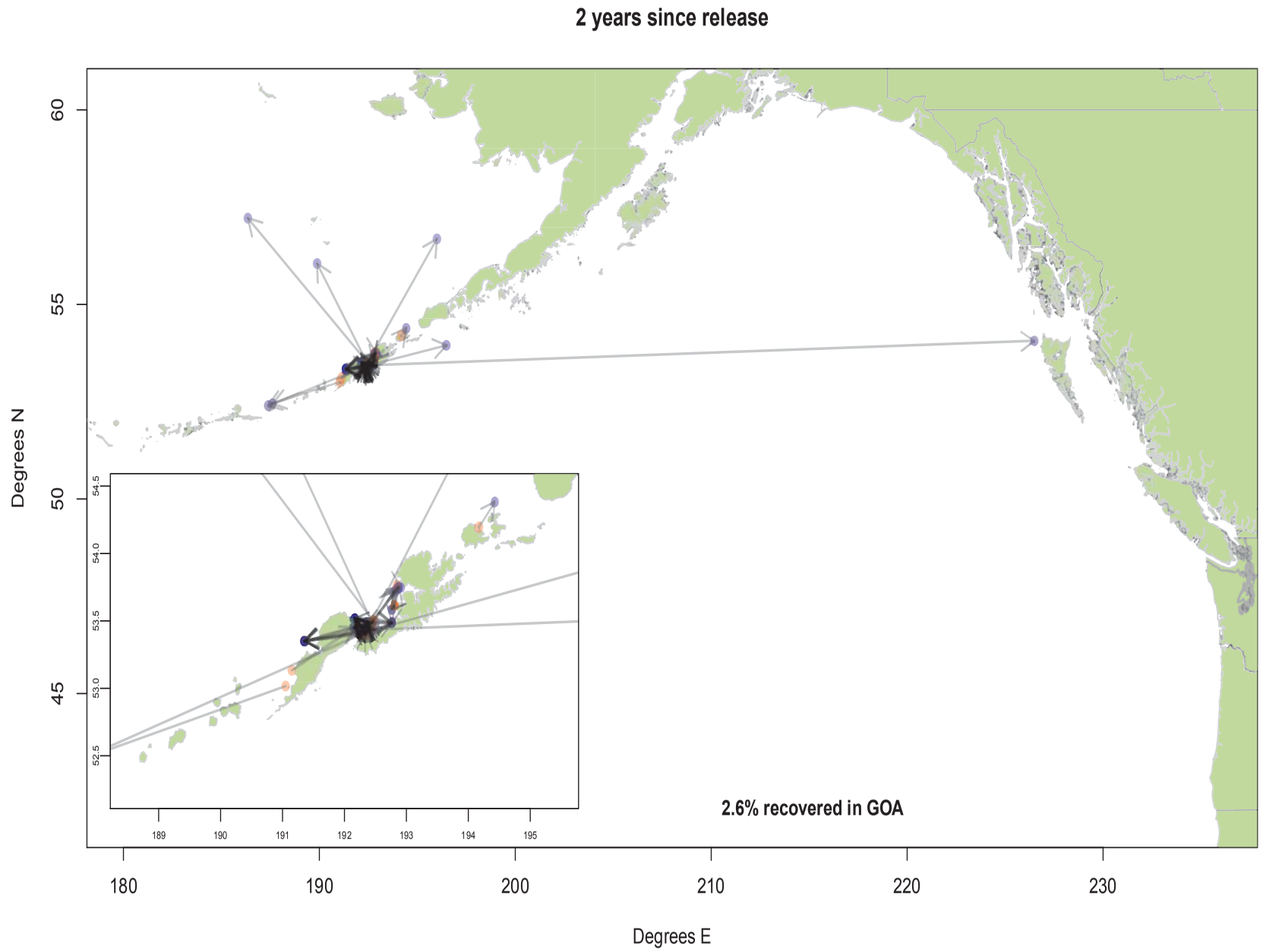


Figure 4b. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands two years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

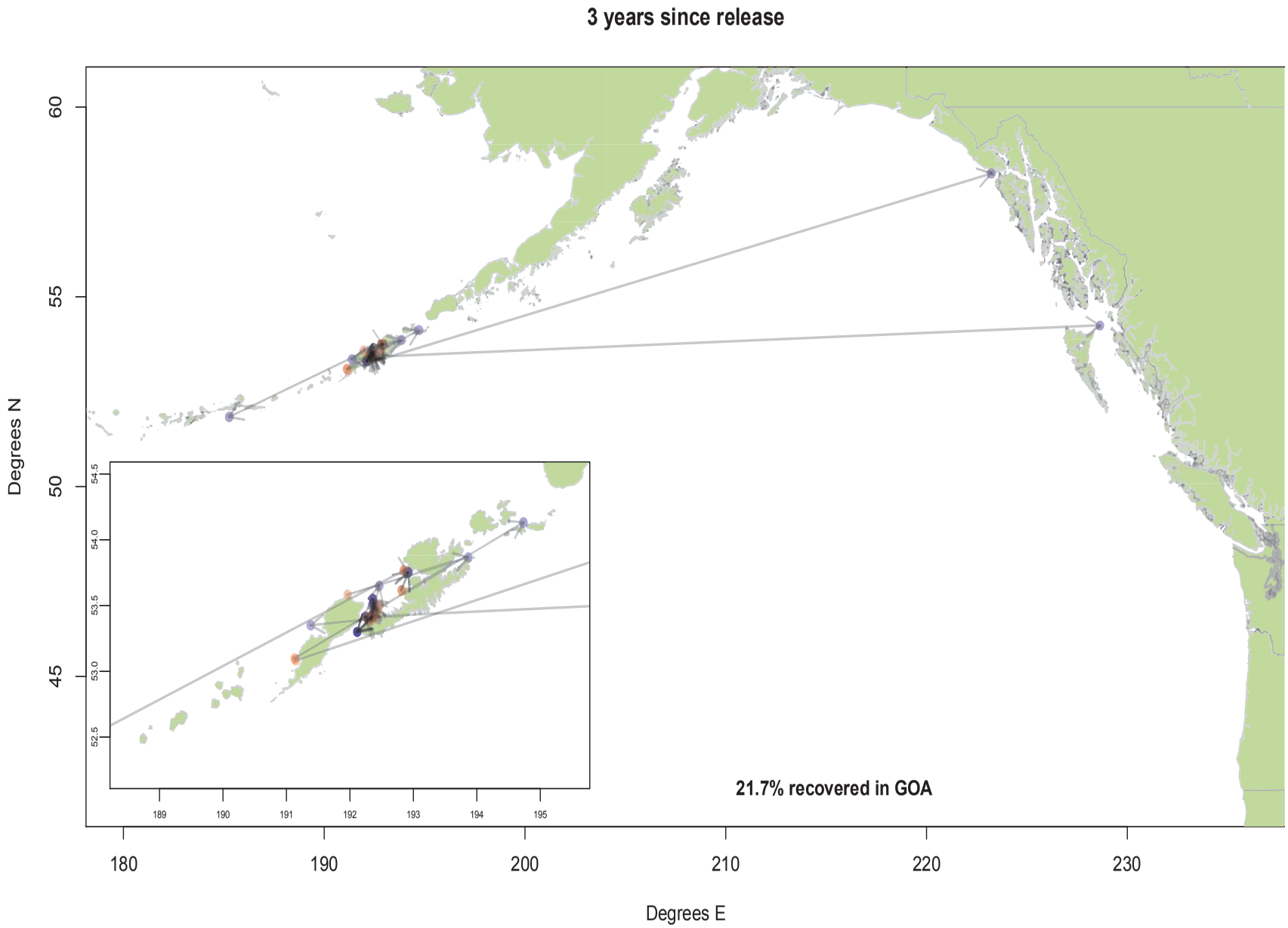


Figure 4c. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands three years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

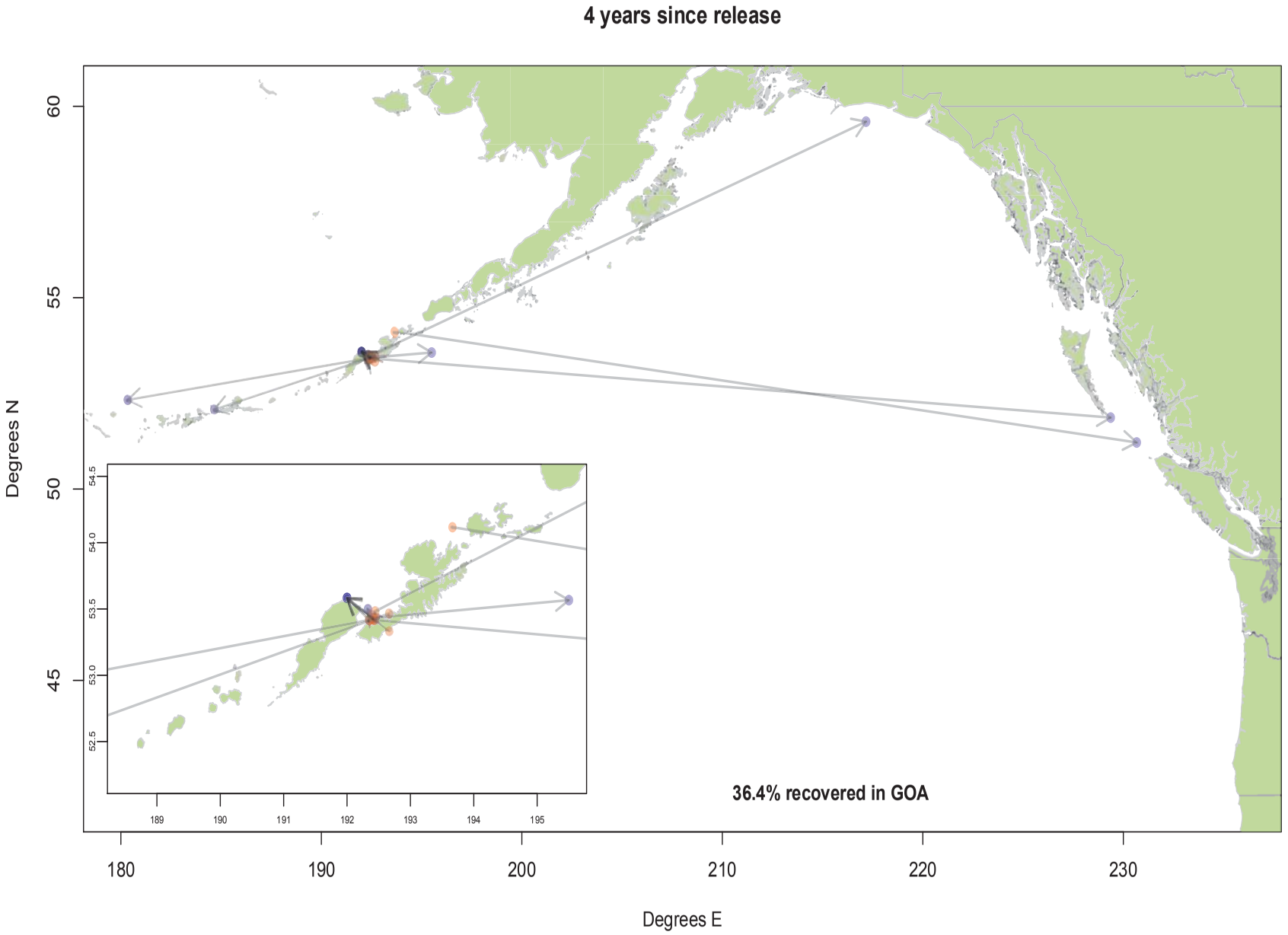


Figure 4d. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands four years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

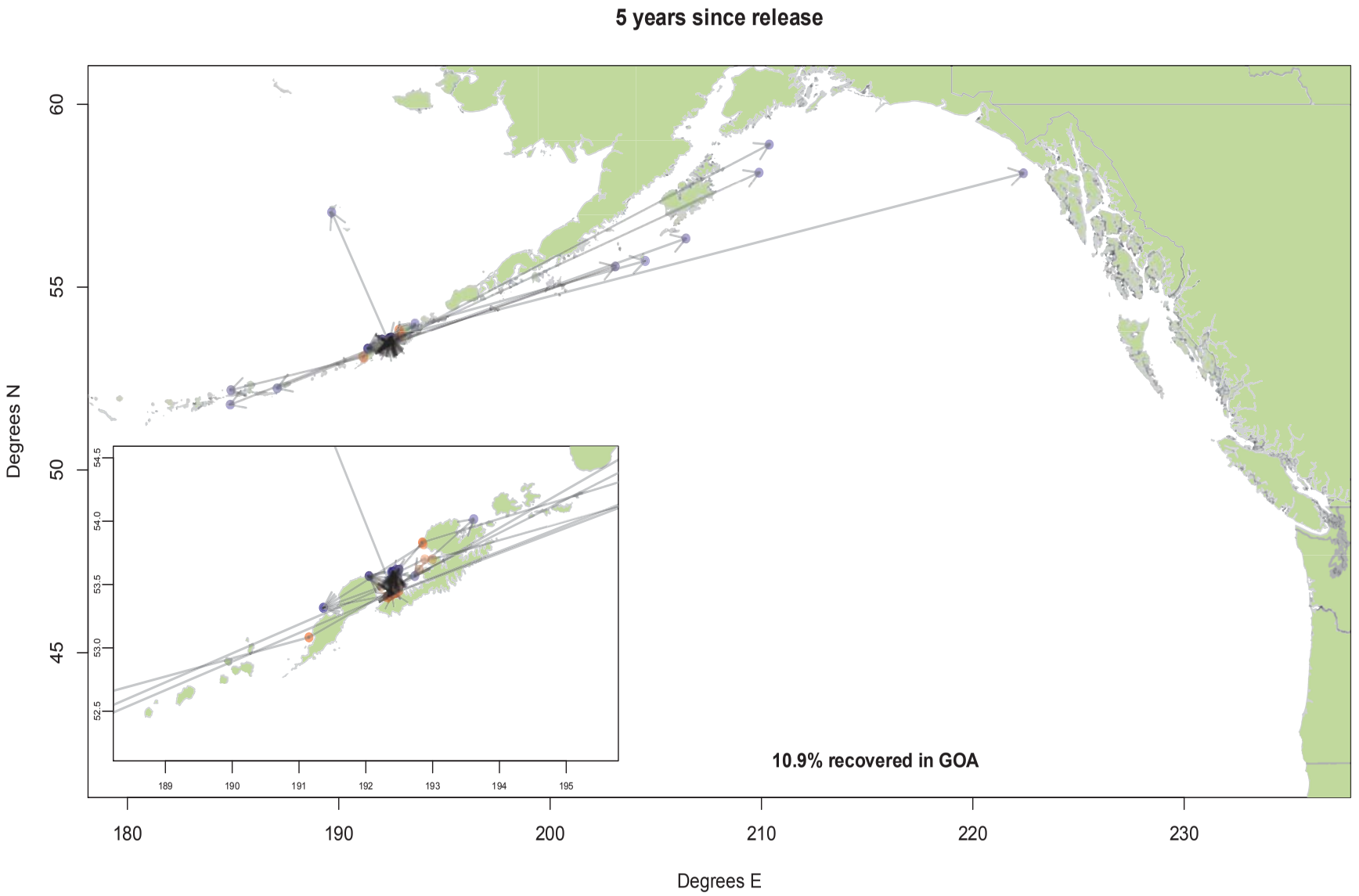


Figure 4e. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands five years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

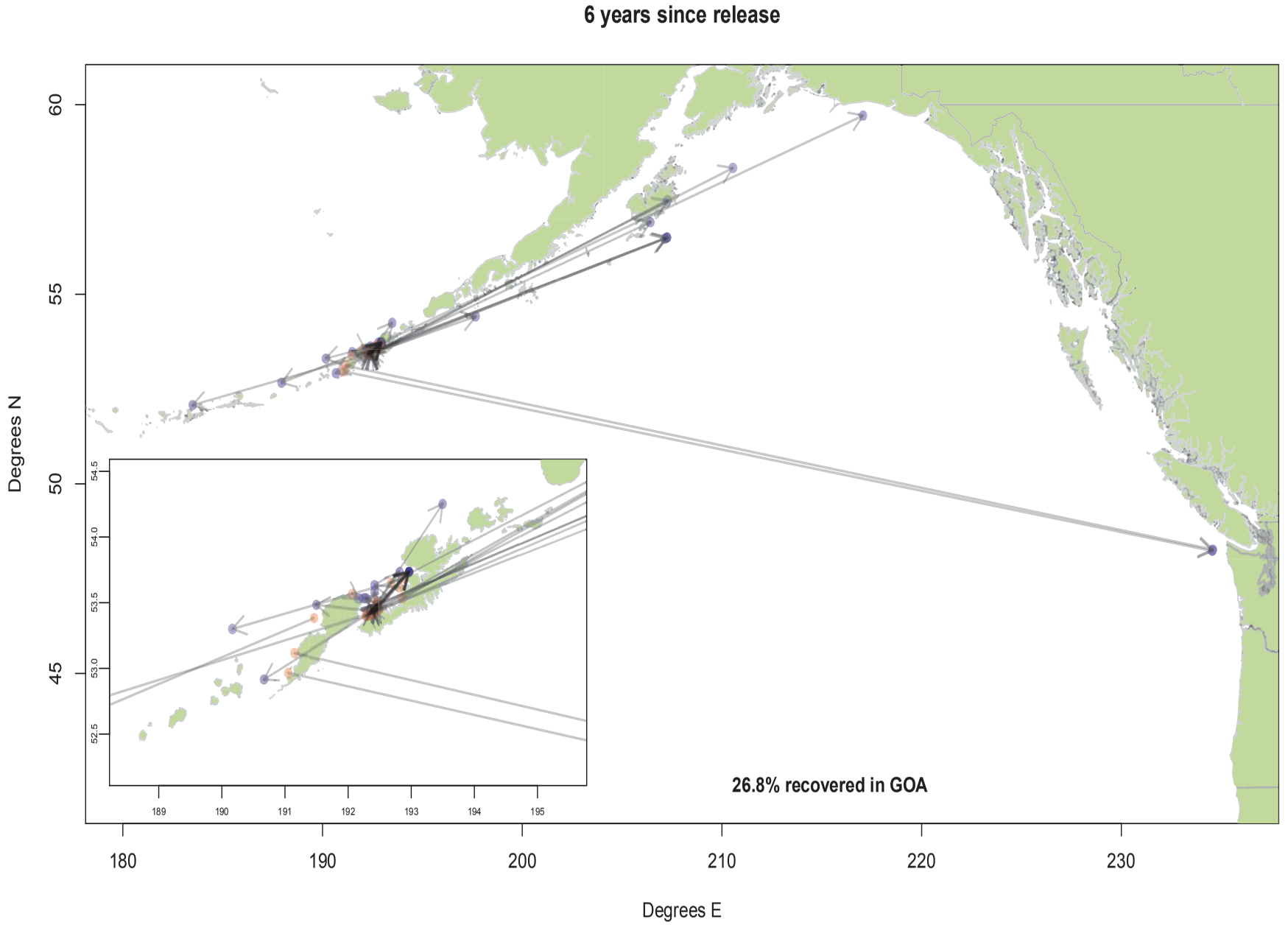


Figure 4f. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands six years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

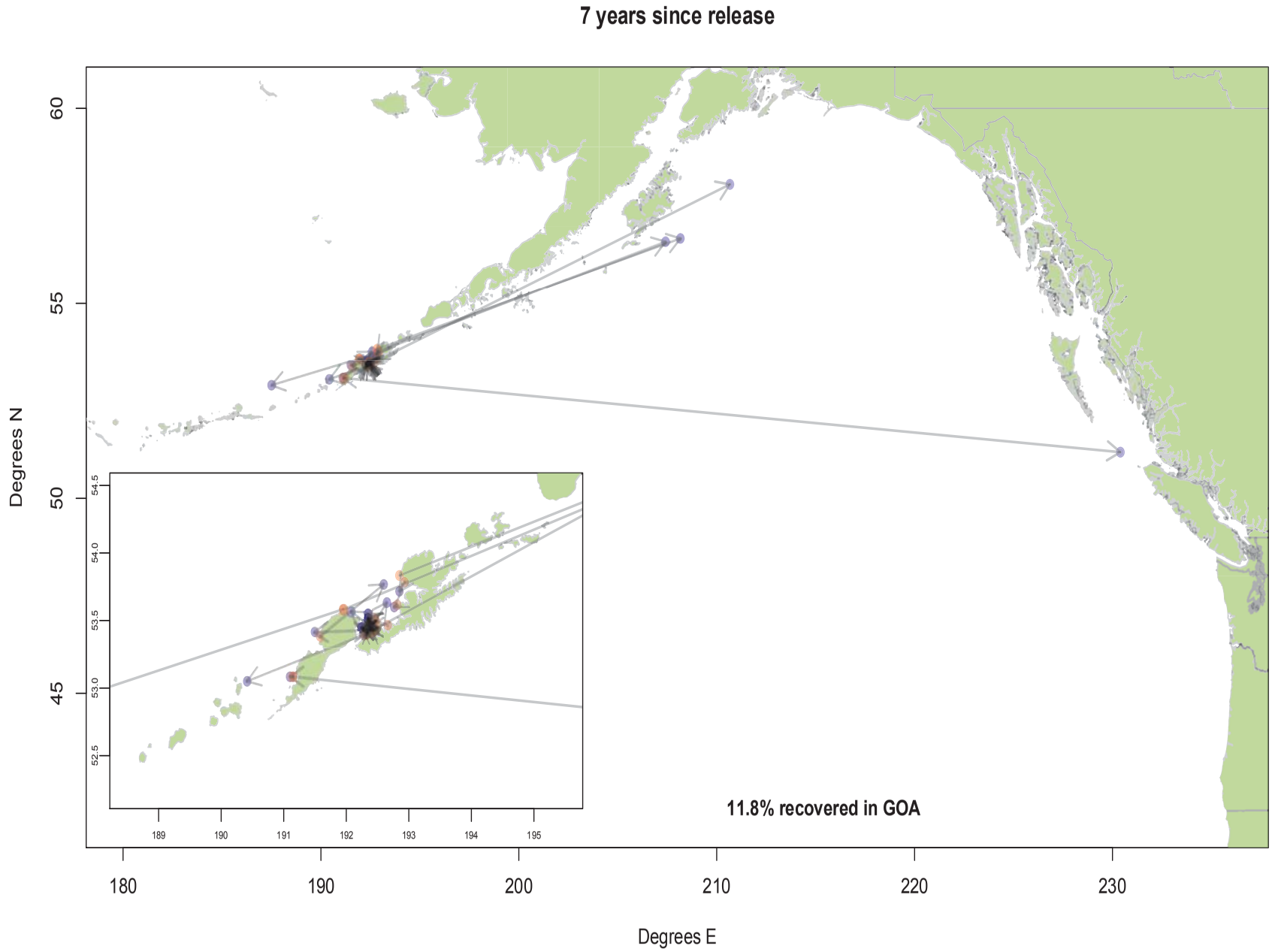


Figure 4g. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands seven years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

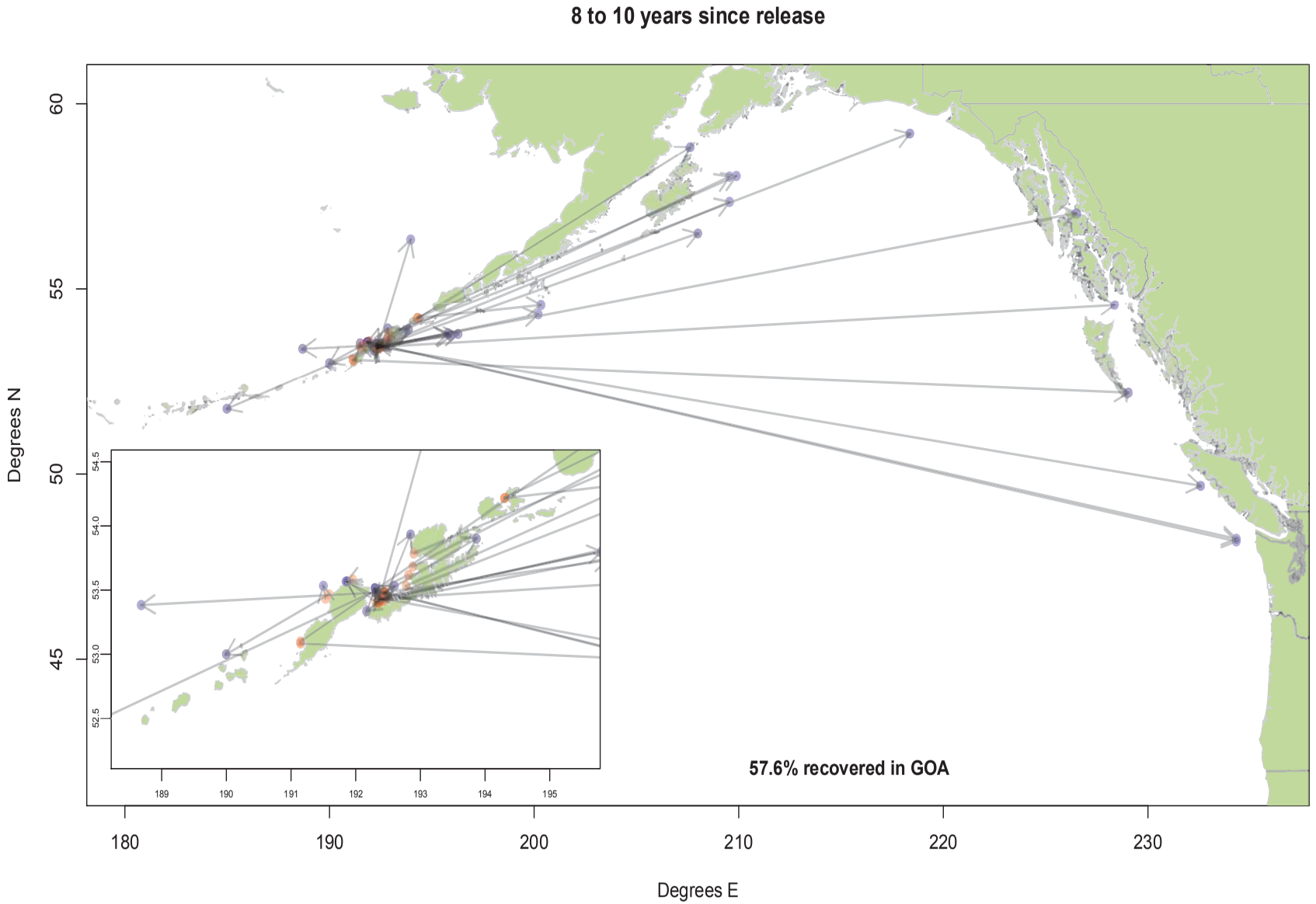


Figure 4h. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands 8 to 10 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

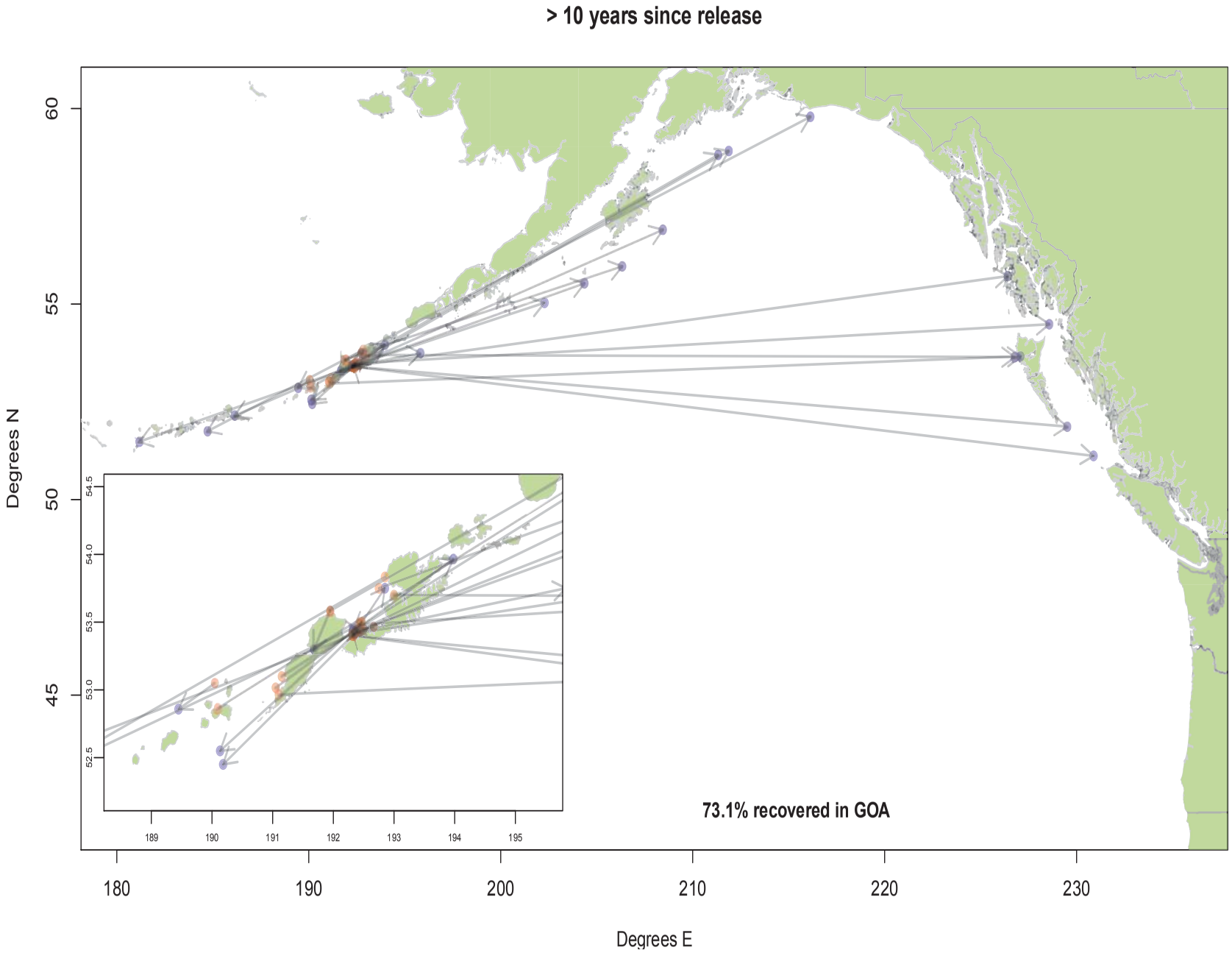


Figure 4i. Release and recovery locations of halibut tagged near Unalaska and Umnak Islands over ten years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

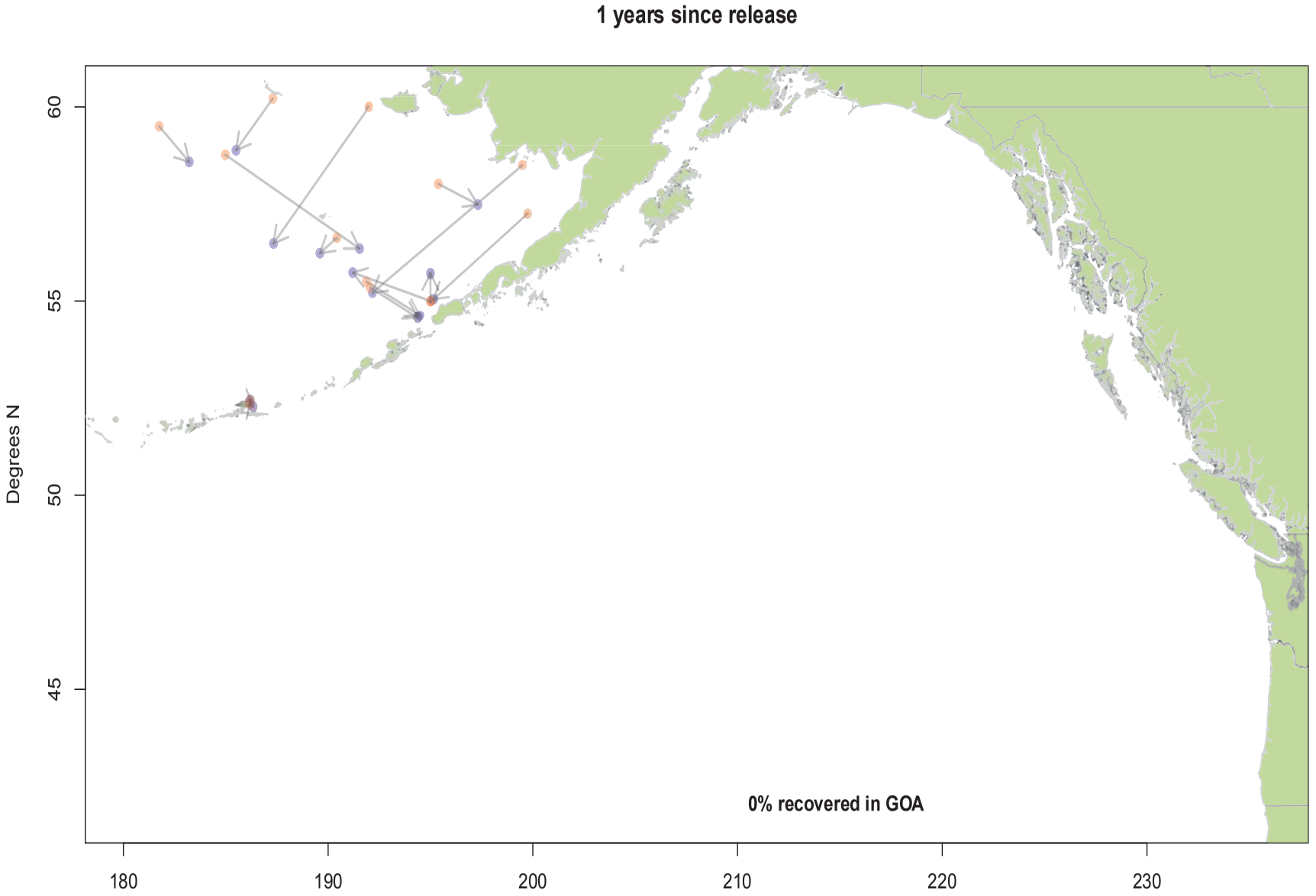


Figure 5a. Release and recovery locations of halibut tagged on the Bering Sea flats and Edge one year following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

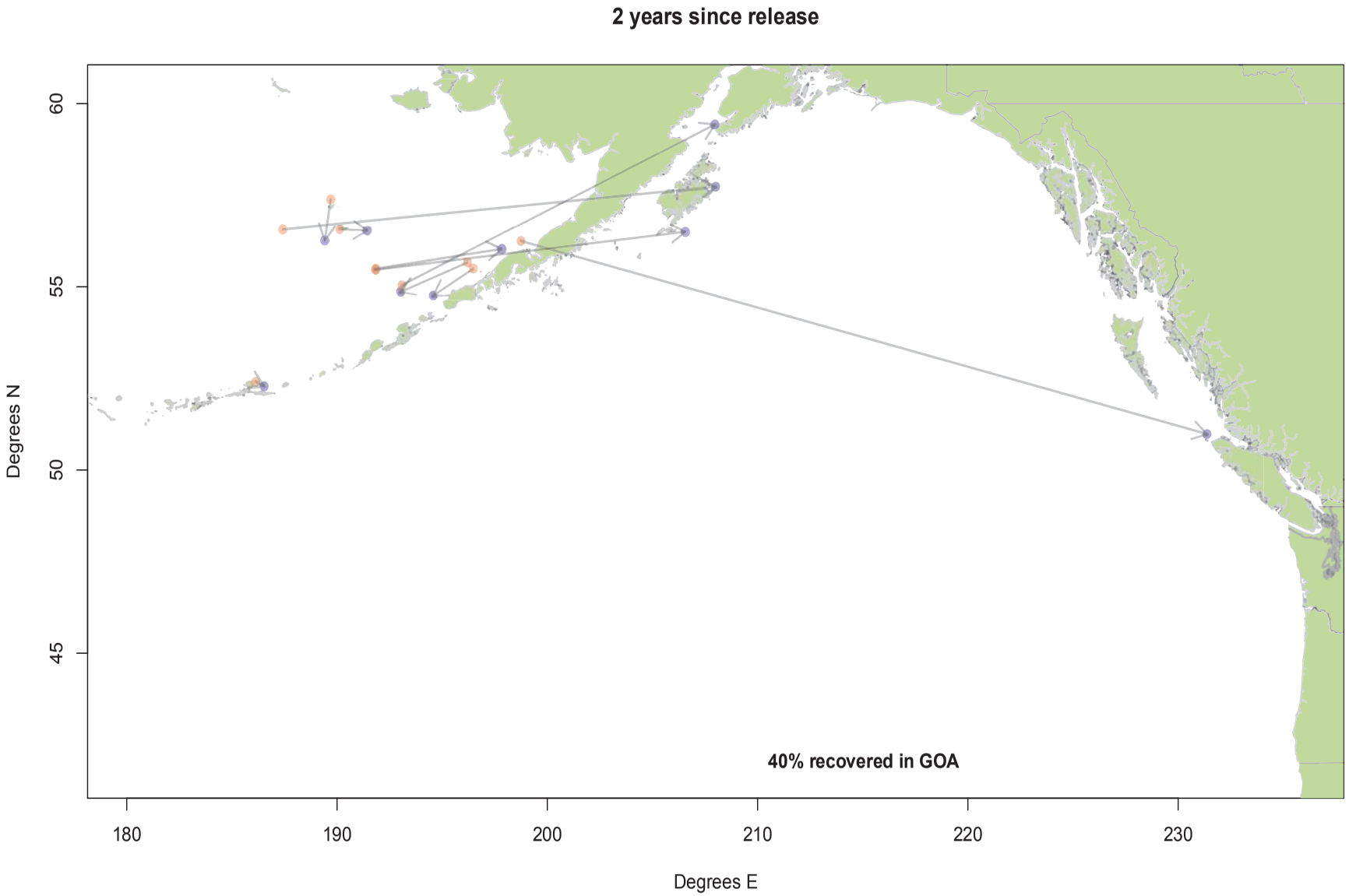


Figure 5b. Release and recovery locations of halibut tagged on the Bering Sea flats and Edge two years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

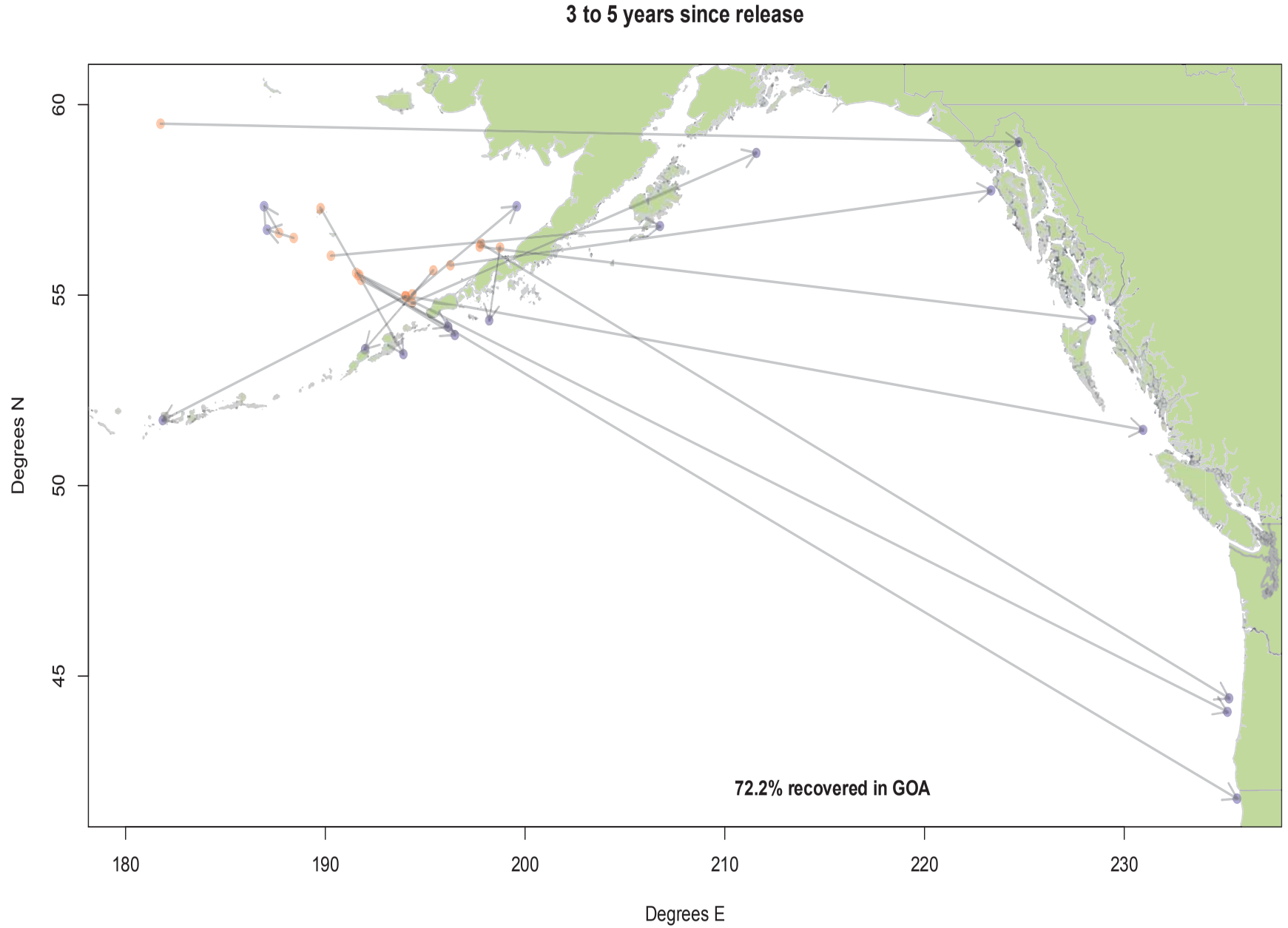


Figure 5c. Release and recovery locations of halibut tagged on the Bering Sea flats and Edge 3-5 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

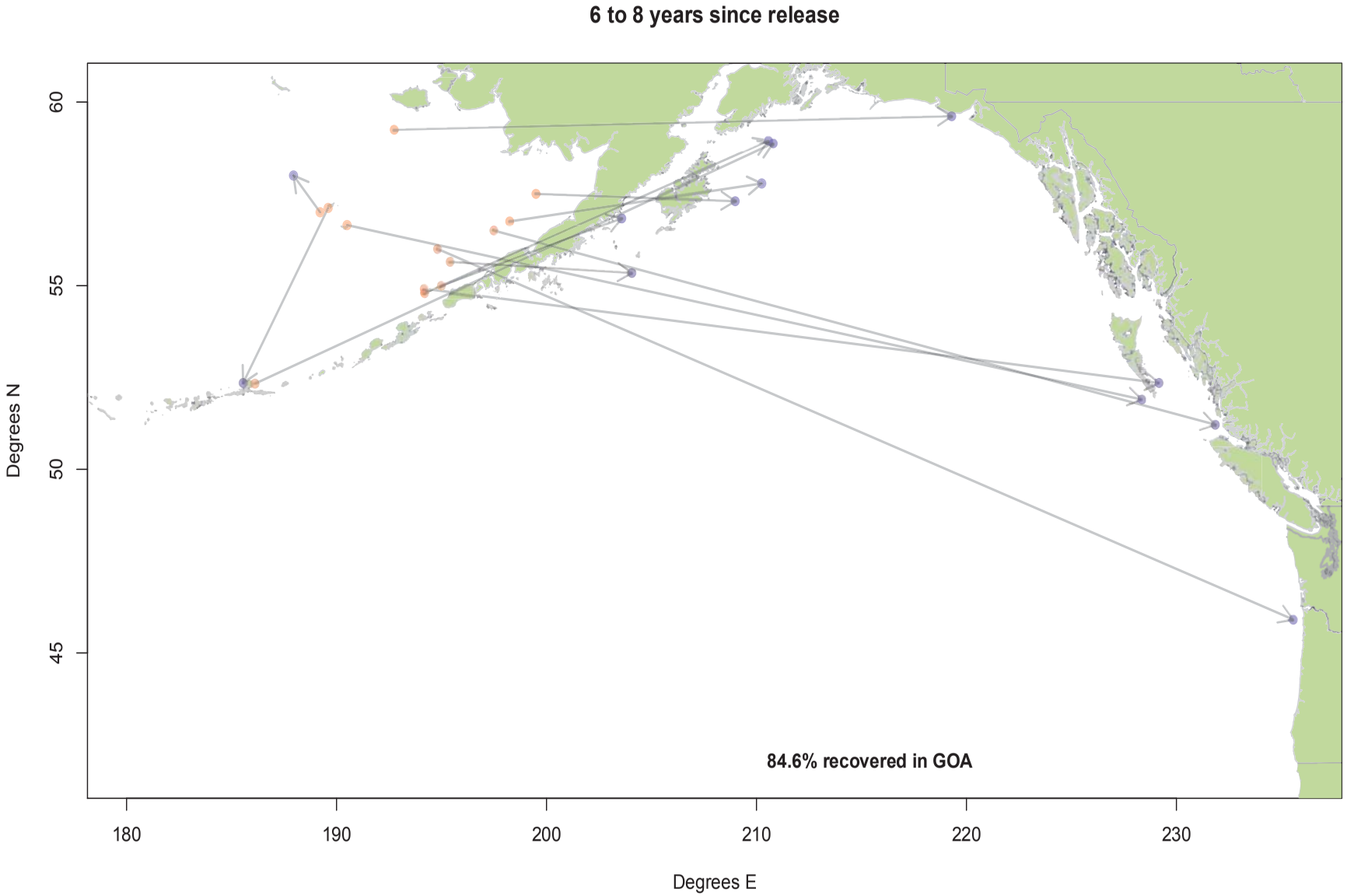


Figure 5d. Release and recovery locations of halibut tagged on the Bering Sea flats and Edge 6-8 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

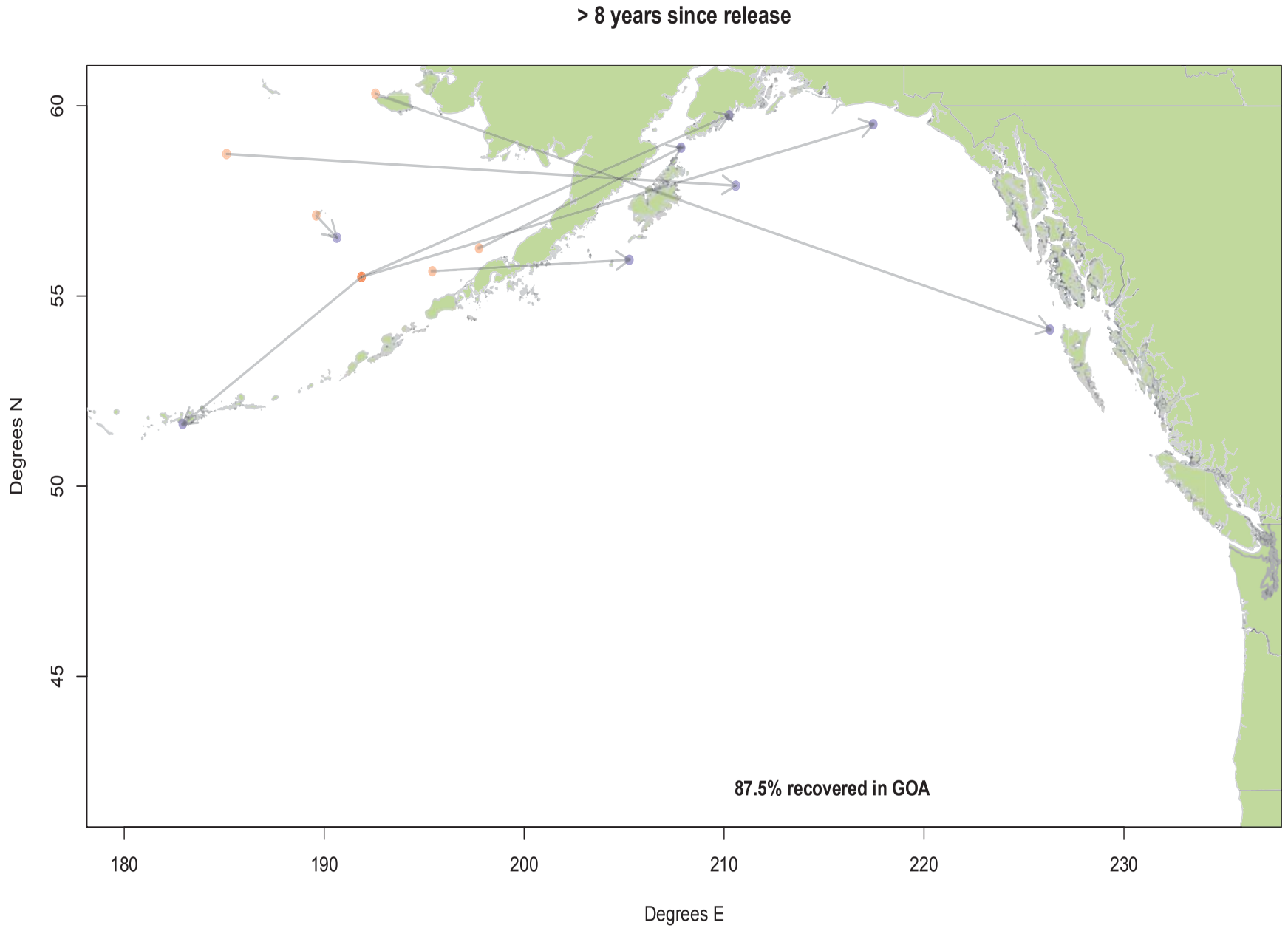


Figure 5e. Release and recovery locations of halibut tagged on the Bering Sea flats and Edge over 8 years following release, combined over TRS and non-TRS releases and all release years. Arrows indicate direction of movement between release and recovery locations.

Modelling mortality and migration as functions of age using PIT tagging data

Raymond A. Webster

Abstract

In fishery applications of tag-recovery models, recovery probabilities are typically parameterised in terms of instantaneous rates of mortality, where the mortality rate can be a function of the size or age of a fish. For age-dependent tag-recovery models, past work on Pacific halibut used a fixed-age approach, in which the age of each fish was fixed at the same value for each halibut of a given length. In this work, we examined age-dependent tag-recovery models that allow for variability in ages. The age of tagged halibut can only be determined for recovered tagged animals, and when modelling data from the International Pacific Halibut Commission's passive-integrated transponder (PIT) tagging study on Pacific halibut, we used auxiliary information from the annual setline surveys to model the age of un-aged fish. Both Bayesian and multiple imputation methods were examined. The former appeared to suffer from problems with parameter identifiability, and ultimately, only the latter was applied to the PIT tag data. The results showed large differences in both mortality and migration rate estimates between models that allowed for variability in age and those that fixed age at a constant value for a given length.

Introduction

From 2003 to 2009, the International Pacific Halibut Commission (IPHC) conducted a coastwide tag-recovery study, which involved the release of around 67,000 tagged halibut from 2003-2004, close to 3,200 of which were recovered during the study period. Halibut were tagged with passive-integrated transponder (PIT) tags which were recovered by electronically scanning catch landed at ports staffed by IPHC scan samplers. The goals of this study included estimation of length-specific mortality rates, and rates of migration among regulatory areas. The design of the study has been described in detail in several IPHC reports, and more recently in Webster et al. (2013). That paper presented tag-recovery models with length-specific selectivity and mortality rates, and a model for migration that allowed migration rates to be a logistic function of length. Since those analyses were completed, there has been interest in fitting models in which mortality and migration rates are functions of halibut age. A relationship between probabilities of migration and age would likely be useful as an input into a spatially-structured stock assessment model, and for constructing simulation models, as part of the IPHC's ongoing management strategy evaluation process.

The challenge with using age in the tag-recovery modelling is that age can only be determined for recovered fish, as a halibut would not survive the removal of its otolith for aging. In the PIT tag study, close to two-thirds of the recovered halibut had ages recorded. Combining this with a coastwide recovery rate of 5% means that 97% of the released fish have no age data. Past approaches for fitting age-structured tag-recovery models for Pacific halibut have made use of length-age keys, where there is a fixed relationship between age and length (Quinn et al. 1990 for

migration rates, and Pollock et al. 1998 for mortality). This approach does not allow for variability among areas, years, or individual halibut.

The work herein also takes advantage of the relationship between age and length, by using observed data to construct a model for the missing data that includes modelling of uncertainty in predictions of age. We examine two approaches for integrating this model into the tag-recovery modelling: using it as a prior distribution for age in a Bayesian framework, and using it as a model for multiple imputation of missing ages.

Predicting age from length

Our goal here is to construct a model for the relationship of age with length. Although all released halibut from the PIT tag study had length at release recorded, only a small proportion have corresponding estimates of age at recovery. These recovered fish are unlikely to be representative of the whole population of released halibut, and therefore, we made use of the large dataset collected on the IPHC setline survey in years of release to model age as a function of length. The setline survey samples around 2000 fish in each regulatory each year, and both age and length are measured on each fish. Released tagged halibut were a subset of all halibut captured on the setline surveys in 2003 and 2004, and, therefore, it is reasonable to assume that any model of the setline survey age and length data will also apply to the relationship between release age and release length of tagged halibut.

We use a generalised additive model (GAM) to model the relationship between age and length at release for 2003 and 2004. Preliminary modelling using standard parametric functions did not produce results that fitted the data well, and therefore, we opted for the more flexible modelling approach provided by GAMs. Age data were first log-transformed, which resulted in approximate normal distributions for log(age). Figure 1 shows the fitted GAM models by area for the 2003 survey data, along with approximate 95% prediction intervals. For a fish of length x_{jk} released in area *j* and year *k*, the model is

$$Age_{jk}\left(x_{jk}\right) \sim Lognormal\left(\mu_{jk}\left(x_{jk}\right), \sigma^2_{jk}\right) \quad (1)$$

where $\mu_{jk}\left(x_{jk}\right)$ is the GAM mean function at length x_{jk} (dashed lines in Figure 1), and σ^2_{jk} is the estimation variance (prediction variance), which for now we assume is not dependent on length.

Bayesian modelling

The first method we examined, for modelling mortality and migration as functions of age, used Equation (1) as a prior in a Bayesian formulation of the tag-recovery models. The models we used were the same as described in Webster et al. (2013), except age replaced length in both the migration and fishery mortality models. Commercial fishing mortality was again parameterised in terms of a selectivity function, with selectivity arbitrarily fixed at 1 for a fish of age 12, and mortality directly estimated for an age-12 halibut. The selectivity (and thus mortality) function was assumed to be piecewise linear, with selectivity assumed to be zero at age 5, and estimated at ages 8, 10, 14, 16, 18, 20, and 22. Selectivity beyond age 22 was assumed to be constant and equal to selectivity at age 22 due to low sample sizes of older halibut.

For the age prior, the values of $\mu_{jk}(x_{jk})$ and σ^2_{jk} estimated from the GAM models were used. An alternative that could be explored in future modelling is to integrate the estimation of these parameters into the Bayesian modelling, so that the parameters would be sampled from their own posterior distributions, along with parameters of the tag-recovery model. Modelling was through Markov chain-Monte Carlo algorithms implemented using the OpenBUGs software, and vague priors were used for all other parameters of the tag-recovery model. In the case of mortality parameters, a number of possible prior distributions were tested to examine the sensitivity of the posterior distributions to the choice of prior. Some degree of sensitivity was found, therefore only results based on priors that resulted in the best convergence criteria are presented here.

Because the original tag-recovery data set is so large, we first tested the modelling on a much smaller, simulated data set designed to capture the key-features of the observed data, while allowing us to implement models relatively quickly. Data for 7,000 halibut released in two areas were generated, with mortality and migration parameters chosen to generally reflect values previously estimated for Areas 2B and 3A, although with fishing mortality rates increased somewhat to generate more recoveries. Mortality parameters are shown in Table 1. We assumed fish move from 2B to 3A with annual probability of 0.02, and in reverse direction with 0.10 probability. Of the 7,000 fish released over two years, each year 1,500 were released in Area 2B and 2000 in Area 3A. "True" age and length pairs for each released fish were randomly sampled from 2003-2004 survey data to ensure these data were as realistic as possible.

Several test models were implemented to help understand the properties of the models and the posterior distributions:

- Age assumed to equal mean from relationship with length (AgeF) for all fish (solid lines on Fig. 1)
- Age unknown for all fish, and given lognormal prior (AgeLN_0)
- Age known for 60% of recovered fish; ages of other fish given lognormal prior (AgeLN_60)
- Age known for 100% of recovered fish; ages of other fish given lognormal prior (AgeLN_100)

The AgeF model is a fixed-age model, and is therefore similar to previous modelling, where age was assigned based on an age-length key. This model could be fitted using both maximum likelihood estimation (MLE) and Bayesian modelling, and does not use observed age data from recovered halibut. AgeLN_0, AgeLN_60, and AgeLN_100 were chosen to examine the effect the proportion of ages recorded at recovery has on posterior distributions.

Figure 2 shows the posterior means of fishing mortality rates by age for a single simulated data set. For models AgeF, the MLEs and posterior means from Bayesian MCMC modelling were almost identical, and we only present the MLEs here. The three models with prior distributions on age show that there was some improvement, as a greater proportion of recovered ages were recorded (fitted values get closer to true values as the proportion of recovered ages increases). However, none of the three models performs well for this example data set, with mortality functions being particularly poorly estimated for simulated Area 2B data. While we expect some deviation from true values, the three models with priors on age generally produce posterior means that are no closer to, or much further from, the true values than the incorrect fixed-aged model, AgeF. Figure 3 provides a sense of what is going on here, by comparing the prior and posterior distributions of simulated fish of similar size released in Area 3A, one unrecovered, and the other recovered (in Area 3A) but not aged. For fish that are not recovered, the posterior distribution

matches the prior, as we would expect, as there is no information on age in the data. For fish that are recovered, apparent information in the data drags the posterior distribution to the left, and results in a much narrower range of likely younger ages than implied by the prior. The apparent strong influence of the data on the posterior was unexpected, and seems to be due to the problems with the identifiability of mortality and age in the model: mortality here is dependent on the age of recovered fish, and for recovered fish with no age data, the posterior of age will also be a function of mortality, and there may not be enough information here to achieve convergence to sensible posteriors for both sets of parameters. Indeed, plots of the three independent MCMC chains run for each model (not presented here), showed poor mixing of chains for mortality and age of recovered fish, with discrete jumps in each chain occurring at numerous points along each plot. Repeating the exercise on additional simulated data sets supported the concerns with this approach, discussed above.

Imputation models

As a result of the apparent problems with identifiability experienced in the Bayesian modelling, a second approach was applied, which places more structure on the model by ensuring that all age values are generated directly from the GAM model distribution. The model specified in Equation 1, again with estimates of parameters from the GAM modelling applied, is used to generate a release age for each un-aged fish. The tag-recovery model is then fitted (using MLE), producing estimates of mortality and migration parameters. This process is then repeated several (K) times, producing a set of K estimates for each parameter. The final estimate of each parameter is the mean of these K estimates. This is the widely used method of multiple imputation presented in Rubin (1987). From applying this approach to some simulated examples, it was clear that the imputation method eliminated the problems with parameter identifiability in the Bayesian modelling, and it was, therefore, applied to the full PIT tag-recovery data set. For comparison with the type of approaches used previously, we again fitted a fixed-age model, where age at length was fixed as the predicted mean value from the GAM model.

In general, the commercial fishing mortality estimates produced from the multiple imputation method show monotonic, increasing functions of mortality with age, leading to an asymptote for older fish (Fig. 4). The exception is Area 4A, where the recovery data is most sparse, and one notable deviation in the Area 2B relationship at 18 years. As we would expect, there is far less variability among estimates from individual model fits for areas with large sample sizes, and for ages with large sample sizes. For example, there is almost no variability among the model estimates for Area 3A, and for most areas, the greatest variability is among estimates for older fish for which sample sizes are generally low. There is a big difference between the imputation estimates and the fixed-age model estimates, with the latter consistently producing non-monotonic mortality functions.

Estimates of annual emigration rates by area are shown in Figure 5. Areas 3A, 3B, and 4A show declining rates of emigration with increasing age, while Area 2B shows little change in migration rate with age. Area 2C appears to show higher rates of movement for older fish, but as shown by the variability among imputation estimates, small sample sizes for older fish mean there is a great deal of uncertainty in these estimates. As with the mortality estimates, the fixed-age model produces quite different estimated relationships than the imputation modelling. The slope of relationships for Areas 3B and 4A is much greater when age is fixed, while the sign of the slope

(positive or negative) is reversed for Areas 2C and 3A relative to the results of the imputation estimates.

Discussion

This work has demonstrated the importance of accounting for variability in age when fitting age-dependent models, where a high proportion of ages are missing. Due to the very high degree of variability in the relationship between age and length (Fig. 1), an approach that assigns each fish the mean age will lead to almost no very old fish appearing in the data, and few very young fish for most lengths. The impact on inference when using such an approach is great: in our example, the resulting compression of the age distribution leads to dome-shaped mortality curves, and estimates of emigration rates that are generally much higher than those that result from models that allow for variability in the ages at a given length. Past approaches that fixed age based on age-length keys (analogous to our fixed-age model) are likely to result in biased mortality and migration estimates.

While using a multiple imputation approach results in a more realistic model than a fixed-age approach, and results in more plausible mortality estimates in the PIT tag application, there are still improvements that may need to be made. In particular, we assumed that variability in ages (on the log scale) was not a function of length. However, Figure 1 appears to show less variability for young fish than this model predicts: the scatter of data is less for smaller fish, and data are almost all well within the 95% confidence intervals. Figure 1 suggests that a model with lower variance for fish <70 cm in length may be an improvement over the one used here.

We have not yet produced variance estimates for the parameter estimates from the imputation modelling. Variance estimates will need to combine both variability among imputations (as demonstrated in Figs. 4 and 5), and the variance of estimates for each imputed data set. For each imputed data set, the latter can obtained as output from the optimisation algorithm by taking the inverse of the estimated information matrix. Our models have a large number of parameters and such calculations are time consuming. To save time, we did not produce variance estimates for the current modelling, preferring instead to focus on the differences in parameter estimates among models and methods. Estimation of variances will be part of future modelling work.

A similar problem to the one considered here is how to model mortality and migration parameters as a function of length in a way that accounts for variability in growth rates among individual fish. Webster et al. (2013) assumed a constant growth rate of 3 cm per year for all fish, but data from recovered PIT tagged fish show a high degree of variability in growth rates. As with fixing age at a constant value for a given length, fixing growth rate may result in fewer small (slow growing) or large (fast growing) fish than in the tagged population, which may also lead to biased estimates of movement rates. For the PIT data, we have release lengths of all halibut, but only a subset of recovery lengths. Direct estimates of growth rate may only be determined from this subset. However, unlike with age data, we do not have a corresponding large survey data set for modelling growth rate (e.g., as a function of length or age) or for obtaining precise estimates of variability in growth rates by year and area. In the case of areas with few recoveries, a growth-rate model used for imputation will not be of the same quality as one developed for age based on survey data. Further, the distribution of growth rates from the tag recoveries could differ from that of the full release sample. Nevertheless, some preliminary modelling along these lines has been carried out, and initial results show far less difference between variable-growth and fixed-growth models than we observed in the age modelling comparisons.

References

Quinn II, T. J., Deriso, R. B., and Neal, P. R. 1990. Migratory catch-age analysis. Can. J. Fish. Aquat. Sci., 47: 2315-2327.

Pollock, K. H., Chen, H., Brownie, C., and Kendall, W. L. 1998. Age dependent tag recovery analyses of Pacific halibut data. Int. Pac. Halibut Comm. Tech. Rep. 38.

Rubin, D.B. 1987. Multiple Imputation for Nonresponse in Surveys. J. Wiley & Sons, New York.

Webster, R. A., Clark, W. G., Leaman, B. M., and Forsberg, J. E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Can. J. Fish. Aquat. Sci., 70. 642-653.

Table 1. Fishing mortality (F) and natural mortality (M) parameters used for generating simulated tag-recovery data for Areas 2B and 3A. Fishing mortality is a piecewise linear function of age, with values nodes at 5, 10, 15, and 20 years shown in the table.

Area	F(5)	F(10)	F(15)	F(20)	M
2B	0	0.24	0.30	0.30	0.15
3A	0	0.09	0.135	0.15	0.15

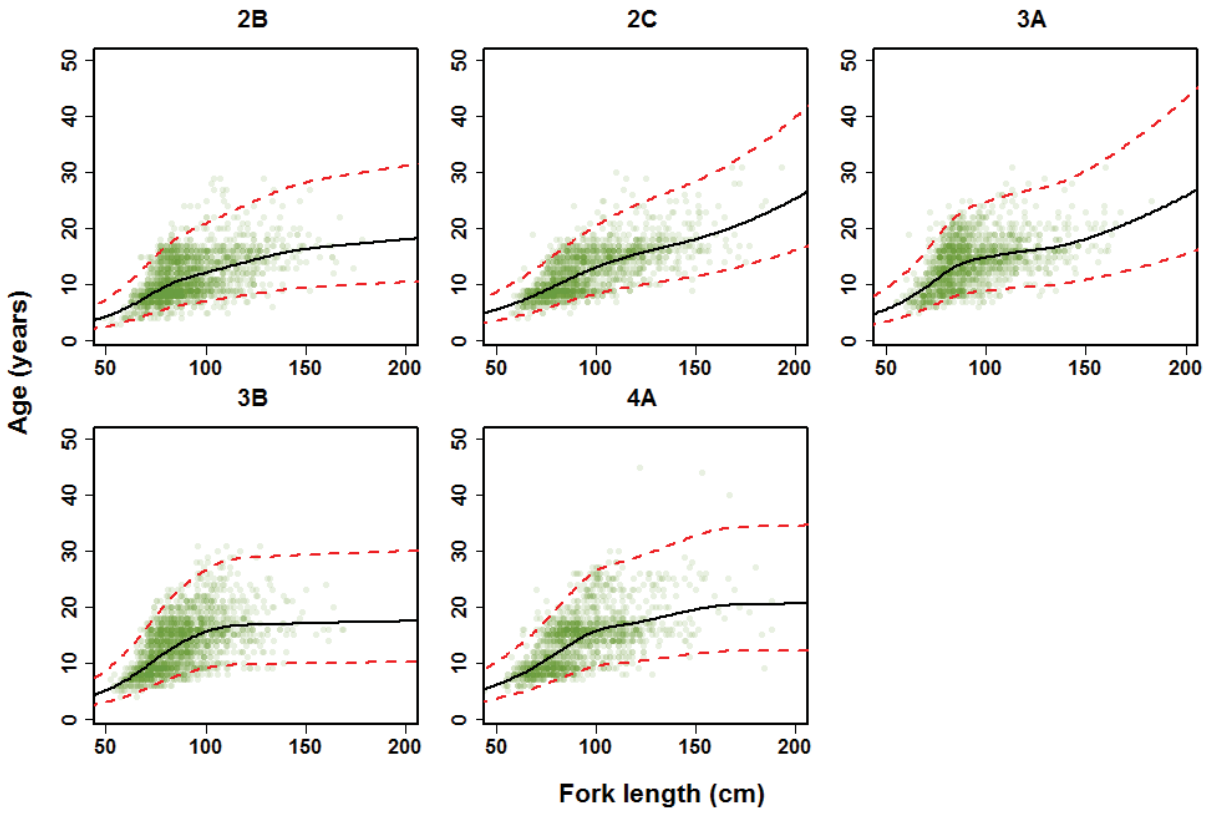


Figure 1. Relationship between age and fork length for setline survey data collected in 2003 by regulatory area. The solid line is the predicted age at length from a GAM model of log(age) as a function of length, and the dashed lines show approximate 95% confidence intervals for individual predictions of age.

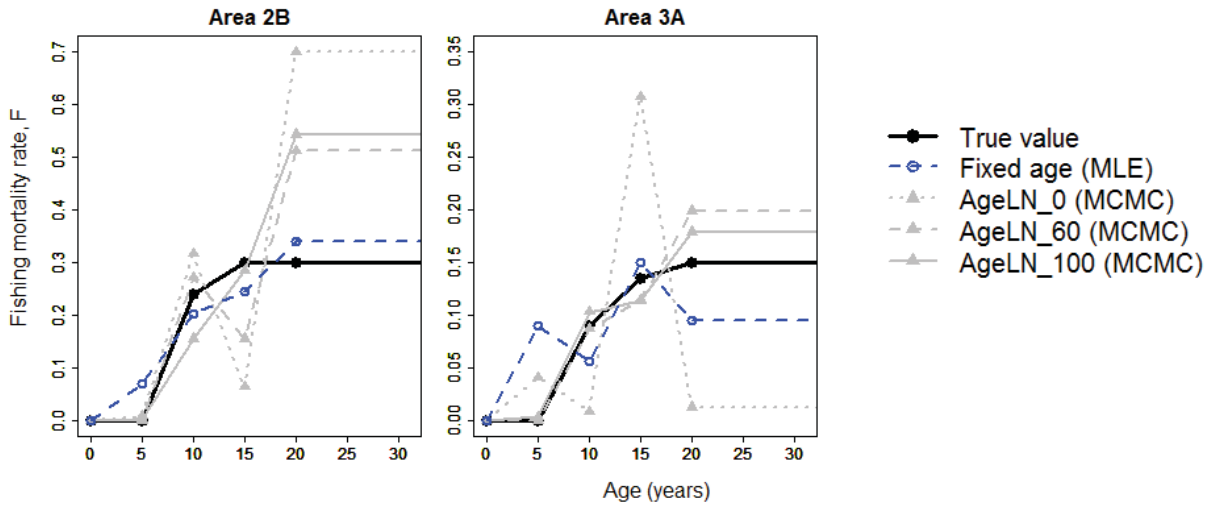


Figure 2. Posterior mean mortality rates by age for age-dependent tag-recovery models applied to a simulated example data set, and compared to known true values for Areas 2B and 3A. See text for model descriptions.

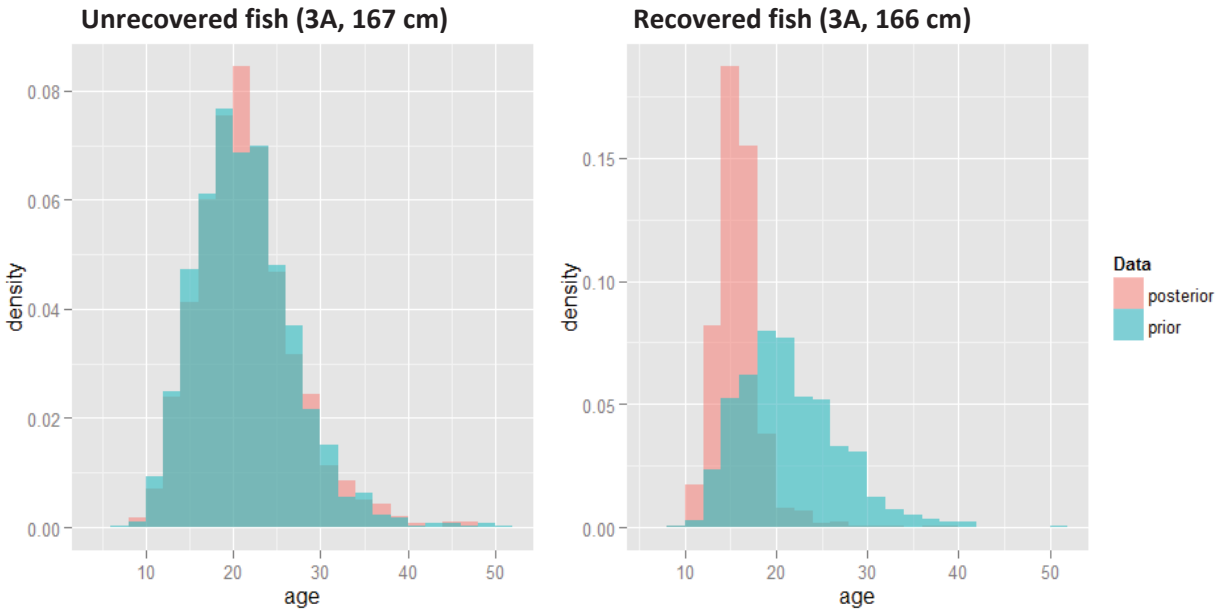


Figure 3. Prior and posterior densities for two simulated halibut from model AgeLN_60, one an unrecovered fish with release length of 167 cm, and the other a 166 cm fish that was recovered (in Area 3A), but not aged.

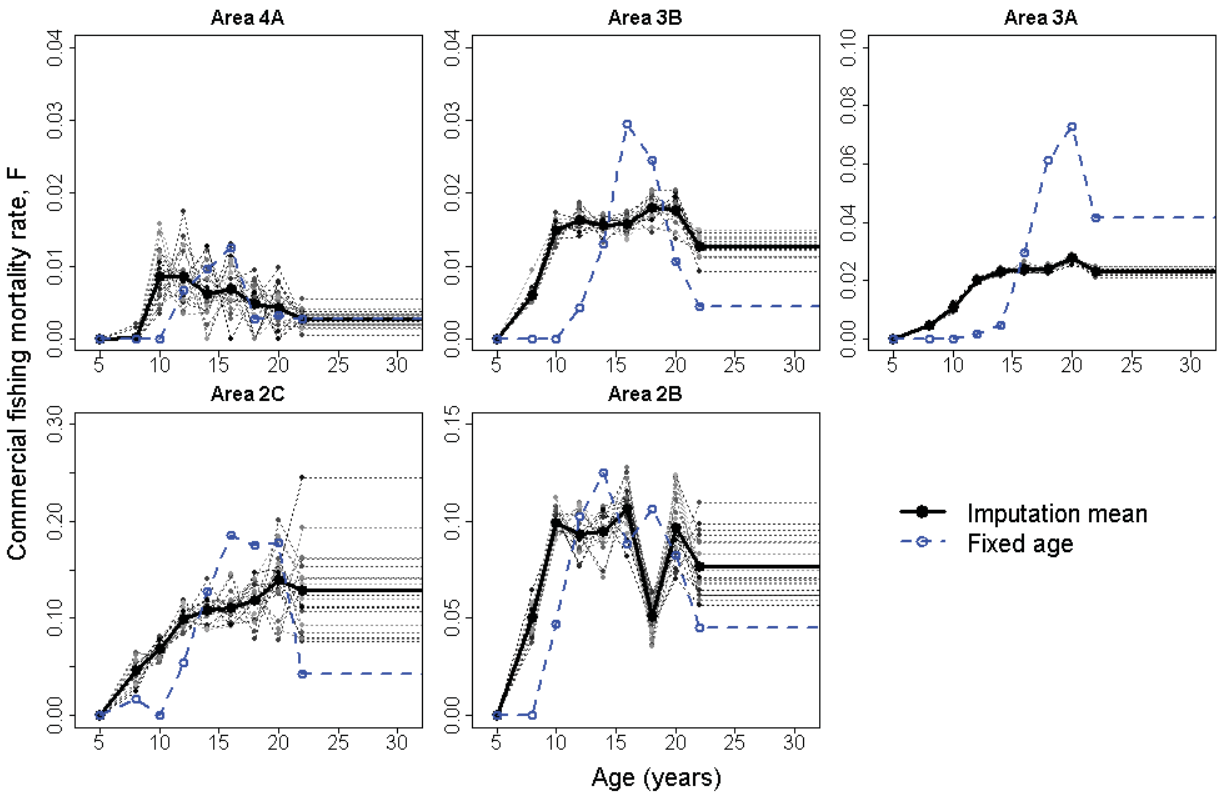


Figure 4. Mean commercial fishing mortality estimates by regulatory area, calculated from 50 imputation estimates (solid line and circles), along with a sample of 20 imputation estimates (dotted lines) to show the degree of variability among imputation estimates. Estimates from the fixed age model are shown with dashed lines and unfilled circles.

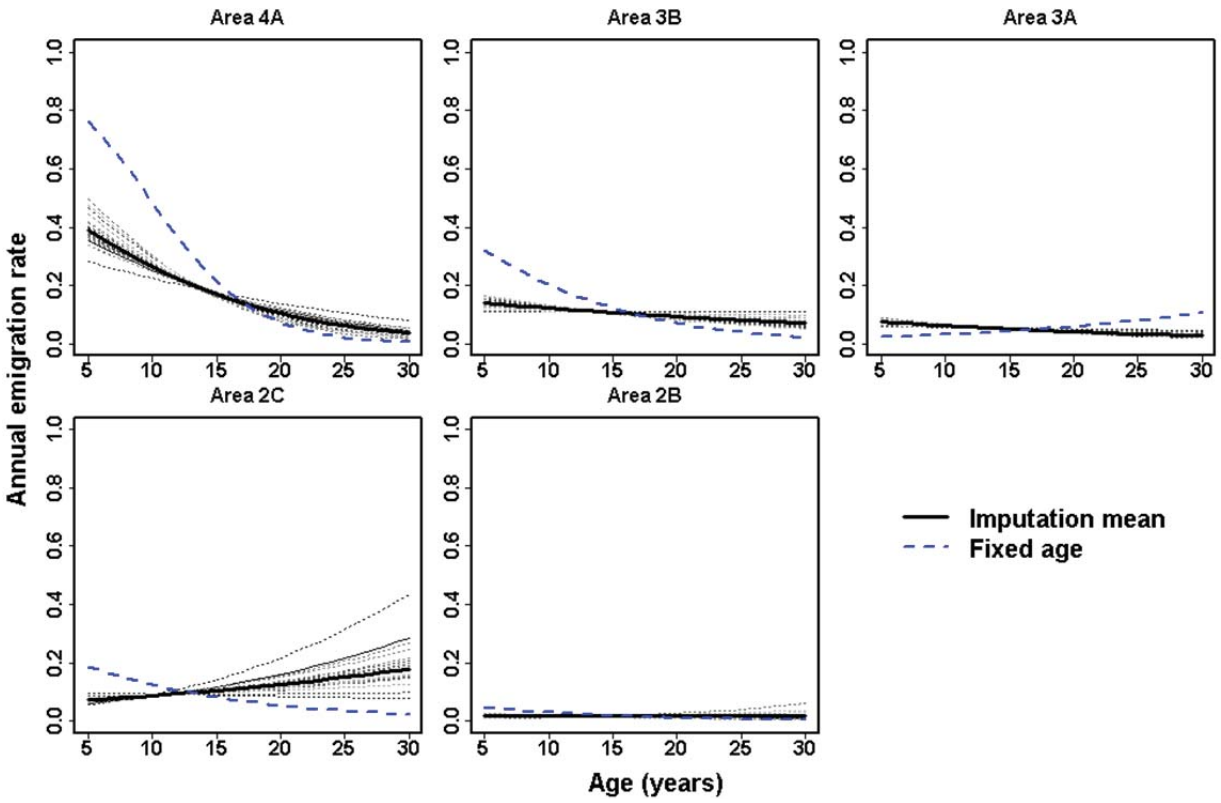


Figure 5. Mean emigration rate estimates by regulatory area calculated from 50 imputation estimates (solid line), along with a sample of 20 imputation estimates (dotted lines) to show degree of variability among individual estimates. Estimates from the fixed age model are shown with a dashed line.

Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal dispersal of Pacific halibut in the southern Salish Sea

Timothy Loher

Abstract

Alternative hypotheses have been suggested regarding the relative isolation or mixing between adult Pacific halibut residing in the Salish Sea, relative to the presumably much larger coastal population. However, little, if any, empirical data exist with which to assess the degree to which the Salish Sea might represent a unique stock component: namely, the potential for the system to contain active spawning group(s), retain viable larvae throughout their developmental period, support nursery habitats, or derive either adult or fishable recruitment from local source(s). In an attempt to begin filling some of the substantial gaps in our understanding of local population function, fishery-independent pop-up archival transmitting tags were deployed during the summer and fall of 2014, at four locations in the US waters (Area 2A) of the southern Salish Sea. These tags were programmed to release from their host fish either during the mid-January spawning season (n = 8) or in late spring of 2015 (n = 4), in order to assess whether Salish Sea halibut remain in the system to spawn, and whether those that might leave the system in winter are likely to return the following summer. One of the tags, programmed to report in January, released prematurely, on October 7, and commenced broadcast from within San Juan Channel, in the heart of the San Juan Islands group.

Introduction

It has been hypothesized that halibut residing within the southern Salish Sea represent a distinct stock component from those found elsewhere in International Pacific Halibut Commission (IPHC) Regulatory Area 2A (Gao 2012). This contention has been based upon analyses of otolith composition that suggest significant differences in the average microchemical properties of otoliths obtained from halibut that had been sampled from tribal fisheries conducted both within the southern Salish Sea and along the outer Washington coast. However, this evidence alone is largely insufficient to establish a conclusion that Salish Sea halibut exist in a state of relative isolation. Unique otolith elemental signatures can be derived from a variety of processes that represent population structuring at scales smaller than those associated with the establishment and maintenance of discrete stocks; such as variability in oceanographic conditions over the course of the hatching and rearing periods of larval cohorts spawned at individual breeding sites, or seasonal and interannual homing and site fidelity in pre-recruits and adults. In order to support a unique population, regions such as the Salish Sea must be capable of supporting local spawning, settlement, and recruitment, thus closing the life cycle within their boundaries. Regions that are not capable of generating self-recruitment may be sufficiently structured to represent externally-dependent pseudopopulations (*sensu* Bouchet and Taviani, 1992; Troyanovsky 1992), but cannot be viewed as unique independent stocks.

Unfortunately, no data exist for the Salish Sea with which to empirically evaluate competing hypotheses regarding local halibut population structure. The current study seeks to begin rectifying this, in small part, by examining: a) whether mature female halibut, resident within the southern Salish Sea during summer months, remain there to spawn, or depart the system in order to spawn in either the northern Salish Sea (i.e., Area 2B) or at outer coastal spawning grounds, and; b) whether individuals that depart the Salish Sea might do so permanently (i.e., potentially represent exported recruitment), or simply do so on a seasonal basis (i.e., represent a migratory, summer-site-faithful (*sensu* Loher 2008) component of the larger coastal population). These questions will be examined via the deployment of fishery-independent pop-up archival transmitting (PAT) tags on large, presumably mature, female halibut while on their feeding grounds; with those tags programmed to report the positions of tagged fish during the winter spawning season, as well as late in the following spring.

Tag deployments

The body of the Mk10 PAT tag (manufactured by Wildlife Computers, Redmond, WA) is shaped much like a hand-held microphone, with a central diameter of approximately 2 cm (0.75 in), a total body length of 17 cm (6.5 in), and a 12 cm (5 in) antenna made of plastic-coated braided cable (Fig. 1). The body of the tag contains light, depth (pressure), and temperature sensors, as well as programming circuitry and a satellite transmitter. The tag is attached to the fish via a dart and leader assembly, in which an 18-cm (7-in) leader constructed of monofilament line covered in black adhesive-lined shrink-tubing is secured to the fish using a titanium dart embedded through the pterygiophores, roughly 4 cm (1.5 in) medial to the dorsal fin, on the eyed-side of the halibut where the body begins to taper towards the tail (Fig. 1). The leader is attached to the tag body via a thin metal wire, through which an electrical current is induced that causes the metal to rapidly corrode on the programmed date, allowing the tag to release from the leader, float to the surface, and begin data transmissions. Data are transmitted to the U.S. National Oceanic and Atmospheric Administration's polar-orbiting satellites, administered by the Advanced Research and Global Observation System. The tag broadcasts summarized temperature and depth data, depth-temperature profiles and light-based geoposition estimates. The tag's endpoint position is determined from the Doppler shift of the transmitted radio frequency in successive uplinks received during one satellite pass (Keating 1995). If a tagged fish is captured and its tag retrieved before the tag pop-up date, or if a tag is found awash following detachment from a fish, the full archival record can be accessed, from which highly detailed environmental data and daily geoposition estimates may be obtained. In addition, recovered tags can be refurbished, via replacement of the release mechanism and battery, and used for subsequent deployment(s).

The tags used in the current study were composed entirely of used, refurbished units, which were programmed to record temperature (0.1° C resolution) and depth (4 m resolution) every 30 seconds and ambient light levels every minute. However, detailed depth and temperature data are not provided in satellite transmissions. Data are transmitted as binned summaries within consecutive 8-hr blocks, within user-defined depth and temperature intervals (i.e., bins) and as depth-temperature profiles. Depth bins were defined as follows: surface, 0-10.0 m, 10.1-50.0 m, 50.1-100.0 m, 100.1-150.0 m, 150.1-200.0 m, 200.1-250.0 m, 250.1-300.0 m, 300.1-400.0 m, 400.1-500.0 m, 500.1-600.0 m, 600.1-700.0 m, 700.1-800.0 m, and >800.0 m. Temperature bins

were defined as: <-1.0° C, -1.0-1.0° C, 1.1-2.0° C, 2.1-3.0° C, 3.1-4.0° C, 4.1-5.0° C, 5.1-6.0° C, 6.1-7.0° C, 7.1-8.0° C, 8.1-10.0° C, 10.1-12.0° C, 12.1-20.0° C, and >20.0° C.

A total of 12 adult halibut were tagged in US waters of the southern Salish Sea: a) six during the 2014 IPHC summer setline survey, on May 27 and 28, and; b) six tagged during a dedicated tagging charter conducted on October 11-12 (Fig. 2). Eight tags (Table 1) were programmed to detach from their host fish and begin satellite transmissions on January 15, 2015; corresponding to the known peak spawning period for Pacific halibut in the eastern Gulf of Alaska (Loher and Seitz 2008). The remaining four tags were programmed to report either 365 days after deployment (i.e., on May 27 or 28, 2015); or, for tags deployed in October, 2014, to report on June 1, 2015. The May-June reporting treatment is necessary in order to evaluate whether any potentially-observed departure of Pacific halibut from the Salish Sea during the winter spawning season is likely to represent true mixing between the Salish Sea and the outer coast (i.e., two-way exchange of individuals), as opposed to the permanent departure of individuals that may have been reared in the Salish Sea (i.e., the Salish Sea representing an independent population that generates exported recruitment, as adults).

Tag deployments were divided into four general locations (Fig. 2; Table 1): 1) southern Strait of Georgia; 2) Boundary Pass; 3) eastern Strait of Juan de Fuca, and; 4) southcentral Strait of Juan de Fuca (Fig. 2). According to the original study design, three fish were to be tagged at each location, composed of two individuals bearing January-reporting tags and one fish bearing a late-spring-reporting tag. However, this proved impossible due to realized fish distributions (i.e., the actual number of large female halibut encountered during standard survey sets), gear conflicts (i.e., inability to effectively fish the southern Strait of Georgia in October due to large amounts of crab gear on the grounds), and financial constraints (i.e., insufficient funding to allow the October charter to extend beyond two days of fishing effort). As such, the total number of fish tagged at each location ranged from 1-5. Tagged fish ranged in fork length from 94-131 cm. All tagged fish were females, as determined via veterinary ultrasound (Loher and Stephens, 2011).

One tag, programmed to detach and report in January and deployed south of the San Juan Islands, detached prematurely from its host fish, on October 7, and commenced satellite transmissions. This fish was still in the Salish Sea, fairly close to its tagging location: it had moved 27 km to the NNE, into San Juan Channel, between San Juan and Shaw Islands (Fig. 2).

References

Bouchet, P. and Taviani, M. 1992. The Mediterranean deep-sea fauna: pseudopopulations of Atlantic species? Deep Sea Res. A 39:169-184.

Gao, Y. 2012. Otoliths speak out: why the Pacific halibut in Puget Sound are different. Environ. Biol. Fish. 95:469-479.

Keating, K.A. 1995. Mitigating elevation-induced errors in satellite telemetry locations. J. Wildl. Manage. 59: 801-808.

Loher, T. 2008. Homing and summer feeding site fidelity of Pacific halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska, established using satellite-transmitting archival tags. Fish. Res. 92:63-69

Loher, T. and Seitz, A.C. 2008. Characterization of active spawning season and depth for eastern Pacific halibut (*Hippoglossus stenolepis*), and evidence of probable skipped spawning. J. Northw. Atl. Fish. Sci. 41:23-36

Loher, T. and Stephens, S. A. 2011. Use of veterinary ultrasound to identify sex and assess female maturity of Pacific halibut in non-spawning condition. N. Am. J. Fish. Mgmt. 31:1034-1032.

Troyanovsky, F. M. 1992. Observations of non-maturing redfish (*Sebastes mentella* Travin) in the Northwest Atlantic. Northw. Atl. Fish. Sci. 14:145-147.

Table 1. Deployment and reporting details for PAT tags deployed on Pacific halibut in the southern Salish Sea in 2014 (see also Fig. 2). All tagged fish were females. Tag S-14008 (denoted in bold) released from its host fish and reported prematurely on October 7, 2014, at a position that was 27 km distant from the deployment location; this tag had been programmed to report on January 15, 2015.

Tag #	Release site	Deploy latitude (N)	Deploy longitude (W)	Fork Length (cm)	Deploy date	Report date
S-14001	southern Strait of Georgia	48.834°	122.887°	108	10/11/14	01/15/15
S-14002	Boundary Pass	48.690°	123.140°	119	10/11/14	01/15/15
S-14003	Boundary Pass	48.682°	123.132°	108	10/11/14	06/01/15
S-14004	eastern Juan de Fuca	48.164°	123.615°	99	05/27/14	01/15/15
S-14005	southcentral Juan de Fuca	48.166°	123.642°	94	05/27/14	01/15/15
S-14006	southcentral Juan de Fuca	48.167°	123.651°	100	05/27/14	05/27/15
S-14007	southcentral Juan de Fuca	48.176°	122.921°	114	05/28/14	01/15/15
S-14008	**eastern Juan de Fuca**	**48.326°**	**123.135°**	**119**	**05/28/14**	**10/07/14**
S-14009	East Juan de Fuca	48.326°	123.135°	118	05/28/14	05/28/15
S-14010	Boundary Pass	48.682°	123.132°	107	10/11/14	01/15/15
S-14011	Boundary Pass	48.691°	123.143°	131	10/12/14	01/15/15
S-14012	Boundary Pass	48.676°	123.112°	122	10/12/14	06/01/15



Figure 1. ***Upper panel*****: A Wildlife Computers MK10 PAT tag bearing the leader and dart assembly. The tag body possesses sensors that record temperature, depth, and light, as well as a release mechanism that jettisons the body from the leader on a pre-programmed date. The tag then floats to the surface and broadcasts the accumulated data to passing satellites, which in turn use the tag's signal to calculate its position.** ***Lower panel*****: An IPHC sampler holds a large halibut bearing a PAT tag.**

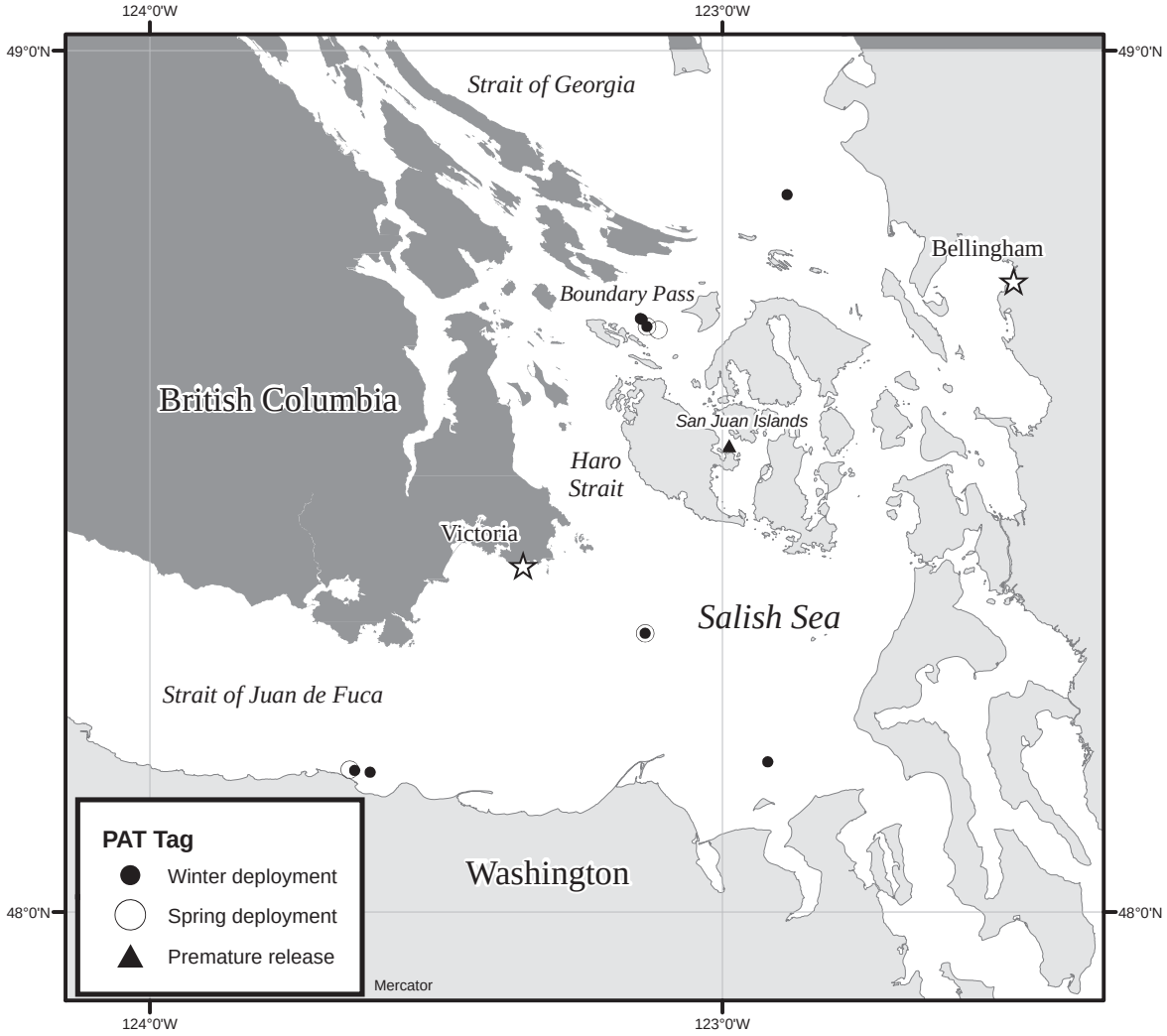


Figure 2. Deployment and reporting locations for PAT tags deployed in the southern Salish Sea during 2014.

2014 Standardized stock assessment survey

Ed Henry, Eric Soderlund, Claude L. Dykstra, Tracee Geernaert, Aaron M. Ranta, and Tom Kong

Abstract

In 2014, eleven commercial longline vessels, six Canadian and five U.S., were chartered by the International Pacific Halibut Commission for survey operations. During a combined 78 trips and 747 charter days, these vessels fished 33 charter regions, covering habitat from northern California to the island of Attu in the Aleutian Islands, and north along the Bering Sea continental shelf edge. All 1,430 survey stations planned for the 2014 survey season were either scouted or completed. Of these stations, 1,417 (99.1%) were considered successful for stock assessment analysis. Approximately 765,419 pounds of halibut, 119,474 pounds of Pacific cod, and 49,501 pounds of rockfish were landed from the standardized survey stations. Compared to the 2013 survey, weight per unit effort (WPUE) increased in Regulatory Areas 2C, 3B, 4A, and 4C. WPUE decreased in areas 2A, 2B, 3A, 4B, and 4D.

Introduction

The International Pacific Halibut Commission (IPHC; the Commission) standardized stock assessment (SSA) survey provides catch information and biological data that are independent of the commercial fishery. These data, which are collected using standardized methods, bait, and gear during the summer of each year, provide an important comparison with data collected from the commercial fishery. The survey fishing effort is only a small fraction of the commercial effort and is restricted to the summer months. The commercial fishery is more variable in its gear composition and distribution of fishing effort over time, and presents a broad spatial and temporal sampling of the stock. Biological data collected on the surveys (e.g., the size, age, and sex-composition of halibut) are used to monitor changes in biomass, growth, and mortality in adult and sub-adult components of the halibut population. In addition, records of non-target species caught during survey operations provide insight into bait competition, rate of bait attacks, and serve as an index of abundance over time, making them valuable to the assessment, management, and avoidance of non-target species.

The Commission has conducted standardized setline surveys in selected areas during most years since 1963 (with a break from 1987 to 1992). Historical information regarding previous standardized survey operations has been presented in IPHC Annual Reports and Survey Manuals 1963-1965, 1976-1986, and 1993-current; IPHC Report of Assessment and Research Activities (RARA) documents 1993-current; and IPHC Technical Reports 18 (Hoag et al. 1980) and 58 (Soderlund et al. 2012). The majority of the current survey station design and sampling protocols have been consistent since 1998.

Survey design and procedures

The 2014 SSA Survey Manual (IPHC 2014a) provides complete details regarding all survey procedures including survey design, setting, hauling, and sampling protocols. Brief descriptions of the grid survey design and procedures follow.

Design

The 2014 survey design encompassed both nearshore and offshore waters of northern California, Oregon, Washington, British Columbia, southeast Alaska, the central and western Gulf of Alaska, Aleutian Islands, and the Bering Sea continental shelf edge. These areas were divided into 33 regions, each requiring between 10 and 47 charter days to complete (Table 1). Stations were located at the intersections of a 10 nmi by 10 nmi square grid within the depth range occupied by Pacific halibut during summer months (20-275 fm in most areas). Figure 1 depicts the survey station positions, charter region divisions, and regulatory areas surveyed.

As part of a multi-year coastwide effort to expand our survey depth profile, depth ranges in Regulatory Areas 2A and 4A included stations as shallow as 10 fathoms and as deep as 400 fathoms. This added 67 stations in Regulatory Area 2A (which is inclusive of all northern California stations that were also intended to extend the survey's southern terminus) and 81 stations in 4A (Fig. 1–4). To help manage this expansion, the historical Unalaska charter region was divided into four new regions, named Unimak East and Unimak West) and Four Mountains East and Four Mountains West) (Fig. 3). The 4A Edge charter region was also divided to create 4A Edge North and 4A Edge South (Fig. 4).

The current standard grid station layout has been in place since 1998, with the addition of stations around the Pribilof Islands and St. Matthew Island beginning in 2006, twelve additional stations in the Washington/Oregon charter regions beginning in 2011, fourteen additional stations fished in Puget Sound in 2014 (a repeat of the 2011 Puget Sound stations), and 27 stations fished this year in northern California (an increase from 15 in 2013). Thirteen stations in southeast Alaska and eight rockfish (Scorpaenidae) index stations in the Washington charter region (described in the Special Projects section of this document) are fished on a different layout than the standard survey and are not included in the IPHC stock assessment dataset.

Seven skates of baited gear were set at each station in all charter regions. Setline survey specifications for gear, setting schedule, and soak time have been consistent among years. Standard survey gear consists of fixed-hook, 1,800-foot skates with 100-16/0 circle hooks baited with 0.25 lb to 0.33 lb of chum salmon (*Oncorhynchus keta*) and spaced 18 feet apart. Gangion length ranges from 24 to 48 inches. Each vessel set one to four stations daily beginning at or after 5 AM, and soaked the gear at least five hours before hauling. Vessels avoided soaking the gear at night when possible. Data from gear soaked longer than 24 hours were not used for assessment purposes.

Sets were considered ineffective for stock assessment if predetermined limits for lost gear, snarls, depredation, or displacement from predetermined station coordinates were exceeded. The fork lengths of all halibut captured at survey stations were recorded to the nearest centimeter; all lengths stated hereafter will be fork lengths. Each fork length was converted to an estimated weight using a standard formula (Clark 1992), and these weights were then used to generate the weight per unit effort (WPUE) data. Average WPUE, expressed as net pounds per skate, was calculated by dividing the estimated catch in pounds (net weight) of halibut equal to or over 32 inches (O32

halibut) by the number of standardized skates hauled for each station, and averaging these values for each area (statistical, charter, or regulatory).

Sampling protocols

Shipboard biologists, or sea samplers, collected data according to protocols established in the SSA Survey Manual (IPHC 2014a). As the gear was set, IPHC samplers evaluated the performance of the bird avoidance devices that were set along with the longline gear and recorded the exact number of hooks set and baits lost per skate of gear fished. During gear retrieval, samplers generally recorded hook status (e.g., empty, returned bait, species captured, bait type) of the first 20 consecutive hooks of each skate; however, processing needs for fish from previous skates, particularly in areas with high catch rates, occasionally affected where in the 100-hook sequence of the skate the sample was taken. The statistical adequacy of these 20-hook counts was examined last year in Webster and Leaman (2014). In the entire Puget Sound charter region, specific northern stations of Area 2A, and all of Area 2B, samplers recorded the status of all hooks in the order in which they were hauled, in lieu of 20-hook counts.

Samplers recorded lengths of all halibut caught along with the corresponding skate number. Vessel crew eviscerated all O32 halibut and then passed them to an IPHC sampler, who determined sex and maturity, prior-hooking injury (PHI) severity, evidence of depredation, and collected otoliths from a randomized subsample for later determination of age. Male halibut were assessed as either mature or immature, and females as immature, mature, spawning, or spent/resting. When the maturity stage of either sex could not be determined, the sampler coded the maturity stage as unidentified. The sex and maturity of halibut under 32 inches (U32 halibut) were recorded only if the fish was randomly selected for otolith collection or was already dead on the line. Samplers used a random sampling table to select targets for otolith removal from a subsample of all halibut caught. All U32 fish not selected for otolith collection were measured and released alive. PHI occurrences were documented for all measured halibut and results can be found in Kaimmer (2015).

At the end of each haul, samplers recorded the presence and abundance of seabird species within a 50-m radius from the vessel's stern. Seabird data are used to determine the spatial and temporal variation in the abundance of seabirds. A discussion of seabird data can be found in Geernaert (2015).

Special projects

The SSA survey often facilitates experiments that are not directly associated with halibut stock assessment, yet which are valuable to IPHC and/or external agencies and researchers. The following is a comprehensive list and description of the projects that the Commission facilitated in 2014:

Rockfish sampling in Regulatory Area 2A

IPHC sea samplers retained all rockfish caught in Area 2A, marked them with a tag, and recorded the station and skate of capture. After the rockfish were offloaded, state biologists from Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), or California Department of Fish and Wildlife (CDFW) collected additional data (such as sex, weight, length, and maturity) and biological material (such as otoliths and fin clips for genetic analysis) from each fish. Tag numbers enabled the biologists to associate the fish at the

dock with the skate of capture, and thereby location and depth. In 2014, state biologists sampled 419 rockfish that were captured in Area 2A.

As in 2013, the vessel contracted for the Area 2A charter regions fished eight rockfish index (RI) stations this year in addition to the standard SSA stations. WDFW selected the index station locations with the intent of targeting more rocky-bottom habitat than the standard SSA survey stations. Rockfish index stations were located at 2.5 nmi intervals within the standard 10-nmi grid around IPHC station 1082 (see IPHC (2014a) for station locations). At each of the rockfish index stations, fishing effort was reduced to three skates to limit impacts on rockfish populations. Halibut captured on rockfish index stations were measured and released alive without removing otoliths or examining gonads for sex and maturity. Data from these stations were not used in the halibut stock assessment. The IPHC has been approached by WDFW to continue the index station work on future surveys, subject to budgets and ongoing design considerations. IPHC intends to continue collaborating with state agencies to collect detailed data about rockfish captured on the standard survey grid stations in Area 2A.

Rockfish sampling in Regulatory Area 2B

In cooperation with Canada's Department of Fisheries and Oceans (DFO) and the Pacific Halibut Management Association (PHMA), IPHC samplers aboard survey vessels working in Regulatory Area 2B recorded round weight, round length, sex, and maturity, and collected otoliths from all *Sebastes* spp. caught on the survey according to the sampling criteria in the 2014 Bycatch Sampling Manual (IPHC 2014b). IPHC samplers in Area 2B sampled 2,883 rockfish (representing 16 different species) for length, sex, and maturity, and collected otoliths from 2,106 rockfish. These data and otoliths were shared with DFO. This project began in 2003, and has since been conducted annually (except for 2013). This project is expected to continue in future years.

Yelloweye rockfish enumeration in Alaska

IPHC samplers recorded the capture of all yelloweye rockfish (*Sebastes ruberrimus*) encountered by survey vessels working in all of Area 2C and in the Fairweather charter region in eastern Area 3A (Fig. 1) at the request of the Commercial Fisheries Division of the Alaska Department of Fish and Game (ADF&G). A total of 1,495 yelloweye rockfish were recorded in 2014.

Oceanography

During survey operations in 2014, sea samplers deployed water column profilers on every station, unless weather or tide conditions were so risky the units could be lost. Water column profilers measured chlorophyll *a* and pH in addition to temperature, depth, salinity, and dissolved oxygen concentration (Sadorus and Walker 2015).

Environmental contaminant sampling

IPHC samplers collected halibut flesh samples for the Alaska Department of Environmental Conservation (ADEC) as part of an ongoing study of environmental contaminants in halibut. Samples were collected from stations that corresponded to high commercial catch within the target site, with a goal of collecting samples from 15 small (80-89 cm), 15 medium (90-112 cm), 30 large (113-148 cm), and 10 extra-large (≥148 cm) halibut. Sixty-four samples were collected in the Fairweather survey region (15 S, 15 M, 30 L, 4 XL), 61 samples were collected in the 4A Edge S region (15 S, 15 M, 30 L, 1 XL), 38 samples were collected in the Puget Sound region (15 S, 15

M, 6 L, 2 XL), and 45 samples were collected in the northern California region (10 S, 15 M, 20 L). Samplers often collect fewer than 10 XL samples in a given target region because extra-large fish have been scarce. Samples will be tested for a broad suite of environmental contaminants, including organochlorine pesticides, dioxins, furans, polybrominated diphenyl ethers, polychlorinated biphenyl congeners, methyl mercury, and heavy metals (arsenic, selenium, lead, cadmium, nickel, and chromium). Continued collaborative work between ADEC and IPHC is anticipated.

Ichthyophonus sampling

In 2014, the IPHC continued investigations into *Ichthyophonus* incidence in Pacific halibut. *Ichthyophonus* is a protozoan parasite from the class Mesomycetozoea, a highly diverse group of organisms with characteristics of both animals and fungi, and has been identified in many marine fish. The 2014 project resampled the three geographically-distinct areas (Oregon, Prince William Sound, and Bering Sea (Area 4D Edge) charter regions) that have been sampled since 2011, in order to investigate temporal stability of *Ichthyophonus* prevalence. At the time of publication, histology results for these samples were still pending.

Spiny dogfish sampling

IPHC samplers recorded the length and sex of the first five spiny dogfish (*Squalus suckleyi*) per station in Regulatory Areas 2 and 3, and all spiny dogfish encountered in Area 4. Spiny dogfish inhabit areas that are more effectively covered by the IPHC than other surveys. Data collected are part of a multi-year project requested by the National Marine Fisheries Service (NMFS) Auke Bay Laboratories to compare IPHC's survey catch rates with those from NMFS sablefish (*Anoplopoma fimbria*) longline surveys. This effort will examine species distribution and data will be used in conjunction with tagging data to test the hypothesis that there may be two biological stocks of dogfish in Alaska: an inside population in southeast Alaska and a second that comprises those that live in coastal waters elsewhere. These data will be used to develop a length-based population dynamics model for the annual dogfish stock assessment. IPHC samplers collected 3,063 spiny dogfish length and sex samples in 2014.

Skate age and maturity sampling

Before the 2014 survey season, NMFS appealed to the Commission to implement a longnose skate (*Raja rhina*) and big skate (*Raja binoculata*) age and maturity collection project in the Gulf of Alaska. This information has been deemed imperative for fisheries managers to understand aspects of skate reproductive biology and development for age, growth, and maturity research. Total length, sex, maturity stage (with photos taken representing each stage), the presence of egg cases inside female skates (as well as measurements of each egg case), and small sections of vertebral column were collected. Six vessels collected 172 big and 265 longnose skate samples.

Coral Sampling

The IPHC collaborated with NMFS to collect information about the coral species seen from IPHC survey vessels in the Bering Sea. It has been proposed that the eastern Bering Sea canyons are unique habitats and that the North Pacific Fisheries Management Council (NPFMC) should consider implementing conservation measures. Coral, as structure-forming epifauna, are an important faunal component of the local ecosystem. Any data collected would be invaluable for further studies of coral species and unique habitat requirements along the outer-shelf and upper slope of the Eastern Bering Sea (EBS).

All coral brought aboard in Regulatory Area 4D, as well as the 4A Edge North and 4A Edge South charter regions, were identified. The *F/V Kema Sue* reported a total of three species. In Area 4A Edge North, *Plumarella* spp. was recorded on two stations and *Halipterus* spp (sea whips) on seven stations. In Area 4D *Anthoptilium* spp was recorded on one station and *Halipterus* spp. was recorded on two stations. *F/V Free to Wander* samplers only reported *Halipterus* spp. corals in Area 4A Edge South on three different survey stations.

Pop-up Archival Transmitting (PAT) tagging

A total of six female halibut ranging from 94-118 cm were tagged aboard the *F/V Pacific Surveyor*, at survey stations 1121, 1123, and 1125 (IPHC 2014a). A full accounting of these deployments and the experiment's objectives can be found elsewhere in this volume (Loher 2015).

Six-gill shark sampling in Puget Sound

Thirty-one bluntnose sixgill sharks (*Hexanchus griseus*) were opportunistically sampled in Puget Sound aboard the *F/V Pacific Surveyor* in a joint project with the Seattle Aquarium. Sex was determined externally, and up to 12 different meristic measurements were made on each shark, and genetic samples were collected from 30 of them.

Pacific cod length frequencies

The NMFS Alaska Fisheries Science Center requested and received data collected from Pacific cod (*Gadus macrocephalus*) captured on IPHC surveys to bolster data currently used by NMFS to assess the Bering Sea and Aleutian Islands Pacific cod stock. Since 2008 (excluding 2010) samplers on the IPHC survey vessel working the Bering Sea continental shelf edge in the Areas 4A and 4D Edge charter regions (Fig. 1) have collected Pacific cod length frequency data on all stations (first 15 fish from each skate). In 2014, samplers aboard the *F/V Kema Sue* and the *F/V Free to Wander* collected 5,422 and 621 Pacific cod lengths, respectively. This project is anticipated to continue in 2015.

Depredation tracking

During gear retrieval, samplers recorded all damaged and missing hooks to establish a baseline rate of gear damage against which to compare stations with suspected interference from depredating species. An index of typical gear damage will help identify stations that were ineffective for stock assessment purposes because of sperm whale (*Physeter macrocephalus*) depredation, which is often difficult to quantify. In the absence of clear signs of gear damage or decreases in catch, both the IPHC and NMFS (for their sablefish survey) struggle to interpret survey data for evidence of depredation at stations where sperm whales were present. Killer whale (*Orcinus orca*) interference with catch tends to be much easier to detect and quantify.

If sea samplers observed any toothed whales or pinnipeds within 100 meters of a survey vessel, the samplers identified the individuals to species level, recorded the number present, position (in relation to the vessel, the gear, and the offal discharge), the hook number at first and last sighting, and the duration of the encounter. Samplers noted all damaged halibut and damaged bycatch retrieved during these encounters.

Bait purchases

The minimum quality requirement for SSA bait is No. 2 semi-bright (Alaska Seafood Marketing Institute grades A through E), headed and gutted, and individually quick-frozen chum salmon.

The IPHC secures most of the bait needed to supply survey operations prior to the start of the survey. In August 2013, staff began arranging bait purchases for the 2014 survey. Approximately 330,000 lb of chum salmon were utilized from four suppliers in the U.S. An additional 10,000 lb of chum salmon were purchased in-season from two Alaskan salmon processors. The amount of bait used varied by vessel and charter region (Table 1). Bait quality was monitored and documented throughout the season and found to meet the standard as described

Fish sales and revenue sharing

As in previous years, O32 halibut that were caught on SSA survey stations and sacrificed in order to obtain biological data were retained and sold. This helps to offset costs of the survey program. Survey vessels also retained for sale incidentally-captured rockfishes and Pacific cod. Rockfishes and cod were retained because they rarely survive the barotrauma resulting from capture. Most vessel contracts provided the vessel a lump sum payment along with a 10% share of the halibut proceeds and a 50% share of the bycatch proceeds. The *F/V Pacific Surveyor* received no share of halibut or bycatch proceeds. The *F/V Kema Sue* received 12% of the halibut proceeds on the 4A Edge North, Four Mountains East, Unimak West, and 4D Edge charter regions. This special cost-sharing arrangement helped offset direct IPHC costs for these remote or low WPUE regions, which are more expensive to survey than other charter regions. The IPHC does not retain proceeds from the sale of incidentally-captured rockfishes and Pacific cod. Instead, for retained bycatch captured in U.S. waters, proceeds are divided equally between the vessel (for handling expenses) and the state management agency. In Canada, DFO receives all proceeds from bycatch captured in Canadian waters, subsequent to deduction of predetermined vessel bycatch processing fees.

IPHC's chartered vessels delivered fish to 26 different ports during the 2014 SSA survey (Table 2). Fish sales were awarded based on the objectives of obtaining a fair market price and distributing sales among buyers and ports. When awarding sales, the Commission considered the price offered, the number of years that a buyer had been buying and marketing halibut, how fish were graded at the dock (including the determination of No. 2 halibut and chalky fish), and the promptness of settlements following deliveries. Obtaining fair market value was the main consideration in awarding fish sales. However, when factors other than fish price were considered, sales were sometimes awarded to buyers not offering the highest prices, thereby meeting the goal of distributing sales among qualified buyers. Individual sales were evaluated after each event to ensure that the buyer was meeting IPHC's standards.

A summary of landings and prices from the SSA survey is provided by species and regulatory area in Table 3. Overall average prices and total pounds landed increased in 2014 compared to 2013.

Field personnel

In 2014, the Commission employed 23 seasonal hires, who worked a total of 1,755 person days, including travel days, sea days, and debriefing days. Additionally, one IPHC port sampler worked 41 days on IPHC surveys this summer. Two permanent staff participated on two different vessel legs as well, for a total of 18 days. The Commission typically employs two samplers aboard each survey vessel. One shipboard biologist works on deck, handling fish and collecting the required data and biological samples. The other sea sampler, in a portable shelter, records data and observations and stores samples collected by the deck sampler. Since catch rates in Regulatory

Area 2A are generally low, one sampler was deployed for all but the first trip in the northern portion of the Washington charter region and the Puget Sound trip, where two samplers were deployed. The IPHC also deployed three samplers on the NMFS trawl surveys (Sadorus and Palsson 2015; Sadorus and Lauth 2015). The *F/V Alaska Provider* was staffed for 74 days during the Aleutian Island survey. On the Bering Sea survey, two samplers split the work: one sampler was aboard the *F/V Vesteraalen* for 31 days and the other sampler was aboard the *F/V Alaska Knight* for 45 days.

Results

Vessel operations

Eleven commercial longline vessels, six Canadian and five U.S., were chartered by the IPHC for survey operations in 2014. A combined 78 trips and 747 charter days were fished to complete the coastwide survey (Table 1). Of the 1,430 survey stations fished, 1,417 (99.1%) were considered effective for stock assessment analysis (Table 1).

Timing of the SSA survey

Each year, the months of June, July, and August are targeted for survey fishing. In 2014, ninety stations, amounting to less than 7% of all stations, were fished outside of this window, during the last full week of May. On a coastwide basis, vessel activity was highest in intensity at the beginning of the survey season and declined in August as boats finished their charter regions (Fig. 5). All survey activity was completed by the end of August.

Typically, most boats chartered to conduct the survey fish multiple charter regions that are sometimes not adjacent to each other. The logistics associated with geographically-separated regions can result in some temporal gaps between the time when a charter region is started and when it is completed. For example, the *F/V Kema Sue* began the Unimak West region during the first week of June, while on its way west to complete the Four Mountains East region and north to fish sections of the Area 4 Edge. The vessel then returned to the Unimak West region roughly six weeks later to fish the remaining stations during an optimal tide window on its way back east (Fig. 5). Over the past five years, the timing of the survey has varied regionally, with little variation in Area 2B and more variation in Area 4D, but with no consistent pattern within regions (Fig. 6).

Weight per unit effort

The SSA survey covers commercial as well as non-commercial fishing grounds, so the average WPUE for all regulatory areas surveyed was below that of the commercial fleet, as it has typically been in the past (Tables 4). Not all of the WPUE data included in this report are used in the analytical stock assessment. Three SSA survey stations which are located in the Closed Area (stations 7041, 7047, and 7048; see IPHC (2014)) fall in the Area 4A Edge North charter region and are listed in Area 4A for this report, but are actually included in Areas 4CDE for stock assessment purposes. Thirteen stations in southeast Alaska's inside waters occur at a spatial density that is not acceptable for the stock assessment, and are not used in assessment or apportionment calculations. Detailed information regarding the number of effective stations, pounds of O32 halibut, and average WPUE by regulatory and statistical area is provided in Table 5.

Compared to 2013 results, survey WPUE increased in Regulatory Areas 2C (+1%), 3B (+2%), 4A (+45%), and 4C (+26%). WPUE decreased in Areas 2A (-25%), 2B (-2%), 3A (-2%), 4B (-12%), and 4D (-8%) (Table 4, Fig. 7).

In Area 2A, survey WPUE decreased by 23% in the Washington charter region, but increased by 5% in Oregon. In northern California the average WPUE of that region decreased by 51% as compared to 2013. The Puget Sound charter region WPUE was 48% greater than that of 2011, the only other year sampled. WPUE decreased in two out of the four regions of Area 2B, with St. James and Goose Island decreasing by 5% and 2%, respectively. The Vancouver charter region WPUE increased by 3%, while Charlotte remained relatively the same. WPUE in Area 2C climbed by 10% and 3% in the Ketchikan and Ommaney charter regions, respectively, while it decreased in the Sitka (-9%) region (Fig. 8). Since 2011, Area 2C's WPUE has exceeded Area 3A, thereby resulting in it having the highest WPUE of all the SSA regions (Fig. 8).

In Area 3A, WPUE increased in Fairweather (3%), Yakutat (16%), PWS (38%), and Shelikof (5%), while decreases were observed in Seward (-25%), Gore Point (-16%), Portlock (11%), and Albatross (-17%) (Fig. 8). Area 3B WPUE decreased in Chignik (-17%), Semidi (17%), and Shumagin (-5%) when compared to last year, while Sanak (36%) and Trinity (4%) increased (Fig. 8). Only one out of three charter regions along the Aleutian chain decreased in 2014 as compared to last year, with Attu region's WPUE falling by 46%. The WPUE of the Unalaska region (comprised of the newly formed Unimak and Four Mountains regions) and the Adak region increased by 32% and 7%, respectively. On the Bering Sea continental shelf, WPUE for St. Paul Island decreased by 38% and stations around St. George increased by 41%. 4A Edge WPUE increased by 33%, while 4D Edge decreased by 10%. WPUE specific to the Eastern Bering Sea island cluster stations can be found in Table 6.

Numbers per unit effort

Trends in the coastwide numbers per unit effort (NPUE) for the past decade are shown in Figure 9 for both O32 and U32 length halibut. There was a 14% increase in the relative numbers of U32 caught and a 1% decrease in catch rates of O32 length halibut when compared to 2013 (Fig. 9). In 2014, there were 26% more U32 halibut captured than O32, which is a 14% increase in difference from 2013 (12%).

Some interesting trends can be seen when NPUE is observed by region (Fig. 10). In particular, Areas 2B, 2C, 3B, and 4A all had a slight increase in the rate of capture of both large and small halibut. In 2014, Area 3A showed a decrease in O32, but an increase in U32 halibut NPUE. Area 3B continues to have the largest gap between O32 and U32 halibut, with 58% difference between the two.

Length distribution

Slightly more than 57% of halibut caught on the survey were smaller than the current commercial legal size limit, with a median length of 79 cm coastwide (Table 7). In 2014, the median lengths of halibut captured increased in Areas 2A, 4A, 4B, and 4C; decreased in Areas 2B, 2C, 3A, and 4D; and did not change in Area 3B (Fig. 11). Most of the western portions of the survey (Areas 3A, 3B, 4A, 4C, and 4D) had average halibut lengths below the commercially-legal size limit (Fig. 12). The largest median length was in Areas 2A (89 cm).

Sex ratio of the catch

The sex composition for O32 halibut from the survey catches showed considerable variation among areas, ranging from 42 - 85% females (Fig. 13). Area 4B had the lowest percentage of females in the catch, while Area 4C had the highest. Most female halibut caught during the survey

period (i.e., summer months) were in the ripening stage and expected to spawn in the upcoming season.

Otolith collection

The otolith collection goal for the 2014 survey was 2,000 otoliths per regulatory area, with a minimum target of 1,500 per area. Fewer than 1,500 otoliths were collected in Areas 2A, 4C, and 4D, as the catch rates were low and there are fewer stations in these areas (Table 8). Information about age distributions for the 2014 survey can be found in Forsberg (2015). Additional otoliths were collected in most regulatory areas for a clean otolith archive collection and details can be found in Tobin and Forsberg (2015).

Bycatch

Approximately 121 species of fish and invertebrates were caught as bycatch during the survey. Though skippers on survey vessels take precautions to avoid marine mammal and bird catch, one black-footed albatross (*Phoebastria nigripes*) was captured in 3B and was provided to the Oikonos organization for genetic sampling. No marine mammals were caught on survey.

Hook occupancy of species-groups varied by regulatory area (Fig. 14). Halibut was the most commonly-caught species coastwide. The most frequently incidentally-captured species overall was sharks, followed by Pacific cod (Fig. 14). The most common bycatch in Areas 2A and 2B was sharks, primarily dogfish. The most frequent bycatch in Areas 3B, 4A, 4C, and 4D was Pacific cod. In Areas 2C, 3A, and 4B, the "other species" category was most common, and was comprised primarily of Aleutian skates (*Bathyraja aleutica*), arrowtooth flounder (*Atheresthes stomias)*, big skates (*Raja binoculata*), longnose skates (*Raja rhina*), white-blotched skates (*Bathyraja maculata),* grenadiers (*Corypaenoididae* spp.), and yellow Irish lord sculpins (*Hemilepidotus jordani*).

Dogfish were the largest component of the shark species category in Areas 2A (96%), 2B (99%), 2C (94%), and 3A (98%). Sleeper sharks were the largest component of the shark species category in Areas 3B (53%), 4A (57%), and 4D (100%).

Trends in bycatch NPUE are presented in Figures 15 through 18. Bocaccio (*Sebastes paucispinus*), canary rockfish (*S. pinniger*), and yelloweye rockfish (*S. ruberrimus*) populations are of concern in Areas 2A, 2B, and 2C, and their numbers often drive catch regulations. Catch rates of bocaccio and canary rockfish are so low on IPHC surveys (Fig. 15) that it is difficult to make any inferences from them. Trends in bycatch NPUE over the last ten years for the other major incidentally-captured species and species groups show that the encounter rate for most remained relatively constant over time (Figs. 15-18).

Depredation Tracking

Marine mammals approached charter vessels during gear retrieval on 65 sets (4.5%); of those, 51 encounters involved either sperm whales or killer whales. Though damaged halibut were observed on 27 of the stations at which whales were present, no sets were deemed ineffective for halibut stock assessment because of depredation. Resolving actual depredation rates will require examining data from all stations and comparing catch among skates within each station. These data will continue to be collected so that these challenging interactions can be further evaluated and quantified.

Future work

The IPHC plans to continue fishing most of the current SSA survey stations, but survey operations have been dependent upon the ability of the project to remain self-funding. Although the surveys are designed exclusively to fulfill scientific needs, IPHC has adjusted fishing effort per station so that the ability to conduct the surveys on budget could withstand limited variation in ex-vessel halibut sale price or WPUE over the long term. However, if average halibut sale prices or WPUE fall substantially in the future, the Commission may need to find alternate sources of funding to collect these important data. Conversely, if the IPHC receives additional funding from the governments, the amount of halibut retained from the surveys will be reviewed. Also, identifying and attracting suitable and professional, fixed-gear longline vessels and crew continues to be a challenge for the survey program.

In 2015, it is anticipated that SSA work will be conducted in all 27 traditional regions. Additionally, the Commission staff is proposing to expand the current areas fished to include coverage in waters on the eastern Bering Sea shelf, in a repeat of the work conducted in 2006. The number of regions surveyed, and the extent of any pilot projects, is subject to change and is dependent upon decisions made at the IPHC's 2015 Annual Meeting.

Acknowledgements

Survey operations occur over a large geographic range, in a wide variety of weather conditions, and often involve long, demanding days. The survey team would like to thank the IPHC sea samplers, charter vessels, skippers and crews, plant personnel, port samplers, and permanent staff, as well as those individuals from outside agencies, whose dedicated contributions and efforts made the 2014 SSA survey operations a success.

References

Clark, W. G. 1992. Estimation of halibut body size from otolith size. Int. Pac. Hal. Comm. Sci. Rep. 75.

Forsberg, J. E. 2015. Age distribution of Pacific halibut in the 2014 IPHC stock assessment setline surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 569-576.

Geernaert, T. O. 2015. Trends in seabird occurrence on stock assessment surveys (2002-2014) . Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 577-586.

Hoag, S. H., Williams, G. H., Myrhe, R. J., and McGregor, I. R. 1980. Halibut assessment data: Setline surveys in the north Pacific Ocean, 1963-1966 and 1976-1979. Int. Pac. Hal. Comm. Tech. Rep. 18.

IPHC. 2014a. 2014 Stock Assessment Survey Manual. Int. Pac. Hal. Comm., Seattle, WA.

IPHC. 2014b. 2014 Protocols for Rockfish data collection in British Columbia. Int. Pac. Hal. Comm., Seattle, WA.

Kaimmer, S. M. 2015. Prior hook injuries: Results from the 2014 IPHC SSA and NMFS trawl surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 645-656.

Lohr, T. 2015. Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal dispersal of Pacific halibut in the southern Salish Sea. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 523-530.

Sadorus, L. L. and Walker, J. 2015. Oceanographic monitoring in 2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 351-358.

Sadorus, L. L. and Lauth, R. 2015. Cruise report for the 2014 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 619-626.

Sadorus, L. L. Palsson, W. A., and Ranta, A. 2015. Results from the NMFS Aleutian Islands biennial bottom trawl survey in 2014. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 635-644.

Soderlund, E., Randolph, D. L., and Dykstra, C. 2012. IPHC Setline Charters 1963 through 2003. Int. Pac. Hal. Comm. Tech. Rep. 58.

Tobin, R. S. and Forsberg, J. E. 2015. Clean otolith archive collections. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Webster, R. A. and Leaman, B. M. 2014. Setline survey hook counts: are the “first 20 hooks” sufficient? Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 421-432.

Table 1. Effort and catch summary by charter region and vessel for all 2014 SSA stations.

Reg Area	Charter Region	Vessel	ADF&G or VRN	Charter Days[1]	Planned Stations	Effective Stations	Halibut Sold[2] (lb)	Avg. Price[3] USD	Chum (lb)
2A	N. California	*Pacific Surveyor*	-	14	27	27	1,575	$6.19	3,232
2A	Oregon	*Pacific Surveyor*	-	33	60	60	10,119	$6.46	17,147
2A	Puget Sound	*Pacific Surveyor*	-	10	14	13	1,951	$7.03	2,830
2A	Washington	*Pacific Surveyor*	-	29	70	70	6,976	$7.12	9,696
2B	Charlotte	*Star Wars II*	20492	22	44	44	36,197	$8.42	10,780
2B	Goose Is.	*Pender Isle*	27282	17	43	43	22,522	$8.14	10,913
2B	St. James	*Star Wars II*	20492	15	42	42	33,445	$8.35	10,290
2B	Vancouver	*Pender Isle*	27282	23	41	41	13,839	$7.77	10,255
2C	Ketchikan	*Pender Isle*	27282	18	41	41	43,103	$7.81	11,195
2C	Ommaney	*Bold Pursuit*	20875	19	40	40	62,148	$7.56	9,950
2C	Sitka	*Bold Pursuit*	20875	21	42	42	40,831	$6.66	9,572
3A	Albatross	*Free to Wander*	29155	22	45	45	42,872	$6.88	9,325
3A	Fairweather	*Bold Pursuit*	20875	18	49	49	40,893	$6.43	10,478
3A	Gore Pt.	*Clyde*	55803	20	45	45	28,620	$6.89	11,220
3A	Portlock	*Clyde*	55803	27	46	46	36,333	$6.68	10,150
3A	PWS	*Waterfall*	25075	24	45	45	34,313	$7.38	10,551
3A	Seward	*Waterfall*	25075	31	48	48	25,780	$7.26	12,920
3A	Shelikof	*Clyde*	55803	25	45	45	25,833	$6.90	10,642
3A	Yakutat	*Free to Wander*	29155	9	18	18	18,074	$6.65	5,000
3A	Yakutat	*Waterfall*	25075	21	33	33	25,405	$6.31	7,680
3B	Chignik	*Van Isle*	21912	23	45	45	13,345	$5.78	9,783
3B	Sanak	*Free to Wander*	29155	21	48	48	25,245	$5.67	13,067
3B	Semidi	*Van Isle*	21912	25	47	47	21,340	$5.94	9,829
3B	Shumagin	*Seymour*	17530	21	44	44	19,774	$5.64	9,637
3B	Trinity	*Van Isle*	21912	24	47	45	20,908	$6.49	9,177
4A	Four Mountains East	*Kema Sue*	41033	14	31	25	12,039	$5.41	6,280
4A	Four Mountains West	*Norcoaster*	38173	17	21	19	18,096	$5.18	4,459
4A	4A Edge North	*Kema Sue*	41033	17	45	45	8,389	$5.73	8,906
4A	4A Edge South	*Free to Wander*	29155	24	48	47	22,191	$5.62	10,389
4A	Unimak East	*Free to Wander*	29155	19	32	32	7,298	$5.34	7,544
4A	Unimak West	*Kema Sue*	41033	17	27	27	6,734	$5.77	7,920
4B	Adak	*Norcoaster*	38173	47	45	45	20,903	$4.87	13,021
4B	Attu	*Norcoaster*	38173	25	44	43	6,826	$4.98	11,060
4D	4D Edge	*Kema Sue*	41033	35	68	68	11,503	$5.57	14,623
Total		**11 Vessels**		**747**	**1,430**	**1,417**	**765,419**	**$6.78**	**329,521**

[1] Days are estimated because some vessels fished two charter regions in one day.
[2] Net weight (head-off, dressed, washed). Poundage may not sum to correct total because of rounding errors introduced by splitting the catch out to region.
[3] Gross prices

Table 2. SSA survey halibut landings by port, 2014[1].

Offload Port	Trips Landed	Halibut Sold (lb)	Total USD	Average Price (USD/lb)
Adak	4	26,136	$ 130,542.50	$ 4.99
Akutan	1	18,098	$ 101,819.90	$ 5.63
Alitak	2	13,576	$ 84,727.31	$ 6.24
Astoria	1	840	$ 5,500.80	$ 6.55
Atka	1	5,251	$ 21,726.92	$ 4.14
Bellingham	3	7,076	$ 51,265.45	$ 7.24
Brookings	3	3,627	$ 23,006.47	$ 6.34
Charleston	1	853	$ 5,581.44	$ 6.55
Cordova	2	30,230	$ 223,384.31	$ 7.39
Dutch Harbor / Unalaska	7	49,127	$ 269,867.34	$ 5.49
Homer	2	19,611	$ 144,218.17	$ 7.35
Juneau / Auke Bay	2	32,963	$ 219,406.89	$ 6.66
Ketchikan	1	18,086	$ 118,468.90	$ 6.55
King Cove	1	5,847	$ 32,566.10	$ 5.57
Kodiak	11	116,875	$ 787,843.85	$ 6.74
Newport	3	8,226	$ 53,164.80	$ 6.46
Petersburg	1	27,780	$ 200,079.00	$ 7.20
Port Hardy	3	25,613	$ 205,316.40	$ 8.02
Prince Rupert	6	118,262	$ 1,002,266.09	$ 8.47
Sand Point	8	71,423	$ 403,336.81	$ 5.65
Seward	4	41,308	$ 295,943.79	$ 7.16
Sitka	2	41,528	$ 270,554.01	$ 6.51
St Paul	2	10,105	$ 55,930.60	$ 5.53
Tofino	1	5,687	$ 42,998.05	$ 7.56
Wrangell	1	25,526	$ 181,322.27	$ 7.10
Yakutat	4	41,766	$ 261,493.70	$ 6.26
	77	765,419	$ 5,192,331.87	$ 6.78

[1] Net weight (head-off, dressed, washed)
[2] Prices based on net weight

Table 3. SSA survey landings by species and regulatory area in 2014[1].

Species		2A	2B	2C	3A	3B	4A	4B	4D	Totals
Halibut	lb	20,621	106,003	146,082	278,122	100,612	74,746	27,729	11,503	765,419
Halibut	USD/lb	$6.72	$8.25	$7.38	$6.82	$5.91	$5.48	$4.89	$5.57	$6.78
Pacific Cod	lb	0	445	833	66,594	38,013	12,953	0	636	119,474
Pacific Cod	USD/lb	-	$0.64	$0.26	$0.39	$0.27	$0.13	-	$0.01	$0.32
Rockfish	lb	2,658	10,650	18,192	17,616	362	23	0	0	49,501
Rockfish	USD/lb	$0.87	$1.29	$1.03	$0.79	$0.40	$0.10	-	-	$0.99

[1]Weights are net pounds offloaded.

Table 4. Average setline survey and commercial WPUE (lb/skate) of halibut from 2010 to 2014[1,2].

Reg. Area	Year	Effective Stations	Survey WPUE	Commercial WPUE	% of Commercial	Areas Surveyed
2A	2010	84	17	149	11.3%	OR-CA Border to Cape Flattery
	2011	106	22	92	24.4%	OR-CA Border to Cape Flattery, Puget Sound
	2012	95	30	120	24.8%	OR-CA Border to Cape Flattery
	2013	111	24	132	18.2%	Northern California to Cape Flattery
	2014	162	18	116	15.5%	Northern California to Cape Flattery, Puget Sound
2B	2010	170	89	222	40.2%	All 2B
	2011	170	80	240	33.4%	All 2B
	2012	170	104	259	40.1%	All 2B
	2013	170	94	269	34.8%	All 2B
	2014	170	92	315	29.2%	All 2B
2C	2010	123	108	158	68.2%	All 2C
	2011	123	133	182	73.2%	All 2C
	2012	122	160	208	77.0%	All 2C
	2013	122	183	227	80.6%	All 2C
	2014	123	185	228	81.1%	All 2C
3A	2010	372	117	285	41.1%	All 3A
	2011	371	121	280	43.1%	All 3A
	2012	373	138	269	51.2%	All 3A
	2013	372	117	240	48.7%	All 3A
	2014	374	115	232	49.6%	All 3A
3B	2010	230	92	173	52.9%	All 3B
	2011	229	80	140	57.1%	All 3B
	2012	231	87	134	65.1%	All 3B
	2013	229	64	113	56.7%	All 3B
	2014	229	65	99	65.7%	All 3B
4A	2010	114	73	182	40.2%	4A Aleutians and 4A Edge
	2011	108	59	189	31.0%	4A Aleutians and 4A Edge
	2012	112	64	191	33.5%	4A Aleutians and 4A Edge
	2013	105	42	164	25.6%	4A Aleutians and 4A Edge
	2014	185	61	134	45.5%	4A Aleutians and 4A Edge
4B	2010	87	68	142	48.2%	4B Aleutians
	2011	86	68	165	41.3%	4B Aleutians
	2012	89	48	154	31.5%	4B Aleutians
	2013	89	57	122	47.0%	4B Aleutians
	2014	89	50	167	29.9%	4B Aleutians
4C	2010	18	55	82	67.5%	St. George and St. Paul Islands
	2011	20	52	75	68.7%	St. George and St. Paul Islands
	2012	20	37	60	61.8%	St. George and St. Paul Islands
	2013	20	35	55	64.3%	St. George and St. Paul Islands
	2014	20	44	60	73.3%	St. George and St. Paul Islands
4D	2010	58	49	188	26.3%	4D Edge and St. Matthew Island
	2011	58	31	166	18.4%	4D Edge and St. Matthew Island
	2012	58	31	162	19.0%	4D Edge and St. Matthew Island
	2013	58	25	151	16.4%	4D Edge and St. Matthew Island
	2014	58	23	167	13.8%	4D Edge and St. Matthew Island

[1] Commercial WPUE data for the current year are preliminary.

[2] Data include all effective stations for that year except the rockfish index stations. This may be different from that used in the stock assessment.

Table 5. Number of stations effectively surveyed, total O32 halibut catch, and average survey WPUE (lb/skate), by statistical area in 2014[1,2].

Reg. Area	Stat. Area	Effective Stations	O32 Halibut Lb.	Avg. WPUE
2A	6	9	110	2
2A	7	8	881	16
2A	8	8	1,009	18
2A	9	10	1,371	19
2A	10	18	5,260	42
2A	20	18	2,290	18
2A	30	16	1,158	10
2A	40	13	1,770	19
2A	50	29	5,039	25
2A Total		**129**	**18,887**	**21**
2B	60	16	4,974	44
2B	70	13	4,463	49
2B	80	5	1,674	48
2B	90	7	4,468	90
2B	91	23	7,277	45
2B	100	1	883	124
2B	102	39	29,715	109
2B	112	31	23,865	110
2B	121	8	7,685	137
2B	130	6	9,988	238
2B	131	3	3,610	172
2B	132	9	5,348	85
2B	133	5	4,412	126
2B	134	3	294	14
2B	135	1	1,267	182
2B Total		**170**	**109,925**	**92**
2C	140	9	15,303	252
2C	141	8	12,917	229
2C	142	13	13,790	151
2C	143	8	5,954	106
2C	144	1	606	86
2C	150	14	27,925	286
2C	151	10	13,729	196
2C	152	3	3,433	167
2C	153	5	4,740	134
2C	160	13	18,764	207
2C	161	4	4,293	154
2C	162	6	8,452	205
2C	163	2	2,526	181
2C	170	7	6,322	129
2C	171	5	3,301	95
2C	173	6	4,925	121
2C	181	4	6,293	225
2C	182	3	3,555	169
2C	183	2	1,682	120
2C Total		**123**	**158,510**	**185**
3A	185	17	18,369	154
3A	190	27	22,568	120
3A	200	27	22,975	121
3A	210	17	15,200	128
3A	220	13	13,846	152
3A	230	21	15,747	107
3A	232	3	4,079	195
3A	240	31	20,035	93
3A	242	9	10,266	165
3A	250	48	28,431	85
3A	260	55	45,784	120
3A	261	19	9,554	72
3A	270	33	26,048	113
3A	271	14	10,165	105
3A	280	29	28,315	139
3A	281	11	8,411	117
3A Total		**374**	**299,792**	**115**
3B	290	52	25,273	69
3B	300	58	25,029	61
3B	310	44	17,181	56
3B	320	32	14,505	65
3B	330	25	15,757	90
3B	340	18	6,881	55
3B Total		**229**	**104,625**	**65**
4A	350	27	6,266	33
4A	360	13	2,111	23
4A	370	10	1,378	20
4A	380	8	5,234	94
4A	390	9	8,446	135
4A	395	2	2,942	208

[1]O32 halibut pounds and WPUE (lb/skate) are calculated from the length distribution of the catch converted to weight using a standard length-weight relationship (Clark 1992), not from recorded weights of halibut sold.
[2]Does not include RI, Shallow Expansion, and Deep Expansion stations.

Table 5. continued.

Reg. Area	Stat. Area	Effective Stations	O32 Halibut Lb.	Avg. WPUE
4A	523169	1	1,172	167
4A	523170	2	491	35
4A	523171	6	6,907	165
4A	530168	3	753	36
4A	530169	3	972	47
4A	530170	1	1,314	189
4A	533166	2	1,236	89
4A	533167	5	2,579	74
4A	540165	4	1,447	52
4A	540166	1	155	22
4A	543165	6	647	15
4A	543166	13	7,106	78
4A	543167	2	3,314	238
4A	550166	8	3,078	55
4A	550167	11	9,931	129
4A	550168	1	126	18
4A	553167	4	1,241	45
4A	553168	11	1,865	25
4A	560168	8	1,073	19
4A	560169	5	516	15
4A	560170	5	572	16
4A	560171	1	183	26
4A Total		**172**	**73,058**	**61**
4B	400	2	1,409	101
4B	410	7	2,740	56
4B	420	7	2,954	60
4B	430	4	3,661	132
4B	440	4	2,406	86
4B	450	2	1,097	78
4B	460	4	630	22
4B	470	5	484	14
4B	480	6	625	15
4B	490	11	1,614	21
4B	500	4	1,122	40
4B	510	1	0	0
4B	513277	1	56	8
4B	513278	1	183	26
4B	520173	4	2,905	104
4B	520174	2	1,717	123
4B	520175	2	1,412	100
4B	520176	1	454	65
4B	520179	4	1,154	41
4B	520277	2	186	13
4B	520278	1	337	48
4B	520279	4	1,961	70
4B	523173	1	126	19
4B	523179	2	639	46
4B	523273	1	0	0
4B	523274	4	903	33
4B	523279	1	0	0
4B	530272	1	253	36
4B Total		**89**	**31,031**	**50**
4C	563169	10	3,941	57
4C	570169	1	81	12
4C	570170	9	2,126	34
4C Total		**20**	**6,148**	**44**
4D	563171	3	198	10
4D	563173	2	147	11
4D	570173	4	370	13
4D	573173	2	204	14
4D	580174	1	196	28
4D	580175	1	620	91
4D	583174	5	474	14
4D	583175	3	433	21
4D	583176	1	18	3
4D	583177	3	551	26
4D	590176	2	49	3
4D	590177	6	691	17
4D	590178	2	705	51
4D	593176	3	40	2
4D	593177	7	1,191	24
4D	593178	4	1,171	42
4D	600172	4	528	19
4D	600173	1	36	5
4D	603172	3	486	23
4D	603173	1	984	143
4D Total		**58**	**9,092**	**23**
Grand Total		**1364**	**811,068**	**85**

Table 6. Average survey WPUE for Eastern Bering Sea island cluster stations, 2014[1,2].

Reg. Area	Stat. Area	Location	Effective Stations	O32 Halibut Lb.	Avg. WPUE
4C	563169	St. George	10	3,941	57
St. George Total			**10**	**3,941**	**57**
4C	570169	St. Paul	1	81	12
4C	570170	St. Paul	9	2,126	34
St. Paul Total			**10**	**2,207**	**23**
4D	600172	St. Matthew	4	528	19
4D	600173	St. Matthew	1	36	5
4D	603172	St. Matthew	3	486	23
4D	603173	St. Matthew	1	984	143
St. Matthew Total			**9**	**2,034**	**48**
	Grand Total		**29**	**8,182**	**42**

[1]O32 halibut pounds and WPUE (lb/skate) are calculated from the length distribution of the catch converted to weight using a standard length-weight relationship (Clark 1992), not from recorded weights of halibut sold.
[2]Values from individual statistical areas are rounded, which may lead to slight discrepancies in total values.

Table 7. Number of halibut caught on survey by 5-cm length category and regulatory area in 2014. The 80-84 cm category is divided to show the U32/O32 split within that category[1].

	Regulatory Area										
Fork Length (cm)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Survey Total	% of Survey Removals
35-39					1					1	0.0
40-44					1					1	0.0
45-49				2	6	2				10	0.0
50-54		2	3	25	62	29	6	3	2	132	0.1
55-59	3	29	35	344	685	162	24	20	16	1,318	1.4
60-64	12	251	352	1,789	2,283	552	161	45	49	5,494	6.0
65-69	35	829	888	4,180	3,559	746	283	69	93	10,682	11.7
70-74	96	1,397	1,207	6,593	3,654	977	353	67	120	14,464	15.8
75-79	159	1,485	1,383	6,951	3,313	1,101	301	84	130	14,907	16.3
80-81	80	624	532	2,412	1,112	427	110	26	47	5,370	5.9
Total U32 Halibut	**385**	**4,617**	**4,400**	**22,296**	**14,674**	**3,996**	**1,238**	**314**	**457**	**52,377**	**57.2**
82-84	108	873	694	2,909	1,381	553	157	55	58	6,788	7.4
85-89	148	1,056	1,046	3,894	1,851	760	262	74	88	9,179	10.0
90-94	126	707	796	2,711	1,082	708	178	47	69	6,424	7.0
95-99	115	500	637	1,729	684	534	153	47	60	4,459	4.9
100-104	96	371	554	1,219	421	401	134	25	38	3,259	3.6
105-109	87	312	488	792	244	326	105	12	31	2,397	2.6
110-114	75	260	386	577	186	181	82	14	21	1,782	1.9
115-119	62	201	266	417	110	127	66	12	12	1,273	1.4
120-124	40	172	271	319	57	66	37	7	11	980	1.1
125-129	23	135	234	209	35	64	34	11	11	756	0.8
130-134	17	91	183	176	35	41	26	1	7	577	0.6
135-139	4	61	145	116	21	32	13	2	4	398	0.4
140-144	1	43	111	79	15	28	12	1	5	295	0.3
145-149		37	69	56	7	13	11		1	194	0.2
150-154	1	24	53	44	7	7	2	1	1	140	0.2
155-159		17	37	21	3	6	4		1	89	0.1
160-164		12	20	14		1	5	1	1	54	0.1
165-169		7	15	16	1	4	4			47	0.1
170-174	1	6	9	8			4			28	0.0
175-179		1	4	7		1	1			14	0.0
180-184		3	6	6			6			21	0.0
185-189		2	4	5					1	12	0.0
190-194		1	1	1						3	0.0
195-199			2	1	1					4	0.0
200-204										0	0.0
205-209		1								1	0.0
210-215				1						1	0.0
Total O32 Halibut	**904**	**4,893**	**6,031**	**15,327**	**6,141**	**3,853**	**1,296**	**310**	**420**	**39,175**	**42.8**
Total Halibut	**1,289**	**9,510**	**10,431**	**37,623**	**20,815**	**7,849**	**2,534**	**624**	**877**	**91,552**	**100.0**

[1]Excludes halibut from RI and ineffective stations.

Table 8. Otolith sampling rates of halibut captured and sampled from standard stock assessment skates during the 2014 survey,[1,2,3].

Reg. Area	Halibut Caught	Halibut Sampled	Sampling Rates			
			Expected	Overall	O32	U32
2A	1,291	1233	100%	95.5%	69.9%	30.1%
2B	9,510	2329	27%	24.5%	53.1%	46.9%
2C	10,431	2147	24%	20.6%	59.5%	40.5%
3A	37,623	2449	7%	6.5%	44.3%	55.7%
3B	20,882	2374	13%	11.4%	31.0%	69.0%
4A	8,042	2824	41%	35.1%	50.5%	49.5%
4B	2,576	1824	80%	70.8%	53.0%	47.0%
4C	624	592	100%	94.9%	49.0%	51.0%
4D	877	839	100%	95.7%	47.2%	52.8%
Total	91,856	16,611				

[1]Includes halibut from ineffective stations, which are not used in stock assessment calculations.
[2]Does not include halibut lost at the roller (i.e., recorded as "0" length).
[3]Sampling rate does not include otoliths collected for the clean otolith archive collection.

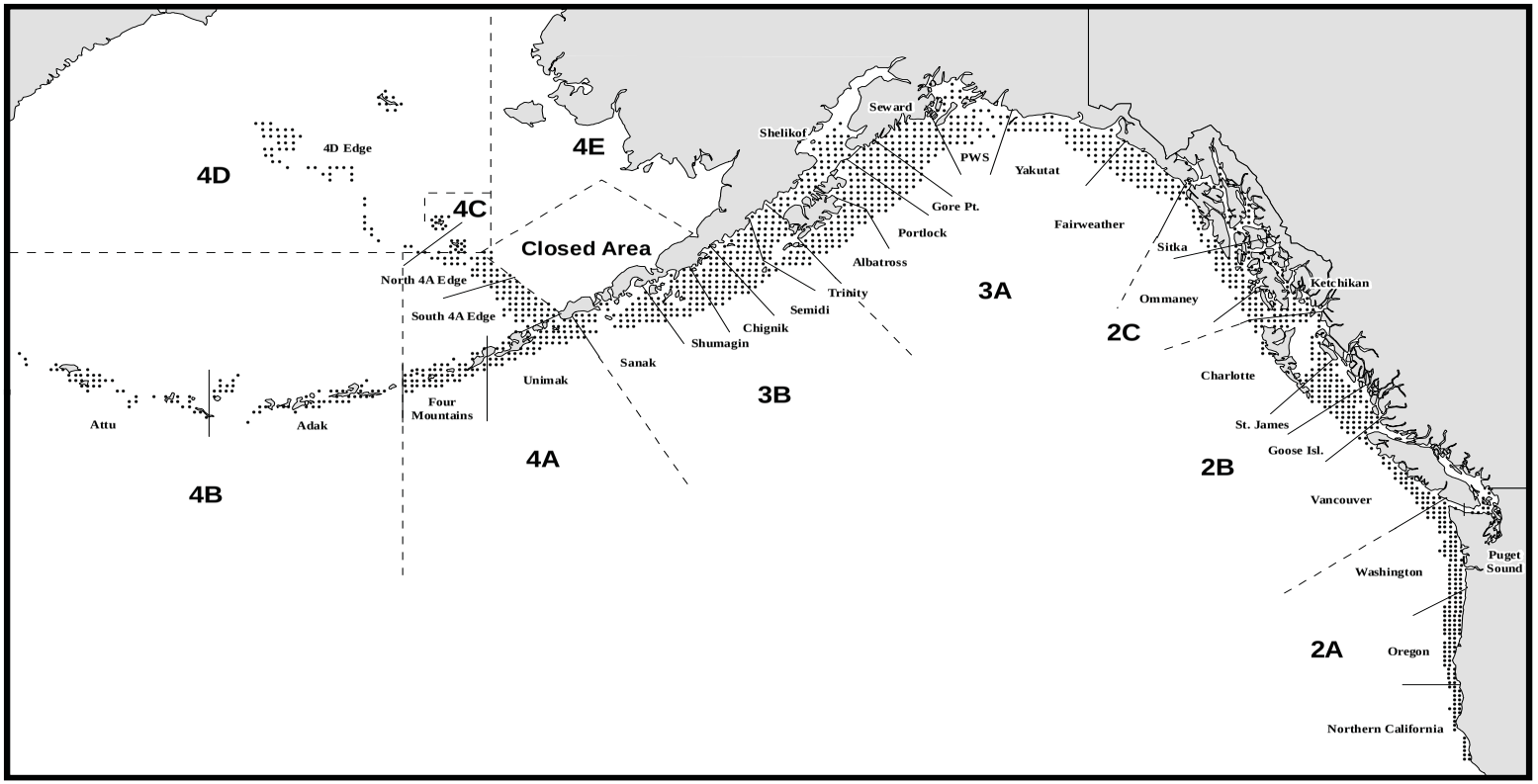


Figure 1. 2014 SSA survey stations with regulatory area (two-character codes) and charter region (formal names) divisions

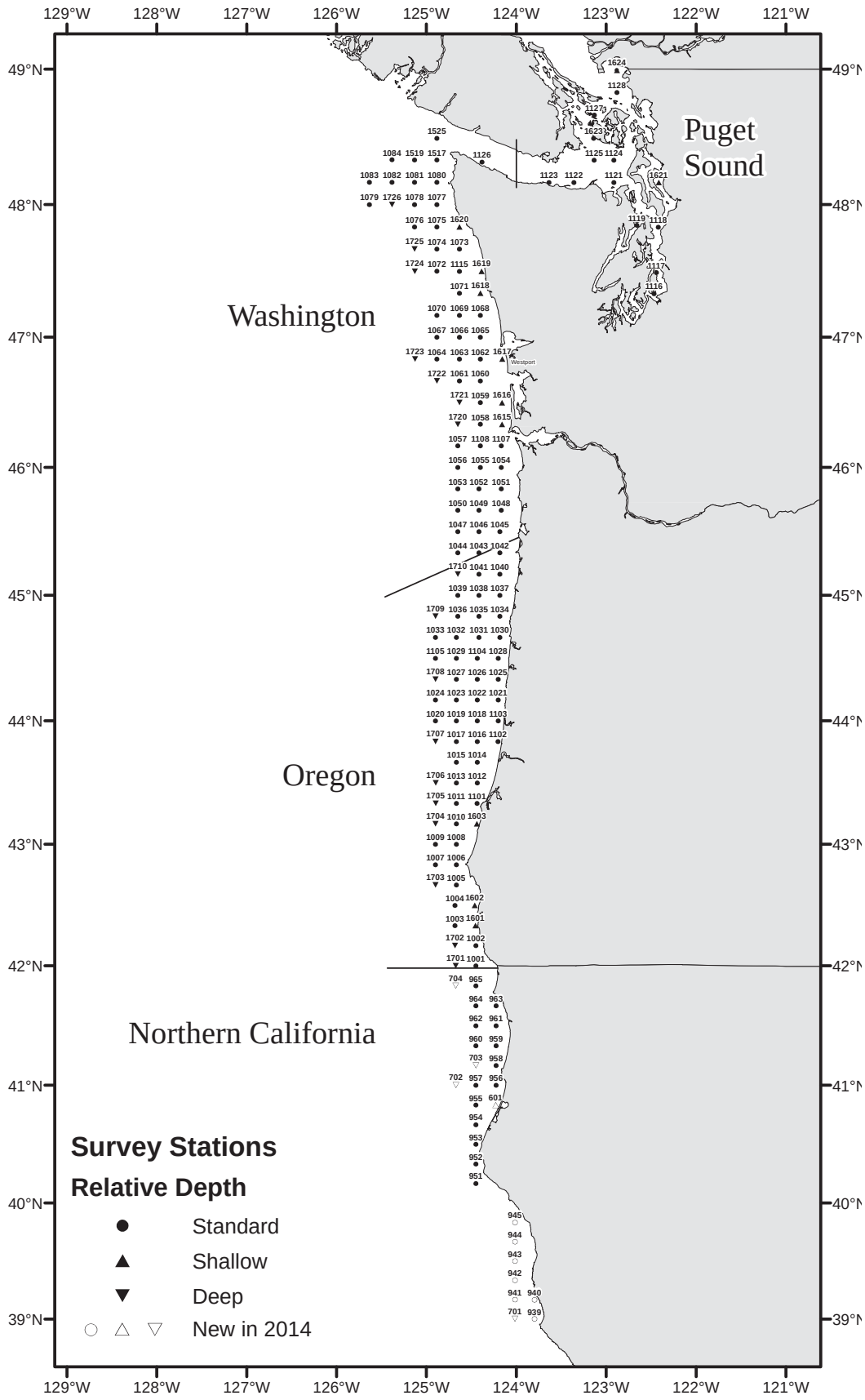


Figure 2. 2014 survey stations in Area 2A, which includes expansion stations added in Puget Sound, Washington, Oregon, and Northern California.

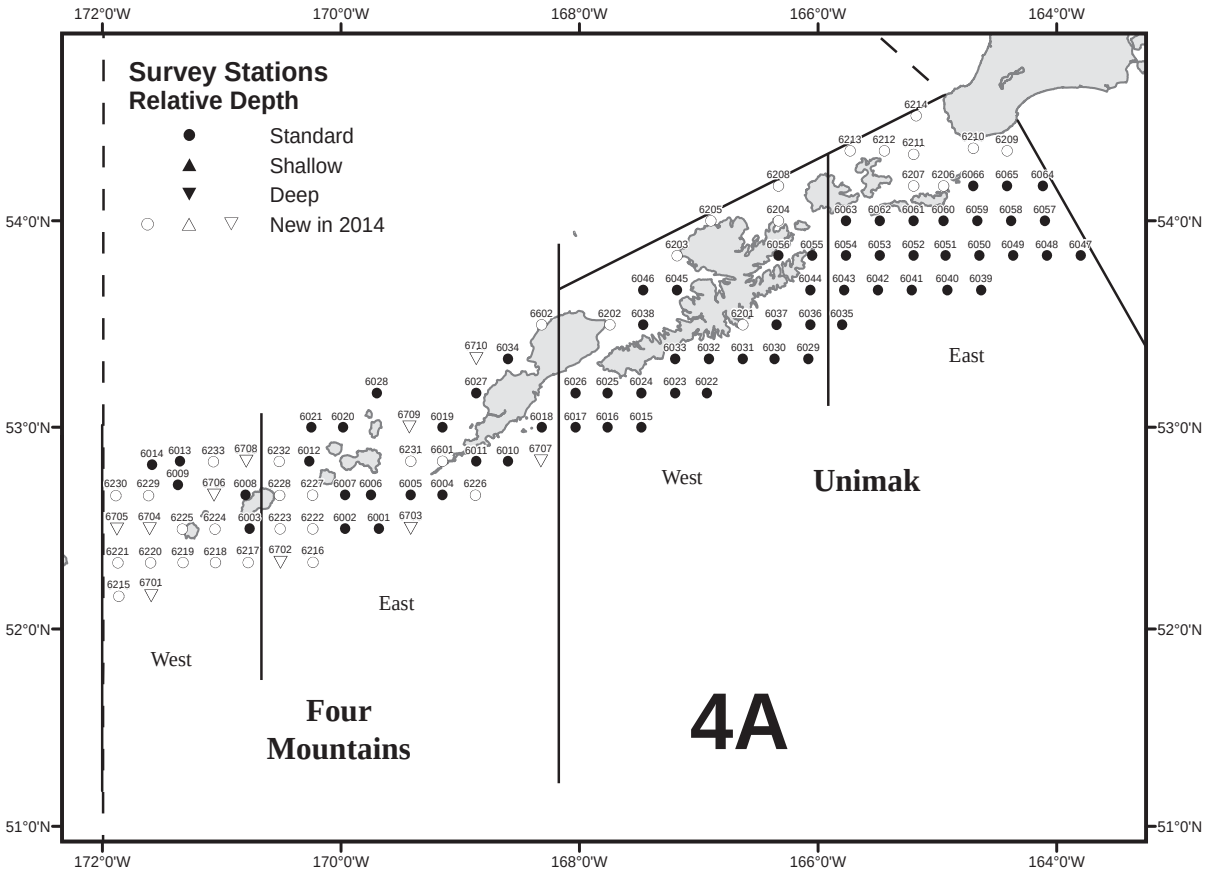


Figure 3. 2014 survey stations in Area 4A, which includes expansion stations added to the Unalaska charter region, which was split into four seperate regions labelled as Four Mountains East and West and Unimak East of West.

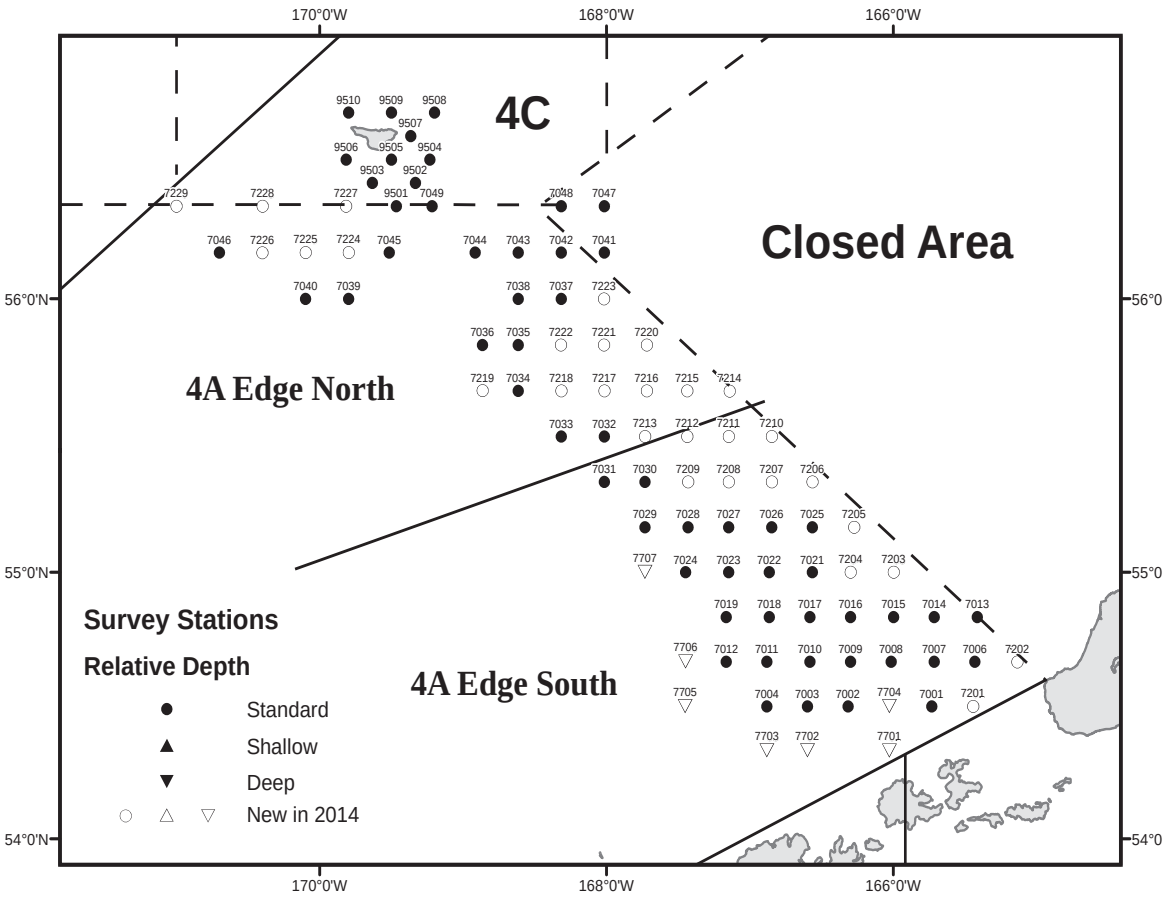


Figure 4. 2014 survey stations in Area 4A, which includes expansion stations added to the 4A Edge charter region, which was split into two separate regions labelled as 4A Edge North and South.

			Week Beginning																
Survey Boat	**Reg Area**	**Charter Region**	**25-May**	**1-Jun**	**8-Jun**	**15-Jun**	**22-Jun**	**29-Jun**	**6-Jul**	**13-Jul**	**20-Jul**	**27-Jul**	**3-Aug**	**10-Aug**	**17-Aug**	**24-Aug**	**31-Aug**	**7-Sep**
Pacific Surveyor		N. California											11%	52%	37%			
Pacific Surveyor	**2A**	Oregon							15%	20%	20%	25%	20%					
Pacific Surveyor		Washington		6%	19%	21%	24%	29%										
Pacific Surveyor		Puget Sound	62%	38%														
Pender Isle		Vancouver	34%	22%	32%	10%	2%											
Pender Isle	**2B**	Goose Is.			19%	40%	23%	19%										
Star Wars II		St. James							21%	17%		14%	21%	26%				
Star Wars II		Charlotte								16%	52%	16%	16%					
Pender Isle		Ketchikan				5%		15%	29%	51%								
Bold Pursuit	**2C**	Ommaney						8%	40%	38%	15%							
Bold Pursuit		Sitka	29%	14%		7%	21%	29%										
Bold Pursuit		Fairweather		22%	35%	31%	12%											
Waterfall		Yakutat		18%	29%									18%		12%	24%	
Waterfall		PWS								33%	27%	24%	16%					
Waterfall	**3A**	Seward					38%	6%	38%			6%	13%					
Clyde		Gore Pt.				7%	33%	20%		27%		13%						
Clyde		Portlock		7%	33%	24%		7%			20%	11%						
Clyde		Shelikof	13%	20%				7%	33%	7%	11%	9%						
Free To Wander		Albatross											27%	27%	40%	7%		
Vanisle		Trinity		16%	27%	11%	13%					33%						
Vanisle		Semidi		15%		15%	15%		4%	30%	17%	4%						
Vanisle	**3B**	Chignik					4%	40%	29%	13%	13%							
Seymour		Shumagin		14%	34%	36%	16%											
Free To Wander		Sanak							6%	25%	25%	44%						
Free To Wander		Unimak East			66%	19%		3%	13%									
Kema Sue		Unimak West		7%								26%	44%	22%				
Kema Sue	**4A**	Four Mtn East		40%	44%							16%						
Norcoaster		Four Mtn West			58%			11%	32%									
Free To Wander		4A Edge South				2%	45%	23%	30%									
Kema Sue		4A Edge North							7%		40%			13%	40%			
Kema Sue	**4D**	4D Edge				12%	31%	19%	18%	18%	3%							
Norcoaster	**4B**	Adak		33%	7%	7%	9%		7%		18%	7%	13%					
Norcoaster		Attu										20%	7%		39%	34%		
By IPHC Regulatory Area																		
2A			5%	6%	7%	8%	9%	11%	6%	7%	7%	9%	9%	9%	6%			
2B			8%	5%	12%	12%	6%	5%	5%	8%	14%	8%	9%	6%				
2C			10%	5%		4%	7%	17%	23%	29%	5%							
3A				9%	13%	8%	10%	5%	9%	8%	7%	8%	7%	6%	5%	2%	3%	
3B				9%	12%	12%	10%	8%	8%	14%	11%	17%						
4A				7%	24%	4%	12%	8%	15%		4%	6%	7%	7%	8%			
4B				17%	3%	3%	4%		3%		9%	13%	10%		19%	17%		
4C								10%	15%	15%	60%							
4D						14%	36%	19%	16%	16%								
Coastwide																		
% Complete				10%	21%	29%	39%	47%	57%	66%	75%	83%	89%	93%	97%	99%	99%	100%
Weekly activity			3%	7%	11%	8%	10%	8%	10%	10%	9%	8%	5%	4%	4%	2%		
			25-May	**1-Jun**	**8-Jun**	**15-Jun**	**22-Jun**	**29-Jun**	**6-Jul**	**13-Jul**	**20-Jul**	**27-Jul**	**3-Aug**	**10-Aug**	**17-Aug**	**24-Aug**	**31-Aug**	**7-Sep**

Figure 5. The percent of each charter region's planned stations that were completed during the week beginning on the date shown for 2014.

Week Beginning		22-May	29-May	5-Jun	12-Jun	19-Jun	26-Jun	3-Jul	10-Jul	17-Jul	24-Jul	31-Jul	7-Aug	14-Aug	21-Aug	28-Aug	4-Sep	11-Sep
	2010						4%	19%	36%	**54%**	68%	86%	100%					
	2011			4%	9%	18%	24%	28%	36%	42%	**54%**	61%	69%	77%	89%	95%	99%	
2A	2012	5%	13%	27%	39%	**51%**	67%	76%	88%	101%								
	2013		11%	22%	34%	45%	**61%**	69%	83%	89%	101%							
	2014	6%	11%	18%	26%	36%	47%	**52%**	60%	67%	76%	85%	94%	100%				
	2010		4%	12%	21%	26%	32%	39%	49%	**60%**	67%	74%	82%	89%	100%			
	2011		12%	19%	28%	36%	44%	**52%**	72%	89%	100%							
2B	2012	4%	12%	19%	29%	39%	48%	**56%**	65%	75%	83%	91%	100%					
	2013		9%	18%	28%	36%	46%	**54%**	64%	79%	84%	92%	100%					
	2014	8%	14%	26%	38%	45%	49%	**55%**	63%	76%	84%	94%	100%					
	2010		20%	39%	**51%**	61%	73%	88%			100%							
	2011		15%	30%	41%	**54%**	67%					83%	98%	100%				
2C	2012	5%	17%	29%	44%	**59%**	68%	80%	93%	100%								
	2013	7%	20%	33%	46%	**60%**	73%	86%	100%									
	2014	10%	15%		19%	26%	43%	**66%**	95%	100%								
	2010		5%	11%	25%	34%	42%	49%	**61%**	74%	81%	87%	94%	95%	100%	100%		
	2011		14%	31%	45%	**59%**	71%	78%	83%	92%	96%	100%						
3A	2012		6%	17%	24%	36%	41%	46%	**52%**	62%	69%	75%	83%	89%	97%	100%		
	2013	3%	9%	16%	26%	37%	48%	**59%**	71%	81%	90%	95%	98%	100%				
	2014	2%	10%	23%	30%	41%	46%	**55%**	63%	70%	77%	84%	90%	94%	97%	100%		
	2010		8%	25%	44%	**58%**	73%	77%	85%	87%		93%	100%					
	2011		14%	29%	46%	**51%**	55%	61%	67%	73%	83%	94%	100%					
3B	2012		2%	13%	17%	26%	34%	40%	49%	**54%**	65%	71%	90%	98%	100%			
	2013			10%	13%	29%	46%	**66%**	82%	96%	100%							
	2014		9%	21%	33%	42%	50%	**58%**	72%	83%	100%							
	2010						19%	45%	**63%**	77%	91%	100%						
	2011					18%	29%	**50%**	62%	78%	80%			98%	100%			
4A	2012		14%	24%			32%	41%	**53%**	63%	88%	100%						
	2013		19%	32%	45%	**55%**	67%	68%				72%	79%	87%	93%	95%	100%	
	2014		7%	30%	34%	45%	**52%**	68%		72%	79%	85%	91%	99%				
	2010		3%	25%	44%	**51%**								61%	83%	100%		
	2011		12%	38%	**51%**									61%	89%	100%		
4B	2012								9%	31%		47%	**62%**	67%	83%	93%	100%	
	2013				19%	26%	33%		40%	**55%**	58%	82%	**97%**	100%				
	2014		17%	20%	24%	28%		31%		40%	**54%**	64%		84%	101%			
	2010										35%	**55%**			85%	105%		
	2011						**50%**					100%						
4C	2012						30%	40%		**100%**								
	2013							40%				**60%**		100%				
	2014						10%	25%	40%	**100%**								
	2010									31%	41%		**60%**	84%	100%			
	2011							3%	34%	**55%**	81%	84%	100%					
4D	2012				26%	48%	**50%**	66%	100%									
	2013							5%	47%	**57%**	90%	100%						
	2014				14%	**50%**	69%	84%	100%									

Figure 6. The cumulative percentage of each regulatory area's planned stations completed and considered effective for stock assessment by the end of the week beginning on the date shown for 2014. Highlighted cells are the week in which 50% of survey work in that area, cumulatively, was completed.

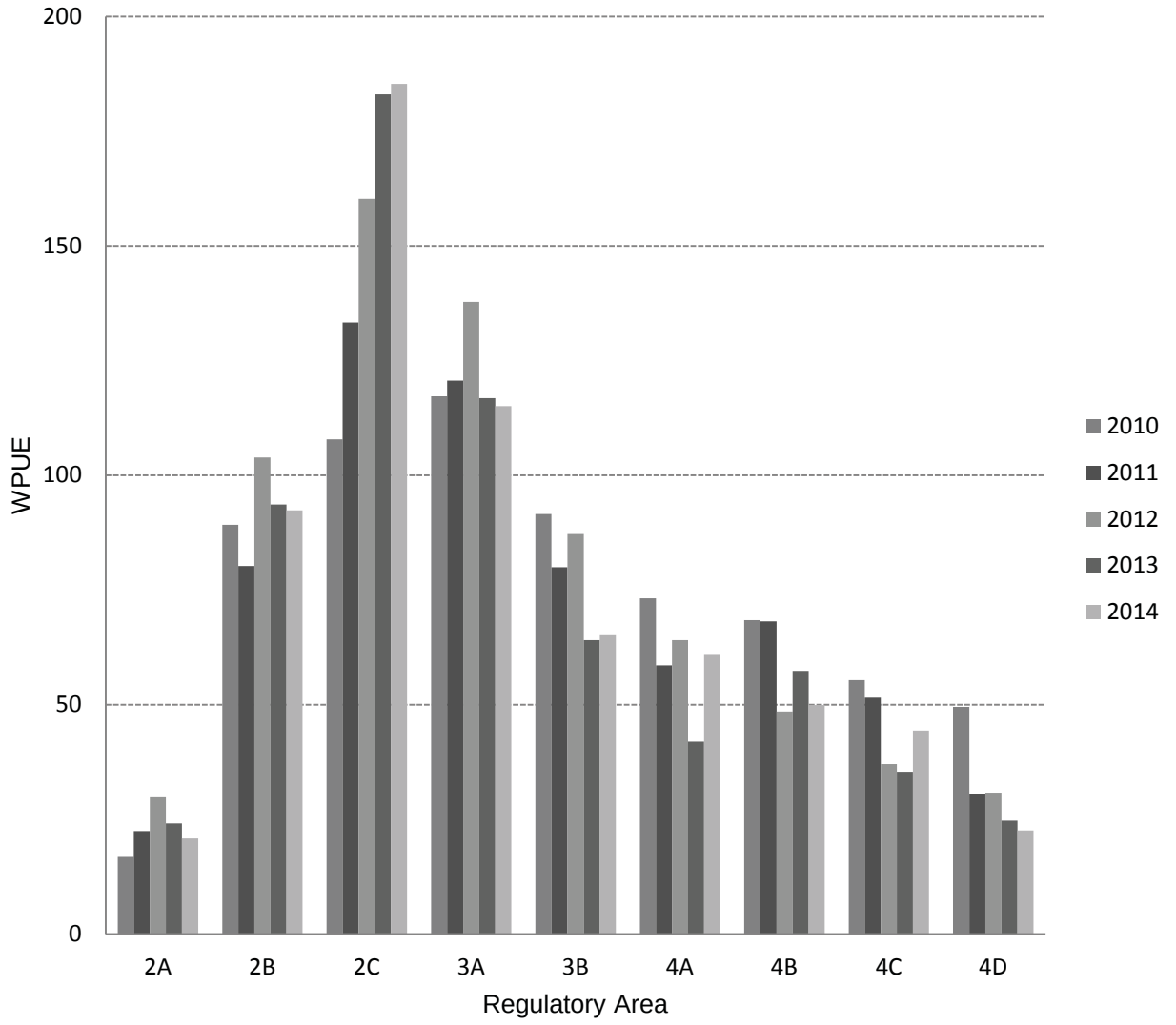


Figure 7. Average WPUE (lb/skate) of halibut by IPHC regulatory area from all effective SG and ES stations occupied on 2010-2014 setline surveys. Includes newly added SG expansion stations in Areas 2A and 4A.

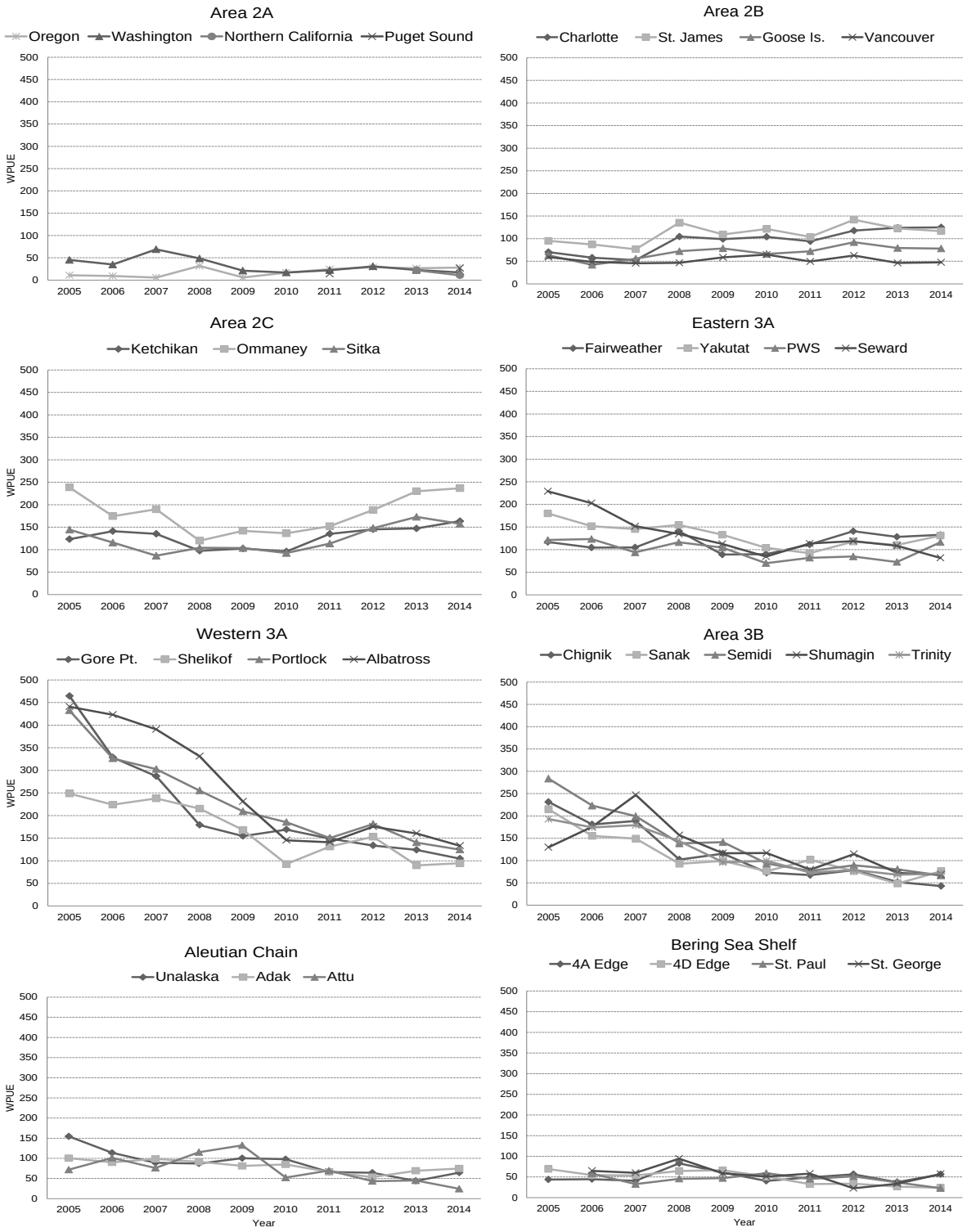


Figure 8. Survey WPUE (lb/skate) by IPHC regulatory area from 2005 to 2014. Individual charter regions are plotted within each regulatory area panel, as indicated. Includes data from SG and ES effective stations.

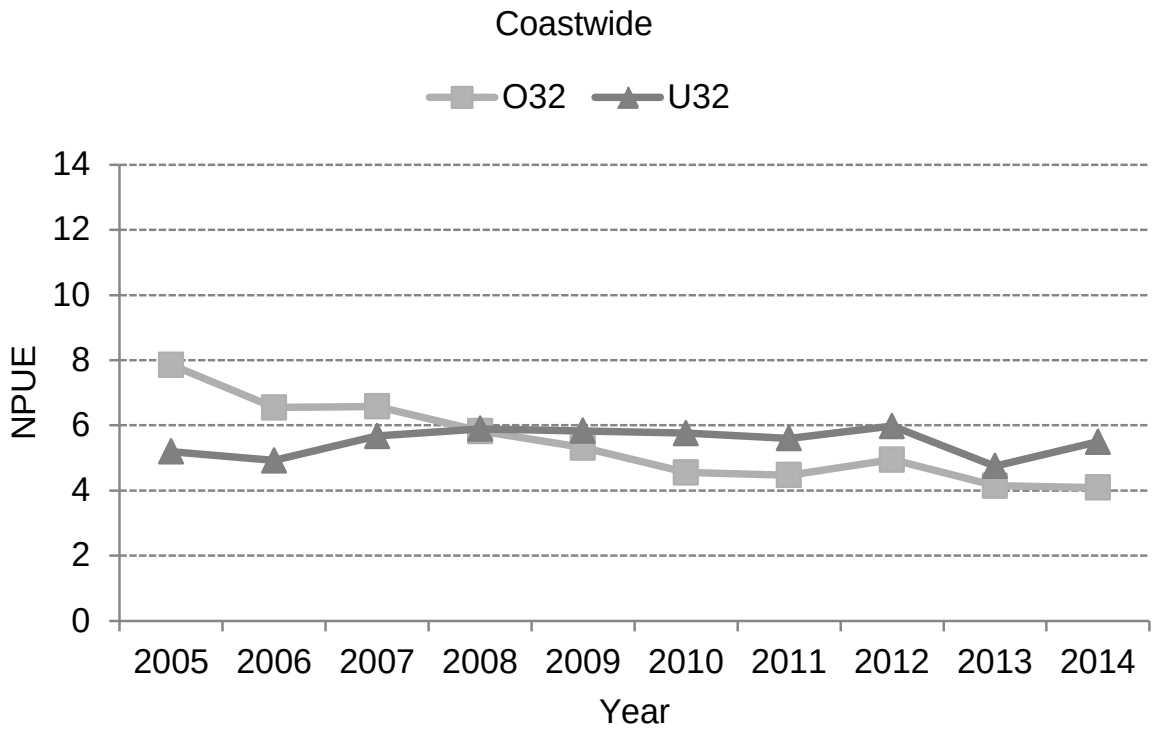


Figure 9. Survey NPUE (halibut/skate) coastwide from 2005 to 2014. Includes data from SG and ES effective stations.

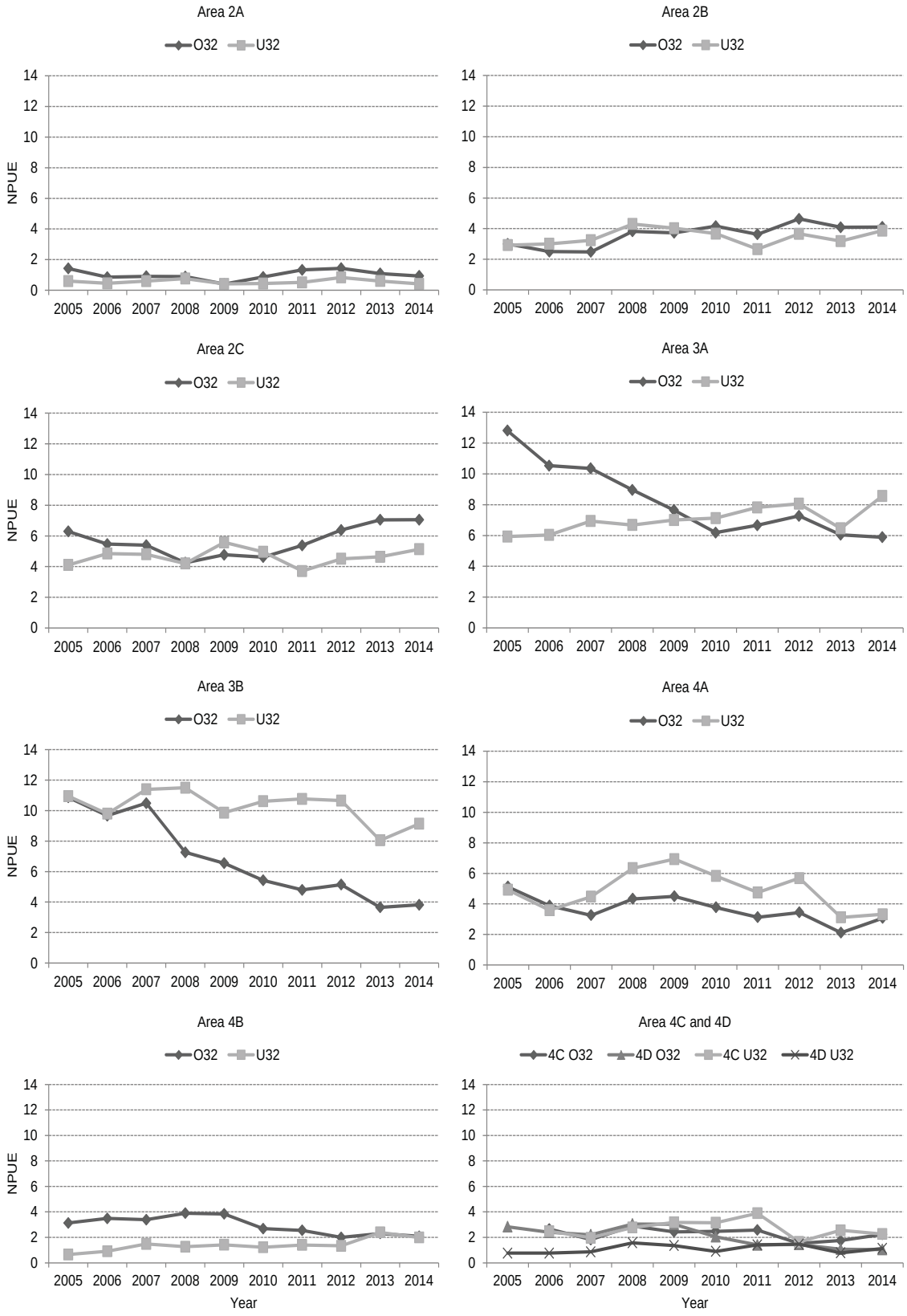


Figure 10. Survey NPUE (halibut/skate) by IPHC regulatory area from 2005 to 2014. Includes data from SG and ES effective stations.

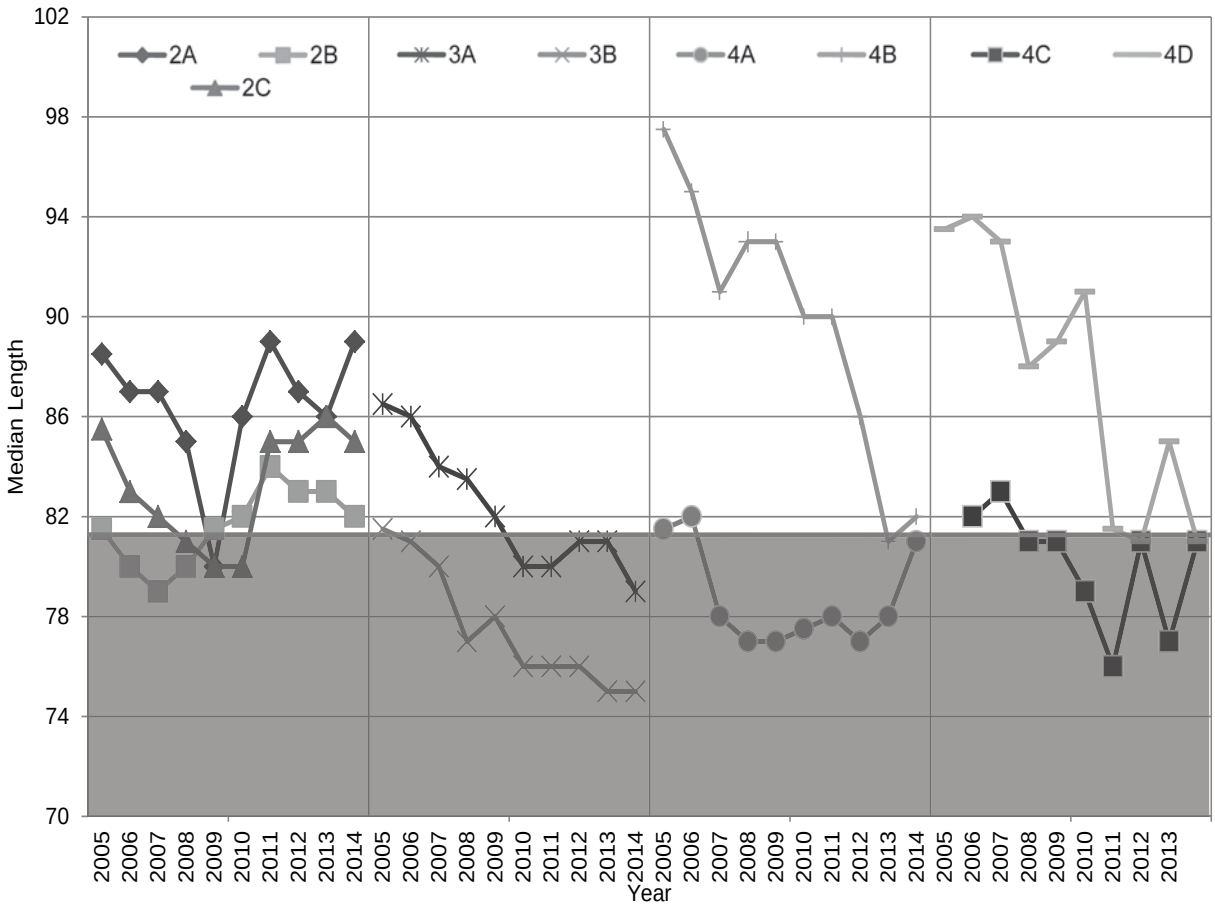


Figure 11. Median length of halibut caught on survey, by regulatory area, from 2005 to 2014. The shaded area shows lengths below the current commercially-legal size limit. Includes data from SG and ES effective stations.

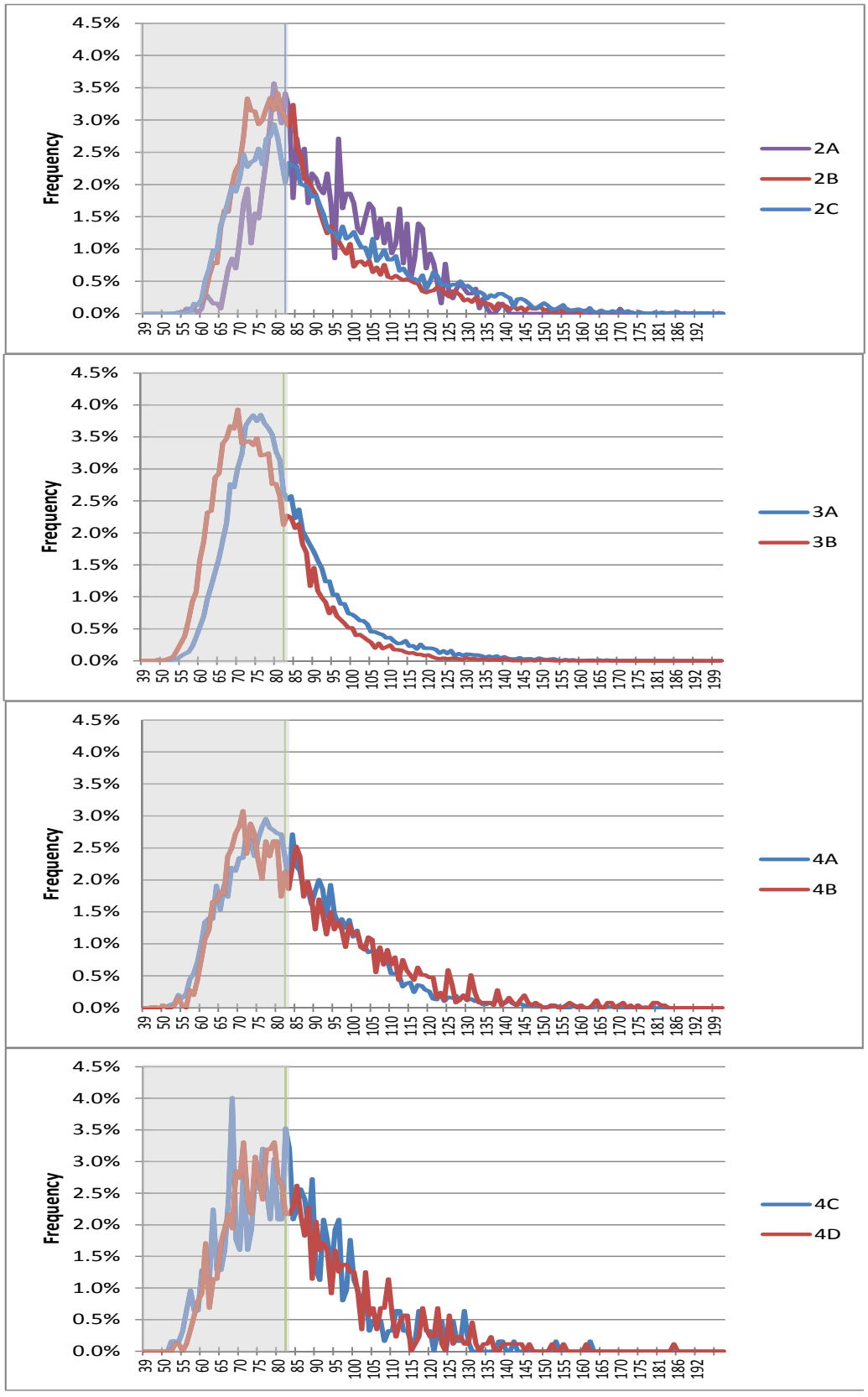


Figure 12. The length (cm) frequency distribution of halibut, by regulatory area, from catches in the 2014 setline survey. Shaded areas denote sizes smaller than the current legal commercial size limit. Catch from RI stations not included.

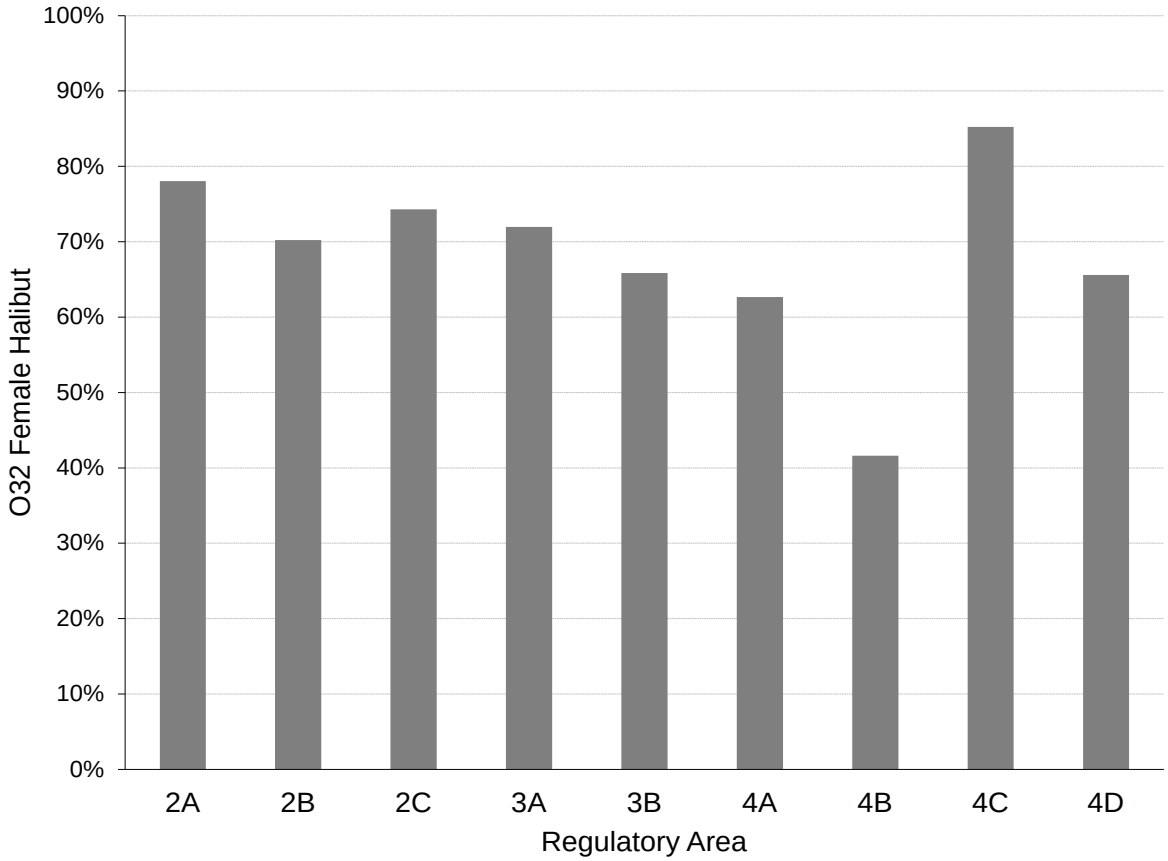


Figure 13. Percentage of total halibut catch that was composed of O32 females, by regulatory area, from catches in the 2014 setline survey. Includes data from all effective stations.

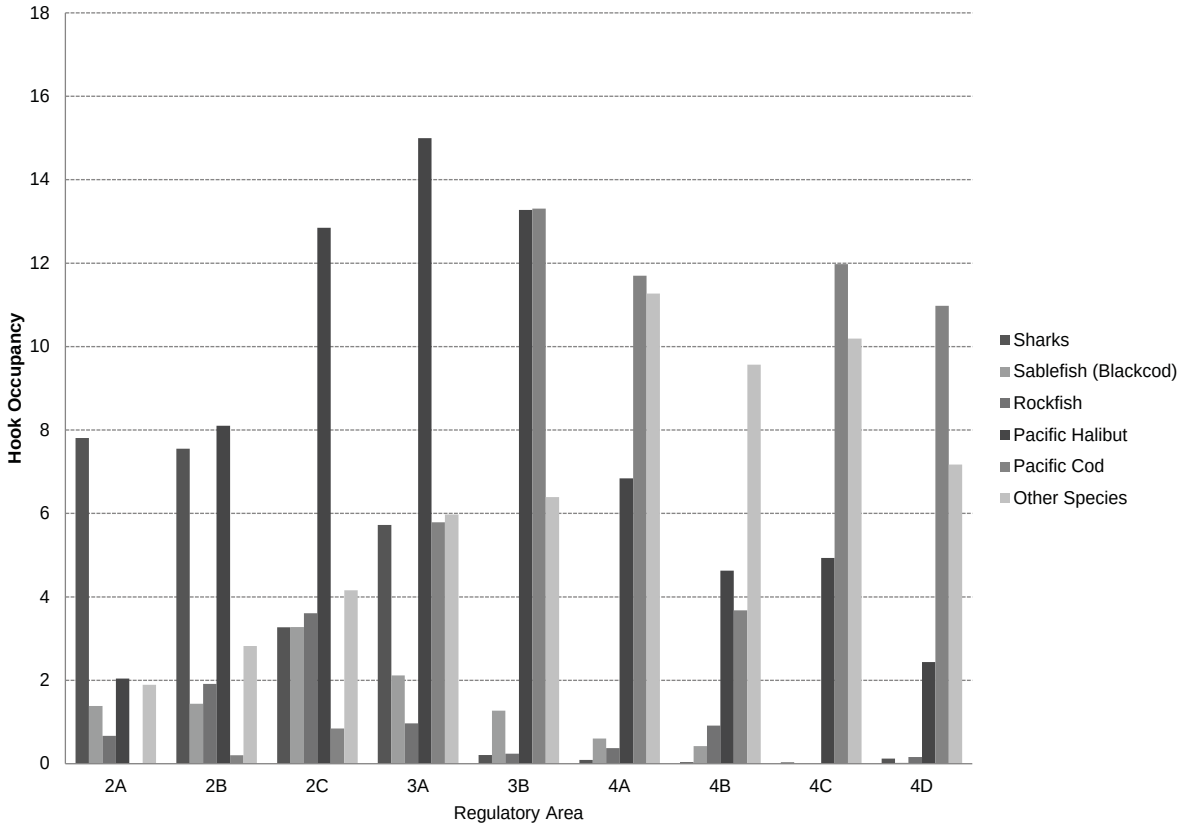


Figure 14. Percent hook occupancy by major species categories from catches in the 2014 setline survey by regulatory area.

Bocaccio

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0	0	0	0.012	0	0	0.009	0	0	0
2B		0.013	0.036	0.019	0.038	0.02	0.011	0.023	0.014	0.0049	0.011
2C		0.012	0.014	0.008	0.012	0	0	0.054	0	0.0066	0

Canary rockfish

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0.043	0.012	0.024	0.024	0	0.037	0.017	0.006	0.0049	0.009
2B		0.058	0.062	0.024	0.044	0.058	0.026	0.034	0.017	0.0588	0.029
2C		0.036	0.02	0.106	0.089	0.071	0.144	0.047	0.048	0.0863	0.097

Yelloweye rockfish

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0.238	0.238	0.238	0.346	0.163	0.179	0.14	0.204	0.1711	0.19
2B		1.007	1.016	0.823	1.004	1.158	1.286	0.952	0.861	0.8479	0.601
2C		2.149	1.699	1.496	0.997	1.325	1.614	1.173	1.381	1.2874	1.389
3A		0.377	0.374	0.212	0.609	0.421	0.51	0.427	0.501	0.3189	0.456

Figure 15. Ten-years of NPUE (numbers per standardized 100-hook skate) for bocaccio, canary rockfish, and yelloweye rockfish on SSA surveys in Regulatory Areas 2A, 2B, 2C, and 3A. No bocaccio or canary rockfish were captured in Regulatory Area 3A.

Arrowtooth flounder

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0.06	0.13	0.12	0.16	0.13	0.11	0.05	0.26	0.25	0.07
2B		1.38	1.03	0.83	1.31	1.59	1.46	1.18	0.94	0.72	0.76
2C		1.27	1.45	1.18	1.53	1.69	1.36	0.96	0.96	0.88	0.87
3A		1.2	1.07	1.42	1.32	1.73	1.2	1.25	1.17	0.95	1.07
3B		3.67	2.97	2.21	2.32	1.23	1.45	1.34	0.5	0.76	1.24
4A		1.07	1.44	0.97	1.92	2.02	0.97	1.14	1.07	0.58	0.83
4D		1.68	0.68	2.42	3.26	1.69	1.4	2.48	1.4	1.05	0.74
4B		1.11	1.24	1.09	1.1	0.94	1.35	1.23	0.29	0.78	0.48

Sablefish (Blackcod)

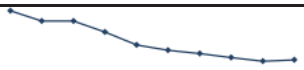
Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		6.81	5.58	5.59	4.34	2.8	2.19	1.81	1.36	0.92	1.08
2B		4.21	2.87	2.38	2.81	2.81	2.98	2.61	1.88	2.18	1.44
2C		5.05	4.84	3.7	3.84	2.92	3.31	4.36	3.26	3.96	3.2
3A		3.8	3.03	3.03	2.65	3.58	2.97	2.93	2.34	1.82	2.09
3B		3.56	2.9	2.84	2.71	2.57	2.11	3.03	1.91	1.04	1.27
4A		1.34	0.92	0.78	0.98	0.54	0.82	0.7	0.8	0.77	0.44
4D		0.12	0.1	0.05	0.1	0.14	0.02	N/A	0.03	0.1	0.02
4B		1.43	0.49	0.66	0.43	0.27	0.27	0.44	0.51	0.46	0.43

Figure 16. Ten-years of NPUE (numbers per standardized 100-hook skate) for arrowtooth flounder and sablefish on IPHC surveys.

Pacific cod

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0.02	0.00	N/A	0.00	0.00	0.00	0.00	0.00	0.02	0.02
2B		0.22	0.16	0.07	0.07	0.08	0.11	0.27	0.11	0.09	0.21
2C		0.59	0.52	0.5	0.51	0.7	1.06	1.34	1.07	0.86	0.83
3A		2.43	3.05	3.38	2.5	5.34	4.75	6.03	3.98	4.27	5.73
3B		8.18	7.85	10.2	12.6	16.1	15.3	15.6	10.6	16.1	13.2
4A		11.6	11.6	11.1	11.8	12.2	10.9	13.8	10.1	11.2	12.6
4D		14.4	18.9	11.7	12.2	8.71	6.28	6.48	7.32	6.28	11
4B		5.63	10.1	8.48	8.43	7.05	2.98	5.81	2.65	4.18	3.62

Spiny dogfish

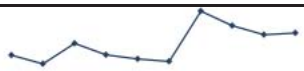
Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		4.11	2.76	5.92	4.17	3.52	3.11	11	8.69	7.31	7.58
2B		12.5	13.8	15.4	10.6	16.2	13	12.8	7.84	10.3	7.51
2C		2.73	4.13	5.36	6.92	6.19	6.49	4.28	4.54	5.2	3.02
3A		14.7	15.6	15.3	16.2	8.35	12.9	7.26	8.68	4.66	5.53
3B		0.14	0.34	0.23	0.25	0.43	0.15	0.15	0.07	0.16	0.09
4A		0.01	0.01	0.02	0.12	0.05	0.05	0.03	0.05	0.11	0.04
4D		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
4B		0.01	0.11	0.09	0.23	0.01	0.04	0.04	0.03	0.07	0.03

Figure 17. Ten-years of NPUE (numbers per standardized 100-hook skate) for Pacific cod and spiny dogfish on IPHC surveys.

Rockfish

Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		0.48	0.46	0.62	0.59	0.44	0.38	0.21	0.44	0.46	0.46
2B		3.5	3.07	2.27	3.26	3.69	3.03	2.65	2.17	2.23	1.91
2C		4.63	3.58	4.06	2.9	3.39	3.54	3.23	2.89	3.46	3.53
3A		0.72	0.65	0.48	1.28	1.05	1.01	0.8	1.14	0.96	0.96
3B		0.21	0.21	0.14	0.16	0.28	0.18	0.22	0.21	0.24	0.24
4A		0.28	0.24	0.25	0.43	0.8	0.4	0.43	0.28	0.3	0.31
4D		0.17	0.1	0.09	0.16	0.29	0.22	0.33	0.16	0.19	0.16
4B		1.14	0.8	1.28	0.75	1.24	1.69	1.35	0.73	1.2	0.92

Skates

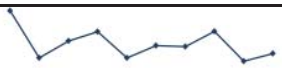
Regulatory Area	Trend	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2A		1.05	0.44	0.66	0.78	0.44	0.6	0.58	0.78	0.4	0.49
2B		1.08	0.96	0.92	1.07	1.16	1.21	1.14	1.16	1.2	1.19
2C		0.89	1.02	1.01	1.55	2.02	1.79	1.49	2	2.63	1.66
3A		1.87	2	2.09	2.55	3.49	2.65	3.05	3.85	2.97	3.53
3B		1.5	1.55	1.89	2.86	2.91	3.42	2.46	2.81	2.95	2.3
4A		3.28	3.47	2.85	4.65	4.17	4.38	4.06	3.67	3.94	4.95
4D		7.06	5.97	2.75	5.51	4.31	2.65	3.14	5.05	3.45	3.7
4B		4.43	4.5	3.86	5.34	5.14	5.66	4.62	2.72	4.67	3.37

Figure 18. Ten-years of NPUE (numbers per standardized 100-hook skate) for rockfish (Sebastes spp only) and skates on IPHC surveys. Area 2A does not include stations in the Puget Sound charter region.

Age distribution of Pacific halibut in the 2014 IPHC stock assessment setline survey

Joan E. Forsberg

Abstract

The age distribution of halibut sampled during the 2014 International Pacific Halibut Commission standard setline stock assessment survey is summarized. Fish ranging from four to 46 years old were captured, with nine-year-olds comprising the largest age group in the overall catch. Average age was higher and average fork length was lower for males than females in all regulatory areas.

Age distribution

The age distribution of Pacific halibut sampled from the 2014 International Pacific Halibut Commission (IPHC) standard stock assessment survey is summarized in Tables 1-3. The 2005 year class (nine-year-olds) accounted for the largest proportion (in numbers) of sampled halibut for all areas and sexes combined (Table 1). The next most abundant year classes were 2004 and 2003 (10- and 11-year-olds, respectively).

Nine-year-olds were the most abundant age class for female halibut sampled from all areas combined, as well as for females in Regulatory Area 2A, 2B, 2C, and 4B (Table 2). The second and third most abundant age classes for sampled females across all regulatory areas were 10- and 11-year-olds, respectively.

The 2004 year class (10-year-olds) was the largest for male halibut from all areas combined, as well as from Area 2A (Table 3). The second and third most abundant age classes for sampled males across all regulatory areas were 11- and 12-year-olds, respectively.

Mean age and fork length (FL) by regulatory area of sampled setline survey halibut for the years 2005-2014 are presented in Table 4. Average length was calculated only from halibut that were aged. Average age was higher and average fork length was lower for males than females in all areas for all years with the exception of Area 4C in 2008, where average age was slightly lower for males than females.

The youngest and oldest halibut in the 2014 setline survey samples were determined to be four and 46 years old (Table 5). There was one four-year-old: a male from Area 2C measuring 58 cm FL; and one 46-year-old: a male from Area 4B with a fork length of 130 cm. The maximum fork length recorded for setline survey-caught halibut in 2014 was 191 cm: a 24-year-old female caught in Area 2B. The smallest halibut sampled in the 2014 setline survey measured 39 cm in fork length: a male from Area 3B aged at eight years.

Ten percent of annual setline survey otoliths are aged a second time by a different reader as a measure of quality control (QC). QC age readings for the 2014 survey otoliths were not available at the time of writing. Between-reader percent agreement for setline survey ages from 2002 through 2013 is presented in Table 6.

Additional otoliths collected

In 2012, a bait study was performed on all stations concurrent with the standard survey. Additional skates of gear using different bait types were fished in the same string as the standard survey skates (Webster et al. 2013). Otoliths from halibut caught on these experimental bait skates were collected and aged, but the ages and lengths of sampled fish from the experimental bait skates were not included in Table 4 because this table is intended to represent the average ages and lengths that have been used in recent IPHC stock assessments. However, QC age reading results reported for 2012 (Table 6) represent all otoliths aged for that year (i.e., otoliths collected on standard skates as well as experimental bait skates); these data reflect the accuracy of the IPHC age-reading process across all experimental collections.

Paired otoliths for the IPHC clean otolith archive collection (COAC) have been collected on the stock assessment survey since 2010. In 2014, COAC otoliths were collected from regulatory areas where sampling rates were not already 100%. A total of 629 otolith pairs were collected on the 2014 stock assessment survey (Tobin and Forsberg 2015).

Reference

Webster, R. A., Kaimmer, S. M, Dykstra, C.L., and Leaman, B. M. 2013. Coastwide comparison of alternative setline survey baits. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012: 569-586.

Tobin, R. S. and Forsberg, J. E. 2015. Clean otolith archive collection. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Table 1. Age distribution of all halibut (male, female, and unknown sex combined) collected in the 2014 setline survey.

Age (years)	Regulatory Area									
	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
4			1							**1**
5		1	5	1	1	3	6	1		**18**
6	4	23	21	20	9	13	14	4	6	**114**
7	24	47	43	46	42	22	30	6	23	**283**
8	84	170	154	124	124	79	153	29	54	**971**
9	281	442	331	262	390	311	303	85	68	**2,473**
10	268	373	285	297	400	394	256	75	124	**2,472**
11	156	222	200	265	316	409	243	138	132	**2,081**
12	140	240	254	260	319	367	169	99	138	**1,986**
13	108	182	199	240	208	259	165	50	71	**1,482**
14	55	179	222	244	174	201	82	32	44	**1,233**
15	31	126	143	224	129	160	49	24	32	**918**
16	16	85	85	107	69	117	40	12	25	**556**
17	8	50	58	82	50	67	21	6	15	**357**
18	3	36	28	68	31	57	35	4	13	**275**
19	1	21	31	40	14	39	16	1	7	**170**
20	1	14	16	35	13	31	31	1	10	**152**
21	1	6	4	25	12	16	38		8	**110**
22		6	3	11	4	12	9		4	**49**
23	1	12	2	13	3	15	13		5	**64**
24		5	4	9	1	24	12		3	**58**
25		8	4	8	7	33	15	1	12	**88**
≥26		14	12	20	8	120	83	1	24	**282**
Total	**1,182**	**2,262**	**2,105**	**2,401**	**2,324**	**2,749**	**1,783**	**569**	**818**	**16,193**

Table 2. Age distribution of female halibut collected in the 2014 setline survey.

Age	Regulatory Area									
(years)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
5		1	2		1	2	2	1		**9**
6	4	20	16	11	6	6	9	3	5	**80**
7	20	30	30	30	26	16	18	5	15	**190**
8	75	125	118	88	88	55	79	18	33	**679**
9	226	324	232	174	270	207	163	75	37	**1,708**
10	214	255	192	195	281	265	108	67	81	**1,658**
11	124	145	134	162	188	278	84	124	88	**1,327**
12	93	150	166	173	177	256	73	78	85	**1,251**
13	77	111	145	145	112	159	59	43	52	**903**
14	33	98	145	135	90	118	25	25	34	**703**
15	20	54	95	114	47	72	10	18	23	**453**
16	9	36	49	37	14	38	10	9	19	**221**
17	6	23	34	32	7	18	6	6	9	**141**
18	2	18	15	19	3	20	13	4	10	**104**
19	1	12	21	14	3	11	2		4	**68**
20	1	5	9	6		7	8	1	6	**43**
21		4	3	4	1	5	3		3	**23**
22		3	2	1		7	3		3	**19**
23	1	4		2	2	6	3		2	**20**
24		1	2		1	8	3		1	**16**
25			2	1		8	3	1	3	**18**
≥26		8	6	2		41	11	1	11	**80**
Total	**906**	**1,427**	**1,418**	**1,345**	**1,317**	**1,603**	**695**	**479**	**524**	**9,714**

Table 3. Age distribution of male halibut collected in the 2014 setline survey.

Age	Regulatory Area									
(years)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
4			1							**1**
5			3	1		1	4			**9**
6		3	5	9	3	7	5	1	1	**34**
7	2	17	12	15	16	6	12	1	8	**89**
8	8	43	34	34	34	22	70	11	20	**276**
9	45	114	94	84	115	98	125	10	30	**715**
10	52	113	91	101	118	122	140	7	43	**787**
11	29	76	64	101	127	127	156	14	43	**737**
12	46	89	86	85	140	105	95	21	50	**717**
13	31	69	53	93	96	98	104	7	18	**569**
14	22	78	74	107	83	82	54	7	10	**517**
15	9	72	48	110	82	86	38	6	9	**460**
16	7	48	34	70	53	78	29	3	6	**328**
17	2	27	24	48	43	49	15		6	**214**
18	1	18	12	49	28	35	22		3	**168**
19		9	10	26	11	28	14	1	3	**102**
20		8	7	29	13	24	23		4	**108**
21	1	2	1	21	11	11	35		5	**87**
22		3	1	10	4	5	6		1	**30**
23		8	2	11	1	8	10		3	**43**
24		4	2	9		16	9		2	**42**
25		8	2	7	7	25	12		9	**70**
≥26		6	6	18	8	79	72		13	**202**
Total	**255**	**815**	**666**	**1,038**	**993**	**1,112**	**1,050**	**89**	**287**	**6,305**

Table 4. Mean age (in years) and mean fork length (in centimeters) of sampled halibut caught on standard survey skates by sex and regulatory area (CLS = Bering Sea closed area), 2005-2014 (F = female, M = male).

		Year																			
Reg		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014	
Area		F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
2A	Age	10.7	13.4	10.4	12.7	11.3	13.1	11.3	11.4	10.3	11.0	11.0	11.1	11.4	12.0	11.8	12.0	11.2	11.6	10.5	11.4
	Length	92.6	87.0	91.6	84.4	94.6	83.5	90.3	78.8	89.5	79.4	93.1	79.1	95.6	81.5	95.1	80.1	94.7	80.4	95.8	81.3
2B	Age	10.5	11.0	9.6	10.4	9.7	10.5	10.6	11.1	11.2	11.8	10.9	11.4	11.1	11.6	11.4	12.3	11.4	12.3	11.2	12.6
	Length	94.3	79.0	89.7	77.4	89.7	76.6	91.0	77.2	93.5	77.4	93.8	78.2	94.6	78.5	95.2	79.8	94.4	79.1	92.1	78.8
2C	Age	11.3	11.4	10.4	10.6	10.5	11.5	11.4	11.5	10.9	11.7	11.0	11.5	11.9	12.0	11.2	11.6	11.9	12.4	11.7	12.3
	Length	98.1	81.3	93.8	79.1	92.3	80.2	93.4	78.8	90.6	78.2	91.0	77.0	96.9	79.8	95.8	80.1	96.4	79.4	97.0	79.9
3A	Age	13.4	16.5	12.8	15.7	12.3	15.5	12.9	16.0	11.7	14.6	12.1	15.0	12.2	14.9	12.2	14.6	12.7	14.3	11.8	13.9
	Length	97.9	83.2	96.6	82.6	94.5	82.3	93.7	81.8	89.5	79.6	89.4	78.7	87.6	78.3	90.1	78.6	89.4	76.4	87.7	75.5
3B	Age	11.5	14.6	11.3	14.9	11.0	14.4	11.1	14.4	10.6	13.5	10.7	13.0	10.8	12.9	10.7	12.5	11.3	13.3	10.9	12.7
	Length	88.5	80.3	87.9	81.1	87.6	81.6	83.0	78.1	82.3	77.6	81.8	75.9	81.5	74.2	81.7	74.9	80.3	73.3	80.5	73.4
4A	Age	12.2	14.4	11.7	13.3	10.7	12.9	10.7	13.5	10.5	12.6	10.6	12.7	10.8	13.2	11.1	13.2	11.3	13.4	12.3	14.7
	Length	94.0	83.3	91.5	80.7	85.2	79.8	82.4	78.6	84.1	77.6	82.6	76.6	83.4	76.5	82.8	76.6	85.8	78.3	88.2	79.7
4B	Age	12.7	15.6	12.5	14.8	12.2	14.1	12.6	15.8	13.1	15.9	12.2	14.9	12.2	15.2	11.8	13.9	11.0	13.6	11.2	13.7
	Length	107.2	94.5	107.1	92.6	102.5	90.1	103.4	92.1	103.8	92.7	100.3	90.3	98.4	89.7	96.6	86.5	89.4	84.1	92.0	84.1
4C	Age	----	----	9.3	11.2	9.8	10.8	10.5	10.4	9.6	10.8	10.2	10.8	10.4	11.2	11.3	13.2	10.6	11.2	11.3	11.4
	Length	----	----	87.9	76.4	89.4	76.0	88.0	72.7	84.1	75.1	84.3	73.8	82.0	72.8	86.3	78.8	80.7	74.2	84.7	72.9
4D	Age	14.8	16.5	13.7	15.8	13.3	15.8	13.4	16.1	13.8	16.6	14.4	17.4	13.2	14.9	12.0	13.7	13.8	15.2	12.3	13.1
	Length	101.8	89.1	102.2	88.6	99.0	88.9	93.8	85.3	94.4	86.7	96.6	87.3	88.4	80.9	86.6	78.5	91.9	81.5	88.2	77.6
4E	Age	----	----	8.7	13.9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Length	----	----	92.7	83.1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
CLS	Age	----	----	9.3	12.3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Length	----	----	82.3	79.6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Table 5. Maximum and minimum age (in years) and fork length (in centimeters) of halibut for which sex was determined, collected in the 2014 setline survey, by regulatory area and sex.

Reg. Area	Sex	Max. age	Min. age	Max. length	Min. length
2A	Female	23	6	170	60
2A	Male	21	7	130	58
2B	Female	36	5	191	59
2B	Male	27	6	121	58
2C	Female	28	5	182	53
2C	Male	36	4	127	58
3A	Female	30	6	169	52
3A	Male	32	5	121	53
3B	Female	24	5	158	49
3B	Male	28	6	110	39
4A	Female	41	5	174	52
4A	Male	42	5	144	47
4B	Female	39	5	181	54
4B	Male	46	5	132	50
4C	Female	27	5	162	52
4C	Male	19	6	97	54
4D	Female	32	6	161	56
4D	Male	38	6	185	53

Table 6. Between-reader percent agreement for setline survey ages 2002-2013. (CV = coefficient of variation, APE = average percent error, % -bias = % of ages where the second age estimated for a fish (age 2) was younger than the intially-estimated age (age 1), % +bias = % of ages where age 2 > age 1).

Year	Total aged	Number aged twice	% agreement (± 1 year)	CV (%)	APE	% -bias	% +bias
2002	13,635	2,229	81.2	4.3	3.0	24.8	33.6
2003	12,613	1,633	83.3	4.3	3.0	22.0	29.3
2004	14,474	1,257	83.3	4.8	3.4	18.5	38.8
2005	14,552	1,361	85.1	3.9	2.8	20.4	30.2
2006	14,977	1,556	90.4	3.2	2.2	23.7	18.8
2007	16,022	1,566	87.2	4.5	3.2	28.1	28.6
2008	15,545	1,579	89.5	3.4	2.4	25.8	21.3
2009	15,706	1,567	91.1	3.4	2.4	26.2	19.0
2010	14,080	1,407	92.8	2.8	2.0	23.7	19.5
2011	14,451	1,448	89.8	3.7	2.6	30.3	19.3
2012	17,459	1,751	91.7	3.5	2.5	26.0	21.1
2013	12,717	1,438	91.9	2.6	1.8	16.9	17.7

Trends in seabird occurrence on stock assessment surveys (2002-2014)

Tracee O. Geernaert

Abstract

Seabird occurrence data have been collected during International Pacific Halibut Commission (IPHC) stock assessment surveys since 2002. The waters off California and northward to Alaska are generally surveyed from June through August. A total of 16,444 observations were conducted over the last thirteen years, with 1,314 occurring in 2014. More than 738,000 birds were recorded since 2002.

Northern fulmar (*Fulmarus glacialis*), glaucous-winged gulls (*Larus glaucescens*), black-footed albatross (*Phoebastria nigripes*), and fork-tailed storm petrels (*Oceanodroma furcata*) represent the most commonly reported species. The observed number of unidentified gulls has continually decreased, inversely correlated with an increased number of observations of glaucous-winged gulls and herring gulls (*L. argentatus*). This shift was likely the result of increased focus on gull identification during annual IPHC sampler training. A total of 262 endangered short-tailed albatross (*Phoebastria albatrus)* sightings were recorded overall, with 20 sightings occurring in 2014.

Introduction

In 2002, the International Pacific Halibut Commission (IPHC), in collaboration with Washington Sea Grant, developed a sampling protocol for collecting seabird occurrence data on the IPHC stock assessment surveys. This was initially a collaborative project between the IPHC, Alaska Department of Fish and Game (ADF&G), and the National Marine Fisheries Service (NMFS) sablefish (*Anoplopoma fimbria*) survey group. The purpose of the project was not only to establish a seabird database for Alaska that could be analyzed for population purposes, but also to make recommendations for regulatory changes to the seabird avoidance requirements for commercial fishing vessels. Several reports that evaluated seabird occurrence using these data were published between 2002 and 2013 (Melvin et al. 2004, 2006; Piatt et al. 2006; Guy et al. 2013). Although the collaboration ended in 2004, the IPHC permanently incorporated the seabird data collection protocols into its annual stock assessment survey program. Observations were conducted between the end of May and the beginning of September, on IPHC setline stations from the coasts of California, Oregon, Washington, British Columbia, southeast Alaska (inside and outside waters), the central and western Gulf of Alaska, Aleutian Islands, and the southeast Bering Sea continental shelf edge. Samplers aboard each survey vessel counted the number of seabirds in the vicinity of the vessel's stern immediately following gear retrieval (i.e., haul). Sampling seabird occurrence after the haul addresses the question of where and when certain seabird species occur. It also aids in the assessment of individual species at risk by providing information that may reflect population trends over time.

Methods

A detailed description of IPHC seabird observation protocols can be found in the IPHC Standardized Stock Assessment Survey Manual (IPHC 2014). Briefly, bird counts have been conducted since 2002 at all IPHC standardized stock assessment grid survey stations, as well as experimental stations not used for assessment purposes (expansion survey stations were not included). After hauling operations were completed at each station, samplers recorded the abundance of seabirds by taking a snapshot estimate of seabirds within a 50-meter radius hemisphere from the vessel's stern (the count zone; Fig.1). This concept is similar to performing a bird feeder count. Binoculars were provided to the samplers by the U.S. Fish and Wildlife Service (USFWS); as well, the IPHC supplied field guides in order to aid bird identification. Data were recorded on forms and entered into the stock assessment survey database, along with the other data collected. Data examined in this report were from grid and experimental stations fished on the annual IPHC stock assessment surveys only, and did not include other agency data, or records from winter surveys or special projects conducted by the IPHC.

Results

A total of 16,444 observations were conducted on the IPHC stock assessment survey over the last thirteen years (2002-2014). Seabird counts were taken on 99% of the IPHC setline stations. The average number of stations per year where bird counts were performed was 1,245, with 2014 higher at 1,314 (Table 1). More than 738,000 bird sightings (composed of 36 unique species) were recorded. The average number of unique species seen annually was 20 and the percentage of the times the species appeared each year ranged from 8-100% (Table 1). Start dates for each year's survey ranged from May 25 to June 7 and the end dates from August 27 to September 14, but the bulk of the surveys took place from June to August (Fig. 2) and most of the counts took place in the Gulf of Alaska (Fig. 3).

The most common species observed in the counts during all years was the northern fulmar (*Fulmarus glacialis*), making up 72% of the cumulative sightings. Glaucous-winged gulls (*Larus glaucescens*) and black-footed albatross (*Phoebastria nigripes*) made up nine and eight percent of the overall sightings, respectively. Fork-tailed storm petrels (*Oceanodroma furcata*) represented two percent, and Laysan albatross (*Phoebastria immutabilis*) and shearwater species each one percent of all sightings (Fig. 4). Counts per year have remained relatively consistent since 2002 with the average at 1,245 (Table 1). Enumerations of four of the top five most frequently observed birds, northern fulmars, black-footed and Laysan albatross and fork-tailed storm petrels, are plotted over the 12-year period (Fig. 5). Northern fulmar numbers have been decreasing for the last two years but the other 3 species show an increasing trend for the first time since 2010. The number of glaucous-winged gull sightings has increased while the unidentified gull numbers have decreased (Fig. 6). The ratio of unidentified birds to total number of individual birds (Fig. 7) has also decreased greatly since 2002 and has remained at or below 0.02 for the last three years.

A total of 262 sightings of the endangered short-tailed albatross (*Phoebastria albatrus)* were made during the counts over the 12-year period. On average, 20 short-tailed albatross were recorded annually since 2002. Most of these birds were seen in the Gulf of Alaska and regions westward (Geernaert 2014). These data are of particular importance because the short-tailed albatross is a rare species and one of considerable interest to management agencies. Regulations surrounding its protection and recovery affect the north Pacific longline fisheries.l

Discussion

The number of unidentified birds within the survey count zones has decreased since the start of the seabird data collection program in 2002, indicating that the IPHC sea samplers have improved their identification skills. The change in glaucous-winged gull numbers over time demonstrates this learning curve. Observation rates of glaucous-winged gulls were inversely correlated with observation rates of unidentified gulls such that, as glaucous-winged gull sightings increased, unidentified gull sightings decreased (Fig. 6). This is likely because IPHC instructors increased their focus on gull field characteristics during annual field staff training and samplers have become better-skilled at identification. The IPHC has also provided samplers with better field guides since 2011.

Black-footed albatross, Laysan albatross, and fork-tailed storm petrels increased this year (Fig. 5) and this may be a good sign for their populations. Conversely and more concerning northern fulmars numbers decreased by nearly 14,000 birds since 2012 but caution should be exercised when using the data. Short-term changes in observed abundance might not necessarily reflect changes in population abundance, but could instead reflect spatio-temporal shifts in distribution that are not captured by the "snapshot" survey. The survey is neither conducted at the same time in each area in a given year, nor is it in a particular area between years, and this can skew the bird sighting information. Further work is needed to more fully examine charter timing and its effect on the bird occurrence data.

Population sizes of many birds species vary from year to year and trends up or down can be indicative of a change in diet, weather, and/or timing of chicks fledging from the nest. Though the surveys offer only a snapshot in time of bird occurrence, they are broad in geographic scope (conducted coastwide) and are repeated in the same spatial pattern annually. By continuing to accumulate data, it is hoped to eventually determine how observations relate to actual abundance levels; specifically, for birds of concern such as the albatrosses. With continued, consistent gathering of these data for all species seen, trends in abundance may be determined that will help predict a species' decline or recovery.

References

IPHC. 2014. 2014 Stock Assessment Survey Manual. Int. Pac. Halibut Comm., Seattle, WA.

Geernaert, T. O. 2014. Trends in seabird occurrence on stock assessment surveys (2002-2013). Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013:441-450.

Guy, T. J, Jennings, S. L, Suryan, R. M., Melvin, E. F., Bellman, M. A., Balance, L. T., Blackie, B. A., Croll, D. A., Deguchi, T., Geernaert, T. O., Henry, R. W., Hester, M., Hyrenbach, K. D., Jahncke, J., Kappes, M. A., Ozaki, K., Roletto, J., Sato, F., Sydeman, W. J., Zamon, J. E. 2013. Overlap of North Pacific albatrosses with the U.S. west coast groundfish and shrimp fisheries. Fish. Res. 147:222-234.

Melvin, E., Dietrich, K., Van Wormer, K., and Geernaert, T. 2004. The Distribution of Seabirds on Alaskan Longline Fishing Grounds: 2002 Data Report. Washington Sea Grant Program, Seattle, WA.

Melvin, E., Wainstein, F. M. D., Dietrich, K. S., Ames, K. L., Geernaert, T. O., and Conquest, L. L. 2006. The Distribution of Seabirds on the Alaskan Longline Fishing Grounds: Implications for Seabird Avoidance Regulations. Washington Sea Grant Program, Project A/FP-7, Seattle, WA.

Piatt, J. F., Wetzel, J., Bell, K., DeGange, A. R., Balogh, G. R., Drew, G. S., Geernaert, T., Ladd, C., and Byrd, V. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross *(Phoebastria albatrus*) in the North Pacific: Implications for conservation. Deep-Sea Res. II 53: 387-398.

Table 1. Number of birds in 2014; average, total since 2002; and percent presence since 2002.

Species	2014	Average 2002-14	Total observed	Percent presence
Northern fulmar	27,305	40,671	528,729	100%
Black-footed albatross	5,604	4,361	56,695	100%
Laysan albatross	1,048	752	9,772	100%
Short-tailed albatross	20	20	262	100%
Glaucous-winged gull	8,034	5,131	66,703	100%
Herring gull	172	311	3,734	92%
Western gull	51	279	558	17%
Mew gull		38	115	25%
Glaucous gull	35	25	147	50%
Heermann's gull		18	90	42%
Sabine's gull		3	19	50%
Slaty-backed gull		7	7	8%
Ring-billed gull		3	6	17%
Bonaparte's gull		3	6	17%
Unidentified gull	307	2,519	32,744	100%
Arctic tern		2	3	17%
Unidentified tern		6	30	42%
Ruddy turnstone		8	8	8%
Pomarine jaeger		4	45	83%
Parasitic jaeger		3	32	75%
Long-tailed jaeger	11	6	18	25%
Unidentified jaeger		6	40	58%
South polar skua		1	1	8%
Fork-tailed storm petrel	1,309	1,244	16,178	100%
Leach's storm petrel	22	57	737	100%
Unidentified storm petrel	139	386	5,017	100%
Black-legged kittiwake	218	373	4,845	100%
Red-legged kittiwake	12	10	124	100%
Unidentifed kittiwake	1	72	937	100%
Short-tailed shearwater	37	135	1,624	92%
Sooty shearwater	384	136	1,767	100%
Pink-footed shearwater	158	48	333	58%
Flesh-footed shearwater		2	2	8%
Unidentified shearwater	53	482	6,263	100%
Common murre	7	5	23	42%
Thick-billed murre		30	30	8%
Unidentified murre	13	19	245	100%
Rhinoceros auklet		1	2	17%
Parakeet auklet		2	2	8%
Tufted puffin	11	7	88	92%
Horned puffin		2	8	42%
Unidentified puffin	3	13	170	100%
Unidentified alcid		1	2	33%
Bald eagle	5	20	79	17%
Unidentified cormorant	5	2	11	50%
Unidentified bird		17	118	58%
Grand total	**44,964**	**57,784**	**738,369**	
Number of counts	1,314	1,245	16,444	
Number of unique species	21	20	36	

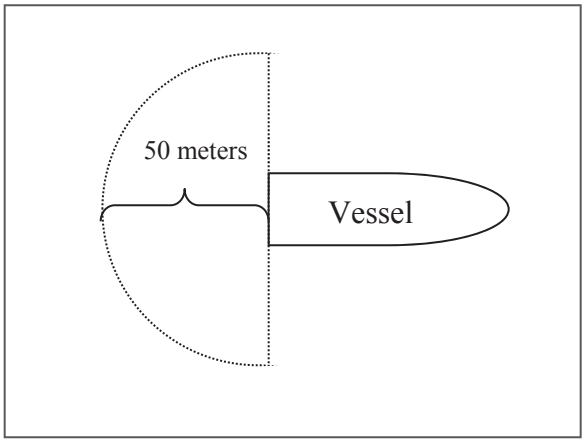


Figure 1. Diagram of the seabird 50-meter hemisphere (count zone) at the stern of the vessel where seabird counts were conducted.

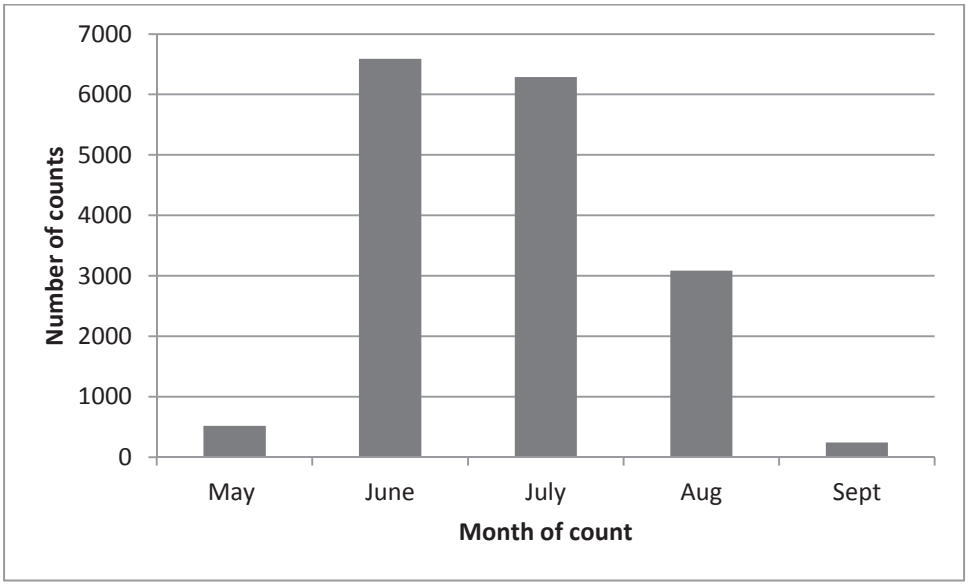


Figure 2. Overall seabird counts conducted on IPHC standardized stock assessment setline survey by month, 2002-2014.

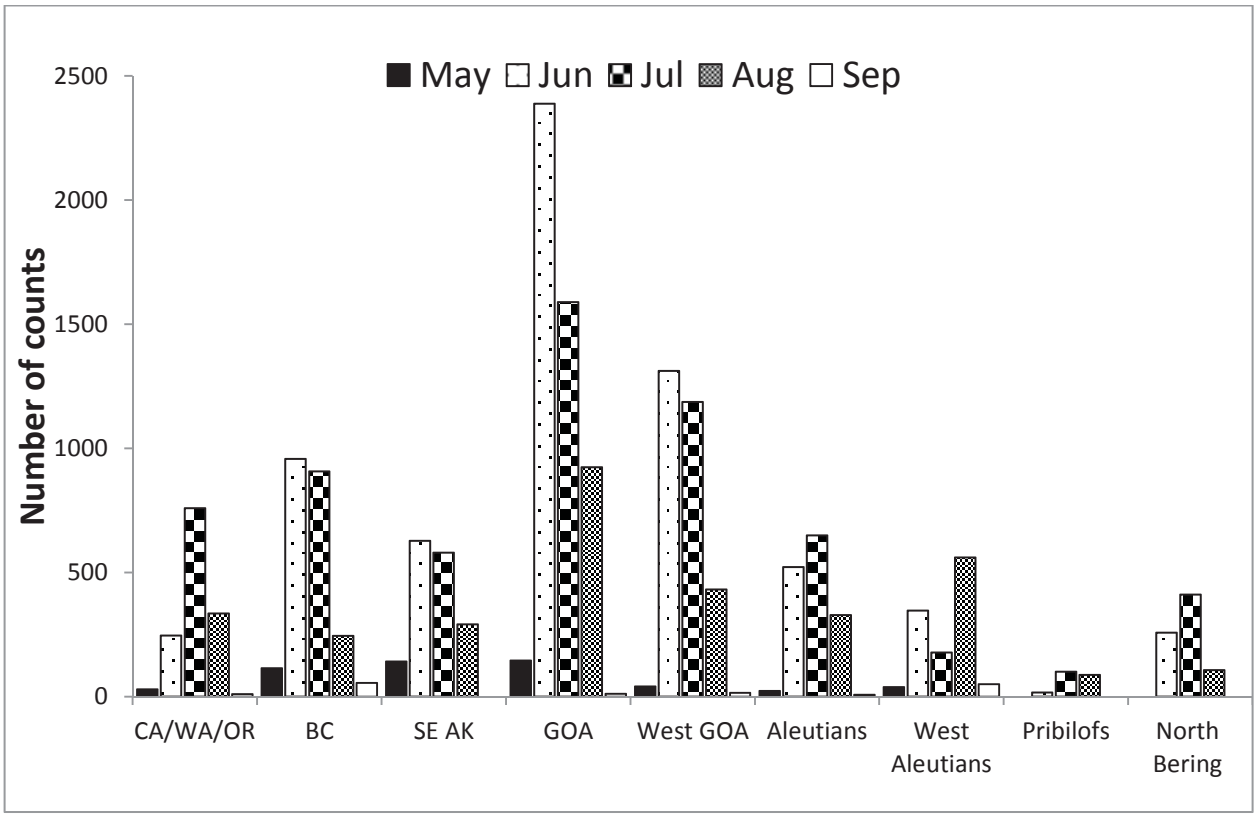


Figure 3. Total number of seabird counts conducted on IPHC standardized stock assessment setline survey, by area and month, 2002-2014. Abbreviated locations are as follows: CA/WA/OR = California, Oregon, and Washington; BC = British Columbia; SE AK = southeast Alaska; GOA = central Gulf of Alaska; West GOA = western Gulf of Alaska.

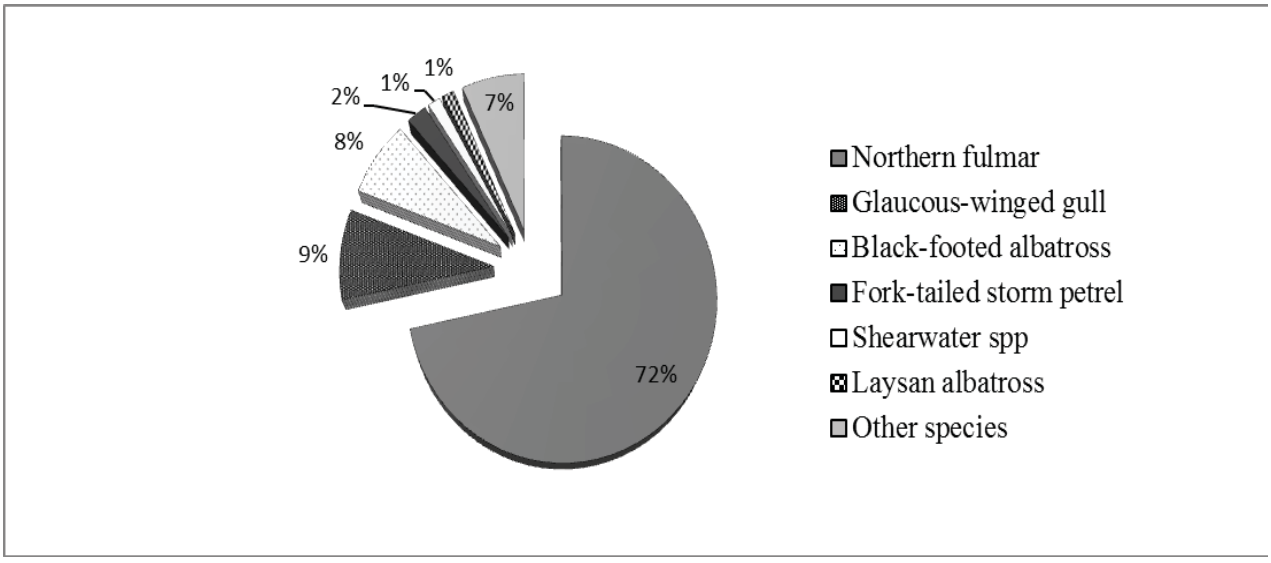


Figure 4. Frequency of observation (%) of common seabird species observed on IPHC standardized stock assessment setline survey, 2002-2014.

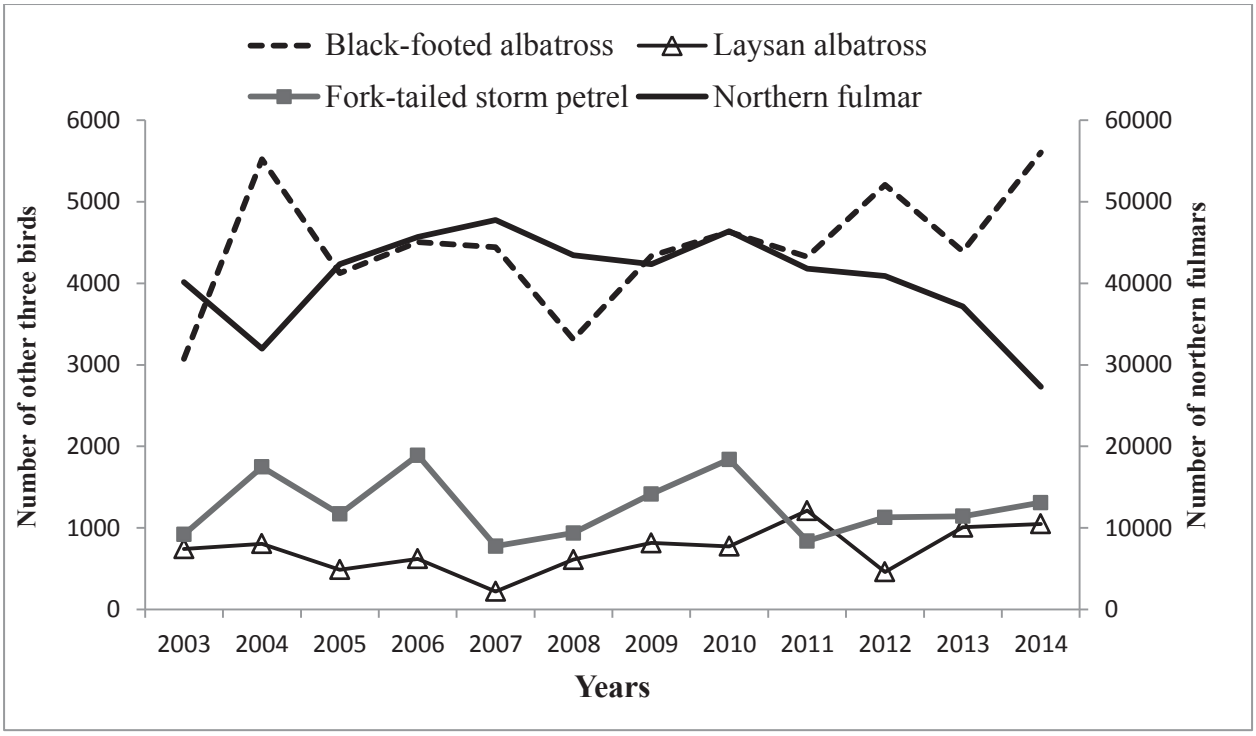


Figure 5. Total number of the four most common bird species observed on IPHC standardized stock assessment setline survey, 2002-2014.

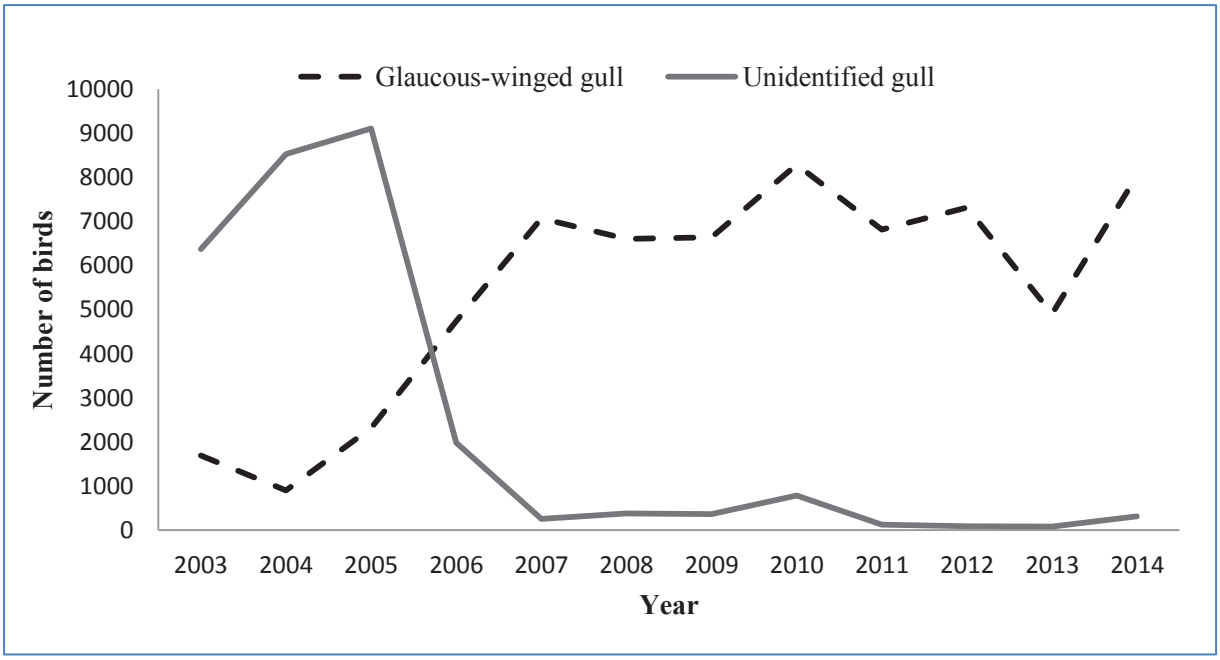


Figure 6. Glaucous-winged gull numbers versus unidentified gull numbers observed on IPHC standardized stock assessment setline survey, 2002-2014.

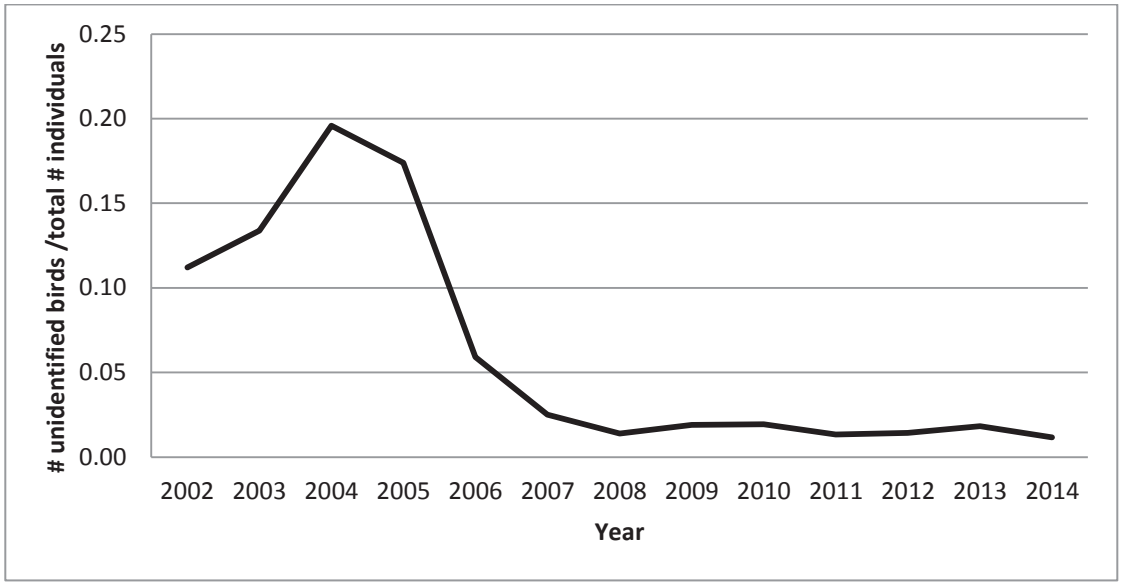


Figure 7. The ratio of number of unidentified birds to total individuals observed on IPHC standardized stock assessment setline survey, 2002-2014.

Setline survey expansion and complementary data sources

Raymond A. Webster, Ian J. Stewart, Bruce M. Leaman, Lauri L. Sadorus, Ed Henry, and Claude L. Dykstra

Abstract

This report reviews the International Pacific Halibut Commission staff's rationale for proposing a series of expansions of the annual setline survey, outlines the current approaches used to estimate indices of relative abundance of halibut, and presents cost projections for each year of the proposed expansion. We also present a review of other sources of survey data that may be useful in improving these indices by providing information in regions and years for which setline survey coverage is incomplete.

Rationale for survey expansion

The International Pacific Halibut Commission (IPHC) setline survey index of abundance and associated biological data provide the most reliable and informative source of data for the annual stock assessment, and the apportionment estimates which feed directly into the current harvest policy. The current IPHC standard setline survey grid with 10 nmi station spacing covers depths from 20-275 fathoms, with coverage in 2013 ranging from 40° N in northern California to the Bering Sea Edge in Area 4CDE. The observation of significant commercial harvest in deep waters, particularly in Area 4A, and in shallow waters in some areas, showed that halibut inhabit depths outside the current survey range, including during the time of the year the survey is undertaken. This led to the use of the 0-400 fathom depth range for estimating the bottom area of each regulatory area used in assessment and apportionment calculations (Hare et al. 2011). There are also gaps in the survey coverage within the 20-275 fathom range, and these gaps can be substantial, particularly in Areas 2B and 4. For these reasons, the IPHC has proposed a number of expansions to current and future survey efforts (Table 1).

Until an expansion is undertaken, the degree of bias caused by unsurveyed habitat cannot be directly estimated. However, past expansions provide examples of what we could expect:

- An expansion of the Area 2B survey to include the area west of Vancouver Island in 1999 showed that a WPUE index excluding this area had an estimated positive bias of 12%.
- The eastward expansion of the survey in Area 3A in 1996 led to the calculation of an adjustment factor of 0.81, implying the mean WPUE from the survey of western Area 3A overestimated the mean for the entire area by 23%.
- The 2011 expansion of the survey in Area 2A to fill in gaps in coverage off the WA/OR coast has led us to estimate that previously the survey was underestimating mean WPUE by around 4% on average.
- The expansions of the Area 2A survey to Puget Sound (2011) and northern California (2013) led to estimates of a combined positive bias of 4% in the mean WPUE of the survey excluding these stations.

- The 2011 expansion to shallow and deep waters in Area 2A led to a mean WPUE for all stations that was 17% less than that for stations only in 20-275 fathoms (Webster et al. 2012). This means that ignoring deep and shallow waters leads to an estimated positive bias of 21% in mean WPUE for Area 2A.

Areas with large regions of unsurveyed habitat (Areas 2B, 4A, 4B, and Area 4D Edge) have the greatest potential for large changes in mean WPUE and a significant effect on apportionment when the survey is expanded as proposed in Webster et al. (2014). Also, the eastern Bering Sea (EBS) flats was surveyed once, in 2006, and its time series is dependent upon a calibration with the National Marine Fisheries Service (NMFS) trawl survey data, and the ratio of setline and calibrated trawl indices in 2006. This region covers 68% of the total Area 4CDE bottom area (Table 1, Webster and Stewart, 2014), so any change in the calibration or the ratio of indices could greatly affect the Area 4CDE index and consequently this area's apportioned share of the coastwide biomass. This is of particular importance given that, in recent years, biomass has been close to the point at which, after accounting for other removals such as bycatch mortality, the commercial fishery could be closed in this area. For this reason, we have prioritised improving the information we have on the Bering Sea through a proposed survey of the EBS in 2015.

While it is relatively simple to hypothesize about the degree of potential bias in specific geographic areas, and therefore the potential change in that area's density estimate that may occur when survey expansions are conducted, the effect of biases in individual areas on annual processes is more complex. The index created from the setline survey provides the basic trend information for the stock assessment models. With differing historical trends among regulatory areas, the proportional contribution of each is important to the coastwide index. Changes in several areas can therefore potentially compound to have a larger effect on our understanding of the stock at the coastwide level. Further, while various estimators are used for unsampled geographic areas (see below), there are currently no methods for extrapolating biological information to these strata. Until they have been directly sampled by the IPHC survey, there is no way to determine the type or magnitude of potential bias in these data. Similarly, for apportionment calculations, small changes among multiple geographic areas can result in relatively large changes to the current estimates of stock distribution; these changes can have very large biological and economic implications, as quota holders cannot easily shift their holdings among regulatory areas.

Current approaches for estimating relative abundance

The IPHC currently uses five methods for estimating the relative abundance of halibut in various geographic regions. In order of confidence in the estimates, these methods are:

1) Annual IPHC setline surveys using the standard 10 nmi grid with coverage representative of all habitats and areas.
2) One or more IPHC setline surveys calibrated to more frequent surveys using other methods (longline or trawl).
3) One or more IPHC setline surveys assuming a constant ratio of catch rates to IPHC annually sampled areas.
4) No direct sampling, estimates calibrated to surveys using other methods based on relationships established in other areas.
5) No direct sampling, estimates based on extrapolation of catch rates in nearby areas.

The reason for this ranked order is that each method makes stronger assumptions than the preceding method. Specifically, Method 1 is a direct estimator for each year and area. Method 2 makes the assumption that the calibration coefficient between the two methods is stable over time, but the stock density can be variable over both space and time. Method 3 makes the assumption that the relative stock density can be variable among areas, but not over time. Method 4 assumes that the calibration coefficient is constant over space and time. Method 5 assumes that the relative density is constant over time and among areas (e.g., the same fraction of the stock occurs in >275 fm depths in all areas).

Each time the IPHC directly surveys a new area, we can move the resulting estimate at least to Method 3, and perhaps to Method 2 depending on other surveys available. Where we find calibrations to be highly variable over time, an analysis of the contribution to total estimates will be needed to determine whether either the assessment, apportionment, or both require more frequent IPHC surveys. At present we are not proposing any change to the annual design. Expansion efforts are targeted to determine variability in existing calibrations, and to leverage as many auxiliary datasets and single survey opportunities to improve estimators in as many places as possible.

Cost estimates and projections for survey expansions

The costs associated with survey expansion, like regular survey costs, are sensitive to assumed or realised catch rates and price per pound of fish recovered from the sale of sampled fish. For this reason, we present only the vessel costs to provide the scalars between regular and expanded survey stations. Revenues from fish sales will affect both regular and expanded surveys in the same manner. Table 2a illustrates the incremental survey expansion assuming the present seven skates fished per station for all areas except the eastern Bering Sea, where five skates per station will be fished to reduce net costs. Expansion stations have been vetted by IPHC staff in consultation with commercial harvesters, U.S. Coast Guard, and NMFS enforcement personnel, and our experience with expansions in Areas 2A and 4A is that very few of these proposed stations will turn out to be unfishable.

In 2011, the staff prepared a projection of vessel costs (costs excluding revenue from fish sales) for expansion into shallow (10-20 fm) and deep (275-400 fm) waters, plus filling in some gaps in coverage within the standard 20-275 fm waters. This projection was updated using 2014 budget figures and indicates that in terms of vessel costs, the staged expansion will lead to increases of 5-12% over the standard survey costs in each year of the project.

Table 2b is a presentation of actual costs incurred in the 2011 and 2014 expansions in Area 2A (including Puget Sound) and the 2014 expansion in Area 4A. In terms of direct vessel costs, not including revenue from catch sales, the realised costs have been slightly below the projected costs. For the 2011 expansion in Area 2A, the projected vessel costs were approximately $196,000 and realised direct vessel costs were approximately $151,000. Final figures are not yet available for the 2014 expansions but revenues are below projections by approximately 58% in Area 2A and above projections by approximately 60% in Area 4A. The net revenue for both expansions combined is currently estimated at approximately -$23,000. Realised losses have been lower than expected due to higher fish prices but lower operational expenses have also contributed.

Over the long-term, the expansion of existing IPHC surveys will need to be approached on a prioritised and opportunistic basis. As noted elsewhere in the document and in Table 1, the priorities identified by the staff for direct IPHC surveys are the calibration study of the eastern Bering Sea

flats, the Area 4D Edge, Area 4B, Areas 2B and 2C, and Areas 3A and 3B. This priority reflects the regions where uncertainties and potential biases are highest. The intensity and frequency of surveys can be evaluated against the impact of uncertainty in the estimates of stock size and yield. Specifically, some of the expansions may be worthwhile repeating in future surveys, depending on their effect on the regulatory area estimates. This type of evaluation will be included in the ongoing Management Strategy Evaluation. In addition, the staff will be examining alternative data sources to supplement expansion of direct surveys, as outlined in the following section.

Repeat of 2006 Eastern Bering Sea calibration with the NMFS trawl survey

In 2006, the IPHC conducted comparison fishing between standard halibut survey gear and the NMFS trawl survey in the eastern Bering Sea flats. This work was completed to establish a calibration so that the IPHC could estimate the abundance of exploitable halibut biomass in this area. Approximately one-half of the 111 stations fished were on the same grid points as the NMFS survey and one-half were offset by 10 nmi from the NMFS grid points. The area was broken into three survey regions and the IPHC bid costs for the survey (five skates/station) were as follows:

St. George:$2,289/stn. 38 stations. (+10% of 7,437 pounds of halibut at the going price of the day). Took 26 days of work.
St. Paul: $2,431/stn. 36 stations. (+10% of 5,418 pounds of halibut at the going price of the day). Took 20 days of work.
St. Matthew: $2,243/stn. 37 stations. (+10% of 5,633 pounds of halibut at the going price of the day). Took 33 days of work.
Total cost for EBS: $257,489

In the same year, the costs for the standard IPHC surveys in the Bering Sea area rest of the Bering Sea were as follows for six skate stations:

4A Edge: $1,745/stn. 47 stations. (+10% halibut sales).
4D Edge: $1,878/stn. 49 stations. (+10% halibut sales).

Thus, the EBS had an average cost of $2,320 per 5-skate station compared to the Edge having an average cost of $1,813 per 6-skate station. The EBS ran 28% higher per station than our typical work for that year despite using fewer skates, and generated very little in offset revenue compared to the Edge. This is likely to be the case for any subsequent survey of the EBS.

In 2014 (using seven skates per station), the average station bid costs for the Bering Sea Areas 4A and 4D ranged from $2,391–$2,410/station. This is approximately 14% higher per skate than in 2006. Assuming that EBS costs are also 14% higher in 2015 than they were in 2006, this leads to a projected cost of $2,645 per 5-skate station, or $529/skate. There are currently 29 of the original 111 EBS expansion stations embedded in the ongoing standard survey grid. The estimated costs assume that we leave these stations (around St. Matthew, St. Paul, and St. George islands) in the current Edge survey regions.

Expansion of the survey into the northern Bering Sea

The only region with no current proposal for expansion is the northern Bering Sea (NBS). At present, density in this region is indexed by combining data from the triennial Alaska Department of Fish and Game (ADF&G) Norton Sound trawl survey (Soong and Hamazaki 2012) with the

2010 NMFS northern Bering Sea trawl survey with the EBS trawl-to-setline calibration applied (Webster 2014). Estimated O32 WPUE values are around 5 lbs/skate for recent years, about half the value of the EBS index, applied to an area about one third the size of the EBS. As shown in Figure 1, its contribution to the biomass of Area 4CDE is estimated to be small compared to the EBS (Area 4S in the figure). For this reason, IPHC staff has prioritised the EBS calibration, as it is likely to have a far greater impact in improving estimates for Area 4CDE than an expansion into the northern Bering Sea. Nevertheless, staff is also examining potential designs for a northern Bering Sea survey in the event that it is decided to add this to the list of future expansion regions. One potential design is to continue the 2006 EBS grid of paired survey stations northwards, which would yield up to 15 new pairs of stations spaced 60 nmi apart. Two challenges are that a large proportion of the region is very shallow (<10 fm deep), and may not be suitable for our standard longline survey gear, and that if the distribution of halibut is very patchy this far north, a sparse grid has a high chance of missing localised areas of high density.

Other data sources to complement the IPHC setline survey

IPHC staff is also investigating the use of data from other surveys to calibrate the IPHC setline survey index in regions that are not sampled annually by the setline survey. Surveys by other agencies that have the potential to be useful for this purpose are described below. Table 3 summarizes the potential application of these surveys' data for improvement of our abundance index, and provides a general ranking of the quality of the data available from each survey for this purpose.

Bering Sea shelf bottom trawl survey

The current standardised NMFS Bering Sea trawl survey began in 1982 and is an annual survey conducted mostly on a 20 nmi-spaced grid, covering the eastern Bering Sea, generally at depths from 30-200 m (16-109 fm) (Sadorus and Lauth 2014), but with a few stations at shallower depths (20-30 m, 11-16 fm, Lauth 2011).

Data from this survey from stations set no deeper than 75 fm on the 20 nmi grid are currently used to create a density index for parts of the Bering Sea surveyed only once by the IPHC in 2006, using a length-based calibration between the two surveys (Webster 2014). Catch-rate data from a one-year expansion of the trawl survey into the northern Bering Sea in 2010 (station depths of 10-200 m, Lauth 2011) are used together with data from the triennial trawl surveys in Norton Sound (see below) to create a density index for this region. Thus, for the southern Bering Sea, estimation of relative abundance indices uses Method 2 described above, while Method 4 is used for the northern Bering Sea.

Halibut length data are typically recorded for 100% of the halibut catch on the NMFS Bering Sea shelf trawl survey, and IPHC staff have sampled otoliths on part of the survey each year beginning in 1998 (Sadorus and Lauth 2014). Age data are also available from the 1983, 1984, and 1991 surveys. Haul and biological data are incorporated annually into the IPHC databases.

Bering Sea upper continental slope trawl survey

From 2002 onwards, this has been a biennial trawl survey (although no surveys were conducted in 2006 or 2014) on the eastern Bering Sea shelf slope. This survey covers depths from 200-1200 m (109-656 fm) (Hoff 2013) and has a stratified random design, with six geographic areas each

divided into five depth strata, giving 30 strata in total. In 2012, 189 locations were sampled. Lengths of halibut are recorded. The IPHC has catch data from the 2002, 2010, and 2012 surveys in its databases, along with some data from much earlier slope surveys dating back to 1975 (Clark et al. 1997).

This survey extends as far north as the Exclusive Economic Zone (EEZ)/Russian boundary, and therefore covers parts of the Area 4D Edge not presently surveyed by the IPHC. It also covers deeper waters than the current IPHC survey. In 2012, halibut were recovered at low densities north of 60°N (the current northern limit of the IPHC Area 4D Edge survey), and at depths from 400-600 m (219-328 fm). No halibut were caught in waters deeper than 600 m. Data from this survey have the potential to be used in computing an index for deep waters in Area 4D, and (possibly in combination with the annual Bering Sea trawl survey) for waters north of the current setline survey.

Norton Sound bottom trawl survey

This trawl survey has generally been conducted triennially, first by NMFS (1976-1991) and thereafter by ADF&G in the Norton Sound region of the northern Bering Sea (Soong and Hamazaki 2012). While survey coverage has varied, a core group of stations has been consistently fished over the duration of the survey. Halibut CPUE data from this survey are available in spreadsheet files. Data from the core Norton Sound stations, together with other NMFS Bering Sea trawl data, are used in creating an index for the entire northern Bering Sea (Webster 2014). Some halibut length data from recent surveys have been provided to the IPHC, but have not yet been used for calibration.

Aleutian Islands and Gulf of Alaska bottom trawl surveys

The Gulf of Alaska (GOA) trawl series began in 1984 and was generally triennial until 1999 and has been biennial since then. The Aleutian Island (AI) survey began in 1991 as a triennial survey and has been performed biennially since 2000 (Sadorus and Palsson 2012, Sadorus et al. 2013). Surveys have a randomised design, stratified by depth zone and NMFS management area, and in the GOA, by habitat type. Depth coverage was originally 10-500 m (5-273 fm) in both surveys, and in 1999 and from 2003 onwards, the GOA survey has also included deeper stations, with maximum depths ranging from around 700- 1000 m (383-547 fm) depending on year.

Measurements of halibut length are made in both surveys. For the AI survey, age data from otolith samples are available from the 1991, 1997, 2000, 2012, and 2014 surveys. Sampled otoliths have been collected routinely since 1996 from the GOA survey. Age data are also available from the 1984 and 1990 surveys. Survey data are available in the IPHC databases.

The deeper water parts of the GOA survey could be used to help create a density index for halibut in waters deeper than 275 fathoms. The trawl survey is not undertaken in inside waters in Area 2C, and therefore excludes some deep water found there.

West Coast groundfish bottom trawl surveys

The NMFS shelf trawl survey began in 1977, and was triennial until 2004. The survey covered depths of 90-460 m (50-250 fm) in 1977, depths of 55-366 m (30-200 fm) from 1980-1992, and depths of 55-500 m (30-275 fm) from 1995-2001 (NMFS 2007, Bradburn et al. 2011). A separate slope survey was also conducted in depths of 183-1280 m (100-700 fm) from 1984 to 2002. Both surveys used a transect design (equally spaced survey tracks, NMFS 2007) and ranged from the U.S.-Canada border to Pt. Conception in southern California (34.5°N).

In 2003, these surveys were replaced with a combined shelf and slope survey covering depths from 55-1280 m (30-700 fm) and the entire U.S. EEZ from the Mexican to Canadian borders (Bradburn et al. 2011). The current design is based on stratified random sampling, with three depth strata (55-183, 183-549, and 550-1280 m) and two geographic strata (north and south of Pt. Conception). The survey region is divided into around 13,000 equally sized cells, which are selected at random within each stratum. Four vessels are each randomly assigned a set of cells each year (> 700 cells for the entire survey), although in 2004 and 2013 only three vessels were used. Some cells are excluded from sampling for various reasons (protected areas, safety issues, military activity, radioactive dumpsites, and mooring/subsurface instruments). Bradburn et al. (2011) state that all species of fish are weighed using an electronic, motion-compensated scale, although it is not clear if individual weights or lengths of Pacific halibut are available.

This survey covers depths beyond the IPHC standard maximum depth of 275 fathoms. There is the potential, therefore, to calibrate the catch rates from the deep part of the trawl survey with the 2011 and 2014 IPHC surveys in 275-400 fm to create an index for deeper waters for years in which the IPHC survey does not fish those waters. The data from southern areas could be used to create an index for parts of California not surveyed each year or not surveyed at all by the IPHC setline survey. IPHC staff recently received data from this survey from NMFS for years up to and including 2013.

Alaska sablefish longline survey

The sablefish survey is conducted annually in the Gulf of Alaska, and biennially alternating in the Bering Sea and around the Aleutian Islands. It covers the upper continental slope and selected gullies of the eastern Bering Sea, Aleutians Islands region, and Gulf of Alaska, sampling depths from 150-1000 m (82-547 fm) during the summer months (Sigler and Lunsford, Unpub[1]). A fixed-station design is used, with longline sets of 80 skates of 100 m length, each skate having 45 hooks 2 m apart, set at each station location. Stations are 20-30 nmi apart. Survey standard bait consists of East Coast or North Atlantic squid (*Illex illecebrosus*), 2-3 count per lb or larger.

Currently, data are available for analysis by the IPHC from annual longline surveys conducted cooperatively by Japan (1979-1994) and the U.S. National Marine Fisheries Service, and Alaska Fisheries Science Center (1988-present). The sablefish survey records the catch of halibut by skate on each station, but no length or biological information is collected. This does, however, present the opportunity for the IPHC to calculate a relative catch-rate as a function of depth.

The primary interest in this survey comes from its coverage of deeper waters from Areas 2C to the Area 4D Edge, and there is the potential for calibration with the IPHC survey to provide an index for deep waters when these are unsurveyed by the IPHC. This survey does not extend to the western Aleutian Islands (western Area 4B), and does not cover inside waters in Area 2C, which also include some deep water habitat (deeper than 275 fathoms). The survey collected halibut lengths from several stations in the Aleutian Islands in 2014 which may allow some comparison to IPHC survey lengths in the area.

[1]Survey protocol for the Alaska sablefish longline survey. http://www.afsc.noaa.gov/ABL/MESA/pdf/LSprotocols.pdf. Retrieved November 2014.

British Columbia bottom trawl surveys

Fisheries and Oceans, Canada (DFO) together with the Canadian Groundfish Research and Conservation Society (CGRCS) undertake bottom trawl surveys that cover most of the British Columbia Coast over a two year period (Rutherford, 2013). There are four survey areas, with surveys in two areas performed each year. The survey areas are: Hecate Strait (begun 2005, odd-numbered years); Queen Charlotte Sound (begun 2003, odd-numbered years plus 2004); West Coast Vancouver Island (begun 2005, even-numbered years); and West Coast Haida Gwaii (begun 2006, even numbered years). A random stratified design (with stratification by depth) is used for each area. Survey sites are located by randomly selecting 2-km^2 blocks within each stratum. Depending on the region, surveys are conducted from May through August. A new spring trawl survey of the Strait of Georgia was carried out in 2012, and is planned to be repeated every three to five years. Its timing is outside the range of the IPHC setline survey, and therefore its data are likely of limited use for indexing halibut.

According to Rutherford (2013), the West Coast Vancouver Island (WCVI) survey has four depth strata, with total depth range of 50-500 m (27-273 fm). It does not, therefore, cover any area not already covered by the IPHC setline survey. The Queen Charlotte Sound survey uses four depth strata and two area strata, and like the WCVI survey, covers a depth range of 27-273 fm (Stanley et al. 2005). The West Coast Haida Gwaii (WCHG) survey covers deeper waters ranging from 180-1300 m (98–710 fm), also divided into four strata. The Hecate Strait survey includes coverage of shallow waters up to 10 m (5 fm), with a maximum depth of 500 m. Thus, both the WCHG and the Hecate Strait surveys offer some limited coverage outside the IPHC setline surveys standard depth range.

Halibut data collected on these surveys include individual lengths, and set location information (from which depths can be estimated). It is not clear if 100% of halibut are measured.

British Columbia inshore rockfish longline surveys

A longline rockfish survey commenced in 2003 in the inshore waters of the Straits of Georgia and Juan de Fuca (Lochead and Yamanaka 2004). Coverage is partial each year: in some years, the narrow waters on the northeastern side of Vancouver Island are surveyed, while in other years, waters to the south (including the Strait of Juan de Fuca) are surveyed (Lochead and Yamanaka 2007). Gear is set at depths of 40-100 m (22-55 fm), with locations selected using a stratified random design based on 2-km^2 sampling units and two depth strata. Hard bottom areas are targeted, as these are more likely to be rockfish habitat. A second, "outside" waters survey began in 2006, covering other inshore waters in BC and using a similar design to the "inside" survey of the Straits of Georgia and Juan de Fuca. Coverage of this survey extends from the US/Canada boundary down through the waters around the west coast of Vancouver Island. Depth coverage on this survey is from 20-250 m (11-137 fm), and it is undertaken in northern and southern waters in alternate years.

Halibut are at least counted on these surveys, and the total weight of the halibut catch is recorded. Due to the preferential selection of rockfish habitat, these surveys could potentially produce biased indices of halibut density. Otherwise, there is some potential for the outside survey to help index shallow waters, possibly in combination with the complementary shallow coverage of the Hecate Strait bottom trawl survey (above). The inside survey by design does not cover the large offshore waters of the two straits, and so is of limited use in constructing an index for these areas.

British Columbia sablefish longline trap survey

This is an annual survey begun in 2003 and taking place in offshore waters in depths of 100 -750 fm (Wyeth et al. 2006). Gear consists of 1200 m strings of 25 traps. The design is stratified random, with three depth strata and five spatial strata. The sampling area was divided into 2 km^2 cells, with cells for sampling selected at random within each of the 15 strata.

Pacific halibut are counted, and at least collectively weighed, although it is unclear from reports if individual weights or lengths are recorded. The survey takes place in October and November, and therefore may be of limited use in creating a deep-water index for halibut calibrated with summer setline data.

References

Bradburn, M.J., Keller, A. A. and Horness, B. H. 2011. The 2003 to 2008 U.S. West Coast bottom trawl surveys of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, length, and age composition. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-114.

Clark, W. G., St-Pierre, G., and Brown, E. S. 1997. Estimates of halibut abundance from NMFS trawl surveys. Int. Pac. Halibut Comm. Tech. Rep. 37.

Hare, S. R., Webster, R. A., Leaman, B. M. and Dykstra, C. L. 2011. Discussion paper on IPHC setline survey expansion. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2010: 201-217.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-258.

Lauth, R. R. 2011. Results of the 2010 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-227.

Lochead, J.K. and Yamanaka, K.L. 2004. A new longline survey to index inshore rockfish (Sebastes spp.): summary report on the pilot survey conducted in Statistical Areas 12 and 13, August 17– September 6, 2003. Can. Tech. Rep. Fish. Aquat. Sci. 2567.

Lochead, J.K., and Yamanaka, K.L. 2007. Summary report for the inshore rockfish (Sebastes spp.) longline survey conducted in Statistical Areas 14 to 20, 28 and 29, from August 11 to September 6, 2005. Can. Tech. Rep. Fish. Aquat. Sci. 2690.

NMFS. 2007. A summary report from the NWFSC bottom trawl survey workshop held October 31 – November 2, 2006 in Seattle, Washington. Retrieved 26 November 2014.ftp://ftp.pcouncil.org/pub/GF_STAR1_2013_D-M_Assessments/Background/Final Summary Report from NWFSC Bottom Trawl Survey Workshop.pdf

Rutherford, K. L. 2013. British Columbia groundfish fisheries and their investigations in 2012, report prepared for the 4th Annual Meeting of the Technical Sub-Committee of the Canada-United States Groundfish Committee April 3 -May 1, 2013, NWAFSC, Seattle, WA.

Sadorus, L. L. and Palsson, W. A. 2012. Cruise report for the 2011 NOAA Fisheries Service Gulf of Alaska trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 601-603.

Sadorus, L. L., Palsson, W. A. and Ranta, A. M. 2013. Results from the Aleutian Islands NMFS bottom trawl survey in 2012. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2012: 601-608.

Sadorus, L. L. and Lauth, B. 2014. Cruise report for the 2013 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 457-462.

Soong, J., and Hamazaki, T. 2012. Analysis of red king crab data from the 2011 Alaska Department of Fish and Game trawl survey of Norton Sound. Alaska Department of Fish and Game, Fishery Data Series No. 12-06, Anchorage.

Stanley, R. D, Olsen, N., Workman, G., Cleary, J., and de la Mare, W. 2007. A review of the Queen Charlotte Sound groundfish bottom trawl survey (2003 - 2005). Can. Tech. Rep. Fish. Aquat. Sci. 2709.

Webster, R. A., Dykstra, C. L. and Hare, S. R. 2012. Area 2A survey expansion. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 331-340.

Webster, R. A. 2014. Construction of a density index for Area 4CDE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 261-288.

Webster, R. A. and Stewart, I. J. 2014. Apportionment and regulatory area harvest calculations. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 197-215.

Webster, R. A., Dykstra, C. L., Soderlund, E. and Kong, T. 2014. Range and depth expansion of the setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 451-456.

Wyeth, M. R, Kronlund, A. R., and Elfert, M. 2006. Summary of the 2004 British Columbia sablefish (*Anoplopoma fimbria*) research and assessment survey. Can. Tech. Rep. Fish. Aquat. Sci. 2660.

Table 1. Summary of current and future methods used for indexing halibut abundance by regulatory area.

Current application				
Method 1	Method 2	Method 3	Method 4	Method 5
Areas 2A-4CDE, 20-275 fm depths, current design	4CDE Bering Sea flats	2A Puget Sound 2A Northern CA north of 40°N	Northern Bering Sea	All areas > 275 fm All areas < 20 fm All gaps in 10 nmi grid 20-275 fa.
Potentially available for 2014				
Method 1	Method 2	Method 3	Method 4	Method 5
Areas 2A-4CDE, 20-275 fm depths, current design	4CDE Bering Sea flats 4A > 275 fm 2A Northern CA > 39 degrees 2A > 275 fm	2A Puget sound 2A Northern CA north of 39°N 4A <20 fm 4A gaps 20-275 fm 2A <20 fm	2C, 3A, 3B, 4D, 4B > 275 fm 2B < 20 fm (Dogfish bank) 2B > 275 fm and gaps 20-275 west of Haida Gwaii 4D, 4E Northern Bering Sea	2B, 2C, 3A, 3B, 4CDE < 20 fm 2B, 2C, 3A, 3B, 4B, 4CDE Edge gaps 20-275 fm
Proposed for future years				
Method 1	Method 2	Method 3	Method 4	Method 5
Areas 2A-4CDE, 20-275 fm depths, current design	4CDE Bering Sea flats – Additional calibration 2015	4D Edge gaps 20-275 fm, > 275 fm in 2016 4B gaps 20-275 fm, > 275, < 20 fm in 2017 2B and 2C gaps20-275 fm, > 275, < 20 fm in 2018 3A and 3B gaps 20-275 fm, > 275, < 20 fm in 2019	Northern Bering Sea	Nothing after 2019.

Table 2a. Numbers of stations of the survey expansion by regulatory area.

	2014		2015	2016	2017	2018		2019		
Depth stratum	**2A**	**4A**	**4CDE (EBS)**	**4CDE (Edge+ Islands)**	**4B**	**2B**	**2C**	**3A**	**3B**	**Total**
Deep (275-400 fm)	21	17	0	7	51	7	4	7	5	**119**
Shallow (10-20 fm)	12	2	0	0	4	19	6	21	10	**74**
Standard (20- 275 fm)	34	62	82	82	49	77	22	57	43	**508**
Expansion total	67	81	82	89	104	103	32	85	58	**701**
Standard grid	96	110	0	81	89	170	110	374	231	**1261**

Table 2b. Actual gross costs (excluding revenue) incurred in recently executed expansions

Area 2A

2011 expansion (6 skates/stn) compared with 2010 (8 skates/stn), corrected for number of skates

	2011	2010
Puget Sound	$2,168/stn (15 stn)	N/A
Washington	$1,371/stn (62 stn)	$1,017/stn (42 stn)
Oregon	$1,317/stn (60 stn)	$947/stn (42 stn)
Total vessel costs	$196,542	$82,488
Expansion delta	**$114,054**	

2014 expansion (7 sk/stn) compared with 2013 (6 sk/stn), corrected for number of skates

	2014	2013
Puget Sound	$2,500/stn (14 stn)	$N/A
Washington	$2,210/stn (62 stn)	$2,500/stn (49 stn)
Oregon	$2,079/stn (60 stn)	$2,308/stn (47 stn)
Total vessel costs	$296,760	$230,976
Expansion delta	**$65,784**	

Area 4A

2014 expansion (7 sk/stn)

	2014	2013
4A Edge	$2,391/stn (93 stn)	$2,702/stn (56 stn)
Unalaska	$2,410/stn (112 stn)	$2,254/stn (65 stn)
Total costs	$492,283	$297,822
Expansion delta	**$194,461**	

Table 3. Summary of other agency surveys and their usefulness to the IPHC. Numbered codes give a general rank of the quality of the survey data for IPHC use, with 1 most useful, and 4 least useful.

1 Annual survey with wide coverage of area not covered by IPHC setline survey

2 Biennial survey with wide coverage of area not covered by IPHC setline survey

3 Biennial or triennial survey with limited coverage

4 Surveys of limited use

Rank	Survey	Current frequency	Complementary coverage	Data currently used?	Potential use for IPHC	Limitations
1	Bering Sea bottom trawl	Annual	4CDE < 75 fm	Yes	Calibrate with setline data to create eastern Bering Sea time series	Only covers southern Bering Sea except for 2010
1	Area 2A bottom trawl	Annual	2A >275 fm, Northern CA >30 fm	No	Calibrate with setline data to create deep water time series; index unsurveyed parts of Northern CA	
1	Alaska sablefish longline survey	Annual	2C-4A, 4D Edge, eastern 4B, > 275 fm	No	Calibrate with setline data to create deep water time series	No coverage of inside waters in 2C, western 4B; no length data
2	GOA bottom trawl	Biennial	2C-3B > 275 fm	No	Calibrate with setline data to create deep water time series;	No coverage of inside waters in 2C
3	Area 2B bottom trawl	Partial annual coverage	West Coast Haida Gwaii >275 fm, Hecate Strait <20 fm	No	Calibrate with setline data to create deep and shallow water time series	Only partial biennual coverage of deep water
3	Bering Sea slope survey	Generally biennial	4D Edge > 275 fm, 4D Edge north of 60°N	No	Calibrate with setline data to create deep water time series; index northern 4D Edge	
3	North Sound trawl survey	Generally triennial	4E Norton Sound	Yes	Combine with other Bering Sea data to create northern Bering Sea time series	Coverage limited to only part of northern Bering Sea
4	Area 2B inshore rockfish longline surveys	Partial annual coverage	2B 10-20 fm outside waters; some coverage inside Strait of Georgia in 20-55 fm	No	Calibrate with setline data to create shallow water index; partial index of Strait of Georgia	Focus on rockfish habitat; limited complementary coverage
4	Area 2B sablefish longline trap	Annual	2B > 275 fm	No	Calibrate with setline data to create deep water time series	Conducted outside of summer months
4	Aleutian Islands bottom trawl	Biennial	Possibly some gaps in 4A and 4B	No	Some potential improvement in Area 4A, 4B 20-275 index	Offers little complementary coverage

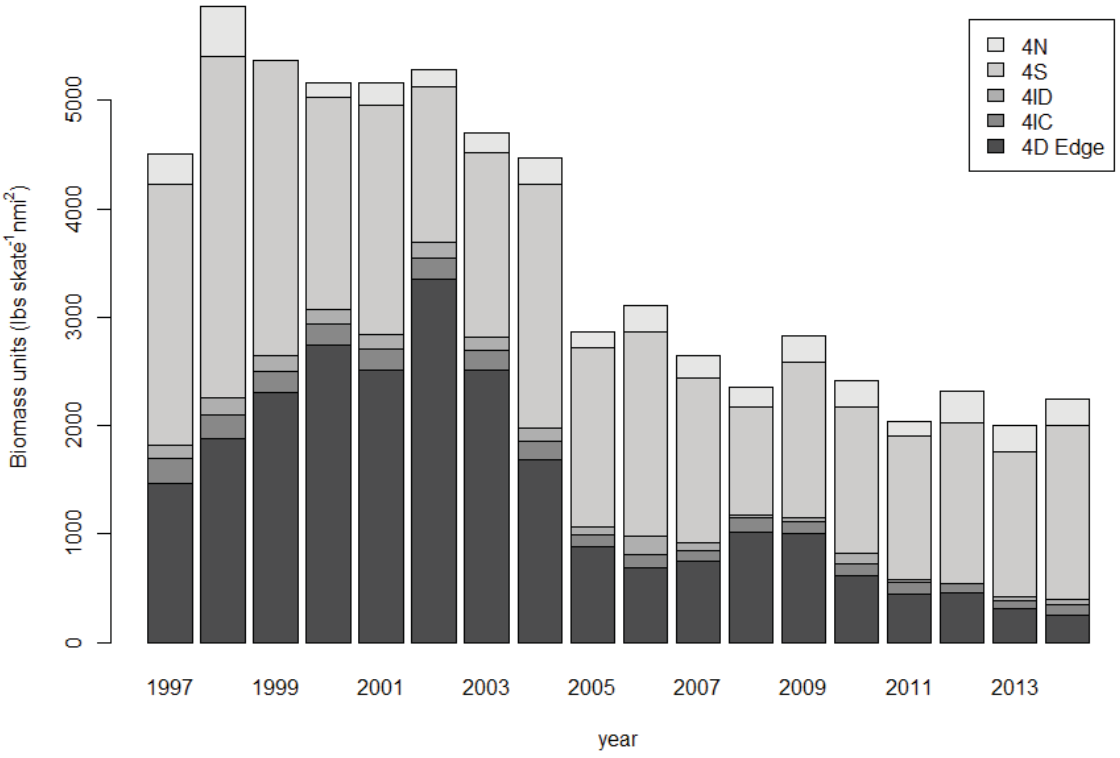


Figure 1. Area 4CDE O32 biomass index (O32 WPUE multiplied by bottom area) for 1997-2014 showing the contributions from the five component areas used for data compilation. Areas 4IC and 4ID are the waters surrounding the Pribilof and St Matthew Islands, while Area 4S is the southern Bering Sea flats covered by the 2006 EBS survey, and Area 4N is the northern Bering Sea.

Setline survey expansions in 2014 and use of sablefish longline survey data for a deep-water density index

Raymond A. Webster, Claude L. Dykstra, Ed Henry, Eric Soderlund, and Tom Kong

Abstract

The first year of the IPHC's planned six-year setline survey expansion was completed in 2014. In Area 2A, the survey was further expanded southward to 39° N in northern California, while the Salish Sea and deep and shallow expansion stations previously fished in a 2011 pilot study, were repeated with the addition of deep and shallow stations in California. In Area 4A, the survey grid was expanded into deep and shallow waters, and into gaps in the standard depth range of 20-275 fathoms. We present the results of these expansions, along with a description of how data from the annual NMFS sablefish longline survey are used to create a deep-water index in Areas 2B, 2C, 3A, 3B, and the 4D Edge.

Introduction

IPHC staff had previously proposed a full expansion of the setline survey taking place from 2014-2018 (Webster et al. 2014b) that would include expansion into deep (275-400 fm) and shallow (10-20 fm) waters, and into gaps in the 20-275 fm waters covered by the standard 10 nmi station grid. This has since been revised to an expansion over six years, ending in 2019 (Webster et al. 2015). The first year of the expansion proposal was carried out in 2014. In Area 2A, the expansion included a repeat of the Salish Sea pilot expansion of 2011 (Webster et al. 2012), an expansion of the California grid to 39° N (when it appeared the 2013 survey to 40° N had not found the southern limit of significant halibut densities), and the expansion of the 10 nmi grid into deep and shallow waters (covering stations fished in Oregon and Washington in 2011, and new stations in California). Area 4A's expansion also included new deep and shallow stations, and the filling of gaps in the standard grid. One large gap was on the Area 4A Edge, where the standard survey had previously gone no shallower than 75 fathoms, which was inconsistent with the depth range around the Aleutian Islands of 20-275 fathoms. Other significant gaps were in the west of the Aleutian Island region of Area 4A, and the region around Unimak Pass.

The primary purpose of the survey expansion is to reduce the potential for bias in the indices of halibut density and abundance. With the expansion being carried out over a six-year time frame due to budget constraints, direct estimates of weight per unit effort (WPUE) or numbers per unit effort (NPUE) in deep and shallow waters will not be available in all areas until 2019. One approach to improving the indices in waters not yet surveyed by the IPHC is to perform calibrations with other sources of data, as is currently done using the National Marine Fisheries Service (NMFS) trawl survey in the Bering Sea. Another survey, the NMFS sablefish longline survey, has generally good coverage of deep waters in Areas 2C, 3A, 3B, and the Area 4D Edge (see Webster et al. 2015), and in this report we describe how data from this survey is used to create a deep-water halibut index for those regulatory areas.

Methods

Survey expansion in Areas 2A and 4A

As described in Webster et al. (2014b), potential new station locations in California and Area 4A were determined by expanding the current setline survey grid outwards (Figs. 1-3). Depths of these station locations were estimated by interpolating values from the global SRTM30 bathymetry database (Becker et al. 2009), and those stations with estimated depths within 10-400 fathoms were included in the 2014 survey. In Area 2A north of California, expansion station locations were previously determined for the 2011 pilot expansion, and these stations were again fished in 2014. In Area 4A, two stations were initially classified as shallow, or "SE" stations, but both were changed to standard grid ("SG", for 20-275 fm stations) once fished, based on the depth soundings recorded by the fishing vessel. This meant that Area 4A had no shallow stations in the expansion. Two proposed deep expansion ("DE") stations in Area 4A were found to be in waters deeper than 400 fm, and although one was fished, these stations are not included in any analyses. Two expansion SG stations in Area 4A were also excluded from the analyses, one due to being too deep (>400 fm) and one that could not be fished due to currents, weather conditions and proximity to a sea lion rookery. During the review phase for expansion stations there was some concern regarding the ability of survey vessels to successfully occupy and fish high-current stations and deep stations. Some creative scheduling of fishing during optimal tide windows, and persistence by experienced skippers and crew, yielded a much higher success rate than was originally anticipated. Out of 81 original expansion stations in Area 4A, only three were not fishable due to depth, one was not attempted, and five were ineffective (mostly due to gear loss in high currents or excessive soak time due to tide interference).

Using sablefish survey data to construct a deep water density index

The NMFS sablefish survey is conducted annually in the Gulf of Alaska, and biennially alternating in the Bering Sea and around the Aleutian Islands. It covers the upper continental slope and selected gullies of the eastern Bering Sea, Aleutian Islands region, and Gulf of Alaska, sampling depths from 150-1000 m (82-547 fm) during the summer months using a fixed-station design (Sigler and Lunsford, Unpub[1]). The sablefish survey records counts of halibut by skate on each station, but size and other biological information is not generally collected. Our primary interest in this survey comes from its coverage of deeper waters from Areas 2C to the Area 4D Edge. Although this survey has some limitations (most importantly, significant gaps in geographical coverage in Areas 4A and 4B), IPHC staff has noted it has high potential for calibration with the IPHC survey to provide an index for deep waters when these are unsurveyed by the IPHC (Webster et al. 2015).

A straightforward approach was applied when using the sablefish survey to index density in deep waters. First, for each area, sablefish NPUE, (i.e., numbers of halibut per 45-hook skate) indices were computed for both deep (275-400 fm) and standard depth (0-275 fathom) waters by averaging the NPUE across all skates in each of the depth ranges. This was converted to a WPUE index for deep water by multiplying by the 20-275 fm setline survey index for each area. This was done for each year that the sablefish survey took place in an area. Thus, for area i and year j, the deep water WPUE index was estimated by

[1] Survey protocol for the Alaska sablefish longline survey. http://www.afsc.noaa.gov/ABL/MESA/pdf/LSprotocols.pdf. Retrieved November 2014.

$$WPUE_{ij}^{DE} = \frac{NPUE_{ij}^{DE}}{NPUE_{ij}^{SG}} WPUE_{ij}^{SG}$$

where DE represents the water deeper than 275 fathoms, and SG represents the region covered by shallower waters (and represented by the standard grid of stations in the IPHC setline survey from 20-275 fathoms). Here it is assumed that the sablefish longline survey skates provided a representative sample of all habitat, and that the ratio of deep to standard sablefish survey NPUEs equals the ratio of deep to standard IPHC setline survey WPUEs. The index for an entire regulatory area was then calculated by weighting the component WPUE values by the number of proposed stations in a full expansion (Table 2a in Webster et al. 2015, Table 2a):

$$WPUE_{ij} = \frac{n^{SE} + n^{SG}}{n} WPUE_{ij}^{SG} + \frac{n^{DE}}{n} WPUE_{ij}^{DE}$$

where $n = n^{SE} + n^{SG} + n^{DE}$. Here SE represents any shallow stations (10-20 fm) in the proposed future expansions, which for now are assumed to have the same density as current standard depth stations. Weighting by proposed number of stations in an expanded survey grid (rather than, for example, by bottom area) ensures the weighting is consistent with what will be used when the proposed expansions are undertaken.

In Areas 4A and 4B, the coverage of the sablefish survey had significant gaps and was insufficient to provide reliable density indices: in Area 4A, there was almost no coverage of the far western Aleutian Island region where the IPHC 2014 survey shows very high densities relative to elsewhere (see below), while the coverage in Area 4B was limited to the eastern part of that area, and was therefore unlikely to be representative of the entire regulatory area. Instead, for Area 4A the standard adjustment factor approach was used based on data from this year's expansion to correct for lack of coverage in previous years, and in Area 4B the setline survey mean WPUE continues to be applied to all depths. In the absence of an extensive deep water survey in Area 2B, the estimated Area 2C index for 275-400 fm was also used as the Area 2B deep water index. For years with no sablefish survey in the Area 4D Edge, the NPUE ratio of deep to standard water is estimated using linear interpolation. The 2013 estimate was used for 2014, as there was no Area 4D sablefish survey this year.

Survey results in Areas 2A and 4A

Of note in this year's Area 2A expansion was the absence of any halibut in the catch south of 40° N (Fig. 4). WPUE was also zero in all deep stations. Catch was down in the part of California also surveyed in 2013, with a 2014 mean WPUE of 15.8 lbs/skate on the 15 stations surveyed in both years, compared to 22.1 in 2013 (Webster et al. 2014a). By contrast, mean WPUE was much higher in the Area 2A part of the Salish Sea (Puget Sound survey region, Fig. 5) this year than in 2011, with an overall O32 mean of 22.5 lbs/skate in 2014 (Table 1) compared to 13.9 lbs/skate in 2011.

In Area 4A, O32 WPUE was higher on average at both the new SG and DE stations than at existing stations (Table 2). The survey region of highest density in 2014 (Four Mountains covering

the western islands, fished as separate West and East regions) previously had the poorest coverage (Fig. 6), while the Unimak region (again fished as Unimak West and Unimak East) around the eastern part of the islands and Unimak Pass had relatively good coverage, but quite low mean WPUE. Only on the Edge, where new stations filled a substantial gap in coverage southwest of the 4A/Closed Area boundary, was the mean of expansion stations lower than the mean of existing stations. Combined, the new SG stations have a mean WPUE of 18 lbs/skate higher than the existing SG stations, while DE stations also have a higher mean than existing stations. The deep water station data confirms the existence of high densities of halibut in 275-400 fm in this area, implied previously by commercial catch data (Fig. 7), which was the original motivation for considering the setline survey expansion.

Calculation of adjustment factors

Setline survey mean WPUE for a regulatory area is considered to apply to the entire area from 0 to 400 fm in depth, although some parts of that area may have limited or no survey coverage. When an expansion of the survey is made into previously unsurveyed parts of a regulatory area, the new information can be used to adjust the mean WPUE from years in which those parts were not surveyed. For example, if WPUE in the newly surveyed region was lower than average for the entire area, there would be a downward adjustment of WPUE in other years to account for the survey estimating lower density in that region. The adjustment factor is calculated as the ratio of the survey WPUE calculated from all stations to that calculated by excluding stations from the area of expansion. When the area of expansion is surveyed in multiple years, the ratio is calculated for each year and the adjustment factor is then the average of those ratios. See Webster and Hare (2012) for an example.

In Area 2A, the approach described above has been used for both the 2011 expansion into the Salish Sea, and the expansion that filled in gaps in the coastal survey grid begun in 2011 and continued through 2014. Webster et al. (2014a) describe how a stratified estimator is constructed to compute adjustment factors when different regions have expansions done in different years (i.e., Salish Sea in 2011 and 2014, California 40-42°N in 2013 and 2014, California 39-40°N in 2014). The most significant change from previous years is that adjustment factors and WPUE indices now make use of all survey data, including data from deep and shallow waters. Adjustment factors for Area 2A from 2011-2014 are shown in Table 3.

The adjustment factor for Area 4A can be easily calculated from the values in Table 3. The mean WPUE of existing stations in 2014 was 55.6, whereas total WPUE of all stations in 2014 was 62.2, leading to a positive adjustment factor of 1.118; that is, values of mean O32 WPUE will be adjusted upwards by 11.8% to account for the expected higher density in regions not surveyed in years in which expansion stations are not fished..

As explained in Webster and Stewart (2015), separate adjustment factors have also been calculated for other indices of interest: total WPUE, O32 NPUE and total NPUE.

Results of sablefish calibration

For Areas 2C, 3A and 3B, the sablefish longline survey captured very few halibut in deep waters. For the period 1996-2014, the ratio of NPUE in 275-400 fathoms to NPUE in 20-275 fathoms ranged from 0-0.021 in Area 2C, 0-0.014 in Area 3A and 0-0.034 in Area 3B, with values consistently less than 0.01 in all three areas in recent years (2008-2014). In the Area 4D Edge,

ratios have typically been much greater, ranging from 0.026 in 1997 to 0.67 in 2004. The most recent survey in 2013 gave a ratio of 0.058, far lower than in other recent surveys (0.35 in 2009 and 0.37 in 2011). Because these ratios are so close to zero in recent years, the WPUE index for each regulatory area created from them (using the method described previously) is almost the same as the 20-275 fm index scaled by the proportion of proposed stations in 0-275 fm depths.

The deep water to standard depth NPUE ratios in Area 4B ranged from 0.009 to 0.059. These imply densities that are far lower than in the part of Area 4A immediately adjacent to Area 4B (Fig. 6), and those implied by the relatively high proportion of commercial catch taken in deeper waters in this area in recent years compared to areas to the east (Fig. 3).

Discussion

The repeat of the 2011 and 2013 expansion stations in Area 2A show that indices of density can vary substantially over time on small spatial scales: WPUE in the Salish Sea in 2014 was almost double the 2011 value, while in northern California there was a marked decline from last year. With relatively few stations in each of these survey regions, we would expect a high degree of variability just by chance. Each of these expansion regions also represents a fairly small proportion of the overall bottom area of Area 2A compared to the Oregon and Washington regions, and so any changes in density indices in these areas have at most a modest influence on the total change for Area 2A, and negligible effect on the index for the entire coast (all regulatory areas combined). Nevertheless, the high degree of variability observed here suggests it may be worth re-surveying these regions on an occasional basis to ensure that the index for Area 2A is capturing the changes in spatial distribution across the regulatory area. Recently, staff received data from the NMFS trawl survey in Area 2A, which may be useful for constructing a density index in deep waters and waters off the California coast to complement the standard grid, while also mitigating the need to frequently re-survey those waters.

The further expansion southwards in Area 2A also required us to increase our estimate of the Area 2A bottom area, used for coastwide data compilation and apportionment purposes, to include the area between 39°N and 40°N. The estimate of bottom area used in 2014 is 17 507 nmi^2, which now covers the area from 39°N to the Canadian border. This is an increase of 5% over the previous bottom area estimate for the area north of 40°N. However, with zero catch from 39°N to 40°N, this change will have no noticeable effect on apportionment estimates for Area 2A. In future years, we also hope to use the NMFS trawl data to index halibut density and monitor changes in spatial distribution south of 39°N.

Now that direct observations from IPHC surveys in Areas 2A and 4A are being used in computing halibut density indices, it is no longer consistent to continue assuming that indices calculated from 20-275 fm survey data in other areas could be applied to 275-400 fm. A simple approach was used to create a deep water index in Areas 2B, 2C, 3A, 3B, and the Area 4D Edge using data from the annual sablefish survey. It may be possible to improve the index by modelling the relationship between NPUE on that survey and depth, and calibrating that relationship with the relationship between IPHC survey WPUE and depth. However, given that for all areas except the Area 4D Edge, NPUE was close to zero in deep water, and that in all areas including the Area 4D Edge, deep habitat is a small fraction of overall habitat (the number of proposed deep expansion stations is 2.5-5% of all stations, Webster et al. 2015), any improvement in the calibration is likely to have a negligible effect on the overall WPUE for these areas.

As already noted, the low Area 4B sablefish survey index was not consistent with other sources of data (western Area 4A survey, commercial catch records), and for this reason, the 20-275 fm survey index values is still applied to all depths in Area 4B. In doing this, it is essentially assumed that Area 4B is more like Area 4A in having high densities in deep water, rather than like areas to the east. This seems the most reasonable assumption to make until an Area 4B expansion can be carried out, particularly given that Area 4B has the greatest proportion of deep water habitat of all areas and application of the sablefish index to this area would have a large negative effect on its density indices. Applying the low Area 2C index to Area 2B is of less concern: that area has relatively little deep water habitat, and data from both adjacent areas (the direct IPHC survey observations in Area 2A and the sablefish data in Area 2C) yield deep water density indices near zero.

As length data are not routinely collected on the sablefish survey, it is not possible to calibrate the sablefish survey's length distribution to the IPHC setline survey length distribution, as has been done for the NMFS trawl survey in the eastern Bering Sea in 2006. If the relationships between selectivity and length do differ between the two surveys, and the underlying halibut size distribution varies by depth, the approach used for indexing halibut density in deep waters may produce biased estimators. Some length measurements were taken in 2014 of halibut captured on sablefish stations, primarily in Area 4B. It is not clear from a preliminary comparison of these data with the data from the 2014 IPHC setline survey in eastern Area 4B whether the length distributions of the two surveys differ or not. However, the comparison is complicated by the fact that lengths of most fish on the sablefish survey were estimated, and these had a somewhat different distribution than a sample of directly measured fish from the same survey. More data from a greater geographical range are required to help answer questions regarding differences in length distributions and the potential for bias when using the sablefish survey data.

References

Becker, J. J., Sandwell, D. T., Smith, W. H. F., Braud, J., Binder, B., Depner, J., Fabre, D., Factor, J., Ingalls, S., Kim, S-H., Ladner, R., Marks, K., Nelson, S., Pharaoh, A., Trimmer, R., Von Rosenberg, J., Wallace, G., Weatherall, P. 2009. Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, Marine Geodesy, 32:4, 355-371.

Sigler, M. F. and Lunsford, C. R. Unpublished report. Survey protocol for the Alaska sablefish longline survey. http://www.afsc.noaa.gov/ABL/MESA/pdf/LSprotocols.pdf

Webster, R. A. and Hare, S. R. 2012. Examination of the high Area 2B survey WPUE values of 1995-1997. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 255-265.

Webster, R. A., Dykstra, C. L., and Hare, S. R. 2012. Area 2A survey expansion. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2011: 331-340.

Webster, R. A., Dykstra, C. L. and Kong, T. 2014a. Southern expansion of the Area 2A setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 415-419.

Webster, R. A., Dykstra, C. L., Soderlund, E., and Kong, T. 2014b. Depth and range expansion of the setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 451-456.

Webster, R. A. and Stewart, I. J. 2015. Setline survey-based apportionment estimates. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 181-194.

Webster, R. A., Stewart, I. J., Leaman, B. M., Sadorus, L. L., Henry, E., and Dykstra, C. L. 2015. Setline survey expansion and complementary data sources. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 587-602.

Table 1. Mean WPUE of O32 Pacific halibut (lbs/skate) by setline survey region and depth in Area 2A in 2014. N represents the number of stations effectively fished in 2014.

	Northern CA		OR		WA		Puget Sound		Total	
Depth	WPUE	N	WPUE	N	WPUE	N	WPUE	N	WPUE	N
SG	10.8	22	28.0	47	17.2	49	26.6	11	20.8	129
SE	10.6	1	7.6	3	26.1	6	0.0	2	15.8	12
DE	0.0	4	0.0	10	0.0	7	-	0	0.0	21
Total	9.2	27	22.3	60	16.1	62	22.5	13	17.8	162

Table 2. Mean WPUE of O32 Pacific halibut (lbs/skate) by setline survey region and depth in Area 4A in 2014. N represents the number of stations effectively fished in 2014.

	Four Mtns		Unimak		4A Edge		Total	
Depth	WPUE	N	WPUE	N	WPUE	N	WPUE	N
SG (old)	93.3	21	27.4	45	66.5	44	55.6	110
SG (new)	135.9	16	59.4	14	46.1	29	73.6	59
DE	110.9	7	-	0	13.2	6	65.8	13
Total	111.6	44	35.0	59	55.0	79	62.2	182

Table 3. Revision of adjustment factors to account for Area 2A expansions in years without data from each expanded region, by survey year.

Expanded region	2011	2012	2013	2014	Mean
OR/WA Coast	1.055	1.100	0.985	0.987	1.032
Puget Sound, DE+SE	0.799			0.867	0.833
N CA (40-42°N)			0.994	0.981	0.988
N CA (39-40°N), DE+SE				0.929	0.929

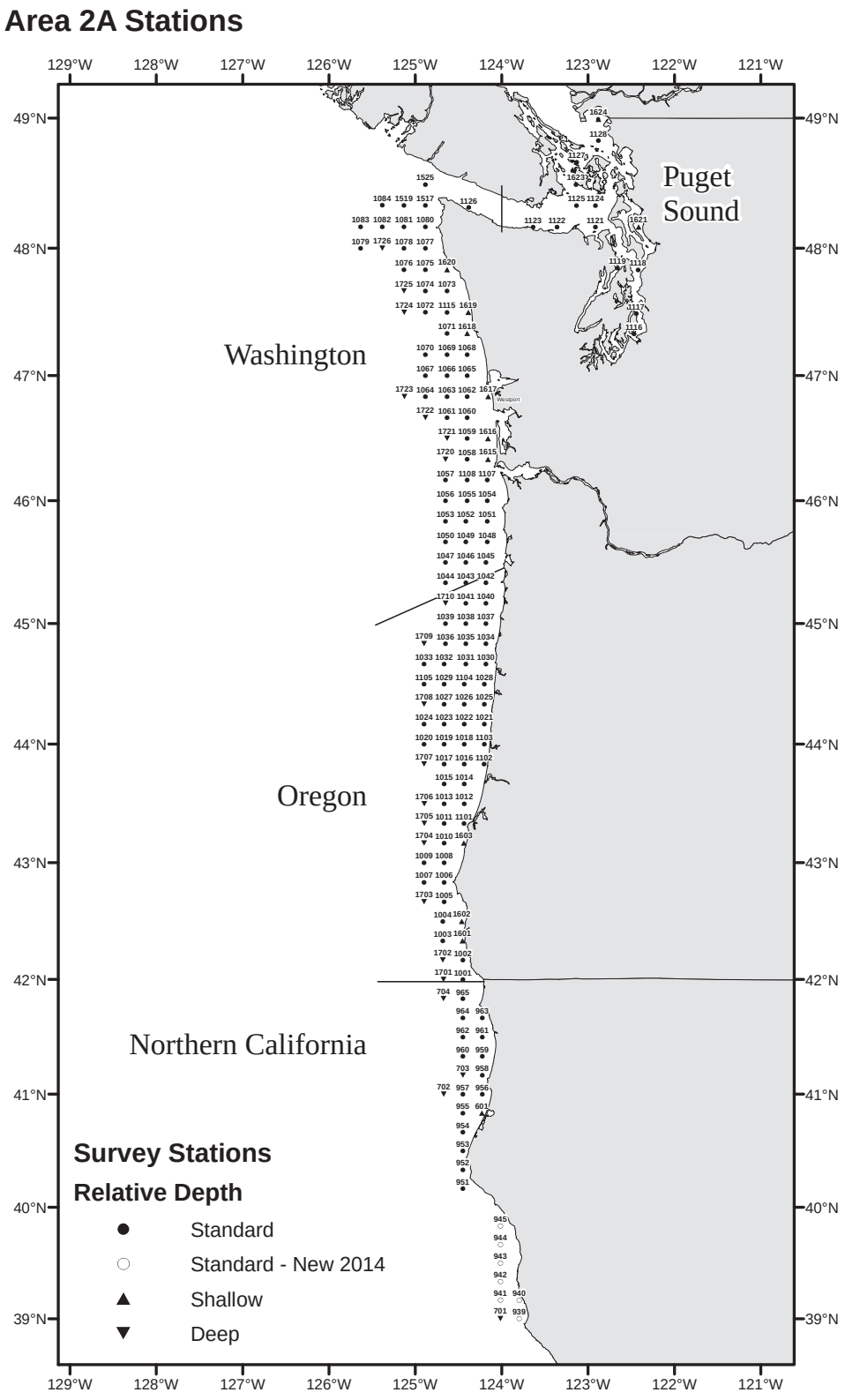


Figure 1. Proposed survey design in Area 2A in 2014. Setline survey regions referred to in the text and tables are also shown.

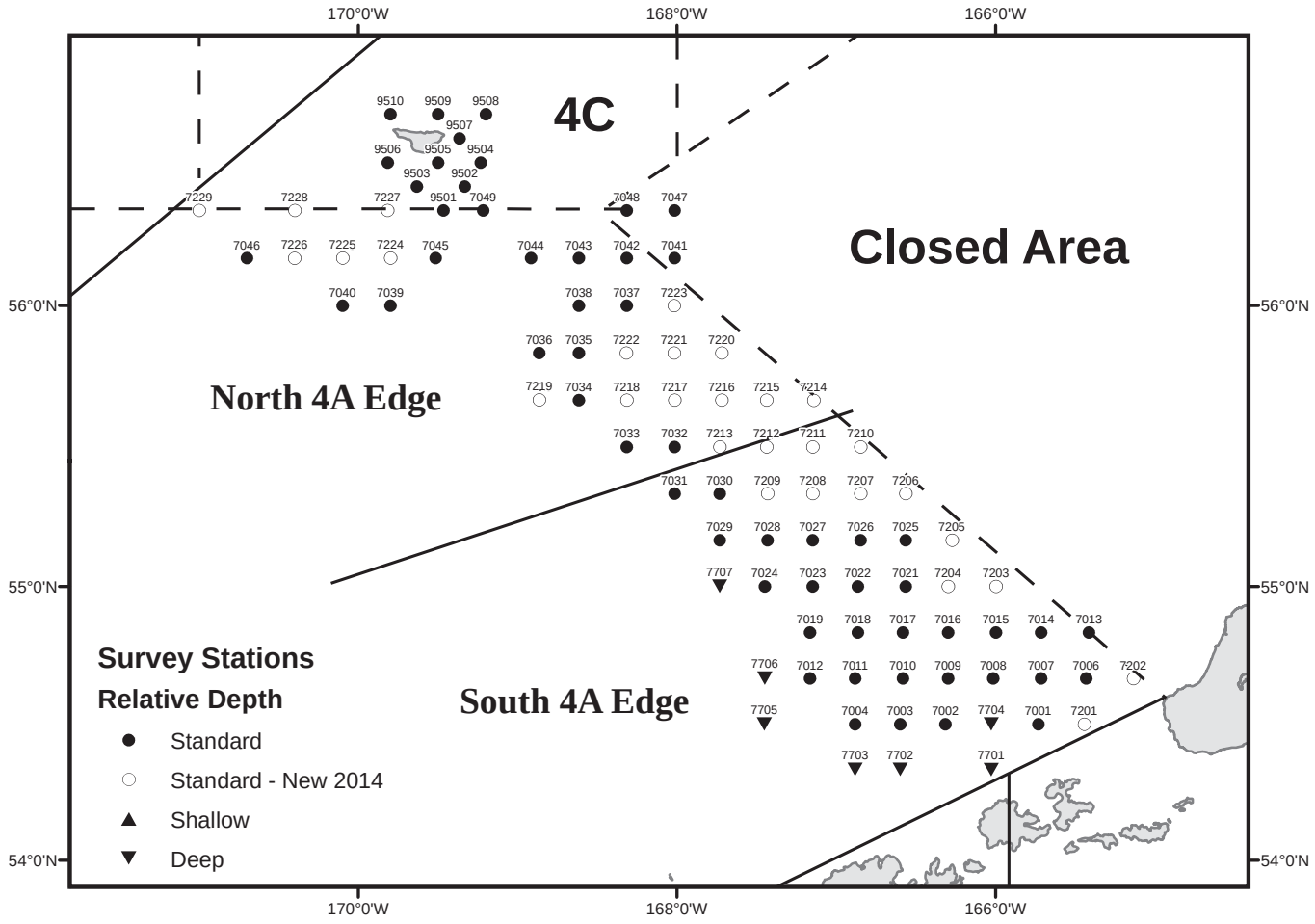


Figure 2. Proposed survey design on the Area 4A Edge in 2014. Setline survey regions referred to in the text and tables are also shown.

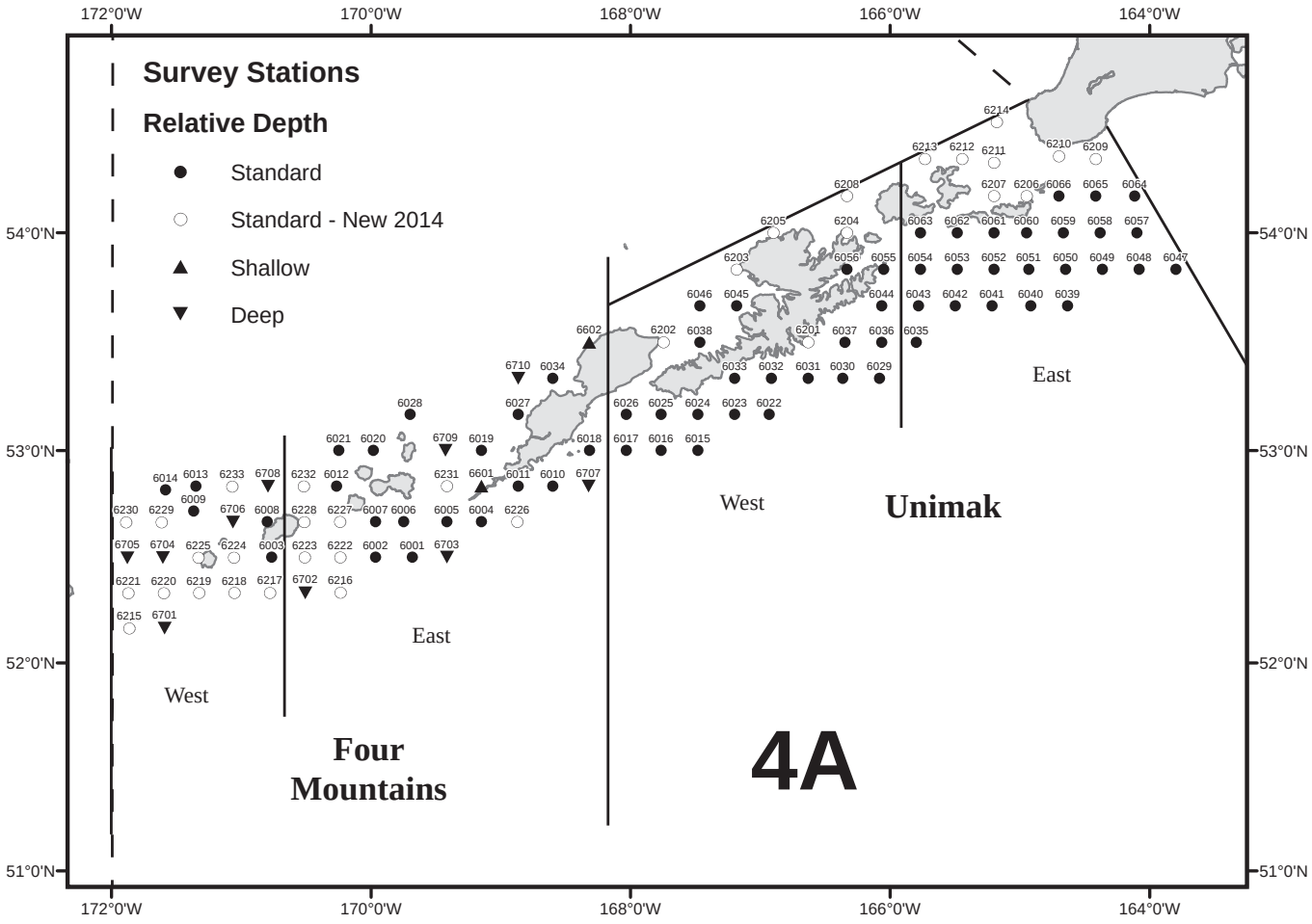


Figure 3. Proposed survey design around the Area 4A Islands in 2014. Setline survey regions referred to in the text and tables are also shown.

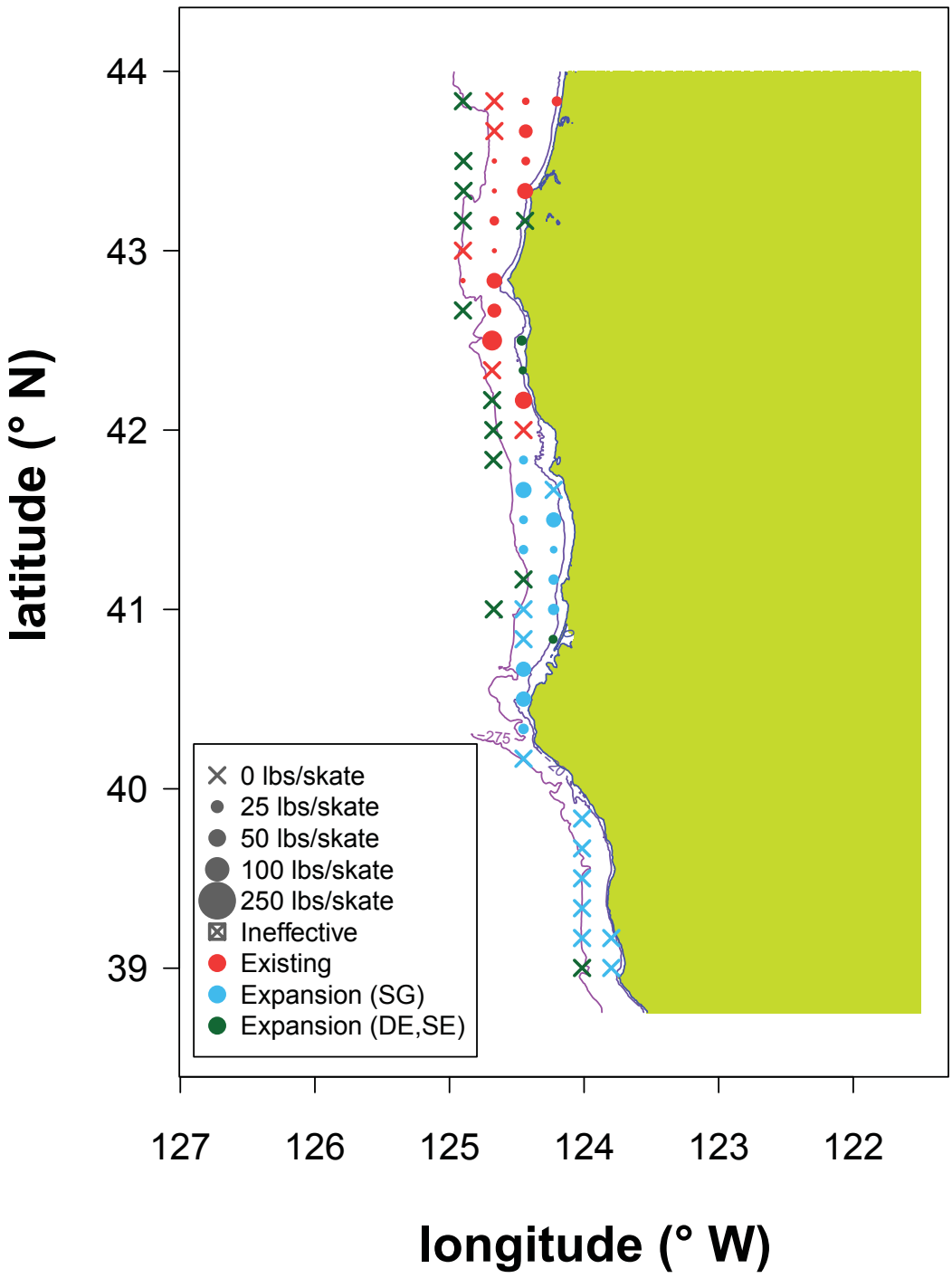


Figure 4. Map of O32 Pacific halibut WPUE by station in southern Area 2A in 2014. Image best viewed electronically in colour.

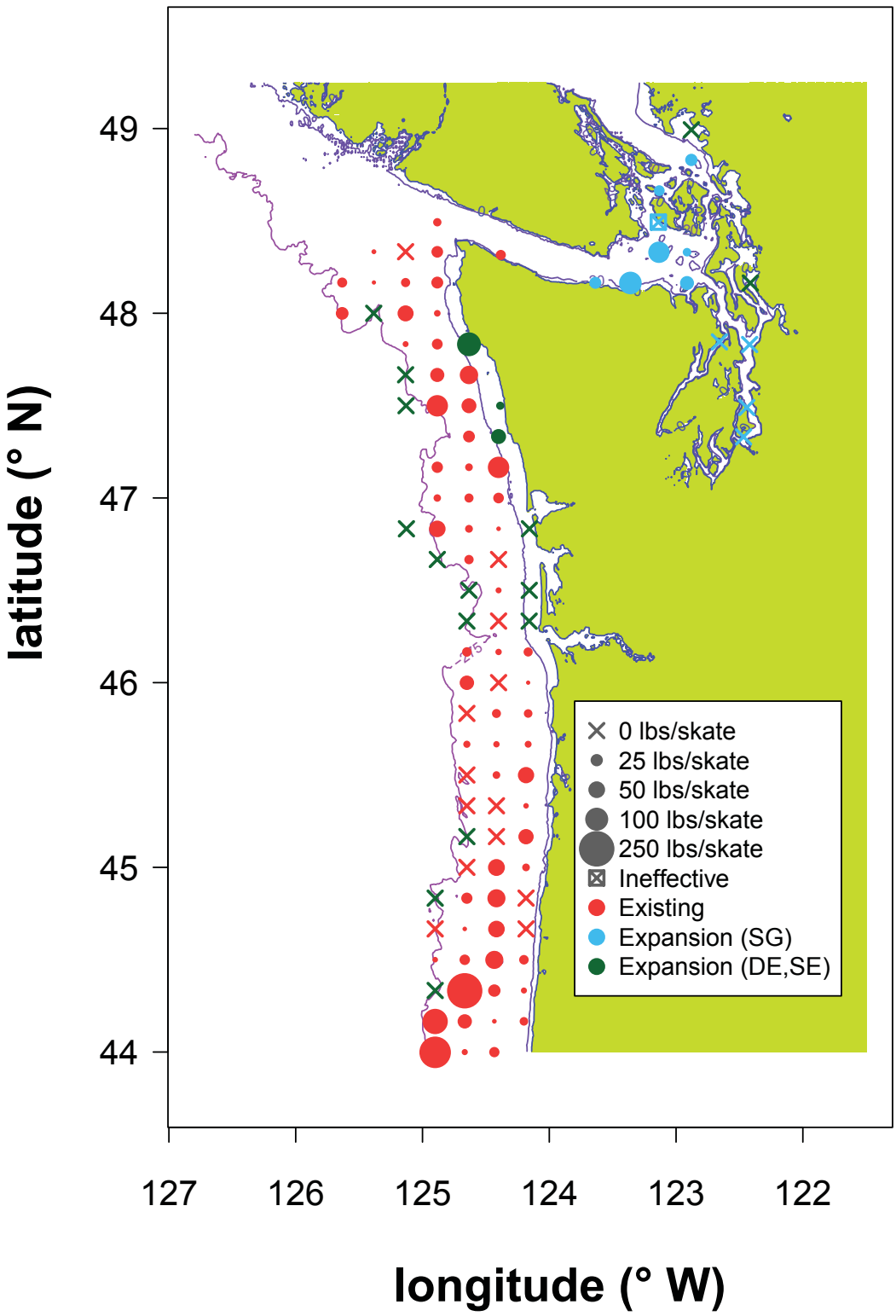


Figure 5. Map of O32 Pacific halibut WPUE by station in northern Area 2A in 2014. Image best viewed electronically in colour.

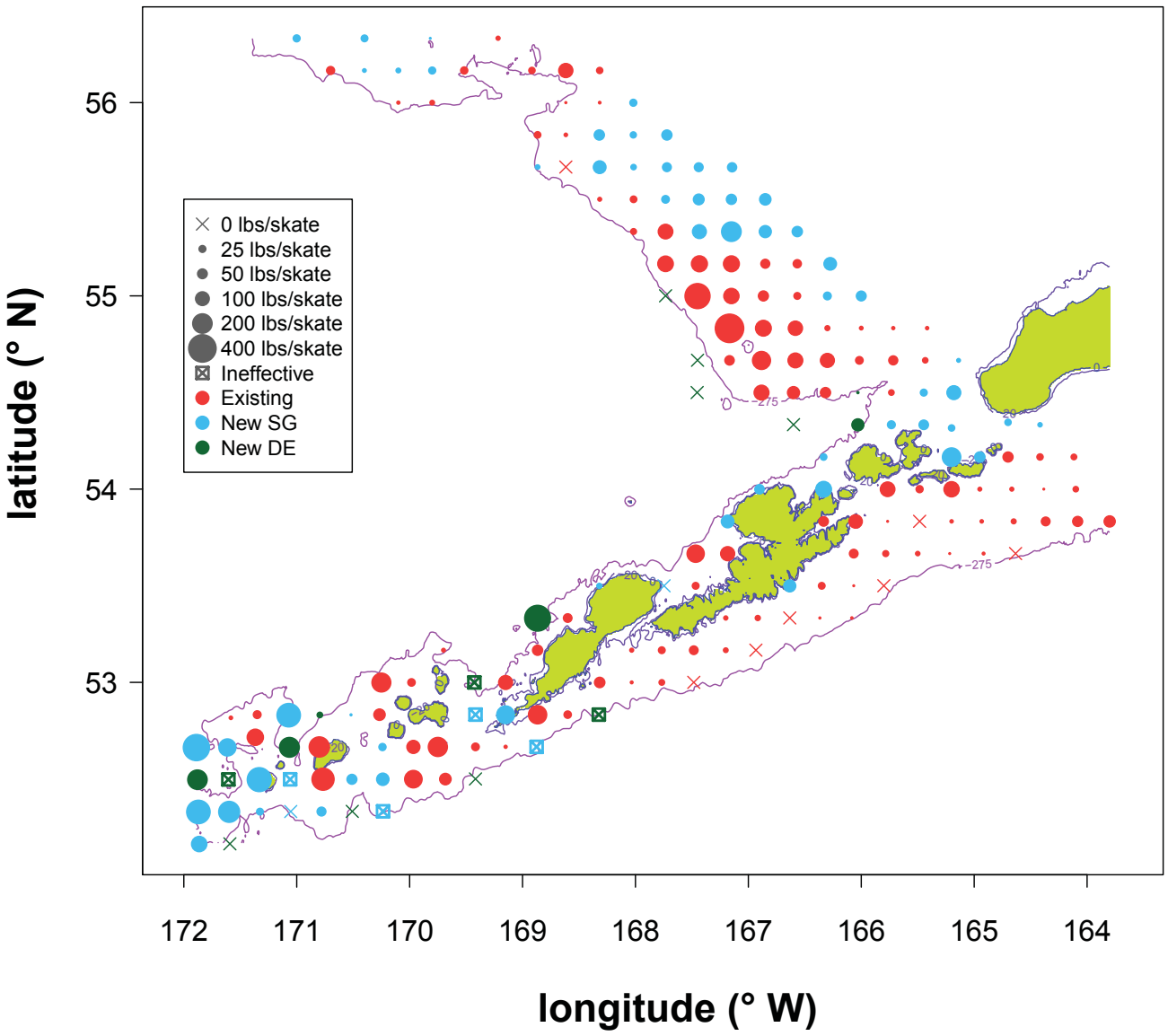


Figure 6. Map of O32 Pacific halibut WPUE by station in Area 4A in 2014. Image best viewed electronically in colour.

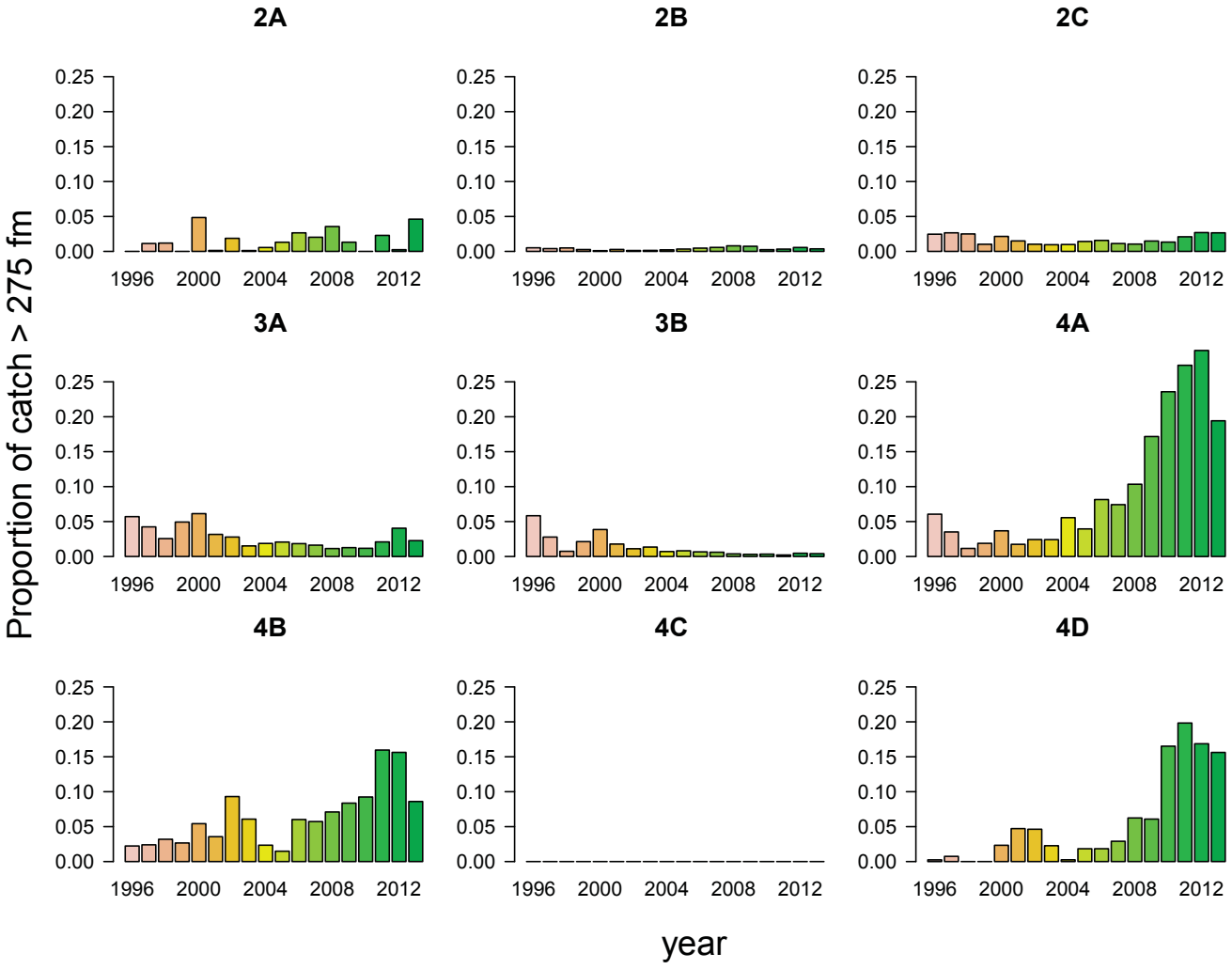


Figure 7. Proportion of commercial catch taken at depths greater than 275 fm by area and year, as estimated from logbook data.

Cruise report for the 2014 NMFS Bering Sea trawl survey

Lauri L. Sadorus
International Pacific Halibut Commission

Robert Lauth
National Marine Fisheries Service

Abstract

The International Pacific Halibut Commission (IPHC) has participated in the National Marine Fisheries Service annual Bering Sea shelf trawl survey since 1998. The 2014 standard survey took place from June 3 to August 4 and included two vessels. An IPHC field biologist was deployed on the *F/V Vesteraalen* for the first trip then on the *F/V Alaska Knight* for trips two and three. The IPHC biologist sampled Pacific halibut for length, otoliths, gender, maturity, and prior hooking injuries, resulting in 1,053 samples. In addition, 133 samples were collected as part of the clean otolith archive collection.

Introduction

In 2014, the International Pacific Halibut Commission (IPHC) participated in the National Marine Fisheries Service (NMFS) annual Bering Sea shelf trawl survey for the 17th straight year. The survey is a continuation of a time series started in 1975, and continued annually since 1979. Data collected on the trawl survey along with IPHC setline survey data and commercial catch information are used to create abundance estimates and to map year-class strengths.

Two chartered fishing vessels, *F/V Vesteraalen* and *F/V Alaska Knight*, were each staffed by six scientific crew, who carried out objectives related to stock assessment and year-class strength estimation for numerous species. An IPHC biologist was deployed on the first trip of the *F/V Vesteraalen* and on the second and third trips of the *Alaska Knight* to sample the halibut caught and to help NMFS personnel achieve their survey goals.

Objectives

The main objectives for the IPHC biologist were:

- Sample 100% of the halibut caught on all standard groundfish tows for fork length, sex, maturity, otoliths, and prior-hooking injuries;
- Collect otoliths for the clean otolith archive (COAC; Tobin and Forsberg 2015).

The primary NMFS objective was to continue the annual series of crab and groundfish assessment surveys for the eastern Bering Sea to provide information to the following groups:

- to the North Pacific Fishery Management Council for understanding the distribution, abundance, and biological condition of important groundfish and crab resources;
- to the U.S. fishing industry for catch-per-unit effort and size composition of commercially-important groundfish species; and
- to stock assessment scientists to support ongoing studies on the biology, behavior, and dynamics of key ecosystem components.

Survey area, vessels, and itinerary

The standard survey spanned a geographical region on the eastern Bering Sea (EBS) continental shelf from inner Bristol Bay to the shelf break, and from Unimak Pass to north of St. Matthew Island. Following several days of set-up and equipment testing, the *F/V Vesteraalen* left Dutch Harbor, AK on June 6 and conducted the first survey tow on June 8. Both survey vessels concluded trip one and returned to Dutch Harbor on June 24 for a crew change. The IPHC biologist boarded the *F/V Alaska Knight* which left town on June 26 and conducted the first tow of trip two on June 27. The last groundfish survey tow was conducted on July 31. The *Alaska Knight* then conducted several days of experimental tows before returning to Dutch Harbor and concluding the charter on August 4.

Survey design

The standard survey consisted of 376 stations positioned on a 20x20 nmi grid on the continental shelf in the EBS, in depths ranging from 30-200 m. The station is fished in the middle of each grid block. In areas surrounding St. Matthew and the Pribilof islands, grid block corners were also sampled to better assess blue king crab (*Paralithodes platypus*) concentrations (Fig. 1). Survey sampling began in Bristol Bay and progressed westward toward the EBS outer shelf along alternate grid columns.

A NMFS 83-112 Eastern trawl, which has a 25.3 m (83 ft) headrope and 34.1 m (112 ft) footrope, was used. The net was attached to 54.9 m (30 fathoms) paired dandylines. Each lower dandyline had a 0.61 m chain extension connected to the lower wing edge to improve bottom tending characteristics. Steel "V" doors measuring 1.8 m x 2.7 m and weighing 816 kg were used to spread the net. Equipment that recorded data about each tow was attached to the trawl gear; net mensuration equipment recorded net height and width while fishing, a Sea-Bird™ data logger recorded temperature and depth, and a tilt sensor was used to detect when the footrope was in contact with the bottom.

Halibut sampling

Halibut were sampled for fork length on all standard survey tows aboard both vessels. Halibut from tows aboard the IPHC-staffed vessel were additionally sampled for otoliths, sex, maturity, and prior-hooking injuries. Halibut caught in tows at corner crab stations and during duplicate tows, were excluded from the individual specimen sampling, but remained eligible for inclusion in the COAC if the random sampling method dictated that the station be sampled as described in the sampling plan (Tobin and Forsberg 2015).

Sex and maturity determinations were made via macroscopic gonad examination for each sampled halibut. Female fish were assessed with four stages of maturity: immature, ripening, ripe/spawning, and spent/resting. Males had two maturity stages: immature and mature. Immature fish, regardless of sex, would not be expected to participate in the upcoming spawning season. The other stages represented various phases of the spawning process. Fish in those categories were considered mature enough that they could participate in the upcoming spawning season.

Information concerning injuries to the mouth, jaw, or eye caused from longline gear has been collected in recent years as part of an IPHC special project. The objective was to assess the types of hooking injuries a fish might sustain and still survive. Full results from this project can be found in Kaimmer (2015).

Results

Results here are presented for the standard survey sample and the COAC sample separately due to slight collection method differences. The standard survey sample is collected at every center station (center of the grid square) (Fig. 1) in which the vessel fishes. The COAC sample is more opportunistic, utilizing standard grid stations, but also corner stations, and re-tows.

Halibut were subject to full sampling during 176 tows. On average, four to five tows were conducted daily. The IPHC sampler collected data from 1,053 halibut for the standard grid sample.

	Trip 1	Trip 2	Trip 3
Number of tows	62	69	45
Number of halibut sampled	804	151	98

The number of halibut caught and sampled at each station surveyed by the IPHC-staffed vessel is shown in Figure 2. From the halibut sampled for the standard survey, 1,000 otoliths were collected and 53 otoliths were crystallized (not useable for aging) or lost. Of those, 52% were female fish and 48% were males. Ninety-seven percent of the females and 34% of the males were assessed as immature (Table 1). Prior-hooking injuries (PHIs) were found on 4.3% of the standard sample fish; 39 had minor damage, 6 had moderate damage, and no halibut had severe damage (Kaimmer 2015).

A total of 133 halibut otoliths were collected for the COAC (Table 2)**.** Forty-three percent of those collected were female and 57% were male. For the COAC sample, the overall incidence rate of PHI was slightly higher at 6.0%.

References

Kaimmer, S. M. 2015. Prior hook injuries: results from the 2014 IPHC SSA and NMFS trawl surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 645-656.

Tobin, R. S. and Forsberg, J. E. 2015. Clean otolith archive collection. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Table 1. Assessed maturity rating of Pacific halibut retained for the general sample during the NMFS Bering Sea trawl survey in 2014. Females are assessed with one of four ratings: 1=immature, 2=ripening, 3=ripe/spawning, 4=spent/resting. Males are assessed with one of two ratings: 1=immature and 2=mature: U=unknown/can't tell.

	Females				Males				Grand
Length (cm)	**1**	**2**	**4**	Total	**1**	**2**	Total	Unknown	Total
15-19					1		1	5	6
20-24	6			6	6		6	63	75
25-29	47			47	42		42		89
30-34	20			20	28	1	29		49
35-39	16			16	22		22		38
40-44	22			22	20	3	23		45
45-49	17			17	20	5	25		42
50-54	41			41	42	24	66		107
55-59	45	1		46	53	16	69	1	116
60-64	79	1		80	40	38	78		158
65-69	59			59	29	38	67		126
70-74	46			46	5	14	19		65
75-79	41	6		47		10	10		57
80-84	28	1	1	30	1	4	5		35
85-89	14	1		15	1	3	4		19
90-94	8		1	9		1	1		10
95-99	4	1		5					5
100-104	3	1		4		1	1		5
105-109	2			2		1	1		3
110-114	1	1		2					2
115-119	1			1					1
Total	**500**	**13**	**2**	**515**	**310**	**159**	**469**	**69**	**1,053**

Table 2. Assessed maturity rating of Pacific halibut retained for the COAC sample during the NMFS Bering Sea trawl survey in 2014. Females are assessed with one of four ratings: 1=immature, 2=ripening, 3=ripe/spawning, 4=spent/resting. Males are assessed with one of two ratings: 1=immature and 2=mature: U=unknown/can't tell.

	Females			Males			Grand
Length (cm)	1	2	Total	1	2	Total	Total
15-19				1		1	1
20-24	1		1	8		8	9
25-29	3		3	3		3	6
30-34	2		2				2
35-39	2		2	3		3	5
40-44	1		1	3		3	4
45-49	1		1	3		3	4
50-54	2		2	4	1	5	7
55-59	2		2	2	10	12	14
60-64	7		7	3	13	16	23
65-69	11		11	2	7	9	20
70-74	4		4	1	6	7	11
75-79	5		5		3	3	8
80-84	6		6		1	1	7
85-89	1	1	2		2	2	4
90-94	3	1	4				4
95-99		1	1				1
100-104	1		1				1
105-109		1	1				1
120-124		1	1				1
Grand Total	**52**	**5**	**57**	**33**	**43**	**76**	**133**

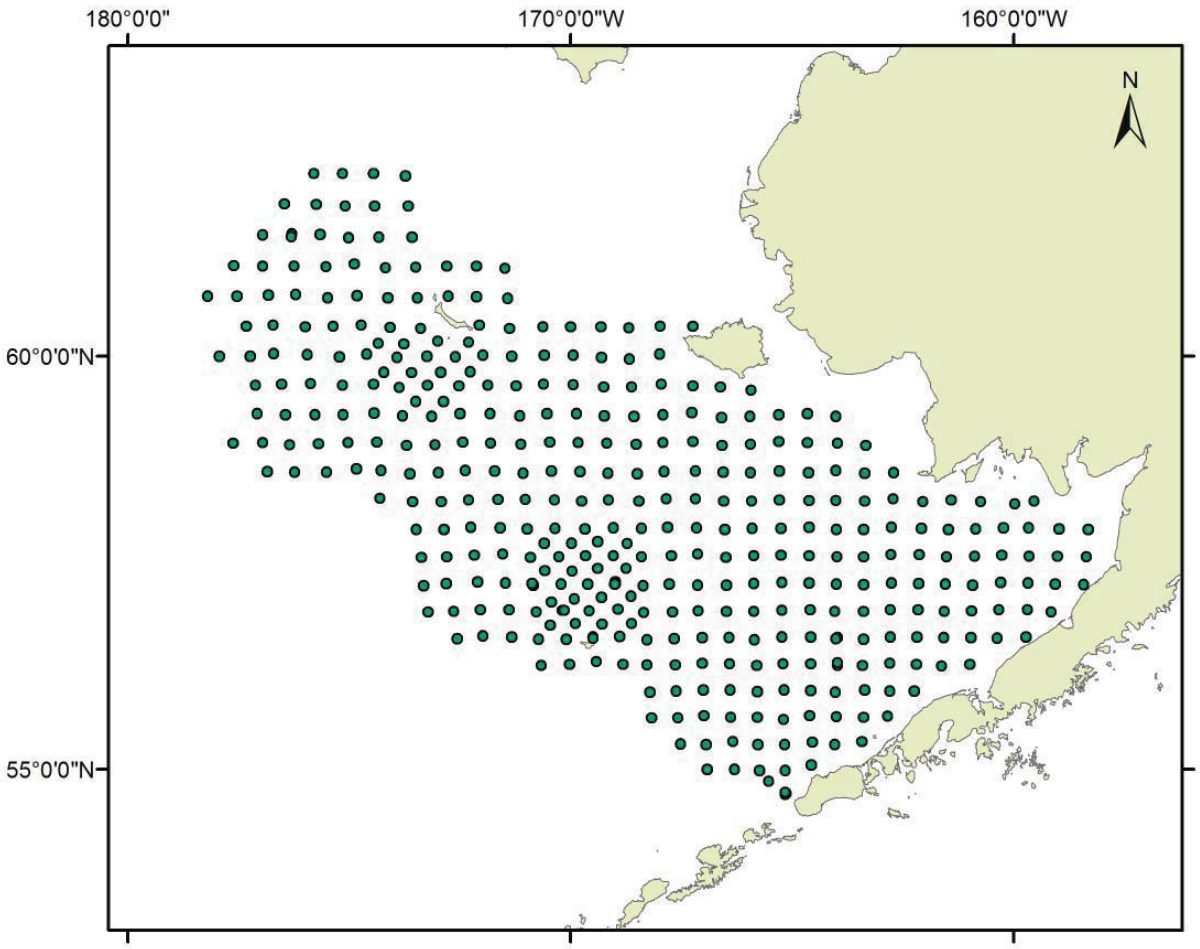


Figure 1. Sampling grid for the Eastern Bering Sea groundfish trawl survey. Each dot represents the center point of a 20x20 nmi square. Two vessels participated in the survey in 2014.

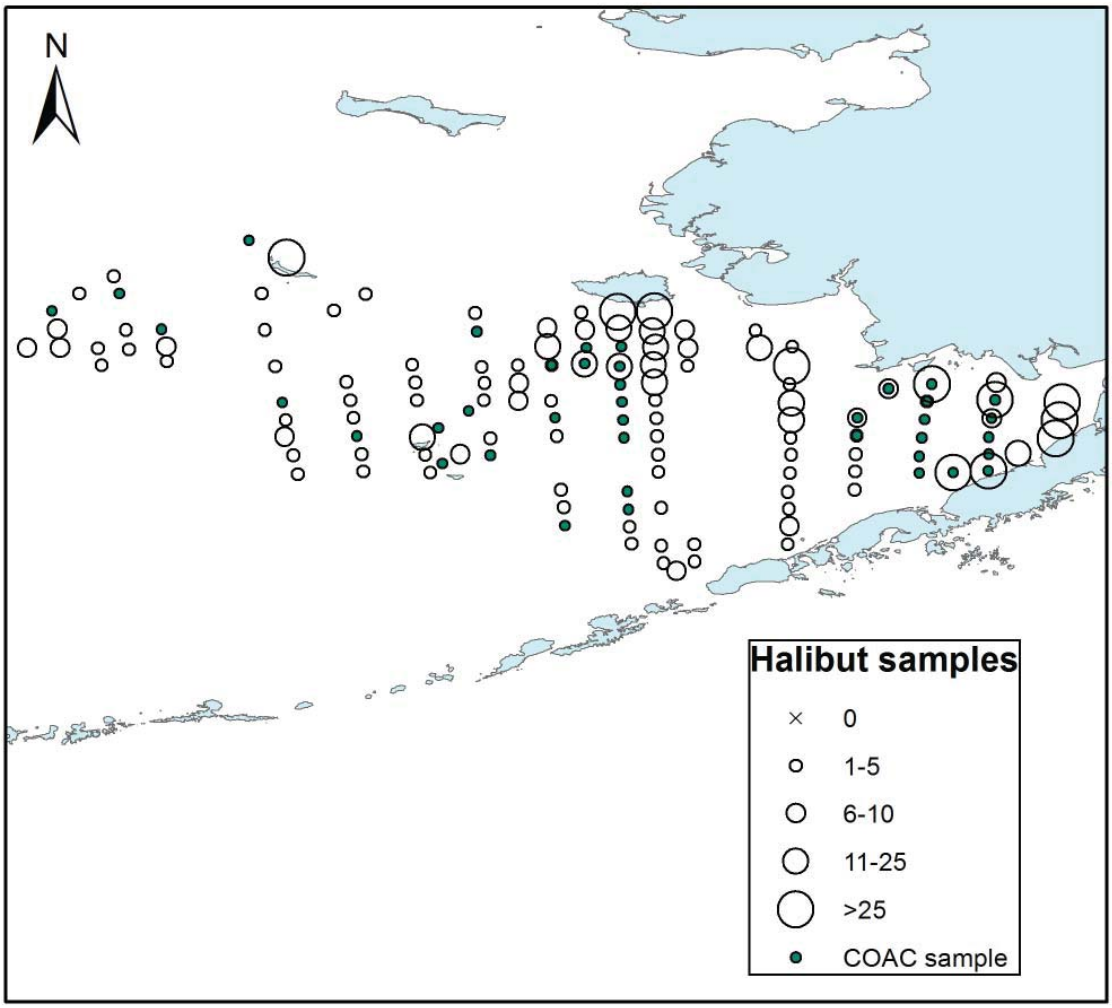


Figure 2. Stations sampled and numbers of halibut samples collected during the 2014 EBS trawl survey. Solid dots represent where COAC halibut were sampled.

Size and age composition of Pacific halibut in NMFS Bering Sea shelf trawl surveys

Lauri Sadorus
International Pacific Halibut Commission

Robert Lauth
National Marine Fisheries Service

Aaron Ranta
International Pacific Halibut Commission

Abstract

The National Marine Fisheries Service eastern Bering Sea shelf trawl survey has been conducted annually since 1979. The survey time series is very useful for tracking particular year classes of Pacific halibut as they move through the population and approach commercial size. The abundance estimate for the Bering Sea in 2014 was 62.8 million halibut, which continues a downward trend in abundance since 2006, but suggests the decline may be leveling out. Biomass has been relatively level the past several years but declined in 2014 to 377 million pounds. Eight-year-olds were the largest contributors to the age sample in 2013.

Introduction

The National Marine Fisheries Service (NMFS) has conducted annual bottom trawl surveys on the eastern Bering Sea (EBS) continental shelf since 1979. The survey was standardized in 1982 and an International Pacific Halibut Commission (IPHC) field biologist has been deployed on the survey every year since 1998 to collect halibut samples. The IPHC operates a coastwide longline survey as the primary fishery-independent source of data for the halibut stock assessment (Henry et al. 2015). However, Pacific halibut occupy a vast area of the Bering Sea shelf for which the IPHC lacks the financial resources to sample in its entirety. Therefore, in most years, the NMFS trawl survey is the only measure of abundance for much of this area. This paper presents abundance and biomass estimates for the EBS for the years 1990-2014 and age composition for 2013.

Survey trawl gear has different size-selectivity than setline gear, making it necessary to apply a selectivity curve to include these data directly in the halibut stock assessment generated by the IPHC. Halibut are vulnerable to the trawl from about 20-100 cm fork length (FL), but a substantial portion of the commercial-sized population (O32 or $\geq$ 81.3 cm FL) exceeds 100 cm. In 2006, the IPHC added shelf stations to its setline survey in the Bering Sea region in order to compare information from setline stations in that area with data collected on the trawl survey. After the study, the IPHC staff concluded that the trawl survey provided an adequate accounting of halibut biomass on the EBS shelf (Clark and Hare 2007) and is a useful tool for constructing a density index for the IPHC stock assessment (Webster 2014). In addition to a stock assessment tool, trawl survey information is useful as a forecasting tool for young cohorts approaching recruitment into the commercial fishery.

Trawl survey description

The current standard trawl survey uses a 20-nmi square grid design extending from inner Bristol Bay to St. Matthew Island, within the 200-m depth contour. The stations are placed at the center of each grid square, and additional stations are placed at the corners of grid cells in areas surrounding St. Matthew and the Pribilof Islands to better assess blue king crab (*Paralithodes platypus*) density (Fig. 1).

In 1987, twenty stations were added north of the standard survey sampling area to better assess abundance and distribution of walleye pollock (*Gadus chalcogramma*) and snow crab (*Chionoecetes opilio*) populations. Data from these stations are included in the abundance estimates herein. From 2000- 2004 and again in 2011-2012, several stations within the 0-30 m depth stratum were added to investigate the nearshore distribution of either juvenile yellowfin sole (*Limanda aspera*) or red king crab (*P. camtschaticus*). Some halibut were caught at these nearshore stations but the results were not incorporated into the NMFS abundance estimates because the stations were not part of the standard grid.

Since 1982, the area has been surveyed using a NMFS 83-112 Eastern trawl with a 25.3 m headrope and 34.1 m footrope. The trawl net was deployed with equipment that recorded data describing each tow. Through 2012, a Netmind[1] trawl mensuration system recorded net height and width, a Sea-Bird[2] data logger recorded temperature and depth, and a tilt sensor was used to detect when the footrope hit the bottom. In 2013, the Netmind system was replaced with the Marport trawl mensuration system[3]. A 30-minute tow was attempted at each station.

Length and age distribution

All halibut caught during the surveys are measured for fork length. Estimates of relative abundance are derived by expanding the survey catches from the area swept by the trawl to the total survey area. Estimates are not adjusted for size-specific selectivity, so the reader should exercise caution when drawing conclusions regarding halibut that are underrepresented in the trawl survey, i.e., halibut greater than about 90-100 cm in length.

Total halibut abundance in the EBS as estimated by the trawl survey in 2014 was just under 62.8 million halibut. Abundance has declined between 4-22% annually since the high of 133 million halibut estimated in 2006. The one exception to this decline was in 2010 when there was a 4% increase in estimated abundance from the previous year.

The size composition curves illustrate the magnitude of the contribution each size class makes to the estimated population in a given year (Fig. 2). In 2006-2007, halibut in the <40-cm size class dominated the overall catch (Fig. 3). However in 2008, the 40-79 cm halibut regained that position and have remained the dominant size class since then. In 2014, the smallest size category (0-39 cm) realized an increase in abundance for the first time since 2006. Overall abundance continued to decline, but the decline was less pronounced than it has been for the last several years, possibly indicating that the population numbers are leveling out. Total biomass was estimated at 377.9 million pounds in 2014 which continues the current downward trend started in 2010 (Fig. 3).

[1] Northstar Technical Inc., 1 Duffy Place, St. John's, NL, A1B 4M6.
[2] Sea-bird Electronics Inc., 13431 NE 20th Street, Bellevue, WA, 98005.
[3] Marport Deep Sea Technologies, AIRMAR Technology Corporation, 35 Meadowbrook Drive, Milford, NH 03055, USA

The age composition for halibut sampled in 2013 is shown in Table 1. Age data for 2014 was not available at the time of writing. The 8-year-olds (born in 2005) made up the largest percentage of the sample at 22% of the total aged. This age class has been the highest contributor to the sample every year since 2008 (as 3-year-olds) with the exception of 2010 when the 2004 year class dominated. In 2006, ages from the sampled fish showed that almost half of the surveyed population were 2-year olds (born in 2004), making this the largest age class represented in the survey since the IPHC began annual otolith sampling in 1998. Fish from the 2004 and 2005 year classes have grown to a size where they are capable of avoiding survey trawl gear which likely results in lower abundance estimates of fish of these sizes.

References

Clark, W. G. and Hare, S. H. 2007. Assessment of the Pacific halibut stock at the end of 2006. IPHC Report of Assessment and Research Activities 2006: 97-128.

Henry, E., Dykstra, C. L., Geernaert, T. O., Soderlund, E., Ranta, A. M., and Kong, T. 2015. 2014 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014. 531-568.

Webster, R. A. 2014. Construction of a density index for Area 4CDE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 261-288.

Table 1. Pacific halibut length (cm) and age (years) composition information from sampled fish for the 2013 NMFS Bering Sea trawl survey standard grid.

Age	Mean fork length (cm)	Std. dev. of fork length	Fish aged	Year class
2	n/a	-	0	2011
3	30.1	2.70	29	2010
4	41.9	3.58	59	2009
5	49.4	4.12	198	2008
6	52.8	4.08	52	2007
7	57.2	5.45	136	2006
8	61.2	6.95	217	2005
9	66.4	8.05	135	2004
10	70.2	7.95	107	2003
11	76.5	9.55	36	2002
12	81.1	12.68	14	2001
13	80.0	11.31	2	2000
14	n/a	-	0	1999
15+	96.5	13.16	13	1998 & earlier
Average	**58.8**	**12.80**	**998**	

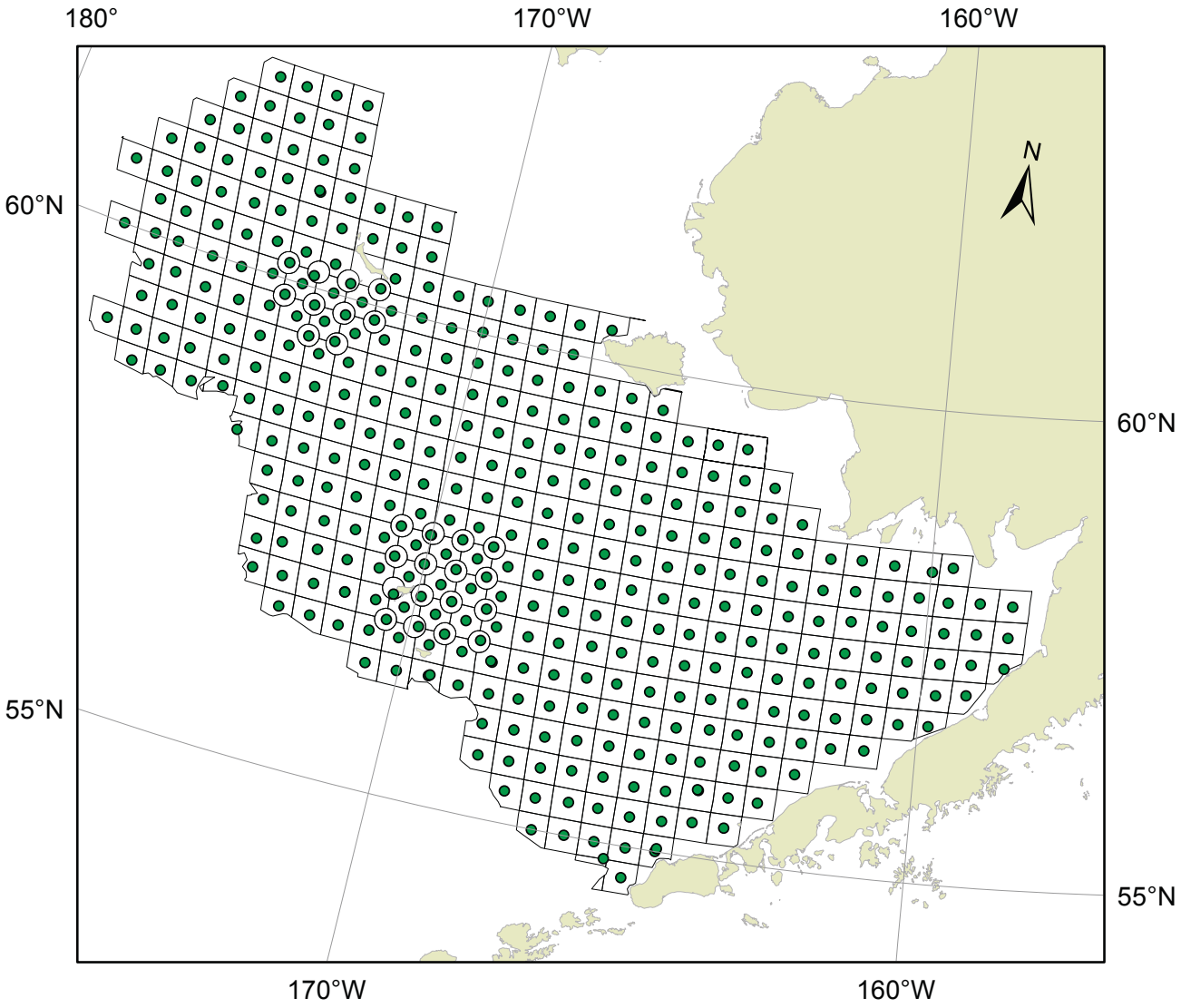


Figure 1. Stations fished during the NMFS Bering Sea bottom trawl surveys.

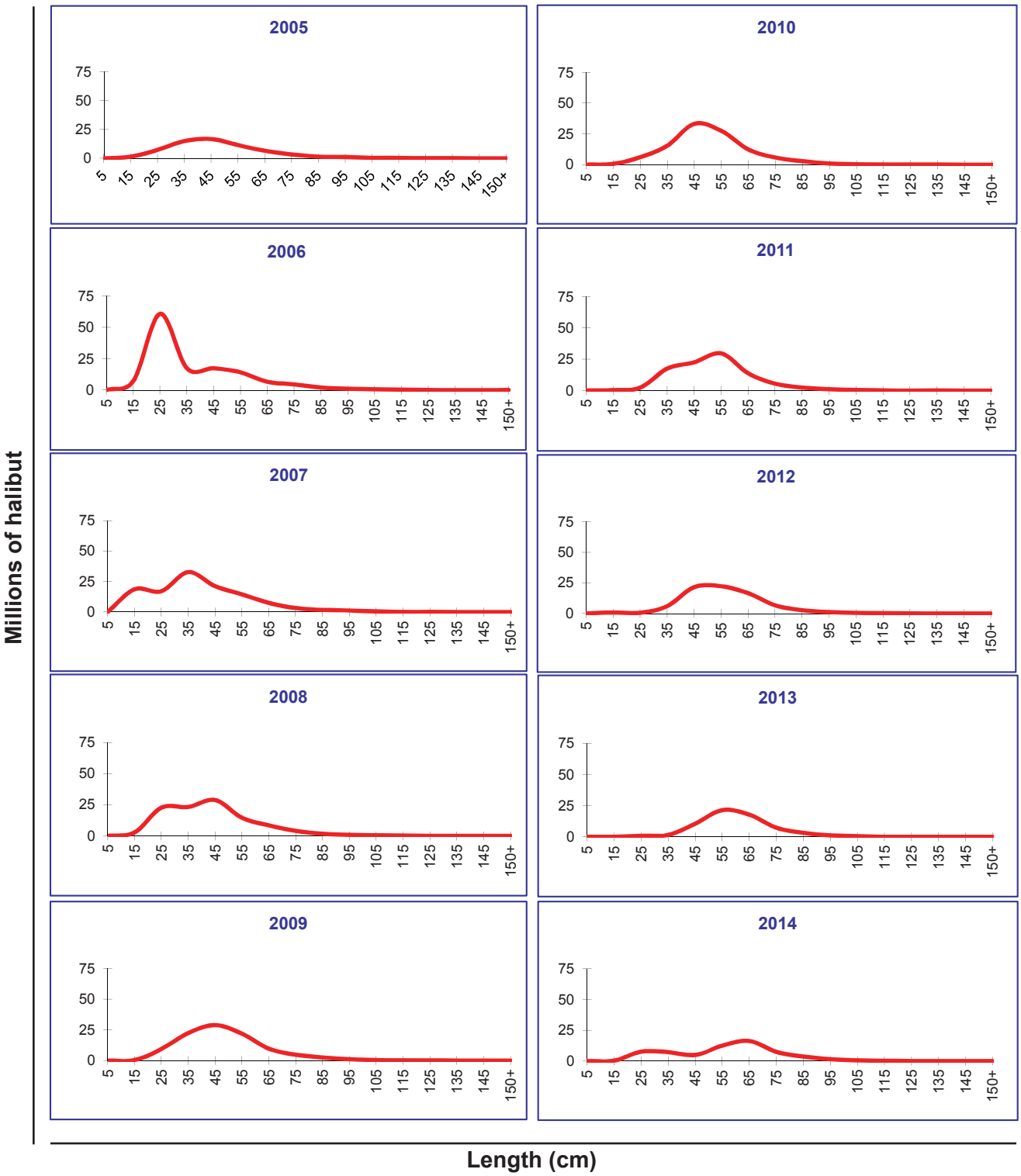


Figure 2. Halibut abundance by size in the Bering Sea as estimated by the NMFS Bering Sea trawl survey for the years 2005-2014. Note: Horizontal axis is fork length Lowess smoothed by 10-cm size category; vertical axis is millions of halibut.

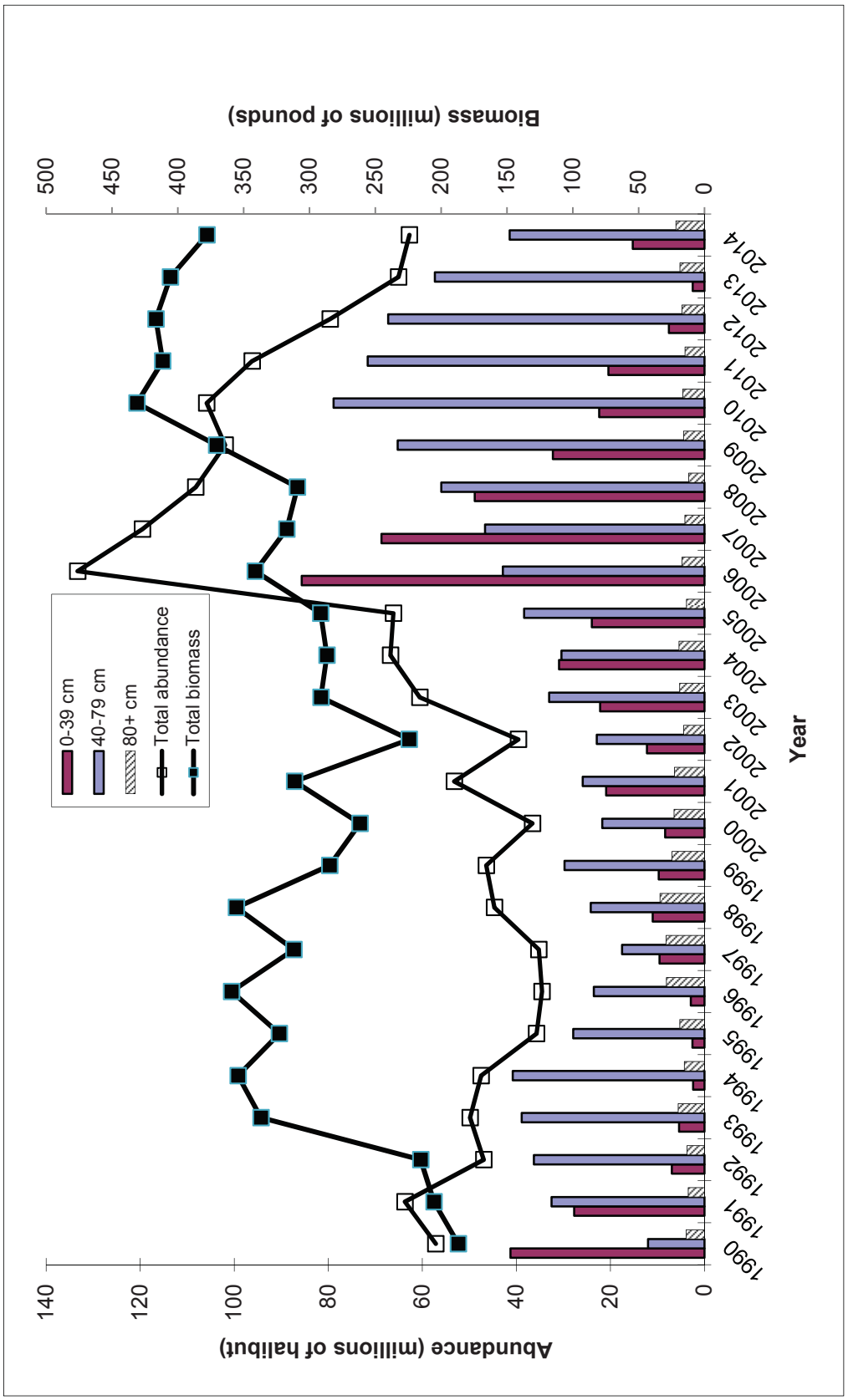


Figure 3. Estimated abundance of Pacific halibut by length category and total biomass as estimated by the NMFS Bering Sea trawl survey from 1990-2014, using swept-area estimates.

Results from the NMFS Aleutian Islands biennial bottom trawl survey in 2014

Lauri L. Sadorus
International Pacific Halibut Commission

Wayne A. Palsson
NOAA Fisheries Service

Aaron Ranta
International Pacific Halibut Commission

Abstract

In 2014, the International Pacific Halibut Commission (IPHC) participated in the National Marine Fisheries Service Aleutian Islands trawl survey for the second consecutive time in recent years. The 2012 survey was the first that IPHC had participated in since 2000. The survey covered the area surrounding the Aleutian Islands between Unimak Pass in the east and Stalemate Bank in the west. A total of 510 Pacific halibut were sampled for length, age structures, sex, maturity, and prior hooking injuries.

Introduction

In 2014 the International Pacific Halibut Commission (IPHC) participated in the National Marine Fisheries Service (NMFS) Aleutian Islands trawl survey for the second time since 2000. This survey has taken place every two years since 2000 and every three years prior to that, dating back to 1980. The IPHC uses the NMFS trawl survey to collect information on halibut that are not yet vulnerable to the gear used for the IPHC longline survey or commercial fishery, serving as an additional data source and verification tool for the IPHC halibut stock assessment.

Objectives

The IPHC objectives were to:

- sample 100% of the halibut caught on one of two vessels for length, sex, maturity, otoliths, and prior-hooking injuries;
- collect a sample of halibut in the round measuring less than 25 cm for the clean otolith archive collection (COAC; Tobin and Forsberg 2015)

NMFS objectives included:

- defining the distribution and relative abundance of the principle groundfish and commercially important invertebrate species inhabiting the Aleutian Islands region;
- obtaining catch and effort data used to estimate the abundance of the groundfish species;

- collecting data to measure biological parameters, such as size, sex, age, growth, length-weight relationships, feeding habits, and spawning condition for selected species;
- monitoring and recording trawl performance information;
- collecting samples and data requested by other researchers or research groups.

Survey area, vessels, and timing

The survey operated from Unimak Pass (longitude 165°W), to Stalemate Bank west of Attu Island (longitude 170°E). Two vessels were chartered by NMFS; *F/V Alaska Provider* and *F/V Sea Storm*. The vessels each fished three survey legs and stayed within close proximity of one another throughout the survey, so that each vessel sampled throughout the survey range. The IPHC biologist was aboard the *Alaska Provider* for the duration of the survey. The survey was scheduled to begin June 5, but volcanic activity from Mt. Pavlof temporarily hampered the effort to get all of the scientific crew into Dutch Harbor, AK and the vessels did not leave port until June 9. The first survey tow was performed on June 11 and the last tow was conducted on August 7. The vessels arrived back in Dutch Harbor on August 11.

Survey design

The Aleutian Island bottom trawl survey conforms to US National Protocols (Stauffer 2004) and was conducted in a similar manner to previous surveys (Rooper 2008, Rooper and Wilkins 2008, von Szalay et al. 2011). The survey design is a stratified random sampling scheme consisting of 420 stations selected randomly from a combination of successful tows completed during previous surveys and sites not previously trawled. The selected sampling sites were allocated to 45 sampling strata defined by geographical location, depth, and regulatory area, ranging from shallow, nearshore depths to approximately 500 m on the continental slope. A 15-minute tow was typically conducted at each station.

Stations were sampled with the Resource Assessment and Conservation Engineering (RACE) Division's standard four-seam, high-opening poly Nor'Eastern survey trawl equipped with rubber bobbin roller gear (Stauffer 2004). This trawl has a 27.2 m headrope and 36.75 m footrope consisting of a 24.9 m center section with adjacent 5.9 m flying wing extensions. Accessory gear for the poly Nor'Eastern trawl includes 54.9 m triple dandylines and 1.8 - 2.7 m steel V-doors weighing approximately 850 kg each.

Halibut sampling

All halibut caught by both vessels were measured and all halibut caught by the *F/V Alaska Provider* were also sampled for otoliths, sex, maturity, and prior-hooking injuries. Left-side otoliths were collected from each halibut brought aboard.

The sex and maturation stage of each sampled fish was identified. Female fish were assessed for four stages of maturity: immature, ripening, ripe/spawning, and spent/resting. Males were assessed for two maturity stages: immature and mature. An immature fish is one that will not participate in the upcoming spawning season. The other stages represent various phases of the spawning process and fish in those categories are considered mature enough that they could participate in the upcoming spawning season.

Information concerning injuries to the eyes, mouth or jaw resulting from halibut being released from longline gear has been collected since the 1990s as part of an IPHC special project. The

objective is to assess the types of hooking injuries a fish might sustain and still survive as well as tracking the prevalence and severity of injuries. Results from this project can be found in Kaimmer (2015).

Halibut otoliths for the COAC (Tobin and Forsberg 2015) are collected coastwide on the surveys and in the commercial fisheries. Because of the geographic overlap of this survey with the IPHC setline survey, only fish < 25 cm (i.e., those caught exclusively by the trawl survey because of their small size) were to be collected whole and sent back to the IPHC laboratory in Seattle for otolith extraction.

Results

The two survey vessels remained in close proximity to one another during the survey and conducted tows from Unimak Pass to the end of the Aleutian chain at Stalemate Bank. Four hundred ten stations were successfully completed. Figure 1 illustrates the catch of halibut during the 2014 survey for the two vessels. Clearly, fewer halibut were encountered as the survey progressed to the west.

The IPHC-staffed vessel, the *F/V Alaska Provider,* conducted 237 tows and caught 510 halibut. A total of 37 otoliths were crystallized and subsequently discarded. The number of tows per day ranged from one to seven, and averaged four to five. The number of tows conducted is:

	Leg 1	Leg 2	Leg 3
Number of tows	78	86	73
Number of halibut sampled	262	224	24

Females accounted for 39% of the catch (201 fish) and males for 61% (309 fish) (Fig. 2). Most (92%) of the females were immature, 6% were ripening, and 2% were spent/resting. No halibut were assessed as actively spawning. Of the males, none were assessed as immature (Table 1). Prior-hooking injuries were found on 33 (6.5%) of the halibut. Of those, 24 were minor, 8 were moderate, and one was severe. There were no halibut caught by the *F/V AK Provider* that were smaller than 25 cm and therefore no halibut were collected for the COAC project.

Abundance and biomass estimates

Following each survey, NMFS scientists estimate the biomass and abundance for the sampled area. These estimates are based upon the area swept technique (Wakabayashi et al. 1985), do not account for catchability or selectivity, and should be considered as a relative index of abundance (Clark et al. 1997). The halibut population index peaked in 1997 with a biomass estimate of 146 million pounds and steadily declined through 2012 to about 70 million pounds. A slight increase to 74 million pounds occurred in 2014 but it will take several more data points to determine if this is the beginning of a long term increasing trend in biomass, or simply survey variability (Fig. 3).

The area-swept abundance-at-length estimates showed that the average length of the halibut caught during the survey was 65 cm in 2014, compared to a 60 cm average in 2012 (Fig. 4). Dominating the sample in the 2012 survey were the 2004 and 2005 age classes (Table 2) which have also shown up proportionally high in the Bering Sea survey for several years, (although relative sizes of these year classes have been inconclusive in the Gulf of Alaska survey). It is possible that the increase in average fork length in the Aleutian survey reflects those year classes

moving through the population, but age data are not yet available for 2014 so this cannot be confirmed.

References

Kaimmer, S. M. 2015. Prior hook injuries: results from the 2014 IPHC SSA and NMFS trawl surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 645-656.

Rooper, C. N. 2008. Data report: 2006 Aleutian Islands bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-179.

Rooper, C. N. and Wilkins, M. E. 2008. Data report: 2004 Aleutian Islands bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-185.

Stauffer, G. (compiler). 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fishery resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-65.

von Szalay P. G., Rooper, C. N., Raring, N. W.,and Martin, M. H. 2011. Data Report: 2010 Aleutian Islands bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-215.

Wakabayashi, K., Bakkala, R. G., and Alton, M. S. 1985. Methods of the U.S.-Japan demersal trawl surveys, p. 7-29. *In* R. G. Bakkala and K. Wakabayashi (eds.), Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May-August 1979. Int. North Pac. Fish. Comm. Bull. 44.

Tobin, R. S. and Forsberg, J. E. 2015. Clean otolith archive collection. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2014: 429-434.

Table 1. Maturity of Pacific halibut sampled during the NMFS Aleutian Islands trawl survey in 2014 aboard the *F/V Alaska Provider*, as assessed by the IPHC sea sampler on board. For females: 1=immature, 2=ripening, 3=ripe/spawning, and 4=spent/resting. For males: 1=immature, 2=mature. For both females and males, U=unknown/couldn't tell.

	Female				Male				
Length (cm)	**1**	**2**	**4**	**Total**	**1**	**2**	**U**	**Total**	**Grand Total**
30-34						1		1	1
35-39	3			3		4		4	7
40-44	3			3		6		6	9
45-49	9			9		10	2	12	21
50-54	10			10		18		18	28
55-59	18			18		36	1	37	55
60-64	35			35		50		50	85
65-69	38			38		60		60	98
70-74	30			30		40		40	70
75-79	15			15		20		20	35
80-84	12			12		17		17	29
85-89	6			6		22		22	28
90-94	3	1	2	6		8		8	14
95-99	1	2		3		6		6	9
100-104	1	1	1	3		2		2	5
105-109		2	1	3		3		3	6
110-114	1	1		2		1		1	3
120-124		1		1		2		2	3
125-129		1		1					1
140-144		1		1					1
145-149		1		1					1
165-169		1		1					1
Grand Total	**185**	**12**	**4**	**201**	**0**	**306**	**3**	**309**	**510**

Table 2. Age composition for Pacific halibut caught during the 2012 Aleutian Islands trawl survey.

Age	Mean fork length	Std Dev of fork length	Sample size	Year class
3	36.8	2.65	15	2009
4	39.4	3.05	74	2008
5	41.8	4.74	34	2007
6	47.9	5.71	67	2006
7	52.9	5.59	157	2005
8	59.5	6.41	106	2004
9	67.3	8.42	53	2003
10	70.8	8.16	30	2002
11	76.5	9.64	21	2001
12	90.5	13.03	13	2000
13	92.3	14.98	16	1999
14	95.7	7.63	6	1998
15	99.2	17.57	6	1997
16	133.0	53.74	2	1996
17	113.0	19.80	2	1995
18+	118.3	18.21	19	$\leq$ 1994
Total			621	

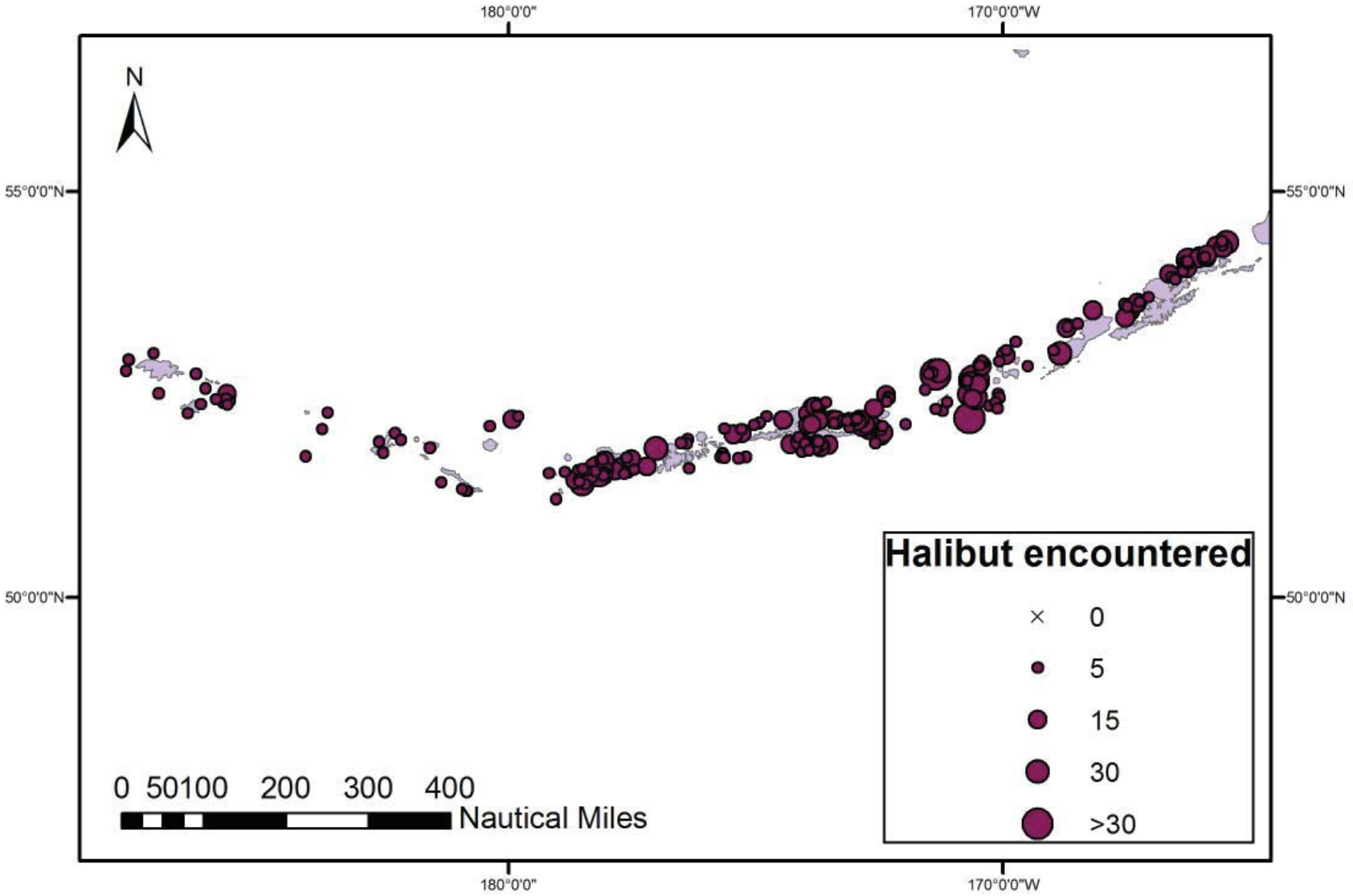


Figure 1. Pacific halibut encountered by location across the Aleutian Islands survey area from both vessels during the NMFS bottom trawl survey. Circles denote numbers of halibut encountered.

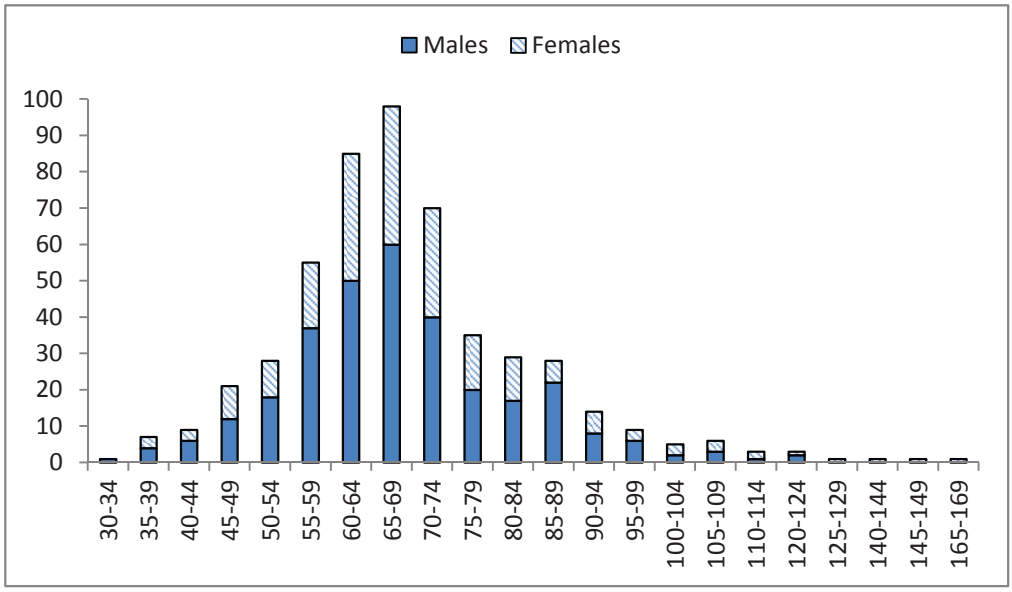


Figure 2. The number of Pacific halibut sampled by length and sex from the *F/V Alaska Provider* during the 2014 NMFS Aleutian Islands bottom trawl survey.

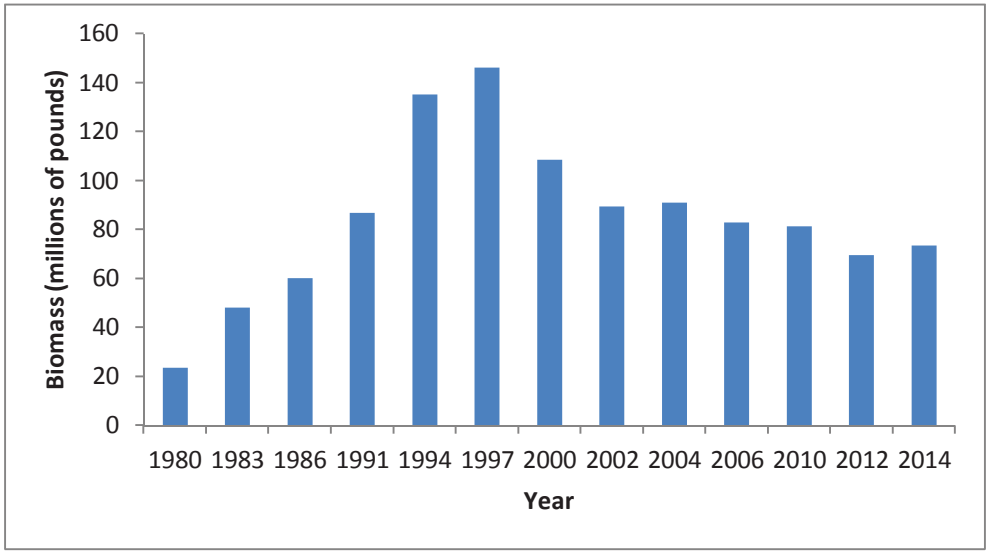


Figure 3. Biomass estimates (millions of pounds) of Pacific halibut from each of the NMFS Aleutian Islands bottom trawl surveys from 1980-2014.

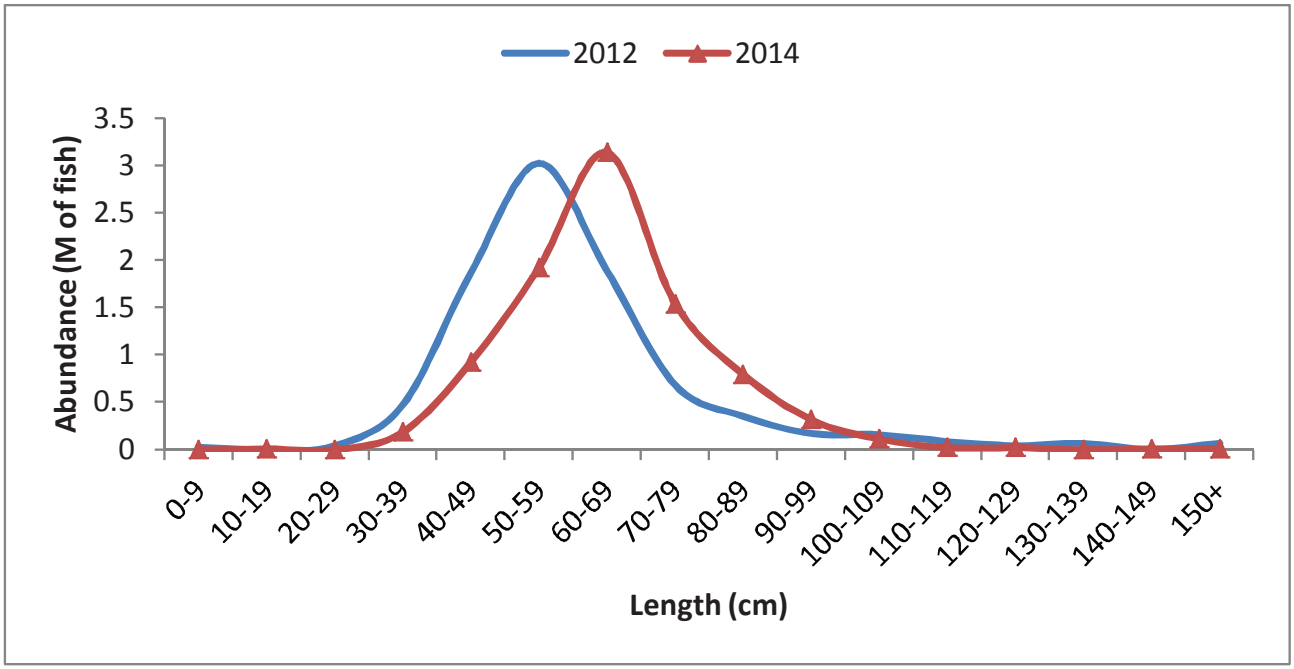


Figure 4. Pacific halibut abundance estimates (numbers of fish) for each 10-cm size category for the Aleutian Islands in 2012 and 2014, as estimated from the NMFS Aleutian Islands bottom trawl survey.

Prior hook injuries: results from the 2014 IPHC SSA and NMFS trawl surveys

Stephen M. Kaimmer

Abstract

Data on the occurrence of prior hook injuries (PHI) of halibut caught on the standardized stock assessment (SSA) surveys have been collected since 1997. For halibut of all sizes, the incidence of PHIs in 2014 increased in Areas 3B and 4A-Bering Sea, stayed about the same in Areas 4A-Aleutians and 4B, and decreased in all other areas. The decrease in Area 4D was substantial. Overall, the coastwide average PHI rate (6.1%) is lower than the 7.5% seen in 2013. The PHI rate observed during the National Marine Fisheries Service (NMFS) Bering Sea trawl survey was 4.4%, down from the 5.1% seen in 2013.

Introduction

The establishment of a coastwide, comprehensive longline survey along the North American west coast by the International Pacific Halibut Commission (IPHC) has provided a unique opportunity to gather information showing geographic differences among components of the Pacific halibut population. In the mid-1990s, halibut fishers began to notice increasing rates of hook injuries from previous captures. Although groundfish and halibut longline harvesters in Alaska are required to practice careful release techniques[1] for all halibut intended for return to the sea, it was suspected that either the regulations were not being observed by all fishers, or that careful release procedures were inflicting worse damage than expected. The IPHC standardized stock assessment (SSA) surveys provide a means of examining geographic and size trends in hook removal injuries across the entire range of halibut in the northeastern Pacific Ocean and southeastern Bering Sea.

In 1997, prior hook injury (PHI) data were collected for the first time during the IPHC coastwide survey. The collection method proved to be successful and allowed us to continue the research of PHI incidence in 1998 and subsequent years. In 1998, the PHI categories were expanded to more closely reflect those used by National Marine Fisheries Service (NMFS) observers. These expanded classifications have provided more detail about the severity of each injury.

Data collection procedures

All halibut captured during the 2014 IPHC SSA survey were examined for the presence of PHIs. PHIs were defined as injuries that appear to have occurred when the fish was being released during a previous capture by hook-and-line gear. Such injuries are observed primarily to the jaw, but may occur to the eye and eye socket, either alone or in conjunction with a jaw injury. The fish may have been hooked recently, in which case the injury should have been easily noticed, or the injury may have happened sometime in the more distant past and the injury would have been scarred-over. Some difficulty in distinguishing between fresh and prior injuries was expected, as prior injuries could be mistakenly attributed to the current capture. Additionally, old injuries may

[1]Accepted careful release techniques include careful shaking, hook straightening, and gangion cutting.

have been difficult to completely document, as they may have been healed sufficiently so as to actually mask or hide the injury altogether.

In 1997, each surveyed fish was coded as having an injury, not having an injury, or that the sampler was unsure as to whether an injury was present. In 1998, the observation codes were revised to capture more specific details of each injury, increasing the total number of categories from three to five. The new condition codes were no injury, a minor injury, moderate injury, severe injury, or unknown (Table 1). These categories have been continued through 2014.

For the analysis that follows, IPHC Regulatory Area 4A was divided into two sub-areas: 4A-Bering Sea and 4A-Aleutians. All stations in Area 4A west of 165º 00' W longitude and north of 54º 20' N latitude were designated as 4A-Bering Sea, and the remainder 4A-Aleutians.

Results

A total of 91,732 halibut were examined during the 2014 IPHC SSA survey (Table 2). This is substantially more than the 67,864 halibut examined during 2013. A total of 9,852 standard survey skates were examined in 2014, substantially more than the 7,608 skates examined in 2013. The addition of new stations as well as fishing 7 skates instead of 6 at each station contributed to the increase in skates fished in 2014. Survey vessels fished a total of 1,410 survey stations in 2014 compared to the 1,276 fished in 2013. In the 2014 survey, 5,540 halibut were found to have a prior injury. On a regulatory area basis, the percentage of all halibut with a prior hook injury ranged from a low of 4.1% (Area 3A) to a high of 13.3% (Area 4D) and averaged 6.1% coastwide. Although we fished 3 stations in the closed area and had a PHI incidence of 14.3%, it was based on seven halibut caught, and this sample size is too small to be an estimator (Table 3 and Fig. 1). The 2014 coastwide PHI rate of 6.1% is lower than the 7.5% observed in 2013 (Kaimmer 2014). The incidence of prior hook injuries on the 2014 survey increased in Areas 3B and 4A-Bering Sea, stayed about the same in Areas 4A-Aleutians and 4B, and decreased in all other areas. The decrease in Area 4D was significant (Fig. 1). For U32 halibut (fork length less than 32 inches or 82 cm) examined during the SSA survey, the overall incidence of PHI was up significantly from that observed in 2013 (6.1%, up from 4.9%). By regulatory area, U32 PHI levels decreased dramatically in Area 2A, and increased dramatically in Areas 4A-Bering Sea and 4C (Table 3). The highest occurrence of U32 PHI (11.9%) was observed in Area 4A-Bering Sea, up from the 8.5% value seen in 2013. PHI rates in all areas have fluctuated over time (Fig. 1). In 2014, the proportion of moderate prior hooking injuries relative to minor injuries on the IPHC SSA survey remained relatively unchanged compared to 2013 with the exception of Areas 4B and 4D, where no moderate or severe injuries were observed in 2014 (see Kaimmer (2014) for 2013 data). The proportion of more severe injuries relative to lesser injuries (Fig. 2) was highest in areas 2C and 3B.

IPHC samplers onboard NMFS trawl surveys in the Bering Sea (annual survey) also gathered PHI data. In the 2014 Bering Sea trawl survey, 1,186 halibut were inspected and PHI rates were determined to be 4.4%, down from the 5.1% seen in 2013. The Gulf of Alaska survey is biennial and was not conducted in 2014.

Since the IPHC started collecting PHI data, the incidence of PHIs in the Gulf of Alaska areas has ranged from 4 to 8%, and has very seldom exceeded 10%. This notwithstanding, the widespread nature of high PHIs is demonstrated by localized PHI observation rates of 25% or more from some individual stations within these areas, including stations off Oregon, Washington,

British Columbia, southeastern Alaska, and south of Kodiak Island (Fig. 3). Stations with observed PHI rates between 15 and 25% were widespread over the entire survey range. Overall mean values in the Bering Sea regions have recently been 8% or more, and in Area 4D the value has often exceeded 20%. In general, a PHI rate of 5 to 15%, and often higher, has been very common at individual locations (Figs. 3 and 4). For example, survey stations along the Bering Sea continental shelf edge, particularly in Area 4D, have shown historically high rates of PHI (Fig. 4). The rate of severe injuries overall is generally fairly low, and in 2014 only 16 fish were noted as having severe injuries, compared to 20 in 2013 and 56 in 2012.

Discussion

The high PHI rates observed on IPHC surveys in the Bering Sea and Aleutians most likely reflect the interception of halibut by the Pacific cod (*Gadus macrocephalus*) groundfish fisheries in those areas (Williams 2014). The impact of halibut PHI likely goes beyond the injured fish that are observed. The PHI observations provide an accounting of only those fish that survived hooking injuries. Studies by IPHC have shown that moderate and severe injuries often kill fish, and that fish that do survive either stop growing or grow at a much-reduced rate (Kaimmer 1994, Kaimmer and Trumble 1997, 1998).

There has to be a relationship between the PHI rate (the tally of those fish that have survived catch and release) and bycatch mortality, but the understanding of that relationship is still elusive. It is clear that the presence of healed hook removal injuries (PHI) in a caught halibut is evidence of prior capture. We know that many halibut are caught and released as unintended bycatch in non-halibut fisheries, and that U32 halibut are released by directed halibut fishers. Intuitively, an increase in the number of observed PHIs seems a bad thing, perhaps reflecting less careful handling by fisheries that catch and then release the halibut. However, many hook removal injuries are minor, and have little if any effect on survival after careful return to the sea. An increase in the PHI rate, at least in the rate of minor injuries, does not necessarily reflect poor handling by fishers. PHI occurrence rates among U32 halibut tend to be about half the rate seen when we consider all halibut caught. The likely interpretation of this result is that the infliction of these injuries does not happen only to smaller-sized halibut, but that injuries continue to accumulate within the stock as the fish survive from year to year. In the Bering Sea fisheries, NMFS observer data indicate steady or decreasing rather than increasing halibut mortality from these fisheries over the last decade (Williams 2014). IPHC survey data suggest that, particularly in the last few years, the Area 4 halibut population has been accumulating a higher proportion of PHIs relative to other areas.

While many fishers undoubtedly handle halibut bycatch with careful release, substantial improvements are unlikely without direct individual incentives for such behavior. The fisher education efforts made in the last decade seem to have only stabilized or reduced the rates of hooking injury. Continued progress in reducing halibut PHI will require the cooperation of all fishers, and may require a more individualized accounting as a disincentive.

The IPHC is currently investigating the PHI data time series to determine whether there are spatial and temporal relationships of injury rates with fishing effort. In particular, we plan to develop models relating injury rates to commercial and sport effort that allow us to examine how such relationships vary through space and time.

References

Kaimmer, S. M. 1994. Halibut injury and mortality associated with manual and automated removal from setline hooks. Fish. Res. 20: 165-179.

Kaimmer, S. M. 2014. Prior hook injuries: Results from the 2013 IPHC SSA and NMFS surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 487-498.

Kaimmer, S., and Trumble, R. 1997. Survival of Pacific halibut released from longlines: hooking and release methods. *In* Fisheries Bycatch: Consequences and Management. *Edited by* B. Baxter and C. Kaynor. Alaska Sea Grant College Program Rep. No. 97-02, University of Alaska, Fairbanks: 101-106.

Kaimmer, S., and Trumble, R. 1998. Injury, condition, and mortality of Pacific halibut bycatch following careful release by Pacific cod and sablefish longline fisheries. Fish. Res. 38: 131-144.

Williams, G. H. 2014. Incidental catch and mortality of Pacific halibut, 1962-2013. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2013: 289-310.

Table 1. Descriptions of the prior hook injury (PHI) categories used on the 1998-2014 stock assessment surveys.

Injury locations	Categories only apply to prior hook injuries, if any. Worst injury of jaw, eye, & eye socket prevails.				Did not check or can't tell
	None	Minor	Moderate	Severe	Unknown
Jaw	No injury	Jaw in one piece, not split or separated from head. Skin of lip may be torn, but jaw is intact.	Upper or lower jaw bone may be torn through, hanging from fish, or torn away on either side of the head. Tear may or may not include tearing through the cheek area. Lower or upper jaw may be split laterally, tearing through either snout or lower mouth.	Removal of hook has torn large flap from side of head, usually originating in cheek area. Flap, usually including part of jaw, is either hanging loosely or missing.	Did not examine the fish, or can't tell.
Eyeball & eye socket	No injury	Eye socket may be torn, but eyeball is undamaged.	Eyeball punctured.		Did not examine the fish, or can't tell.

Table 2. Prior hooking injury (PHI) data collected on 2014 standardized stock assessment grid survey. Length group definitions: U32 is ≤ 81 cm; O32 is ≥ 82 cm (32 in). This table does not include 1,869 halibut for which the length was not recorded.

Reg. Area	Length Group	Injuries: None No.	None %	Minor No.	Minor %	Moderate No.	Moderate %	Severe No.	Severe %	Unknown No.	Unknown %	Total
2A	U32	388	94.4%	11	2.7%	2	0.5%		0.0%	10	2.4%	411
	O32	799	91.8%	39	4.5%	6	0.7%		0.0%	26	3.0%	870
	Total	1,187	92.7%	50	3.9%	8	0.6%		0.0%	36	2.8%	1,281
2B	U32	4,305	93.0%	167	3.6%	39	0.8%		0.0%	118	2.5%	4,629
	O32	4,427	90.5%	188	3.8%	54	1.1%		0.0%	223	4.6%	4,892
	Total	8,732	91.7%	355	3.7%	93	1.0%		0.0%	341	3.6%	9,521
2C	U32	3,978	91.1%	139	3.2%	74	1.7%	2	0.0%	172	3.9%	4,365
	O32	5,339	88.5%	326	5.4%	109	1.8%	1	0.0%	256	4.2%	6,031
	Total	9,317	89.6%	465	4.5%	183	1.8%	3	0.0%	428	4.1%	10,396
3A	U32	20,516	92.1%	783	3.5%	115	0.5%	2	0.0%	866	3.9%	22,282
	O32	14,162	92.4%	476	3.1%	101	0.7%		0.0%	588	3.8%	15,327
	Total	34,678	92.2%	1,259	3.3%	216	0.6%	2	0.0%	1454	3.9%	37,609
3B	U32	13,234	89.9%	885	6.0%	362	2.5%	5	0.0%	232	1.6%	14,718
	O32	5,493	89.0%	392	6.4%	156	2.5%	1	0.0%	130	2.1%	6,172
	Total	18,727	89.6%	1,277	6.1%	518	2.5%	6	0.0%	362	1.7%	20,890
4A-Aleu	U32	3,733	86.4%	326	7.5%	48	1.1%		0.0%	215	5.0%	4,322
	O32	3,162	83.4%	319	8.4%	63	1.7%	4	0.1%	244	6.4%	3,792
	Total	6,895	85.0%	645	7.9%	111	1.4%	4	0.0%	459	5.7%	8,114
4A-BSea	U32	825	81.8%	48	4.8%	8	0.8%		0.0%	128	12.7%	1,009
	O32	1,259	84.7%	54	3.6%	7	0.5%	1	0.1%	166	11.2%	1,487
	Total	2,084	83.5%	102	4.1%	15	0.6%	1	0.0%	294	11.8%	2,496
4B	U32	238	86.5%	23	8.4%		0.0%		0.0%	14	5.1%	275
	O32	321	91.2%	25	7.1%		0.0%		0.0%	6	1.7%	352
	Total	559	89.2%	48	7.7%		0.0%		0.0%	20	3.2%	627
4C	U32	369	89.1%	29	7.0%		0.0%		0.0%	16	3.9%	414
	O32	343	90.7%	21	5.6%	2	0.5%		0.0%	12	3.2%	378
	Total	712	89.9%	50	6.3%	2	0.3%		0.0%	28	3.5%	792
44D	U32		-		-		-		-		-	0
	O32	5	83.3%	1	16.7%		0.0%		0.0%		0.0%	6
	Total	5	83.3%	1	16.7%		0.0%		0.0%		0.0%	6
CLS	U32		-		-		-		-		-	0
	O32	5	83.3%	1	16.7%		0.0%		0.0%		0.0%	6
	Total	5	83.3%	1	16.7%		0.0%		0.0%		0.0%	6
Grand Total		82,896	90.4%	4,252	4.6%	1,146	1.2%	16	0.0%	3,422	3.7%	91,732

Table 3. Summary of PHI data collected during the 2014 standardized stock assessment grid survey. This table does not include 1,771 2,643 halibut where the PHI was coded as 'unknown'.

			All halibut				U32 halibut (<82cm)		
Reg. Area	**No. of sets**	**No. std. skates**	No. examined	No. with injury	% with injury	No .inj .per std. Skate	No. with injury[1]	% with injury	No .inj. per std. skate
2A	162	1,134.8	1,286	59	4.6%	0.05	13	3.2%	0.01
2B	170	1,194.1	9,282	455	4.9%	0.38	206	4.6%	0.17
2C	123	857.4	10,226	680	6.6%	0.79	215	5.1%	0.25
3A	374	2,605.0	36,962	1,504	4.1%	0.58	900	4.2%	0.35
3B	229	1,607.0	20,827	1,830	8.8%	1.14	1,252	8.6%	0.78
4A-Aleu.	72	502.6	3,318	185	5.6%	0.37	115	6.0%	0.23
4A-Bsea	110	766.7	4,517	601	13.3%	0.78	259	11.9%	0.34
4B	89	621.4	2,274	120	5.3%	0.19	56	6.4%	0.09
4C	20	138.9	615	48	7.8%	0.35	23	8.8%	0.17
4D	58	403.8	862	57	6.6%	0.14	29	7.3%	0.07
CLS	3	20.7	7	1	14.3%	0.05	0	0.0%	0.00
Total	1,410	9,852.4	90,176	5,540	6.1%	0.56	3,068	6.1%	0.31

Table 4. Prior hook injury data collected by IPHC samplers on the 1998-2014 National Marine Fisheries Service trawl surveys. Note that the Gulf of Alaska survey is biennial, whereas the Bering Sea survey is annual.

	1998	1999	2000	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bering Sea halibut																
Total number examined	903	831	661	1,002	843	835	883	2,955	1,570	1,711	1,844	1.855	1,664	1,054	1,180	1,186
Number without injuries	839	814	630	958	54	806	846	2,905	1,535	1,670	1,775	1,800	1,609	1,025	1,119	1,133
Minor injuries	24	6	24	30	45	23	20	24	20	18	42	26	30	28	46	46
Moderate injuries	28	6	7	12	9	4	15	13	12	23	18	25	25	1	13	7
Severe injuries	12	5	-	2	-	2	1	1	3	0	5	4	-	0	1	0
Unknown or not examined	-	-	-	-	-	-	1	12	4	0	4	0	-	1	1	0
Percent with PHI	7.1%	2.8%	4.7%	4.4%	6.3%	3.5%	4.2%	1.3%	2.2%	2.3%	3.5%	3.1%	3.3%	2.8%	5.1%	4.4%
Gulf of Alaska halibut																
Total number examined	-	2,347	-	3,176	-	8,954	2,599	-	2,598	-	5,228	-	3,076	-	1,147	-
Number without injuries	-	2,279	-	3,083	-	8,248	2,505	-	2,472	-	3,252	-	2,968	-	1,107	-
Minor injuries	-	23	-	34	-	30	34	-	73	-	137	-	48	-	20	-
Moderate injuries	-	26	-	46	-	82	51	-	45	-	48	-	51	-	18	-
Severe injuries	-	19	-	5	-	10	7	-	6	-	6	-	2	-	0	-
Unknown or not examined	-	-	-	8	-	584	2	-	2	-	1,785	-	7	-	2	-
Percent with PHI	-	2.9%	-	2.7%	-	1.5%	3.6%	-	4.8%	-	5.6%	-	3.3%	-	3.3%	-

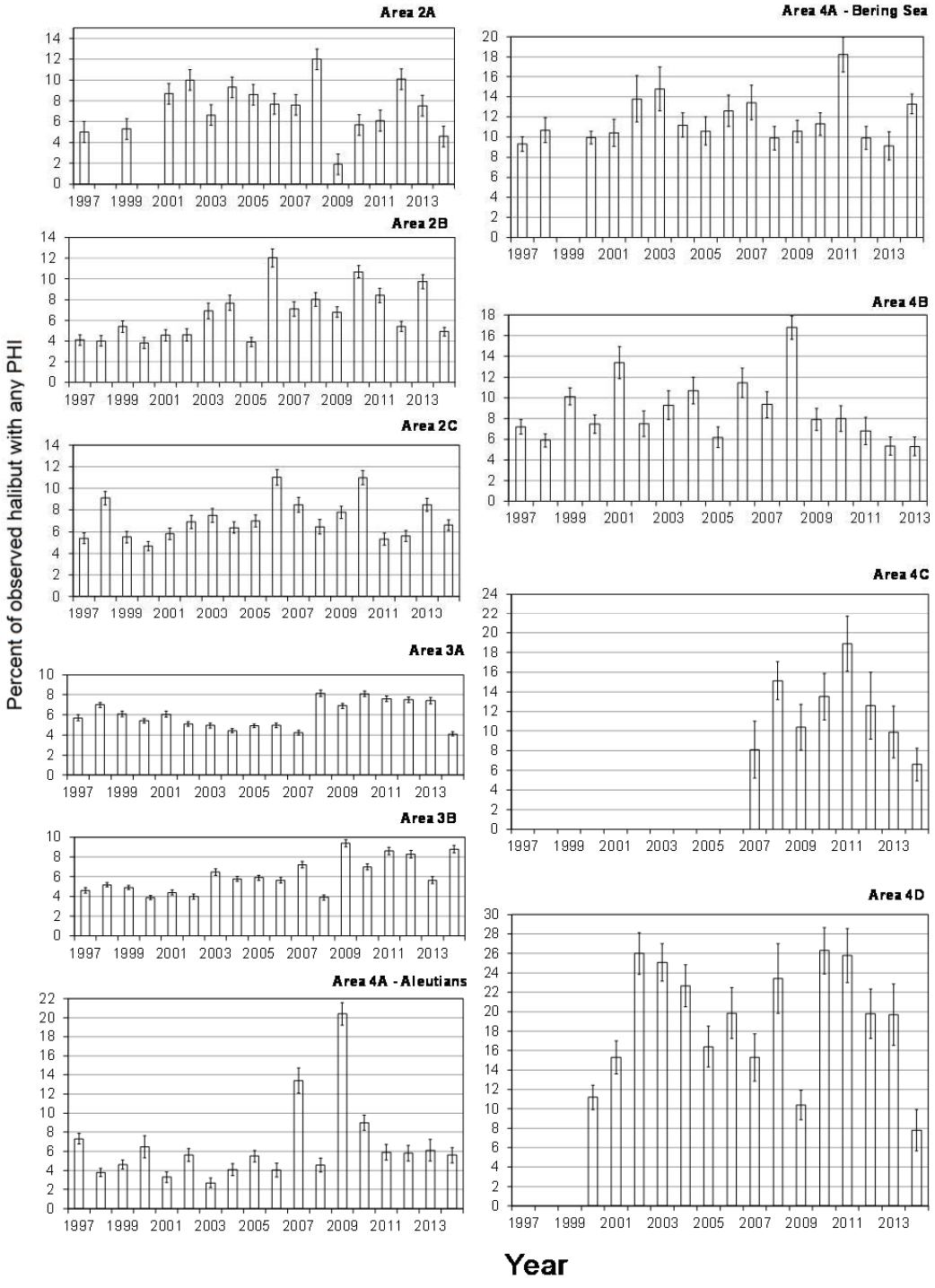


Figure 1. Trends in the percent of halibut observed with any prior hook injuries (PHIs) during the 1997-2014 IPHC standardized stock assessment (SSA) surveys. Vertical bars indicate approximate 95% confidence intervals.

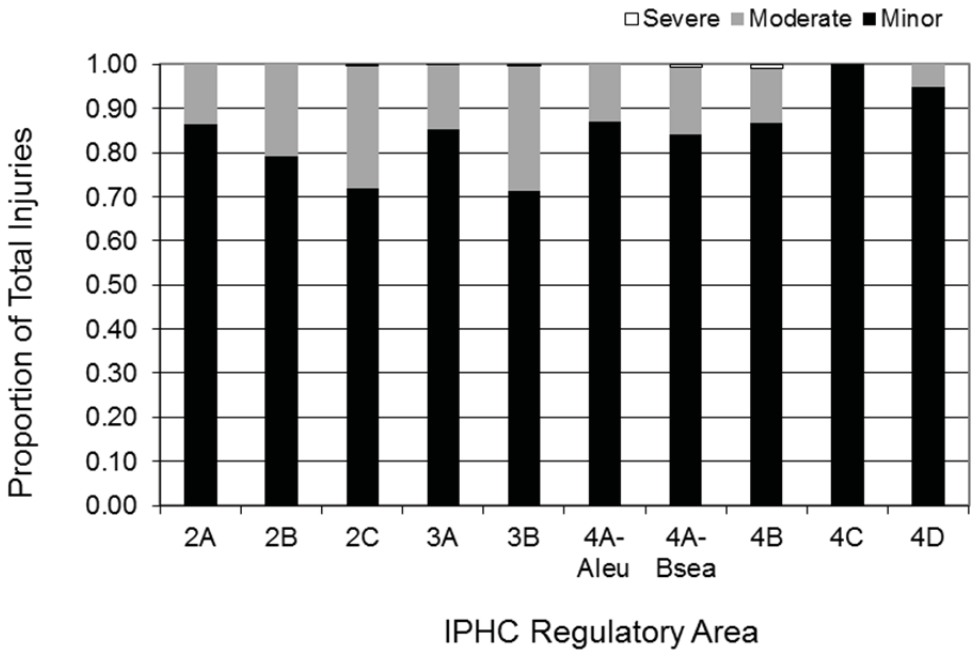


Figure 2. Frequency distribution of injury severity for fish with injuries sampled during the 2014 standardized stock assessment survey. For Regulatory Area 4A, Al = Aleutians and BS = Bering Sea.

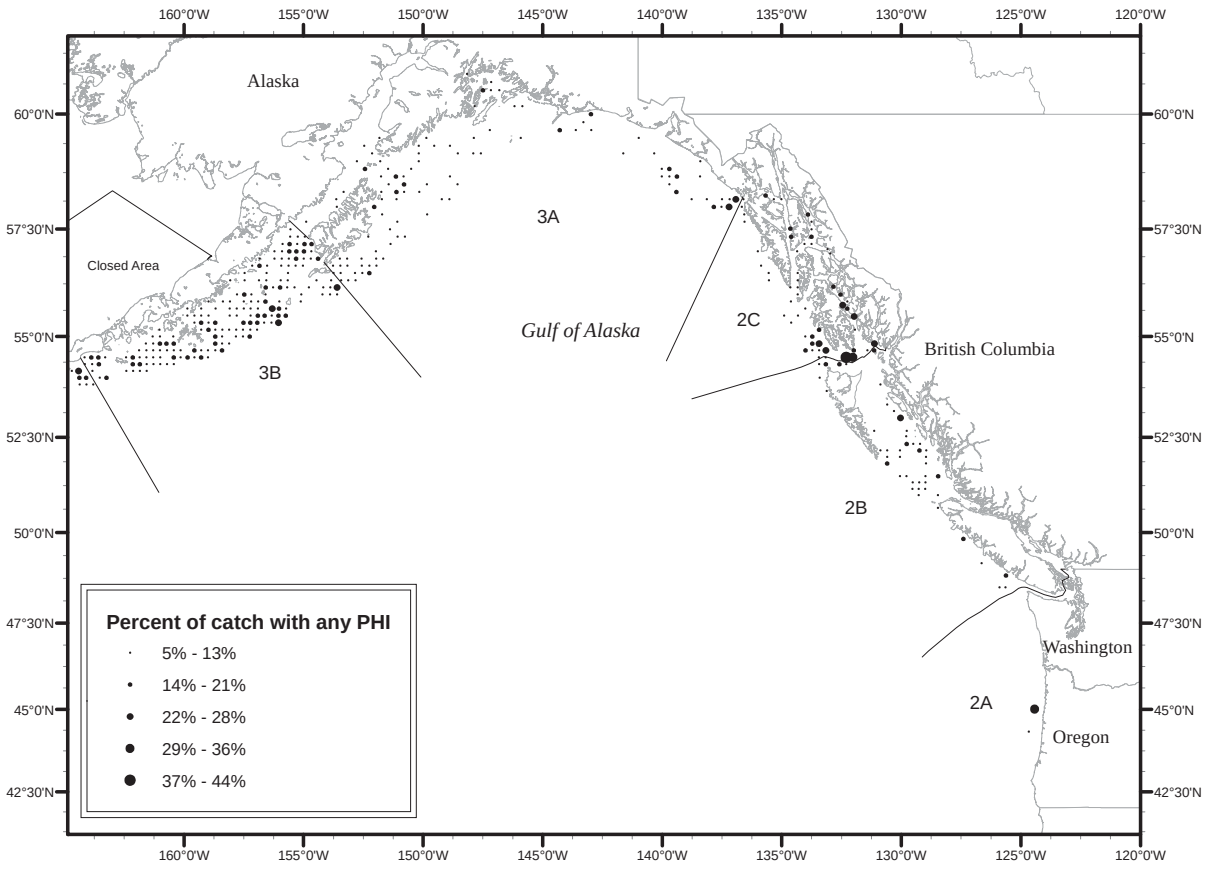


Figure 3. Spatial distribution of the proportion of prior hook injuries (PHIs) among observed halibut in the Gulf of Alaska, British Columbia, and U.S. West Coast standardized stock assessment survey regions in 2014. Stations with <5% PHI observed are not shown because PHIs are common throughout the geographic range.

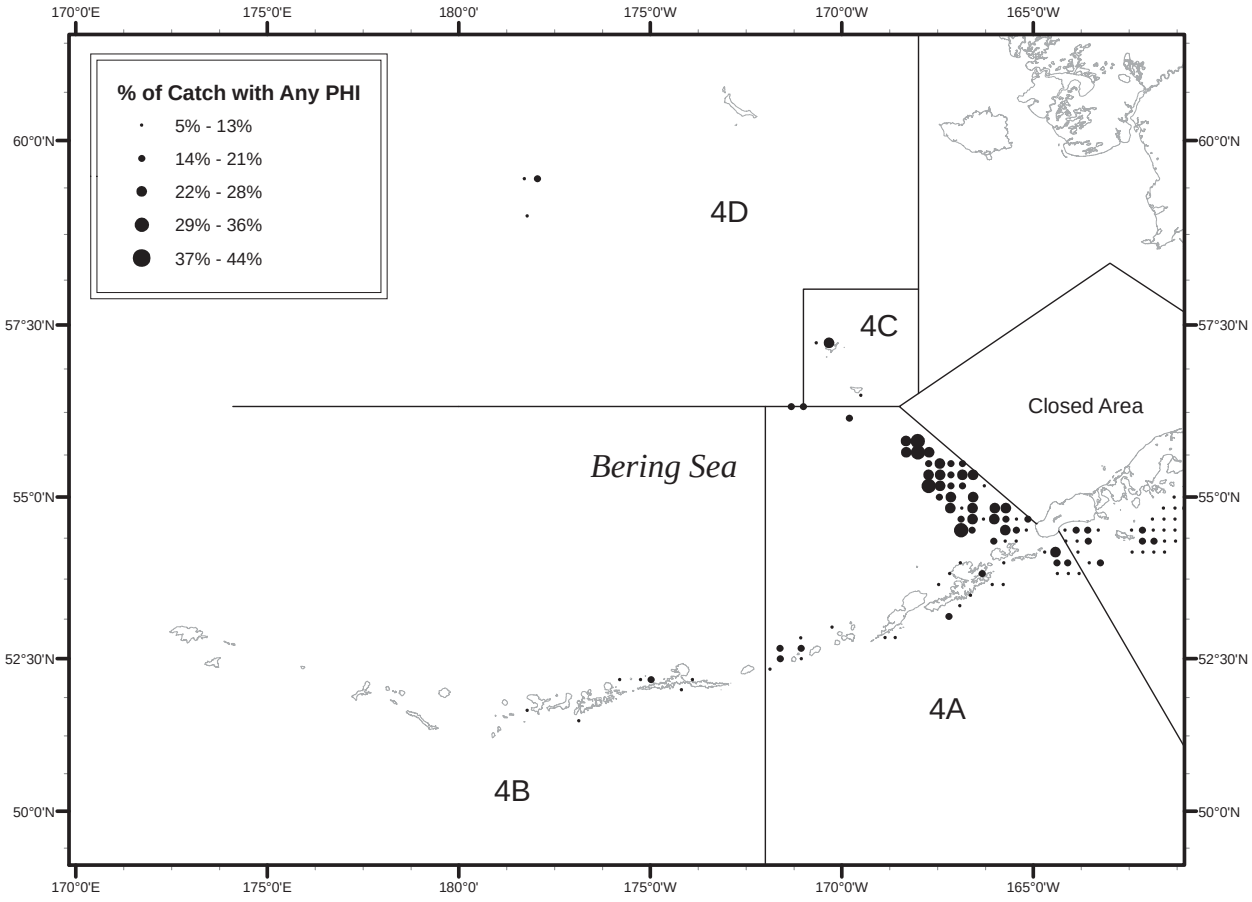


Figure 4. Spatial distribution of the proportion of halibut with any prior hook injuries (PHIs) among all observed halibut in the far western Gulf of Alaska and Bering Sea standardized stock assessment survey regions in 2014. Stations with <5% PHI observed are not shown because PHIs are common throughout the geographic range.