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Below the Surface *Fish and Our Changing Underwater World*





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Below the Surface: Fish and Our Changing Underwater World

Carol Ann Woody, National Park Service (retired)

Alaska has over three million lakes, 12,000 rivers, and an estimated 6,640 miles of ocean coastline. Below the surface swim some of the world's most abundant, healthy, all-wild fish, including salmon, halibut, and eulachon. Fish sustained Alaska Natives for millennia and continue to represent food and economic security for many people.

Citation:

Woody, C. A. 2020. Below the surface: Fish and our changing underwater world. *Alaska Park Science* 19(1):1-3.

Alaska encompasses over three million lakes, 12,000 rivers, and an estimated 6,640 miles (10,686 km) of ocean coastline. Below the mirrored surface swim some of the world's most abundant, healthy, all-wild fish, including iconic salmon, massive halibut, and oil-rich eulachon. Fish sustained Alaska Natives for millennia and now represent food and economic security for many more people.

Alaska's fish harvest is divided among diverse user groups. Commercial fisheries dominate, comprising about 98.6% of total harvest; in 2016, the 5.6-billion-pound seafood harvest created 99,000 full time jobs and \$12.8 billion in national economic output (McDowell Group 2017). Alaskans rely on seafood jobs with over 21,200 rural and 56,800 total residents employed during 2015/2016 (McDowell Group 2017). Compared to commercial fisheries, similar data valuing Alaska's recreational fisheries is surprisingly scarce. Sport fisheries harvest less than 0.5% of Alaska's annual total (Fall 2017), but this fishery is both popular and valuable. Review of 2018 statistics show about 152,000 Alaskans and 305,000 non-residents bought sport fishing licenses in 2018, netting state coffers over \$26 million. But that number doesn't include trip expenditures or jobs created. Analysis of 2007 data (Lew and Larson 2012) indicates Alaskan resident angler average trip values ranged from \$246-\$444 while non-resident trip values ranged from \$2,007-\$2,639. Expanding these numbers using the upper trip value suggests

Alaskans may spend up to \$68 million and non-residents up to \$806 million on recreational fishing annually.

Perhaps most important to rural Alaskans are subsistence fisheries. State and federal laws define subsistence as the "customary and traditional uses" of wild resources for food, clothing, fuel, transportation, construction, art, crafts, sharing, and customary trade. Though comprising less than 0.5% of annual fish and game harvests, subsistence is a major component of rural Alaskan food supplies (Fall 2018). About 34 million pounds (15.4 million kg) of fish and game were harvested by rural residents in 2017, about 276 pounds (125 kg) per person, of which 54% was fish (Fall 2018). These harvests supply about 176% of rural resident protein needs; and this value captures some of the culturally-central resource sharing with non-rural relatives. Replacing these wild foods would be extremely expensive; replacement value for rural communities is estimated at \$170-\$454 million annually (Fall 2018).

Despite the importance of Alaska's fisheries, surprisingly few national park studies focus on fish and their primary habitat: water. Here we share a range of park-related research on various population- and species-specific fish topics, such as: [how bears led biologists to unknown salmon streams](#); [what salmon surveys revealed along a proposed mining road](#); [that halibut really are home bodies](#); [what sonar showed about coho salmon abundance](#); [how](#)

A female sockeye salmon seeks a nest site in the Tazimina River, Lake Clark National Park and Preserve.
PHOTO COURTESY OF MICHAEL MELFORD

[tiny, oil-rich, and still largely mysterious eulachon](#) fueled generations of humans; [how a water sample can reveal fish biodiversity](#); [proof that ancient Alaskans fished for deep-water cod](#); and the [historical importance of a Bristol Bay cannery](#). Those studies are complemented by articles on some current and projected impacts on fish habitats from: the [changing climate](#) and [implications of thawing permafrost](#); [sources of mercury in our fish](#); [mining impacts and restoration](#); and finally, [studies and implications of an invasive aquatic plant](#).

We hope this edition of *Alaska Park Science* gives you a deeper understanding of what lies below the surface in Alaskan waters and inspires you to get your feet wet exploring further.

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A male sockeye salmon struggles through the shallows on his way to the spawning grounds, Tazimina River, Lake Clark National Park and Preserve.
PHOTO COURTESY OF MICHAEL MELFORD





Salmon Sleuths: GPS-collared Bears Lead Researchers to Unknown Salmon Streams in Interior Alaska

Mathew S. Sorum, Kyle Joly, Matthew D. Cameron, David D. Gustine, and Grant Hilderbrand, National Park Service

Movement data from GPS-collared bears provides valuable information to improve conservation efforts not only for bears, but also for salmon. This study describes the discovery of an unexpected relationship between bears and salmon in the Arctic Interior and the out-sized role salmon have on diet and movement patterns of grizzly bears living in a nutrient-limited system.

Citation:

Sorum, M. S., K. Joly, M. D. Cameron, D. D. Gustine, and G. V. Hilderbrand. 2020. Salmon sleuths: GPS-collared bears lead researchers to unknown salmon streams in Interior Alaska. *Alaska Park Science* 19(1): 4-9.

Grizzly bears (*Ursus arctos*) are brown bears living away from coastal areas. Grizzly bears are food generalists (omnivores), which allows them to take advantage of a wide variety of food resources. Yet, their simple digestive system and seasonal hibernation when food is scarce, requires them to locate large quantities of seasonally abundant, energy-rich foods to satisfy yearly energetic requirements (Pritchard and Robbins 1990). While coastal-dwelling brown bears typically rely heavily on salmon and other marine resources, interior grizzly bears are thought to rely on terrestrial meat sources (Hilderbrand et al. 1999). The need for efficient energy acquisition is pressing for grizzly bears above the Arctic Circle, since they hibernate up to seven months of the year, limiting their time to satisfy annual food requirements.

The Arctic is extremely limited in terms of energy-rich plant resources (Swanson 2017). The combination of winters that can endure eight months and cool summer temperatures leads to lower plant productivity than in other biomes. Poor soil conditions and permafrost also limit vegetative growth. This low primary productivity leads to low densities of herbivores such as moose (*Alces alces*), Dall's sheep (*Ovis dalli*), muskox (*Ovibos moschatus*), and caribou (*Rangifer tarandus*) that grizzly bears could potentially use as food. Owing to these environmental factors, grizzly bears in Arctic Alaska are living at the species' northern-most extent and are noticeably smaller in comparison to

the southern, salmon-fed coastal bears (Hilderbrand et al. 2018).

Northwest Alaska is one of the least developed regions in the world. Within this region, a 220-mile (354 km) industrial road (the [Ambler Road](#)) is proposed that would parallel the southern flank of the Brooks Range. A road here could potentially affect fish and wildlife in and around Gates of the Arctic National Park and Preserve (NP&Pres), including bears. Grizzly bears are considered good indicators of ecosystem health because they are apex predators and long-lived (some live more than 20 years). We wanted to better understand the ecosystem prior to industrial development because past studies show that human development and activity can alter bear behavior and habitat use (Gibeau et al. 2002, Fortin et al. 2016). With this in mind, we designed a study to improve our understanding of grizzly bear habitat use and ecology in Gates of the Arctic NP&Pres to help inform how bears might be affected by road development and increased human activity in the region.

We began tracking movement patterns of grizzly bears across the landscape using Global Positioning System (GPS) collars in 2014. During the next three years, we collected movement and morphological data (e.g., body size and lean mass; Hilderbrand et al. 2018) from 53 bears. The GPS data allowed us to identify habitats most frequented by bears and provided a better understanding of their ecological

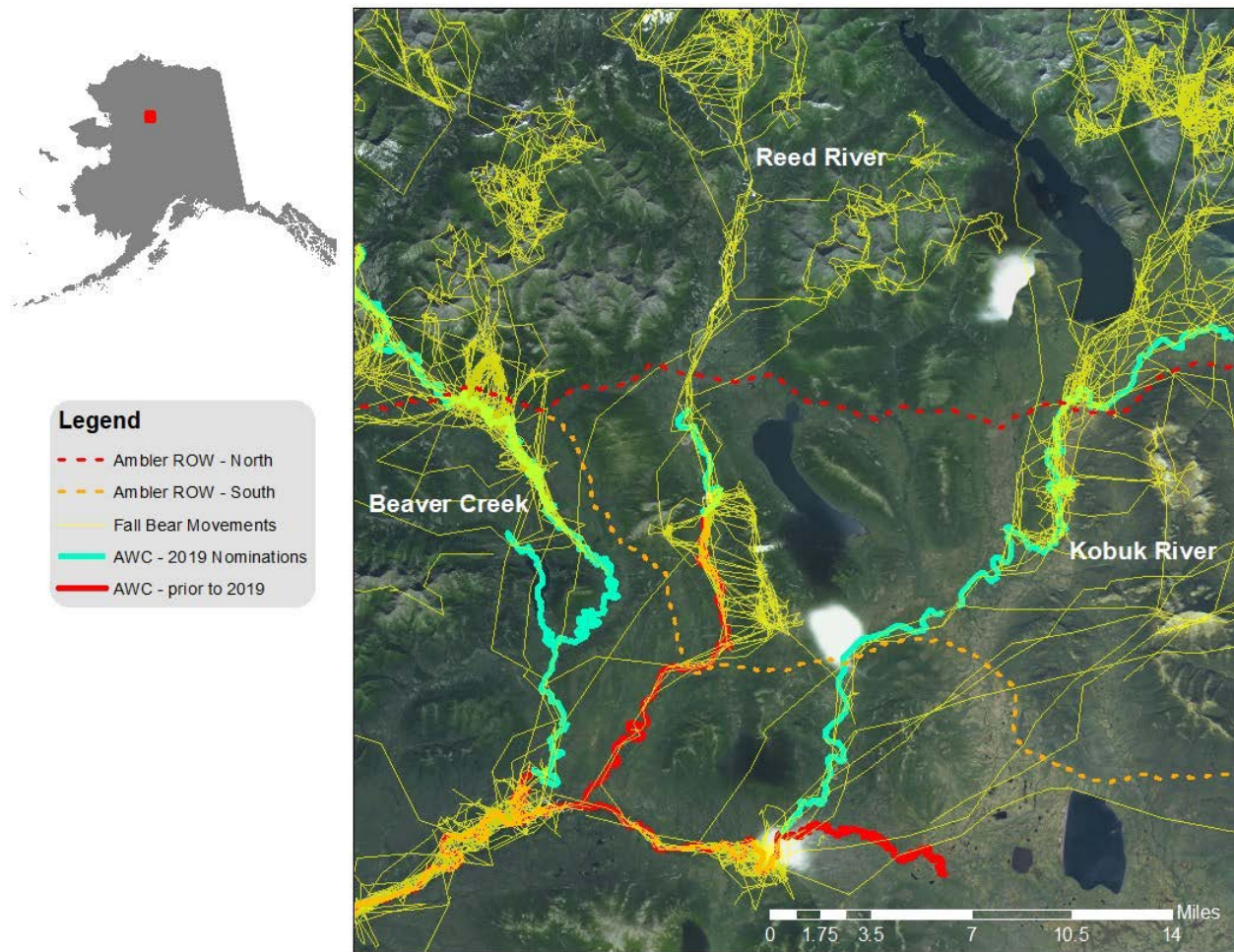


Figure 1. Movement data collected from GPS-collared grizzly bears showing high use of streams near areas transected by the proposed Ambler Road.

importance. Not surprisingly, collared bears dened in the mountains and generally remained there throughout the spring. What was surprising was that beginning in mid-July, many grizzly bears began concentrating movement near streams at the headwaters of the Kobuk and Koyukuk rivers. This behavior is typical for bears when streams contain a food resource, such as salmon, however many of the streams visited by bears were not known to support salmon (Figure 1). We took to the field to investigate why bears were frequenting these streams.

Our field investigations of streams in and around Gates of the Arctic NP&Pres used by grizzly bears revealed not only the presence of chum salmon (*Oncorhynchus keta*), but also that bears were taking advantage of this energy-rich resource; a fact highlighted by the piles of salmon jaw bones we found lining the banks (Figures 2 and 3; Sorum et al. 2019). The GPS data suggested that bears were fishing up to 15 different streams throughout the upper Kobuk and Koyukuk watersheds, many of which had not been previously identified as supporting salmon. A stable isotope diet analysis was conducted and results from this analysis provided additional evidence that salmon were an important food item for grizzly bears within the region (Mangipane et al. *In review*). In fact, salmon contributed to a significant portion (>25%) of the diet for at least half of the collared grizzly bears, which was unexpected.

Our field investigations documented chum salmon presence in three streams not yet listed in the Alaska Department of Fish and Game's (ADF&G) [Anadromous Waters Catalog](#) (AWC); Alaska's regulatory catalog of waters known to support salmon and other anadromous (sea-going) fish. Nominations of those streams to the AWC spurred discussion with ADFG's Fresh Water Fish Inventory team regarding the lack of systematic surveys focused on salmon distribution within the upper Kobuk and



Figure 2. A well-worn trail along the bank of Beaver Creek created by bears fishing for chum salmon.
NPS/MATT CAMERON



Figure 3. Piles of chum salmon remains, such as this one found along Beaver Creek during field investigations, suggest that salmon are fully consumed, leaving only the jaws. August 2016, Alaska.
NPS/MATT CAMERON

Koyukuk drainages that might be impacted by the proposed Ambler Road. We forged a collaboration between ADF&G and NPS to begin filling this data gap by conducting fish surveys across the upper Kobuk and Koyukuk watershed during summer of 2018. This collaborative effort documented nearly 400 miles (644 km) of previously unknown salmon habitat for nomination to the AWC including 11 streams crossed by the proposed Ambler Road (see [Cathcart and Giefer this issue](#)). Designation into the AWC for these salmon streams will add additional regulatory protections to help reduce impacts to salmon habitat from road development.

Movement data from GPS collared bears provided valuable information to improve conservation efforts not only for bears, but also for salmon. We plan to further study the dynamics between bears and salmon by determining how salmon influence movement patterns, habitat selection, and survival of grizzly bears across the Arctic Interior.

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Fish Inventories of the Upper Kobuk and Koyukuk River Basins

Nate Cathcart and Joe Giefer, Alaska Freshwater Fish Inventory Program, Division of Sport Fish-Research and Technical Services, Alaska Department of Fish & Game

Fish inventories in the Brooks Range added hundreds of new miles to the Anadromous Waters Catalog, improving overall knowledge of fish species assemblage, distribution, and abundance in the region. This information will help guide management actions on the proposed Ambler Road and future studies of aquatic resources.

Citation:

Cathcart, C. N. and J. Giefer. 2020. Fish inventories of the upper Kobuk and Koyukuk river basins. *Alaska Park Science* 19(1): 10-17.

The Alaska Freshwater Fish Inventory (AFFI) program was established by the Alaska Department of Fish & Game (ADF&G) in 2002. Tasked with documenting freshwater fish species assemblages throughout the state, this program is a major contributor to ADF&G's [Catalog of Waters Important for the Spawning Rearing or Migration of Anadromous Fishes](#) or the Anadromous Waters Catalog (AWC). Alaska state law affords special protection to lakes and rivers that support anadromous fish species under the Anadromous Fish Act (Alaska Statute 16.05.871). Qualifying water bodies are recorded in the AWC. There are physical maps and an [online mapping application](#) of the AWC that specify the location and extent of water bodies that are documented by ADF&G to support anadromous fishes and are therefore protected by state law. Anadromous describes a life history strategy where fish are born in freshwater, migrate to the ocean as juveniles, then return to freshwater to spawn as adults. The most commonly acknowledged species of anadromous fish in Alaska are the five species of Pacific salmon, but there are at least 21 species of anadromous fish documented in Alaska including Dolly Varden (*Salvelinus malma*), Arctic lamprey (*Lampetra camtschatica*), and three whitefish species, including sheefish (*Stenodus leucichthys*). In addition to documenting the distribution of anadromous fishes, these inventory efforts also document various freshwater resident fish species including round whitefish (*Prosopium cylindraceum*), longnose

sucker (*Catostomus catostomus*), northern pike (*Esox lucius*), and Alaska blackfish (*Dallia pectoralis*). Some species have variable life histories in Alaska, whereby some populations can have both freshwater resident and anadromous life histories such as Dolly Varden, rainbow trout (*Oncorhynchus mykiss*), and sheefish.

Each year, AFFI project staff identify a project area with a high concentration of water bodies with limited or no fish distribution information. Typically, staff use helicopters to access these remote areas where they conduct a rapid, systematic inventory of fish species using multiple gear types including electrofishers, minnow traps, seine nets, and hook-and-line gear. Data on aquatic and riparian habitats are also gathered at each site. Ultimately, the information collected is added to the AFFI database and streams found to support anadromous fish species are nominated to the AWC. All collected data are available through an [interactive mapping application](#) available on the ADF&G website.

In late 2017, AFFI staff were contacted by a wildlife biologist with the National Park Service (NPS) who had recently tracked GPS-collared grizzly bear (*Ursus arctos*) movement concentrated in stream corridors along the southern boundary of the Gates of the Arctic National Park & Preserve, one of the northernmost national parks in the United States. In several instances they documented bears feeding on chum salmon (*Oncorhynchus keta*) in tributaries of the upper Koyukuk and Kobuk river basins. NPS

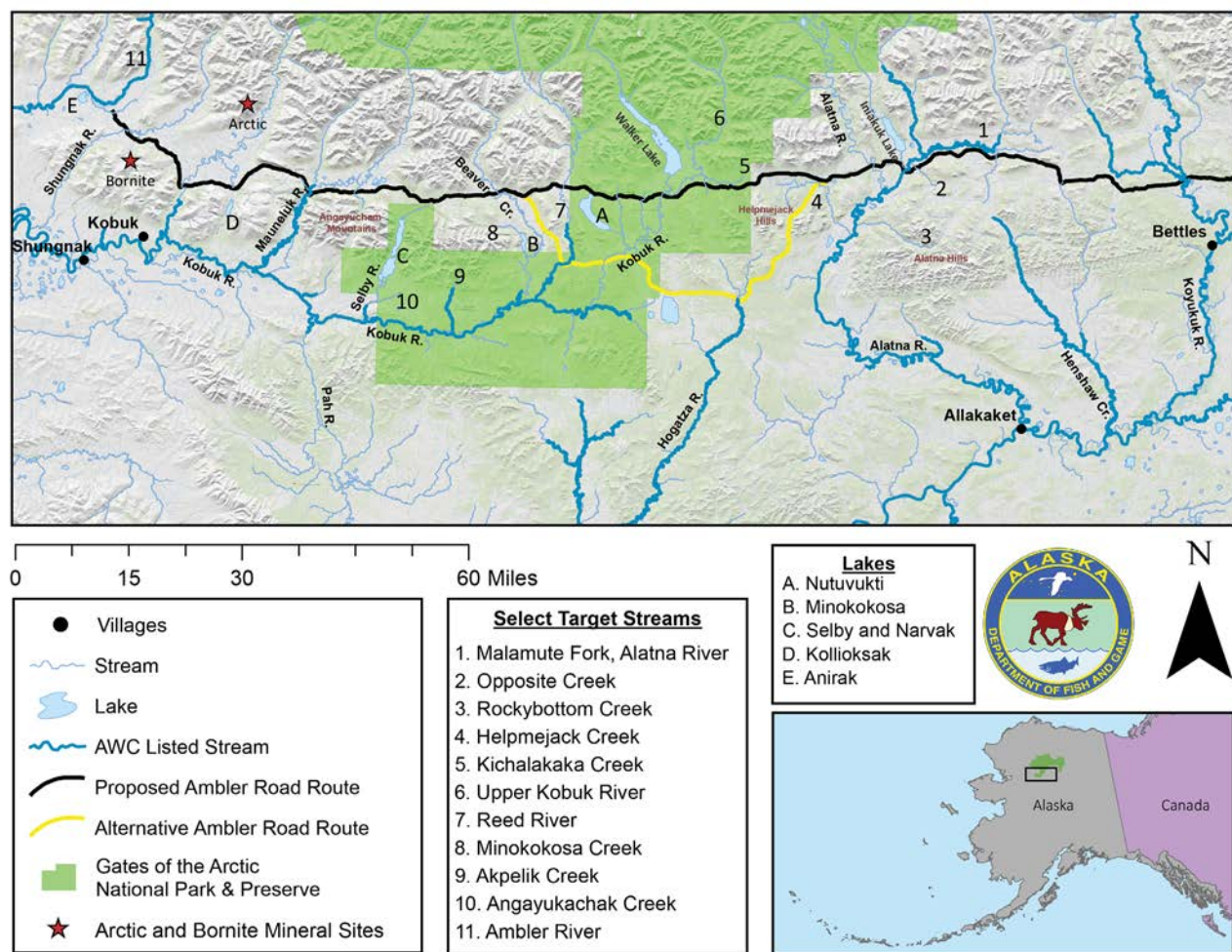


Figure 1. Proposed Ambler road corridor and a portion of the study area relative to Gates of the Arctic National Park & Preserve with select target streams, notable lakes, and relevant landforms identified.

staff noted that the extents of anadromous species distribution in several of these water bodies were not accurately represented in the AWC. Together, NPS and AFFI staff designed a field survey to meet AFFI objectives and provide valuable fisheries information to the NPS by inventorying fish communities along the southern edge of the Brooks Range in the upper Koyukuk and Kobuk river basins.

Kobuk and Koyukuk River Basins

The 2018 AFFI project study area covered roughly 400 square miles (1,036 km²) of the upper

Koyukuk and Kobuk river basins just north of the Arctic Circle. The landscape within the project area is made up of low, rolling mountains, interspersed with boggy lowlands underlain by permafrost, and bordered along its northern edge by the tall rugged mountains of the Brooks Range. In 1980, the United States Congress designated a portion of the upper reaches of the Koyukuk and Kobuk rivers as part of the National Wild and Scenic Rivers System. The focus of this article is on a stretch of land between the easterly village of Bettles and the western village of Kobuk (Figure 1). The water bodies across this area had not previously been systematically sampled, although some traditional information pertaining to fish distributions exists as a helpful guide (Yukon River Drainage Fisheries Association 2008).

These two river systems support important subsistence and commercial fishery harvests. The most recent ADF&G annual report published by the Division of Subsistence in 2017 (Fall et al. 2017) indicates that 101,772 salmon and 187,465 non-salmon fish were harvested within these subsistence fisheries areas in 2014. In 2017, approximately 462,000 chum salmon were harvested in the commercial fishery in Kotzebue Sound near the mouth of the Kobuk River. The Koyukuk River appears to be the largest single contributor to the summer chum salmon run on the Yukon River. The Koyukuk River drainage Chinook salmon (*Oncorhynchus tshawytscha*) run has been identified by ADF&G as a Stock of Concern (5 AAC 39.222) since 2000 and is an important subsistence fishery.

These lands and waters are remote, largely undeveloped, and support subsistence lifestyles; however, the area has some industrial development and is open to potential development in the future. Accurate fish distribution data are critical to the agencies that manage these lands and the stakeholders that rely on the fish resources of the region. Active

and proposed developments include the Bornite and Arctic mines, respectively, in the Ambler Mining District (Figure 1). Another proposed development is the Ambler Road, a 211-mile (339 km) industrial access road starting at the Dalton Highway, south of Wiseman, and stretching west to its terminus north of Kobuk, near Lake Anirak. This longitudinal corridor is bordered by the Brooks Range to the north and a progression of foothills rising to the south. The southern boundary includes the Alatna Hills of the Koyukuk Basin, the Helpmejack Hills (a conjunctive landform between the Kobuk and Koyukuk river basins), and the Angayucham Mountains of the Kobuk River valley. In 1980, the Alaska National Interest Lands Conservation Act (ANILCA) established a right-of-way across Gates of the Arctic National Park & Preserve for the proposed industrial road to access the Ambler Mining District. Documenting fish distributions here will assist management agencies, local villagers, and private companies in making informed decisions about important fish communities that may be sensitive to resource development, changing land uses, or shifting climate patterns.

From Bear Surveys to Fish Surveys

Within the project area, geographic information system (GIS) mapping software was used to select and rank potential sample sites. The highest rank was given to the site that would add the most mileage to the AWC if anadromous fish were documented. Additional considerations were made to ensure that sampling efforts would not be too concentrated in certain drainages and to ensure that sample sites were accessible given helicopter fuel and payload limitations. Once in the field, staff navigated to selected sites using professional judgement to identify a safe landing zone proximal to selected target sites. Fortunately, AFFI staff had the additional benefit of information from the NPS wildlife biologist who

provided valuable data on grizzly bear distributions that identified specific locations where salmon were likely to be spawning.

Due to the remoteness of the project areas, AFFI staff relied on two helicopters to transport two 2-person crews that primarily used electrofishing methods to sample fish. Electrofishing involves passing a current through the water to induce “taxis” where fish are briefly immobilized or involuntarily forced to swim toward the source of the electrical current. Once immobilized or attracted toward the electrical source, fish are netted, then transferred to a bucket or livewell before being identified, measured, photographed, and released following a period of recovery. There are three major benefits of electrofishing: (1) when performed correctly, the majority of fish are not harmed; (2) it is less selective than many capture methods, allowing staff to collect a broad range of species and life stages in a single effort and; (3) it is time efficient, allowing crews to visit a greater number of sites per day. On a typical day, the raft crew floated one stream, continuously sampling for several miles, while the headwater crew visited four to eight sites sampling a 500 to 1,000 feet (150 to 300 m) stream reach at each site.

Electrofishing was the primary method of fish sampling, but not the sole method. Aerial surveys were used to determine if adult salmon were present or spawning in water that was clear enough to identify species from the air. The headwater crew occasionally used hook-and-line surveys in deeper waters where electrofishing was less effective, and minnow traps to sample for juvenile salmon (and other fishes). Non-lethal tissue samples were collected for genetic testing by the ADF&G Division of Commercial Fisheries. Voucher specimens and tissue from select fish species were also collected for the University of Alaska Fairbanks Museum of the North for their collection of Alaskan fish species.



Katelyn Zonneville holds two large Arctic grayling from a tributary that flows into Narvak Lake.
ADF&G/NATE CATHCART



Max Newton holds a male chum salmon ready to spawn from a tributary to the Kobuk River.
ADF&G/JOE GIEFER



Freshwater resident fish commonly sampled include, clockwise from top left, round whitefish, longnose sucker, and northern pike.

ADF&G/NATE CATHCART



A Dolly Varden from Minokokosa Creek, upstream of Lake Minokokosa.

ADF&G/NATE CATHCART



A juvenile Chinook salmon from Opposite Creek, a small tributary of the Malamute Fork Alatna River.

ADF&G/NATE CATHCART



Flying over Narvak Lake looking south toward Lake Selby and the Kobuk River.

ADF&G/NATE CATHCART

AFFI field crews also recorded baseline habitat data at each target stream and took photos of the sample reach. Habitat data included a suite of riparian and geomorphic habitat measurements as well as water quality parameters. These variables provide a qualitative and quantitative assessment of the sample locations and provide some information about the habitat quality for various fish species and life history requirements (i.e., size of stream substrates, pH, presence of large wood for cover, or water temperature).

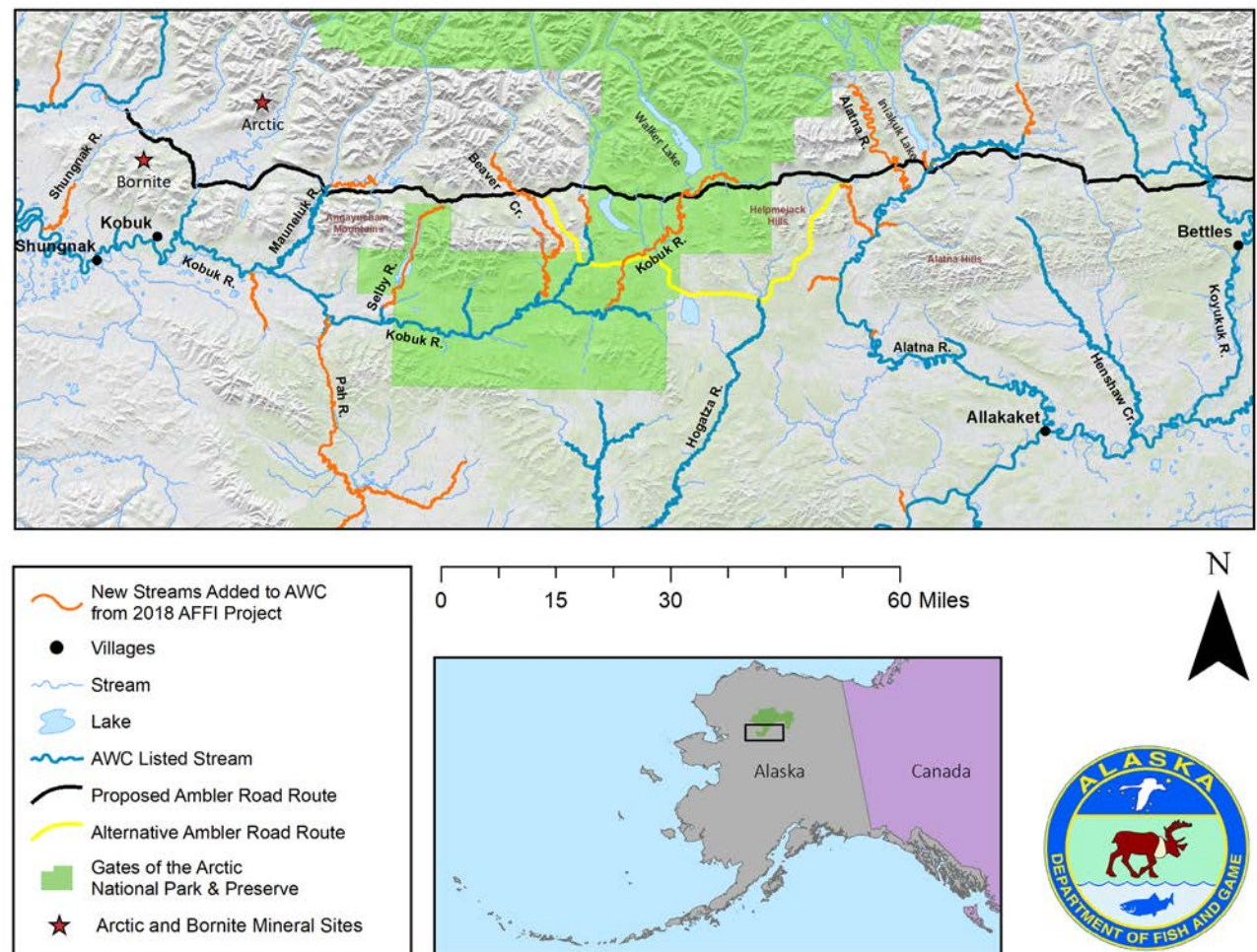
Project Outcomes

From July 24 to August 13, 2018 the two AFFI field crews spent 20 days in the field and documented 14 fish species in total across the project area, 13 of

which were present in waters adjacent to the proposed road corridor. Individual fish ranged from 3-inch (76 mm) Alaska blackfish to large adult sheefish reaching 3.5 feet (914 mm) in length. Anadromous species encountered along the proposed Ambler Road corridor included Dolly Varden, chum salmon, Chinook salmon, and humpback whitefish (*Coregonus pidschian*). Freshwater residents were represented by Arctic grayling (*Thymallus arcticus*), lake trout (*Salvelinus namaycush*), round whitefish, burbot (*Lota lota*), longnose sucker, northern pike, and slimy sculpin (*Cottus cognatus*). The 14 species documented in 2018 by the AFFI program accounts for almost 25% of the approximately 55 Alaskan fish species that inhabit freshwater during some part of their lives (Morrow 1980). AFFI sampling efforts

likely underestimated the actual diversity in the study area because staff did not encounter species previously documented such as broad whitefish (*Coregonus nasus*), least cisco (*Coregonus sardinella*), coho salmon (*Oncorhynchus kisutch*), and lake chub (*Couesius plumbeus*; Mecklenburg et al. 2002). This is likely a result of our sampling timeframe, effort, and location relative to those species' life histories. Although sampling was scheduled when anadromous fish were expected to be present in the target waterbodies, natural variation in species distributions and run timing does not exactly coincide with all sampling efforts. Another limitation of the project is work was focused primarily on streams and, in general, AFFI staff do not target fish communities in lakes. Accordingly, Iniakuk, Walker, Nutuvukti, Minokokosa, Narvak, Selby, and Kollioksak lakes will need further examination to document fish species dependent on these lake habitats.

This field work culminated in adding or extending 41 streams to the AWC, totaling 481.4 miles (774.7 km) of newly documented anadromous fish habitats. In the proposed road corridor, 12 AWC streams were added or extended that would be crossed by the proposed Ambler Road (Figure 2), along with resident fishes documented throughout. Observations of spawning adult and rearing juvenile Chinook salmon were limited to the upper Koyukuk River basin including Helpmejack Creek and the Malamute Fork Alatna River and its tributaries. Chum salmon were present throughout this corridor including the Alatna River and its tributaries (Rockybottom and Helpmejack creeks) in the Koyukuk River drainage; they were also in the upper Kobuk River, Reed River, Beaver Creek, Mauneluk River, Shungnak River, and a tributary to the Ambler River (i.e., the end of the proposed road) from the Kobuk River drainage. Other creeks peripheral to the corridor that supported chum salmon and Dolly



Varden included Akpelik Creek and the Selby River downstream of Angayukachak Creek. Dolly Varden were also found far upstream in the easternmost site of the Kobuk River drainage, Kichalakaka Creek, and upstream of Minokokosa Lake. Interestingly, a single humpback whitefish was captured at the outlet of Walker Lake; this is an anadromous whitefish species with no prior documented presence in the Kobuk drainage raising further questions about their distribution and abundance in Alaska.

Figure 2. Streams added to the Anadromous Waters Catalog (AWC) based on results of the 2018 AFFI fish sampling.



Nate Cathcart holds a humpback whitefish from Walker Lake.

ADF&G/KATELYN ZONNEVILLE

Post-field season, AFFI staff contacted village residents and biologists familiar with the area. This was done in an attempt to locate supplemental information that would corroborate AFFI sampling results in locations where the sampling efforts did not capture species that were anticipated or only in limited numbers. For example, searches for additional documentation of species in lakes of the upper Koyukuk River drainage led to information on (and pictures of) the presence of least cisco in Iniakuk Lake as well as evidence of chum salmon spawning in the lake's tributaries—observations

project staff did not experience. Information such as this can be used to guide additional sampling efforts.

Summary

The 2018 AFFI season in the Brooks Range added hundreds of new miles to the AWC and improved overall knowledge of fish species assemblage, distribution, and abundance in this region. The information gathered by this study will be useful for stakeholders of this region and can guide management actions and future studies of aquatic resources.

The two crews had extraordinarily nice weather for the three weeks of field work that equated to about 20 minutes spent in rain gear. This not only kept morale high and flying safe, but also allowed for more effective sampling on the water and in the air since our vision was not impeded by rippled water. Indeed, aerial surveys identifying spawning chum salmon provided the bulk of miles added to the AWC by the headwater crew. Proposed future work seeks to build off this success by performing more aerial surveys later in the year when chum salmon (and potentially coho salmon) would be more likely to have reached their spawning locations. Unfortunately, the wonderful run of good weather should not be considered typical.

All AFFI data are publicly accessible and stakeholders are encouraged to use the online tools provided by the ADF&G. To visualize the AWC and explore AFFI sampling events, the annually updated Fish Resource Monitor Internet Map Service can be accessed from the ADF&G website or found in our references. Users can view species distributions, note sampled locations and unsampled streams, dive deeper into site-specific data (including pictures), and download a form to nominate water bodies for inclusion in the AWC.

Acknowledgments

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Marine Protected Area Research in Glacier Bay Leads to Insights into Halibut Behavior

Julie K. Nielsen and Andrew C. Seitz, College of Fisheries and Ocean Sciences, University of Alaska Fairbanks

The halibut movement studies conducted in Glacier Bay as part of marine protected area research provide important insights into halibut behavior that may have implications for the management of halibut at larger scales. High rates of year-round residency combined with winter commercial fisheries closures when fish migrate suggest that the Glacier Bay MPA could provide year-round refuge from commercial harvest for both resident and migrant fish.

Citation:

Nielsen, J. K. and A. C. Seitz. 2020. Marine protected area research in Glacier Bay leads to insights into halibut behavior. *Alaska Park Science* 19(1): 18-25.

Pacific halibut (*Hippoglossus stenolepis*) is an iconic fish species in the North Pacific Ocean due to its large size and economic, ecological, and cultural importance. Pacific halibut (referred to subsequently as “halibut”) is one of the largest flatfish species, reaching lengths of almost nine feet (2.7 m) and weighing up to 500 pounds (227 kg; Mecklenburg et al. 2002). It is highly sought by commercial, sport, and subsistence fisheries for the large, mild, and delicate fillets it provides.

Halibut is one of the most important commercially fished species in Glacier Bay National Park and Preserve (GBNP), where commercial fishing has occurred since the early 1950s (Mackovjak 2010). In 1990, the Alaska Wildlife Alliance sued the National Park Service for allowing commercial fishing to occur in GBNP ([Alaska Wildlife Alliance v. Jensen](#)). Commercial extraction activities are not allowed in parks unless specifically authorized by the park’s enabling legislation; commercial fishing was not authorized in GBNP’s enabling legislation (1916 Organic Act, Pub.L. 64–235, H.R. 15522, 39 Stat. 535). In addition, motorized vessels were prohibited in portions of the park designated as Wilderness Waters under the Alaska National Interest Lands Conservation Act (ANILCA) of 1980. This suit initiated a dialogue about commercial fishing in GBNP and the National Park Service (NPS) began to discuss plans for implementing commercial fisheries closures in part or all of GBNP marine waters (Mackovjak 2010).

Congress passed legislation in 1999 to close all commercial fisheries (not including charter fishing) in the interior waters of GBNP known as “Glacier Bay Proper” (Figure 1). The commercial halibut fishery is being phased out by allowing existing fishers to continue fishing until they retire. In 2009, Glacier Bay was designated a marine protected area (MPA) and thus joined a nation-wide system of MPAs designed to advance marine conservation and sustainable use. Although the technical boundary for the Glacier Bay National Park Marine Protected Area extends to the outside waters, here we refer to the interior waters as “the MPA” because the majority of commercial fishing and vessel traffic regulation by the NPS occurs there.

Closing areas to fishing can lead to increases in biomass, size, and diversity of fishes within the closed areas (Edgar et al. 2014). However, information on fish movement patterns is critical for understanding whether specific area closures are likely to provide such benefits. For example, increases in fish abundance and size structure can occur in a MPA that is large enough to encompass the range of typical fish movements (Gruss et al. 2011). However, when plans for fisheries closures in GBNP were first discussed in the early 1990s, very little information on small-scale movement patterns of halibut existed that would allow insights into potential benefits of fisheries closures for halibut in GBNP. On the contrary, because halibut are strong swimmers capable of traveling long distances (Skud 1977,

Andrew Seitz (right) and Mark Evans (left) attach a Pop-up Satellite Archival Tag to a Pacific halibut in Glacier Bay National Park. UNIVERSITY OF ALASKA FAIRBANKS/KEVIN SIWICKE

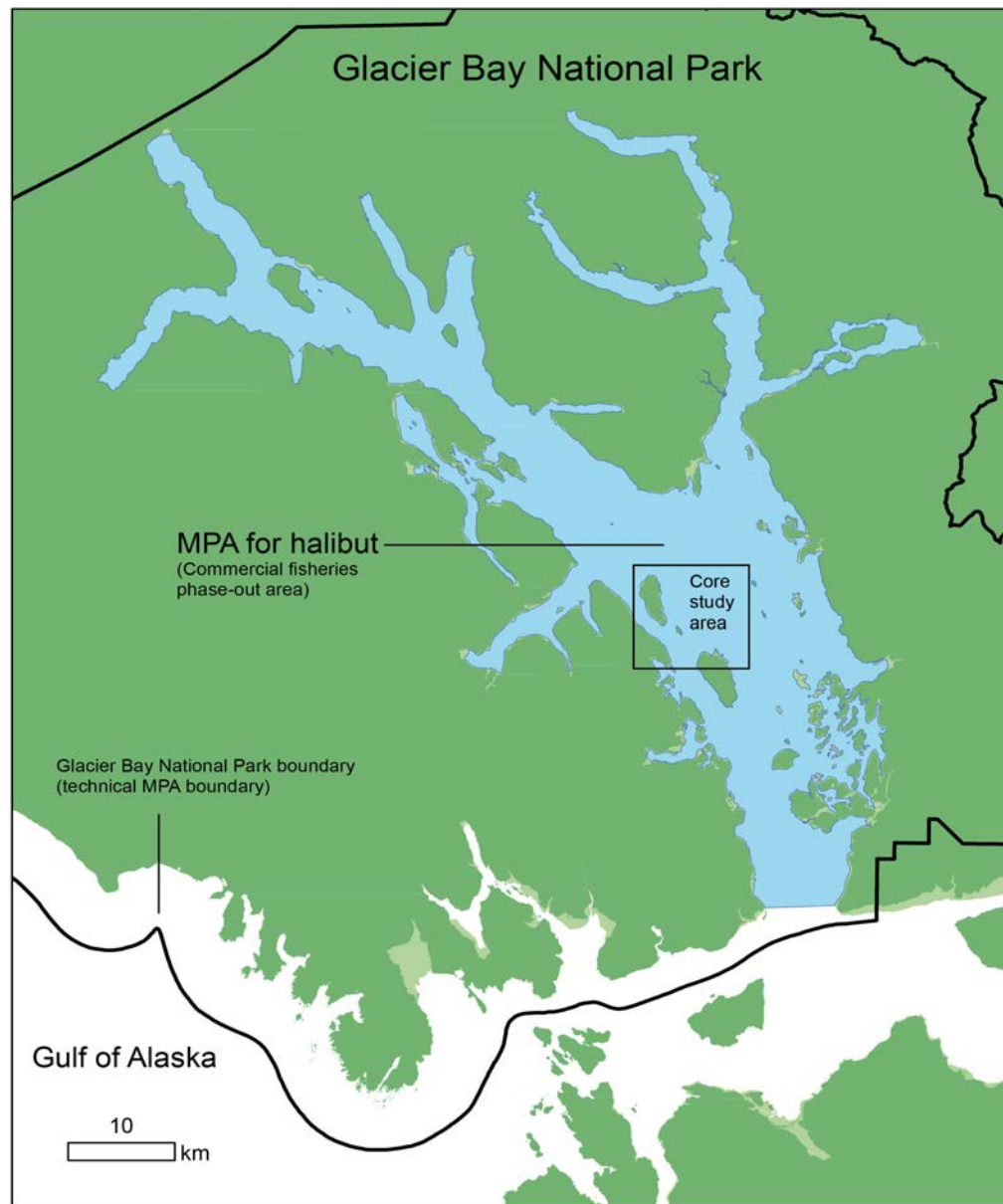


Figure 1. Map of study area showing the marine protected area (MPA) for halibut (blue area) in Glacier Bay along with the national park boundary (black line) that serves as the technical boundary for the Glacier Bay National Park MPA. The core study area for the 2013 research is indicated by the black box in the middle of the MPA.

Loher and Seitz 2006), MPAs were not expected to be an effective halibut management strategy.

Using Acoustic Telemetry and Pop-up Satellite Archival Tags to Track Halibut Movements

To address the lack of movement information for halibut in Glacier Bay, NPS researchers initiated an acoustic telemetry research project in 1991 (Nielsen et al. 2014). Acoustic telemetry research is conducted by attaching an electronic tag to the fish that transmits a ping; when the ping is detected by a hydrophone on a vessel or a stationary mooring, a position for the tagged fish can be estimated. When the first acoustic-tagged halibut was released, the researchers expected it to swim away rapidly, possibly leaving the park in a matter of hours. They were prepared to follow the tagged halibut with a hydrophone-equipped research vessel around the clock for several days. But this first tagged halibut did not lead the researchers on a non-stop multi-day tracking adventure. Instead, it remained in the vicinity of the release location for days that turned into weeks and months. After the third year of research, results from tracking 43 acoustic-tagged adult halibut documented that halibut in Glacier Bay exhibited a strong tendency to spend most of their time within very small areas: most tagged halibut limited their movements to a radius of 0.6 miles (1 km). Some tagged fish were observed to depart their “halibut homes” temporarily but eventually returned, demonstrating the ability to navigate back to previously occupied locations (Nielsen et al. 2014). The results of this first acoustic telemetry study suggested that after commercial fishing is eventually phased out (estimated to occur between 2040 and 2050), the MPA is likely to protect adult halibut from commercial harvest during the summer because of their limited range of movements during the summer months.

However, because adult halibut are known to undertake large-scale migrations during winter to spawn (Loher and Seitz 2006, Loher and Seitz 2008), information on year-round movement of halibut relative to MPA boundaries also was needed to assess its potential effectiveness as a refuge from commercial harvest that operates approximately nine months of the year. Therefore we initiated a second tagging study in 2013 to characterize seasonal and annual movement patterns of adult halibut in and around the MPA (Nielsen and Seitz 2017). We used Pop-up Satellite Archival Tags (PSATs) to characterize annual movement patterns year-round (inside and outside the MPA) and acoustic tags to further characterize small-scale movement patterns within the MPA during summer. PSATs are external electronic tags that are attached to halibut with a dart and tether. They record continuous depth, temperature, and light data until they are programmed to release from the fish. Then they float to the surface of the ocean and transmit their data to satellites. PSAT data can then be used to infer a fish's location for each day by comparing data from the PSAT to known conditions in the study area.

We attached 25 PSATs to adult halibut ranging from 3.4 to 5.6 feet in total length (1.0 – 1.7 m) caught on longlines inside the MPA during the summer (Figure 2). Ten PSATs were programmed to release from the fish in winter, when migrating fish were expected to leave the MPA on spawning migrations, and 15 PSATs were programmed to release from the fish one full year after they were tagged. Depth and temperature data from PSATs were used to infer whether fish were inside or outside of the MPA for each day that the tag was attached to the fish. Fifteen of the halibut tagged with PSATs also received a surgically implanted acoustic transmitter. Acoustic-tagged fish were tracked every other week for two months during the summer of 2013 and again



Figure 2. Julie Nielsen (right), Andy Seitz (center), and Michael Courtney (left) surgically implant an acoustic transmitter into a Pacific halibut. NPS/JOHN RODSTROM

during June and July of 2014. Tagged halibut could be detected within a radius of 0.3 miles (500 m) and locations could generally be determined with a precision of 492 feet (150 m).

The results from the second satellite tagging study suggest that not only do adult halibut in GBNP occupy small “homes” within the MPA during the summer, but they can leave the MPA during the winter and return to their previously occupied locations within the MPA. Estimated summer behavior and movement scales were remarkably

similar between the older and newer studies (Figure 3). We described the spatial scale of areas the tagged fish occupied (“home ranges”) as the radius of a circle that describes the average range of fish movement. In the 1991 movement study, the average movement radius was 1,315 feet (401 m) to 1,693 feet (516 m; $n=27$). Individual movement radii ranged from 341 feet (104 m) to 4,902 feet (1,494 m). The average movement radius for the 2013 study was 1,591 feet (485 m) to 2,654 feet (809 m; $n=12$) and individual home range sizes ranged from 282 feet (86 m) to 5,594 feet (1,705 m).

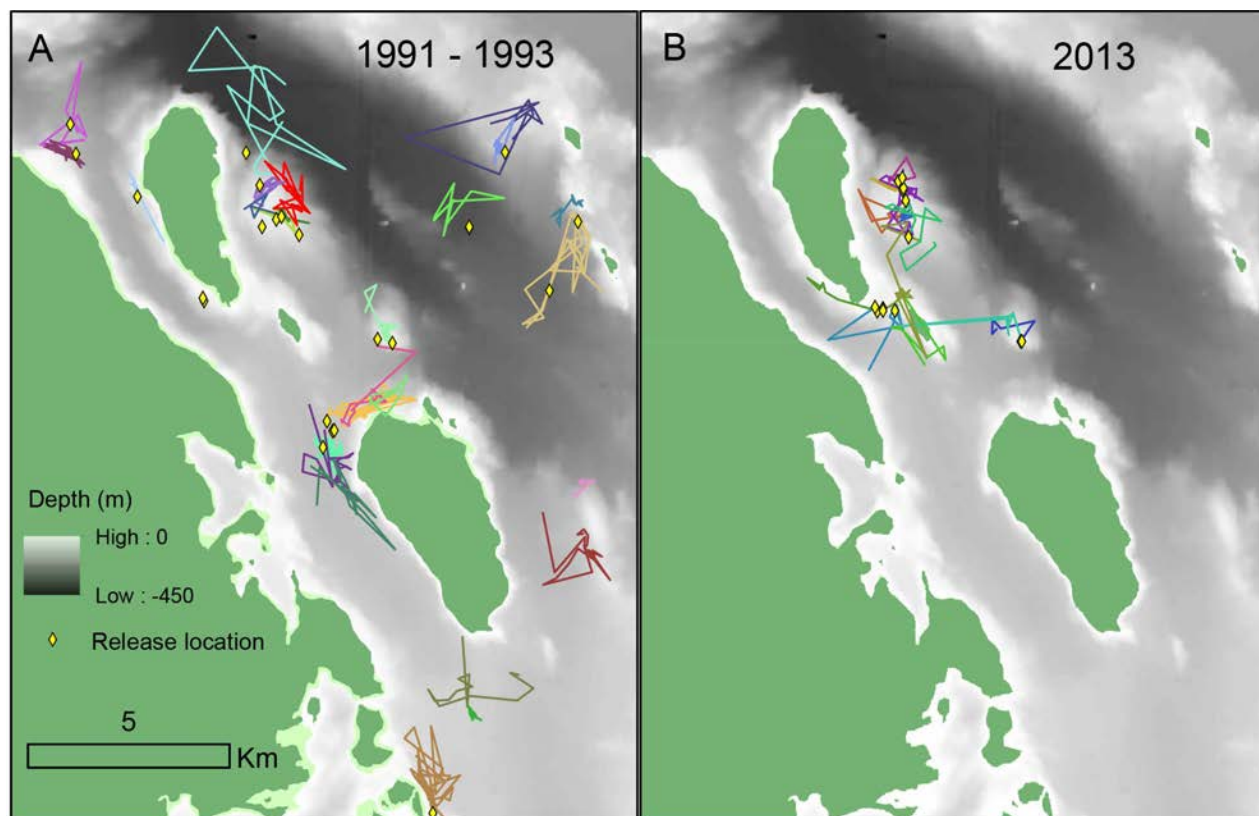


Figure 3. Acoustic-tagged halibut trajectories (colored lines for each halibut) during home range behavior for (A) the 1991 telemetry study ($n=27$) and (B) the 2013 study ($n=12$). Tagging locations are indicated by yellow diamonds. Note that Figure 3A depicts only a portion of the results, as tagging and tracking were conducted over a larger area during the 1991 study.

We also found high rates of MPA year-round residency. The majority of fish with PSATs that provided data (15 out of 21) remained within the MPA during the winter. However, six halibut did leave the MPA in December, and four of the six migrants returned to the MPA by mid-March. Migration largely coincided with the closure of the commercial fishery during winter (Figure 4), so tagged fish were vulnerable to commercial fishing outside the MPA for only a very small proportion of their migration time.

We were also able to determine that scales of movement from year to year are just as small as the movement scales observed within a summer. By double-tagging halibut with both PSAT and acoustic tags, we were able to determine that one migrant fish returned to within 0.6 miles (1 km) of its release location following a spawning migration to a location outside of the MPA (likely somewhere in the Gulf of Alaska). The median movement distance between the release locations and locations determined the following summer was 0.8 miles (1.3 km) and ranged from 0.2 miles (0.3 km) to 16.5 miles (26.5 km; $n=14$).

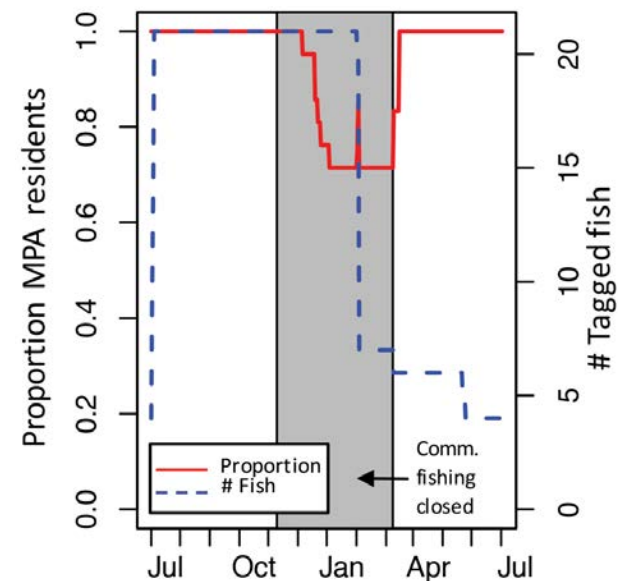


Figure 4. Proportion (red line) and number (dashed blue line) of tagged halibut residing within the MPA for each day from July 1, 2013, to July 1, 2014. Dates when the commercial fishery was closed are indicated by the gray rectangle.

Implications for Halibut Management

The halibut movement studies conducted in Glacier Bay as part of marine protected area research have provided important insights into halibut behavior that may have implications for the management of halibut at larger scales. Both studies indicate that Glacier Bay halibut are capable of establishing small homes from which they may leave, but to which they can return. This behavior is similar to lingcod (Beaudreau and Essington 2011) and certain rockfish species (Mitamura et al. 2012), though the spatial scales for halibut in Glacier Bay are slightly larger. Important work remains to understand how movement patterns and spatial scales are related to geographic region, habitat type, or halibut size and to further understand the prevalence of this

behavior in the overall Pacific halibut population. However, if seasonal and annual site fidelity at small spatial scales proves to be a common behavior throughout their range of distribution, halibut populations may have more spatial structure than currently thought. Spatial population structure has implications for stock assessment (Cadrian and Secor 2009) and the potential for local depletion (Trumble et al. 1991, Hare 2005) among other management considerations. Recent PSAT studies in other regions of the North Pacific Ocean suggest that site fidelity is observed in other areas as well (Loher 2008, Seitz et al. 2011), but the scales of site fidelity in those studies was not established with the level of precision that acoustic telemetry data provide.

In addition to observations of small-scale site fidelity, the research on annual movement patterns revealed that the majority of tagged fish did not participate in seasonal spawning migrations. Additional research should be conducted to determine whether non-migratory fish are skip-spawning or are spawning within the MPA. If a large proportion of adult fish are not spawning every year, then the current spawning biomass is over estimated.

If halibut in other areas have similar patterns and scales of site fidelity to Glacier Bay halibut, MPAs could play a role in conservation of spawning biomass. High rates of year-round residency combined with winter commercial fisheries closures when fish migrate suggest that the Glacier Bay MPA could provide year-round refuge from commercial harvest for both resident and migrant fish. Availability of multiple management options may be valuable for addressing recent declines in halibut biomass, which dropped by 50% from 1996 to 2011, but has since stabilized (Stewart and Hicks 2019).

Acknowledgments

We thank Philip Hooge and Jim Taggart for initiating the pioneering work on halibut site fidelity in Glacier Bay. We also thank Chad Soiseth and Craig Murdoch for arranging National Park Service funding for publishing the 1991 research and conducting the 2013 study, during which they assisted with almost every stage of the research. In addition, we thank the Rasmuson Fisheries Research Foundation, the Pollock Conservation Cooperative Research Center, the North Pacific Research Board, and the University of Alaska Fairbanks Undergraduate Research and Scholarly Activity program for providing funds that contributed to this research. We also thank the many people who assisted with the fieldwork for both studies.

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Andrew Seitz (top), Zack Stenson (middle), and Michael Courtney (bottom) release a tagged halibut.
NPS/JOHN RODSTROM



SONAR Project Provides Coho Salmon Baseline for Glacier Bay National Park and Preserve

Craig Murdoch, National Park Service

Despite concerns about increased harvest, there is no indication that recreational fishing is jeopardizing a natural and healthy coho salmon population in the Bartlett River of Glacier Bay National Park and Preserve. High-resolution sonar and sampling techniques provide a solid baseline by which salmon population numbers can be monitored into the future.

Citation:
Murdoch, C. 2020. SONAR project reveals coho salmon baseline for Glacier Bay National Park and Preserve. *Alaska Park Science* 19(1): 26-33.

Pacific Salmon are a quintessential symbol of wildness and vitality. They are also a critical component of Glacier Bay National Park and Preserve's (NP&Pres) ecosystem. Not only are they an important food source for many creatures, including bears (*Ursus arctos* and *U. americanus*), wolves (*Canis lupus*), harbor seals (*Phoca vitulina*), bald eagles (*Haliaeetus leucocephalus*), and people, they also fertilize streams and nearby forests with their decomposing bodies (Gende et al. 2007). Each summer Glacier Bay National Park and Preserve's Bartlett River is home to runs of sockeye (*Oncorhynchus nerka*), pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), and coho (*Oncorhynchus kisutch*) salmon. Glacier Bay National Park managers are working to ensure that healthy salmon runs continue within one of the park's most heavily fished rivers.

Glacier Bay NP&Pres managers prioritized a study estimating coho salmon escapement (passage upstream to spawning grounds) and harvest in anticipation of increased fishers due to improved regional ferry service. Fisheries staff responded by deploying high-resolution sonar (Dual-frequency IDentification SONar or DIDSON) to image and count coho salmon migrating up the Bartlett River during 2012-2014. Therefore, the park prioritized obtaining coho salmon escapement (passage upstream to spawning grounds) and harvest estimates. Though Glacier Bay NP&Pres is a relatively remote wilderness park, the Bartlett

River draws anglers from far and wide. Our objective was to determine baseline abundance and harvest information to ensure current and future levels of coho salmon harvest are sustainable.

The Bartlett River is a relatively small wilderness stream that follows the lateral moraine left by the Glacier Bay ice sheet several hundred years ago (Figure 1). The river has experienced much change in its approximate 250-year history due to the retreat of the Glacier Bay ice sheet, isostatic rebound, and successional processes. Today, typical summer stream flows are between 100 and 300 cubic feet per second (2.8-8.5 m³/sec). Several small mid-basin lakes buffer flows and serve as sockeye salmon spawning and rearing habitat. The headwaters derive from Excursion Ridge just 22 river miles (35.4 km) from its mouth near Bartlett Cove. The ridge bears karst geologic features, which have been associated with a positive influence on fish productivity and invertebrate diversity and abundance (ADFG 2014).

Early commercial ventures in salmon canning and salting near the mouth of the Bartlett River suggest it was once teeming with salmon. The Bartlett Cove saltery packed 120,000 pounds of sockeye fillets during the summer of 1899, which would equal approximately 30,000, six-pound sockeye. The following year approximately 24,000 pounds or 3,500 coho salmon were salted; most are believed harvested from the Bartlett River. Cannery operator August Buschmann estimated the Bartlett River

Field staff take a quick length measurement of a coho salmon captured during tangle netting.
NPS/CRAIG MURDOCH

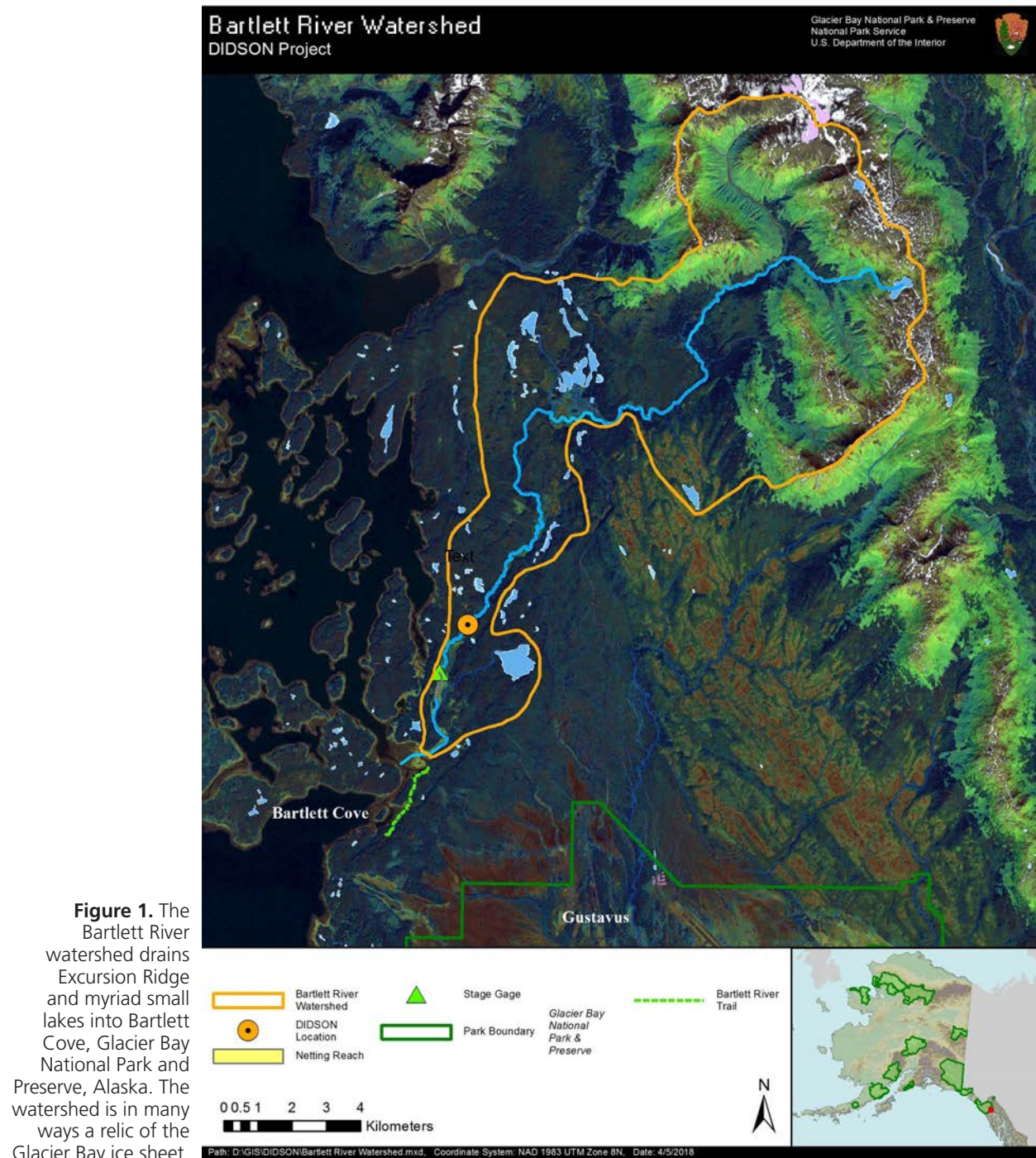


Figure 1. The Bartlett River watershed drains Excursion Ridge and myriad small lakes into Bartlett Cove, Glacier Bay National Park and Preserve, Alaska. The watershed is in many ways a relic of the Glacier Bay ice sheet.

held 75,000-100,000 “beautiful large red salmon” in 1901 (Buschmann 1960). That same year, naval commander Jefferson Moser (Moser 1898) during his investigation of Alaska salmon fisheries estimated that the Bartlett River could produce 50,000 sockeye salmon in a good year. Though commercial salmon fishing in Bartlett Cove continued during the early 1900s, the saltery went bankrupt in 1903. By 1924, Congress passed the White Act to limit commercial fishing. Glacier Bay was one of 15 areas considered depleted of salmon in Southeast Alaska, and it was completely closed to all forms of commercial salmon fishing (Mackovjak 2010).

Today, salmon fisheries in Alaska are far better managed. Though the Alaska Department of Fish and Game estimates Southeast Alaska monitored coho stocks experience substantial, but moderate exploitation rates ranging between 38-64% (average 52%) of annual returns from 2006 through 2010, stocks have remained productive and healthy (ADFG 2011). Commercial harvest rates of Bartlett River coho are likely average or less than average due to the river’s distance from other intercept fisheries, such as the Lynn Canal gill net fisheries. Beyond commercial salmon trolling, mostly outside Glacier Bay, it’s likely that only recreational anglers harvest salmon from the Bartlett River.

Recreational fishing is a treasured American pastime and many parks were explicitly set aside to encourage recreation, including sport fishing. Shortly after Congress created the National Park Service (NPS) in 1918, Department of the Interior Secretary Lane wrote to the first director, Stephen Mather, announcing “Mountain climbing, horseback riding, walking, swimming, motoring, boating and fishing will ever be the favored sports”...within National Parks (Lane 1918:50). This is still true today, though an increased emphasis on preserving native fish has evolved.

NPS Policy is to "...maintain all the components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006: 36). Further, policies stipulate that the service will allow harvesting of plants and animals only when monitoring is conducted and the NPS has determined that the harvest will not unacceptably impact park resources and natural processes (NPS 2006). Goal 18 of the Alaska Natural Resource Program Implementation Plan (Adema 2014:23), states that "... managers have adequate information to manage harvested resources to a natural and healthy standard." Yet in the past one hundred years little new information on salmon abundance in the Bartlett River has been attained and few estimates of harvest exist.

Fisheries scientists use a variety of techniques for estimating the size of salmon runs, but recent technological advancements in sonar and power generation provided a relatively low-impact wilderness-friendly approach. DIDSON uses 96 high-frequency sound pulses (1.1 or 1.8 MHz) to create near video-quality images of migrating fish. Our DIDSON system autonomously and continuously recorded 8 frames a second or roughly a gigabyte of data an hour, day and night for the duration of each survey season. DIDSON requires only 45 watts of power, making it feasible to use a quiet, clean methanol fuel cell (45 dB, water and CO₂ emissions) rather than a gasoline generator (Figure 2).

The largest challenge we faced using DIDSON was its inability to differentiate between fish species. Though DIDSON can be used to accurately and precisely measure fish length, length alone is an inadequate predictor of species when multiple species with overlapping length distributions are simultaneously migrating (Burwen et al. 2010,

ADFG 2007; Figure 3). Our pilot study in 2011 determined that pink and chum salmon and, to a lesser extent, Dolly Varden (*Salvelinus malma*) exhibited overlapping length distributions and run timing with the coho migration. Though DIDSON's inability to differentiate between species may make it a suboptimal tool, there are methods of estimating mixed stock migrations of salmon.

One commonly used method of estimating the proportion of species is by sampling migrating fish with a tangle net. We used a 40-50 foot- (12-15 m) long tangle net with appropriately sized mesh to entangle the head, jaws, and teeth of migrating fish. The objective of tangle net sampling of upstream migrating fish was to obtain an unbiased, representative sample of upstream migrating species composition in order to apportion the contribution of coho salmon relative to overall DIDSON imaged salmonids.

The use of DIDSON in conjunction with tangle netting and creel surveys successfully revealed a productive coho stream, with little angler harvest. We estimate minimal escapement estimates of between 4,600-13,900 coho for the years 2012-2014 respectively (Table 1, Figure 4). Our minimum estimates of coho escapement are consistent with ADFG's determination that Southeast Alaska streams with lake systems on average produce escapements of 1,000-8,000 coho annually (ADFG 1989).

Recreational fishing effort and harvest were highly variable. We estimate between 179 and 442 anglers harvested 158, 2,019, and 300 coho over the three years (Table 2). Our estimates of effort and harvest are relatively consistent with existing ADFG Statewide Harvest Survey estimates, which also suggest relatively low and variable harvest and effort compared to other streams of similar size elsewhere in Southeast Alaska. Annual recreational harvest



Figure 2. The Bartlett River DIDSON site displaying the DIDSON attached to the H-mount, upstream of the partial weir. The green electronics box containing batteries, fuel cell, computer, hard drives and DIDSON switch box is located in the center background.

estimates ranged greatly from 2% to 43% of our escapement estimates. Though 43% is high for 2013, our estimate of coho escapement was delayed due to high numbers of pink salmon spawning near in the vicinity of the sonar. Had the escapement estimate started in the 3rd week of August as in 2012 and 2014 the recreational harvest would be a much smaller percent of total escapement.

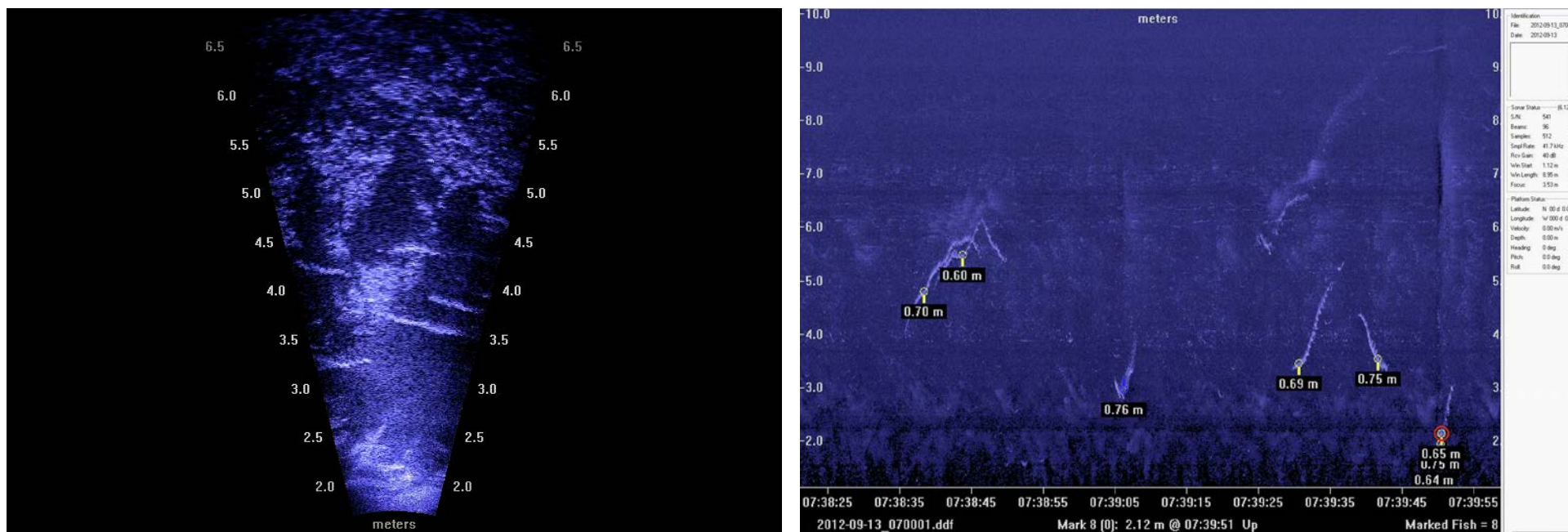


Table 1. Annual net coho passage estimates and 95% confidence intervals, 2012-2014.

Year	2012 ^a	2013	2014
Annual Net Coho Estimates	7,207	4,651 ^b	13,902
95% CI Annual Net Coho Passage	5,362-10,577	3,389-5,914	11,784-16,019
Period of Record	8/19-10/27	9/12-10/26	8/17-10/26

^aInadequate net sampling prevented species apportionment in 2012. This estimate includes all salmonids greater than 40 cm.

^bOur 2013 estimate of coho escapement is truncated due to large numbers of pink salmon spawning near the sonar site during the early coho run.

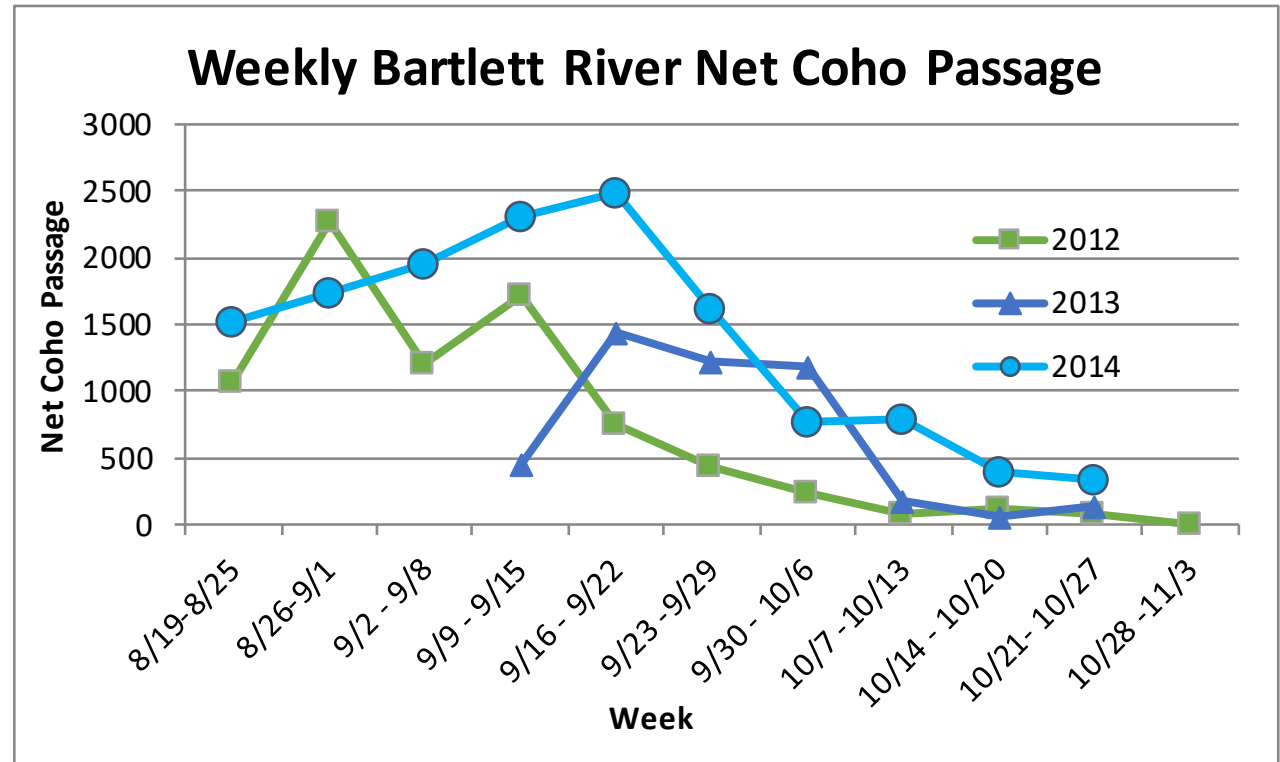
Table 2. Recreational coho salmon fishing survey results, 2012-2014.

Year	2012*	2013	2014
Annual Anglers	179, 1SE 33	442, 1SE 57	230, 1SE 40
Coho Harvest	158, 1SE 128	2,019, 1SE 587	300, 1SE 144
% of Escapement	2%	43%*	2%

*Large pink salmon returns and spawning near the sonar site truncated our escapement estimate. Recreational harvest as a percent of escapement is biased high for this reason.

There are several factors that likely contribute to the large year-to-year variation in recreational harvest and effort. It is likely a product of environmental conditions, angler success dissemination, and salmon run size. According to the Western Regional Climate Center (WRCC 2020) average precipitation in September for Bartlett Cove near the Bartlett River is 10.02 inches (25.5 cm). While 2012 had average precipitation, 2013 was nearly 2 inches (5 cm) less than average. Wet fall conditions are often favorable for salmon migration while often making fishing more challenging for anglers to target. Dry, low-water conditions result in salmon holding in the lower river where anglers can target them. Further, wet conditions degrade trail conditions and make the 2-mile (3.2 km) hike more challenging. When catch rates are high, word travels fast, leading to increased angler effort. Poor angler success likely has the alternate effect. 2013's relatively high coho harvest is also a consequence of high returns. ADFG reported record salmon returns across Southeast Alaska in 2013 (ADFG 2013).

Despite concerns about increased recreational harvest from new Alaska Marine Highway Ferry service to Gustavus, there is no indication that recreational fishing harvest is jeopardizing a natural and healthy coho salmon population in the Bartlett River. Recreational fishing effort and harvest are currently low and variable, and though the largest component of harvest (i.e., commercial) is unknown, our escapement estimates indicate the Bartlett River exceeded biological escapement goals set by ADFG for other similar drainages in Southeast Alaska (Situk River 3,300-9,800, Ford Arm Creek 1,300-2,900; ADFG 2014). Though, there is currently no threat of impairment, this work highlights the importance of baseline information as a reference point to assess future change. Further, it is imperative for managers to have clear management objectives and biological



thresholds by which to manage. Given the looming dark clouds on the horizon in the form of climate change, ocean acidification, and increased human demands, baseline information is the first step in avoiding diminished, less resilient ecosystems.

Acknowledgements

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Figure 4. Weekly estimates of upstream migrating coho salmon 2012-2014. As expected, peak run timing and numbers of coho varied over the period of record. Unfortunately, in all years we were unable to capture the beginning of the run, which likely starts in early August, well before staff anticipated.

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Field staff collect morphometric measurements and DNA samples from a coho salmon before releasing it.
NPS/CRAIG MURDOCH





Environmental DNA: An Emerging Tool for Understanding Aquatic Biodiversity

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Aquatic surveys are important management tools, but are expensive and difficult to complete. Environmental DNA techniques are a promising tool to identify fish and other organisms present from water samples. This new technique is being developed to improve long-term monitoring of fish and other aquatic species and for early detection of invasives.

Citation:

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Field surveys for aquatic organisms provide critical information that is important for robust resource management. However, such surveys are expensive and labor intensive, particularly in large, remote landscapes like those that characterize much of Alaska. Traditionally, characterizing aquatic biodiversity necessitated the physical capture and identification of individual organisms, which required that field crews have some level of expertise in identifying the species likely to be present. Many other limitations of surveys that rely on direct observation of aquatic organisms have been noted (Evans and Lamberti 2018). However, what if it were possible to identify all of the species present at a site without having to capture or even see them? While we are not there yet, the recent revolution in environmental DNA (eDNA) technology is bringing us closer to that goal (Thomsen and Willerslev 2014).

Analysis of eDNA using sophisticated genetic techniques holds the promise of being able to identify unseen species from material collected in water samples. The National Park Service, along with other agencies and researchers in Alaska, is actively developing eDNA-based methods for the identification of fish and other aquatic organisms, including both native and potentially invasive species (Table 1). The objectives of this effort include improving long-term monitoring of fish and other aquatic species and early detection of aquatic invasive species.

The term *environmental DNA* refers to DNA that organisms shed into the environment. Sources of eDNA can include shed skin cells, feces, hair, and reproductive secretions. In terrestrial ecosystems, eDNA generally ends up in the soil. However, in aquatic ecosystems, eDNA can be present at relatively high densities in both the bottom sediments and in the water itself (e.g., Barnes and Turner 2016). This eDNA can be easily recovered from the water column either by filtration, centrifugation, or precipitation, and preserved for later analysis in the laboratory (Goldberg et al. 2016). Generally, multiple water samples, ranging in volume from about 8-34 ounces (250 mL to 1 liter), are collected from a site and then filtered and prepared for analysis in the laboratory.

The quantity of recoverable eDNA present in a lake or stream is a product of many factors that can influence its generation and degradation (Barnes and Turner 2016). The density of organisms is important as species present in large numbers tend to generate more eDNA than species that are rare and there is evidence that the quantity of recovered eDNA may be related to species biomass (e.g., Evans and Lamberti 2018). Environmental factors also play a role by affecting the persistence of eDNA over time, influencing the quantity of eDNA that can be successfully recovered. For example, ultraviolet light rapidly degrades DNA, so eDNA will disappear more quickly in systems subject to considerable exposure to sunlight relative to those protected from sunlight. Other major agents of degradation for

All organisms shed DNA into the environment. Using the right analysis tools, environmental DNA (eDNA) can be used to determine the identities of the species that were present at the time of sample collection.

IMAGE COURTESY OF FISHBIO

Table 1. Examples of studies employing eDNA in Alaska. Note that data from some of these studies have not yet been published.

Project Description	Target Habitat	Assay Type	Institution(s)	Reference
Detection of invasive pike before and after eradication	Kenai Peninsula Lakes	qPCR	US Fish and Wildlife Service, Alaska Dept. of Fish and Game	Dunker et al. 2016
Detection of wood frogs	Ponds in Interior Alaska	qPCR	University of Alaska Fairbanks	Spangler et al. 2018
Population structure of harbor porpoises	Ocean in Southeast Alaska	metabarcoding	National Marine Fisheries Service	Parsons et al. 2018
Estimating run abundance for sockeye and coho salmon	Auke River in Juneau	qPCR	National Marine Fisheries Service, Oregon State University, University of Alaska Southeast	Levi et al. 2018
Detection of 5 fish species on the North Slope	Lakes in the National Petroleum Reserve	qPCR	Bureau of Land Management, NASA, Utah State University	Rodgers et al. 2017
Mapping juvenile Chinook salmon habitat use	Streams in the Chena River basin	qPCR	University of Alaska Fairbanks	Matter et al. 2018
Detection of multiple fish species	Lakes and streams on the North Slope and in DENA and WRST	metabarcoding	National Park Service, US Geological Survey	Menning et al. 2018
Species composition of Quaternary plant communities	Soils in Interior Alaska	metabarcoding	Various	Willerslev et al. 2014
Detection of ancient mammoths and horses	Soils in Interior Alaska	metabarcoding	Various	Haile et al. 2009
Detection of 5 loon species	Lakes in northwest Alaska	metabarcoding	National Park Service, US Geological Survey	Not yet published
Analysis of loon diet from scat	Lakes in northwest Alaska	metabarcoding	National Park Service, US Geological Survey	Not yet published
Detection of the invasive aquatic plant Elodea	Lakes and streams in Alaskan national parks	metabarcoding	National Park Service, US Geological Survey	Not yet published
Detection of the invasive aquatic plant Elodea	Lakes and streams across Alaska	qPCR	US Fish and Wildlife Service	Not yet published
Detection of multiple aquatic invasive species	Lakes and streams in Alaskan national parks	metabarcoding	National Park Service, US Geological Survey	Not yet published
Detection of multiple native aquatic and semi-aquatic species	Lakes and streams in Alaskan national parks	metabarcoding	National Park Service, US Geological Survey	Not yet published
Detection of multiple rockfish species	Ocean in Southeast Alaska	metabarcoding	National Marine Fisheries Service	Not yet published



Collection of an eDNA sample from a stream. On-site filtration using peristaltic pumps is a common method (note the blue filter unit visible at the end of the intake tubing in the upper left).

IMAGE COURTESY OF US FOREST SERVICE
ROCKY MOUNTAIN RESEARCH STATION

aquatic eDNA include microbes and extracellular enzymes in the water. Because temperature affects microbial metabolism and enzyme activity, eDNA tends to degrade faster in warmer temperatures. Other factors such as pH, salinity, and oxygen levels also likely influence degradation rates. Although the extent to which life history stage or species-specific differences play a role in the generation or persistence of eDNA is unclear, such differences may also influence detectability. Finally, the persistence and detectability of eDNA is affected by the hydrology of the system. In streams and rivers, eDNA is rapidly transported downstream, but also persists in sediments from where it can be periodically resuspended. In lakes, recoverability of eDNA likely depends on drivers such as the presence or absence of inflows and outflows, currents, lake stratification, and the turnover time of water in the lake (how long, on average, the water remains in the lake). Synergistically, these factors may result in significant differences in the detectability of aquatic species using eDNA. Many researchers are currently focused on addressing how these differences may influence the conclusions we are able to draw from eDNA studies, but much work remains to be done (Barnes and Turner 2016, Goldberg et al. 2016).

There are two main approaches to the analysis of eDNA recovered from environmental samples. Most often, eDNA is used to detect the presence of individual species of interest, such as invasive or rare and endangered species (Barnes and Turner 2016). A technology called *quantitative polymerase chain reaction* (qPCR) is a powerful way to determine whether eDNA corresponding to a particular target species is present. In qPCR analyses, researchers look, typically in the genomes of intracellular organelles like mitochondria or chloroplasts, for short stretches of DNA with nucleotide sequences unique to the target species. Mitochondrial DNA is generally the focus of eDNA studies involving animal species, since animal cells contain many more copies of it than of nuclear DNA (a single cell may contain several hundred mitochondria) and it may be more resistant to degradation. These unique sequences are targeted in qPCR reactions to make millions of copies of the DNA (this is called *amplification*), which can be detected, indicating that eDNA from the target species is present in the sample. If there is no eDNA in the sample that contains these species-specific sequences, then no detectable copies will be created. This method is generally precise and sensitive, but because a separate test must be used for each species, it is best suited for the detection of no

more than three or four species. Several examples of this approach are listed in Table 1.

The other commonly used method, designed to simultaneously detect many species in the same test from the same environmental sample, is referred to as *metabarcoding*. For animal species, metabarcoding typically involves an initial PCR amplification of mitochondrial DNA, but is otherwise quite different from qPCR analyses. Briefly, target gene(s) specific to particular groups of species (e.g., salmonid fishes) are amplified from the eDNA mixture, using group-specific DNA sequences. The amplified products are pooled into what is referred to as a *library*. This library is then compared, using advanced DNA sequencing technology, to a reference library composed of many sequences derived from species of known identity. If a sequence obtained from the eDNA sample matches that from a known species in the reference library, either exactly or above a threshold of similarity (generally 98-99%), a hit is recorded, indicating that the species' DNA was present in the original sample. While metabarcoding provides an efficient way to describe biodiversity, one of the challenges in developing metabarcoding tests is properly accounting for the DNA sequence differences that exist between individuals within a

species and how that compares to the differences that exist between different species. That is, the target DNA sequences should vary among species to facilitate accurate species identification, but if within-species genetic diversity is not accounted for in the test design, problems can arise. For example, if the sequence similarity threshold is set too stringently, then small sequence differences within a species may lead to a failure to detect that species even when it is, in fact, present. On the other hand, if the threshold is set too loosely, then a closely related species may be mistakenly identified when it is not present.

Using eDNA to Conduct Fisheries Surveys

The National Park Service has been collaborating with the US Geological Survey Alaska Science Center to develop several metabarcoding tests aimed at assessing aquatic communities, including the detection of invasive species. The first of these was designed to detect any of 37 freshwater and anadromous fish species known to occur in Alaska (Menning et al. 2020). The goal of the research was to allow freshwater fish surveys to be conducted using analysis of eDNA collected in water samples, rather than relying on traditional capture-based surveys, which are expensive and labor intensive, and therefore impractical for the collection of comprehensive fish community data across our large and remote parklands. As described in Menning et al. (2020 b), we used a set of genetic markers from the mitochondrial 12S ribosomal RNA and cytochrome oxidase I (COI) genes to develop the test. Targeting multiple genetic markers is important for reducing the chance of spurious detections or false positives. We validated this method using eDNA samples obtained from a number of lakes and rivers where the expected fish species composition was known, based on the results of traditional capture-based fish surveys. The sites were located in both Denali National Park and Preserve and Wrangell-St. Elias

National Park and Preserve, as well as on the North Slope of Alaska. A second validation step involved tests of eDNA from aquarium samples with a known fish community. The results showed that, in most cases, this method accurately identified all of the species known to be present in a system. In the aquarium sample, we identified 100% of species known to be present. Across all national park and North Slope sites, we detected nearly 90% of the species expected to be present. In addition, at many sites we detected additional species that had not been captured using capture-based surveys. This finding is consistent with other studies that have found eDNA can be more sensitive than capture-based surveys in detection of fish species (reviewed in Evans and Lamberti 2018). Based on these initial experiments, we recently developed additional genetic markers to improve discrimination among some sets of closely related species (sculpin, *Cottus* spp.; char, *Salvelinus* spp.; whitefish, *Coregonus* spp.; salmon and trout, *Oncorhynchus* spp.) that can be difficult to distinguish genetically. We have also successfully applied this test to determine the fish species composition of loon diets in Bering Land Bridge National Preserve and Cape Krusenstern National Monument by analyzing eDNA isolated from loon feces (Menning et al. in prep).

Using eDNA for Early Detection of Invasive Species

A second collaborative metabarcoding project is designed to detect the presence of multiple aquatic invasive species (AIS). AIS are an enormous and growing problem in much of the world, with significant negative effects on native species, aquatic ecosystems and infrastructure (Pejchar and Mooney 2009, Gallardo et al. 2015). Alaska, however, is (so far) relatively free of AIS, providing a unique opportunity to limit the negative impacts of invasions. A cornerstone of effective invasive species management is early detection (Lodge et al. 2006);

however, detection of invasive species when they are still rare is extremely challenging using traditional surveys that rely on capture or observation, especially across large remote landscapes. The sensitivity of eDNA-based methods suggests that they are well-suited for implementation of a robust early detection system, and there are multiple examples of the use of qPCR for the detection of individual AIS (reviewed in Barnes and Turner 2016). A metabarcoding approach has the advantage that we can test simultaneously for the presence of a large number of potential AIS, which is important since it is unclear, with a few exceptions, which species are expected to appear first in Alaska. Based on consultation with staff from state and federal agencies, we have prioritized a list of 18 species for inclusion in this test (Table 2). We are targeting numerous genes for detection and are including multiple markers for each species to minimize the chance of false positives. For plants, our metabarcoding approach targets multiple genes in the chloroplast genome. For the other species on the list, we are targeting a set of mitochondrial and nuclear ribosomal RNA genes, in addition to the mitochondrial COI and cytochrome b genes.

The initial stages of this project focus on the detection of *Elodea* spp., a highly invasive aquatic plant that has recently begun to spread to multiple water bodies in Alaska ([Larsen et al. this issue](#)). Replicate eDNA samples were collected from two locations where *Elodea* was present (Chena Slough and Tokchaket Slough), as well as from 52 lakes in four national parks and one national wildlife refuge sampled in 2016 and 2017 that comprise part of an extensive and ongoing field survey for *Elodea* being conducted in lakes thought to be at high risk for *Elodea* infestation. Vouchered specimens representing both *Elodea* species known to be present in Alaska were also analyzed to ensure that species detection was accurate. Our test detected *Elodea*

Table 2. List of invasive and potentially invasive species that are targets of the National Park Service eDNA assay.

Common Name	Scientific Name	Current Status
American waterweed	<i>Elodea canadensis</i>	Present and spreading
Nuttall's waterweed	<i>Elodea nuttalli</i>	Present and spreading
Northern pike	<i>Esox lucius</i>	Present and invasive south of the Alaska Range, spreading?
Red swamp crayfish	<i>Procambarus clarkia</i>	Present, reproduction documented
Northern Pacific tree frog	<i>Pseudacris regilla</i>	Present, reproduction documented
Northern red-legged frog	<i>Rana aurora</i>	Present, reproduction documented
Chytrid fungus	<i>Batrachochytrium dendrobatidis</i>	Present as of 2008, status unclear
Atlantic salmon	<i>Salmo salar</i>	Occasionally detected
American shad	<i>Alosa sapidissima</i>	Rarely detected
Purple loosestrife	<i>Lythrum salicaria</i>	Was present, eradicated?
New Zealand mud snail	<i>Potamopyrgus antipodarum</i>	Not yet documented
Quagga mussel	<i>Dreissena bugensis</i>	Not yet documented
Zebra mussel	<i>Dreissena polymorpha</i>	Not yet documented
Signal crayfish	<i>Pacifasticus leniusculus</i>	Not yet documented
Whirling disease parasite	<i>Myxobolus cerebralis</i>	Not yet documented
Chinese mitten crab	<i>Eriocheir sinensis</i>	Not yet documented
Spiny waterflea	<i>Bythotrephes longimanus</i>	Not yet documented
Brazilian waterweed	<i>Egeria densa</i>	Not yet documented

in both locations where it is known to be present, although the signal strength was low, suggesting that eDNA concentrations were also low. In particular, although Tokchaket Slough is extensively infested with *Elodea*, the eDNA test resulted in marginal detection in the samples collected there; only one of four replicates met the criterion for detection (two additional replicates were also positive, but below the detection threshold). This result may be because the eDNA samples were collected nearly a mile downstream of the infestation, where already low *Elodea* eDNA concentrations may have been

further diluted and/or degraded. Some other recent studies also suggest that eDNA-based methods may be less sensitive for plants than for animals, probably as a result of lower eDNA concentrations (Anglès d'Auriac et al. 2019, Kuehne et al. in review). No *Elodea* was detected, either by traditional physical surveys or using eDNA, at any of the 52 lakes. Ongoing experiments being conducted by the US Fish and Wildlife Service should shed light on how proximity of sample collection to *Elodea* plants affects its detectability in eDNA tests, which may influence how negative results are interpreted. The

next phase in the AIS detection project, conducted in collaboration with the US Forest Service, involves field validation of our ability to detect two exotic amphibian species in southeast Alaska (northern Pacific tree frog, *Pseudacris regilla* and northern red-legged frog, *Rana aurora*) using eDNA. We plan to continue testing the detectability of additional species from the list in Table 2 in the near future. Once completed, this will allow for multiple potential AIS to be detected in a single test, allowing us to begin implementation of a robust early warning program for AIS in Alaska.

Future eDNA Surveys Expanded to Other Species

The third collaborative metabarcoding project is aimed at using these same methods for the detection of a wide variety of native aquatic species of interest, including native amphibians (6 species), birds (18 species), and mammals (5 species). This will provide a powerful tool to rapidly test for the presence of multiple species of potential interest, some of which are difficult or expensive to reliably detect using traditional field surveys. We have already determined that we can use this method to detect all 5 species of loons (*Gavia* spp.) present in Alaska from lake water samples. This project is still in its pilot stages.

In summary, eDNA is an emerging and powerful approach for detecting aquatic species and is already beginning to revolutionize aquatic science. The methods we have outlined here will allow us to simultaneously test waterbodies in Alaska national parklands for multiple native vertebrate species (fish, amphibians, mammals, and birds) as well as for nearly 20 potentially invasive species, using water samples that can be easily and rapidly collected. Because these are relatively new techniques, much work remains to optimize field and laboratory methods and to determine how species detectability and the potential for both false positive and false negative detections are affected by environmental and biological factors. However, the potential of eDNA-based methods to improve the characterization of aquatic biodiversity is enormous. This in turn will substantially enhance our capacity for understanding aquatic ecosystems in park landscapes and provide critical information for monitoring change.

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Eulachon: A Little Fish with Many Names and a Big Ecological Impact

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Each spring in Southeast Alaska, wildlife and people alike eagerly await the same phenomenon—schools of a small, silvery, oily fish. But we know very little about the dynamics of the fishery, especially in the Taiya River in Klondike Gold Rush National Historical Park. This two-year study pointed to further research questions.

Citation:

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Each spring in Southeast Alaska, people and wildlife eagerly await the same phenomenon: silvery schools of a small nutrient-rich fish. Called hooligan or candlefish by Alaskans, but referred to as eulachon by biologists, *Thaleichthys pacificus* is an anadromous smelt. Southeast Alaska spawning populations spend most of their life feeding and growing in cold North Pacific waters before migrating to rivers during spring to reproduce. One of these rivers is the Taiya, which flows from the Coast Mountains, through Klondike Gold Rush National Historical Park (NHP), finally spilling into an estuary near Dyea, a former gold rush town. Although Taiya River eulachon fueled generations of people and wildlife, we know little about them or their current population status. Such information would be valuable since southern populations are in decline and the Taiya River has hydroelectric potential, which could impact the species (Johnson and Twenhofel 1958, Municipality of Skagway 2014).

Eulachon once ranged from northern California to the Alaska Peninsula and southeast Bering Sea (Brown et al. 2005, Gustafson et al. 2012); today southern runs are severely depleted or extinct. During 2010, the population segment that spawns in California, Oregon, and Washington was listed as threatened under the Endangered Species Act (NOAA 2010) while spawning populations south of the Nass River in British Columbia are of “special concern” (BC Conservation Data Centre 2017). Changes in ocean conditions, declines in quantity

and quality of spawning habitat, and overfishing are all linked to eulachon declines (Gustafson et al. 2012). Because the species is not commercially harvested, basic data is lacking for most populations even though they fueled West Coast Native cultures and trade for generations.

Oil, medicine, food, and trade items provided by this diminutive fish influenced generations of indigenous peoples leading anthropologists to consider eulachon a keystone species of West Coast Native culture (Senkowsky 2007). Since eulachon runs occur when human food supplies historically ran low, some tribes called them “salvation fish” (MacKinnon 2015). High in oils, up to 20% of the eulachon mass is fat (Wilson et al. 2006) and just 150 ml (5 oz) provides half an adult human’s daily energy needs (MacKinnon 2015). The buttery oil is produced by fermenting large quantities of whole fish and then extracting the resulting nutrient-dense oil. The oil is added to other foods or consumed alone for medicinal purposes. The fish itself is prized as a delicacy and when dried it can be ignited for a light source, hence the name *candlefish*. The famous Chilkoot Trail’s history reflects the species importance. During the 1890s gold rush, about 30,000 individuals (Karl Gurcke, pers. comm. 2016) traversed the Chilkoot across the rugged Coast Mountains on their way to the Klondike Gold Fields. However, before the gold rush, generations of Alaska Natives used the famous Chilkoot Trail and similar trails to trade eulachon oil with their interior

neighbors, such trails were nicknamed “grease trails” (Flannery et al. 2009). Today subsistence fishers harvest eulachon throughout Southeast Alaska (Brown et al. 2005). Little is known regarding the extent of eulachon subsistence use in the Taiya River or Skagway, but nearby in Haines and Klukwan, 95% of households reported using eulachon and subsistence fishers reported a harvest of 162,060 pounds during 2012 (ADFG 2020).

Not only do eulachon sustain human cultures, but this small silvery-blue fish also supports diverse Alaskan wildlife predators. Spawning runs in Southeast Alaska typically arrive at estuaries and rivers in early spring, a time of high energy demand for sea lions, river otters, harbor seals, and migrating shorebirds, all of which feast on eulachon (Sigler et al. 2004). Sea lions haul out near eulachon migration paths (Womble et al. 2005), and the little energy-dense fish helps sustain the massive pregnant females and migrating males. Whales, dolphins, sharks, bears, wolves, ravens, eagles, seabirds, salmon and many other species exploit eulachon when available (Willson et al. 2006). A eulachon study by Marston and others (2002) indicated that “predator abundance rose rapidly at the beginning of the runs and was significantly correlated with an index of eulachon abundance within years.” Since eulachon return to Southeast Alaska when other prey is scarce, they are considered an ecological cornerstone for coastal systems (Marston et al. 2002).

Like salmon, most eulachon are semelparous, meaning reproduction is fatal—fish die soon after a single spawning event (Clarke et al. 2007). Eulachon generally spawn during spring in lower river reaches once they reach age 2-5 and are about as long as a pencil (6.3-9.8 inches or 160-250 mm; fork length—tip of nose to fork of tail). Females produce 7,000-60,000 eggs which are broadcast over gravel or sand (Willson et al. 2016). The sticky fertilized eggs attach



Biologists record information on weather, habitat conditions, and wildlife presence while preparing to trap adult eulachon.

SARAH APSENS, ALASKA SEAGRANT STATE FELLOW

to substrate and hatch in 3-8 weeks depending on water incubation temperature; embryos develop and hatch faster in warmer waters and slower in cooler waters (Willson et al. 2006). Eulachon spawn in different rivers and regions across a wide range of river temperatures (32°-50°F or 0°-10°C) including under ice (Willson et al. 2006, Gustafson et al. 2012).

Estimates suggest fewer than 60 Alaskan rivers host anadromous eulachon runs (Willson et al. 2006). While studies exist for some southeast Alaska rivers, research is lacking for the park’s Taiya River. The Chilkoot Indian Association and the Takshanuk Watershed Council studied eulachon population trends in the nearby Chilkoot River during 2010-2016. Based on their success, park biologists, the Skagway Traditional Council, and the Taiya Inlet



A biologist records length, weight, and sex data from adult eulachon captured in the fyke trap.

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Watershed Council initiated the first study of eulachon in the Taiya River in an effort to gather basic population information.

During 2017 and 2018, biologists sampled Taiya River eulachon run timing, relative abundance, sex ratios, adult weight and length, female fecundity, and larval distribution. Biologists installed a fyke trap in mid-April, to sample upriver migrating adults. Trapping occurred during daylight, five days a week, for one hour each incoming, outgoing, and slack tide. Captured fish were counted, sexed, weighed, measured then returned to the river. A subset of females was sacrificed to determine fecundity. Presence of sea lions, an indicator of eulachon run strength (Marston et al. 2002), was noted prior to daily sampling. Sampling for out-drifting eulachon larvae

and eggs as an indicator of spawner distribution and habitat began three weeks after the first adult eulachon were captured; sampling occurred weekly at 10 different sites (Figure 1).

During both study years, the Taiya River spawning run began in early May and lasted approximately one week in 2017 and approximately two weeks in 2018. Catch Per Unit Effort (CPUE) indicated low abundance both years with peak catch being 0.06 fish/minute in 2017 and 4.7 fish/minute in 2018 (Figure 2). Low eulachon abundance was also reflected in the number of sea lions observed. One sea lion was observed in 2017 and none in 2018; in contrast, 75 sea lions were observed at the study site during 2016 (Jami Belt, personal communication, 2016) indicating a larger eulachon run. It is not possible to draw conclusions regarding Taiya River eulachon abundance trends from a two-year study and past studies show some eulachon runs are reliable from year to year while others are sporadic (Willson et al. 2006). Studies of total eulachon abundance in the nearby Chilkoot River showed wide fluctuations during 2010-2016, ranging from 319,586 to 12.6 million fish, with more than a million fish documented in five of the six study years (CIA 2017). Because census of eulachon abundance requires significant human and financial capital—both limited for Klondike Gold Rush NHP—the need for and means to obtain such information should be carefully considered. In addition to standard census techniques, the utility and cost of advancing genetic tools such as eDNA, SNPS, and microsatellites should be evaluated if abundance estimates are again considered (see [Simmons et al. this issue](#), Candy et al. 2015, Carraro et al. 2018). Pochardt and others (2020) tested an eDNA approach for estimating abundance during spawning using 2017 eDNA samples from the Taiya River that yielded promising results.

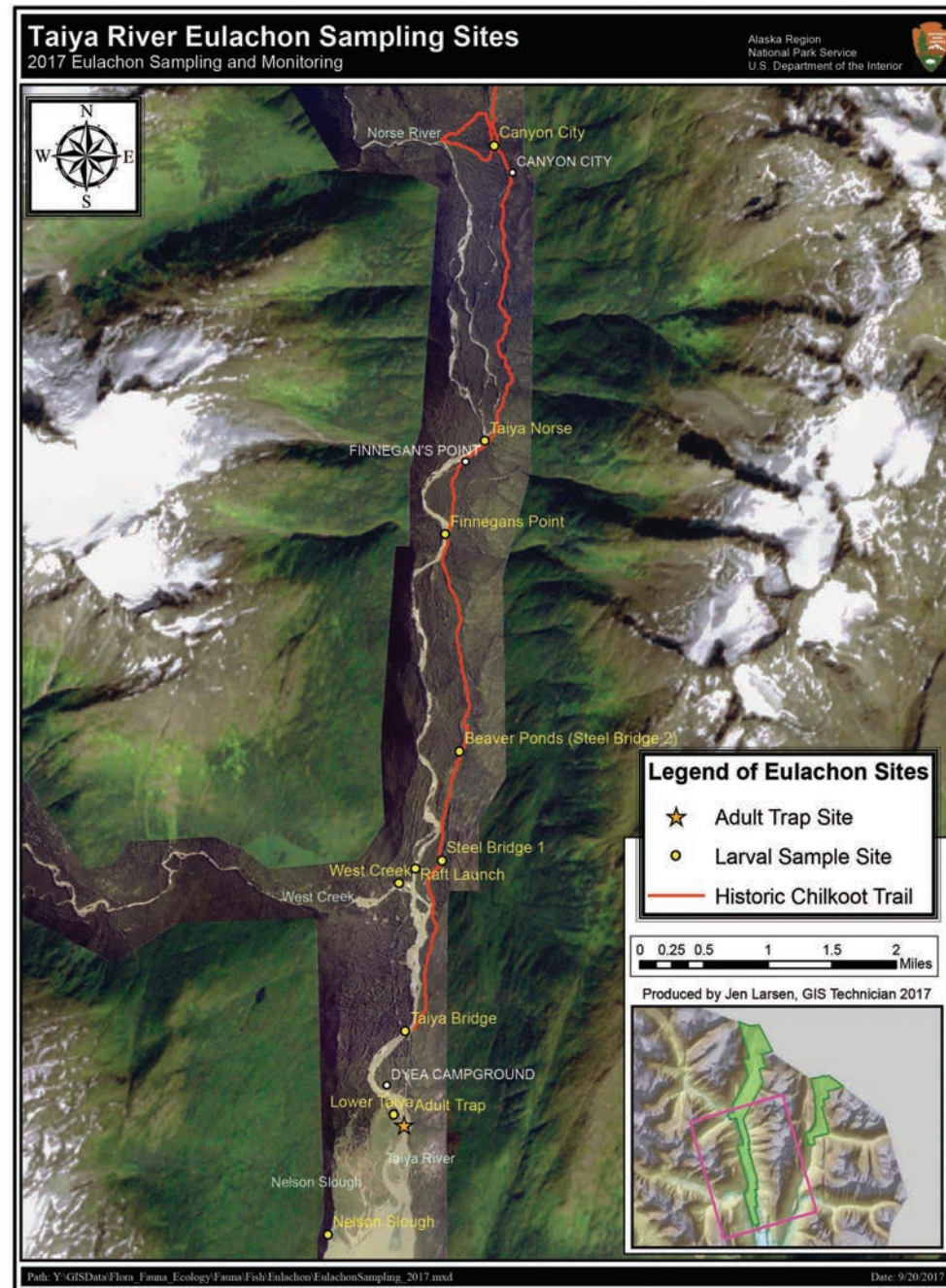


Figure 1. A map of the study area and sample sites.

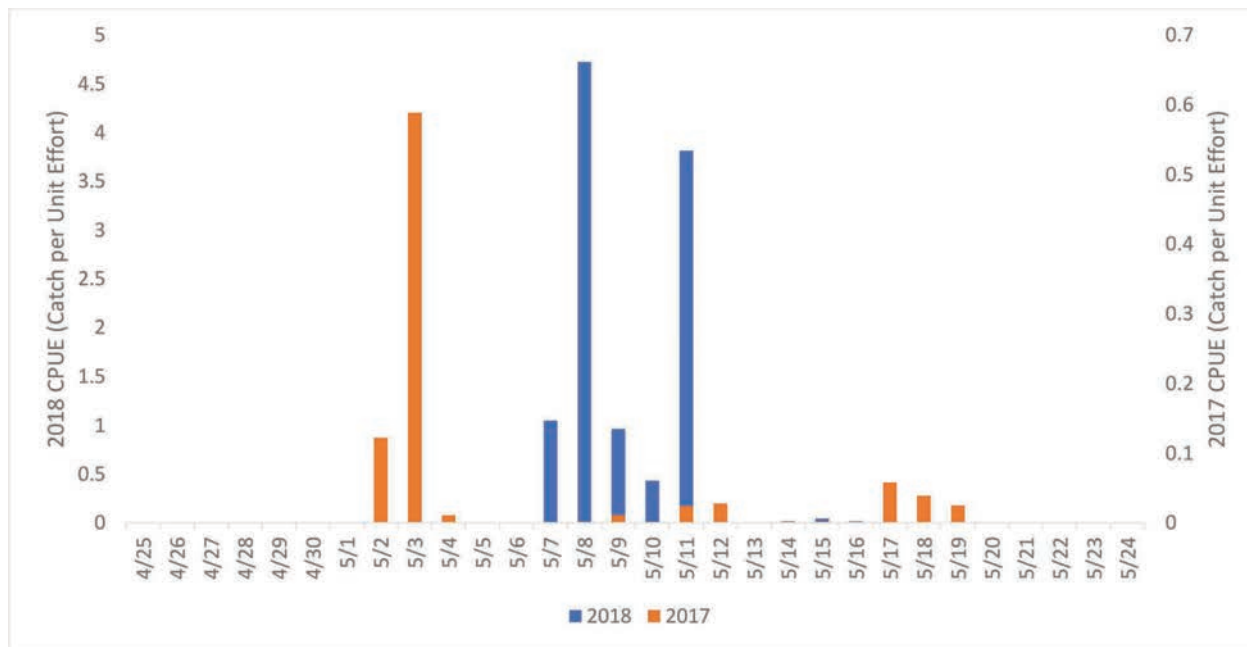


Figure 2. Eulachon catch per unit effort (# fish per hour) in spring 2018 and 2017.

Taiya River eulachon size, sex ratio, and fecundity varied between study years. These traits are important since they can provide clues regarding eulachon population health and trends. For example, changing environmental conditions such as high temperatures or reduced food supply can stress fish contributing to higher fish mortality and selecting for a younger, smaller, less fecund reproductive population (Heino and Kaitala 1999, Sutherland et al. 1986). During the 2017 Taiya River study, both sexes were similar in size averaging 1.1 oz (about 32.1 g) and 6.7 inches long (about 170.3 mm); in 2018, females were smaller than males, and smaller than in 2017, averaging 0.9 oz (25.5 g) and 6.2 inches (157.9 mm). Males averaged 1.1 oz (29.9 g) and 6.5 inches (166.0 mm) similar to 2017. Female fecundity in 2017 averaged 16,012.12 eggs per female (range=10,798.99-27,798.55) 2017 and in 2018 averaged 16,553.03 eggs per female

(range=2,436.94-26,169.18). These results are comparable to observations of other Southeast Alaska eulachon populations (Willson et al. 2006) and provide the first life history baseline information for the Taiya River eulachon.

No larvae or eggs were observed in or above West Creek during the two-year study, suggesting spawning did not occur in those areas. Uppermost presence of eulachon documented in both years was at the bridge south of the Beaver ponds, approximately five river miles from the estuary and well above tidal influence contrary to numerous studies indicating eulachon only spawn in tidally influenced reaches. Our results provide some basic information on eulachon spawning distribution in the Taiya River which can aid future conservation of essential habitat should hydroelectric or other development occur.

Taiya River eulachon face an uncertain future. Similar to other high-latitude seas, the Gulf of Alaska is predicted to become more acidic and warmer in the future (Fabry et al. 2009). Ocean acidification may impact distribution and abundance of eulachon prey, while warming water effects include: increased fish metabolism and changes to normal growth and maturation rates; changes in spawn run timing; changes in egg incubation rates, and changes in mortality rates, to name a few. This study provides the first brief glimpse into the abundance and characteristics of Taiya River eulachon. Their persistence will likely be tied to their ability to adapt to future changes and conservation of their essential habitats.

To learn more about this project, check out this [short video](#) about the eulachon monitoring project in Klondike Gold Rush National Historical Park.

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Zooarcheology of a 3,500-year-old Fishery on the Katmai Coast

Rhea Hood, National Park Service

Zooarcheology—the study of animal remains from archeological sites—reveals more than just a list of food items, it tells us how our natural surroundings and our climate have changed over time, how past peoples sustained their resources or over-harvested them, how our technology has advanced to allow our survival, how we relate to animals and each other, and how some things have remained the same.

Citation:

Hood, R. 2020. Zooarcheology of a 3,500-year-old fishery on the Katmai coast. *Alaska Park Science* 19(1): 48-53.

The heaps of fish bone were coated in a black greasy residue. Most of the bones were Pacific cod, the others were sculpins, Pacific halibut, and only a smattering of vertebrae from salmon and Pacific spiny dogfish (Table 1).

The salmon bones were so rare that each vertebra was a surprise when it materialized out of piles of fish bones on melamine lunch trays in the zooarcheology lab. It was exhilarating to know that I was working with a collection of food leftovers so old that it predated the salmon surplus revolution. It was a surplus of cod.

These cod and halibut were so large they had to have been caught in the open sea. I had proof in my hands that by 3,500 years ago, members of this ancient Alaskan society regularly ventured far from the Katmai coast in boats to deep sea fish, and they knew exactly what they were doing. These bones would teach us more about the ingenuity of people who were in Alaska long before us.

Little Takli Island

Over 20,000 soot-covered fish bones and fish bone fragments were unpacked from an archeological excavation that was only 6.5 square feet (2 m²), and in a layer tightly compressed to roughly 16 inches (40 cm) thick. Much more of this larger refuse pile already eroded into the bay as sea level has risen, and the remainder is still unexcavated (National Park Service 2010).

The Little Takli Island site (XMK-031) produced unexpected findings—almost no fishing tools among all the fish bones. The site has two distinct layers of artifacts from two different periods. The first layer of artifacts dates to 3,570 calibrated years before present (cal BP; 1620 BC; laboratory identification number Beta-256599) and the second layer has a later date of 1,010 cal BP (AD 940; laboratory identification number Beta-256600). The island is over half a mile (1 km) long and has three other archeological sites on it.

Amalik Bay Archeological District National Historic Landmark

The Little Takli Island site is one of 28 pre-contact archeological sites in the Amalik Bay Archeological District National Historic Landmark. Amalik Bay seems to overflow with islands, small and large, that are dotted with archeological sites. These sites are the ancient remains of villages, middens, and scatters of stone tools.

The Amalik Bay Archeological District National Historic Landmark is part of Katmai National Park and Preserve. National Park Service archeologists, and their academic counterparts, are salvaging what data they can from a handful of the most endangered sites as bit by bit the stone and bone artifacts erode into the ocean. The Little Takli Island site is one of only four archeological sites in the National Historic Landmark that have been examined in detail. Their research pieces together a story that goes back well

Amalik Bay and archeological excavation units at the Little Takli Island site in 2009.
NPS/L. BARTON

Table 1. Percentage of fish bones uncovered by family.

Family of Fish	Number of Bones	Percent
Gadidae (Pacific cod and walleye pollock)	11,595	55.77
Cottidae (sculpins)	1,935	9.32
Pleuronectidae (Pacific halibut and other flatfishes)	1,228	5.89
Salmonidae (salmon and trout)	154	0.74
Hexagrammidae (greenlings)	140	0.67
Squalidae (Pacific spiny dogfish)	50	0.24
Sebastidae (rockfishes)	35	0.17
Indeterminate (bones too fragmented to conclusively identify)	5,657	27.20

over 6,000 years (Clark 1977, Dekin and Green 1993, Schaaf 2007 and 2009, National Register of Historic Places 2005).

When Cod Was King (and Not Salmon)

The first step any zooarcheologist must take is to identify the animals present and get an idea of their relative distributions. I identified the taxonomic classifications of the fish bones present by using modern fish skeletons from a reference collection to compare with the archeological fish bones. I found that 55.77 percent (n=11,595) of the fish bones were from the Gadidae family—cod. Most of these were Pacific cod (n=7,790) with just a handful of walleye pollock (*Theragra chalcogramma*, n=108; Hood 2013). This high frequency of a single species paired with much lower frequencies of a wide variety of animal species (other fish, sea and land mammals, and birds) shows that Pacific cod was the main food for the people who stayed at the Little Takli Island site.

I followed three lines of evidence to identify fishing methods and techniques used to catch all these cod: the size of the fish told me their age and,

thus, their habitats; the frequency of each taxonomic class of fish told me where people spent most of their efforts; and ethnographic and historical records of fishing methods for these same fish provided other information.

Catching the Big One

To find how big the Pacific cod were when they were alive, I used comparative formulae to estimate their length and weight based on the size of their head bones. The constants in the formulae were developed by measuring live Pacific cod then dissecting them and measuring their bones (Orchard 2003). The variables were measurements of a specific selection of bones from the archeological collection (Hood 2013).

To estimate the cod’s length, I used the equation: $Y = \alpha + \beta X$. A fish’s length has a linear relationship to the size of its bones. Y is the fish’s length, α and β are constants from modern fish, and X is the measurement I took of the archeological specimen (Orchard 2003). A fish’s weight has an exponential relationship to the size of its bones, instead of a linear relationship as with its length. So, the linear

regression needed a logarithmic transformation to resolve this exponential relationship which gives us $Y = \alpha X^\beta$ (Orchard 2003).

The average length of the archeological Pacific cod is 28 inches (71 cm). At this length they are over three years old and mature. From late winter to early spring, mature Pacific cod migrate nearshore and by mid-summer they move to deeper water where they dwell near the ocean floor. The largest cod in the sample was 39 inches (99 cm) long and 27 pounds (12 kg) when it was caught (Hood 2013).

A study of Atlantic cod (*Gadus morhua*) capture methods conducted in 2000 was used as an analogue to compare with the Little Takli Island archeological collection. In this study, the researchers found that 90 percent of the Atlantic cod caught with hook and line fishing were between 22 to 33 inches (56-84 cm) long (Huse et al. 2000). The Little Takli Island cod lengths had a strikingly similar distribution of fish sizes and 86 percent of them were between 24 and 35 inches (61-89 cm) long (Hood 2013).

Another big fish from the deep sea is Pacific halibut (*Hippoglossus stenolepis*). Nearly six percent (5.89%; n=1,228) of the fish bones in the collection were Pleuronectidae (flatfishes; Hood 2013). Many were smaller, nearshore species of flatfishes, like flathead sole (*Hippoglossoides elassodon*; n=19), butter sole (*Isopsetta isolepis*; n=17), northern rock sole (*Lepidopsetta polyxystra*; n=135), and others. Almost half of the flatfish bones were halibut (n=590), and they were observably much larger than all other fishes in the collection. This told me they were mature and came from deeper waters, probably around 980 feet (300 m) deep (Mecklenburg et al. 2002) in Shelikof Strait.

Catching a Slew of the Big One

A whopping 75 percent ($n=20,794$) of the animal bones from the archeological site were fishes. Over a third ($n=7,790$) of the fishes were Pacific cod. Because of the fragility of fish bone, 27.20 percent ($n=5,675$) of the bones in the collection were broken fragments that could not be identified (Hood 2013). If the unidentified fish bone fragments are “discounted,” then Pacific cod were 51.46 percent of the fish.

The other Gadidae species were walleye pollock, but there were only 108 of their bones in the entire collection. They were estimated to have an average length of 21 inches (53 cm). This would put them in the same habitat zones as Pacific cod. This told me that the pollock were bycatch, used as bait, or had arrived in the stomachs of larger prey such as seals or even larger fish.

The same stories could be told of the greenlings and spiny dogfish in the collection. They too were less than 1% each of the fish bones (Hood 2013) and they live in the same habitat zones as Pacific cod during the spring and summer.

The sculpin bones show the variation in people’s diets and ways of getting food. Sculpins prefer living in rocky tidepools nearshore, and catching them requires different tools than deep-sea fishing. Sculpins were the second-most frequently identified fish in the collection (9.32 percent), and were mostly red or yellow Irish Lord species (*Hemilepidotus* spp.; Hood 2013).

The salmon bones are trickier to interpret. Salmon bones are soft and can become even softer after spawning, making it likely that only their vertebrae will survive in the archaeological record. Still, there were only 154 salmon bones (0.74 percent), much fewer than sculpin (Hood 2013). The low frequency was evidence that the salmon were caught as bycatch,

came to the site in the stomachs of larger prey, or were only occasionally targeted while Little Takli Island was occupied.

Fishing Tackle

Fishermen and women can control the type and size of fish they catch by where and how they fish. The evidence for fishing equipment at the archeological site is sparse. Fishing lines decompose and hooks carved from bone wear down, break, and disappear from the archeological record. But one bone composite fishhook shank was uncovered during excavation and a handful of large plummet-style weights sculpted from cobbles were scattered around the site (National Park Service 2010). Were these the tools used to catch cod here 3,500 years ago?

Documentation of traditional method for catching cod, flatfishes, and sculpins in Alaska, describe a method of placing fishhooks along a single hand-thrown fishing line or along a horizontal bar attached to the fishing line (Stanek 2000). Plummets are fastened to key points along the fishing line (Stanek 2000).

The large stone plummets could also have been used to catch Pacific halibut in the past. In the Pacific Northwest, halibut hooks are usually U-shaped or V-shaped, and the stones hold the fishing line in the water column so that the hooks are just a few inches above the seafloor (Stewart 1982). The plummets might have also come in handy for bottom-dwelling sculpins, rockfishes, and small flatfishes.

The only way to find more fishing tackle would be to excavate more of the site. However, that wouldn’t guarantee that artifacts would be preserved whole or have not been lost to the sea.



Composite fishhook shank carved from bone from the Little Takli Island site.
NPS/R. HOOD

What if it was just this small part of the Little Takli Island site that held a lot of cod? I needed to find other archeological sites in Alaska that had similar faunal collections that had already been studied. I found three of them.

Mink Island Site (XMK-030), Amalik Bay; Horseshoe Cove Site (KOD-415); and the Rice Ridge Site (KOD-363), Kodiak Island

The Mink Island site provides an intriguing comparison. The fish bones from this large village site were extensively examined by a doctoral student for her dissertation. McKinney (2013) found many of the same fish species as those found on Little Takli

Table 2. Archeological tool traditions of the Gulf of Alaska.

Archeological Tool Tradition	Time of Existence
Ocean Bay I	7,500 to 5,500 years ago
Ocean Bay II	5,500 to 4,000 years ago
Early Kachemak	4,000 to 2,700 years ago
Late Kachemak or Norton (Katmai area)	2,700 to 800 years ago
Thule (Katmai area) or Koniag (Kodiak area)	800 to 200 years ago
Western contact	Over 200 years ago

Island and she estimated the size for Pacific cod in that collection, too.

The islands in Amalik Bay are heavily eroded. The Mink Island site is only 109 yards (100 m) west of the Little Takli Island site, and it is likely that both islands were once part of a larger Little Takli Island before rising sea levels created the smaller islets in the bay (Crowell and Mann 1996).

The two layers of occupation at the Mink Island site both predated and postdated the occupation I was studying from the Little Takli Island site. Mink Island was used from 6,300 to 4,000 cal BP (Schaaf 2007 and 2009). The early occupation at Little Takli Island was from 3,570 to 3,370 cal BP (Hood 2013). After a break, the Mink Island site was used again in 2,000 to 500 cal BP (Schaaf 2007 and 2009) and the Little Takli Island site was used again during that period around 1,010 cal BP. Together these sites span the archeological eras known as the Ocean Bay traditions I and II (7,500 to 4,000 years ago), the Early and Late Kachemak traditions (4,000 to 800 years ago), and the Koniag tradition (800 to 300 years ago, Table 2; Clark 1974, Clark 1977, Dumond 2011, Fitzhugh 2003, Saltonstall et al. 2006). This allows for comparisons of the average size of cod caught, and the number of cod relative to other fish, over a long time. During the Ocean Bay period of occupation at Amalik Bay, the main source of protein were

sea mammals caught nearshore. The fish species found from that period—sculpins, small flatfishes, and smaller Pacific cod—can be found in the same nearshore areas where sea mammals were harvested (McKinney 2013). As the Kachemak tradition progressed, there is a marked increase in Pacific cod bones in Amalik Bay archeological sites that correlates with a decrease in harvesting sea mammals. The frequency and length of Pacific cod harvested peaks during the Early Kachemak. Pacific cod is then gradually replaced by an increase in salmon and sculpin. The increase in salmon harvest continues through the following Koniag period. The changes in size and quantity of Pacific cod captured around Amalik Bay over time may reflect environmental changes or differences in fishing methods.

The Rice Ridge site (KOD-363) on the eastern coast of Kodiak Island was used between 6,000 and 3,900 cal BP. Sea mammals, Pacific cod, and salmon were important parts of the diet (Kopperl 2003). The results of the Rice Ridge study reflected the increase in harvesting Pacific cod around the same time that the Little Takli Island site was occupied (Kopperl 2003).

The Horseshoe Cove site (KOD-415) is across the strait from Amalik Bay on Uganik Island in the Kodiak Islands. Hays (2007) examined the fish bone from the 3,850 to 3,400 cal BP occupation. Like the

Little Takli Island site, Pacific cod dominated other species in the collection. What made the site even more fascinating was the discovery of large fire pits lined with cobble stones and filled with wood charcoal. The archeologists who excavated the site wonder if these were large earth ovens for smoking fish (Hays 2007, Saltonstall et al. 2006).

The More Things Change, the More They Stay the Same

Zooarcheology of Amalik Bay Archeological District reveals a broad range of sea and land animals that were gathered over thousands of years. Through their bones we can see patterns in the animals’ sizes, ages, and abundance. There are no clear-cut answers when trying to unravel events from so long ago, but archeological interpretations can become more precise over the course of time as archeologists and other scientists gather more information about people and the environments of the past.

The animal bones from archeological sites around the Gulf of Alaska show that the people who settled the region more than 7,000 years ago practiced a distinct sea mammal hunting tradition. Gradually, people concentrated their efforts on catching more Pacific cod, which seemed to peak during the Early Kachemak tradition (between 4,000 to 2,700 years ago; Hays 2007, Hood 2013, Kopperl 2003, McKinney 2013). The Late Kachemak and Koniag traditions that followed (between 2,700 to 800 years ago and from 800 years ago to after Western contact) are well known as the period of developing the salmon surplus traditions that Alaska thrives on to the present day.

People depended on Pacific cod long before the salmon surplus. It’s still one of the most popular seafoods distributed all over the world. You probably have some in your freezer right now and there’s a good chance it’s from Alaska.

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The Role of the Diamond NN Cannery in Interpreting the History of the Naknek River Fishery

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The NN Cannery was one of the longest-running canneries. It employed hundreds of residents and thousands of transient workers who produced more canned salmon than any cannery in Alaska. Contained in its century-old buildings are stories of the historical manifestations of capitalism, incorporation, industrialization, immigration, world wars, global pandemics, statehood, resource management, unionization, segregation, and equal rights.

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Upriver

Located in the heart of Katmai National Park and Preserve (Katmai NP&Pres) is the 1.5-mile (2.4 km) Brooks River, a tributary of the Naknek River on the Upper Alaska Peninsula in southwest Alaska. Each summer, a stream of visitors from near and far flock to the river's viewing platforms to witness one of nature's most extraordinary scenes: The world's largest concentration of Alaska brown bear catching with powerful jaws and claws the world's largest run of sockeye salmon. The salmon, with primal, undaunted instinct, leap the six-foot (1.8 m) cascading Brooks falls, often sailing past the furry fishers, on a mission to complete their life history spawning the next generation of Naknek River sockeye salmon and also carrying needed marine nutrients inland.

Those who come to observe this renowned, spectacular setting, describe it as a visitor's paradise—an isolated, natural wonder where humans take a back seat (Birkedal 1993). But what most visitors to Katmai's wild river do not realize is that those salmon, soaring over the Brooks falls and evading the clutches of the Brooks bears, are part of an escapement—or the proportion of fish allowed by Alaska state fisheries biologists to “escape” the commercial fishery to return to spawn in their natal streams, which directly links the Brooks River experience to the red salmon commercial fishery, down the Naknek River, in Bristol Bay. Unlike the

Brooks bears, Bristol Bay gillnet fishermen must sit idle with dry nets, waiting restlessly until fish counts reach estimated spawning goals upriver before they are allowed to fish.

Historic evidence of the commercial salmon fishery abounds at Brooks, in the form of the defunct fish ladder, the old Bureau of Commercial Fisheries research laboratory and remnants of a weir that biologists once used to count sockeye salmon migrating to Brooks Lake. The drive to better understand the largest, most valuable and most sustainable sockeye salmon fishery in the world led biologists to ask questions about the Naknek River's ancient run sizes, sparking decades-long archeological investigations that culminated in the designation of the Brooks River Archeological District National Historic Landmark (Ringsmuth 2013).

More than a foil to Brooks bears, the salmon serve as a cultural, historical, and physical conduit that courses through the 35-mile (56 km) Naknek River, from its headwaters to its outlet into Bristol Bay. The salmon escapement moves beyond park boundaries, and places Katmai's fish story in the larger historic context of the canned salmon industry and ties the natural drama of the Brooks River to the global story taking place downriver.



Bureau of Commercial Fisheries biologist counts red salmon at Brooks Weir in fall of 1958.

Bristol Bay's salmon crash in 1919 due to wartime overcapitalization and over-fishing, initiated a more rational approach, guided by the rigors of science in managing the fishery. This meant shaping fisheries laws according to the scientific and utilitarian doctrine of maximum sustainable yield (MSY). Biologists discovered, that if they could figure out what that optimal number was to maintain future runs at sustainable levels, then they could create a stable fishery that would last forever. They calculated the maximum sustainable yield of each salmon run and limited fishing to that point, thereby allowing a certain amount of upriver "escapement," the term salmon managers used for the number of fish who reached the spawning grounds. The counting activities at the Brooks River weir were important because they allowed the Bureau of Commercial Fisheries (BCF) to estimate how many fish made it up the river to spawn, thereby reducing the threat of future over-harvests. After a predetermined number of salmon reached the grounds, the remaining salmon could be harvested by the commercial nets.

NARA AK RG 370, BOX 2

Downriver

The 130-year-old Diamond NN Cannery is situated on the south bank, near the mouth of the Naknek River, one of five major pristine rivers—Kvichak, Nushagak, Ugashik, Egegik, and Naknek—that drain to Bristol Bay, the eastern-most arm of the Bering Sea. The NN Cannery was part of the broader pattern of commercialized Pacific salmon packing that, before 1937, was the third largest extractive industry in the West, with greater value than gold and copper mining in Alaska (Friday 1994, Gregory and Barnes 1939). The cannery was built by the Del Monte subsidiary, the Alaska Packers Association (APA), which, not only was a corporate juggernaut that dominated Alaska's fishing industry, but was part of a technological, commercial, and global system that revolutionized the way the world ate (Parkin 2006).

The packing and preparing of salmon for commercial sale transformed the Bristol Bay region. "Of all the agents of change," writes ethnographer James Vanstone, "none had a greater or more lasting effect...than the commercial fishing industry" (Vanstone 1967: 63). Anthropologist Alan Boraas agrees, noting that salmon canneries, like APA's Diamond NN Cannery, "represented the Industrial Revolution of the North" (Boraas 1996: 11).

From its establishment as a four-building saltery, to its expansion into a globally reaching, 51-building industrial complex, the NN Cannery was one of the largest, longest running canneries in Alaska. Built in 1890 and processing salmon nearly every summer until 2001, it remains one of the best examples of an intact, twentieth century, Bristol Bay salmon cannery, and constitutes one of the most significant remnants of the canned salmon industry on the West Coast.

Unlike many other Bristol Bay canneries, the NN complex never experienced fire, nor was it ever repurposed for anything other than canning salmon. Contained in its century-old buildings are stories that underpin the historical manifestations of capitalism, incorporation, industrialization, immigration, world wars, global pandemics, statehood, resource management, unionization, segregation, and equal rights.

Importantly, the cannery employed hundreds of residents and thousands of transient workers who produced more canned salmon than any cannery in Alaska. Over time, these cannery workers developed unique identities and stories, which today remain little known or understood.

People from around the world journeyed to South Naknek to can salmon for 120 seasons. Before 1952, APA employed mostly immigrants from Europe to gillnet salmon in double-ender sailboats. These men were from the fishing nations of Italy, Croatia, Norway, and Sweden. Skilled immigrants not only fished but built and maintained both the cannery complex and the salmon boats. The cannery hired Asian crews to process the salmon—first from China, then from Japan, and later, the Philippines—whose distinct cultures and traditions shaped the cannery's labor landscape and directly linked the Alaskan cannery to the broader Pacific World.

In addition to Chinese, Japanese, and Filipino crews, historically lesser-known Mexicans, Puerto Ricans, and Hawaiians also labored at the NN Cannery, representing, in the case of Mexican workers, the largest ethnic group to labor at the cannery before WWII. Erased from historical memory, graffiti etchings on the old bunkhouse walls are some of the scant enduring traces that these people left behind. Indigenous Alaskans also worked



Winterman Nick Zimin on left and "One Arm" Nick Melgenak, Chief of Savonoski, at the APA Cannery in South Naknek in the 1930s.

The indigenous Alaskans who worked at the cannery were descendants of Katmai people and culturally connected to the Brooks River Area's Archeological District National Historic Landmark at Katmai National Park and Preserve. Villagers migrated downriver and established South Naknek when Novarupta volcano destroyed Savonoski village and created the Valley of 10,000 Smokes in 1912. The Spanish Flu pandemic and red salmon crash of 1919 drove indigenous people to seek cannery work and they became integral contributors to and caretakers of the operation. Historically, they supplied salmon to the cannery, constituted the "spring/fall" crew that readied and winterized the operation, and served as winter watchmen who protected the collective structures and stored boats throughout the offseason. The cannery's operational longevity is a testament to their vigilance. Cannery buildings that convey the indigenous experience and influence on cannery work include the Laundry, where local women not only found jobs, but controlled the workspace and activities therein. Equally significant are the Alaska Native Bunkhouse and the "white" Mess Hall, both of which reveal the ethnic and racial segregation policies that were prevalent in all Alaska salmon canneries.

CARVEL ZIMIN SR, KATMAI PHOTO ARCHIVE, KATMAI NATIONAL PARK AND PRESERVE



Filipino cannery workers filling the butchering machine in the fish house at the NN Cannery.

With the passage of the Chinese Exclusion Act 1882, Chinese cannery workers began aging out of the work force, and by the turn of the century, thousands of young Filipino men, many of them college students, began arriving on the West Coast looking for work. Following the Spanish-Philippine-American War in 1898, the U.S. annexed the Philippines, and these men, now considered American nationals, began to replace the Chinese on cannery slime lines, eventually becoming known as the "Alaskeros." The Alaskeros commenced the decadelong history of Filipino unionization that would eventually end the practice of racial segregation in Alaska canneries by 1979.

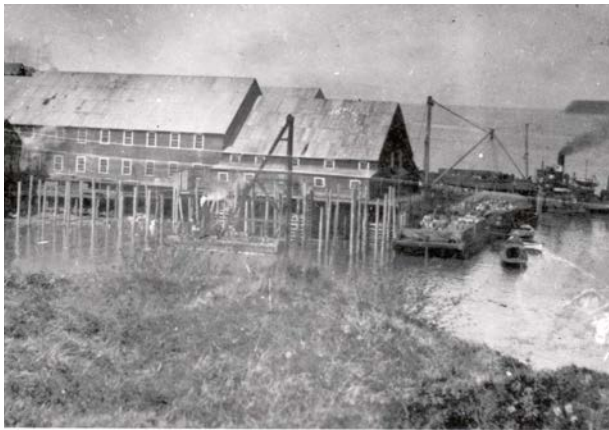
TOM CONNELLY



The Croatian Flag carved into a table in the common area in the Fisherman's Bunkhouse.

The Alaska Independent Fishermen's Marketing Association, formed in 1966 and dominated by Croatians, organized spirited, albeit ineffective, Bristol Bay strikes in 1980 and 1991 that, according to one labor historian, "ended the last significant vestiges of collective bargaining and unionism in the country's most important fishery." Still, the independent fishermen associations continued to serve as an advocate for fishermen's concerns and interests. The identities of the Croatian fishermen shaped the cannery experience and, whether company fishermen or independents, where significant actors in the cannery community.

NN CANNERY HISTORY PROJECT



Above: APA Diamond NN Cannery at South Naknek in 1914, San Francisco Maritime National Historical Park. Top: NN Cannery History Project logo.

Built originally in 1890 as a saltery by the Arctic Packing Company (APC), the operation was absorbed in 1892 by APA who converted the APC saltery into a salmon cannery in 1894. APA assigned its new asset the initials, NN, likely for NakNek. Using a diamond-shaped accounting symbol around the initials, the cannery was rebranded as the <NN> (pronounced as "Diamond NN" and as shown in the NN Canery Project logo, top) and quickly became the crown jewel of APA's well-known trademark: "the diamond canneries."

NN CANNERY HISTORY PROJECT

at the cannery. Katmai Sugpiaq migrated downriver to South Naknek after the Novarupta volcano destroyed the Savonoski village in 1912 (Dumond 2010). The Spanish Flu pandemic of 1918 drove the survivors to seek cannery work. Despite traditional lifeways lost to cannery work, indigenous residents became major contributors to and caretakers of the operation (APA 1923). Moreover, because the cannery property has never been archeologically investigated, the grounds have the potential to continue the Brooks River archeological story and offer a more complete interpretation of the Naknek River's cultural past.

The Alaska Packers Association recognized the contributions of its diverse cannery crew. In a 1928 draft report on Alaska's Salmon Industry, APA President A.K. Tichenor attributed APA's success to the skilled and dependable cannery people:

The company sends to Alaska each year over 4,000 men and employs in addition, a large number of Eskimos, Indians and other residents of Alaska. 1,000 are Superintendents, Physicians, Bookkeepers, Mechanics, Beachmen, etc. About 1,000 are Fishermen, and the balance consists of other cannery employees. Many nationalities are represented amongst these men, but the Fishermen are usually composed of Italians and Scandinavians. These races [men from fishing nations] seem fitted for this particular branch of the industry.

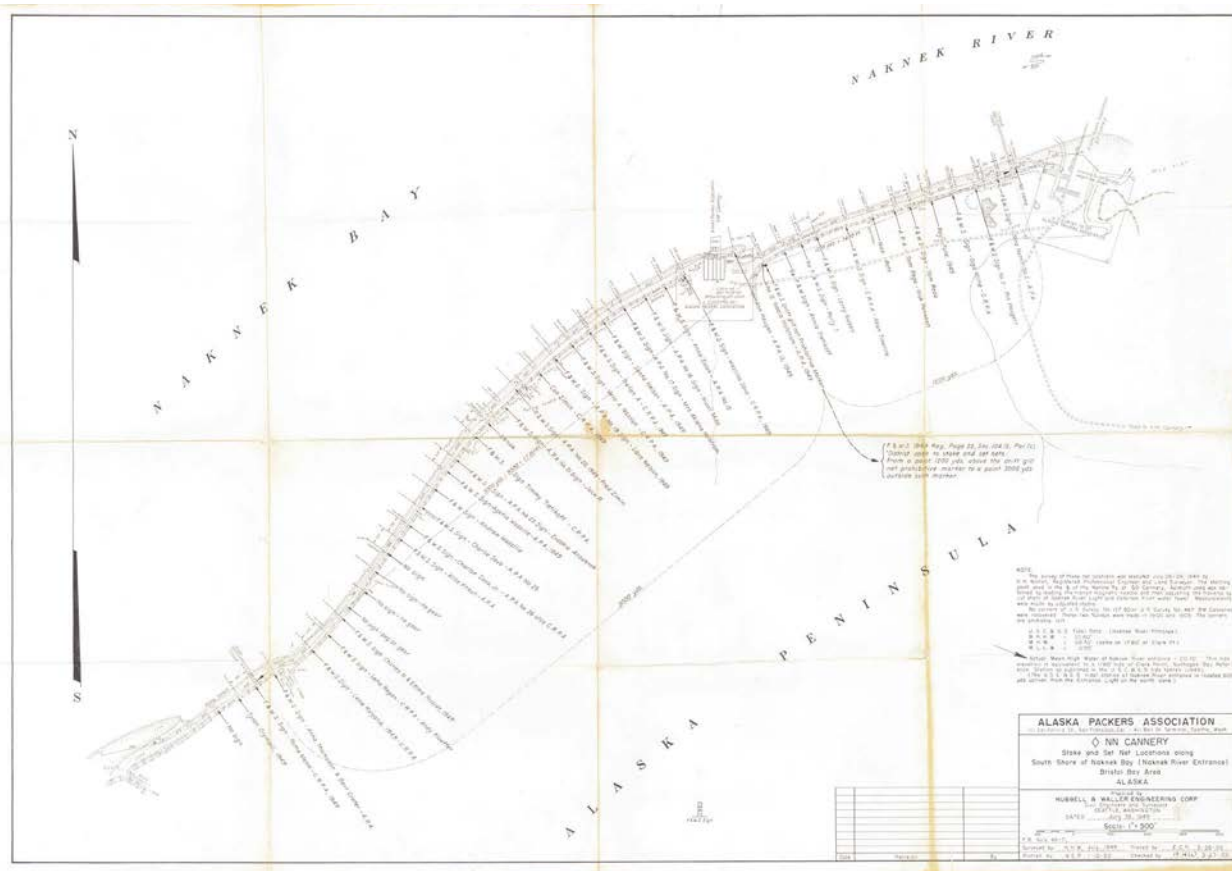
The more salient features of the Alaska salmon industry are the amount of effort that must be expended in assembling the outfit of material and personnel, their transportation to the fishing grounds, the making of cans, cases, etc. the driving of traps and preparation of fishing gear, upon arrival. The repair of wharves and buildings carried away or damaged by ice and snow during the long winters—so that when the "run" starts the plant may be ready in every particular way.

Owing to the shortness of the canning season, which lasts only about four weeks in Bristol Bay, and the short time which we have for the preparation of the pack, the loading and shipment of salmon in the transporting vessels, before winter sets in, it is essential that the outfit be completed in every respect and that the personnel be composed of men who are dependable and willing workers. (Tichenor 1928: 2).

Despite their knowledge of the operation, machines, and the salmon, cannery workers have existed in the shadows, eclipsed by romantic stories of fishermen—the so-called "Iron Men of Bristol Bay"—and marginalized, exotified, or ignored by writers, curators, even park rangers in the historical narratives of Alaska's most important salmon fishery. To fully understand the significance of the canned salmon industry and its expansion throughout the West, Alaska and Bristol Bay, historian Donald Worster writes that consideration must be given to "the ethnic histories of the residents, migrants, and immigrants involved in the extraction of the region's great natural wealth" (Worster 1992). Whether they came from China, Mexico, the Philippines, or simply upriver, the NN Cannery people found dignity through their laborious interactions and forged a deep connection to the surrounding environment. Their diverse traditions left a mark on Naknek history and culture. Their work mattered.

Without a doubt, canneries were and continue to be natural resource extractors—they used technical and organizational skills, engineering knowledge, and energy to transform natural resources—sockeye salmon—into a commodity for world markets. But canneries like APA's Diamond NN Cannery are also important sites of maritime and labor history that retain the overlooked stories of America's past.

Trident Seafoods closed the NN Cannery in 2015, opening a rare window for historians to



Alaska Packers Association set net map, 1946.

It is believed that set netting started as a means for indigenous women, children and the elderly to participate on the commercial fishery. By the 1940s, the fishing method had become an alternative to gillnet boats. Roy Fure, who had a set net site and sold fish to the APA's NN Cannery, also built a cabin on Naknek Lake, which is furnished with items he acquired at the cannery. This is another example of the historic connection between Katmai National Park and Preserve and South Naknek. **TRIDENT SEAFOODS**

share the collective stories of these “dependable and willing workers.” A grassroots organization sprouted the following year and the NN Cannery History Project began to bring awareness of the history contained in the industrial landscape. Because the NN Cannery has the ability to inform the public about the importance of the salmon, the industry, and its diverse participants, the NN Cannery History Project, with the support of the National Park Service and the Alaska State Historic Preservation Office, is nominating the property as the APA Diamond NN Cannery Maritime Historic District to the National Register of Historic Places. Once designated, the NN Cannery will be the first

historic salmon cannery from Bristol Bay to be listed and recognized for its role in interpreting the history of the Naknek River, and its historic ties to the nation and the rest of the Pacific. The cannery’s discarded machines parts, broken boardwalks, skeletal bunkhouses, and graffiti etchings are today’s reminders of Bristol Bay’s forgotten workforce that provide a more comprehensive understanding of the natural, cultural, and economic history of the Naknek River. Like the salmon, cannery people connected the land-based operation to the Pacific waterscape and created an ethnically diverse, economically vital cannery culture. Just as the Brooks River platforms are sites of interpretation of the extraordinary natural

history of Katmai, the NN Cannery can interpret the forgotten history of the canned salmon industry, a history built on the foundation of the pristine habitat and unparalleled sockeye salmon runs upriver.

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The APA canned salmon exhibition at the 1904 World's Fair in St. Louis.

APA was the epitome of a twentieth century American company with a presence on the world stage. Exhibited at its headquarters in San Francisco, APA exhibited its world-class, museum-quality collection of bidarkas, cannery models, Native artwork and corporate mementoes. The company participated in world fairs, gaining recognition for its mechanical canning line exhibit at the 1900 World's Fair in Paris. APA introduced the first canned salmon recipe book at the 1904 World's Fair in St. Louis, to teach women how to cook and eat tin fish.

NN CANNERY HISTORY PROJECT



So Goes the Snow: Alaska Snowpack Changes and Impacts on Pacific Salmon in a Warming Climate

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Snowpack, or annual persistent snow, affects hydrology, water temperature, and other freshwater characteristics. As air temperatures generally increase, snowpack and the many factors it influences will change, but in different ways in different watersheds. The rapid rate of climate change impacts exceeds what we know salmon have been able to adapt to in the past. It is even more important to reduce additional stressors on fisheries.

Citation:

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In Alaska's watersheds, climate change is altering the nature and role of the snowpack, defined as snow accumulation that melts in spring. Generally, the amount of precipitation that falls as snow and the length of the snow-cover season both decrease as temperatures exceed 0°C (32°F) more frequently. The impacts of climate change on snowpack vary among watersheds. In southern, coastal parts of Alaska, large decreases in spring snowpack are expected by the mid-21st century, even with more winter precipitation because temperatures warm to above freezing, causing a shift from snow to rain or more melt during the winter. In contrast, modest early spring increases in the snowpack are expected in watersheds where temperatures remain below freezing. In these locations temperatures warm but remain cold enough for the extra winter precipitation to fall as snow, even though the snowpack will begin accumulating later in the fall and melt earlier in the spring as temperatures rise during those warmer seasons. Because potential impacts on hydrological and ecological systems will vary among watersheds, it is difficult to generalize the resulting ecological impacts at broad spatial scales. Here, we explore likely impacts on hydrology in critical anadromous fish habitat in southwest Alaska.

The Role of Snow in Alaska and its National Parks

In much of Alaska, the landscapes and species we think of as characteristic of place are directly tied to snow. Iconic glaciers define many watersheds

and mountain ranges in the state, the result of snow accumulation over centuries, perhaps even millennia. Snow forms a crucial habitat for many familiar species including snowshoe hare (*Lepus americanus*), wolverine (*Gulo gulo*), and lynx (*Lynx canadensis*) whose tracks we see in winter, or redpolls (*Carduelis flammea*) that can survive cold Arctic nights by burrowing into the snow.

Perhaps less obvious are the many indirect influences of snow on Alaska's ecosystems (e.g., Cox et al. 2017). The length of the snow-free season determines, in part, which plants dominate tundra environments. (e.g., Wahren et al. 2005). The timing of snowmelt, along with other factors, affects the onset of the fire season in the boreal forest (e.g., Kitzberger et al. 2017). Snow is also crucial for recreation and transportation throughout Alaska. In parts of the state, local hydroelectric power systems and municipal water supplies are dependent on snowpack.

This article focuses on snowpack, or snow that accumulates on the ground, persists through winter, and melts later in the year. The distribution and abundance of the snowpack determines the timing and amount of snowmelt, which affect streamflow, water temperature, and many other attributes of freshwater habitats (e.g., Prowse et al. 2006). These attributes, in turn, influence the growth, movement, reproduction, and survival of Pacific salmon (*Oncorhynchus* spp.) during the freshwater phases

of their lifecycle, which include both juvenile and adult stages (e.g., egg, fry, spawner). For example, lower flow volume can affect outmigration success, or higher water temperature can serve as a migration barrier to incoming spawners.

To address the potential implications for salmon, we first review current understanding of climate change impacts on snow in Alaska and the subsequent expected impacts on streamflow regimes. We then provide a brief overview of potential impacts on salmon resulting from hydrologic changes, focusing on southwest Alaska. We focus on qualitative predictions due to the complexity and challenge of quantitatively predicting the cumulative impacts of the many pathways through which streamflow and water temperature impact salmon distribution and abundance.

How Climate Affects Snow

At first it seems obvious that as climate warms, snowpack should decrease. The Northern Hemisphere's annual snow cover has very likely decreased due to anthropogenic climate change since at least the 1970s (Najafi et al. 2016). But how such changes unfold depends a lot on which snowpack features are considered (Callahan et al. 2011). For instance, different places in Alaska have very different snow season durations—when snow tends to fall, accumulate, and melt. In the Arctic and the high Alaska Range and Brooks Range, historically (1970–1999) it could snow eight or more months of the year and the snow that fell would likely accumulate much of the year (McAfee et al. 2014, Shulski and Wendler 2007, Stone et al. 2002). But at sea level in coastal southeast Alaska, the reliable snow season was much shorter, as short as one month or less. So as temperature increases, places where much of the snow historically fell within a few degrees of freezing will experience changes in snowfall and snowpack

much more quickly than places where temperatures were reliably colder. Snowpack is also affected by the amount and timing of precipitation. The term “snow drought” has been used to describe these two climatic influences on snowpack—lower-than-normal winter precipitation that leads to lower snow accumulation, or warmer-than-normal temperatures that cause precipitation to fall as rain rather than snow or that melt the snow earlier than normal (Harpold et al. 2017). The effects of climate on snowpack also depend on what aspect of snow we measure—for example, how much precipitation falls as snow or rain, whether snow accumulates, whether it melts or is blown away by wind, how much water is entrained in snowpack, and how deep it is.

Here, we use several metrics to describe how snow in Alaska is likely to respond to climate change. The first is snow day fraction, which describes the fraction of wet days in a month where the precipitation falls as snow. Depending on storm characteristics, snow can fall when temperature measured near the earth is above freezing or when it is quite cold, and regional differences in the tendency for snow to fall near freezing or colder conditions affects the snow we actually experience. Estimates of future snow day fraction are based on analysis of the temperature on rainy and snowy days at weather stations across the state. The second is snowfall equivalent, which describes the amount of water in precipitation falling as snow and is driven by both temperature and precipitation amounts. A third is winter precipitation snow index, which describes the amount of precipitation from October to March (the cool season) that remains in the snowpack on April 1st. This is defined as the ratio of April 1st snowfall equivalent to total cool-season precipitation. While April 1st is sometimes earlier than the peak snow accumulation for the year in Alaska, it is the traditional date for snowpack measurement. Finally,

we can estimate the months with reliable snow. Here, we assume that if the snow day fraction is above 70%, most of the precipitation arrives as snow and it is cold enough for most of it to accumulate and persist.

Ideally, we would have enough weather stations to measure snow, and the water contained in it, accurately everywhere that matters. But especially in Alaska, long-term weather stations are limited. These four metrics (snow day fraction, snowfall equivalent, winter precipitation snow index, and months with reliable snow) can be derived from regional models of past weather and from global circulation models of future climate, thus allowing us to understand the likely changes in snowpack across regions even where on-the-ground measurements are severely limited.

Climate Change and Snow in Alaska

In the examples that follow, we rely on comparisons between historical conditions (1970–1999, from weather station data and gridded climate data) and future simulated climate from climate models. Technical details underlying these results are described by Littell et al. (2018). We focus on the middle of this century (2040–2069) and use averages of five climate models that work well over Alaska during the historical period. Even without climate change, the amount of snow an area gets, how much of it accumulates, and when it melts varies substantially from year to year and even between decades. Snowpack tracks the high variability in temperature and precipitation, which are in turn driven by ocean temperatures and atmospheric circulation (Shulski and Wendler 2007) that have been shown to affect streamflow in southeast Alaska (Neal et al. 2002). For purposes of vulnerability assessment or adaptation planning, climate change and natural persistent climate variability both contribute to future uncertainty (Hawkins and Sutton 2009).

Climate warming will very likely decrease snow day fraction by decreasing the fraction of total precipitation that falls as snow (McAfee et al. 2014, Lader et al. 2019). Warming will also decrease the duration of the snow season across all of Alaska, by delaying the onset of snow accumulation in autumn and speeding up onset of melt in spring (Littell et al. 2018). These changes will affect places with temperatures commonly near freezing sooner and more drastically than places with temperatures commonly cold enough for snow to accumulate. For example, in southcentral Alaska, from the coast north to Denali National Park and Preserve and west to Lake Clark National Park and Preserve, lower elevations will likely experience decreases of three to five months of reliable snow cover by 2040-2069, or most of the historical reliable snow season (Table 1). In Gates of the Arctic National Park and Preserve and Noatak National Preserve, the reliable snow cover season could change less, decreasing one to two months at lower elevations and less than one month at higher elevations (Figure 1).

Yet, even as snow day fraction decreases everywhere, the higher elevations (above 4,900 feet or 1,500 m) north of the Alaska Range and much of the North Slope will possibly see snowfall equivalent modestly increase (from 10% to 30%, depending on location). This counterintuitive result is due to the fact that even though temperatures increase, they remain near or below freezing much of the winter, and so the likely increases in precipitation result in more snow. In contrast, the lower and middle elevations (up to about 4,900 feet or 1,500 m) for most of southeast, southcentral, and southwest Alaska, are likely to see snowfall equivalent decrease 20% to 40%, depending on location. Later in the 21st century (2070-2099), many of the northern higher elevation areas eventually may begin to experience decreased snowfall equivalent, though snow in the

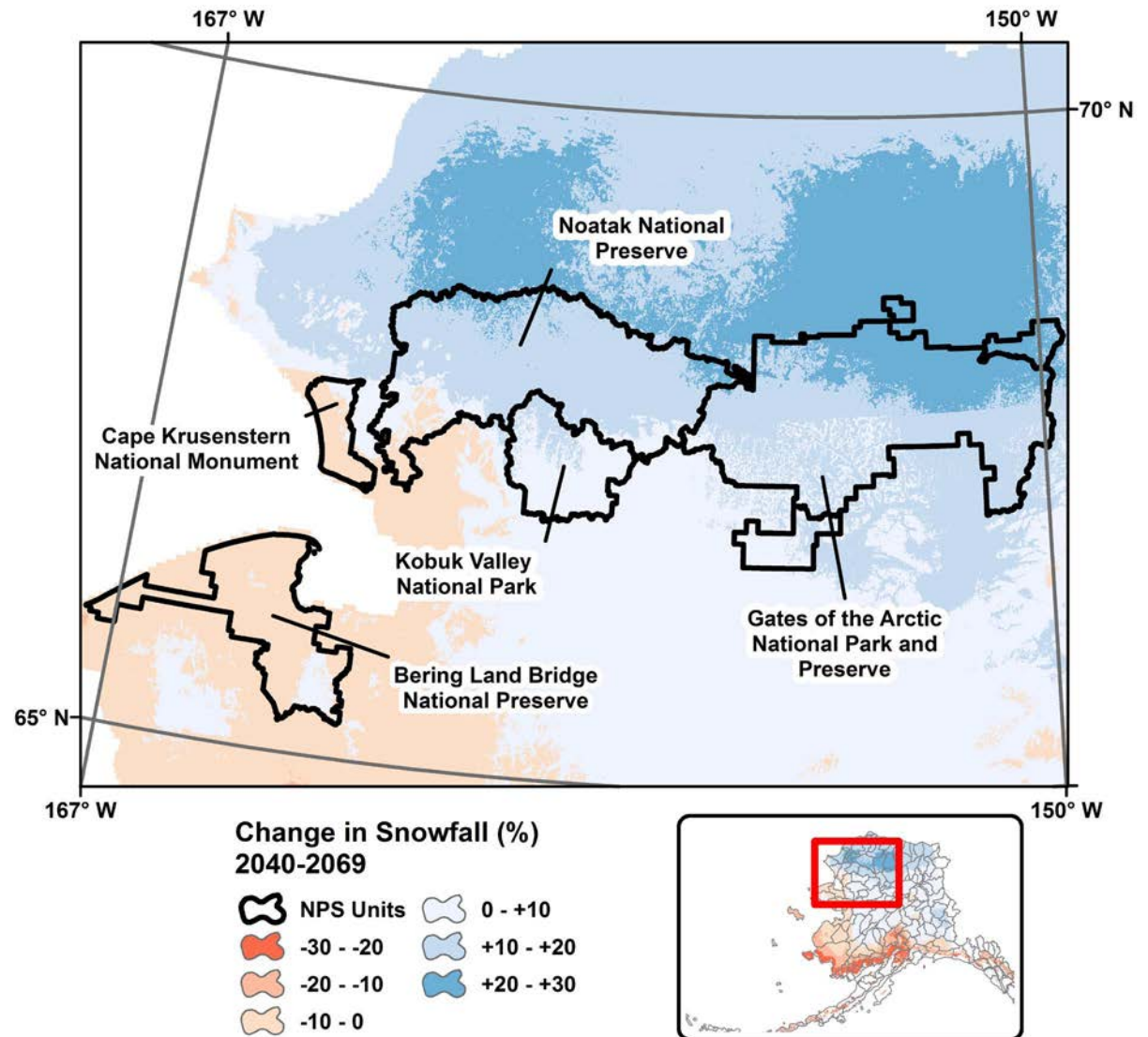


Figure 1. Change in snowfall equivalent, 2040-2069 relative to historical (1970-1999). The decrease in snow day fraction is offset by precipitation increases in Gates of the Arctic National Park and Preserve and most of the Noatak National Preserve. Bering Land Bridge National Preserve experiences the opposite effect, with a decrease in snowfall equivalent over most of its area. The mapped scenario is the average of snowfall projections from five climate models, based on higher emissions scenarios (RCP8.5). DATA: LITTELL ET AL. 2018.

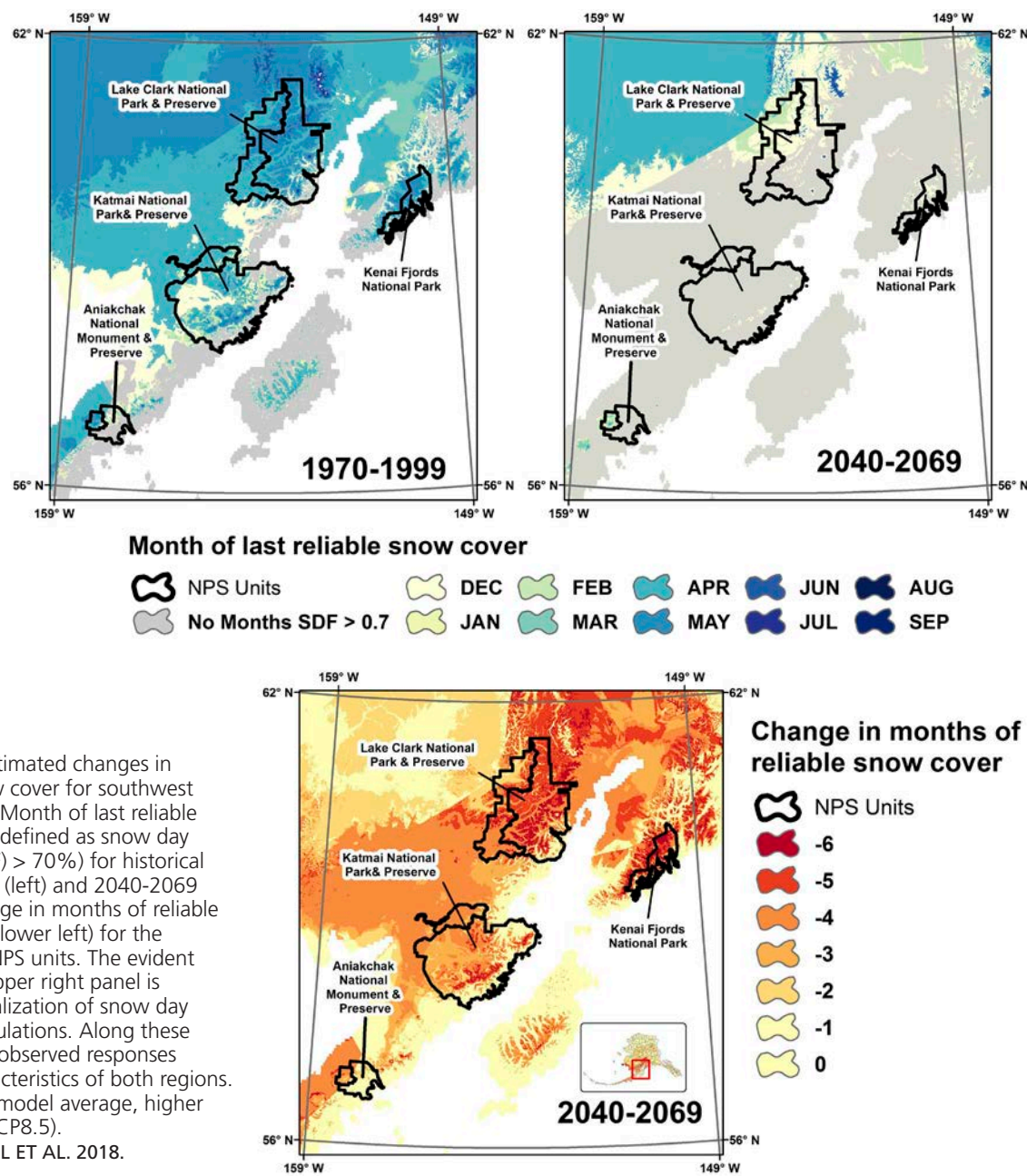


Figure 2. Estimated changes in reliable snow cover for southwest Alaska. Top: Month of last reliable snow cover (defined as snow day fraction, SDF) > 70% for historical (1970-1999) (left) and 2040-2069 (right). Change in months of reliable snow cover (lower left) for the region and NPS units. The evident line in the upper right panel is from regionalization of snow day fraction calculations. Along these boundaries, observed responses exhibit characteristics of both regions. Five climate model average, higher emissions (RCP8.5). DATA: LITTELL ET AL. 2018.

western Brooks Range is expected to continue to increase. The Arctic parks are a regional example of these projected contrasting trends (Figure 1).

Regional Highlight: Southwest Alaska

Southwest Alaska provides a unique opportunity to learn about climate, snowpack changes, and their effects on ecosystems because of its geographic position at climatic and ecological transitions and its world-renowned wild salmon runs. In this vignette, we examine the changes in snowpack metrics under projected climate and discuss their likely effects on salmon via changes to streamflow in important salmon watersheds of the region. Lake Clark National Park and Preserve, Katmai National Park and Preserve, Aniakchak National Monument and Preserve, and Kenai Fjords National Park—all located in southwest Alaska—include glacier-to-ocean freshwater systems with rivers supporting abundant wild salmon runs.

Climate projections suggest that southwest Alaska will experience some of the largest regional changes in snow day fraction. While some coastal areas historically experienced only brief snow seasons, much of the region supported snow until April or May, with the highest elevations snow-covered until June (Figure 2, upper left panel). By the 2050s, the snow season for much of the region is projected to decrease by one to five months and parts of the region may have no months with persistent snow cover (Figure 2, upper right panel; e.g., most of Katmai National Park and Preserve and all of Alagnak Wild River; for results by park, see Table 1).

The ratio of April 1 snowfall equivalent to total precipitation from October to March (the winter precipitation snow index) gives a good estimate of the amount of water stored in the snowpack and available for runoff during the summer. At values over about 40%, the annual spring melt generates the

Table 1. Summary of three snowpack metrics (snowfall equivalent, winter precipitation snow index, and months with reliable snow cover) for park units in Alaska. Metrics are estimated for various thirty-year periods ("1980s" denotes 1970-1999, "2050s" denotes 2040-2069, and "2080s" denotes 2070-2099) or as a change between two periods (1980s vs. 2050s).

NPS Park Unit	Snowfall Equivalent (1980s vs. 2050s) ^a			Winter Precipitation Snow Index ^b			Months with Reliable Snow Cover ^c	
	Min. % Δ	Max. % Δ	Mean % Δ	Mean % 1980s	Mean % 2050s	Mean % 2080s	Last Month 1980s	Last Month 2050s
Alagnak Wild River	-35	-29	-33	55	34	32	Apr	No cover
Aniakchak National Monument	-37	-1	-26	74	51	44	May	Feb
Aniakchak National Preserve	-46	-21	-37	47	28	25	Jan	No cover
Bering Land Bridge National Preserve	-10	3	-2	92	76	72	Late Jun	Jun
Cape Krusenstern National Monument	-11	6	-2	94	78	73	Jul	Late May
Denali National Park	-26	21	0	91	78	75	Jul	Mid Apr
Denali National Preserve	-24	11	-3	87	73	71	Mid Jun	Mar
Gates of the Arctic National Park	4	26	16	99	94	92	Mid Jul	Late Jun
Gates of the Arctic National Preserve	5	24	13	98	92	90	Mid Jul	Jun
Glacier Bay National Park	-55	10	-35	49	33	30	Mid Feb	Jan
Glacier Bay National Preserve	-50	-37	-48	24	13	10	No cover	No cover
Katmai National Park	-52	-4	-34	54	33	31	Late Feb	No cover
Katmai National Preserve	-39	-27	-32	58	36	35	Late Mar	No cover
Kenai Fjords National Park	-52	-6	-29	63	42	40	Late Mar	Jan
Klondike Gold Rush National Historical Park	-43	-8	-26	58	42	38	Mar	Mid Jan
Kobuk Valley National Park	1	19	8	97	88	85	Jul	Jun
Lake Clark National Park	-41	6	-23	68	47	45	May	Jan
Lake Clark National Preserve	-37	-1	-19	72	52	50	May	Mid Jan
Noatak National Preserve	-9	22	14	99	93	92	Jul	Late Jun
Sitka National Historical Park	-52	-52	-52	16	8	6	No cover	No cover
Wrangell-St Elias National Park	-48	20	-4	85	73	70	Mid Jun	May
Wrangell-St Elias National Preserve	-47	17	2	91	80	79	Mid Jun	May
Yukon-Charley Rivers National Preserve	-2	12	6	96	88	87	Jul	May

^a For details regarding this metric, see the caption for Figure 1. "% Δ" = percent change between two time periods.

Values are averaged over each park unit listed, but topography can contribute to important variation within each unit; min and max changes in snowfall equivalent represent ranges for each unit.

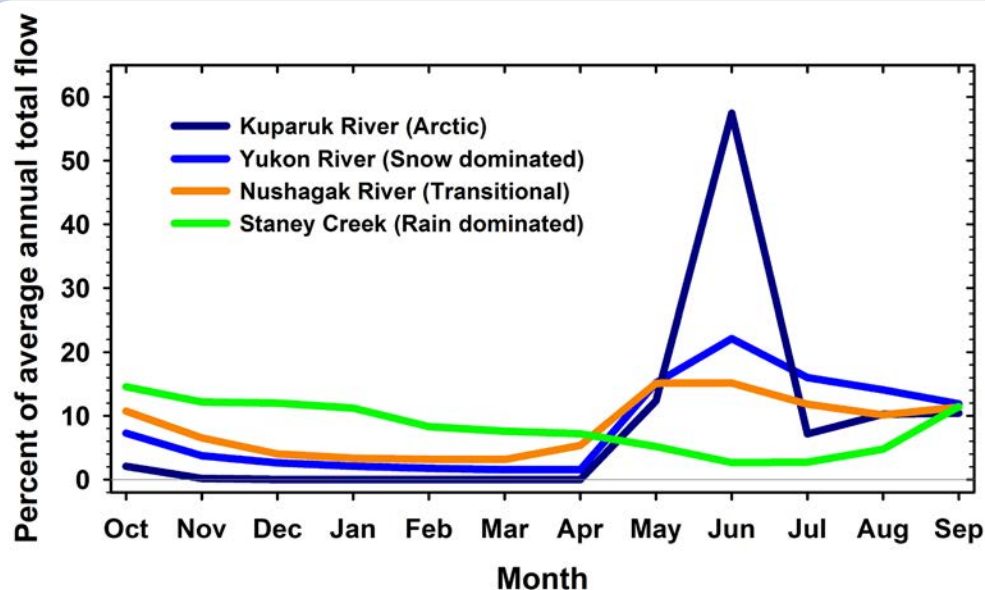
^b For details regarding this metric, see the caption for Figure 3.

^c For details regarding this metric, see the caption for Figure 2. Here, we show only the last month projected to have reliable snow cover in any given winter. Months listed without a designated timing (e.g., Jan, not mid or late Jan) imply the variation in the resulting simulations limit a more precise conclusion.

The changes listed here are for a scenario consistent with higher emissions (RCP8.5). Changes in snow would not change very much on average for the 2040-2069 period because emissions trajectories consistent with the different RCPs do not diverge until then. Actual emissions more consistent with RCPs 4.5 or 6.0 could well occur, in which case the changes in snow would be less in the 2070-2099 period.

How Different Snowpacks Affect Streamflow

The timing of peak streamflow in watersheds depends on what factors drive the daily, monthly, and seasonal changes in water runoff. In the high Arctic, runoff nearly or entirely ceases for several months during the winter, then increases (often rapidly) with the onset of spring, and stays high as long as snowmelt is available. Runoff may then decrease or stay high if late summer and autumn rains provide runoff before freezing again. On another extreme, in warmer climates with little freezing or snow accumulation, the seasonal cycle of rainfall determines the expected peak streamflow. Calculated over many years of measurement, the average streamflow provides a characteristic seasonal profile, called a hydrograph. Hydrographs (below) illustrate the difference in annual streamflows across a gradient from Arctic snow-dominant (Kuparuk River), to snow-dominant (Yukon River), to transitional (Nushagak River), to rain-dominant (Staney Creek). Each line indicates the mean monthly percentage of annual streamflow for the available years of data. Note the differences in the seasonal peak streamflow and mid-summer responses. While the size of these watersheds varies considerably, the point remains—changes in climate affect snowpack and thus streamflow volume, water availability, and seasonal timing of runoff.



Kuparuk River at Deadhorse: 1972–2017; Yukon River at Stevens Village: 1977–2017,
Nushagak River at Ekwok: 1977–1993; Staney Creek near Klawock: 1990–2017
DATA: USGS

highest peak in the hydrograph of annual streamflow (see inset); watersheds where at least 40% of the cool-season precipitation falls as snow are considered *snow dominant* in terms of runoff. Between 40% and about 10%, watersheds are labeled *transitional* in their seasonal runoff peaks, often with a peak in the spring and early summer driven by snowmelt, a decrease in streamflow during the summer, and a second peak in the autumn with the usual increase in precipitation. If snowfall equivalent is less than 10% of the cool-season precipitation, watersheds are considered *rain dominant* and the seasonal hydrograph reflects the annual precipitation cycle.

Historically, most southwest Alaska watersheds were considered snow dominant, with a few coastal watersheds experiencing transitional hydrographs. Projected climate conditions (for 2040–2069) push watersheds toward transitional status in all of southwest Alaska. Many lower-elevation watersheds cross the threshold, and a greater fraction of the landscape, especially in Aniakchak and Katmai, become transitional (Figure 3). The detailed hydrologic modelling of future flows that has occurred in a few areas of southwest Alaska (e.g., sections of the upper Nushagak and Kvichak watersheds) suggest that by 2100 at least some streams will have fully shifted to a rain-dominant regime (Wobus et al. 2015).

While changes in snowpack accumulation and snowmelt can be expected to affect streamflow as described above, many of the watersheds in southwest Alaska are also partially influenced by glaciers. Glacier-derived runoff will modify the impacts of changes in snowmelt and snowpack on streamflow and freshwater species, at least temporarily. For example, as climate warms, glaciers initially will contribute increased runoff as they melt. Unlike snowmelt runoff, glacier contributions extend later in the summer and autumn. Consequently, glaciers

may offset some changes due to decreasing snowpack early in the runoff season, but also contribute to higher than historical runoff during peak flow in mid and late summer. Therefore the timing of peak flow may shift from that seen in snow-dominant streams. Eventually, the meltwater from receding glaciers will no longer buffer streamflow from the effects of declining snowpack. Meanwhile, salmon and other aquatic organisms will need to adjust to significant changes in streamflow, sediment supply, thermal regimes, and water chemistry as glacier inputs temporarily make up more and more of the streamflow, then decline.

We do not have regional-scale quantitative estimates of how decreasing snowpack or increasing glacier melt will change future streamflows. The watershed configuration and internal processes of glacier response to climate vary greatly, so predicting watershed-level vulnerability to climate change requires more specific modeling. A step towards understanding the combined effects of snowpack and glacier changes is given by a qualitative approach from the Chugach National Forest Climate Change Vulnerability Assessment (Hayward et al. 2017). In a chapter on salmon, Chilcote and others (2017) classified watersheds based on two variables: (1) the winter precipitation snow index (described above), and (2) the current amount of glacier cover in the watershed. Applied to southwest Alaska, this same classification suggests streams will shift toward transitional precipitation status in many watersheds in southeastern Lake Clark and Katmai national parks and preserves (Figure 4). This classification could help prioritize watersheds and stream systems for further study in evaluating impacts of change in snow-driven streamflows on salmon and other ecological resources.

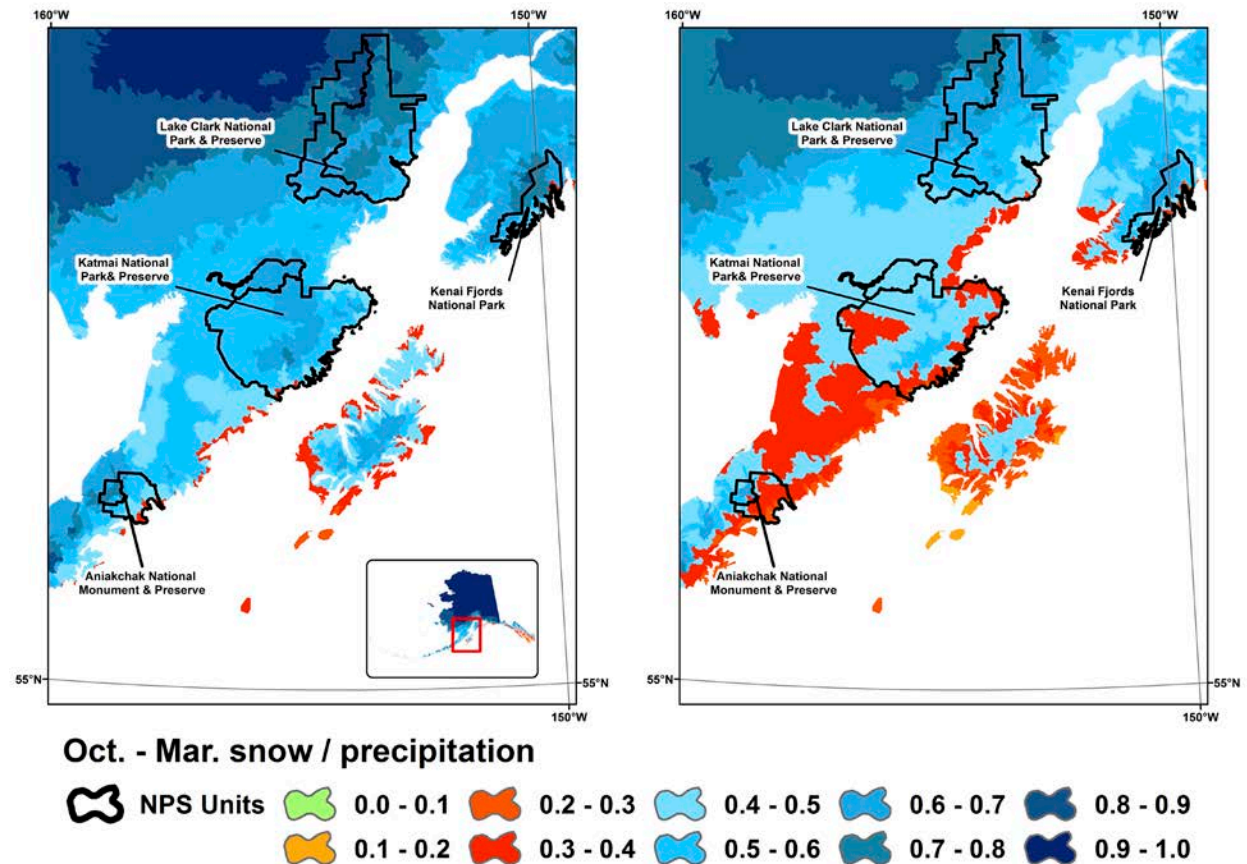


Figure 3. Fraction of October to March snowfall equivalent stored in April 1 snowpack. Historical (1970-1999, left) and five climate model average (2040-2069, right) higher emissions (RCP8.5). DATA: LITTELL ET AL. 2018.

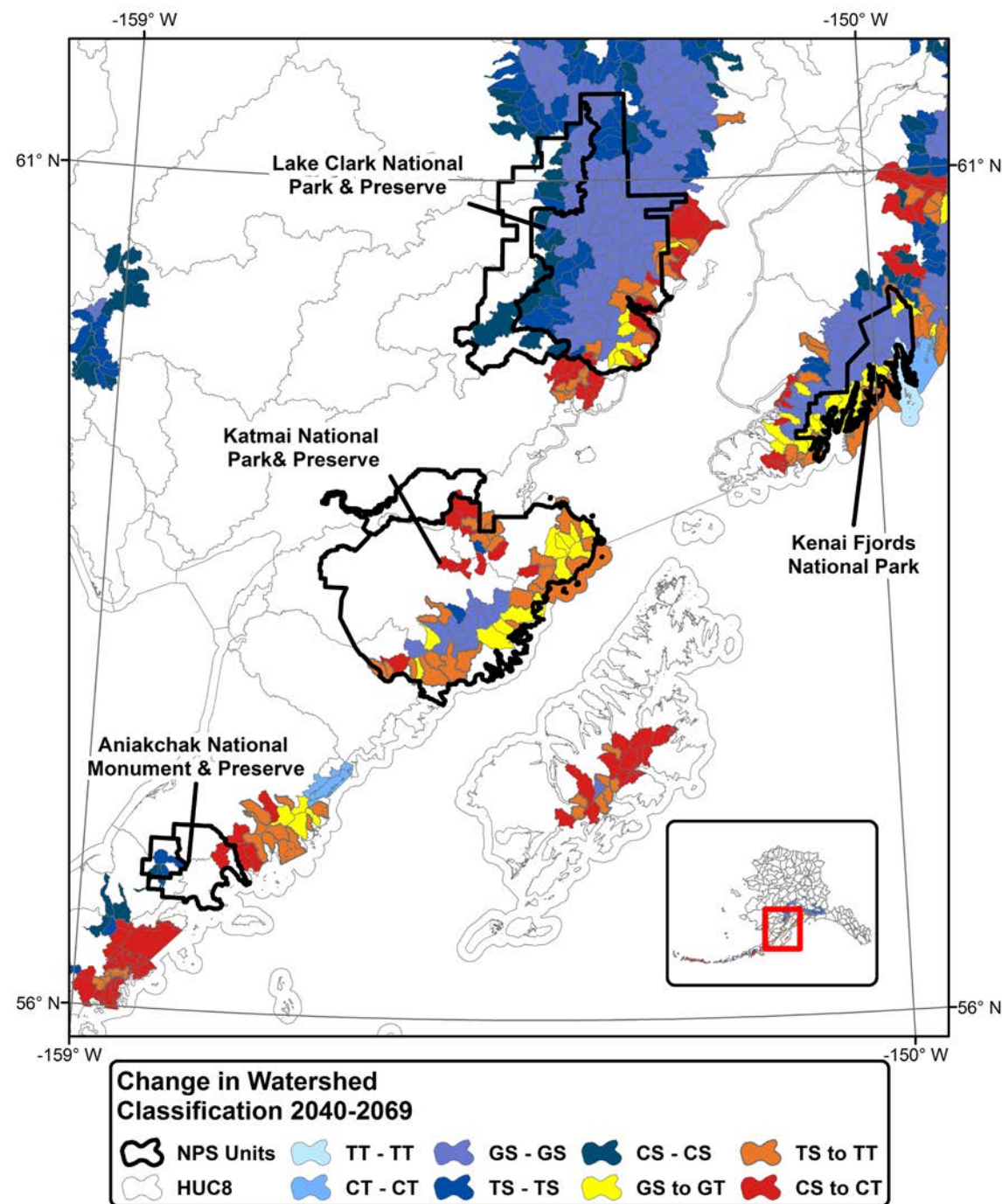


Figure 4. Watersheds classified by current glacier cover and change in October to March precipitation in snowpack (current versus 2040-2069), after Chilcote et al. (2017). Blue values indicate no change in status by 2040-2069; yellow, orange, and red indicate classification changes. Five climate model average, higher emissions (RCP8.5). White indicates watershed without significant glacial coverage.

CS = Clear water streams that are snow dominant (<1% glacial)
 CT = Clear water streams that are snow transitional (<1% glacial)
 TS = Transitional glacial streams that are snow dominant (1-10% glacial)
 TT = Transitional glacial streams that are snow transitional (1-10% glacial)
 GS = Glacial streams that are snow dominant (>10% glacial)
 GT = Glacial streams that are snow transitional (>10% glacial)

Potential Impacts on Salmon

Predicting the impacts of climate change on snowpack, water quantity and quality, and salmon is difficult in southwest Alaska. The available baseline information for weather, climate, streamflow, and salmon is thin compared to the size of the state and the diversity of habitat types therein. Moreover, climate variability is high in this region, with the combined influences from the North Pacific and the Arctic difficult to simulate and predict. For these reasons, we summarize snowpack conditions over 30-year periods rather than describing annual or decadal changes. Likewise, salmon spawning in different streams and lakes within a single watershed, let alone across watersheds, can differ in their genetic, phenotypic, and behavioral traits.

However, we can draw qualitative conclusions regarding likely impacts on salmon due to changes in streamflow and water quality expected to result from changes in snowpack between the historical (1970-1999) and future (2040-2069) periods (Figure 5). First, it is virtually certain that the changes in snowpack will be large enough eventually to shift many streams' hydrographs from snow dominant to transitional or even rain dominant (Figure 4). In those locations, streamflow would be expected to increase during winter months when salmon eggs are present in the gravel, increasing the possibility of scouring, and consequent egg mortality, during storms (Montgomery et al. 1996). The same changes in snowpack imply that spring peak flow would be expected to decrease (e.g., see Wobus et al. 2015). Changes in the timing and magnitude of streamflow could also lead to changes in the timing of migration for both juveniles moving downstream and adults returning upstream, possibly leading to mismatches between timing and optimal conditions in the modified habitat.

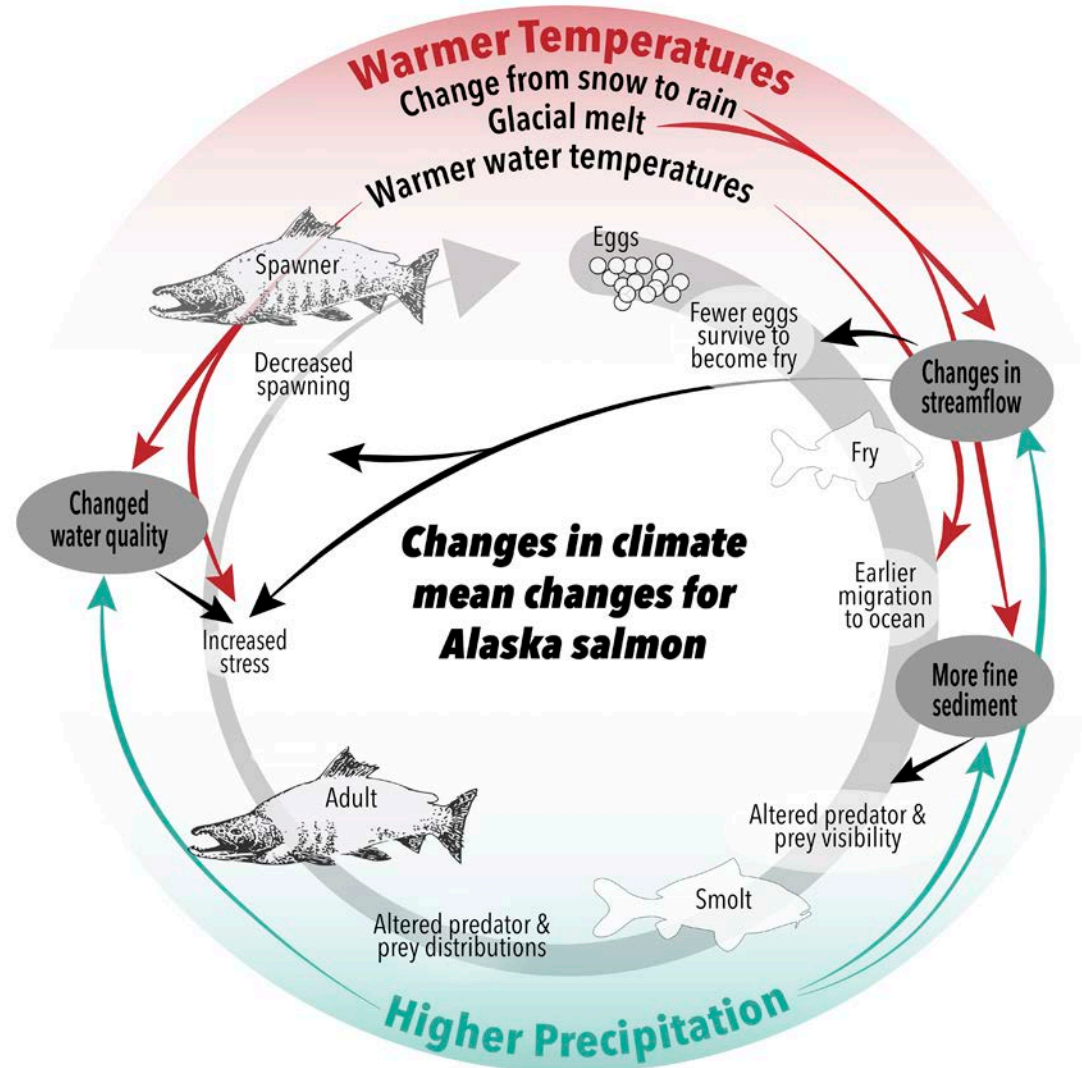


Figure 5. This diagram summarizes some of the ways the changes in snowpack distribution and abundance expected in southwest Alaska likely will influence stream habitat quality and quantity experienced by Pacific salmon, as well as some of the subsequent physiological, behavioral, or ecological impacts expected on various phases of the salmon lifecycle. We restrict attention to impacts during freshwater stages of the lifecycle and do not attempt to capture impacts of these changes on the marine stage of the lifecycle. For example, the shift of winter precipitation from snow to rain (Figures 2, 3) will lead to increased water temperatures which will increase development rates of incubation salmon eggs and growth of fry (during winter and spring) yet may also increase physiological stress on adult salmon migrating to natal systems to spawn (during summer). Similarly, the changes in snowpack described in the text are expected to change the hydrographs of many streams (e.g., the magnitude, duration, frequency, and timing of runoff) from *snow-dominated* to *transitional* or *rain-dominated* (see Figure 4), decreasing egg-fry survival, etc.

ADAPTED FROM CLIMATE IMPACTS GROUP 2009.

The loss of snowpack influence will remove its buffering effect on maximum stream temperatures, increasing the sensitivity of stream temperature to air temperature (Lisi et al. 2015). During the period of increased rate of glacial melt, fine sediment loads will increase downstream, decreasing survival of eggs to fry (through suffocation or entrapment; Jensen et al. 2009), and limiting the amount of suitable spawning habitat (because suitability depends, in part, on sediment particle size and distribution; Kondolf et al. 2008). Increased fine sediment, when suspended in the water column, could also reduce visibility of prey and predators alike (Gregory and Levings 1998).

Reduced snow cover and winter precipitation as snow, along with increased air temperature, are expected to increase stream water temperature. During winter and spring, warmer waters could hasten development and growth of salmon eggs and fry, possibly leading to earlier life stage transitions (i.e., egg-to-fry and fry-to-smolt; Beacham and Murray 1990). During summer, warmer waters could increase physiological stress on adult salmon migrating to spawning grounds, potentially reducing spawning rates (Sauter et al. 2001). Reduced spawning rates would also result from thermal barriers during migration, such as stretches where water temperatures exceed salmon thermal tolerances (Eliason and Farrell 2016). These are just a few of the expected impacts on specific aspects of salmon lifecycles.

In addition, changes in streamflow, fine sediments, and water temperatures will, ultimately, impact the quantity and quality of accessible salmon habitat, as well as habitat connectivity and complexity. In general, habitat complexity will likely decrease due to declines in glacially influenced systems and losses of snow-dominant hydrographs. This loss of habitat complexity may, eventually, reduce diversity in salmon run timing and thus duration of the period

during which returning adult salmon are available for consumption by aquatic, avian, and terrestrial predators (Schindler and Smits 2017).

Lastly, changes in snowpack will simultaneously affect not only salmon but other species in freshwater and marine foodwebs, hinting at the difficulty of trying to account for and synthesize the many potential impacts to any given salmon population. The snowpack and watershed classifications presented here provide a framework for anticipating the most substantial changes in snowpack within Alaska's national parks. This framework can thus be used as a basis to understand potential responses of salmon to climate-induced changes, which are mediated through cascading changes in salmon habitat conditions.

And So Goes the Snow?

Thriving salmon populations underpin the ecological, economic, and cultural health of southwest Alaska. These salmon populations have gradually adapted, since the last glaciation, to a diversity of habitats. This habitat diversity, and the associated diversity in salmon populations, is called the portfolio effect and is hypothesized to underlie the resilience of these salmon populations in the face of various stressors over the decades (Schindler et al. 2010). However, the rapid rate of the climate change impacts described here far exceeds the historical rates of change that have confronted salmon in the past. The reduction and loss of salmon populations at lower latitudes clearly demonstrates their limited ability to rapidly adapt to human stressors, often termed the “four Hs”: harvest, hydropower, hatcheries, and habitat loss (Ruckelshaus et al. 2002). Alaska, and especially southwest Alaska, strongly benefits from having largely intact freshwater ecosystems and (currently) very limited amounts of other development-related stressors known to negatively impact salmon stocks.

Projected climate change impacts are expected to reduce snowpack and promote glacial melt, reducing salmon habitat quality and diversity. Resource managers tasked with managing and protecting these vulnerable habitats may place greater priority on improving the understanding of stressors affecting salmon habitats to devise solutions for limiting their influence, and thus help sustain the ecological, subsistence, economic and cultural systems that depend on salmon.

Further Information

- [National Climate Assessment 4 – Alaska Chapter](#)
- Statistically downscaled projections of snow/ rain partitioning for Alaska, [McAfee et al. 2014](#).
- Alaska snowpack response to climate change: Statewide snowfall equivalent and snowpack water scenarios, [Littell et al. 2018](#).
- The portfolio effect regarding the sockeye salmon of southwest Alaska in Biocomplexity and fisheries sustainability, [Hilborn et al. 2003](#).
- Introduction to potential climate change consequences for a portion of Alaska including overviews of glacier, snow, and salmon, [Climate Change Vulnerability Assessment for the Chugach National Forest and the Kenai Peninsula](#).

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Sockeye salmon in the Tazmina River, Lake Clark National Park and Preserve.
PHOTO COURTESY OF MICHAEL MELFORD



Permafrost Carbon in Stream Food Webs of Arctic Alaska

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Across the Arctic, permafrost stores vast amounts of organic carbon, much of which has been kept “in the freezer” for thousands of years. When permafrost thaws, this ancient carbon can be released into the atmosphere as the greenhouse gases carbon dioxide and methane. It can also be transported by groundwater flow and erosion from soils to streams and lakes. What impact does this old carbon have on aquatic organisms and ecology?

Citation:

O'Donnell, J. A., M. P. Carey, J. Koch, and C. E. Zimmerman. 2020. Permafrost carbon in stream food webs of Arctic Alaska. *Alaska Park Science* 19(1): 76-79.

Across the Arctic, permafrost stores vast amounts of organic carbon, much of which has been kept “in the freezer” for thousands of years (Hugelius et al. 2014). When permafrost thaws, this ancient permafrost carbon can be released into the atmosphere as the greenhouse gases carbon dioxide and methane. Most research to date has focused on the release of *permafrost carbon* as a feedback to the Earth's climate, which could speed up current rates of warming (Schuur et al. 2015). However, this ancient carbon can also be transported by groundwater flow and erosion from soils to streams and lakes (Aiken et al. 2014). Will this ancient permafrost carbon be transported by streams and rivers to the Arctic Ocean? Will it also be broken down by stream microbes and released to the atmosphere? How will it affect aquatic organisms, such as algae, invertebrates, and fish?

Here, we discuss some results from collaborative research conducted by a team of ecologists and hydrologists from the US Geological Survey and the National Park Service (O'Donnell et al. in press). Over the past five years, we studied these questions in the headwater basins of the Noatak National Preserve, Kobuk Valley National Park, and Bering Land Bridge National Preserve in northwest Alaska. To address these questions, we examined patterns in stream hydrology, chemistry, and biology. As the climate warms and permafrost thaws, it is expected that more of the carbon in these Arctic streams would be from the ancient stores released from thawing

permafrost. Because previous studies have found that the age and chemistry of carbon in these Arctic streams varies among watersheds and across seasons (O'Donnell et al. 2014, 2016), the range of ecosystems provides a natural laboratory for examining how the contribution of ancient permafrost carbon to stream organisms varies and to explore why and how this contribution may change as permafrost thawing continues.

In twelve watersheds, we measured carbon isotopes to determine the age and sources of dissolved carbon to these streams, as well as in the stream organisms themselves, including biofilm (algae, microbes), invertebrates, and juvenile fish. While the proportion of the stable carbon isotope (^{13}C) reflects the carbon source based on different plant types, radiocarbon (^{14}C) reflects the “age” of the carbon, or the elapsed time since living organisms fixed carbon from the atmosphere. We understand that carbon enters the food web through lower trophic levels, like photosynthetic algae and microbial communities (benthic biofilm; Figure 1). Invertebrates then “consume” algae and microbes and, in turn, fish feed on these invertebrates. Interestingly, our ^{14}C measurements indicated that juvenile resident fish, like Dolly Varden (*Salvelinus malma*) and Arctic grayling (*Thymallus arcticus*), use carbon that is up to 3,500 years old. Similar ages were observed in algae growing on streambed rocks and invertebrates, such as stoneflies and chironomids.



Mike Carey and Josh Koch electro-fishing in a tributary of the Agashashok River in Noatak National Preserve.
NPS/JON O'DONNELL



Arctic grayling samples collected from a headwater stream for analysis of carbon isotopes.
NPS/JON O'DONNELL

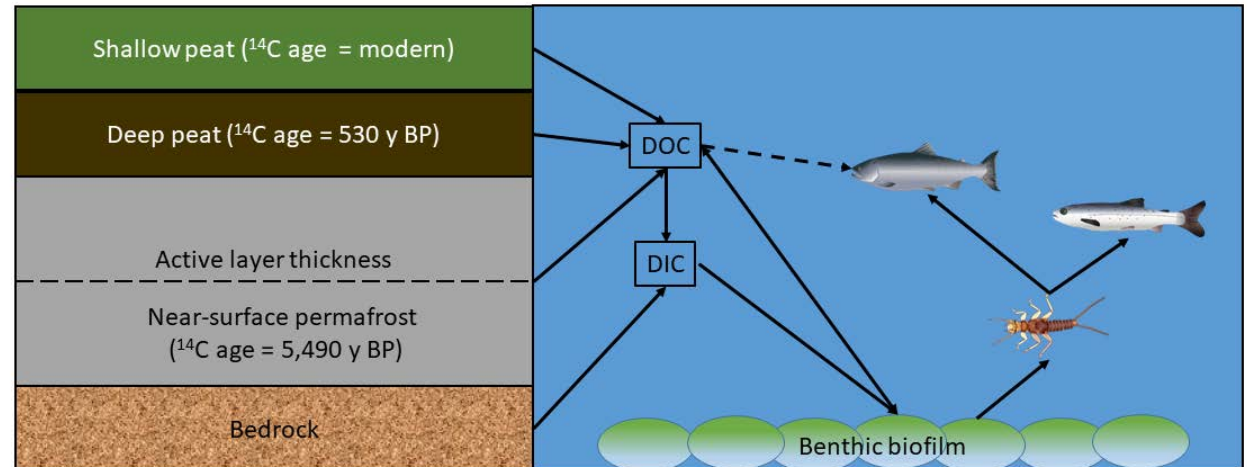


Figure 1. Diagram illustrating the likely pathways of carbon transport from terrestrial to aquatic ecosystems and incorporation into the stream food web. Benthic biofilm is a mixture of both algae and microbes that reside on the streambed surface. Radiocarbon ages are reported in years before present (y BP). The arrows represent direct (solid) and indirect (dashed) pathways of carbon transport.

Based on our isotope measurements, we modeled how much fish and other stream organisms rely on old carbon from deep peat horizons (500-1500 years before present) and permafrost (>5,000 years before present) versus modern carbon (carbon captured since the 1950s in the form of leaf litter and moss). These models offered three insights. First, carbon enters the stream food web in two forms: dissolved organic carbon (DOC) used by microbes and dissolved inorganic carbon (DIC) taken up by algae. Second, nearly 80% of the stream DOC originates from the terrestrial ecosystem (not aquatic or marine ecosystems); of that terrestrial DOC, the majority is released from ancient decomposed peat and permafrost. Third, Arctic grayling and Dolly Varden incorporate both invertebrates and DOC in almost equal measure for food. However, we still need to work out the pathways of DOC movement through the food web, since fish cannot consume it directly.

Projected climate warming will likely cause widespread permafrost thaw across the Arctic

(Panda et al. 2016) and with it, more ancient carbon will be released into streams (Spencer et al. 2015). Our findings indicate that as fish use more ancient carbon in their diet, it may have important consequences for fish growth. Fish that rely more heavily on ancient carbon tend to be smaller and have fewer energy reserves. Because no one understands how ancient carbon results in smaller and skinnier fish, we will need to conduct further experiments to better understand these processes. Ultimately, our goal is to forecast the long-term consequences of the increasing release of ancient carbon into our stream fishery resources.

Acknowledgements

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Drivers of Mercury in Top-predator Lake Fish from Southwest Alaska Parklands

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Ryan F. Lepak, Jacob M. Ogorek, and David P. Krabbenhoft, *US Geological Survey*

Some resident lake fish sampled from southwest Alaska parks have elevated concentrations of mercury (mostly methylmercury, a potent neurotoxin and endocrine disrupter). Why do these fish—that inhabit some of the most remote and supposedly pristine waters in North America—have such elevated mercury levels? Answering this question requires an understanding of mercury cycling, or the processes by which mercury moves through the environment.

Citation:

Bartz, K. K., T. L. Wilson, D. B. Young, R. F. Lepak, J. M. Ogorek, and D. P. Krabbenhoft. 2020. Drivers of mercury in top-predator lake fish from southwest Alaska parklands. *Alaska Park Science* 19(1): 80-85.

The Southwest Alaska Network (SWAN) is part of the National Park Service (NPS) Inventory & Monitoring Division, which was created in 1998 to quantify the status and trends of select indicators or “vital signs.” One of the vital signs monitored by SWAN is resident lake fish (i.e., non-migratory freshwater species). Resident lake fish are key indicators of ecosystem health due to their continuous exposure to lake waters, which integrate conditions from the surrounding land and air (Schindler 2009). For this reason, and also because resident lake fish are important for subsistence and recreational fishing in Alaska, it is crucial to better understand their contamination levels and sources.

From 2005 to 2015, NPS researchers sampled more than 300 resident lake fish for contaminant analyses. These fish included 9 species from 13 lakes in 2 southwest Alaska parks. Results indicated that some samples had elevated concentrations of mercury, the majority of which was methylmercury, a potent neurotoxin and endocrine disrupter. Compared with resident lake fish sampled in 21 parks from 10 monitoring networks in the western United States, mercury concentrations in fish from southwest Alaska were among the highest, although considerable variation existed among lakes (Eagles-Smith et al. 2014). Why do these fish—that inhabit some of the most remote and supposedly pristine waters in North America—have such elevated mercury levels? Answering this question requires an understanding of mercury cycling, or the processes

by which mercury moves through the environment (Figure 1).

Mercury is a toxic element with no known essential biological function. It occurs naturally as a solid in various minerals, and as a gas from volcanic eruptions and human activities, particularly mining and coal burning. Gaseous elemental mercury can be transported atmospherically to areas far from original sources, after which it can be oxidized and deposited on the earth’s surface in the form of rain or snow. Under anaerobic conditions, typical of wetland sediments, bacteria can convert this deposited inorganic mercury to organic methylmercury. Methylmercury may then accrue in aquatic organisms through the intake of both water and food. In fish, methylmercury readily crosses biological membranes, excretes slowly relative to its rate of uptake, and accumulates to concentrations vastly exceeding those in surface waters (Wiener et al. 2003).

Factors driving mercury concentrations in fish can be grouped into four broad categories: loading, methylation, bioaccumulation, and biomagnification (Table 1). *Loading*, or the amount of mercury entering an ecosystem, quantifies the sources of mercury, which can be distant or local. *Methylation*, or the process by which mercury is converted to methylmercury, is determined by local ecological conditions. *Bioaccumulation*, the increase in methylmercury over time in an organism, and

Figure 1. Simplified diagram of mercury cycling, highlighting processes of interest in southwest Alaska. Letters correspond to factors listed in Table 1. Arrow widths do not correspond to mercury load.

Art credit: Tracey Saxby and Dylan Taillie, [IAN Image Library](#)

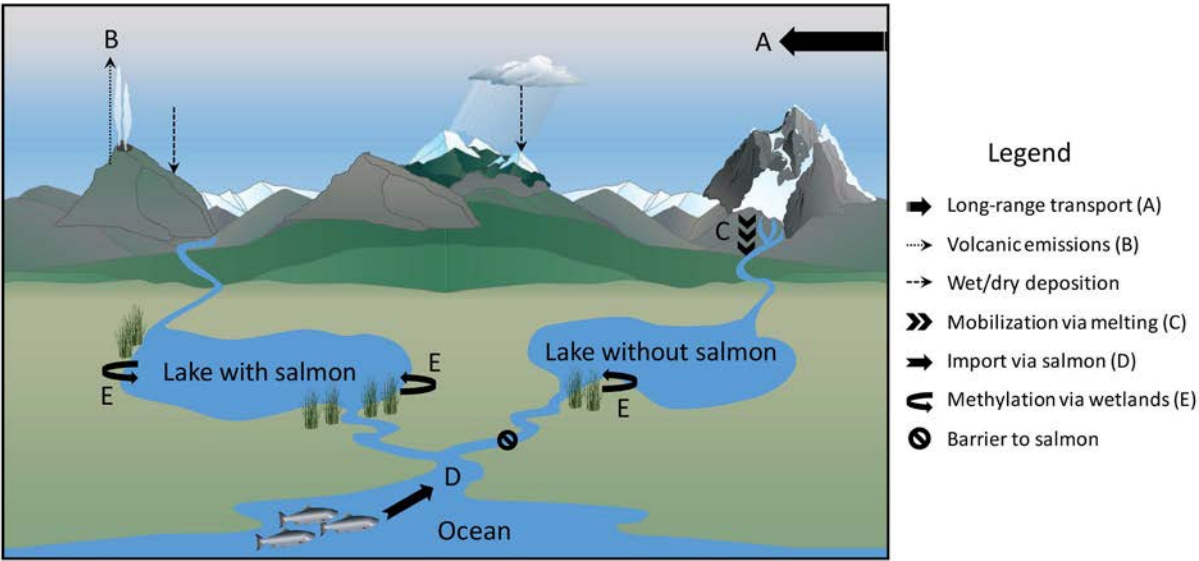


Table 1. Distant and local factors hypothesized to drive fish mercury concentrations in SWAN parklands. The first five factors (A-E) are also depicted in Figure 1.

Scale	Category	Factor	Explanation
Distant	Loading	Atmospheric transport (A)	Mercury-rich emissions from coal-fired power production are transported and deposited to distant habitats.
Local	Loading	Underlying geology (B)	Bedrock and surface soils may be enriched in mercury where natural deposits or active volcanoes exist.
Local	Loading	Melting glaciers (C)	Glaciers contain latent reservoirs of atmospherically deposited mercury, as well as entrained geologic materials.
Local	Loading	Spawning salmon (D)	Adult salmon import not only marine-derived nutrients but also bio-available mercury to lake food webs.
Local	Methylation	Wetland cover (E)	Wetlands provide favorable conditions for methylation and yield compounds that increase mercury bioavailability.
Local	Methylation	Water quality	Water quality conditions, such as pH and turbidity, are believed to control the bioavailability of inorganic mercury.
Local	Bioaccumulation	Fish age and size	Mercury absorption into tissues outpaces removal, so mercury levels increase over time in individual fish that are older and larger.
Local	Biomagnification	Fish trophic position	Piscivorous top predators tend to have elevated mercury because concentrations increase toward the top of the food web.

biomagnification, the increase in methylmercury at higher levels of the food web, are driven by local fish biology and food web differences, respectively. Based on our understanding of mercury cycling, we hypothesize that at least seven key factors could be at play in southwest Alaska lakes (Table 1).

To discern the relative importance of these factors, we partnered with the US Geological Survey (USGS) Mercury Research Laboratory in Wisconsin. The ensuing study focused on a long-lived piscivorous species (lake trout; *Salvelinus namaycush*) in two parks (Katmai and Lake Clark national parks and preserves). The first two years of the study involved sampling water, sediment, plankton, and fish—both lake trout and sockeye salmon (*Oncorhynchus nerka*). Samples were collected from 13 lakes with a range of glacier, wetland, and salmon influences (Figure 2). They were then analyzed for mercury, methylmercury, and other analytes including stable isotopes of mercury, carbon, and nitrogen. Our goal was to answer two main questions: what drives the relatively high mercury levels observed in resident lake fish from southwest Alaska and what controls among-lake differences in those mercury levels?

Preliminary results indicate that: (1) lake trout exhibit a wide range of total mercury levels, both among parks and among lakes; (2) the median value of lake trout total mercury in 6 of 13 lakes is above the State of Alaska's guidance for unlimited fish consumption by at-risk groups; and (3) by comparison, sockeye salmon total mercury levels are consistently low and exhibit little variability (Figure 3). Ongoing work involves developing quantitative models to relate mercury in lake trout with potential drivers. These models include variables measured at both the “fish-level” (i.e., variables recorded once per individual fish, such as age) and the “lake-level” (i.e., variables recorded once per lake, such as wetland cover in the watershed). The fish-level variables

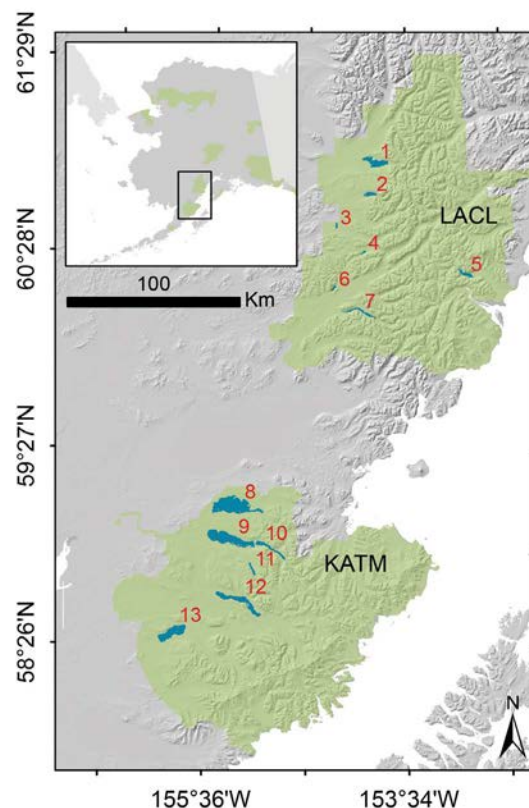


Figure 2. Map of 13 study lakes spanning 2 parks: Lake Clark National Park and Preserve (LACL) and Katmai National Park and Preserve (KATM), shown in green. Study lakes are shown in blue with red numbers indicating lake names: (1) Telaquana, (2) Turquoise, (3) Snipe, (4) Lachbuna, (5) Crescent, (6) Kijik, (7) Kontrashibuna, (8) Kukaklek, (9) Nonvianuk, (10) Kulik, (11) Hammersly, (12) Grosvenor, and (13) Brooks.

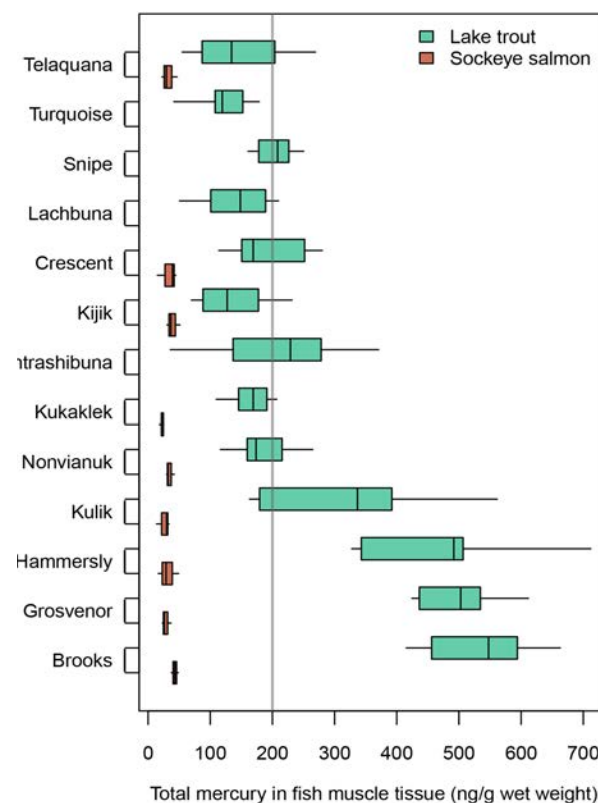


Figure 3. Boxplots of mercury in lake trout and sockeye salmon, organized geographically from top (north) to bottom (south) in the diagram. The midline of each box signifies the median value of 10 lake trout or 3 sockeye salmon per lake. The gray line represents the upper limit for unlimited human consumption of Alaska-caught fish, specifically for women of childbearing age, nursing mothers, and children under the age of 12 (Hamade 2014).

that best explain lake trout mercury concentrations are age, body condition, and diet specialization. Specifically, mercury tends to be higher in older, skinnier lake trout that feed offshore. The lake-level variables, either individually or in combination, do not improve the models' abilities to explain lake trout mercury concentrations. Notably absent in our results to date is a significant effect of sockeye salmon on lake trout mercury concentrations. Hence, sockeye salmon are unlikely to be a major driver of differences in mercury among these lakes.

Results from this study are being summarized in two complementary manuscripts. One, led by USGS, focuses on the mercury stable isotopes; the other, led by SWAN, describes the quantitative models. Both will be submitted to peer-reviewed journals in 2020 or 2021 (for updates, see [Freshwater Contaminants](#)). Also in 2020, we plan to launch a related project covering five parks in Alaska. Like the earlier study, this project will use lake trout as a focal species, but will also include associated prey species and primary producers to assess the bioaccumulation of mercury through the food web and to determine whether specific energy pathways (e.g., offshore vs. nearshore) promote greater buildup.

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Setting up a net pen to hold lake trout caught at Kulik Lake in Katmai National Park and Preserve.
NPS/EVAN BOOHER





Eldorado: Treasure, Tragedy, and Triumph in the Kantishna Hills

*Paul Burger, Chad Hults, and Shannon Coykendall,
National Park Service*

Andrew Kirby, Arizona State University

Where legacy mining effects have impaired stream water quality in Alaska parks, the NPS is developing restoration techniques. Understanding the potential for recovery in these streams will help the NPS to prioritize those areas where intervention is needed over those areas that are recovering naturally, where disturbance might do more harm than good.

Citation:

Burger, P., C. Hults, A. Kirby, and S. Coykendall. 2020. Eldorado: Treasure, Tragedy, and Triumph in the Kantishna Hills. *Alaska Park Science* 19(1): 86-91.

Mining has played an important role in Alaska's national parks, but has left scars and contamination behind that the Park Service is working to clean up. Mining brought awareness to the vast beauty of the state and contributed iconic structures such as the Kennecott Mill in Wrangell-St. Elias National Park and Preserve. The gold rush of 1897-1898, as commemorated in Klondike Gold Rush National Historical Park, brought hundreds of people north into the wilds of Alaska and Canada. As opportunities diminished in Dawson, these pioneers chased gold in Nome and spread out into the interior of Alaska, looking for riches and adventure.

In 1903, James Wickersham and several other men attempted the first ascent of Mount McKinley (Norris 2008). Although they were unsuccessful, Wickersham discovered gold in the stream gravels in the northern Kantishna Hills, in what is now Denali National Park and Preserve, on his way back to Fairbanks (Norris 2008). The following year, gold was found on Friday and Eureka creeks, setting off a stampede by several thousand miners to the Kantishna Hills. Most of the stampeders left the new district by early 1906, because it became obvious that only a few streams carried paying quantities of gold.

From 1901 to 1905, the presence of galena (a lead sulfide), stibnite (an antimony sulfide), and silver prompted a few miners to prospect for lode deposits (Salisbury and Dietz 1984). One of the most significant discoveries of 1905 was a rich deposit of

antimony ore in upper Slate Creek (Figure 1; Buzzell 1988). Antimony is considered a strategic metal used for hardening lead and creating semiconductors, diodes, batteries and cable sheathing. More than 325 tons of ore was mined from 1905 to the end of World War II.

People involved in mining operations and related geological and transportation activities helped bring the exceptional scenery and wildlife of the Denali area to the public's attention. Widely publicized mountaineering expeditions and naturalist Charles Sheldon's early efforts to protect the area's wilderness and wildlife led Congress to establish Mount McKinley National Park in 1917 (renamed Denali National Park in 1980).

As antimony mining continued in Slate Creek, deregulation of the price of gold in 1972 brought about a major resurgence of placer mining in the 1970s and early 1980s. Placer mining involving heavy equipment occurred in Moose Creek while smaller operations using mostly hand tools occurred in Eldorado Creek, one of its tributaries.

Expansion of Denali National Park and Preserve in 1980 brought these mines and placer deposits within park boundaries and ended major mining operations in the Kantishna Hills, although placer mining continues. The mining legacy remains in the many miners and their descendants that operate lodges and other visitor services and in the many historic mining structures and features that remain.

Slate Mine site looking downstream with the active channel running through the mine tailings. The row of wooden spikes seen behind the helicopter marks the edge of the now-abandoned constructed channel.

NPS/PAUL BURGER

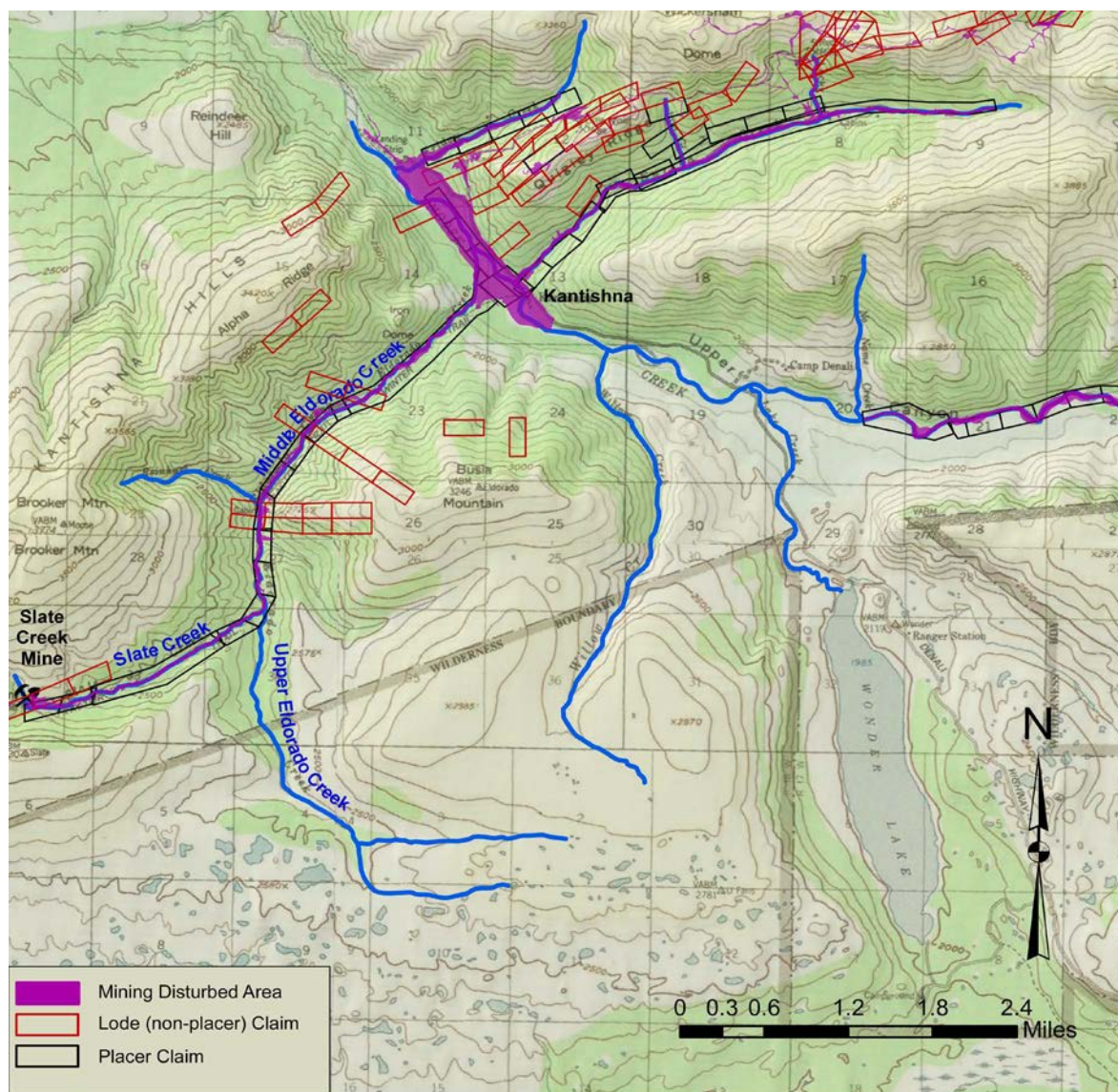


Figure 1. Kantishna area showing major streams and Slate Creek Mine.

The Effects

Not as visible as the old mining-era buildings and equipment, but critical to park resource conservation, are changes mining made to stream channels, aquatic habitats, and water quality. Mining channelized Eldorado Creek, which reduces available habitat for

aquatic insects, fish spawning and rearing (Harvey and Lisle 1998, OCAFS 2017). Channelization and removal of large rocks and natural debris from mining reduced habitat complexity, which can reduce aquatic biodiversity (Ward 1998, OCAFS 2017). Land stripped of vegetation for mining erodes more easily and allows fine sediments to wash into streams, that can fill in pores among gravels that are important to developing fish eggs, as well as providing aquatic insect habitat (Waters 1995). Water scientists measure turbidity, how easily light passes through water, as a way to describe the amount of fine sediments suspended in water. Generally, increased turbidity leads to decreased invertebrate density, which are fundamental to stream food webs and can also cause: fish mortality, physical and physiological damage; fish avoidance of turbid areas, and a shift in local aquatic species abundance and composition (Waters 1995, Wenger et al. 2016, OCAFS 2017).

In 1994, the Environmental Protection Agency (EPA) designated Slate Creek as an impaired waterway from its headwaters to its confluence with Eldorado Creek because of excess sediment caused by erosion of the old mine tailings (ADEC 2006). To reduce these effects, reclamation projects in 1997-1998, and again in 2010, included the removal of mining debris and tailings from the floodplain, re-contouring the slopes around the creek, and restructuring the stream channel (Figure 2). These efforts dramatically reduced erosion and testing in 2008-2011 showed that the stream was meeting water quality standards for turbidity (Brabets and Ourso 2013).

However, that testing also revealed that metals from the mine site were in the sediments and water downstream. Antimony, arsenic, cadmium, copper, and iron were all present in concentrations many times above levels that have been shown to have a negative effect on aquatic organisms (Brabets and Ourso 2013).



Figure 2. Conditions before (June 1, 2010; left) and after (September 2010; right) reclamation at Slate Creek. (Source: Brabets and Ourso 2013)
USGS/TIM BRABETS (LEFT), NPS (RIGHT)

Arctic Grayling Declines

Biologists conducted electrofishing surveys throughout the summer of 1982 to inventory fish abundance and distribution in the Kantishna Hills; the first such surveys was in the Slate/Eldorado Creek basin (Meyer and Kavanagh 1983). While the section of Eldorado Creek downstream of the confluence with Slate Creek had low Arctic grayling (*Thymallus arcticus*) abundance, averaging 4.6 fish per kilometer, researchers found Eldorado Creek above the confluence (Figure 1) had the highest Arctic grayling densities of all streams sampled in the Kantishna Hills, averaging 33.3 fish per kilometer (Meyer and Kavanagh 1983:24), suggesting that while the quality of grayling habitat below Slate was poor, fish were still able to move through it to reach Upper Eldorado.

Mining had been dormant for several years on Slate Creek when the 1982 fish survey was conducted,

but placer mining was active at the mouth of Eldorado Creek. Despite this activity, Arctic grayling were distributed throughout Eldorado Creek with an observed average of 7.5 fish per kilometer (Meyer and Kavanagh 1983: 24, 73). The following year, the Slate Creek Mine became active again. A fish survey found fewer grayling in lower Eldorado than the previous year, especially starting 300 feet downstream of the confluence with Slate Creek (Deschu and Kavanagh 1986). No further surveys were done until 2017.

During 2017 and 2018, the park conducted fish surveys in Eldorado Creek. At this time, suction dredging was active in Eldorado Creek. Four targeted visual surveys were performed in 2017, and one electrofishing and three targeted visual surveys were conducted in 2019. No fish were detected in Eldorado upstream of Slate Creek in either year.

Eldorado Creek above the Slate confluence still has excellent physical habitat, good water

quality, and a thriving aquatic macroinvertebrate community (A. Kirby, written communication 2019). During 2017-2018, there were no long-term physical barriers to migration from Moose Creek to the summer foraging habitat upstream of Slate Creek; streamflow and water temperatures are similar to those recorded in the 1980s. Until 2016, no mining had occurred within the watershed for over 30 years. However, habitat below the confluence with Slate Creek exhibits significantly disturbed channel. Water quality degradation from Slate Creek and naturally mineralized springs along Eldorado Creek continues to contribute heavy metals (e.g., arsenic, antimony, and iron) to the creek.

The 2017-2018 study indicates a number of factors that have influenced grayling presence, abundance, and movement in the Eldorado watershed, primarily destruction of habitat and poor water quality. Both may be improved through restoration efforts.

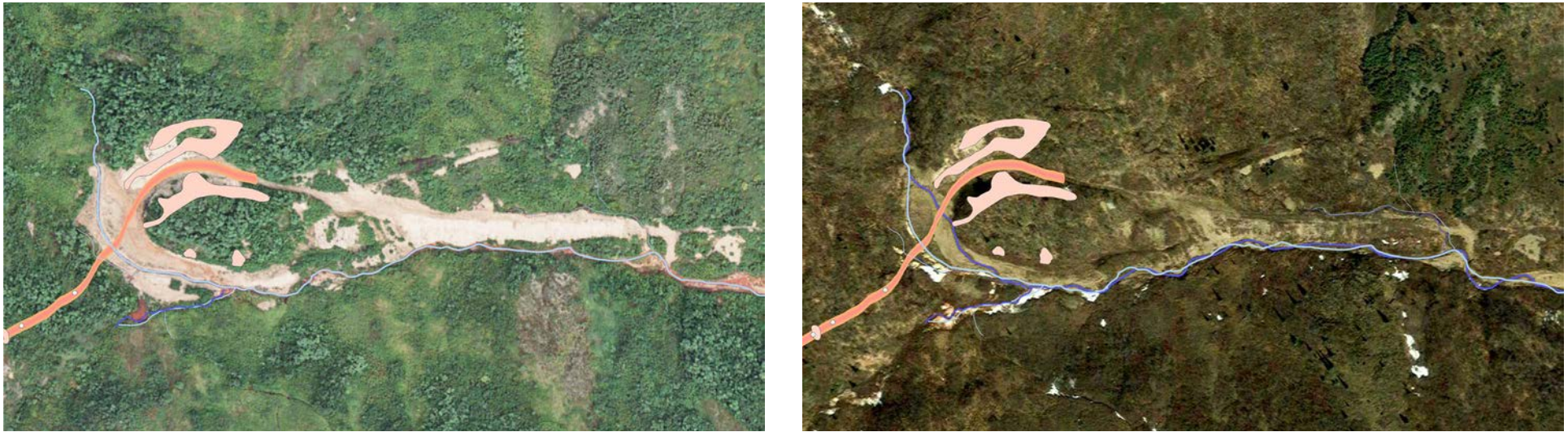


Figure 3. Slate Mine in 2010 following reclamation project (left) and in 2017 (right) after 2014 flooding. Pink = bedrock outcrop, orange band = antimony mineralization zone, light blue lines = 2010 stream; dark blue lines = 2017 streams.

2014 Flooding Leads to a Reimagining of Restoration

In the spring of 2014, a massive rainstorm hit the Kantishna area, washing out roads and changing the course of many streams and rivers in the area. At the Slate Creek mine site, a channel constructed to keep water away from the main ore deposit completely failed after showing signs of deterioration three years before. The stream returned to its pre-reclamation position in the valley and many of the erosion-control structures were washed away (Figure 3).

Stream restoration and reclamation has evolved quickly in the past decade. We now look not only at restoring the overall shape and pattern of a stream, but also what is needed to restore natural function. Stream function refers to the physical, chemical, functions and biological processes that occur in these ecosystems. In 2017, a major effort was made by the park to revisit the site and to gather data needed to develop a strategy to improve physical and biological stream function.

What Does the Future Hold?

In 2017, the National Park Service, in cooperation with the Bureau of Land Management and Stream Mechanics, PLLC Inc., surveyed unmined streams in the Slate Creek/Eldorado Creek watershed. Stream width, depth, area, bed material sizes, and slope were measured and used to determine how much water they could transport. To determine what a naturally functioning stream in the area should look like, the team evaluated channel stability and aquatic habitat by measuring physical characteristics such as pool and riffle spacing.

These measurements were repeated on sections of Slate Creek that have been impacted by mining or that were modified to provide access to the mine site. By comparing the measurements of the disturbed areas versus the natural areas, we can quantify the amount of change that has taken place in the stream. We can also use this information to create a restoration design for returning the stream to a more natural, stable state.

Analysis of the information led to the development of alternative stream restoration designs that the park is evaluating for cost and feasibility. The hope is to create a robust approach for restoring natural function to Slate Creek and improve habitat to facilitate the recovery of native aquatic species.

This project has provided a model for evaluating all of the major mined sites in the park over the next several years. Understanding the potential for recovery in these streams will help the National Park Service to prioritize those areas where intervention is needed over those areas that are recovering naturally, where disturbance might do more harm than good. This approach to stream restoration will serve to improve stream habitat in the park where the legacy of mining has left its mark.

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Elodea: Alaska's First Invasive Aquatic Plant Continues to March Across the State

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There are over three million lakes and 12,000 rivers in Alaska, many of which harbor prime habitat for an invasive aquatic plant, *Elodea*. Alaska's parks encompass a substantial portion of this habitat and include some of Alaska's most iconic lakes and rivers. While no infestations have yet been found in parks, we are developing detection methods and monitoring so we can address it early, if we find it.

Citation:

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Elodea spp. (waterweed) is a hardy aquatic plant that grows in cold, clear, slow-moving water (Figure 1). It is considered a circumpolar invasive plant; its native range extends from Florida to southern British Columbia. *Elodea* was first found growing in Eyak Lake, a large lake in Cordova, Alaska, in 1982. In 2010, it was subsequently found in the Chena River by US Forest Service employees trying to familiarize themselves with invasive plants. Their discovery spurred a large state-wide campaign to raise awareness about invasive aquatic plants in Alaska and to treat the known infestation. The long lag time between the two discoveries was due to a lack of research on native aquatic plant distributions and our limited understanding of aquatic invasive species. Over the past eight years, 29 invasive aquatic plant infestations have been identified across Alaska, including lakes within Anchorage, Fairbanks, Cordova, Nenana, Kenai, and the Matanuska-Susitna Borough as well as riverine systems near Fairbanks and Cordova (Figure 2). In Alaska, introductions of *Elodea* probably occurred when people dumped their aquariums into nearby lakes and streams, possibly believing the aquarium plants and animals wouldn't survive. Unfortunately, they often did. New infestations are being found each year, further and further from urban populations. Land managers have applied herbicides to successfully eradicate *Elodea* from eight lakes and are working on the remaining water bodies.

Elodea is the first known freshwater invasive plant to be found in Alaska and with it come significant environmental concerns. Once a bed of *Elodea* becomes established, it grows rapidly, blocking light and taking up nutrients other plants might use to grow and essentially creating a monoculture (Rorslett et al. 1986, Spicer and Catling 1988). *Elodea* often grows so profusely that it slows stream flow and mixing rates (Spicer and Catling 1988, Gollasch 2006), allowing sediment and fine particles to settle out of the water and cover the gravel in areas where salmon, whitefish, and grayling spawn. Its explosive growth is typically followed by a sudden die back, which then decomposes in the water. The organisms decomposing all the dead vegetation rapidly consume the oxygen in the water, making it difficult for fish and other aquatic organisms to survive (Simberloff and Gibbons 2004, Buscemi 1958, Pokorný et al. 1984).

Elodea spreads easily; it only takes a small piece of stem, 2 inches (5 cm) long, for the plant to become established in a new location. It can withstand extended periods of drying as well as freezing (Nichols and Shaw 1986). Because it's so hardy, it can easily be dispersed by floatplanes and outboard motors that travel long distances. It can live in lakes as well as streams and even grows during winter, under the ice, when native plants die. Anglers have reported pulling large, live, green strands of *Elodea* from their ice-fishing holes. During the spring, tiny fragments are carried downstream with the ice and spread to other lakes and streams many miles away.

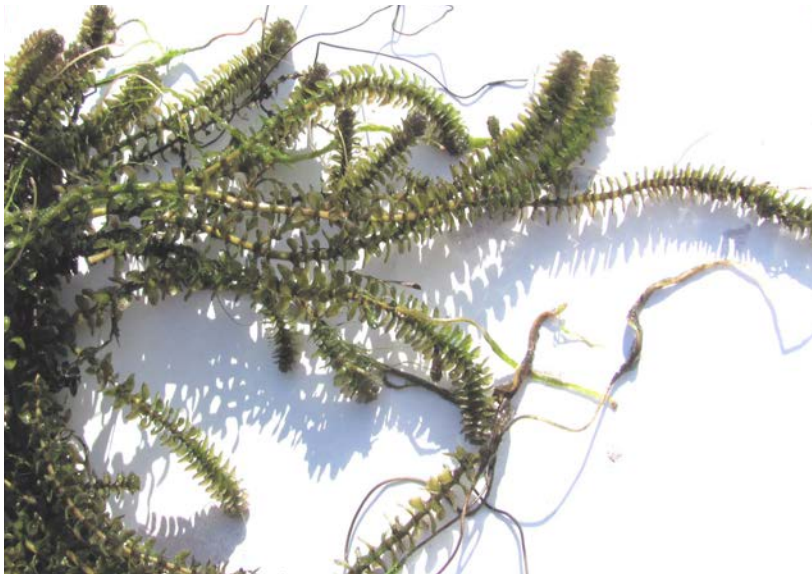


Figure 1. *Elodea* is a submerged aquatic plant with several distinctive characteristics. If you see this plant call 1-877-invasive.

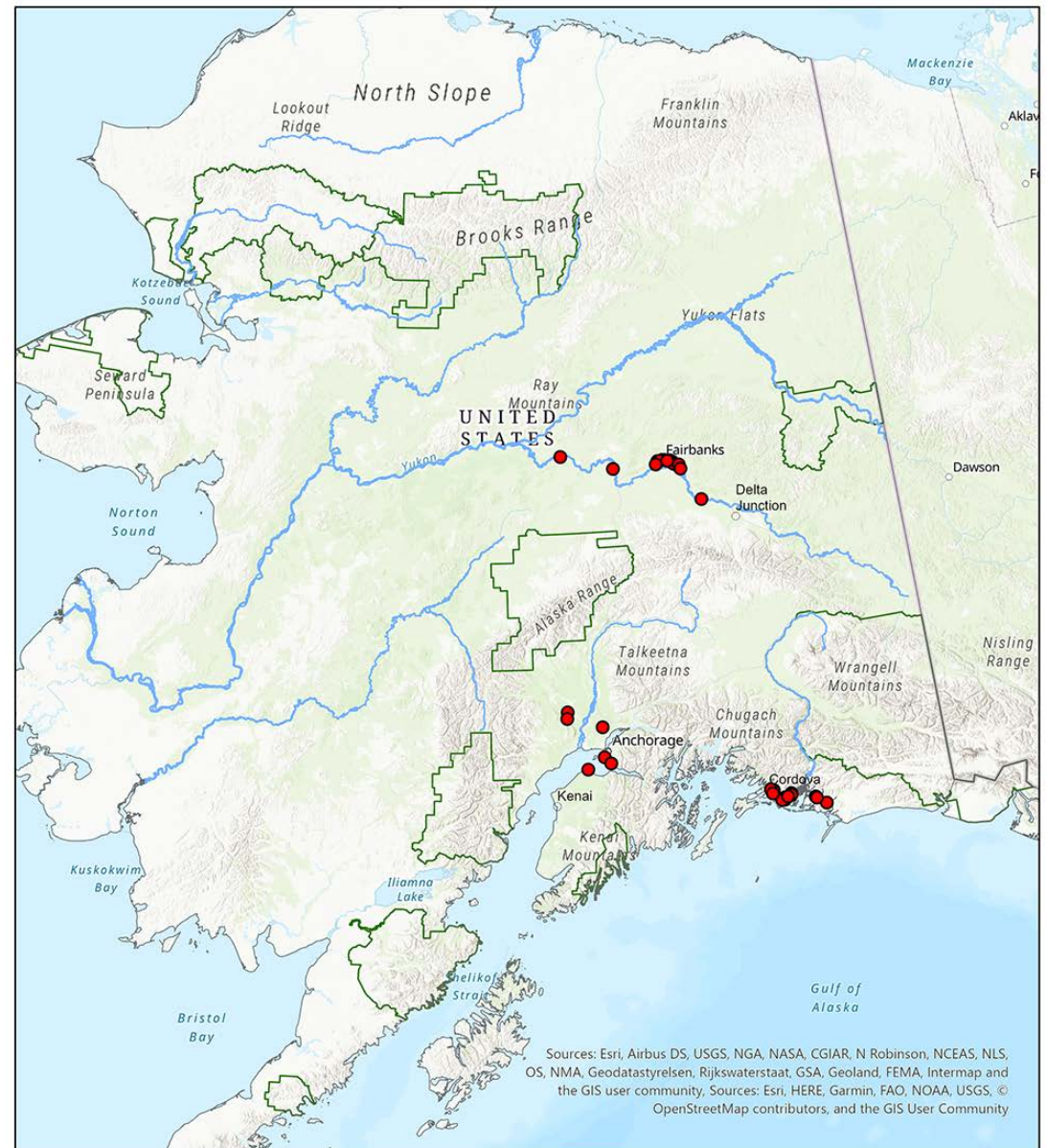


Figure 2. Current *Elodea* infestations across Alaska (red dots), relative to some of Alaska's largest communities and national parks (green outline).

Not only does *Elodea* cause environmental damage, but it can also impede watercraft navigability and create hazardous conditions for floatplane operators (Schwoerer et al. 2019a) and other recreationists. According to a recent survey, Alaska floatplane pilots said they would reduce the frequency of flights, or even stop visiting lakes and streams completely, if the landing areas became infested with *Elodea*. A recent economic analysis of personal floatplane flights estimates that an *Elodea* infestation could reduce the recreational value of a trip by \$185 per flight (Schwoerer 2019a). Given the more than 3,000 floatplane-certified pilots in the state, *Elodea* could cause a significant loss in recreation opportunities. In other states it has reduced property values (Zhang and Boyle 2010) and visitor use (Josefsson and Andersson 2001). Large infestations reduce the scenic quality of natural settings. Once established, *Elodea* infestations can be costly to eradicate. For example, the United Kingdom spends 40 million dollars annually on *Elodea* eradication (Simberloff and Gibbons 2004).

In addition to its impacts on recreation, *Elodea* could also affect Alaska's commercial salmon fisheries. Economic research suggests that if *Elodea* is not eradicated and spreads into the state's most productive salmon watersheds, commercial sockeye salmon fisheries are likely to become less productive, resulting in decreased harvest. An economic study that simulated the potential effect of *Elodea* on salmon productivity with consequences for wild salmon markets, estimated that *Elodea* could potentially reduce revenue to commercial harvesters by an average of \$97 million annually. This loss is equivalent to 16% of the statewide average wholesale value for sockeye salmon over the past ten years (Schwoerer et al. 2019b).



A Landscape at Risk

There are over three million lakes and 12,000 rivers in Alaska, offering prime opportunities for *Elodea* to thrive. Alaska's national parks encompass a substantial portion of this habitat and include some of Alaska's most iconic lakes and rivers (Figure 3). This, combined with high visitor use, puts National Park Service (NPS) lands at high risk of becoming infested.

Nearly half of the infestations in Alaska are in floatplane-accessible water bodies. The infestation of Alexander Lake, 60 miles (96.5 km) south of Denali National Park and Preserve, originated from Sand Lake, Anchorage, and the infestations of Bering and Martin lakes, 35 miles (56.3 km) south of Wrangell-

Figure 3. A Cessna 185 taxis to the beach on Upper Twin Lake in Lake Clark National Park and Preserve. NPS/D. YOUNG

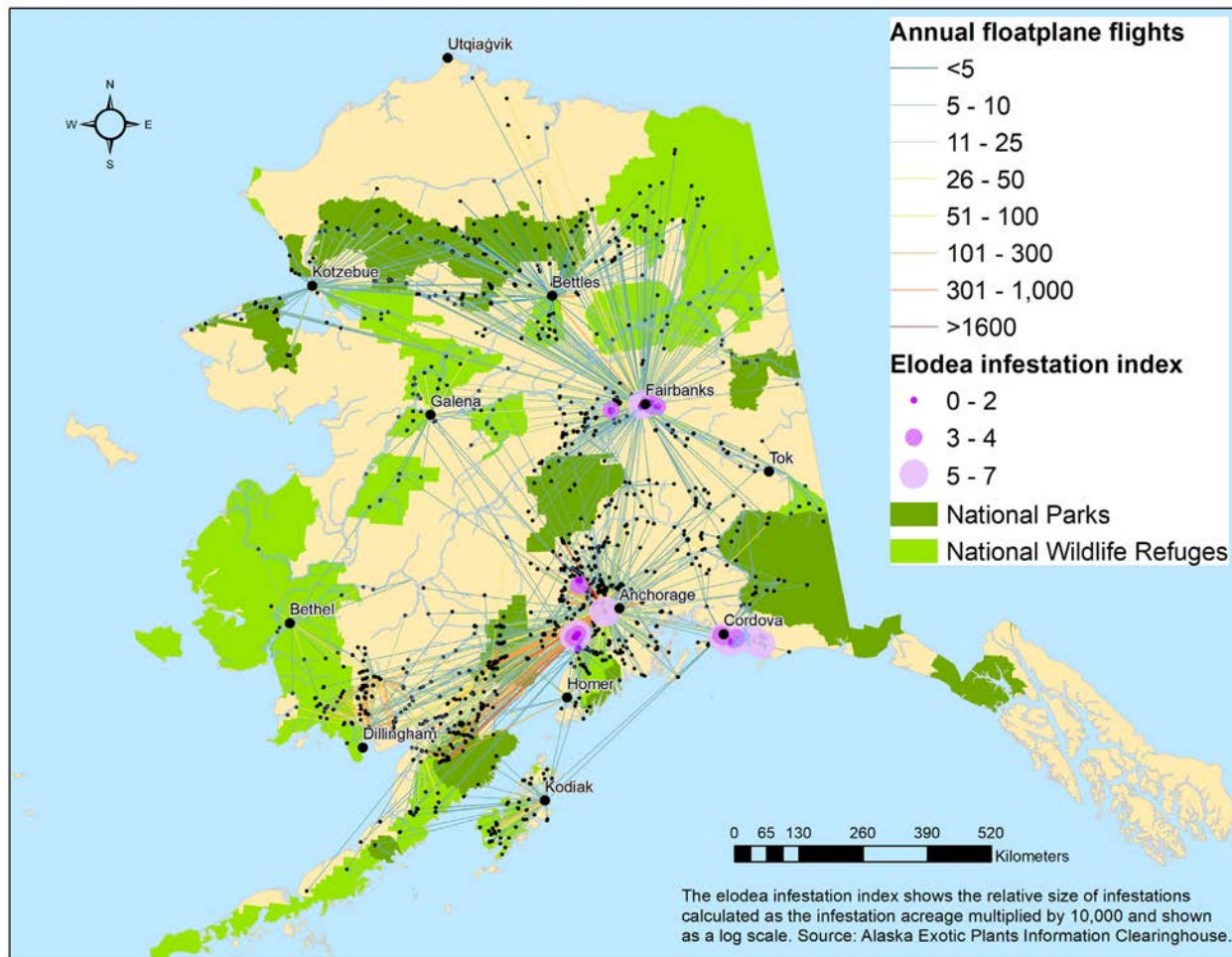


Figure 4. Flight paths as reported by respondents to a statewide survey with Alaska's floatplane pilots. The map shows floatplane bases and destinations in relation to known *Elodea* infestations (Schwoerer 2017). Pink dots indicate the number of infested sites in the area, as reported in the Alaska Exotic Plants Information Clearinghouse.

St. Elias National Park and Preserve, originated from Eyak Lake, Cordova. The most notable infestation was in Lake Hood, the world's busiest floatplane base, where more than 69,000 floatplanes take off or land each year. Survey data show that flights from Lake Hood terminate in hundreds of lakes and rivers throughout the state, many of which are in national parks in southwest Alaska (Figure 4; Schwoerer 2017). In total, more than 9,000 flights terminate in NPS water bodies each year, most of which originate in Lake Hood and terminate in Katmai, Lake Clark,

and Wrangell-St. Elias national parks and preserves. Fortunately, the State of Alaska successfully eradicated *Elodea* from Lake Hood in 2015 and it has remained clear of infestation since.

Outboard motor boats can also spread *Elodea* when it becomes entangled on a prop or anchor and is transported to new locations hundreds of miles away. Many of Alaska's national parks and wildlife refuges are accessed from public boat launches with existing infestations of *Elodea*. Two such infestations remain uncontrolled; one of these is located near a public boat launch in Manley Hot Springs, a small community along the Tanana River, and the other is located in the Alaganik Slough in the Copper River Delta. A 2018 statewide survey (Schwoerer et al. 2020a) of Alaska's registered boat owners showed that boaters routinely access Denali and Wrangell-St. Elias national parks and preserves via rivers connected to these boat launches.

Over the past two years, NPS scientists have surveyed some of the most frequently visited sites in southern Alaska parklands, including iconic lakes such as Lake Clark and Katmai Lake. Although these surveys have found no *Elodea*, scientists are concerned the plant may be present but is not being detected. The surveys cover only a fraction of the lakes and streams that could be infested and many of the lakes are large, with complex shorelines that are expensive and time consuming to survey; infestations could easily be overlooked. To help address these challenges, NPS is working to develop survey techniques that will increase the chances of finding an infestation in its early stages so it can be treated quickly. Eradication of invasive species has the greatest chance of success early on before they become established.

One technique for early detection that shows great promise involves the use of environmental DNA

(eDNA), which is DNA that organisms constantly shed into their environment. It can be easily collected by filtration of water samples taken from streams or lakes and can detect the presence of aquatic species without requiring their physical capture or observation. NPS scientists are collaborating with scientists from the US Geological Survey and US Fish and Wildlife Service to develop these techniques for determining the presence of *Elodea* ([Simmons et al. this volume](#)). This tool will allow scientists to detect not only *Elodea*, but also other invasive aquatic species that may be present. Using these approaches, eDNA samples from 58 lakes in Lake Clark, Katmai, and Wrangell-St. Elias national parks and preserves and Kenai Fjords National Park have been tested so far. No *Elodea* was detected at any of these locations. *Elodea* DNA was successfully detected in samples taken from water bodies with known infestations, giving the scientists confidence that the technique works. The success of these eDNA assays suggests that *Elodea* might be reliably detected even when plants are not physically observable. This would allow for rapid and inexpensive surveys to be conducted using water samples, potentially eliminating the need for exhaustive and costly surveys. However, this technology is still relatively new and more work remains to be done, particularly in terms of quantifying its sensitivity to the presence of *Elodea* in low densities. Nevertheless, early detection is the key to quickly and effectively eradicating *Elodea* infestation and eDNA may allow detection before the infestation becomes difficult and costly to treat (Carey et al. 2016).

On-the-ground surveys will still be required anytime a potential infestation is detected using indirect methods like eDNA. In addition to confirming the presence of *Elodea*, physical surveys provide information on infestation size and location, as well as data on the waterbody itself, information

that is critical in determining what kind of treatment will be most effective.

Finding invasive plants in terrestrial settings is relatively straightforward and there are several standardized methods to conduct field surveys in a repeatable fashion, yielding data that can be compared to other surveys and studies. However, finding and documenting aquatic plants is more challenging due to poor visibility, limited accessibility, and a heterogeneous environment. These factors lower the probability of detecting *Elodea* and confidence that it is truly absent from the lake. For example, a field survey of a Kenai lake failed to detect *Elodea*, but was found to be common in a subsequent survey with a more careful approach. Currently there are no statistically rigorous methods for invasive aquatic plant surveys in Alaska and land managers want to be confident that they have the best available information.

NPS is working with the Alaska Center for Conservation Science at the University of Alaska Anchorage (UAA) to develop a standardized protocol that can help compensate for low detection rates. The UAA team has been testing a statistical survey method that is commonly used in wildlife studies and produces an unbiased estimate of species presence. To date, the UAA team has documented new *Elodea* occurrences in already infested lakes to help improve detection methods and identify preferential habitat. Early results are encouraging; using this method novice and expert observers are equally effective at detecting *Elodea*, allowing for flexibility of who can perform the survey. Early results also indicate that native aquatic vegetation is typically sparse or non-existent in cobble to boulder lake substrates and deeper waters, but *Elodea* can occupy these habitats, making it a truly weedy species.

The UAA team searched for *Elodea* in lakes of the Wrangell-St. Elias National Park and Preserve in 2018 and Gates of the Arctic National Park and Preserve in 2019; *Elodea* was not detected during these surveys. For 2020, the UAA team plans to search for *Elodea* in the Yukon-Charley Rivers National Preserve.

UAA's Institute of Social and Economic Research is working with the NPS to develop both aviation and motorboat use models to help prioritize search efforts. Pilot surveys have identified 255 floatplane-accessible destinations within, and near, NPS lands (Schwoerer 2017). Most (two-thirds) of these locations are infrequently visited (<10 flights per year), less than a quarter receive between ten and 50 flights a year, and the remaining 26 lakes receive more than 50 flights a year. Sixteen of these are frequently visited and receive more than 100 flights a year. A probabilistic model of the observed flights shows the lakes and rivers with the highest probability of infestation are concentrated in southcentral and southwest Alaska. The model estimates, with high confidence (low variance), that sites within Denali, Lake Clark, Wrangell-St. Elias, and Katmai national parks and preserves are at greatest risk of infestation (Figure 5).

NPS Works to Prevent Future Infestations and Make Ready for a Possible Discovery

Invasive species management techniques vary considerably, but recent research suggests that the best strategy is to first eradicate known infestations and then to prevent its spread (Lodge et al. 2016). Keeping urban source locations, such as Lake Hood, clean of aquatic invasive species is paramount to keeping remote conservation lands free of infestation. Close monitoring of these potential source areas following treatment is the most effective way to maintain healthy urban waterways.

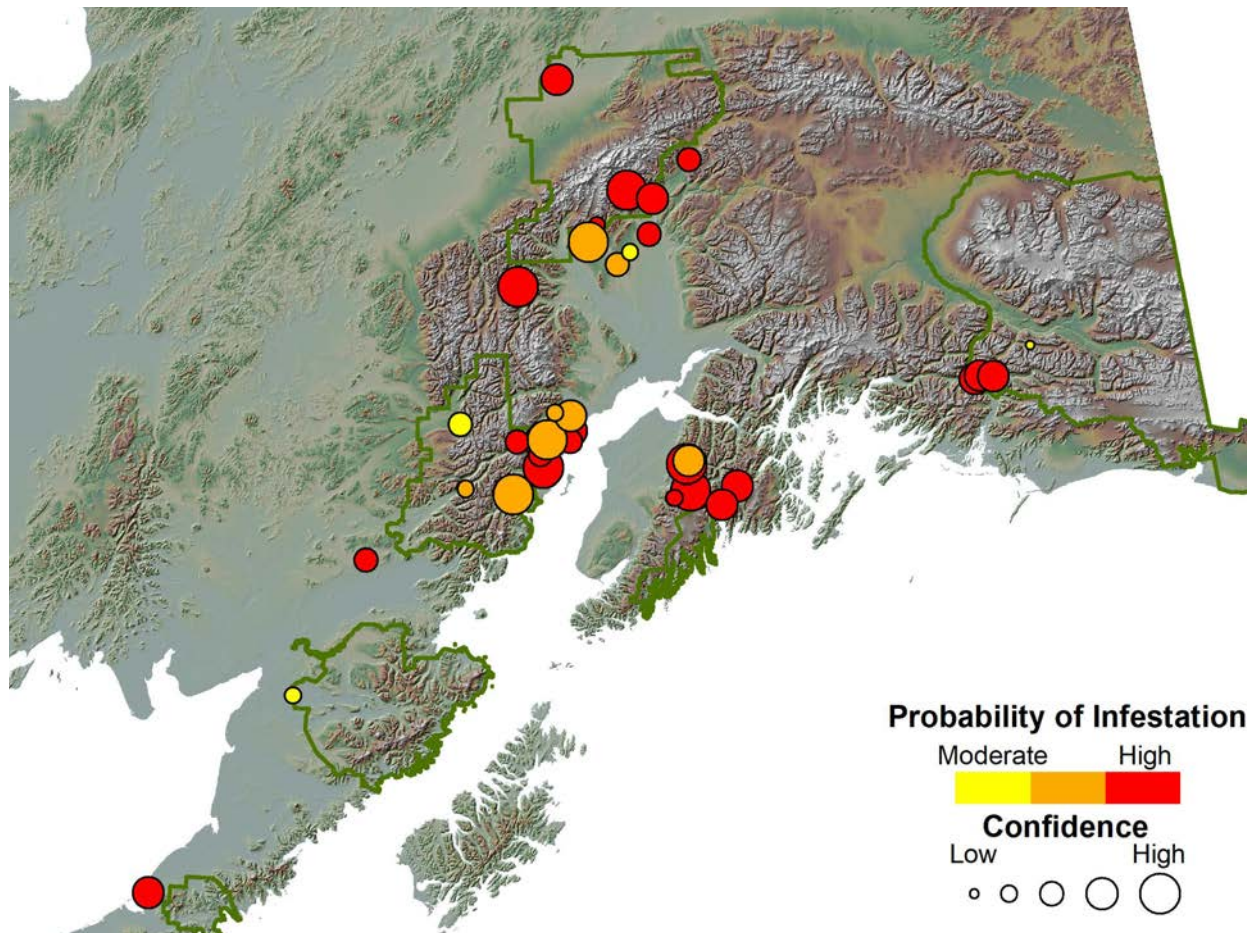


Figure 5. Floatplane flight patterns were used to identify lakes and rivers at risk of infestation. The color-coded dots indicate sites with a high probability of becoming infested; the size of the dots indicates how confident the model is that the site will become infested. Sites with a large red dot are lakes with both the high confidence and probability an infestation will occur (Schwoerer et al. 2020b).

Prevention methods have proven to be highly effective in managing aquatic invasive species when applied in coordination with local, state, and other federal agencies. Since *Elodea* remains in Eyak Lake and other waterbodies accessed by motorboats and floatplanes, these source locations continue to threaten conservation lands, either directly through flights and motorboat transport, indirectly by passive flow of rivers and streams, or by expansion of existing infestations. Until these populations can be eradicated, *Elodea* poses a serious risk to lakes

and streams in Alaska's national parks. NPS staff have been collaborating with partners throughout the state to produce educational materials to prevent the spread of *Elodea*. Pilots have been a primary audience for outreach, as have all tour operators and concessionaires working in parks.

Treatment of *Elodea* infestations with herbicides and restoration of treated waterbodies is time consuming and costly. For example, treatment of an 11-mile (17.7 km) section of Chena Slough is expected to take four years and cost a million dollars. Native plant richness quickly rebounds after *Elodea* is eradicated (Sethi et al. 2017), demonstrating the positive effects herbicide application has on the native aquatic plant flora. If the NPS can prevent an infestation, it can avoid the high cost of treating and restoring its aquatic ecosystems.

Alaska's parks are some of the state's most treasured destinations and home to some of the state's most vital salmon fisheries. A multitude of federal, state, and private partners are actively working to eradicate *Elodea* from Alaska by sharing ideas, information, and resources. Since invasive species do not recognize political or management boundaries, it is critical that NPS do its part in stewarding this land by protecting these resources from degradation. Preventing the spread of *Elodea* into parks is the most cost-effective and ecologically conservative means to do so.

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