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Environmental Science

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AN EVALUATION OF COMMERCIAL FISHING OPERATIONS WITHIN AND
ADJACENT TO ASSATEAGUE ISLAND NATIONAL SEASHORE

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Introduction

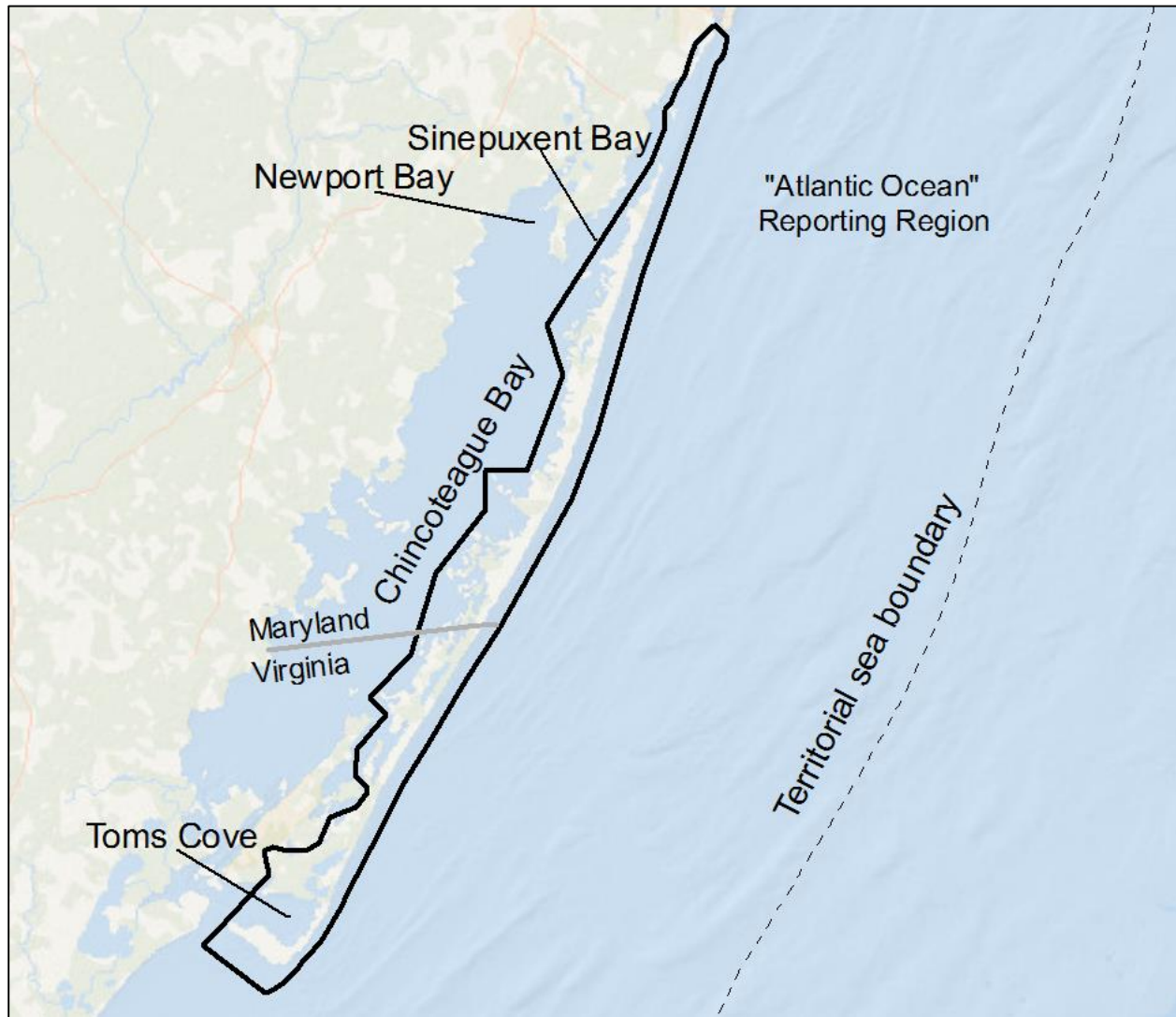
Assateague Island is a 37-mile barrier island that encompasses lands and submerged bottomlands managed by the National Park Service, State of Maryland, Commonwealth of Virginia, and U.S. Fish and Wildlife Service. The National Park Service (NPS) manages approximately 22,393 acres of coastal bay and ocean waters within the 0.5 mi-boundary surrounding the Assateague Island National Seashore (Department of the Interior 2016), hereafter referred to as ASIS (shorthand for ASsateague ISland National Seashore). Numerous commercial fisheries and aquaculture activities are prosecuted in the vicinity of ASIS (Kirkley 1997); however, the status and impacts of fishing activities in the ASIS area have not been summarized since the 1970s (Boynton 1970). The goal of this report is to provide a current, comprehensive summary of local commercial fishing activities and their potential impacts on marine ecosystems and the visitor experience in order to inform management of marine and estuarine resources within ASIS waters (Department of the Interior 2015, 2016).

Each report section below addresses one or more of the six project objectives outlined by NPS for this project:

- [Commercial harvest](#): identifies the number of currently active commercial operators within ASIS boundaries and adjacent coastal waters (Objective 3), characterizes and quantifies commercial harvest by species and gear type within and adjacent to ASIS boundaries (Objective 1), and provides estimates of the economic value of commercial harvest by species within and adjacent to ASIS (Objective 4).
- [Trends in local stocks and habitats](#): summarizes trends in local fishery-independent surveys of finfish and shellfish stock abundance, and indicators of critical habitat (Objective 2).
- [Potential ecological impacts](#): provides an evaluation of potential ecological impacts of commercial wild fishery gear, aquaculture, and overall harvest on ASIS marine and estuarine resources (Objective 2).
- [Potential impacts to the visitor experience](#): identifies ways in which the visitor experience may be affected by commercial gear and harvest within and adjacent to ASIS (Objective 5).
- [Data needs](#): outlines additional data necessary to better address the first 5 study objectives (Objective 6).

Throughout this report we broadly define the “ASIS area” as the coastal bays and nearshore oceanic waters within state boundaries (0-3 nm offshore) adjacent to ASIS (Figure 1). When referring to waters within the seashore boundary, we use the term “in ASIS waters”.

Figure 1. Maritime boundaries and major embayments within the Assateague Island National Seashore (ASIS) area. Solid black indicates the ASIS 0.5-mile maritime boundary. Gray line indicates the boundary between Maryland and Virginia coastal bay waters. Dashed black line denotes the 12 nm territorial sea boundary defining the extent of state waters and the “Atlantic Ocean” fisheries reporting region. Ocean waters 12-200 nm offshore are managed NOAA Fisheries.



Commercial fishing operations

Commercial fisheries in the ASIS area are monitored by the Maryland Department of Natural Resources (MDNR) and the Virginia Marine Resources Commission (VMRC). Commercial harvest reporting and licensing in Maryland and Virginia is often not specific with regard to location. Reporting regions typically include specific embayments (e.g., Chincoteague Bay) or are designed to align with state and federal marine boundaries (Figure 1); therefore, MDNR and VMRC reporting regions do not align with ASIS boundaries.

All harvest and operator statistics presented below are reported at the finest scale allowed by federal and state laws established to protect confidentiality of individuals involved in each fishery. Confidential data are data that can lead to the identification of the contributing individual or individuals. Data presented below follow the “rule of 3” for commercial catch data which requires a minimum of three different contributors to fisheries data. Contributors can be harvesters or dealers. In this report, some confidential data were excluded or combined across gears or years in order to comply with state and federal confidentiality laws.

Number of currently active commercial operators

The number of active wild and aquaculture harvesters and aquaculture leases are summarized by state below at the finest spatial resolution possible given harvest reporting and licensing requirements.

Maryland

MDNR provided the number of active finfish and blue crab harvesters in Maryland by year and region from 2005 to 2015 (Table 1). In Maryland, blue crabbers report all harvest as being located in “All Ocean Bays”; therefore, the number of crab harvesters cannot be identified by embayment. The number of active crabbers in the Maryland Coastal Bays region averaged approximately 150 participants and was substantially larger than that of finfishers in state waters of the Atlantic Ocean which averaged 34 participants. The number of active crabbers varied without trend over the last decade.

The number of active finfish harvesters in Maryland waters of the Atlantic Ocean was the second largest by region, ranging from 20 to 55, and fluctuated over the last decade with relative peaks in 2008-2009 and 2012-2014 (Table 1). The number of finfish harvesters in Chincoteague and Sinepuxent Bays is relatively small (average of 19 and 7 participants, respectively), and has doubled over the last decade.

Table 1. Annual number of active Maryland harvesters in the coastal bays and state oceanic waters by region and type.

Harvester type	Region	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Finfishers	Chincoteague Bay	13	10	14	18	21	19	22	18	21	28	22
	Sinepuxent Bay	4	4	4	4	9	5	12	9	8	5	8
	All Ocean Bays										5	4
	Atlantic Ocean²	20	26	21	38	46	31	24	55	43	39	27
Crabbers¹	All Ocean Bays	159	141	148	129	157	179	161	149	147	133	138

¹All crabbing activity is reported as Ocean Bays. Finer spatial resolution is not available.

²0-3 miles (state waters, extending from DE to VA)

Virginia

The number of active commercial wild fishery and aquaculture harvesters and aquaculture leases in the Chincoteague and Watts Bay regions of Virginia waters were provided by VMRC for the period 2006-2015. Aquaculture leases are contracts between

The Commonwealth of Virginia and individual harvesters that allow private shellfish culture on or above state-owned submerged land.

The number of wild harvesters has remained relatively stable over this period with an average of 53 participants. Although the number of active aquaculture leases has remained relatively stable in recent years with an average of 58 leases, the number of aquaculture harvesters has increased from 20 harvesters in 2007 to 33 in 2015.

Table 2. Number of active commercial wild fishery and aquaculture harvesters and aquaculture leases in Chincoteague and Watts Bay, 2006-2015.

Year	Wild harvesters	Aquaculture harvesters	Aquaculture leases
2006	48	-	-
2007	41	20	59
2008	52	19	58
2009	53	22	56
2010	55	22	68
2011	55	29	61
2012	61	23	43
2013	56	29	51
2014	57	35	67
2015	47	33	60

The number of active horseshoe crab permits issued by VMRC increased from a low of 16 permits in 2009 to a peak of 41 in 2012, then declined to an average of 25 in the last 4 years (Table 3). A gear-specific limited entry program began in 2013. The average number of eligible permits in recent years has been 139.

Table 3. Number of eligible and active Virginia horseshoe crab permits in the ASIS area.

Year	Numer of active permits	Numer of eligible permits
2009	16	
2010	16	
2011	28	
2012	41	
2013	27	
2014	29	135*
2015	23	140
2016	21	143

* Gear-specific limited entry permitting was implemented in 2013.

Commercial harvest

Commercial harvest is summarized by species and gear, where possible. Scientific names of all species described in this section can be found in Appendix 1. Harvest statistics focus on the most recent decade to facilitate nonconfidential summaries of fisheries statistics at the finest spatial and gear resolution allowed. For comparison, long-term (1950-2015) trends in total landings for the primary species discussed below by state are provided in Appendices 2 and 3. Trends in harvest do not necessarily reflect trends in stock abundance because changes in fishing effort also affect harvest.

Maryland

MDNR summarized recent (2005-2015) wild fisheries harvest of blue crabs in the coastal bays, and other wild fisheries by embayment or state ocean waters. Harvest was reported by species, gear, and region. Aquaculture harvest in the coastal bays is limited at present and was not included here because MDNR does not allow aquaculture leases to be established within ASIS waters.

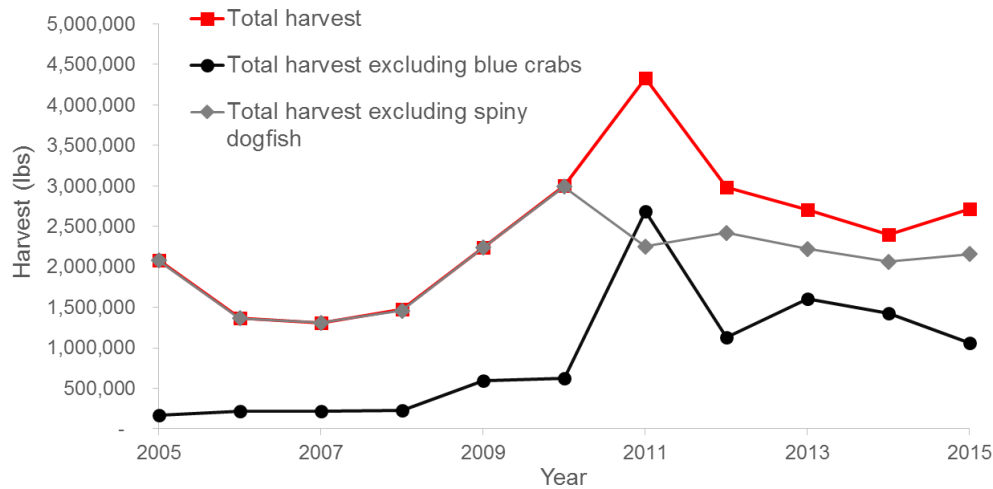
Spatial regions defined by Maryland for harvest reporting vary in specificity. The five regions used by MDNR harvester reporting in the ASIS area are Chincoteague Bay (Maryland portion), Sinepuxent Bay, All Ocean Bays (i.e., any Maryland coastal bay), Atlantic Ocean (state waters 0-3 miles offshore), or All Atlantic Ocean (Figure 1). The All Ocean Bays and the two Atlantic Ocean regions span the entire Maryland coastline. Therefore, regional assignment of landings should be interpreted with caution. For example, all blue crab landings are reported as being harvested in the All Ocean Bays region even though only some of that harvest occurred in Chincoteague and Sinepuxent Bays.

Blue crabs have historically comprised a large portion of the landings from the ASIS area (Boynton 1970). In the last decade (2005-2015), harvest by Maryland watermen has been dominated by blue crabs and totaled more than 15 million lbs between 2005 and 2015 in the coastal bays region (Table 4, Figure 2). Total Maryland harvest of blue crabs from the coastal bays increased between 2008 and 2010 then declined (Figures 1 and 2) similar to harvest in Chesapeake Bay. Total harvest of other wild fisheries from local embayments and from state oceanic waters rose across between 2008 and 2015 in large part due to an increase in spiny dogfish oceanic catches (Figure 2) observed across the Mid-Atlantic (Diddon 2015).

Table 4. Total harvest (lbs) and average annual harvest (lbs per year) for primary species (>100,000 lbs total) landed by Maryland watermen by region, 2005-2015. Horseshoe crab harvest is reported below in Table 5. For species with harvest reported in multiple regions, regions are listed in descending order by magnitude of harvest. Chincoteague Bay harvest includes only the portion caught within Maryland waters. Some blue crab harvest reported here comes from coastal bays not adjacent to ASIS waters.

Species	Total harvest (lbs)	Average annual harvest (lbs)	Regions (ordered)
BLUE CRAB (HARD)	15,675,849	1,425,077	All Ocean Bays
SPINY DOGFISH	4,057,783	450,865	Atlantic Ocean
ATLANTIC MENHADEN	1,573,869	143,079	Chincoteague Bay/Atlantic Ocean/Sinepuxent Bay/All Ocean Bays
BLUE CRAB (SOFT)	960,531	96,053	All Ocean Bays
CONCHES	854,751	77,705	Atlantic Ocean/Chincoteague Bay/Sinepuxent Bay/All Ocean Bays
STRIPED BASS	523,064	47,551	Atlantic Ocean/Chincoteague Bay/Sinepuxent Bay
SMOOTH DOGFISH	322,383	53,731	Atlantic Ocean
SPOT	320,234	29,112	Chincoteague Bay/Atlantic Ocean/Sinepuxent Bay
SUMMER FLOUNDER	237,086	23,709	Atlantic Ocean/Sinepuxent Bay/Chincoteague Bay
BLUEFISH	194,054	17,641	Atlantic Ocean/Chincoteague Bay/Sinepuxent Bay/All Ocean Bays
ATLANTIC CROAKER	164,558	16,456	Atlantic Ocean/Chincoteague Bay/Sinepuxent Bay
BLACK SEA BASS	134,396	14,933	Atlantic Ocean
JONAH CRAB	122,680	61,340	Atlantic Ocean
AMERICAN EEL	115,565	11,557	Chincoteague Bay/Sinepuxent Bay/Atlantic Ocean

Figure 2. Total Maryland harvest (lbs) from the Atlantic Ocean, All Ocean Bays, Chincoteague Bay (Maryland portion), and Sinepuxent Bay regions, 2005-2015.

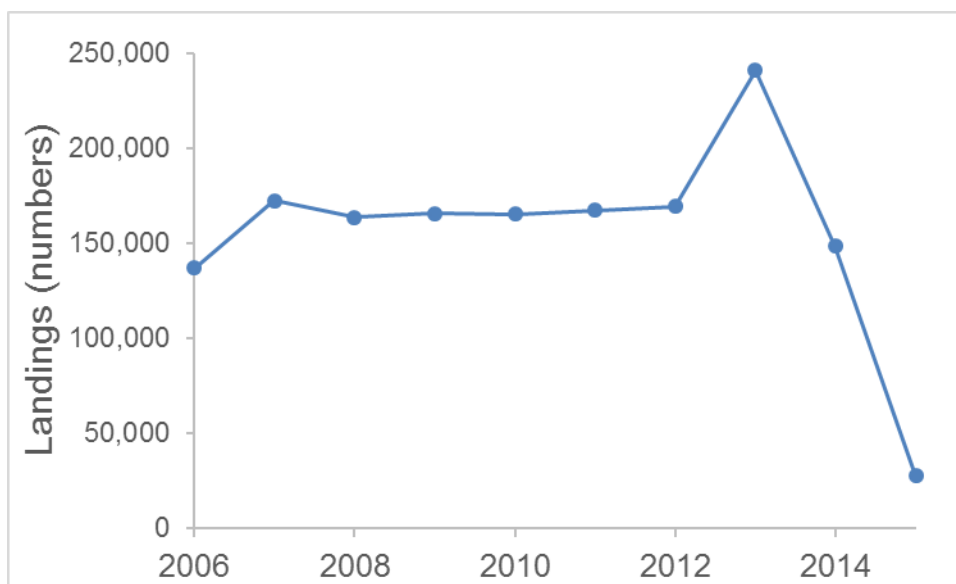


Horseshoe crabs are harvested in Maryland primarily in state oceanic waters by otter trawls and are sold as bait for the conch fishery (ASMFC 2013). Some harvest also supports the biomedical industry which extracts *Limulus amoebocyte* lysate from horseshoe crab blood for use in detection and quantification of bacterial endotoxins. Since 2013, harvest has been restricted to male crabs. Maryland horseshoe crab harvest of both males and females remained at or just below the quota of 170,653 crabs between 2006 and 2012 (Table 5, Figure 3). When the quota was increased to 255,980 crabs in 2013, the harvest was restricted to male crabs only. The recent drop in harvest is attributed to reduced demand for local male crabs in the bait industry (MDNR 2016).

Table 5. Landings of horseshoe crabs (numbers) in Maryland, 2006-2015.

Year	Landings (numbers)
2006	136,733
2007	172,117
2008	163,495
2009	165,434
2010	165,344
2011	167,053
2012	169,087
2013	240,688
2014	148,269
2015	27,494

Figure 3. Maryland landings (numbers) of horseshoe crabs, 2006-2015.



For harvest specifically reported as coming from Chincoteague or Sinepuxent Bays, the largest harvests by volume were that of Atlantic menhaden, spot, and American eel (Table 6). Blue crab may comprise a large portion of the harvest in these bays as well. However, all crabbing activity is reported as occurring in the “All Ocean Bays” region that encompasses ASIS area bays as well as Assawoman Bay and Isle of Wight Bay; additional spatial resolution of crab harvest is not available.

Table 6. Total harvest (lbs) and average annual harvest (lbs per year) for primary species (>10,000 lbs total) reported as being harvested from Chincoteague Bay (Maryland portion) and Sinepuxent Bays by Maryland watermen, 2005-2015. Blue crab is likely the most commonly caught species in these bays; however, all crabbing activity is reported as occurring in the All Ocean Bays region (see Table 4).

Bay	Species	Total harvest (lbs)	Average annual harvest (lbs)
Chincoteague	ATLANTIC MENHADEN	1,137,191	103,381
	SPOT	216,929	19,721
	AMERICAN EEL	77,377	8,597
	BLUEFISH	42,769	3,888
	ATLANTIC CROAKER	31,812	3,181
	STRIPED BASS	31,016	2,820
	CONCHES	11,293	1,412
Sinepuxent	ATLANTIC MENHADEN	121,696	12,170
	AMERICAN EEL	22,008	3,144
	SPOT	13,846	1,978
	STRIPED BASS	11,654	1,665

Maryland blue crab harvest in the coastal bays varied over time, exhibiting relative peaks in 2005, 2010-2012, and 2015 (Figure 4). As noted earlier, spiny dogfish harvest (oceanic) exhibited a marked increase since 2011 in Maryland and across the Mid-Atlantic (Figure 4). Additional increases were observed in the harvest of Atlantic menhaden since 2008, and conches between 2009-2011 (Figure 4). Small declines were reported for soft shell blue crabs, smooth dogfish, and summer flounder (Figure 4).

Figure 4. Trends in total harvest (lbs) of primary species caught by Maryland watermen, 2005-2015. Blue crab harvest is from all coastal bays. All other harvest is from Chincoteague and Sinepuxent Bays and state oceanic waters.

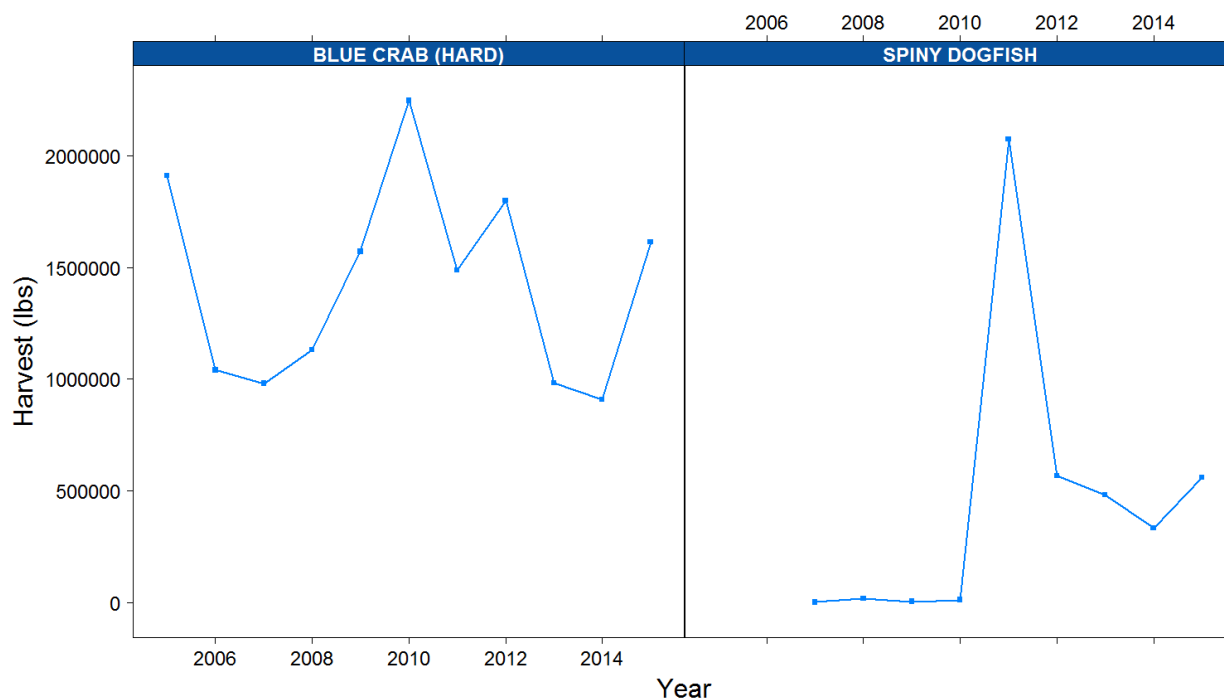
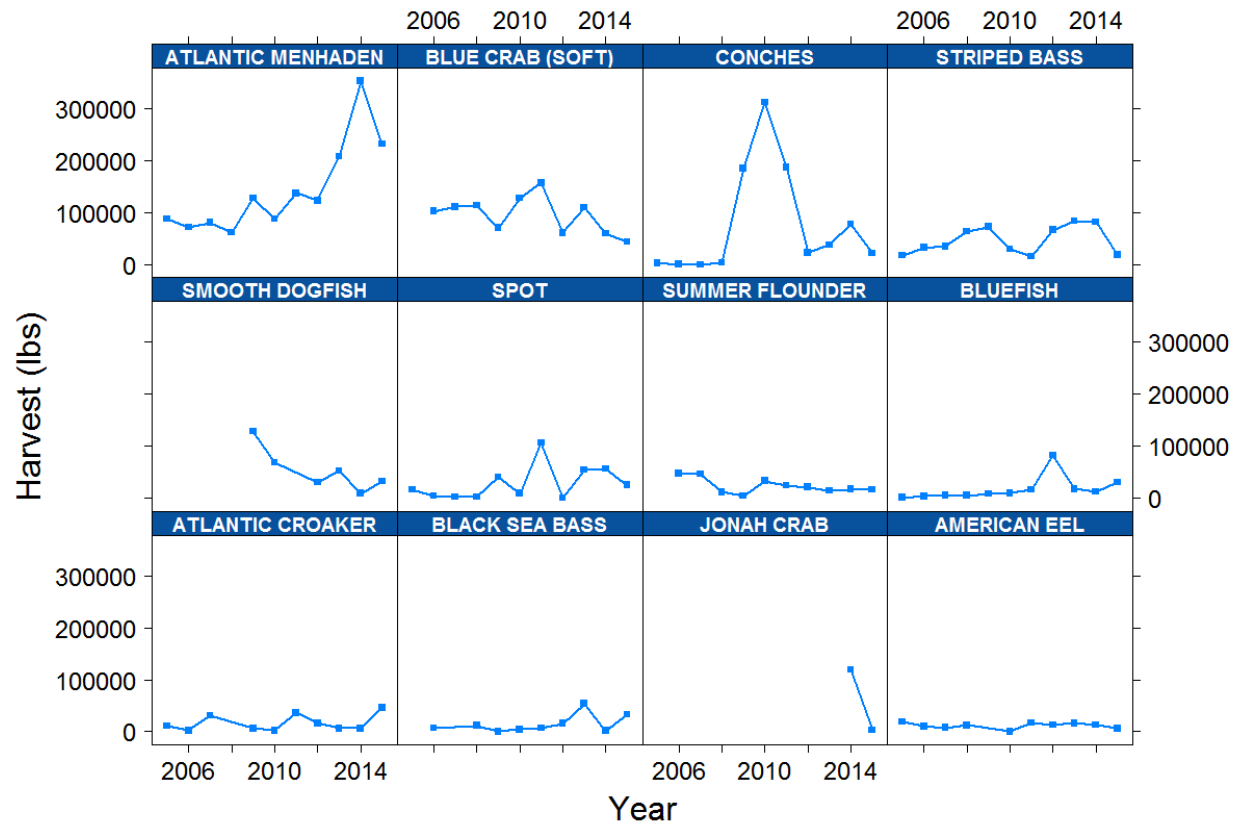
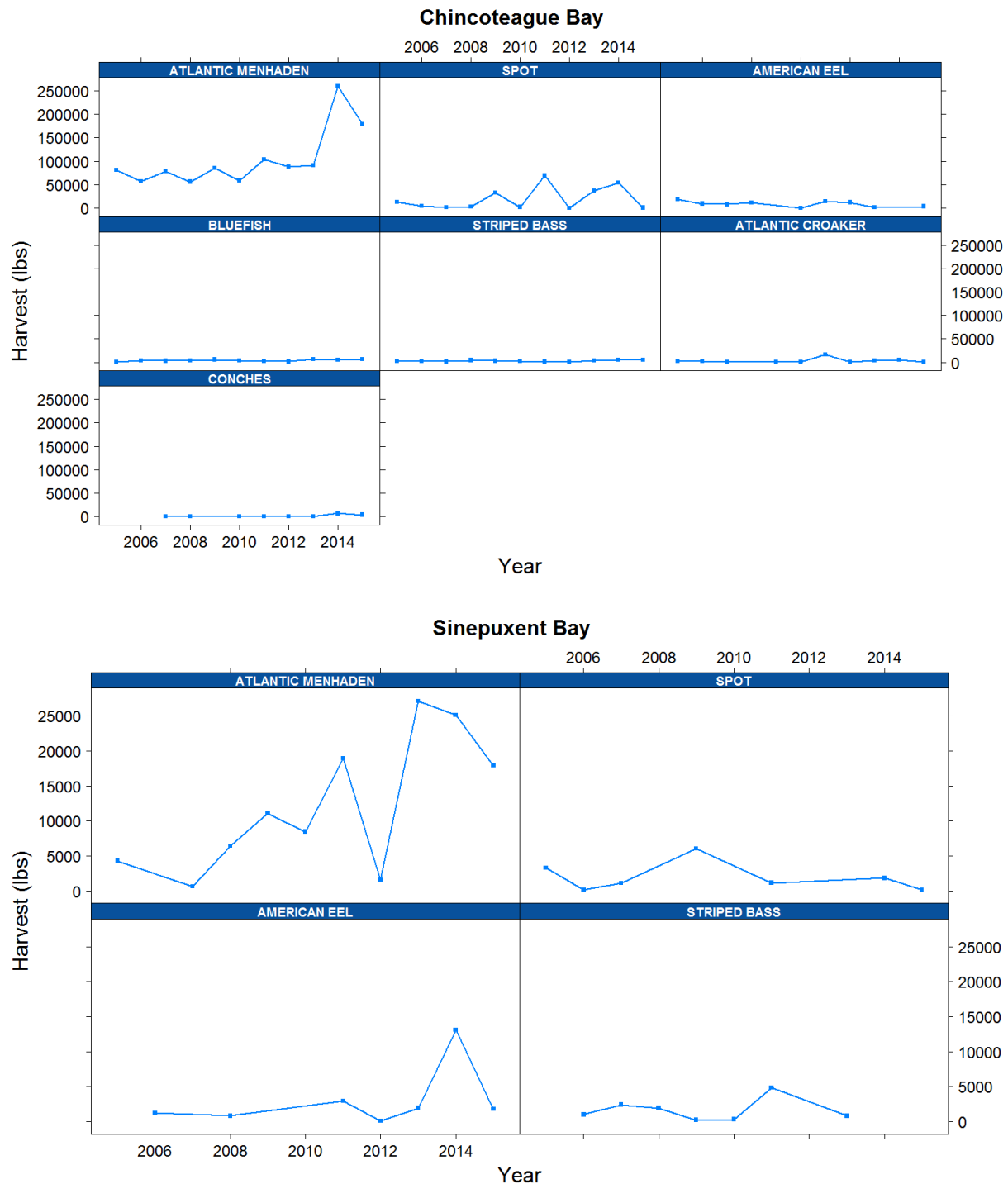


Figure 4 (cont'd).



For harvest reported explicitly as coming from Chincoteague Bay (Maryland portion) and Sinepuxent Bay, most species did not exhibit any clearly discernable trend in harvest; however, increasing trends were observed in harvest of Atlantic menhaden in the last two years of the time series such that harvest doubled (Figure 5).

Figure 5. Trends in total harvest (lbs) of primary species caught by Maryland watermen in the Maryland portion of Chincoteague Bay (top) and Sinepuxent Bay (bottom), 2005-2015.



Blue crab pots, gill nets, and otter trawls are the most common gear used by Maryland fishermen (Table 7). All blue crab pot harvest was reported as occurring in the coastal bays. Approximately 66% of gill net harvest occurred oceanside, 30% in Chincoteague Bay, and 4% in Sinepuxent Bay. Given trawling has been prohibited in the coastal bays

and coastal ocean within 1 mile of shore since 1933, over 96% of recent otter trawl harvest was reported as having occurred in the Atlantic Ocean region greater than 1 mile off the coastal shore. The remaining 4% of otter trawl landings inshore were likely reporting or database coding errors.

Table 7. Total Maryland harvest (lbs) from the ASIS area by gear type, 2005-2015. Blue crab pot harvest includes all Maryland coastal bays. Other gears include Chincoteague Bay, Sinepuxent Bay, and state oceanic waters.

Gear Type	Total harvest (lbs)
Pots - Blue crab	16,534,102
Gill nets	4,705,083
Mixed	2,453,738
Otter Trawl	1,765,279
Traps & Pots	974,595
Trotlines	101,148
Dredges	37,847
Fyke nets ¹	11,656
Hook & Line	7,077
Long Lines	4,500
Unknown	3,866

¹Fyke nets are largely present on the western shore of Maryland's coastal bays (i.e., not ASIS waters).

Gill nets were used to harvest the majority of the catch reported explicitly as coming from Chincoteague and Sinepuxent Bays (Table 8). In Chincoteague Bay, most of the gillnet harvest is composed of Atlantic menhaden, spot, bluefish, and striped bass; most catch from traps and pots was composed of American eel. In Sinepuxent Bay, gillnet harvest is largely composed of Atlantic menhaden followed by spot and striped bass.

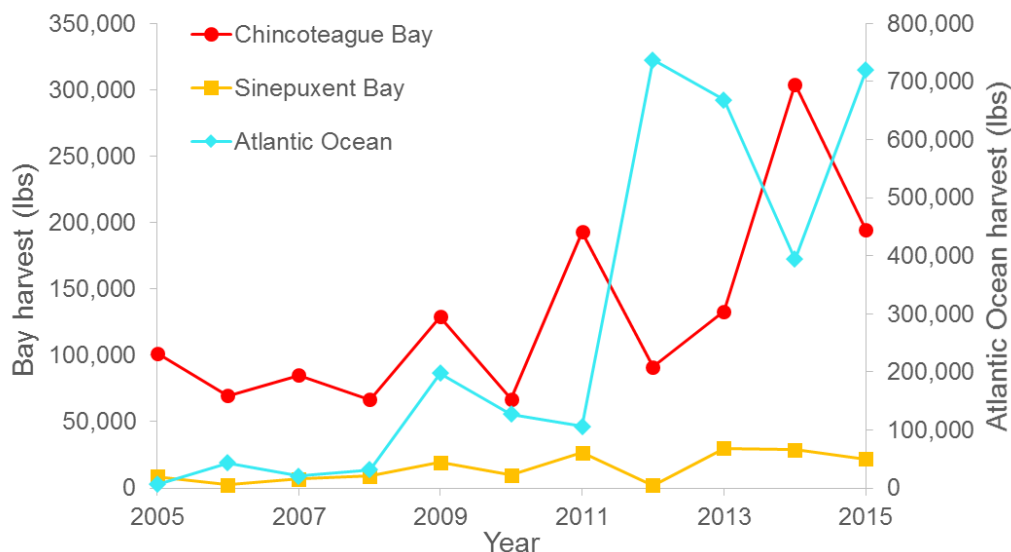
Table 8. Total Maryland harvest (lbs) reported from the ASIS area by gear type, 2005-2015, excluding blue crab pots which are reported at a larger spatial scale (see Table 7). Total Maryland harvest (lbs) from the ASIS area by gear type, 2005-2015. Blue crab pot harvest includes all Maryland coastal bays. Other gears include Chincoteague Bay, Sinepuxent Bay, and state oceanic waters.).

Bay	Gear type	Total harvest (lbs)
Chincoteague	Gill nets	1,434,752
	Traps & Pots	121,218
	Fyke nets	11,656
	Mixed	10,332
	Otter Trawl*	2,567
	Unknown	558
Sinepuxent	Gill nets	165,386
	Mixed	2,759
	Hook & Line	100

*Otter trawls are prohibited in the MD coastal bays. These landings likely represent reporting error.

Most gears showed little trend in harvest through time. Harvest by gill nets over the last decade nearly doubled in Chincoteague Bay and more than doubled in Sinepuxent Bay (Figure 6). Increased gillnet harvest in Chincoteague Bay was due to increased catch of Atlantic menhaden, spot, and bluefish, respectively. In Sinepuxent Bay, increased gillnet harvest was due to increased catch of Atlantic menhaden. In the Atlantic Ocean, increased gillnet harvest was due in large part to increased catches of spiny dogfish.

Figure 6. Total gill net harvest (lbs) by Maryland fishermen in the ASIS area, 2005-2015, from Bays (left) and the Atlantic Ocean (right).

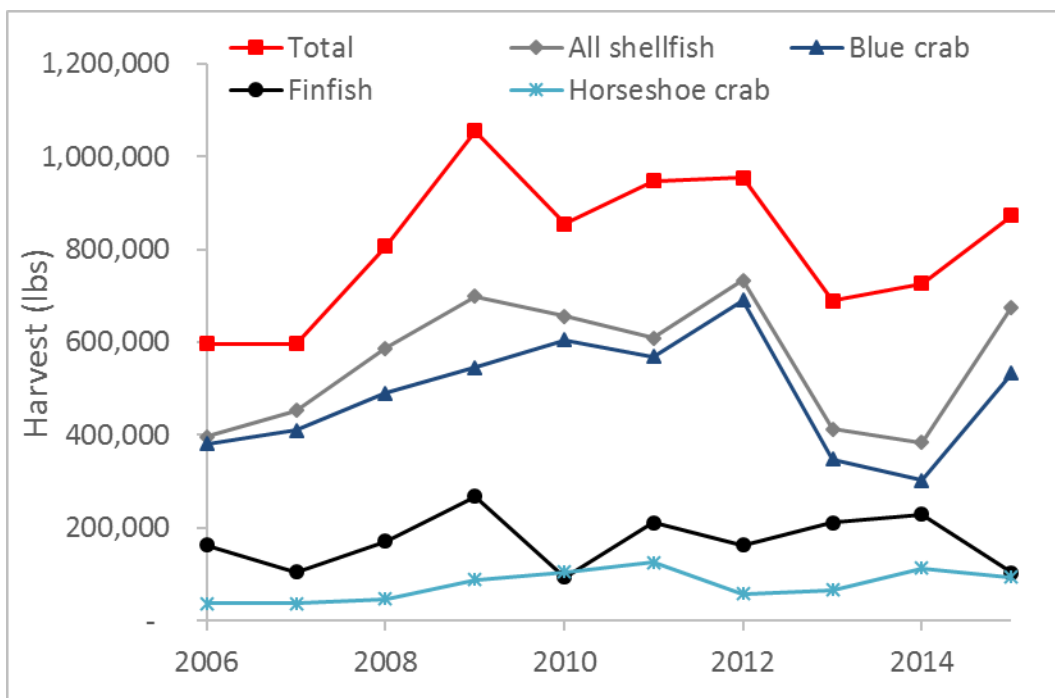


Virginia

VMRC's fisheries reporting system allows for more specific regional assignment of all harvest than that of Maryland. As a result, VMRC was able to provide harvest records from the last decade (2006-2015) for Chincoteague and Watts Bays. Due to the small number of harvesters and dealers operating in the Virginia portion of the ASIS area, the figures and tables below may include empty years or cells or exclude pounds landed because of confidentiality issues; also, harvest of hard clam (quahog) and Eastern oyster from aquaculture and wild public (wild) harvest have been combined.

Total commercial harvest in the Virginia waters of Chincoteague Bay and Watts Bay increased between 2006 and 2009, then declined slightly over the last decade (Figure 7). Total shellfish harvest comprised 69% of total harvest, far exceeding that of finfish or horseshoe crab harvest.

Figure 7. Total harvest, harvest of all shellfish (including blue crabs), harvest of blue crabs, harvest of all finfish, and harvest of horseshoe crabs by volume (lbs) from the Virginia portion of Chincoteague Bay and Watts Bay, 2006-2015.

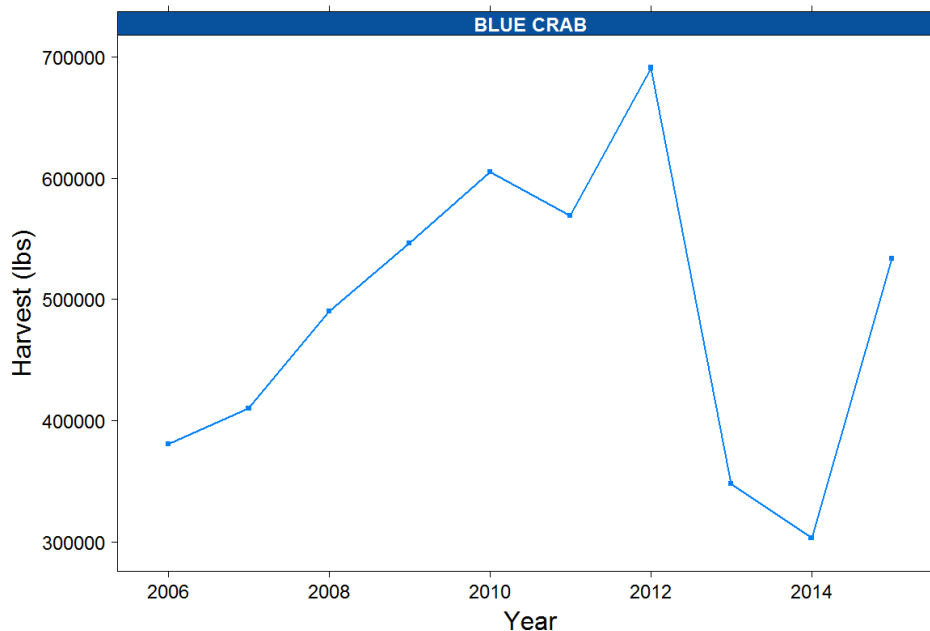


As in Maryland, the primary species harvested in the Virginia portion of the ASIS area is blue crab (Table 9, Figure 7). Blue crab landings comprised approximately 87% of total shellfish harvest and 60% of the total harvest in the last decade. Blue crab harvest increased from 2006-2012, then declined before rebounding again in 2015 (Figure 8).

Table 9. Total harvest (lbs) and average annual harvest (lbs per year) for primary species (>10,000 lbs total) landed in Watts Bay and the Virginia portion of Chincoteague Bay, 2005-2015. Confidential harvest statistics have been replaced with an asterisk.

Species	Total harvest (lbs)	Average annual harvest (lbs)
BLUE CRAB	4,877,442	487,744
HORSESHOE CRAB	777,089	77,709
HARD CLAM	553,411	55,341
SPOT	404,796	40,480
ATLANTIC CROAKER	327,096	32,710
MINNOW	*	*
MENHADEN	*	*
EASTERN OYSTERS	164,730	18,303
OTHER INDUSTRY FISH	123,990	12,399
BLUEFISH	99,414	9,941
STRIPED BASS	*	*
SPINY DOGFISH	*	*
ATLANTIC SILVERSIDE	*	*
ALEWIFE	*	*
NORTHERN PUFFER	27,423	2,742
SUMMER FLOUNDER	19,664	1,966
WEAKFISH	14,799	1,480

Figure 8. Trends in total harvest (lbs) of blue crab in the Virginia portion of Chincoteague Bay and Watts Bay, 2006-2015.

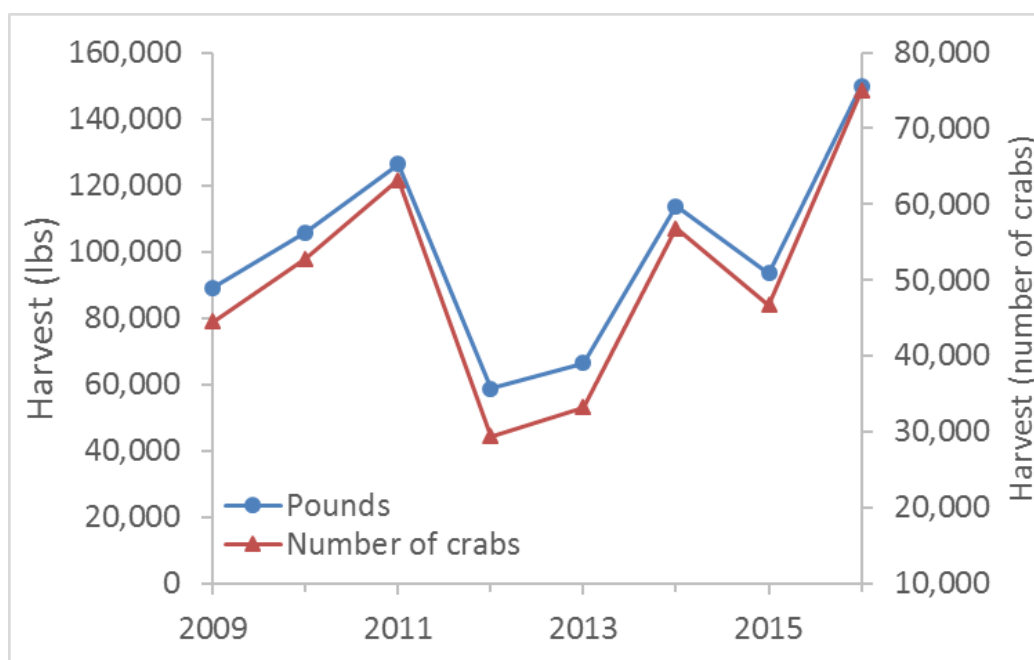


The next highest landings were that of horseshoe crab (Table 9), which is harvested in ASIS waters primarily in the Toms Cove area via gillnet during the migratory striped bass fishery and via hand harvest. Harvest of horseshoe crabs from state waters outside the coastal bays is limited to trawl and dredge gears. The primary use of horseshoe crab harvest from the ASIS area is for bait in the conch fishery. Horseshoe crab harvest in the ASIS area increased in Virginia between 2008 and 2011, declined through 2012, then largely increased again through 2016 (Table 10, Figure 9).

Table 10. Virginia harvest (lbs and number) of horseshoe crab from Chincoteague and Watts Bays and Toms Cove, 2009-2016.

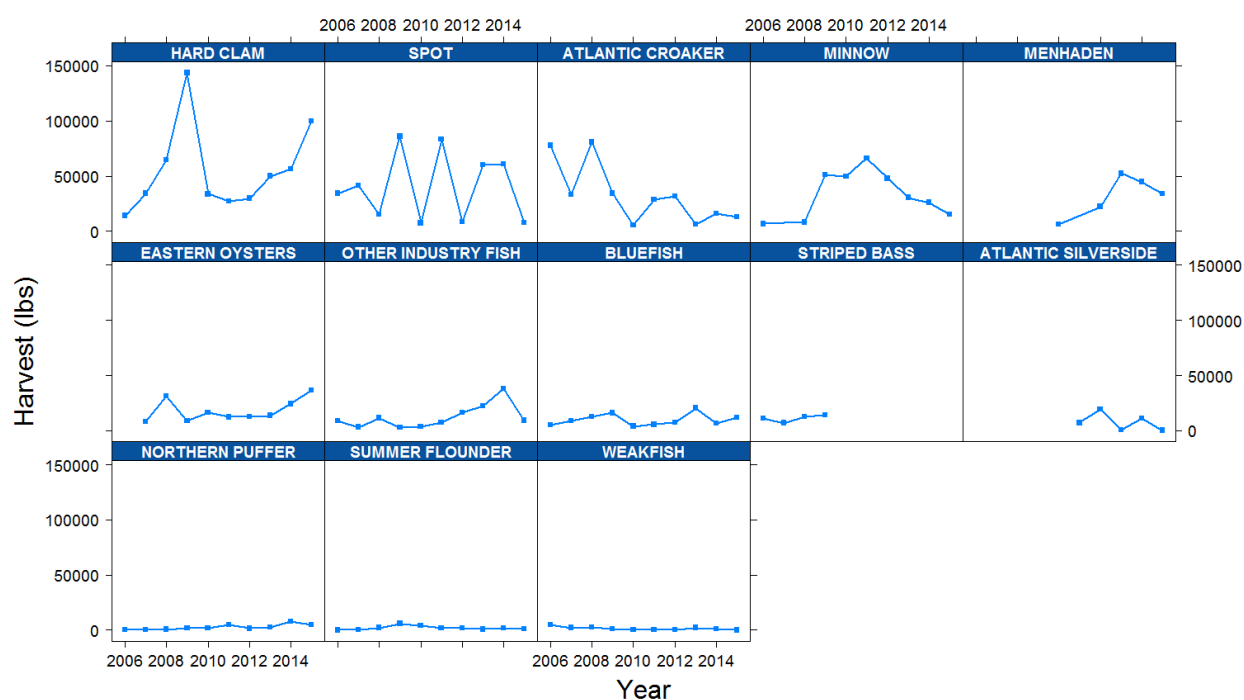
Year	Harvest (lbs)	Harvest (number)
2009	89,052	44,526
2010	105,670	52,835
2011	126,328	63,164
2012	58,736	29,368
2013	66,510	33,255
2014	113,693	56,847
2015	93,472	46,736
2016	149,940	74,970

Figure 9. Trends in total annual Virginia harvest (in lbs and number) of horseshoe crabs in the ASIS area, 2009-2016.



Hard clam harvest (both aquaculture and wild) exhibited peaks in 2009-2011 and 2008-2009, respectively (Table 9, Figure 10). Spot exhibited high interannual variability in harvest whereas Atlantic croaker harvest declined in the last decade. Minnows exhibited a relative peak in 2009-2012. Atlantic menhaden and eastern oyster harvest increased slightly in recent years; increased oyster harvest is likely attributable to increases in the aquaculture industry.

Figure 10. Trends in total harvest (lbs) of primary commercial species in the Virginia portion of Chincoteague Bay and Watts Bay, 2006-2015. Missing years of data for menhaden, striped bass, and minnow are confidential and therefore cannot be displayed; similarly, confidential spiny dogfish and alewife landings were not displayed.



Virginia's nearshore oceanic harvest was not summarized for this report because the reporting area spanned the entire Virginia coastline and fish harvested near the Chesapeake Bay mouth south to the North Carolina border are not necessarily representative of fish harvested in the ASIS area. Many of the species typically harvested in nearshore ASIS waters are similar to that of Maryland. One exception is the purse seine reduction fishery for Atlantic menhaden which does not operate along the Maryland portion of the ASIS shoreline, but often fishes adjacent to ASIS in Virginia waters (Figures 4.1.3.4.1-3 in SEDAR 2015). The magnitude of menhaden reduction harvest oceanside of ASIS is confidential.

Given the small number of operators and dealers involved in the Virginia Chincoteague and Watts Bay fisheries, harvest by gear is confidential; however, a ranked list of gears by total harvest, 2006-2015, shows that blue crab pots and traps are the primary gear used in the ASIS area (Table 11). Gill nets are the second largest gear by total harvest,

followed distantly by hand harvest, pin (seine) nets, and numerous other gears such as dredges, rakes, and aquaculture gears (e.g., bottom cages, rack and bag). Trawls are not included in this list because trawling has been banned in Virginia state waters since 1989.

Table 11. Gears used in the Virginia commercial fisheries of Chincoteague Bay and Watts Bay, 2006-2015. Gears are ranked in descending order based on the magnitude of the total Virginia harvest (lbs) by gear in Chincoteague and Watts Bays, 2006-2015, such that the gear with the largest total harvest (blue crab pots and traps) is listed first. Gears with total harvest, 2006-2015, that was less than 10,000 lbs were not included.

GEAR
BLUE CRAB POTS + TRAPS
GILL NET (SINK/ANCHOR, OTHER)
BY HAND (OTHER)
GILL NET (DRIFT, OTHER)
PIN NETS
FISH POTS + TRAPS
MINNOW POTS
CONCH DREDGE
CRAB DREDGE
COMMON HAUL SEINE
SHINECOCK/BULL RAKE
BY HAND (OYSTERS)
BOTTOM CAGES
PEELER POTS
RACK AND BAG
CLAM DREDGE

Economic value of commercial harvest

We characterized the economic value of each primary fishery in the ASIS area by dockside value, defined as the amount paid by dealers for harvest purchased from fishermen. Dealer data used to estimate dockside value does not include dockside sales of harvest directly to buyers and may be an underestimate for some species. It is important to recognize that dockside value is a minimum estimate of the value of a fishery; the total economic value of a given fishery to the local or regional economy for some species often exceeds dockside value.

Maryland

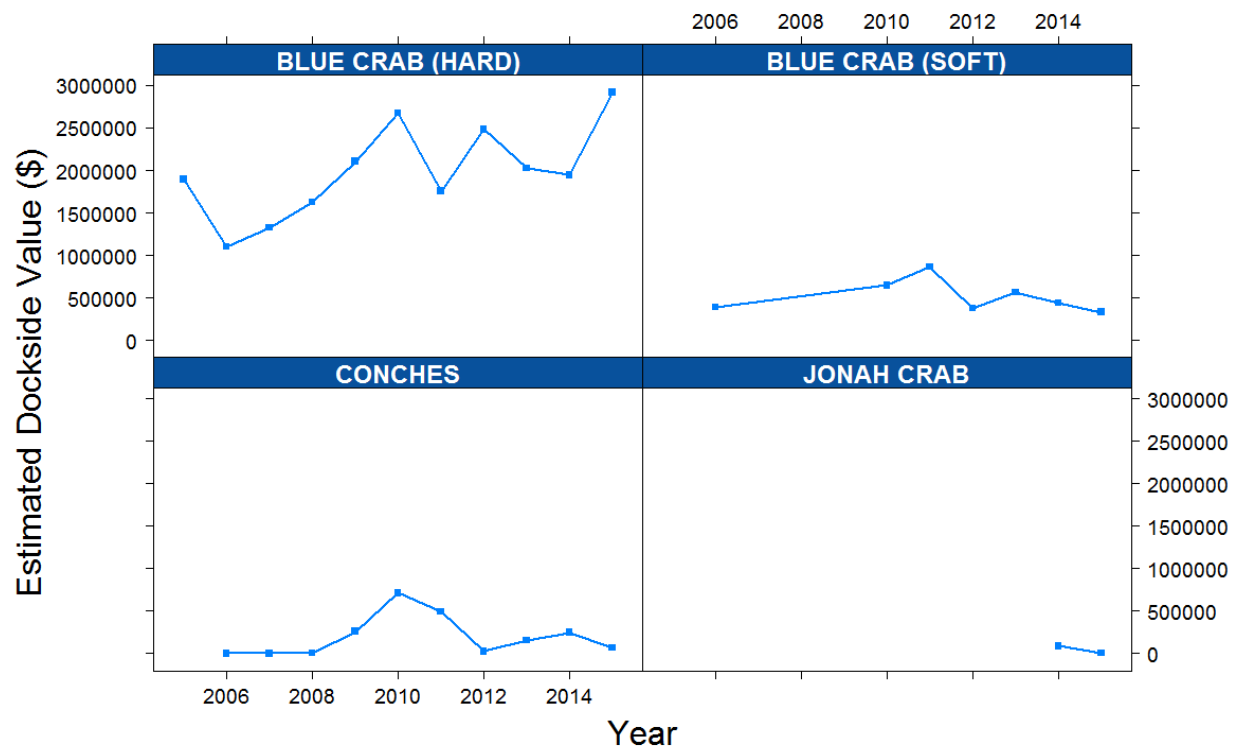
To estimate dockside value of harvest, we multiplied total annual harvest of each species by the average annual price per pound for each species reported by Maryland dealers in the [NOAA commercial fisheries statistics database](#). Dockside value is summarized below for the species with >10,000 lbs total harvest, 2005-2015 (Table 12, Figure 11).

Dockside value of blue crabs far exceeded that of all other species caught in the ASIS area. Even though the magnitude of blue crab harvest value estimated here represents that of the entire coastal bays region which cannot be broken down into finer spatial resolution, blue crab is certainly the highest value species caught by Maryland watermen in the ASIS area (Kirkley 1997). Hard shell blue crab value increased during the last decade in contrast to that of softshell blue crab and conch harvest which declined from 2011 to 2015 (Table 12, Figure 11).

Table 12. Top ten species by total dockside value (USD), 2005-2015, harvested from the Maryland coastal bays (blue crab) and the Maryland portion of the ASIS area. An unknown percentage of the blue crab harvest value reported here includes crabs harvested from coastal bays not adjacent to ASIS waters.

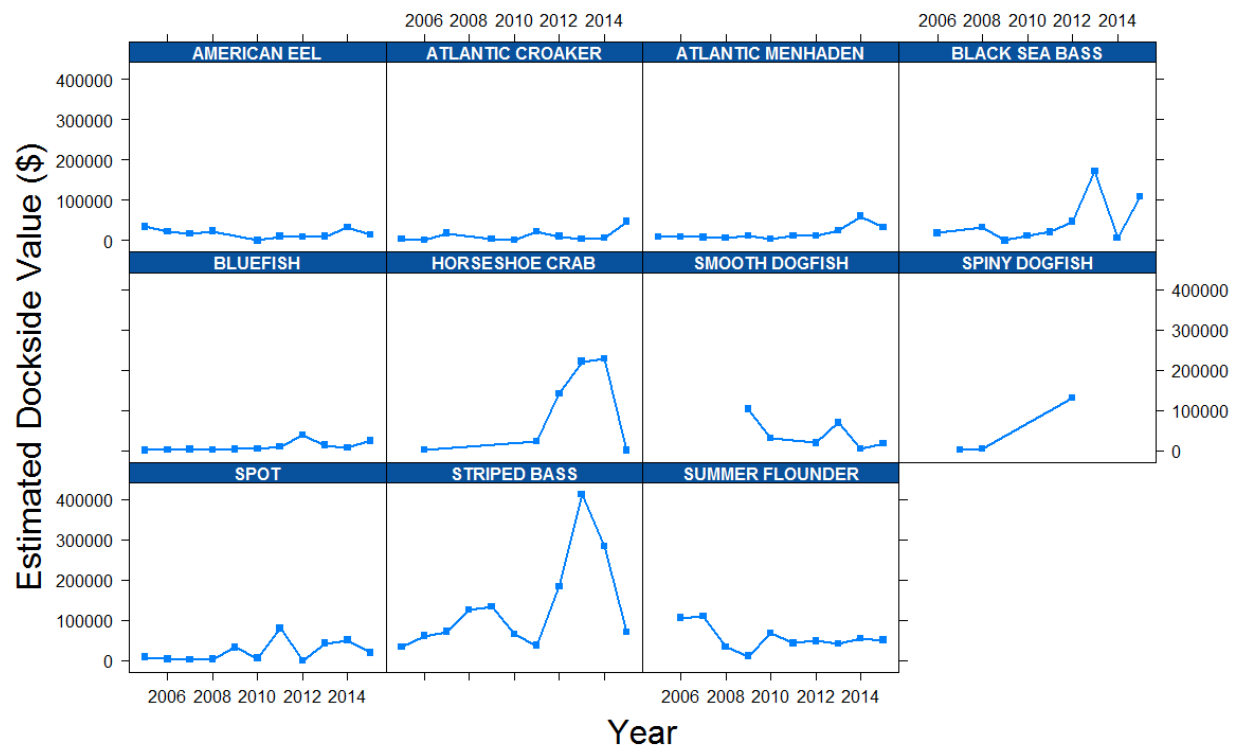
Species	Value (\$)
BLUE CRAB (HARD & SOFT)	25,467,538
CONCHES	1,976,825
STRIPED BASS	1,480,542
HORSESHOE CRAB	614,159
SUMMER FLOUNDER	569,280
BLACK SEA BASS	418,909
SPOT	252,328
SMOOTH DOGFISH	242,728
ATLANTIC MENHADEN	190,650
AMERICAN EEL	173,818

Figure 11. Estimated dockside value (nominal USD) of hard and softshell blue crab harvest in the Maryland coastal bays and conch and Jonah crab harvest in the ASIS area.



Dockside value of most finfish varied without trend across the last decade (Figure 12). Two exceptions were the value of striped bass and horseshoe crab harvest which increased between 2011 and 2014 before returning to average levels.

Figure 12. Estimated dockside value (USD) of the primary finfish and horseshoe crabs harvested by Maryland watermen in the ASIS area.



Few formal economic evaluations of Maryland's seafood industry have been conducted. Although the exact economic impact of commercial fisheries on Worcester County (population 52,000) has not been quantified, the seafood industry and associated tourism businesses (e.g., restaurants) are likely an important component of the local economy. Existing studies indicate that the economic value of blue crabs far surpasses that of any other species harvested in Maryland (Greeley and Polhemus 2001, National Marine Fisheries Service 2016). Statewide, blue crabs make up 80% of the total seafood landings revenue (National Marine Fisheries Service 2016).

Virginia

Dockside value of Virginia's wild and aquaculture harvest from Chincoteague and Watts Bay as reported by dealers was summarized below for the primary species caught in the Virginia portion of the ASIS area. The largest total dockside value across the last decade by species was that of blue crab, followed by hard clam, Eastern oyster, horseshoe crab, and spot (Table 13).

Table 13. Top ten species by total dockside value (USD) harvested in Virginia waters of Chincoteague Bay and Watts Bay, 2006-2015.

SPECIES	Value (\$)
BLUE CRAB	4,798,193
HARD CLAM	3,523,752
EASTERN OYSTERS	987,694
HORSESHOE CRAB	777,079
SPOT	504,050
MINNOW	314,116
ATLANTIC CROAKER	242,048
STRIPED BASS	165,676
NORTHERN PUFFER	100,539
BLUEFISH	66,116

Blue crab value far exceeded that of horseshoe crab and finfish (Figure 13) and was comparable in many years to that of hard clam (quahog) aquaculture (Table 14). The value of blue crab harvest increased from 2006 to 2008 then varied annually without trend. Horseshoe crab harvest and value has increased across the time series (Table 15, ASMFC 2013). Minnow harvest value increased between 2008 and 2011 then declined. All other species exhibited interannual variability in harvest value but no overall trend.

Figure 13. Dockside value (USD) of the primary species harvested from the Virginia portion of Chincoteague Bay and Watt Bay, 2006-2015. Missing years of data for menhaden and striped bass were confidential and not included; similarly, spiny dogfish and alewife landings were confidential across all years reported and were thus not displayed

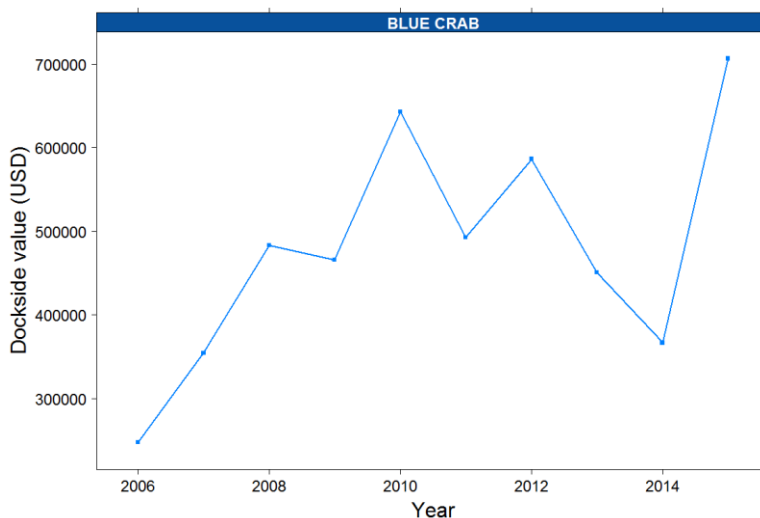


Figure 13 (cont'd).

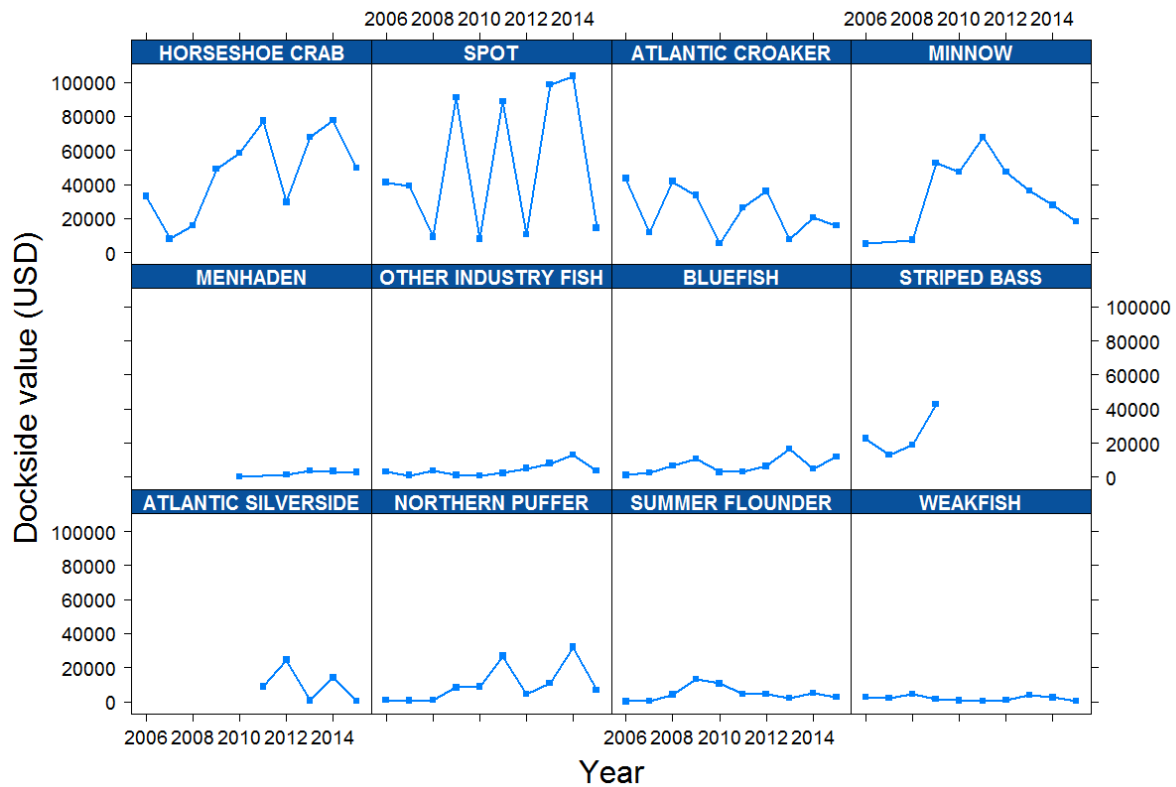


Table 14. Value (USD) of aquaculture hard clam (quahog) and Eastern oysters in the Virginia portion of Chincoteague Bay and Watts Bay, 2007-2015.

Year	Hard clam value (\$)	Eastern oyster value (\$)
2007	\$41,641	\$24,366
2008	\$375,944	\$111,809
2009	\$889,867	\$25,571
2010	\$91,521	\$53,519
2011	\$126,161	\$44,574
2012	\$144,006	\$64,892
2013	\$316,241	\$89,138
2014	\$447,107	\$164,390
2015	\$873,507	\$258,260

Table 15. Total annual harvest (lbs) and value (USD) of horseshoe crab harvest in Chincoteague and Watts Bays, 2006-2015.

Year	Harvest (lbs)	Value
2006	37,760	\$ 32,888
2007	38,102	\$ 8,006
2008	47,766	\$ 15,782
2009	89,052	\$ 56,091
2010	105,670	\$ 58,401
2011	126,328	\$ 80,890
2012	58,736	\$ 43,284
2013	66,510	\$ 85,806
2014	113,693	\$138,375
2015	93,472	\$105,278
2016	149,940	\$161,874

The total value of hard clam and Eastern oyster aquaculture harvest in Virginia is available from 2007 to present and far exceeds that of wild caught hard clams and oysters. Since 2007, the value of hard clam aquaculture production from Chincoteague and Watts Bay fluctuated, ranging from <\$100,000 per year to >\$800,000 (Table 14). Following a peak in 2008, the value of Eastern oyster aquaculture production dropped then increased steadily from 2009 to 2015 (Table 14).

Commercial fishing benefits to the ASIS area economy are extensive in Accomack County. In 2004, Accomack County was second only to the Newport News/York/Hampton area with regards to the economic activity generated by the seafood industry (Kirkley et al. 2005). As estimated by Kirkley et al. (1997), the seafood industry in Accomack County, which has a population of approximately 33,000 individuals, generated full-time employment for over 800 people through jobs in fishing, restaurants, wholesaling, processing, retail, and support.

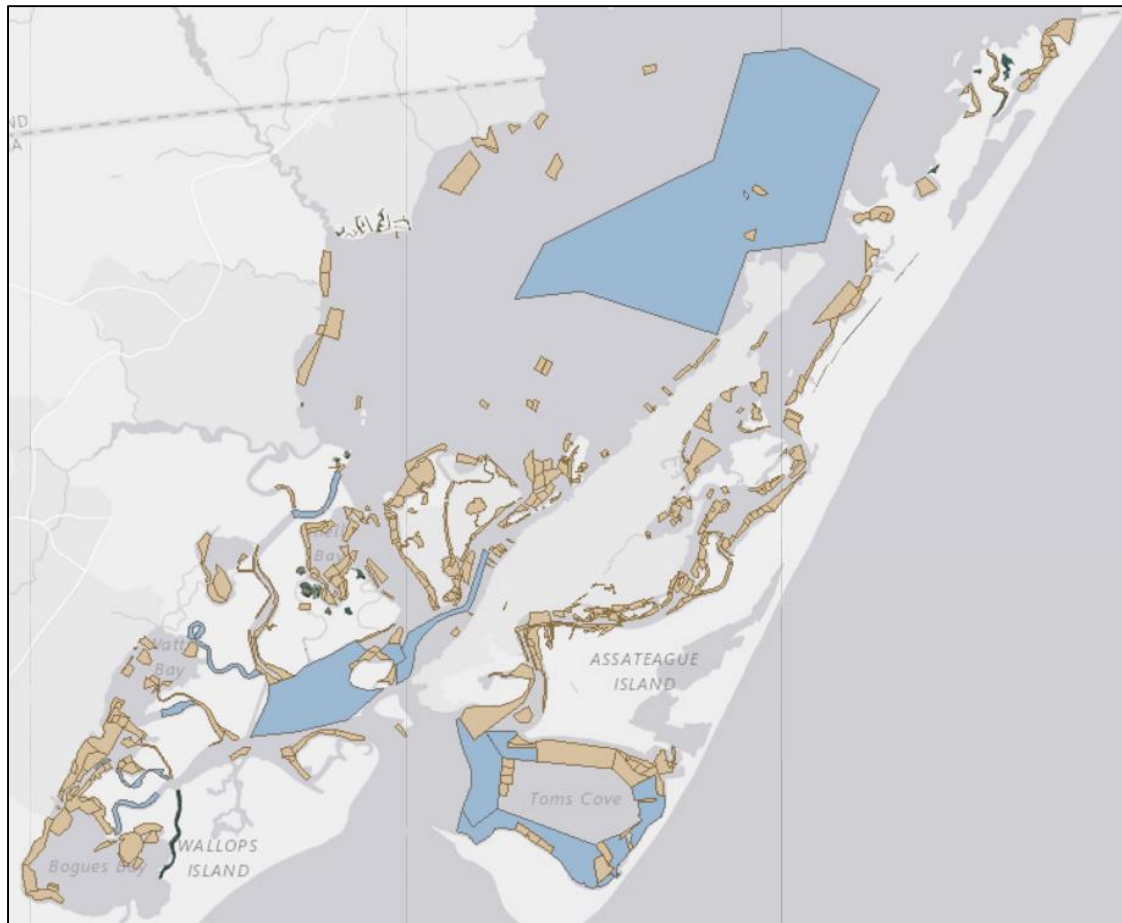
Economic evaluations of Virginia's commercial fishing industry highlight the importance of blue crabs and menhaden statewide (Kirkley 1997, Kirkley et al. 2005). After scallops, the blue crab and menhaden reduction fisheries place second and third in terms of seafood sales or outputs generated for the Virginia economy (Kirkley et al. 2005). The contribution of the blue crab fishery to the economic value of commercial fisheries in Virginia's coastal bays is in the range of \$400,000 to \$700,000 in recent years (Figure 13). Statewide, blue crabs generated the second highest level of economic impact from the seafood industry when evaluated in 2004, namely \$46.2 million in sales or output, \$26.9 million in value-added, and 422 full and part-time jobs (Kirkley et al. 2005). Although the menhaden reduction fishery has high economic value, the majority of the fishery is prosecuted in the lower Chesapeake Bay and nearshore waters outside the ASIS area. Also, fish meal and oil processing occurs in Reedville, Virginia. Therefore, the menhaden reduction fishery does not contribute substantially to the ASIS area

economy. In contrast, low-value finfish (e.g., spot and croaker) generate the second highest level of employment in the Virginia seafood industry after scallops, with 467 full and part-time jobs, despite the small sales and income values generated (Kirkley et al. 2005). Although economic impacts of the horseshoe crab fishery in the ASIS area have not been formally evaluated, the local dockside value is approximately \$135,000 in recent years (Table 15), and the statewide economic value of this fishery was estimated in 2006 to be between \$1.1 million and \$1.8 million (Industrial Economics Inc. 2008).

The hatchery-based aquaculture industry for hard clam (quahog) and oysters has grown rapidly throughout Virginia in the last few decades (Hudson and Murray 2016). In 2015, the farm gate value (net value of the product when it leaves the aquaculture farm, after marketing costs have been subtracted) of Virginia's hard clam and oyster aquaculture was \$48.3 million (Hudson and Murray 2016); two thirds of that value was generated by hard clams. Production of oysters is growing rapidly (Table 14) such that Virginia is now the primary producer of aquaculture hard clams in the US and Eastern oyster on the US East Coast (Hudson and Murray 2016). Estimated total employment in Virginia's hard clam aquaculture industry has risen from an average of 200 jobs from 2005-2012 to an average of 300 from 2013-2015; the majority of this industry's employment is full time (Hudson and Murray 2016). Estimated total employment in Virginia's oyster aquaculture industry has increased from approximately 125 in 2009 to 225 jobs in 2015, with a trend toward increasing full vs. part-time employment (Hudson and Murray 2016).

Aquaculture leasing in the ASIS area covers most of the Virginia bayside shoreline and that of neighboring embayments and islands (Figure 14). Not surprisingly, aquaculture in the ASIS region is a significant contributor to the local economy. In a 2004 economic assessment, hard clam aquaculture was determined to be the most valuable single agricultural commodity produced on Virginia's Eastern Shore (Murray and Kirkley 2005).

Figure 14. Aquaculture leases (brown polygons) and public clamming grounds (blue polygons) in the ASIS area (map courtesy Center for Coastal Resources Management, 2015).



Trends in local stocks and habitats

The combined effects of environmental influences, commercial fishing operations, and other anthropogenic effects on exploited stocks are often evident in the catch per unit effort trends generated from fishery-independent surveys (Hilborn and Walters 1992). We analyzed data collected in two bayside and two oceanside fishery-independent surveys for apparent trends in relative abundance of the primary species encountered in the ASIS area. Primary species included those regularly caught across most years of the survey. In addition, we explored the potential effects of commercial gears and fishing operations on bottom habitat through analysis of local surveys for benthic invertebrates (indicators of habitat quality) and submerged aquatic vegetation.

Fishery-independent surveys

MDNR Coastal Bays Trawl and Beach Seine Survey

The Maryland Coastal Bays Trawl and Beach Seine Survey operated by MDNR is a multispecies fixed station survey spanning 1989 to present (Figure 15). Trawl sampling

is conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October, typically beginning in the third week of the month. Beach seine sampling is conducted from shore in shallow water at 19 fixed sites beginning in the second weeks of June and September. We summarized trends in the geometric mean number caught by gear type for the primary species encountered in all Sinepuxent and Chincoteague Bay stations. Geometric means were calculated by calculating the average of the natural log of the catches plus half the smallest observed number (0.5), then back-transforming that value. Trawls and the 100' beach seine survey data were analyzed separately because each gear typically encounters different species or life stages with seines targeting smaller forage and juvenile fish. This survey rarely samples in submerged aquatic vegetation beds. A small pilot study began in 2012 to explore the utility of sampling this habitat type using a bag seine (Barker et al. 2014); this survey may prove useful in the future for monitoring composition and trends in submerged aquatic vegetation in the immediate ASIS area.

The trawl survey encountered high numbers of blue crab. Mean catch per tow of blue crab increased through the mid-1990s, declined through 1998, remained moderately stable through 2009, spiked in 2010, declined to a time series low in 2013, and began increasing again in recent years (Figure 16). Trends in this survey mirror Maryland-wide trends in other fishery-independent information such as the Chesapeake Bay blue crab winter dredge survey used in blue crab management. The cause of recent fluctuations in blue crab dynamics is unknown.

High interannual variability in mean catch per tow was observed for many species caught by the trawl, including American eel, Atlantic croaker, Atlantic herring, bluefish, northern puffer, scup, spot, and summer flounder (Figure 16). Recent increases were observed in catch of forage fish such as Atlantic silverside, bay anchovy, and silver perch in the ASIS area and survey-wide, but the cause is unknown.

Horseshoe crab exhibited low trawl survey catches in the ASIS area at the beginning of the time series and has returned to those low levels in the last 6 years (Figure 16). It is not clear what is driving these local trends given they are not correlated with local harvest and do not correspond with overall CBFIS survey trends or other regional surveys. However, survey locations are limited to the few deeper areas within the coastal bays in which the trawl can operate; it is possible this focus on deeper sites may affect the catchability of some species in this survey such as horseshoe crab, resulting in a situation where the mean catch per tow does not reflect trends in abundance.

Mirroring coastwide dynamics (ASMFC 2016), weakfish catch per tow exhibited a downward trend across most of the last decade (Figure 16). Despite very low commercial harvest of this species in Maryland and Virginia, apparent increased natural mortality has caused continued weakfish stock declines in recent years.

Figure 15. MDNR Coastal Bays Fishery Independent Trawl and Beach Seine sampling sites, 2014. Map courtesy MDNR (Barker et al. 2014).

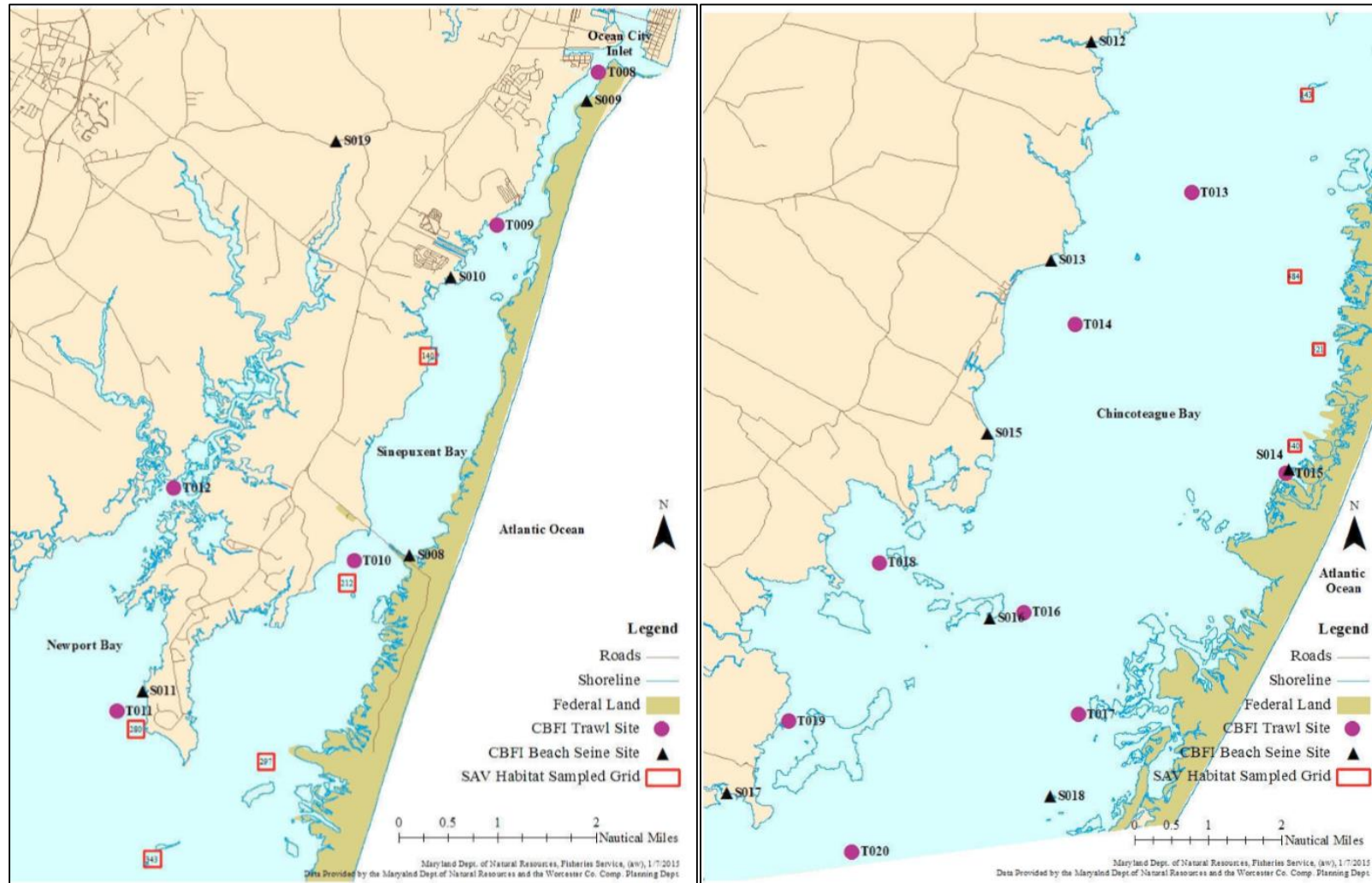
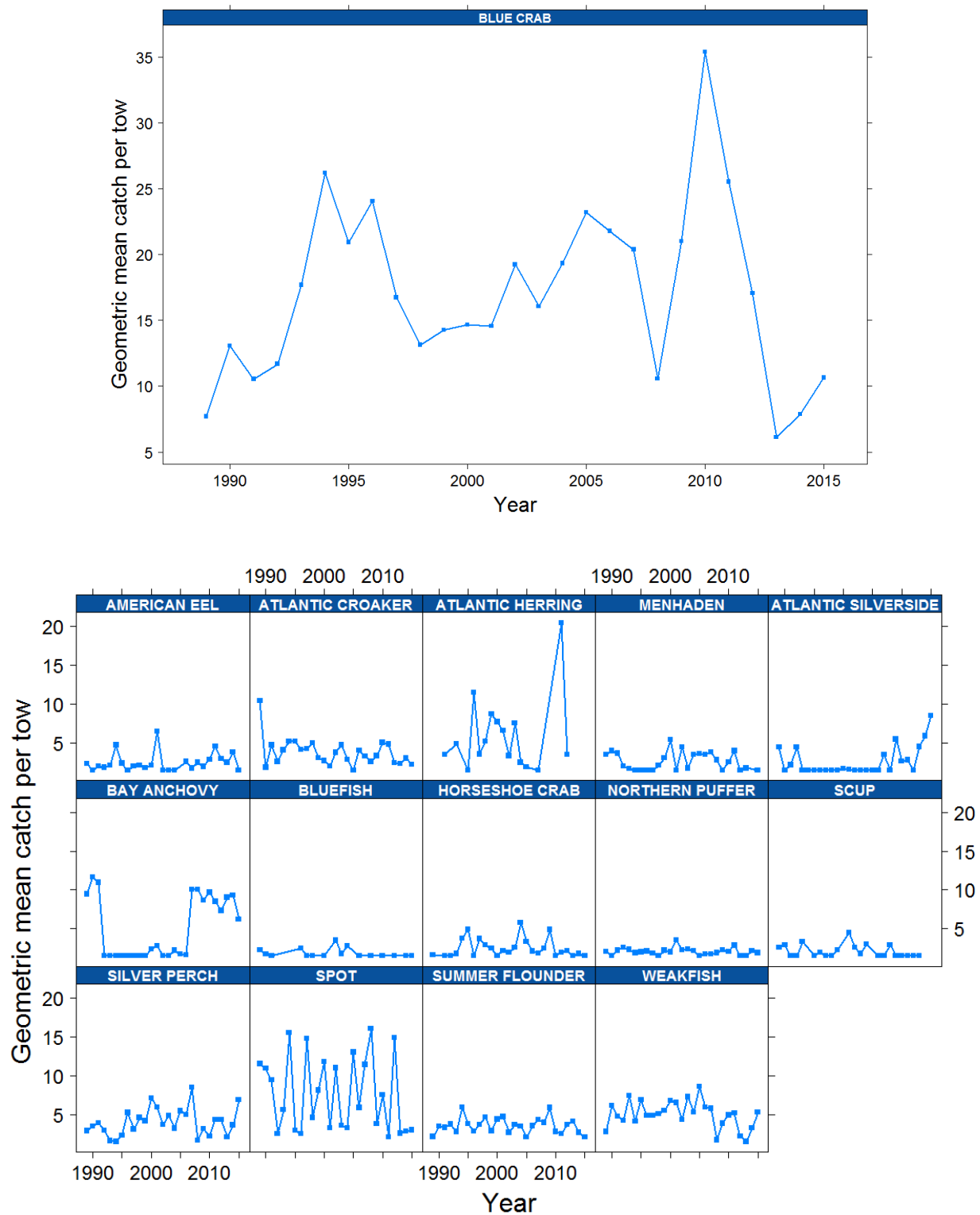


Figure 16. Annual geometric mean catch per tow for primary species caught by the Maryland Coastal Bays Trawl Survey in Sinepuxent and Chincoteague Bays, 1989-2015.



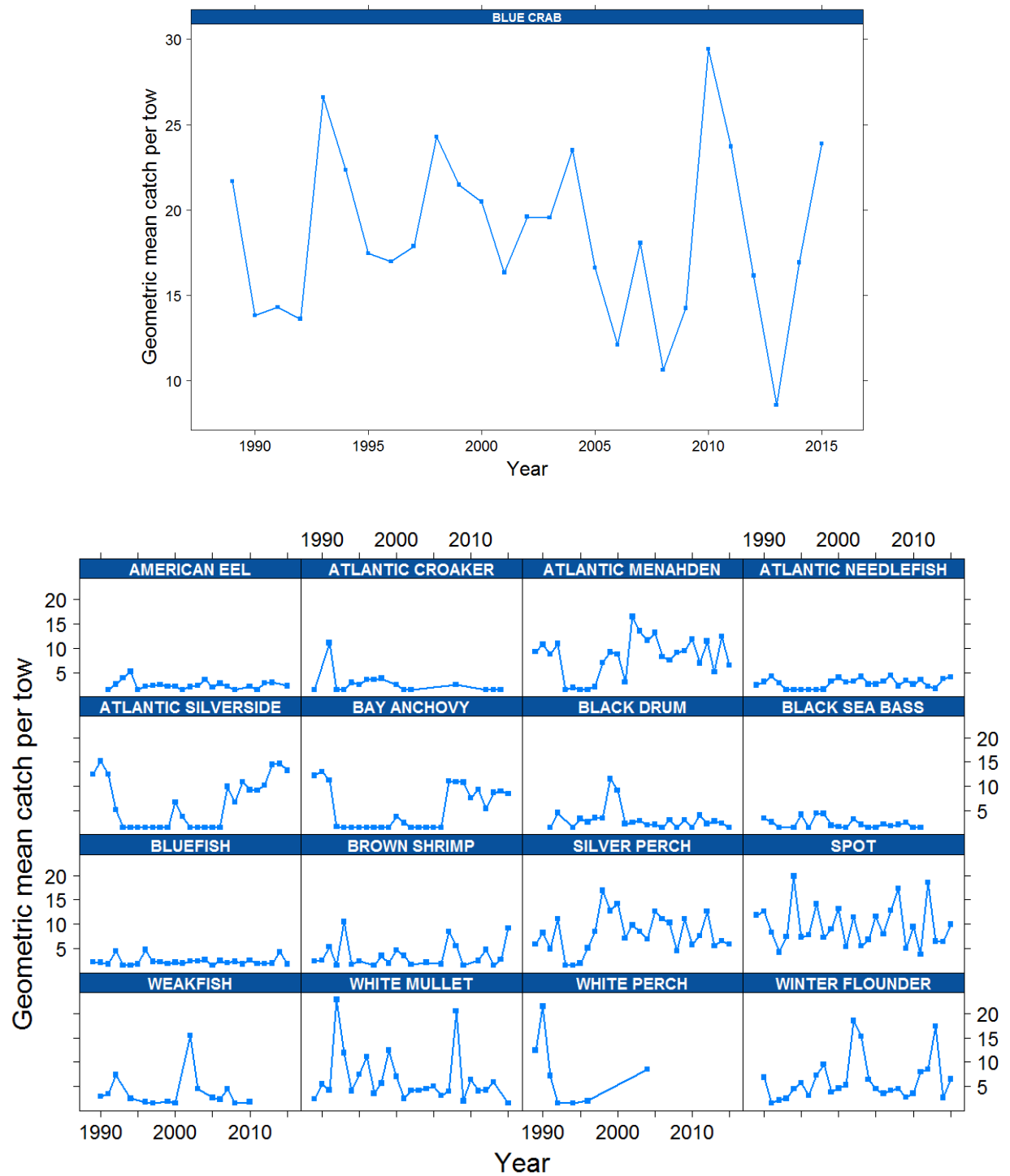
Similar to the MDNR Coastal Bays Trawl Survey, the Coastal Bays Beach Seine Survey also exhibited a substantial peak in blue crab catch in 2010 (Figure 17). Mean catch per tow of blue crab exhibited interannual variability across most of the time series, spiked in 2010, declined through 2013, then increased to average levels in 2014-2015. High catches in 2010-2011 mirrored Maryland-wide trends in harvest and other fishery-independent surveys. In the Mid-Atlantic, synchrony in blue crab dynamics has been observed across Delaware Bay, Chesapeake Bay, Maryland and Virginia Coastal Bays, and North Carolina (Colton et al. 2014). As mentioned above, the cause of recent fluctuations in blue crab dynamics is unknown.

Low, but largely stable, catches were observed for American eel, Atlantic croaker, Atlantic needlefish, black drum, black sea bass, and bluefish (Figure 17). High interannual variability in mean catch per tow was observed for brown shrimp, spot, white mullet, and white perch. Similar to the trawl survey, weakfish survey trends declined since the mid-2000s.

Highly variable, but recently stable catches were observed for bay anchovy (Figure 17). As observed in the trawl survey, Atlantic silverside trends increased in recent years. Atlantic menhaden and silver perch exhibited low catches during 1993-1995 and 1993-1997 respectively, but have both returned to average levels since the early late 1990s. Given there is no commercial harvest of silver perch and Maryland bait harvest of menhaden during that time was quite stable, the cause of fluctuations for both these forage fish may be environmentally driven.

Winter flounder trends largely increased between 1990 and 2003, declined through the mid-2000s, and exhibited another peak between 2011 and 2013 (Figure 17). Although winter flounder are not frequently caught commercially in the ASIS area, the Maryland coastal bays trawl survey trends correspond almost exactly with Maryland-wide trends in harvest and estimated trends in spawning stock biomass coastwide, indicating the fishery may track availability of this resource due to bycatch allowance possession rules (Northeast Fisheries Science Center 2011).

Figure 17. Annual geometric mean catch per tow for primary species caught by the Maryland Coastal Bays Beach Seine Survey in Sinepuxent and Chincoteague Bays, 1989-2015.



MDNR Coastal Bays Shellfish Survey

MDNR has conducted a fishery-independent hard clam dredge survey in the Maryland Coastal Bays from 1993 to present. A steady decline in hard clams was observed from 2000 to 2010 (Figure 18). Following the Maryland ban on mechanical dredging in 2008, commercial harvest of hard clams was reduced to minimal levels. During the first few years following the dredge ban, hard clam densities in Chincoteague Bay continued to decline, then began increasing to levels observed in the mid-1990s. Recent density of hard clams in Chincoteague Bay remains at approximately 20% of densities observed in the survey of 1953 (MDNR 2016). However, in Sinepuxent Bay, hard clam density has doubled since 2012, and has achieved over 70% of the density observed in 1953.

Figure 18. Annual hard clam densities estimated by the MDNR Coastal Bays Shellfish Survey, 1993-2015, for Chincoteague Bay (top) and Sinepuxent Bay (bottom). Vertical red bar from 1953 reflects historical reference density and the dashed red bar indicates enactment of the hydraulic dredge ban in September 2008. Figure courtesy MDNR (2016).

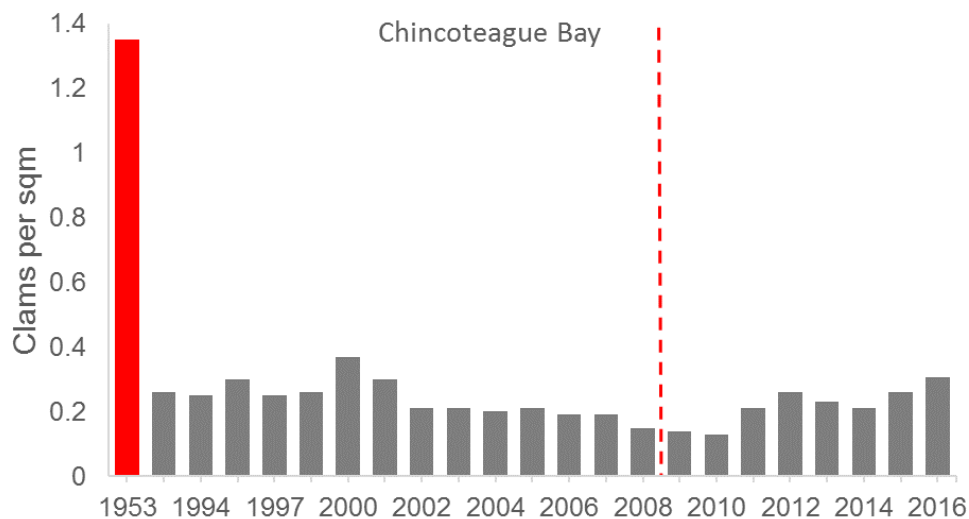
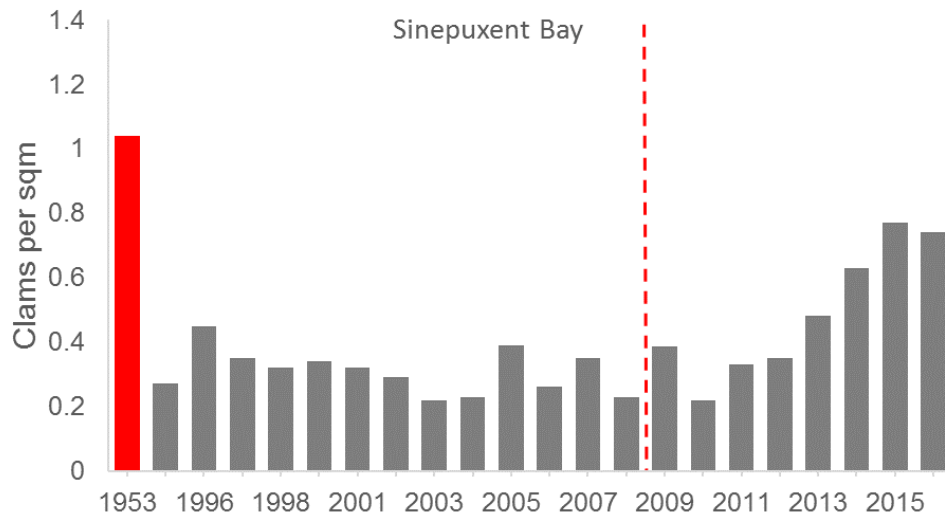


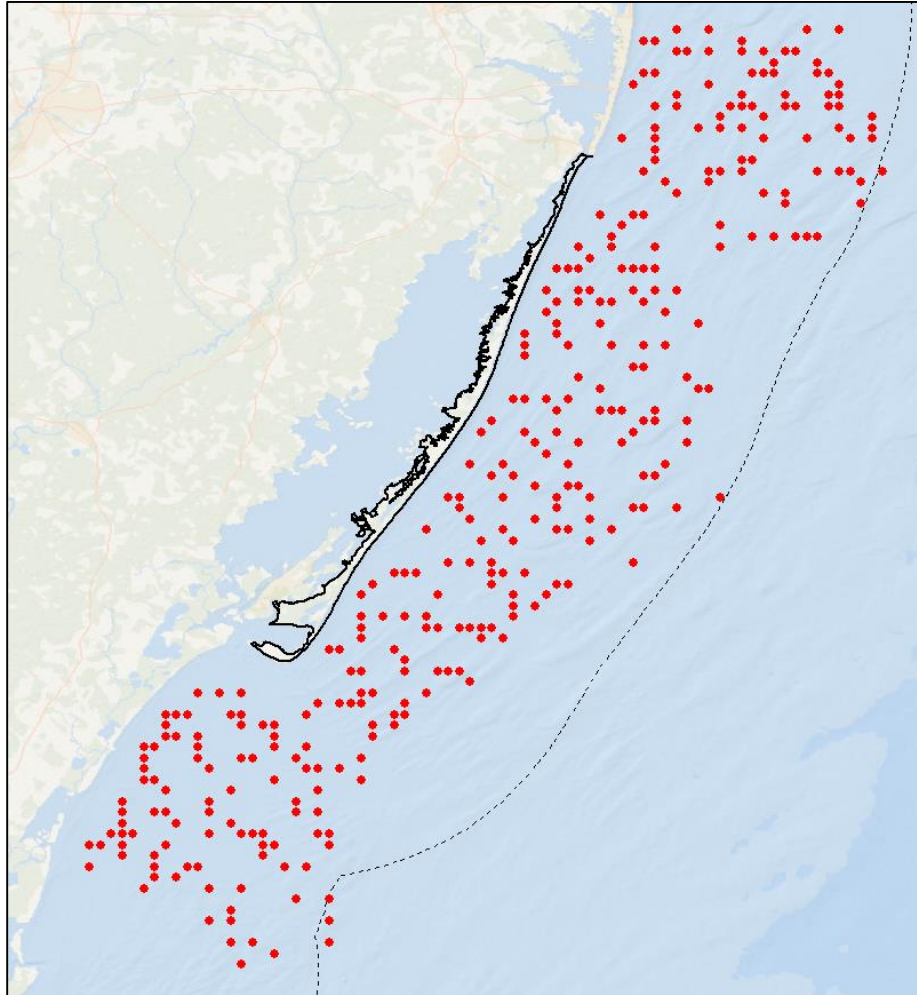
Figure 18 (cont'd).



NorthEast Area Monitoring and Assessment Program (NEAMAP)

NEAMAP is a multispecies bottom trawl survey operated in spring and fall by the Virginia Institute of Marine Science (VIMS). Survey data span from fall of 2007 to the present and contain samples from nearshore ocean waters from depths of 20 to 120m. To explore potential effects of commercial fishing activities in the nearshore oceanic portion of the ASIS area, we summarized trends in geometric mean catch per tow by season for the primary species caught by NEAMAP at 386 sampling stations located between Metompkin Bay and the Maryland/Delaware border (Figure 19). Geometric means were calculated as described above (see MDNR Coastal Bays Trawl and Beach Seine Survey).

Figure 19. NEAMAP survey site locations sampled in the ASIS area, fall 2007 to spring 2016. Solid black indicates the ASIS 0.5-mile maritime boundary. Gray line indicates the boundary between Maryland and Virginia coastal bay waters. Dashed black line denotes the 12 nm territorial sea boundary defining the extent of state waters



Mean catch per tow for blue crabs by NEAMAP was low because blue crabs prefer depths of <40m and thus are not targeted well by NEAMAP. However, relatively high NEAMAP mean catch per tow of blue crabs in 2015 (Figure 20) does correspond with high harvest for both Maryland and Virginia in that same year (Figure 2, Figure 8).

Atlantic croaker and spot catches by NEAMAP exhibited interannual variability, but no apparent trend. Bluefish and knobbed whelk (conch) exhibited interannual variability that did not correspond with harvest. Similar to coastwide trends (ASMFC 2016), the weakfish fall NEAMAP index declined across the time series.

Figure 20. Annual geometric mean catch per tow by season in the NEAMAP survey for primary commercially-caught species from stations located in the ASIS area, fall 2007-spring 2016.

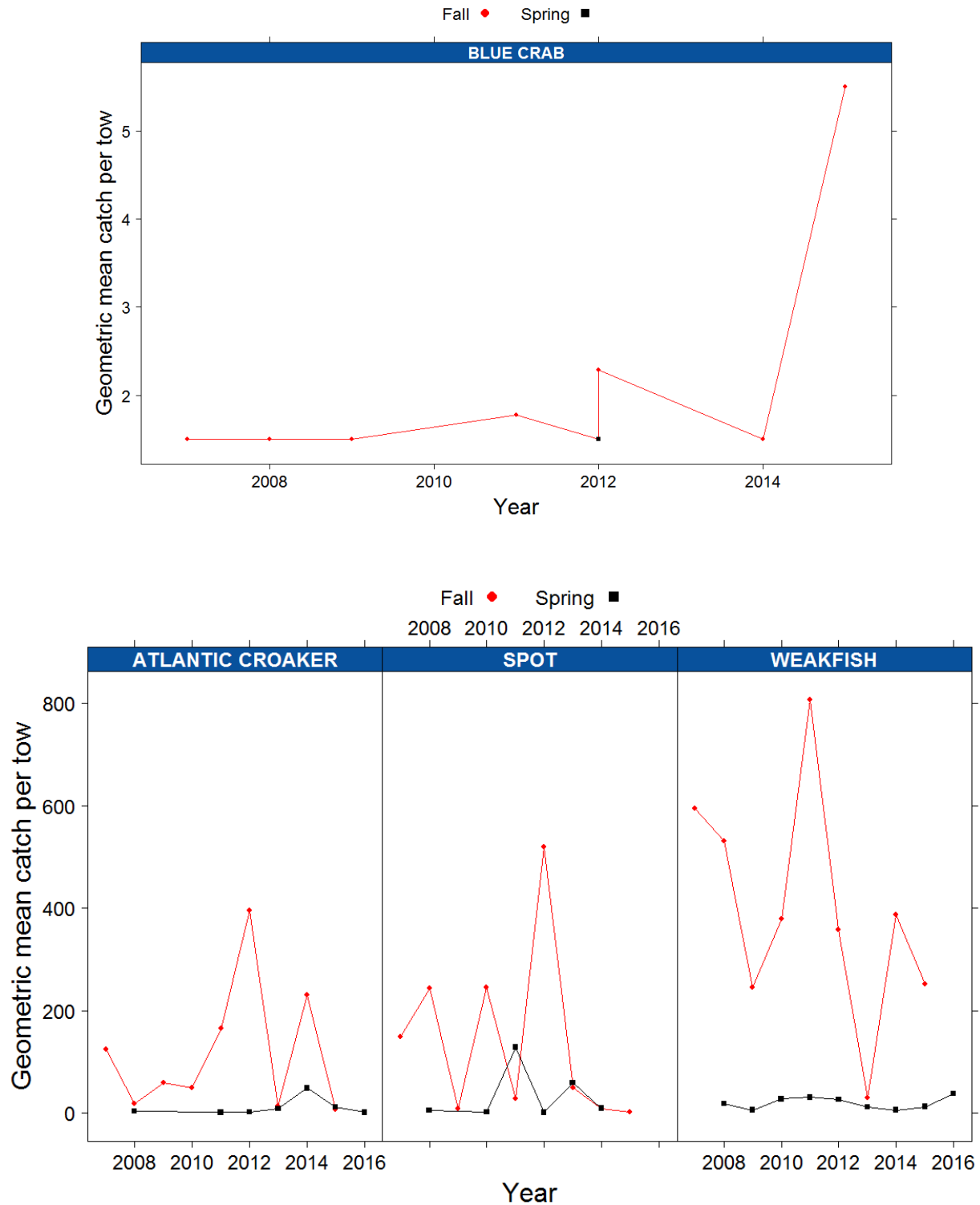
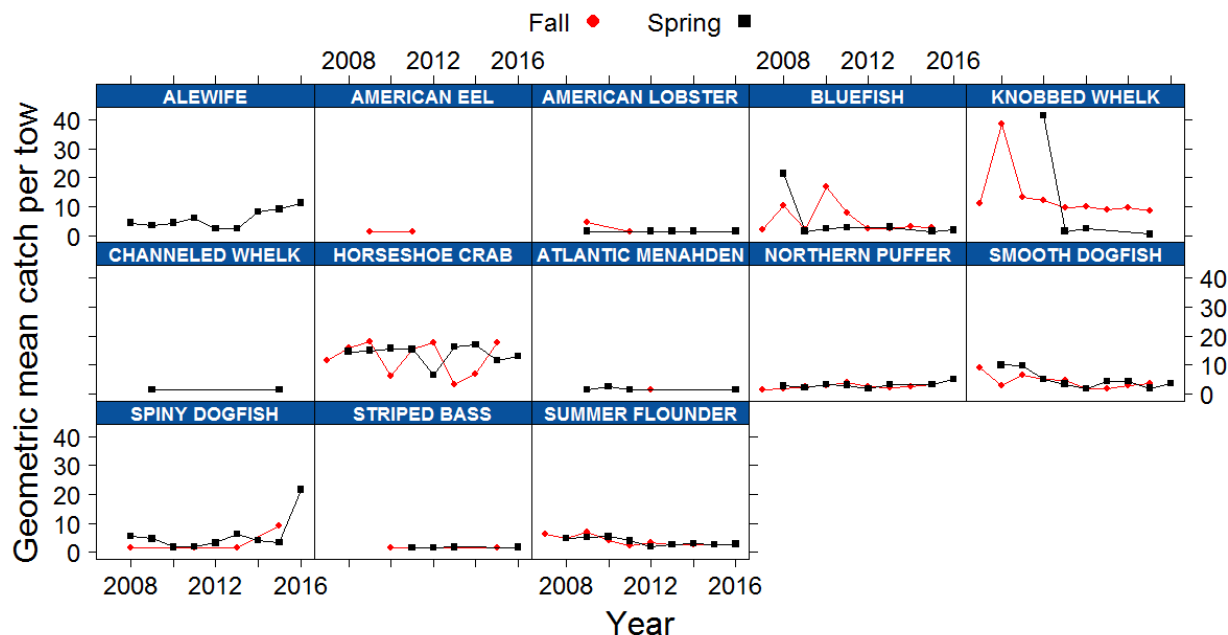


Figure 20 (cont'd).



Increasing recent NEAMAP catches of alewife in the ASIS area potentially represent a positive stock response to closure of the Maryland fishery in 2011 and the Virginia fishery in 2012 (Figure 20).

Horseshoe crab exhibited no trends in the NEAMAP survey despite spikes in local harvest in 2012-2013 in Maryland and 2009-2011 in Virginia; these results reflect the 2013 stock assessment update (ASMFC 2013) which indicated population trends in this region are stable (see also Virginia Tech Horseshoe Crab Trawl Survey).

Smooth dogfish exhibited a downward trend in both NEAMAP catch per tow and Maryland harvest; however, there is no assessment of this stock that can be used to place regional harvest and survey trends in a stock-wide perspective.

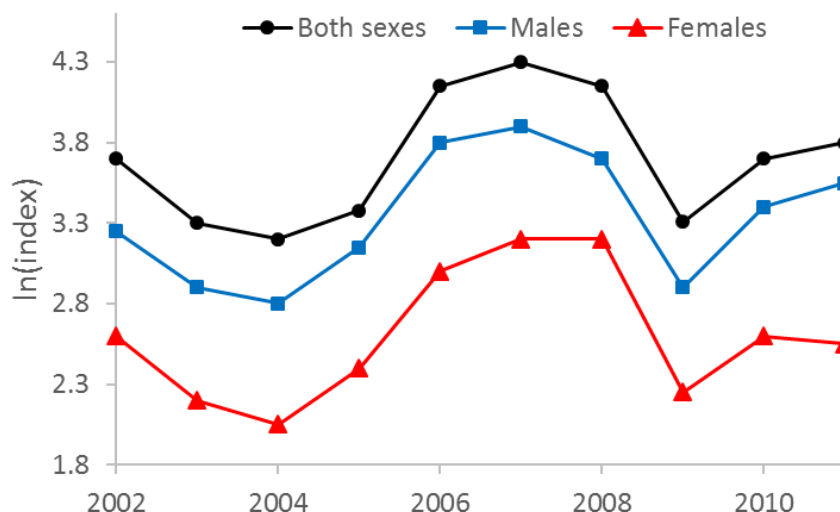
Other species commonly caught by commercial fisheries in the ASIS area (e.g. menhaden, striped bass) were rarely caught by NEAMAP in the ASIS area. Those that were caught on occasion did not exhibit much trend across the available time series. Although several other species not targeted by commercial fisheries in the ASIS area were caught by NEAMAP in high abundance (e.g. longfin inshore squid, striped and bay anchovies, butterfish, scup, silver perch), none had known associations with ASIS area fisheries (e.g. bycatch issues).

Virginia Tech Horseshoe Crab Trawl Survey

The ASIS area is included within the “Delaware Bay” horseshoe crab management area surveyed by the Virginia Tech horseshoe crab trawl survey which was conducted annually from 2002 to 2011. During 2006-2008, the survey index of abundance

displayed a peak for both sexes then returned to levels observed in the early 2000s (Figure 21). Horseshoe crabs in this region of the stock's coastwide range has been declared stable (ASMFC 2013).

Figure 21. Virginia Tech Trawl index of horseshoe crab abundance by sex for the Delaware Bay region, 2002-2011 (final year of the survey).



Although demand has increased for horseshoe crabs as bait for the whelk (conch) fishery, horseshoe crab index trends (Figure 20, Figure 21) across the Maryland and Virginia Coastal Bays region have not declined in recent years. Potentially favorable spawning conditions and regulation changes (e.g., sex-specific harvest restrictions, spawning season harvest restrictions, biomedical catch requirements that crabs be returned to area caught) may be contributing to relatively stable trends.

Habitat indicators

Benthic macroinvertebrate survey

We analyzed recent trends in benthic macroinvertebrates in the ASIS area using all available years of the National Aquatic Resource Surveys (Environmental Protection Agency 2016) at sites in Sinepuxent, Chincoteague, and Newport Bays spanning 1999-2001, 2005-2006, and 2010. Benthic invertebrates sampled include many worms, mollusks, crustaceans and other invertebrates found on bottom substrates, some of which are indicators of habitat quality because they are pollution-sensitive or responsive to excessive turbidity in coastal ecosystems.

For survey years prior to 2010, 32 sites located within the Maryland and Virginia portion of Chincoteague Bay, Sinepuxent Bay, and lower Newport Bay were selected for analysis. In 2010, two sites in the ASIS area were sampled and included in analysis, both from the Maryland portion of Chincoteague Bay. Only orders caught in multiple years were included in this analysis (Table 16). A wide range of taxa were observed, indicating relatively low degradation (Wazniak et al. 2004). Few trends were apparent in mean catch by order across the time series with the exception of Amphipods which

exhibited a steady decline due in part to a large catch of *Ampelisca abdita* at multiple sites in 2000 (Figure 22). Absence of pollution-tolerant species (e.g., Tubificidae, detritus worms in the order Naididae) may indicate low levels of nutrient enrichment in the ASIS area where the benthos was sampled.

Figure 22. Trends in mean catch per site of benthic macroinvertebrates by order from the National Aquatic Resource Surveys, 1999-2001, 2005-2006, and 2010.

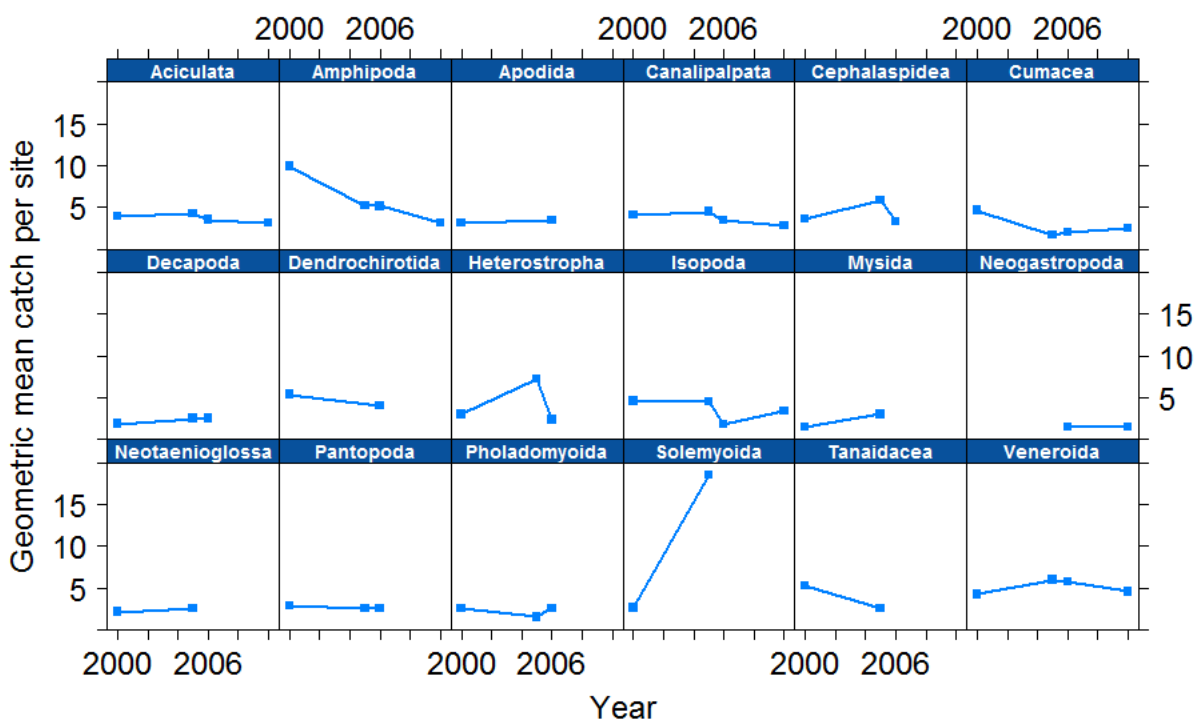


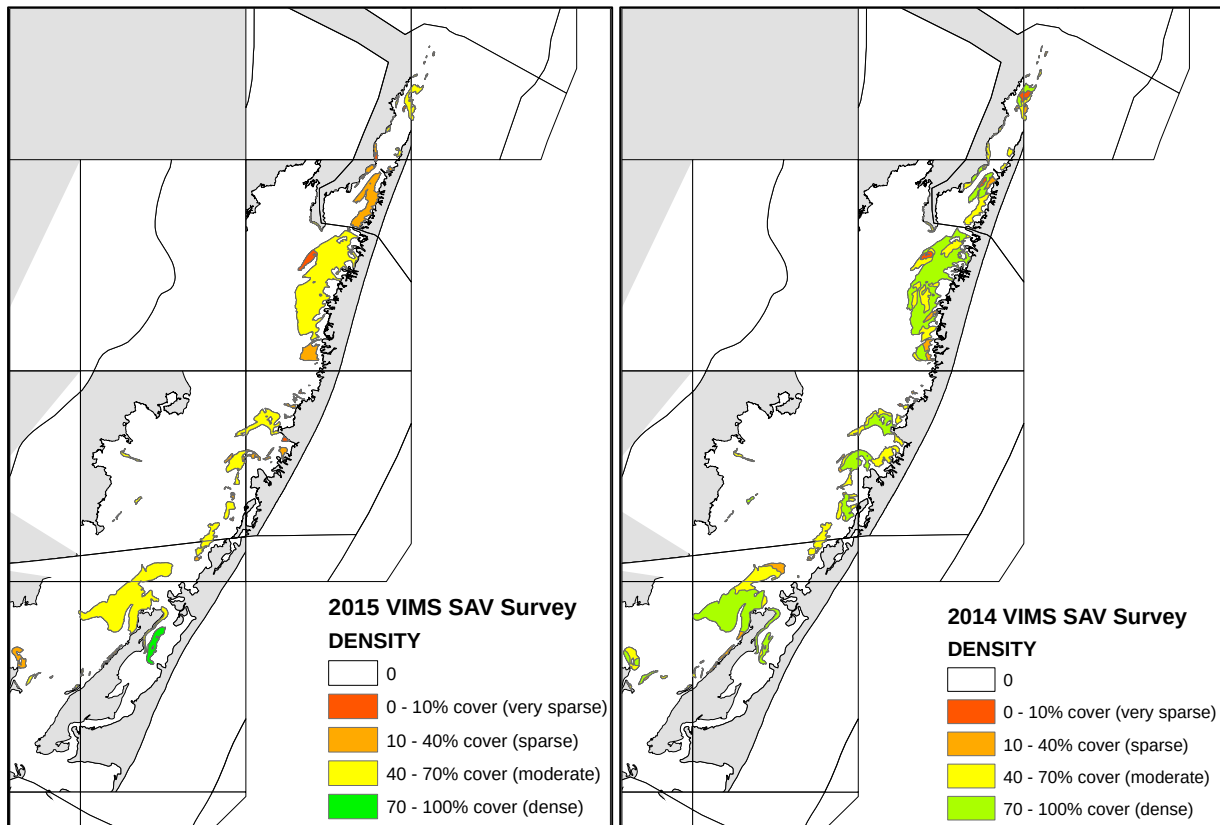
Table 16. Short description of orders included in analysis of National Aquatic Resource Survey of benthic macroinvertebrates.

Order	Description
Aciculata	Polychaete worms found in marine and brackish water
Amphipoda	Amphipods, crustaceans with no carapace
Apodida	Sea cucumbers found in littoral to deep-sea habitats
Canalipalpata	Fan-head polychaete worms
Cephalaspidea	Headshield slugs and bubble snails
Cumacea	Hooded/comma shrimp
Decapoda	Crabs, lobsters, and shrimp
Dendrochirotrida	Sea cucumbers with branched tentacles
Heterostrophia	Sea snails
Isopoda	Aquatic woodlice and relatives
Mysida	Opossum shrimps
Neotaenioglossa	Sea snails
Pantopoda	Sea spiders
Pholadomyoida	Saltwater clams, marine bivalve molluscs
Solemyoida	Small marine bivalves
Tanaidacea	Shrimp-like crustaceans
Veneroida	Bivalve molluscs
Neogastropoda	Sea snails

Submerged aquatic vegetation

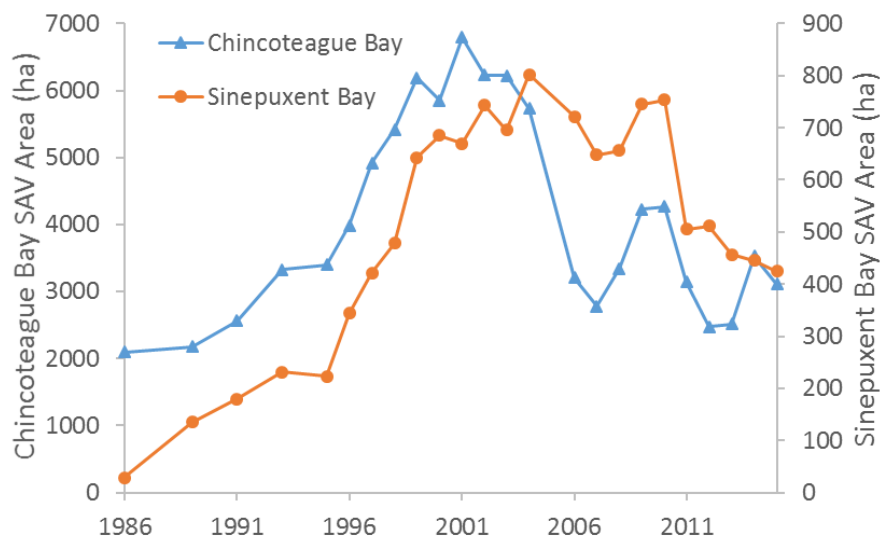
Submerged aquatic vegetation (SAV) serves as critical fish and shellfish habitat in coastal bays (Beck et al. 2001, Kritzer et al. 2016). In the ASIS area, eel grass (*Zostera marina*) is the primary SAV species observed followed by widgeon grass (*Ruppia maritima*) (Barker et al. 2014). The areal extent of SAV in the Coastal Bays region has been mapped annually since 1986 by VIMS using multispectral digital imagery supplemented with black and white aerial photographs in some areas when necessary (Orth et al. 2015). The density and extent of SAV bed varies annually; however, the western shore of ASIS supports the highest concentration of SAV beds in the region, providing critical habitat for local fish and shellfish (Figure 23).

Figure 23. Density of submerged aquatic vegetation in the ASIS area in 2015 and 2014 as estimated by the [VIMS SAV Survey](#).



The total area of SAV exhibited a marked decline in Chincoteague Bay between 2000 and 2007, then stabilized at lower levels similar to those observed in the early 1990s (Figure 24). The area of SAV in Sinepuxent Bay remained stable from the late 1990s through to 2010 then declined sharply.

Figure 24. Trends in area of submerged aquatic vegetation (ha) in Chincoteague and Sinepuxent Bays, 1986-2015 (Data source: [VIMS SAV Survey](#)).



Historically, water quality in Sinepuxent and Chincoteague Bays has far surpassed more developed, northerly regions of the coastal bays, and Sinepuxent and Chincoteague Bays were able to support extensive SAV habitat (Wazniak et al. 2007). Relatively low turbidity and nutrient loads helped prevent algal blooms which create low light conditions that inhibit SAV photosynthesis (Boynton et al. 1996, Wazniak et al. 2004). Recent declines in ASIS area SAV have been attributed to a combination of degrading water quality conditions and high water temperature and turbidity (Lambert et al. 2009, Orth et al. 2015).

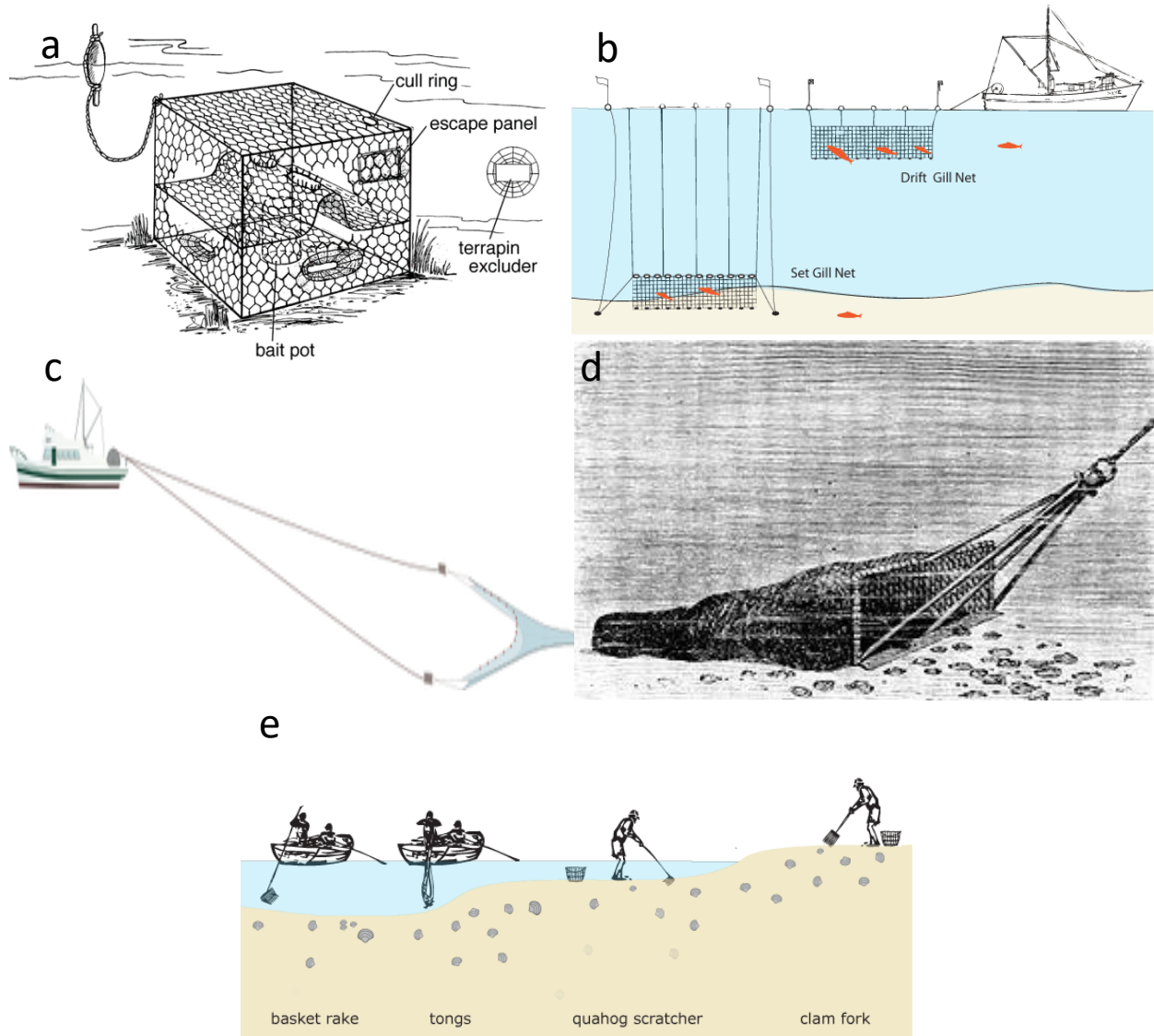
Potential ecological impacts

The potential ecological impacts of commercial fishing activities on the ASIS marine ecosystem depend on the type of gear employed, fishery effort, and the type of aquatic habitats in which fishing occurs. Below we discuss the primary potential ecological impacts of both wild fisheries and aquaculture prosecuted in the ASIS area. Wild fisheries are categorized by gear type, either passive (e.g., traps/pots, pound nets, fyke nets) or active gear (e.g., trawl, dredge) given differences in their likely effects on different types of local aquatic habitats. Potential ecological impacts of the Virginia horseshoe crab fishery on local wildlife are discussed as well.

Wild fisheries – passive gears

Traps/pots: The commercial blue crab fishery is by far the largest fishery in the ASIS area in terms of pounds landed and economic value. Crab traps/pots typically used in the coastal bays are vinyl-coated wire or plastic square cages marked with floating buoys (Figure 25). Traps/pots may be baited and include a cull ring and escape panel to allow sublegal crabs and other bycatch to exit as well as an excluder device to reduce terrapin bycatch mortality.

Figure 25. Examples of commercial fishery gear typically used in the ASIS area. a) crab trap/pot (image courtesy Virginia Institute of Marine Science), b) set and drift gill nets (image courtesy Monterey Fish Market), c) otter trawl (image courtesy [Integration and Application Network](#), UMCES), d) oyster dredge, e) rakes and tongs (image courtesy Monterey Fish Market).



The impact of the crab trap/pot fishery on seagrass habitats such as those found in the ASIS area have been shown to be temporary; seagrass can rebound from damage due to trap/pot placement if gear is removed within a matter of weeks (Barnette 2001, Uhrin et al. 2005, Uhrin and Schellinger 2011). However, permanent damage can be done to SAV if traps/pots are left in place for an extended period and SAV becomes buried (ASMFC 2000).

Another potential ecological impact of the blue crab trap/pot fishery on the ASIS ecosystem is the effect of derelict fishing gear and the subsequent “ghost fishing” of blue crabs and other species that occurs when gear that has been abandoned continues to fish (Arthur et al. 2014, Scheld et al. 2016). Crab pots and traps are typically constructed of vinyl-coated wire or plastic that may take up to 10 or more years to degrade to the point that they stop ghost fishing (Stevens 2000, Bilkovic et al. 2014). Recent studies in the Virginia portion of the Chesapeake Bay have estimated blue crab ghost pot loss rates to be 12.7% in creeks, 19.7% in the mainstem and main tributaries, and 12-20% baywide (Bilkovic et al. 2016); other studies have estimated loss rates as high as 30% (Havens et al. 2008). Derelict trap harvest was estimated to be 5% of the commercial catch (Bilkovic et al. 2016). Studies across Virginia’s portion of Chesapeake Bay and the Coastal Bays found that derelict blue crab traps primarily caught blue crabs, but also caught other non-target species such as striped bass, Atlantic croaker, oyster toadfish (*Opsanus tau*), spot, black sea bass, diamondback terrapins (*Malaclemys terrapin*), and ducks (Havens et al. 2008, Havens et al. 2011). More than half of blue crabs caught in ghost traps in Virginia were found to be mature females of which 10% were egg-bearing (Havens et al. 2011). Fish, whelk, and eel trap/pot usage in the ASIS area is much smaller in magnitude than that of blue crab traps/pots, but can have similar ghost fishing effects (Radzio and Roosenburg 2003, Gilman 2009, Bilkovic et al. 2014).

Additional bycatch mortality of wildlife and fish may occur in the trap/pot fisheries if animals become entangled in buoy lines. Diamondback terrapin mortality may also occur if bycatch reduction devices required by both Maryland and Virginia are not installed (Bilkovic et al. 2016).

Gill nets: The second largest passive wild fishery gear employed in the ASIS area is gill nets. Gill nets are mesh nets that are either anchored to the bottom or allowed to drift (Figure 25). All nets are marked by floating buoys. The size of the mesh used in a given area is subject to state regulations, determined by the species targeted, and can result in different types and amounts of bycatch.

Impacts to SAV and benthos from gill nets are thought to be minimal (ASMFC 2000, Barnette 2001); however, lost and abandoned nets can ghost fish and entangle seabirds and other wildlife (Barnette 2001, Gilardi et al. 2010). Given the non-specificity of gill net gear, bycatch of non-target species is the most common gear conflict, especially when mesh size is small (ASMFC 2000). The extent to which bycatch of finfish and shellfish species affects local stock trends is unknown. Of particular concern is the potential for incidental take of depleted (e.g., American shad/alewife) and

protected species (e.g., sea turtles and Atlantic sturgeon) which can be caught in gill nets (Gilman 2009, Hilton et al. 2015). In the absence of coastal fishery bycatch surveys, the magnitude of non-target bycatch and protected species incidental take in the bays portion of the ASIS area is unknown. Oceanside of ASIS, gillnet fisheries operating largely outside ASIS waters are a source of sea turtle and Atlantic sturgeon bycatch (National Marine Fisheries Service and Atlantic States Marine Fisheries Commission 2013). Sea turtle stranding records from 2004-2013 along the ASIS shoreline primarily include gillnet entanglements of juvenile loggerheads (*Caretta caretta*) in spring and summer (Barco and Swingle 2014). Kemp's Ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), and leatherback (*Dermochelys coriacea*) sea turtle strandings have also reported.

Wild fisheries – active gears

Trawls and dredges: Otter trawls and dredges (e.g., crab dredges) are nets or metal buckets/frames, respectively, which are dragged along the sea bottom for variable amounts of time before the catch is hauled onboard for sorting and storage (Figure 25).

Determining the exact impacts of active gears on bottom habitats depends on many factors, including the location of fishing activity, gear used, fishing frequency and duration, and type of bottom habitat. Otter trawling is prohibited in ASIS waters and, more broadly, in Virginia state waters and the state waters of Maryland up to 1 mile offshore. These regulations effectively limit the ecological effects of trawling to Maryland waters more than 1 mile offshore (Table 7, Table 8). Given the fact that otter trawling occurs outside ASIS waters, local ecosystem effects are likely to be limited (DeAlteris et al. 1999, Collie et al. 2000, Kaiser et al. 2002). However, lost or intentionally discarded nets that drift into ASIS waters could continue to ghost fish, causing unintended mortality (ASMFC 2008). These gears are referred to as derelict fishing gears, and as they are made of synthetic material may persist for a long time in the marine environment. An ecological impact of potential concern to ASIS is the incidental catch of protected species such as marine mammals, sea turtles, and Atlantic sturgeon in otter trawls (ASMFC 2008); however, the magnitude of total ecological impacts on protected species by otter trawls in the ASIS area may not be great given gear modifications such as bycatch excluder devices have greatly reduced bycatch mortality (Hall et al. 2000) and survival rate estimates for Atlantic sturgeon caught in otter trawls has been estimated to be high (Beardsall et al. 2013). Ghost fishing of lost nets is another potential ecological impact that has not been well documented (ASMFC 2008).

Dredges are a mobile gear, similar to trawling, which have the potential to impact local ecosystems depending on habitat and type of dredge. Historical widespread damage to seagrass beds in the ASIS area caused by hydraulic clam dredges and modified oyster dredges led to restrictions on the use of these gears to protect local species of SAV which are highly sensitive to the direct damage and increased turbidity (University of Maryland Natural Resources Institute 1970). However, conventional dredging for clams and horseshoe crabs still occurs in Virginia waters in the ASIS area. Horseshoe crab dredging is limited to waters east of the COLREGS line (oceanic waters outside the coastal bays). Dredging in Maryland in the last decade targets sea scallops and occurs

oceanside of ASIS. Similar to otter trawling, the ecological effects of dredging depend on bottom type, complexity, natural disturbance regimes, and magnitude of fishing (Collie et al. 2000). Dredging directly in sand or mud bottom habitats may cause short-term disturbance to benthic fauna and increased turbidity (Auster 1998, ASMFC 2000). Dredging repeatedly or directly over sensitive bottom habitats (such as SAV beds or oyster reefs) can cause long-term alteration and damage (DeAlteris 1988, DeAlteris et al. 1999, Collie et al. 2000). Chapter 14 of Jennings et al. (2009) provides a comprehensive review of the potential effects of bottom gear on a wide array of habitats.

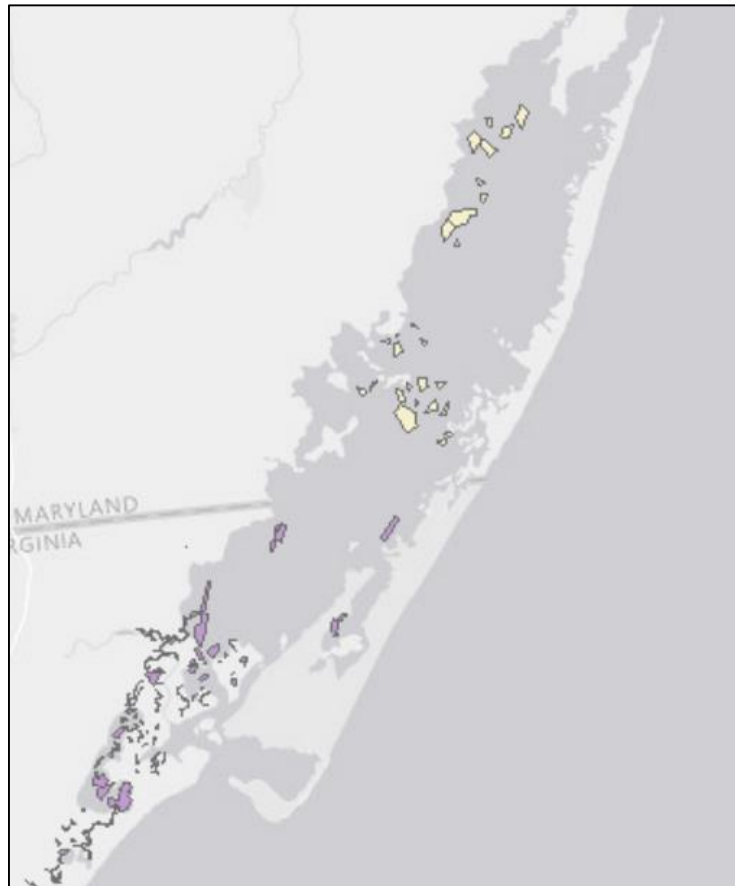
Other potential long-term impacts of dredging near sensitive ASIS habitats include prevention of the recovery of native bay scallop (*Argopectin irradians*), which require eelgrass habitat (University of Maryland Natural Resources Institute 1970, Peterson et al. 1988, Wazniak et al. 2004, Orth et al. 2006). However, it is unlikely that dredging activities in the ocean have an effect in the coastal bays.

Rakes and tongs: Hand-operated gears include long-handled metal rakes and tongs used to grab bivalves such as oysters and clams off reefs or out of sandy bottom substrates (Figure 25).

Rakes and tongs used to harvest wild clams and oysters can impact local bottom habitats and reefs. Conventional rakes and bull rakes are used to harvest hard clams in Virginia waters of the ASIS area where the bulk of wild clamming occurs. Experimental studies have shown that bull rakes can cause temporary damage to SAV by removing >80% of shoots, roots and rhizomes (Peterson et al. 1988, ASMFC 2000). Immediately following raking experiments, seagrass biomass dropped by ~25% below controls; however, damage appeared to be temporary, and full recovery was observed within one year.

Wild harvest of oysters on public grounds in the coastal bays is currently conducted using tongs. Hand-operated tongs are among the least destructive commercial gear used to harvest oysters. Given most natural oyster reefs are located outside ASIS waters (Figure 26), impacts of wild oyster harvest on ASIS ecosystems are limited. However, continued harvest of already depleted wild oyster stocks in the coastal bays exacerbates the many existing problems facing oyster recovery (Beck et al. 2011).

Figure 26. Location of historical oyster reefs in Maryland (yellow polygons) and Virginia (purple polygons), courtesy [Center for Coastal Resources Management](#).



Hook and line: Hook and line commercial fishing in the ASIS area is targeted primarily at striped bass. Bycatch mortality of sublegal and non-target fish in hook and line fisheries varies widely and depends on a number of factors, including how deeply hooks are ingested, the type of hook used, and the species caught (Bartholomew and Bohnsack 2005, ASMFC 2008). Both active and lost/discarded gear can result in wildlife entanglements, injury, and mortality (NOAA Marine Debris Program 2014). Habitat impact of hook and line gear beyond that on coral reefs is largely unknown (Barnette 2001).

Aquaculture

Shellfish aquaculture in Maryland and Virginia has expanded rapidly in recent decades (Hudson and Murray 2016), providing enhanced economic development opportunity, especially in the Virginia portion of the coastal bays (Murray and Kirkley 2005). However, aquaculture may introduce new ecological changes and use conflicts with other natural resources and outdoor activities.

In the ASIS area, two primary methods of oyster aquaculture are employed, namely intensive culture, also called “off bottom” culture, and extensive culture, often called “on

bottom” or “spat-on-shell” culture (Hudson and Murray 2016). Intensive culture is aimed at the half-shell market and typically involves the growing of individual, hatchery-raised oysters in cages or bags sitting off the lease bottom. Floating cages and other methods of off-bottom rearing are utilized as well. Extensive culture is aimed at the shucking market and involves a combination of initial rearing in tanks followed by planting and harvesting off the lease bottom. Hard clam (quahog) aquaculture typically involves planting beds with hatchery-raised seed in mudflats and covering the bed with a net to avoid predation.

Compared to finfish aquaculture, clam and oyster aquaculture is thought to have relatively low ecological impact because shellfish filter feed existing phytoplankton and do not require external nutrient sources (Dumbauld et al. 2009, Forrest et al. 2009). In addition, shellfish aquaculture can ameliorate poor water quality by improving light penetration for seagrasses and enhancing removal of nitrogen (Newell 2004, Dumbauld et al. 2009, Kellogg et al. 2014). However, the extent to which aquaculture combats eutrophication varies based on a number of factors, including tidal exchange conditions, proximity to phytoplankton sources, residence time, and shellfish density (Dumbauld et al. 2009). Oyster denitrification rates can vary dramatically among sites and may not enhance water quality as much as restored reefs (Kellogg et al. 2013, Kellogg et al. 2014). Restoration of Eastern oyster reefs may have greater potential than aquaculture to reduce turbidity and facilitate ongoing efforts to restore seagrass (Newell and Koch 2004, Kellogg et al. 2014). Also, sediment deposition by aquacultured oysters may actually be higher in farmed areas if currents are not strong enough to redistribute fecal deposits (Cranford et al. 2006, Testa et al. 2015). As with oysters, aquaculture clam operations have been shown to result in either a net removal or a net addition of nitrogen depending on local ecosystem conditions (Murphy et al. 2016).

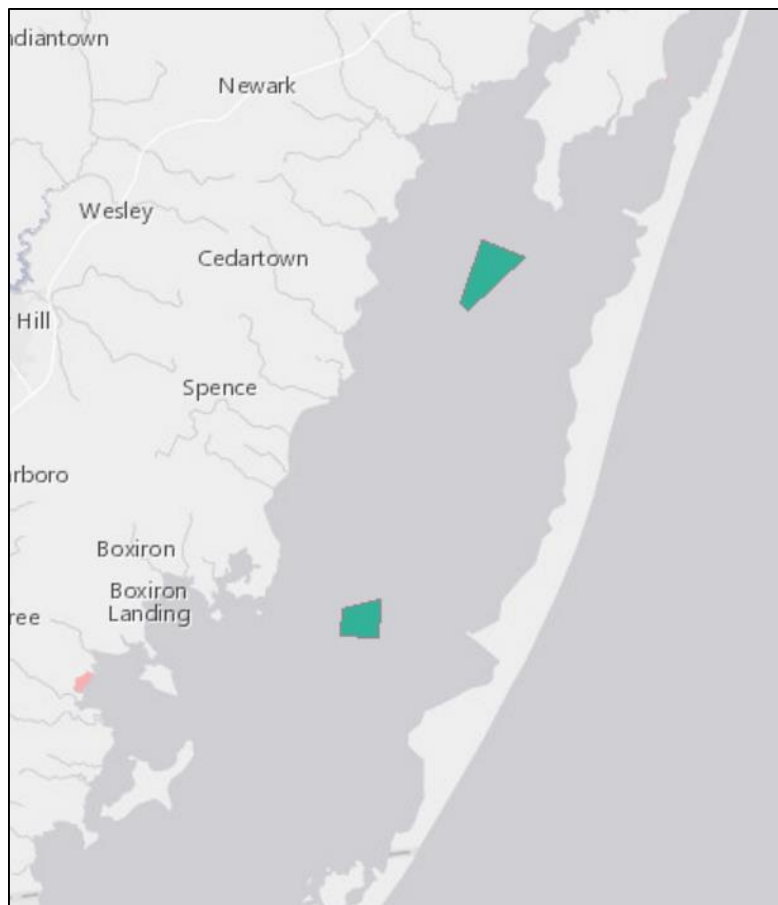
With the exception of use conflicts (discussed below), clam aquaculture is thought to have relatively little negative ecological impacts beyond that of higher macroalgae biomass which accumulates on net surfaces (Luckenbach et al. 2016). However, lost or improperly discarded predation exclusion nets used in clam aquaculture are an additional concern in the ASIS area because derelict nets can entangle fish and wildlife and become a boating hazard (Virginia Coastal Zone Management Program 2011).

An additional potential ecological impact of aquaculture is the risk of introduction and spread of pests (Forrest et al. 2009). Potential pests including non-native species, predators and parasites of native species, fouling species, toxic microalgae, and diseases organisms (Naylor et al. 2001). Impacts of pest introductions can be felt over a wide region and cause significant economic impacts as well as chronic damage to native populations and aquaculture stocks. For example, several species of non-native crayfish have been introduced and widely spread across Maryland freshwater systems as a result of aquaculture practices (Kilian et al. 2010).

Below we highlight localized aquaculture use conflicts in Maryland and Virginia that could impact the ASIS ecosystem.

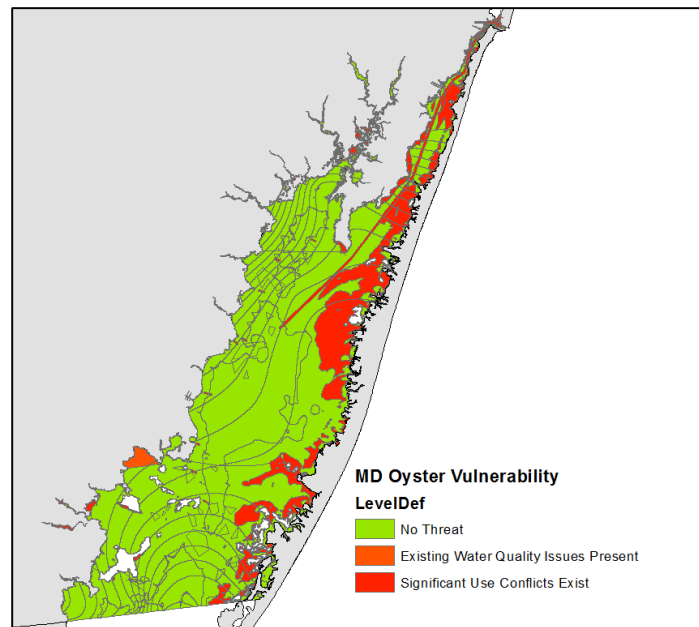
Maryland: Maryland aquaculture is currently concentrated in Chesapeake Bay, but is likely to continue expanding into the coastal bays in the near future. Preapproved leasing areas near ASIS are currently limited but oyster aquaculture development plans encourage expansion into the coastal bays (Figure 27). MDNR does not approve aquaculture leases within ASIS waters or within an “SAV Protection Zone”, which is defined as “an area of submerged aquatic vegetation as mapped in aerial surveys by the Virginia Institute of Marine Sciences in 1 or more of the 5 years preceding the designation of an Aquaculture Enterprise Zone or an application for a lease”. Given these restrictions, the ecological impacts of Maryland aquaculture to ASIS habitats is likely to remain limited to disease and pest introductions, genetic introductions, and water quality changes both positive and negative.

Figure 27. Aquaculture enterprise zones (pink) and pre-approved aquaculture lease sites (green) in Maryland waters near ASIS ([Maryland Aquaculture Siting Tool](#)).



Models of oyster aquaculture vulnerability highlight ASIS waters as being at high risk for significant use conflicts largely due to a high concentration of SAV along ASIS's northwestern shore (Figure 28). Should Maryland's aquaculture lease restrictions be lifted in the future, some of the ecological implications discussed below for aquaculture practices in Virginia are likely to apply.

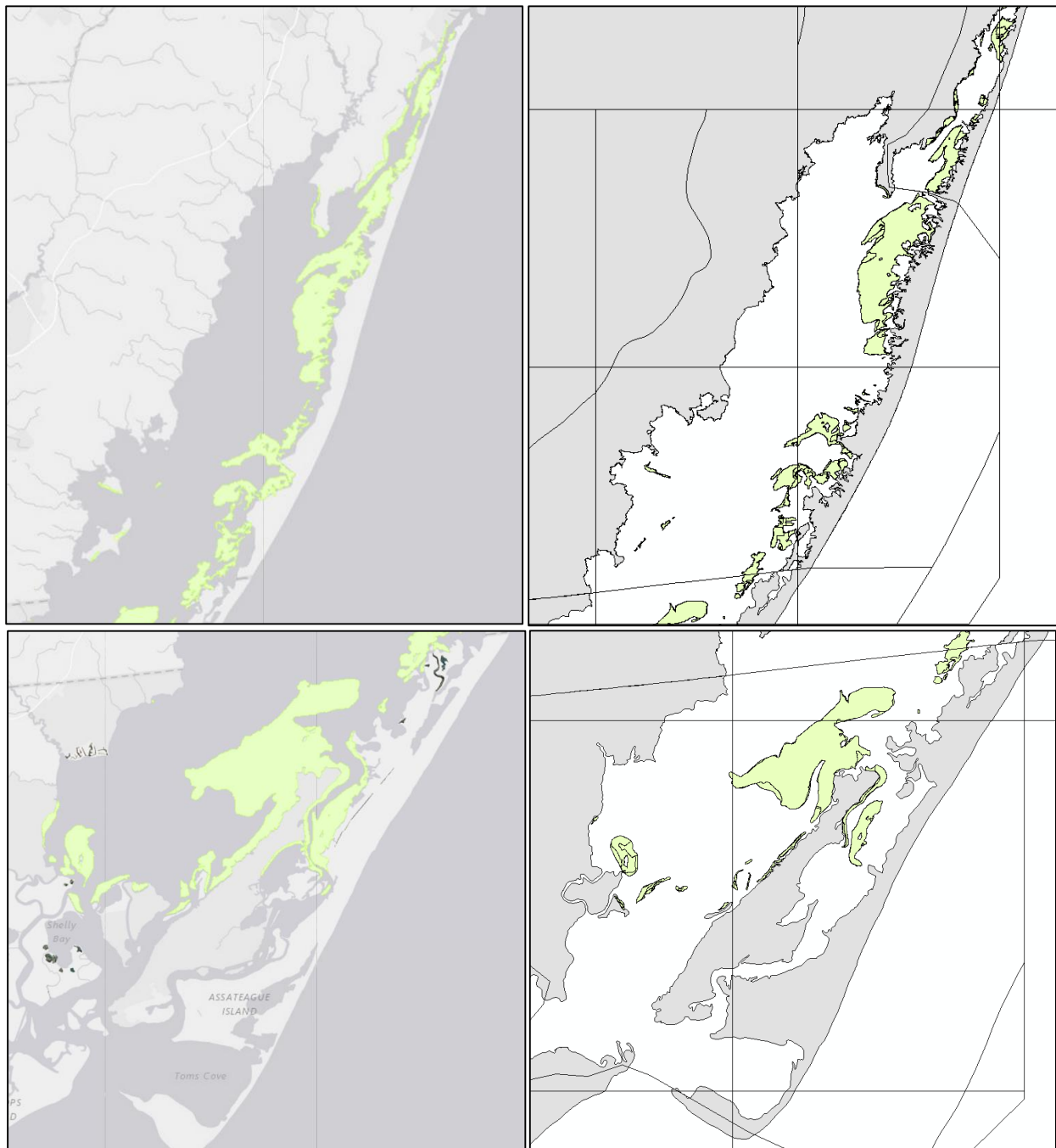
Figure 28. Potential conflicts between potential oyster aquaculture activities and either water quality or existing uses as of June 2012 ([Center for Coastal Resources Management](#)).



Virginia: The hatchery-based aquaculture industry for hard clam (quahog) and oysters has grown rapidly in the last few decades such that Virginia is now the primary producer of aquacultured hard clam in the US and of Eastern oyster on the US East Coast (Hudson and Murray 2016). A large proportion of aquaculture leases in the ASIS area can be found along the western shore of ASIS, including Toms Cove (Figure 14, Figure 30).

In areas where SAV is absent, aquaculture can enhance local fish habitat and species diversity above non-vegetated areas, whereas the response of water birds appears to be species and region-specific (Dealteris et al. 2004, Dumbauld et al. 2009, Forrest et al. 2009). However, placing oyster aquaculture farms in areas with existing SAV beds may lead to complete seagrass loss due to increased tidal erosion, shading, and pulse activity during planting, grading, and harvesting (Everett et al. 1995, Dumbauld et al. 2009). The extent of SAV coverage in the coastal bays varies over time (Fonseca and Uhrin 2009), but has been shrinking recently in the ASIS area due in part to water quality degradation and warm water temperatures (Figure 29). The majority of recent SAV in Virginia waters can be found in the SAV sanctuary (Figure 30). Expansion of aquaculture and continued wild harvest in Virginia could contribute to the prevention of SAV recovery in the ASIS area and thereby reduce available fish and shellfish nursery habitat in Chincoteague Bay. On the US West Coast, conflict between SAV recovery goals and aquaculture has led industry to abandon farms or switch to off-bottom culturing techniques that have lower SAV impacts (Dumbauld et al. 2009).

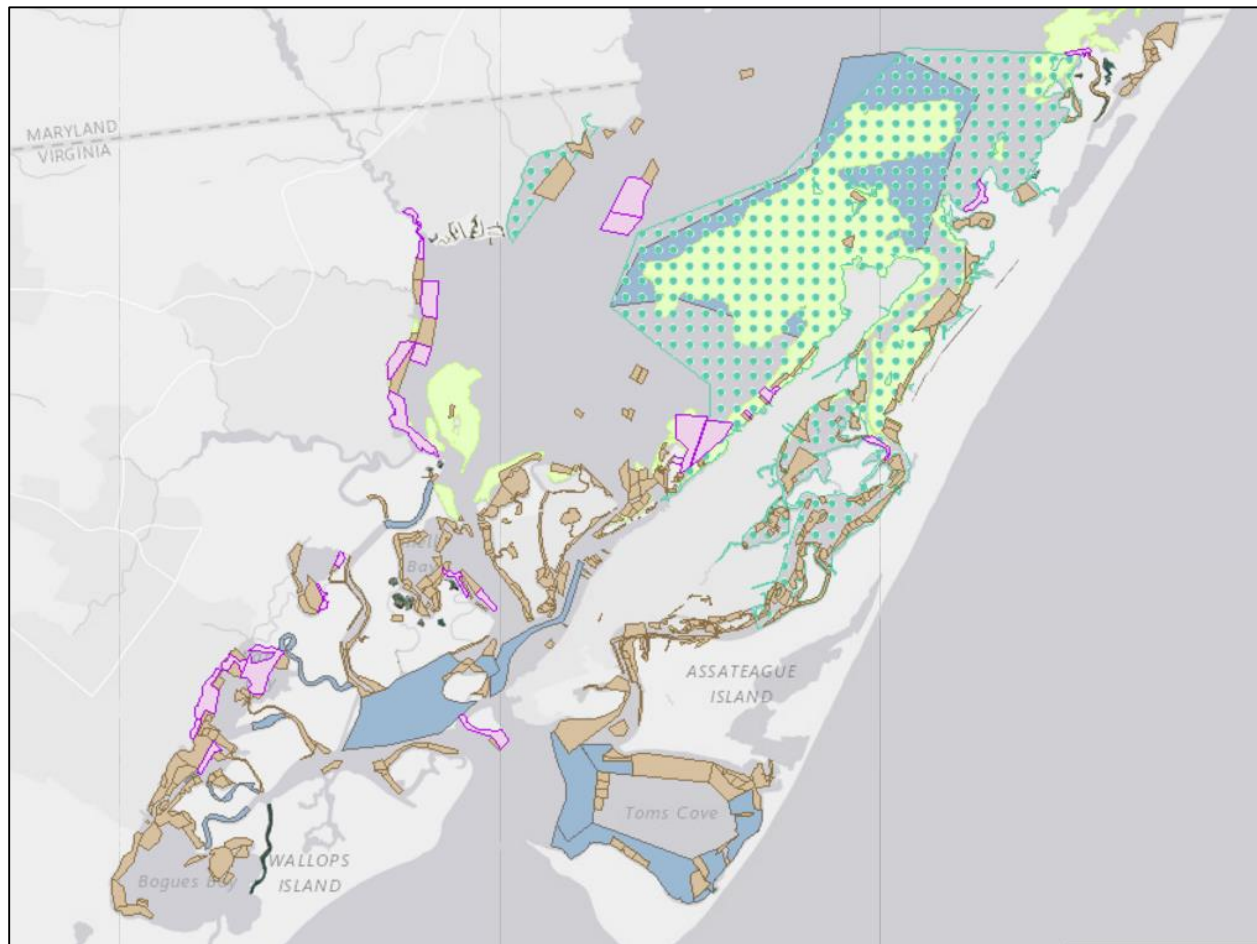
Figure 29. Extent of SAV in 2009-2013 (left) vs. 2014-2015 (right) in Maryland (top) and Virginia (bottom). Maps courtesy [Center for Coastal Resources Management](#).



Hard clam aquaculture operations often overlap with seagrass beds (Figure 30) which provide nursery habitat for finfish and shellfish (Orth et al. 2006). Of particular concern are use conflicts between plans to recover bay scallop and clam aquaculture. Bay scallops rely on eelgrass beds during early life stages (Orth et al. 2006, Fonseca and Uhrin 2009). The expansion of clam aquaculture could contribute to the prevention of

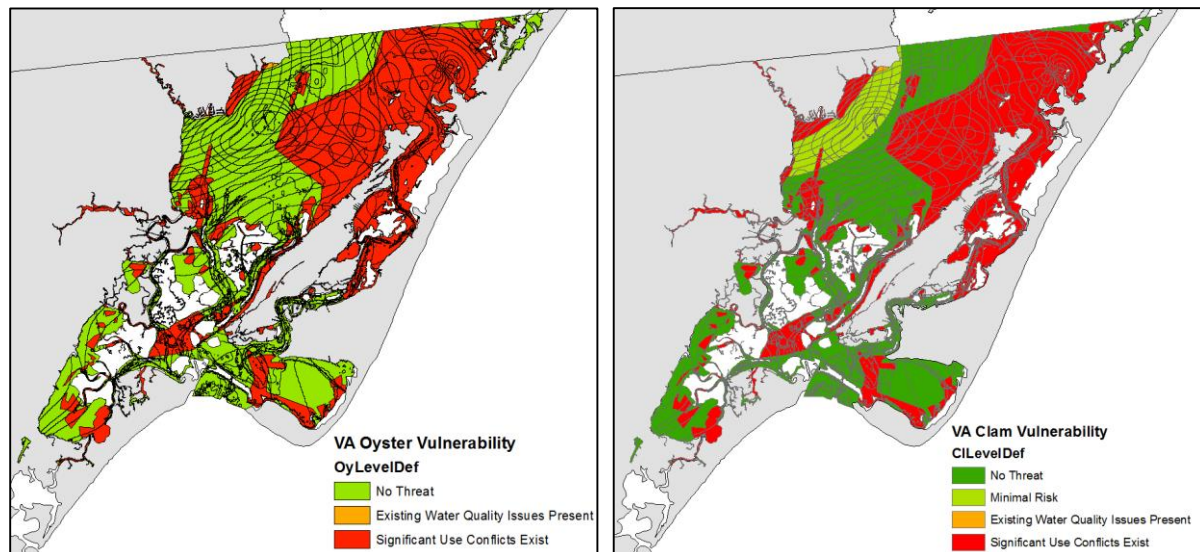
SAV recovery along ASIS's western shore, thereby inhibiting bay scallop restoration goals (Virginia Coastal Zone Management Program 2011).

Figure 30. Location of private aquaculture leases (brown polygons), lease applications (pink), public clamming grounds (blue), SAV sanctuary (green dots), and SAV habitat (yellow polygons) in the ASIS area. Map courtesy [Center for Coastal Resources Management](#).



As in Maryland, aquaculture vulnerability models highlight ASIS waters as being at high risk for significant use conflicts in Virginia largely due to a high concentration of SAV habitat and the SAV sanctuary located along ASIS's southwestern shore (Figure 31).

Figure 31. Potential use conflicts between oyster (left) and hard clam (right) aquaculture activities and either water quality or existing uses as of June 2012 ([Center for Coastal Resources Management](#)).



Horseshoe crab fishery

Horseshoe crab eggs provide food for migratory shorebirds in some stopover locations (Novcic et al. 2015). Increases in horseshoe crab harvest have been linked to decreasing red knot (*Calidrus canutus rufa*) population trends in Delaware Bay, a primary migration stopover site (Niles et al. 2009, Karpanty et al. 2011). In response, the Atlantic States Marine Fisheries Commission, the agency responsible for interstate management of horseshoe crab stocks, adopted an Adaptive Resource Management (ARM) Framework for setting horseshoe crab quotas in the Delaware Bay management region, which spans New Jersey, Delaware, Maryland, and Virginia (Millard et al. 2015). The ARM Framework incorporates both shorebird and horseshoe crab abundance levels to set optimized harvest levels for horseshoe crabs in the Delaware Bay management region (McGowan et al. 2015). However, the impacts of recent fishery management efforts on red knots which visit the ASIS area is not known. Recent diets studies indicate that red knots, which forage along alternative stopover sites such as Virginia's Eastern Shore (including the southern portion of Assateague Island), feed primarily on coquina clams (*Donax variabilis*) and crustaceans (Cohen et al. 2010). Without additional, long-term local diet and population monitoring studies for red knot and other shorebird species, it will be difficult to quantify the direct impact of the local horseshoe crab fishery on migratory bird foraging success in coastal Maryland/Virginia.

Potential impacts to the visitor experience

ASIS receives over 2 million visitors per year (Carruthers et al. 2011), many of whom engage in activities involving fisheries and wildlife (Eppley Institute for Parks & Public Lands 2007, MARCO 2012). Most ASIS visitors who have been surveyed expected to find clean beaches, wildlife, fresh air, clear views, and clean water (Eppley Institute for

Parks & Public Lands 2007). Over 90% of visitors surveyed indicated they would like to experience wildlife in natural setting, and 76% expressed an interest in experiencing scenic views. A small number of respondents also indicated that fishing activities occurring in the same area as swimming negatively impacted their visit; however, it is unclear if these fishing activities were recreational or commercial (Eppley Institute for Parks & Public Lands 2007).

The Mid-Atlantic Regional Council on the Ocean (MARCO) synthesized information on how the public uses coastal and ocean spaces and created a GIS layer of recreational activities through participatory workshops in 2012 (MARCO 2012). We summarized MARCO data included within the ASIS boundary and created a ranked list of primary recreational activities engaged in by visitors to ASIS (Table 17). Visitor activities that are most likely to be impacted by commercial fishing include general shore use, wildlife and scenic viewing, motorized boating, recreational fishing (shore, charter/party boat), SCUBA/snorkeling/diving, and recreational shellfish harvesting.

Table 17. Ranked list of top 20 recreational activities engaged in by public visitors to ASIS as identified by the Mid-Atlantic Regional Council on the Ocean (MARCO).

Recreational activities
Shore use
Wildlife viewing (charter)
Scenic viewing (charter)
Recreational kayaking
Paddling
Motorized boating
Recreational fishing (shore)
Historic cultural activities
Charter boat fishing
SCUBA/snorkeling/diving
Wildlife viewing (foot)
Hunting
Sailing
Surface water sports
Recreational shellfish harvesting
Swimming
Scenic viewing (foot)
Party boat fishing

Recreational fishing opportunities such as shore, private boat, and charter/party boat fishing are of particular interest to the public (MARCO 2012). When surveyed about their plans for visiting ASIS, approximately 17% of respondents said they planned to fish and 8% planned to go clamming (Eppley Institute for Parks & Public Lands 2007). The most common planned activity written in by respondents was crabbing. When asked

what they liked most about their trip to ASIS, 3% of visitors indicated crabbing was what they like most about visit and 1.3% indicated fishing. In a survey of oversand vehicle (OSV) and backcountry visitors, 74% of OSV participants indicated the main reason for their visit was to surf fish, and most of these respondents repeatedly visited ASIS throughout the year (Eppley Institute for Parks & Public Lands 2008). OSV survey respondents indicated that catching a lot of fish contributed to a quality experience (Eppley Institute for Parks & Public Lands 2008), a sentiment likely shared by other recreational anglers.

The ability to catch fish and shellfish contributes to some visitors' overall experience (Eppley Institute for Parks & Public Lands 2007, 2008). The most likely localized impacts of commercial fishing on the visitor experience are practices that affect sensitive aquatic finfish and shellfish habitats such as SAV such as dredging, raking, and aquaculture (DeAlteris et al. 1999, Barnette 2001, Orth et al. 2006). Crabs, clams, and juvenile finfish utilize seagrass habitat which can be disturbed by local fishing practices such as blue crab pots (extended placement and derelict), dredging, and pulse disturbances by aquaculturists (see also Potential ecological impacts). Juvenile finfish clearly utilize local SAV for nursery habitat (see MDNR Coastal Bays Trawl and Beach Seine Survey), which can be negatively affected by commercial fisheries. However, the extent to which local nurseries ultimately drive adult abundance in a given area is not well understood. Most finfish stocks of interest to recreational anglers such as striped bass, weakfish, black sea bass, and summer flounder are migratory and exhibit dynamics that are driven by large-scale coastal processes (Pincin et al. 2014). Given the nature of available commercial fisheries data and the regional scale at which fishing affects migratory stocks, it is difficult to determine exactly how local commercial fishing practices are contributing to the success of ASIS anglers.

Oyster aquaculture and industrial fishing operations may have a visual impact on the visitor experience given many visitors surveyed indicated "clear views" and "natural settings" were an important aspect of their experience (Eppley Institute for Parks & Public Lands 2007). If visitors consider ASIS waters "ocean wilderness", they may perceive commercial fishing as incompatible with preserving important wilderness attributes, values, and qualities (Barr and Kliskey 2014, Rossi et al. 2015). Off bottom gear such as floating cages, stakes, and other surface equipment could interrupt the natural view valued by most visitors surveyed (Eppley Institute for Parks & Public Lands 2007). Also, the experience of some motorized boaters may also be negatively impacted depending on the extent of aquaculture operations in popular boating areas and restrictions on accessing those areas (Virginia Coastal Zone Management Program 2011).

A potential benefit of local aquaculture could come in the form of denitrification and reduced turbidity of bayside waters (Newell and Koch 2004, Dumbauld et al. 2009). Approximately 68% of respondents to the 2007 visitor survey claimed that they expected to find clean water at ASIS. Depending on the density and local current conditions of aquaculture operations, improved water quality may result to the benefit of ASIS visitors (see also Aquaculture).

Another way in which the visitor experience could potentially be impacted by commercial finfish fisheries is through encounters with dead bycatch that washes ashore. Some harvest may be returned to the water by commercial fishers because the fish caught are too small or large relative to size limits, the quota has been reached, the species is not marketable, or the species is protected by state or federal legislation (Hall et al. 2000). A portion of the bycatch returned to the water does not survive and may float ashore where visitors encounter them on the beach or while swimming.

Dead bycatch may also result from recreational catch and release fishing conducted from shore, on private boats, or on “for hire” charter boats permitted to operate in ASIS waters (Commercial Use Authorization permit holders). A growing recreational fishing bycatch issue in the Chesapeake and Coastal Bays that may impact the visitor experience is recreational bowhunting and trophy fishing for cownose rays (*Rhinoptera bonasus*), which can result in discarding and washing ashore of unused dead fish (Virginia Sea Grant Program 2006, Chesapeake Bay Program 2015). Cownose rays are native species that primarily feeds on soft clams (*Mya arenaria*; Smith and Merriner 1985). However, rays are opportunistic feeders that can cause significant localized damage to valuable shellfish aquaculture operations (Virginia Sea Grant Program 2006, Chesapeake Bay Program 2015). Conflicts between cownose rays and commercial fisheries has contributed to directed, unregulated recreational fishing which could ultimately harm the stock given their life history suggests the species is highly susceptible to overexploitation (Virginia Sea Grant Program 2006, Fisher et al. 2013). The Maryland legislature recently considered a bill (HB0211) that would require MDNR to initiate a cownose ray Fishery Management Plan by December 31, 2018 and would prohibit cownose ray fishing contests in state waters until July 1, 2019; if this bill becomes law, the cownose ray FMP could impact the visitor experience, recreational fishing opportunities, and commercial aquaculture operations in the ASIS area.

In addition to finfish bycatch, incidental interactions and bycatch mortality of protected species may impact the visitor experience given surveyed visitors have expressed a high level of interest in threatened and endangered species (Eppley Institute for Parks & Public Lands 2007). The eastern shore of ASIS experiences numerous sea turtle strandings between April and December which occur largely as a result of vessel strikes and fishing gear entanglements (Barco and Swingle 2014). Commercial fishing operations seaside of ASIS likely contribute to sea turtle strandings; although turtle strandings occur on the seashore, it is unknown whether the interaction between fishery and turtle which led to the stranding was inside ASIS waters.

More broadly, ASIS area commercial fisheries help support the local economy and contribute to the tourism industry (Kirkley 1997, Kirkley et al. 2005, Hudson and Murray 2016). Most respondents to the 2007 visitor survey indicated that they visited other nearby towns and attractions (Eppley Institute for Parks & Public Lands 2007). A potential positive impact of commercial fishing on the visitor experience is the production and availability of fresh local seafood typically valued by beach going tourists for sale in local markets and restaurants (Rodrigues and Villasante 2016). Also, commercial fishing is an historical activity in the area and part of the local heritage.

Some visitors may expect to and enjoy observing fishing activities. Visits to local historical museums such as the Oyster and Maritime Museum and the Museum of Chincoteague Island are a common visitor activity (MARCO 2012) and contribute to the local tourism industry.

Data needs

To better assess the impacts of commercial fisheries on ASIS marine resources, several data gaps will need to be addressed. Below we provide a list of recommendations for improved data collection and new studies that could enhance understanding of commercial fisheries and their impacts on both local ecosystems and the visitor experience.

Commercial fishing

1. Increased spatial resolution of data reporting requirements for commercial fishers operating in ASIS waters. For example:
 - Increased regional specificity in MDNR and VMRC harvest reporting (especially Maryland blue crab) that would allow for impact assessments by region (e.g., oceanside vs. bayside harvest, high density visitor areas vs. remote areas)
 - Permits and required harvest and effort reporting by species, gear, region within ASIS for all commercial operators fishing in ASIS waters
 - Required bycatch reporting or onboard observer sampling of commercial trips in ASIS waters
2. Generation of a detailed set of maps with official ASIS and state maritime boundaries delineated for fisher navigation and agency enforcement purposes.
3. Creation of a memorandum of understanding between NPS, MDNR, VMRC, and NOAA that would allow NPS staff to regularly review confidential commercial data for monitoring and management purposes.

Ecological impacts

1. Research and data collection aimed at quantifying the impacts of local commercial fishing and aquaculture operations on aquatic habitats in ASIS waters, including:
 - a. Effects of active and passive gears and aquaculture practices on SAV
 - b. Effects of shellfish aquaculture on water quality in ASIS waters
 - c. Monitoring database and impact studies of derelict gear
 - d. Long-term diet and population monitoring studies of red knot and other shorebird species.
2. Monitoring database of confirmed wildlife strandings, gear entanglements, and major habitat disturbances by ASIS staff.

Socio-economic impacts

1. Updated economic studies of the impact of seafood industries in Accomack and Worcester County, including IMPLAN or other economic impact modeling tools.
2. Social science studies that evaluate visitor experiences and perceptions related to fishing activities and that quantify activities impacted by commercial fisheries.
3. Visitor activity data collection, including:
 - a. Updated estimates or ongoing monitoring of the number of visitors engaged in activities impacted by fishing (e.g., guided wildlife viewing/scenic tours, recreational fishing, boating, wildlife viewing, seafood consumption, heritage tourism)
 - b. Spatial location of visitor activities within ASIS
 - c. A creel survey of recreational anglers fishing in ASIS waters that is conducted either through an interview sampling program or self-reporting by recreational angling mode (shore, private boat, party/charter boat*)
 - d. Characterizing visitor satisfaction with fishing opportunities, and
 - e. Identifying real and perceived conflicts between general visitors, recreational fishers, and commercial fishery stakeholders.

*Limited recreational angler interview and party/charter boat harvest and effort information may be available to ASIS upon request through the Marine Recreational Information Program (<http://www.st.nmfs.noaa.gov/recreational-fisheries/index>) or the Atlantic Coastal Cooperative Statistics Program (<http://accsp.org/for-hire-fisheries?key=fisheries>).

Summary

In the last decade, the largest commercial fishery by volume and economic value in the ASIS region has been the Maryland/Virginia pot fishery for blue crab (Table 4). The next largest commercial fisheries by volume harvested by Maryland watermen in the ASIS area were Atlantic menhaden (primarily caught in gill nets in Chincoteague Bay), conch, horseshoe crab, and striped bass (all primarily caught in state oceanic waters; Table 6). Following blue crab, the largest commercial fisheries by volume harvested by Virginia fishermen in Chincoteague and Watts Bays were horseshoe crab and hard clams (Table 9).

Dockside value of blue crabs in Maryland far exceeded that of all other species caught in the ASIS area. In Virginia, the largest total dockside value across the last decade by species was that of blue crab, followed by hard clam, Eastern oyster, horseshoe crab, and spot. Horseshoe crab harvest and value has increased across the time series. The hatchery-based aquaculture industry for hard clam (quahog) and oysters has grown rapidly throughout Virginia in the last few decades (Hudson and Murray 2016). In 2015, the farm gate value (net value of the product when it leaves the aquaculture farm, after marketing costs have been subtracted) of Virginia's hard clam and oyster aquaculture was \$48.3 million (Hudson and Murray 2016); two thirds of that value was generated by hard clams. Production of oysters is growing rapidly (Table 8) such that Virginia is now

the primary producer of aquaculture hard clams in the US and Eastern oyster on the US East Coast.

Specific conclusions regarding the effects of local commercial fishing on fish stocks are difficult to draw because abundance of many fish species in the coastal bays is driven by large-scale, coastal processes (Pincin et al. 2014). Indices of abundance generated from fishery-independent surveys in the ASIS area were largely uninformative with the exception of consistent increases in several forage species, spiny dogfish (a coastwide trend), and alewife. Consistent decreases in recent years were observed for weakfish, a trend that has been observed coastwide. Shellfish surveys indicate hard clam stocks are recovering in the ASIS area, although Chincoteague Bay is recovering more slowly than Sinepuxent Bay.

The primary potential ecological impact of the large blue crab fishery in the ASIS area is likely degradation of existing SAV beds from extended active and derelict trap placement on existing seagrass. Aquaculture for hard clams and oysters also has the potential to impact local seagrass beds through displacement of potential SAV habitat and direct disturbance of existing SAV. Although, bivalve aquaculture also has the potential to improve water clarity and increase habitat quality for SAV. SAV serves as shellfish habitat and nursery habitat for many species of finfish. Thus, balancing commercial fisheries interests with their effects on SAV may be important to the long-term health of these stocks. Gill nets have the potential to cause bycatch of non-targeted finfish and protected species while actively fishing or as derelict gear. Potential impacts of mobile gears such as dredges are hard to quantify given lack of data on spatial location of operations and frequency. Localized impacts of mobile gears, such as increased turbidity and destruction of sensitive bottom habitats, are possible. Other potential impacts include protected species gear interactions and bycatch of non-targeted and protected species.

Popular visitor activities that are most likely to be impacted by commercial fishing include general shore use, wildlife and scenic viewing, motorized boating, recreational fishing (shore, charter/party boat), SCUBA/snorkeling/diving, and recreational shellfish harvesting. Potential impacts of commercial fishing operations on the visitor experience include reduced recreational fishing success due to local hard clam, crab, and finfish habitat degradation. Extensive local aquaculture production has the potential to improve the visitor experience by improving local water quality. Although visitors who value the wilderness qualities of ASIS may consider commercial fishing operations, including semi-permanent floating aquaculture cages, a detraction from their experience. Both commercial and recreational fisheries have the potential to impact the visitor experience by generating dead bycatch which washes ashore. However, commercial fishing provides benefits to the local economy and may impact the broader visitor experience of those who value the local commercial fishing heritage and access to local seafood.

Increased spatial resolution of harvest reporting and updated, local economic studies would be required to improve our understanding of the ecological and economic impacts commercial fisheries have in the ASIS area. A memorandum of understanding between

NPS, MDNR, VMRC, and NOAA would allow NPS staff to regularly review confidential commercial data for monitoring and management purposes. Studies of commercial gear impacts on local benthic habitat such as SAV and bycatch monitoring in the coastal bays and nearshore waters would also provide information on the extent to which specific fisheries and gears affect shellfish and finfish habitat. To better assess impacts of commercial fishing on the visitor experience, new social science studies focused on evaluating visitor experiences and perceptions related to fishing activities would be needed.

Literature Cited

- Arthur, C., A. E. Sutton-Grier, P. Murphy, and H. Bamford. 2014. Out of sight but not out of mind: harmful effects of derelict traps in selected US coastal waters. *Marine Pollution Bulletin* **86**:19-28.
- ASMFC. 2000. Evaluating Fishing Gear Impacts to Submerged Aquatic Vegetation and Determining Mitigation Strategies. ASMFC Habitat Management Series # 5.
- ASMFC. 2008. Report of the Fishing Gear Technology Work Group to the Management and Science Committee.
- ASMFC. 2013. Horseshoe crab stock assessment update. ASMFC, Arlington, VA.
- ASMFC. 2016. Weakfish benchmark stock assessment and peer review report. Arlington, VA.
- Auster, P. J. 1998. A conceptual model of the impacts of fishing gear on the integrity of fish habitats. *Conservation Biology* **12**:1198-1203.
- Barco, S., and W. M. Swingle. 2014. Sea Turtle Species in the Coastal Waters of Virginia: Analysis of stranding and survey data.
- Barker, L., S. Doctor, C. Kennedy, G. Tyler, C. Weedon, and A. Willey. 2014. Investigation of Maryland's coastal bays and Atlantic Ocean finfish stocks.
- Barnette, M. C. 2001. A review of the fishing gear utilized within the Southeast Region and their potential impacts on essential fish habitat. NOAA Tech. Memo. NMFS-SEFSC **449**:60.
- Barr, B. W., and A. D. Kliskey. 2014. Perceptions of wilderness and their application to ocean and coastal waters. *Ocean & Coastal Management* **96**:1-11.
- Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. *Reviews in Fish Biology and Fisheries* **15**:129-154.
- Beardsall, J. W., M. F. McLean, S. J. Cooke, B. C. Wilson, M. J. Dadswell, A. M. Redden, and M. J. Stokesbury. 2013. Consequences of incidental otter trawl capture on survival and physiological condition of threatened Atlantic sturgeon. *Transactions of the American Fisheries Society* **142**:1202-1214.
- Beck, M. W., R. D. Brumbaugh, L. Airoidi, A. Carranza, L. D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, and M. C. Kay. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. *Bioscience* **61**:107-116.
- Beck, M. W., K. L. Heck Jr, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, and T. J. Minello. 2001. The

- identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience* **51**:633-641.
- Bilkovic, D., H. Slacum, K. Havens, D. Zaveta, C. Jeffrey, A. Scheld, D. Stanhope, K. Angstadt, and J. Evans. 2016. Ecological and Economic Effects of Derelict Fishing Gear in the Chesapeake Bay.
- Bilkovic, D. M., K. Havens, D. Stanhope, and K. Angstadt. 2014. Derelict fishing gear in Chesapeake Bay, Virginia: Spatial patterns and implications for marine fauna. *Marine Pollution Bulletin* **80**:114-123.
- Boynton, W. 1970. The commercial fisheries of Chincoteague Bay—past, present and future. *Assateague Ecological Studies, Part I(J)*:357-374.
- Boynton, W., L. Murray, J. Hagy, C. Stokes, and W. Kemp. 1996. A comparative analysis of eutrophication patterns in a temperate coastal lagoon. *Estuaries and coasts* **19**:408-421.
- Carruthers, T., K. Beckert, B. Dennison, J. Thomas, T. Saxby, M. Williams, T. Fisher, J. Kumer, C. Schupp, and B. Sturgis. 2011. Assateague Island National Seashore natural resource condition assessment: Maryland, Virginia. Natural Resource Report NPS/ASIS/NRR-2011/405. National Park Service, Fort Collins, CO.
- Chesapeake Bay Program. 2015. Cownose rays in the Chesapeake Bay: What do we know?
- Cohen, J., S. Karpanty, J. Fraser, and B. Truitt. 2010. The effect of benthic prey abundance and size on red knot (*Calidris canutus*) distribution at an alternative migratory stopover site on the US Atlantic Coast. *Journal of Ornithology* **151**:355-364.
- Collie, J. S., S. J. Hall, M. J. Kaiser, and I. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* **69**:785-798.
- Colton, A. R., M. Wilberg, V. Coles, and T. Miller. 2014. An evaluation of the synchronization in the dynamics of blue crab (*Callinectes sapidus*) populations in the western Atlantic. *Fisheries Oceanography* **23**:132-146.
- Cranford, P. J., R. Anderson, P. Archambault, T. Balch, S. S. Bates, G. Bugden, M. D. Callier, C. Carver, L. Comeau, and B. Hargrave. 2006. Indicators and thresholds for use in assessing shellfish aquaculture impacts on fish habitat. DFO Canadian Scientific Advisory Secretariat Research Document **34**.
- DeAlteris, J., L. Skrobe, and C. Lipsky. 1999. The significance of seabed disturbance by mobile fishing gear relative to natural processes: a case study in Narragansett Bay, Rhode Island. Pages 224-237 *in* American Fisheries Society Symposium.
- DeAlteris, J. T. 1988. The geomorphic development of Wreck Shoal, a subtidal oyster reef of the James River, Virginia. *Estuaries and coasts* **11**:240-249.
- Dealteris, J. T., B. D. Kilpatrick, and R. B. Rheault. 2004. A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation and a non-vegetated seabed. *Journal of Shellfish Research* **23**:867-874.
- Department of the Interior, Fish and Wildlife Service. 2015. Chincoteague and Wallops Island National Wildlife Refuges Comprehensive Conservation Plan. U.S. Fish and Wildlife Service. Chincoteague, VA.

- Department of the Interior, National Park Service. 2016. Draft General Management Plan and Environmental Impact Statement, Assateague Island National Seashore, Maryland and Virginia. Assateague Island National Seashore. Berlin, MD.
- Diddon, J. 2015. Spiny Dogfish Advisory Panel (AP) Informational Document. Mid-Atlantic Fisheries Management Council, Dover, DE.
- Dumbauld, B. R., J. L. Ruesink, and S. S. Rumrill. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam culture in West Coast (USA) estuaries. *Aquaculture* **290**:196-223.
- Environmental Protection Agency. 2016. National Coastal Condition Assessment 2010. Available from U.S. EPA website: <http://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys>. Accessed: March 2017.
- Eppley Institute for Parks & Public Lands. 2007. Assateague Island National Seashore Visitor Survey Report.
- Eppley Institute for Parks & Public Lands. 2008. Visitor attitudes and experiences associated with the oversand vehicle zone and backcountry camping areas at Assateague Island National Seashore.
- Everett, R. A., G. M. Ruiz, and J. Carlton. 1995. Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. *Marine Ecology Progress Series* **125**:205-217.
- Fisher, R. A., G. C. Call, and R. D. Grubbs. 2013. Age, growth, and reproductive biology of cownose rays in Chesapeake Bay. *Marine and Coastal Fisheries* **5**:224-235.
- Fonseca, M. S., and A. V. Uhrin. 2009. The status of eelgrass, *Zostera marina*, as bay scallop habitat: consequences for the fishery in the Western Atlantic. *Marine Fisheries Review* **71**:20-33.
- Forrest, B. M., N. B. Keeley, G. A. Hopkins, S. C. Webb, and D. M. Clement. 2009. Bivalve aquaculture in estuaries: review and synthesis of oyster cultivation effects. *Aquaculture* **298**:1-15.
- Gilardi, K. V., D. Carlson-Bremer, J. A. June, K. Antonelis, G. Broadhurst, and T. Cowan. 2010. Marine species mortality in derelict fishing nets in Puget Sound, WA and the cost/benefits of derelict net removal. *Marine Pollution Bulletin* **60**:376-382.
- Gilman, E., editor. 2009. Proceedings of the Technical Workshop on Mitigating Sea Turtle Bycatch in Coastal Net Fisheries. 20-22 January 2009, Honolulu, U.S.A. Western Pacific Regional Fishery Management Council, IUCN, Southeast Asian Fisheries Development Center, Indian Ocean – South-East Asian Marine Turtle MoU, U.S. National Marine Fisheries Service, Southeast Fisheries Science Center: Honolulu; Gland, Switzerland; Bangkok; and Pascagoula, USA.
- Greeley, V., and R. Polhemus. 2001. An assessment of the economic value of the Coastal Bays natural resources to the economic of Worcester County, Maryland. West Chester, PA
- Hall, M. A., D. L. Alverson, and K. I. Metuzals. 2000. By-catch: problems and solutions. *Marine Pollution Bulletin* **41**:204-219.

- Havens, K., D. M. Bilkovic, D. Stanhope, and K. Angstadt. 2011. Fishery failure, unemployed commercial fishers, and lost blue crab pots: an unexpected success story. *environmental science & policy* **14**:445-450.
- Havens, K. J., D. M. Bilkovic, D. Stanhope, K. Angstadt, and C. Hershner. 2008. The effects of derelict blue crab traps on marine organisms in the lower York River, Virginia. *North American Journal of Fisheries Management* **28**:1194-1200.
- Hilborn, R., and C. J. Walters. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty/Book and Disk*. Springer Science & Business Media.
- Hilton, E. J., R. Latour, P. McGrath, B. Watkins, and A. Magee. 2015. Monitoring Relative Abundance of American shad and River Herring in Virginia's Rivers. 2015 Annual Report to the Virginia Marine Resources Commission. Contract No. F-116-R-17, 15 April 2016.
- Hudson, K., and T. J. Murray. 2016. Virginia Shellfish Aquaculture Situation and Outlook Report. VIMS Marine Resource Report No. 2016-4.
- Industrial Economics Inc. 2008. Economic assessment of Mid-Atlantic horseshoe crab and dependent fisheries including a qualitative discussion of the potential effects of Addendum IV. Cambridge, MA.
- Jennings, S., M. Kaiser, and J. D. Reynolds. 2009. *Marine fisheries ecology*. John Wiley & Sons.
- Kaiser, M. J., J. S. Collie, S. J. Hall, S. Jennings, and I. R. Poiner. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. *Fish and Fisheries* **3**:114-136.
- Karpanty, S. M., J. Cohen, J. D. Fraser, and J. Berkson. 2011. Sufficiency of horseshoe crab eggs for red knots during spring migration stopover in Delaware Bay USA. *The Journal of Wildlife Management* **75**:984-994.
- Kellogg, M. L., J. C. Cornwell, M. S. Owens, and K. T. Paynter. 2013. Denitrification and nutrient assimilation on a restored oyster reef. *Marine Ecology Progress Series* **480**:1-19.
- Kellogg, M. L., A. R. Smyth, M. W. Luckenbach, R. H. Carmichael, B. L. Brown, J. C. Cornwell, M. F. Piehler, M. S. Owens, D. J. Dalrymple, and C. B. Higgins. 2014. Use of oysters to mitigate eutrophication in coastal waters. *Estuarine, Coastal and Shelf Science* **151**:156-168.
- Kilian, J. V., A. J. Becker, S. A. Stranko, M. Ashton, R. J. Klauda, J. Gerber, and M. Hurd. 2010. The status and distribution of Maryland crayfishes.
- Kirkley, J. E. 1997. Virginia's commercial fishing industry: its economic performance and contributions. Virginia Institute of Marine Science, School of Marine Science, College of William and Mary.
- Kirkley, J. E., J. D. Murray, and J. Duberg. 2005. *Economic Contributions of Virginia's Commercial Seafood and Recreational Fishing Industries: A User's Manual for Assessing Economic Impacts*. Virginia Institute of Marine Science, School of Marine Science, College of William and Mary.
- Kritzer, J. P., M.-B. DeLucia, E. Greene, C. Shumway, M. F. Topolski, J. Thomas-Blate, L. A. Chiarella, K. B. Davy, and K. Smith. 2016. The importance of benthic habitats for coastal fisheries. *Bioscience* **66**:274-284.
- Lambert, M. S., G. Ozbay, and G. P. Richards. 2009. Seawater and shellfish (*Geukensia demissa*) quality along the Western Coast of Assateague Island

- National Seashore, Maryland: an area impacted by feral horses and agricultural runoff. *Archives of Environmental Contamination and Toxicology* **57**:405-415.
- Luckenbach, M. W., J. N. Kraeuter, and D. Bushek. 2016. Effects of Clam Aquaculture on Nektonic and Benthic Assemblages in Two Shallow-Water Estuaries. *Journal of Shellfish Research* **35**:757-775.
- MARCO. 2012. <http://portal.midatlanticocean.org/data-catalog/recreation/>.
- McGowan, C. P., D. R. Smith, J. D. Nichols, J. E. Lyons, J. Sweka, K. Kalasz, L. J. Niles, R. Wong, J. Brust, and M. Davis. 2015. Implementation of a framework for multi-species, multi-objective adaptive management in Delaware Bay. *Biological Conservation* **191**:759-769.
- MDNR. 2016. 2015 Maryland Fishery Management Plan Report (August 2016) Section 11. Maryland Coastal Bays Hard Clam (*Mercenaria mercenaria*) Annapolis, MD.
- Millard, M. J., J. A. Sweka, C. P. McGowan, and D. R. Smith. 2015. Assessment and management of North American horseshoe crab populations, with emphasis on a multispecies framework for Delaware Bay, USA populations. Pages 407-431 *Changing Global Perspectives on Horseshoe Crab Biology, Conservation and Management*. Springer.
- Murphy, A. E., K. A. Emery, I. C. Anderson, M. L. Pace, M. J. Brush, and J. E. Rheuban. 2016. Quantifying the effects of commercial clam aquaculture on C and N cycling: an integrated ecosystem approach. *Estuaries and coasts* **39**:1746-1761.
- Murray, T., and E. Kirkley. 2005. Economic Activity Associated with Clam Aquaculture in Virginia - 2004. VIMS Marine Resource Report No. 2005-5.
- National Marine Fisheries Service. 2016. Fisheries Economics of the United States, 2014. U.S. Dept. of Commerce, NOAA Tech. Memo. NMFS-F/SPO-163, 237p.
- National Marine Fisheries Service and Atlantic States Marine Fisheries Commission. 2013. Workshop on Sea Turtle and Atlantic Sturgeon Bycatch Reduction in Gillnet Fisheries. Jan 22-23, 2013, Ocean City, MD. 48 pp.
- Naylor, R. L., S. L. Williams, and D. R. Strong. 2001. Aquaculture--A gateway for exotic species. *science* **294**:1655-1656.
- Newell, R. I. 2004. Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. *Journal of Shellfish Research* **23**:51-62.
- Newell, R. I., and E. W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. *Estuaries and coasts* **27**:793-806.
- Niles, L. J., J. Bart, H. P. Sitters, A. D. Dey, K. E. Clark, P. W. Atkinson, A. J. Baker, K. A. Bennett, K. S. Kalasz, N. A. Clark, J. Clark, S. Gillings, A. S. Gates, P. M. González, D. E. Hernandez, C. D. T. Minton, R. I. G. Morrison, R. R. Porter, R. K. Ross, and C. R. Veitch. 2009. Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working? *Bioscience* **59**:153-164.
- NOAA Marine Debris Program. 2014. Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States. Silver Spring, MD. 28 pp.
- Northeast Fisheries Science Center. 2011. 52nd Northeast Regional Stock Assessment Workshop (52nd SAW) Assessment Report. US Dept Commer, Northeast Fish

- Sci Cent Ref Doc. 11-17; 962 p. Available online at <http://www.nefsc.noaa.gov/nefsc/publications/>.
- Novcic, I., D. S. Mizrahi, R. R. Veit, and W. O. Symondson. 2015. Molecular analysis of the value of Horseshoe Crab eggs to migrating shorebirds. *Avian Biology Research* **8**:210-220.
- Orth, R. J., M. L. Luckenbach, S. R. Marion, K. A. Moore, and D. J. Wilcox. 2006. Seagrass recovery in the Delmarva coastal bays, USA. *Aquatic Botany* **84**:26-36.
- Orth, R. J., D. J. Wilcox, J. R. Whiting, A. K. Kenne, L. Nagey, and E. R. Smith. 2015. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Coastal Bays. Virginia Institute of Marine Science. Gloucester Point, VA.
- Peterson, C. H., H. C. Summerson, and S. R. Fegley. 1988. Ecological consequences of mechanical harvesting of clams. *Fishery Bulletin* **85**:281-298.
- Pincin, J., M. J. Wilberg, L. Harris, and A. Willey. 2014. Trends in abundance indices of fishes in Maryland's Coastal Bays during 1972–2009. *Estuaries and coasts* **37**:791-800.
- Radzio, T. A., and W. M. Roosenburg. 2003. Diamondback terrapin mortality in eel pots and evaluation of a by-catch reduction device.
- Rodrigues, J. G., and S. Villasante. 2016. Disentangling seafood value chains: Tourism and the local market driving small-scale fisheries. *Marine Policy* **74**:33-42.
- Rossi, S. D., J. A. Byrne, C. M. Pickering, and J. Reser. 2015. 'Seeing red' in national parks: How visitors' values affect perceptions and park experiences. *Geoforum* **66**:41-52.
- Scheld, A., D. Bilkovic, and K. Havens. 2016. The dilemma of derelict Gear. *Scientific reports* **6**.
- SEDAR. 2015. SEDAR 40 – Atlantic Menhaden Stock Assessment Report. North Charleston, SC
- Smith, J. W., and J. V. Merriner. 1985. Food habits and feeding behavior of the cownose ray, *Rhinoptera bonasus*, in lower Chesapeake Bay. *Estuaries and coasts* **8**:305-310.
- Stevens, B. 2000. Ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots off Kodiak, Alaska: pot density and catch per trap as determined from sidescan sonar and pot recovery data. *Fishery Bulletin* **98**:389-399.
- Testa, J. M., D. C. Brady, J. C. Cornwell, M. S. Owens, L. P. Sanford, C. R. Newell, S. E. Suttles, and R. I. Newell. 2015. Modeling the impact of floating oyster (*Crassostrea virginica*) aquaculture on sediment-water nutrient and oxygen fluxes. *Aquaculture Environment Interactions* **7**:205-222.
- Uhrin, A. V., M. S. Fonseca, and G. P. DiDomenico. 2005. Effect of Caribbean spiny lobster traps on seagrass beds of the Florida Keys National Marine Sanctuary: damage assessment and evaluation of recovery. Page 579 in *American Fisheries Society Symposium*. AMERICAN FISHERIES SOCIETY.
- Uhrin, A. V., and J. Schellinger. 2011. Marine debris impacts to a tidal fringing-marsh in North Carolina. *Marine Pollution Bulletin* **62**:2605-2610.
- University of Maryland Natural Resources Institute. 1970. The commercial fisheries of Chincoteague Bay—past, present and future. Assateague Ecological Studies, Part II.

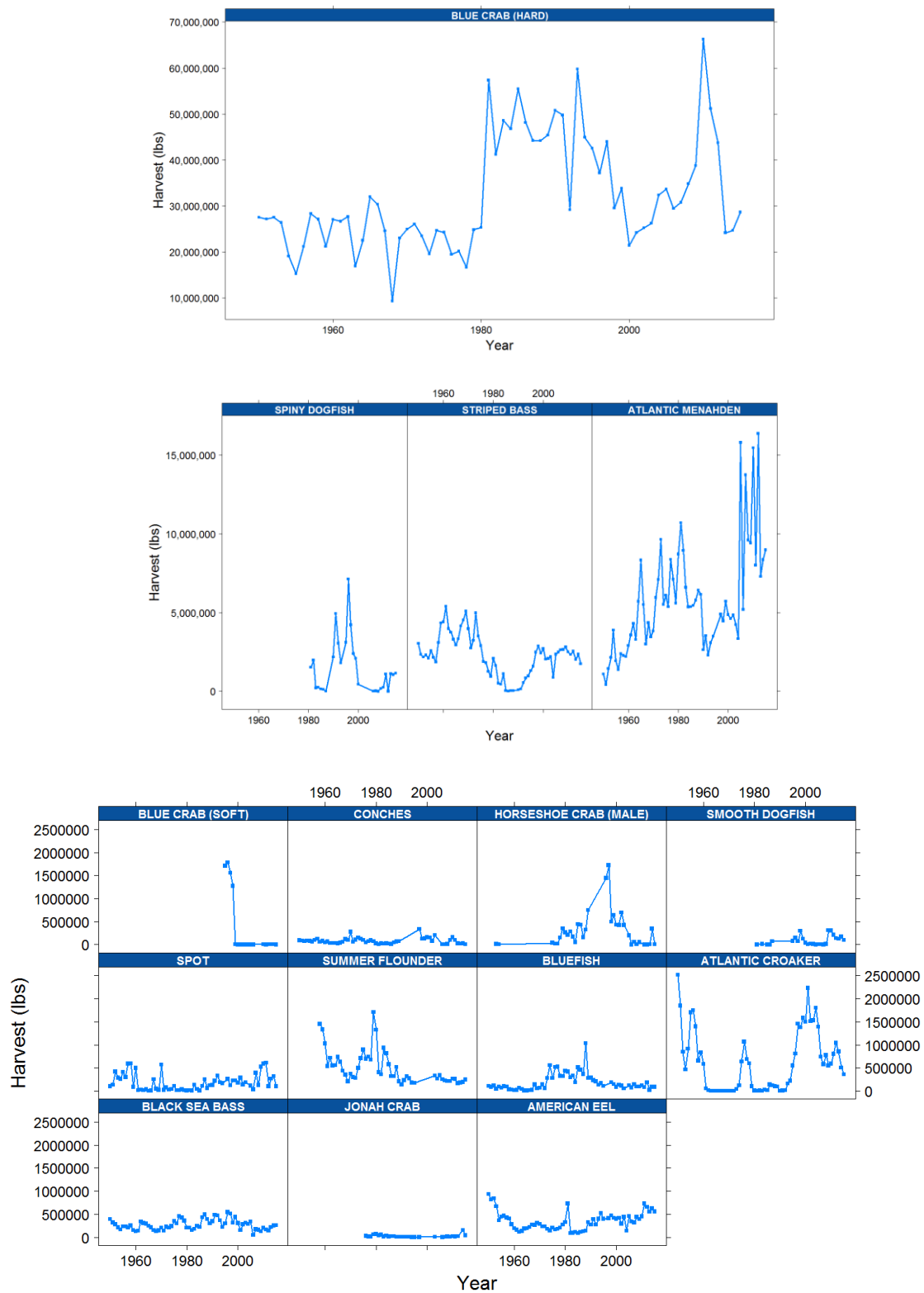
- Virginia Coastal Zone Management Program. 2011. Section 309 Needs Assessment & Strategy.
- Virginia Sea Grant Program. 2006. Regional Workshop on Cownose Ray Issues Identifying Research and Extension Needs. VIMS Marine Resource Report 2009-6.
- Wazniak, C. E., M. R. Hall, C. Cain, D. Wilson, R. Jesien, J. Thomas, T. Carruthers, and W. Dennison. 2004. Maryland's Coastal Bays: Ecosystem Health Assessment. Maryland Department of Natural Resources. Annapolis, MD.
- Wazniak, C. E., M. R. Hall, T. J. B. Carruthers, B. Sturgis, W. C. Dennison, and R. J. Orth. 2007. Linking water quality to living resources in a mid-Atlantic lagoon system, USA. *Ecological Applications* **17**:S64-S78.

Appendices

Appendix 1. Common and scientific names of all primary commercial species in the ASIS area.

Common Name	Scientific Name
ALEWIFE	<i>Alosa pseudoharengus</i>
AMERICAN EEL	<i>Anguilla rostrata</i>
AMERICAN LOBSTER	<i>Homarus americanus</i>
ATLANTIC CROAKER	<i>Micropogonias undulatus</i>
ATLANTIC SILVERSIDE	<i>Menidia menidia</i>
BLUE CRAB	<i>Callinectes sapidus</i>
BLUEFISH	<i>Pomatomus saltatrix</i>
CONCHES/WHELKS	<i>Busycon carica</i> (knobbed whelk) <i>Busycotypus canaliculatus</i> (channeled whelk)
EASTERN OYSTER	<i>Crassostrea virginica</i>
HORSESHOE CRAB	<i>Limulus polyphemus</i>
JONAH CRAB	<i>Cancer borealis</i>
ATLANTIC MENHADEN	<i>Brevoortia tyrannus</i>
MINNOWS	<i>Cyprinidae</i> (multiple species)
NORTHERN PUFFER	<i>Sphoeroides maculatus</i>
QUAHOG/HARD CLAM	<i>Mercenaria mercenaria</i>
SMOOTH DOGFISH	<i>Mustelus canis</i>
SPINY DOGFISH	<i>Squalus acanthias</i>
SPOT	<i>Leiostomus xanthurus</i>
STRIPED BASS	<i>Morone saxatilis</i>
SUMMER FLOUNDER	<i>Paralichthys dentatus</i>
WEAKFISH	<i>Cynoscion regalis</i>

Appendix 2. Trends in total Maryland landings (lbs), 1950-2015, for the species most commonly caught in the ASIS area. Data from [NOAA National Marine Fisheries Service](#).



Appendix 3. Trends in total Virginia landings (lbs), 1950-2015, for the species most commonly caught in the ASIS area. Data from NOAA [National Marine Fisheries Service](#).

