2020 State of the Ecosystem
Mid-Atlantic

NOAA FISHERIES

Total commercial fishery landings were scaled to ecosystem productivity. Primary production required to support Mid-Atlantic commercial landings has been declining since 2000.

Engagement in commercial fishing has declined since 2004 for medium to highly engaged Mid-Atlantic fishing communities. This may be related to the overall downward trend in commercial landings since 1986 and the decline in total revenue since 2004.

2018 retained recreational catch in the Mid-Atlantic was the lowest observed since 1982. There is also a similar, although less steep decline in recreational fishing effort. The party/charter sector is expected to continue to shrink. Recreational species catch diversity has been maintained by increased catch of South Atlantic and state managed species.

Habitat modeling indicates that summer flounder, butterfish, longfin squid, and spiny dogfish are among fish species highly likely to occupy wind energy lease areas. Habitat conditions for many of these species have become more favorable over time within wind lease areas.

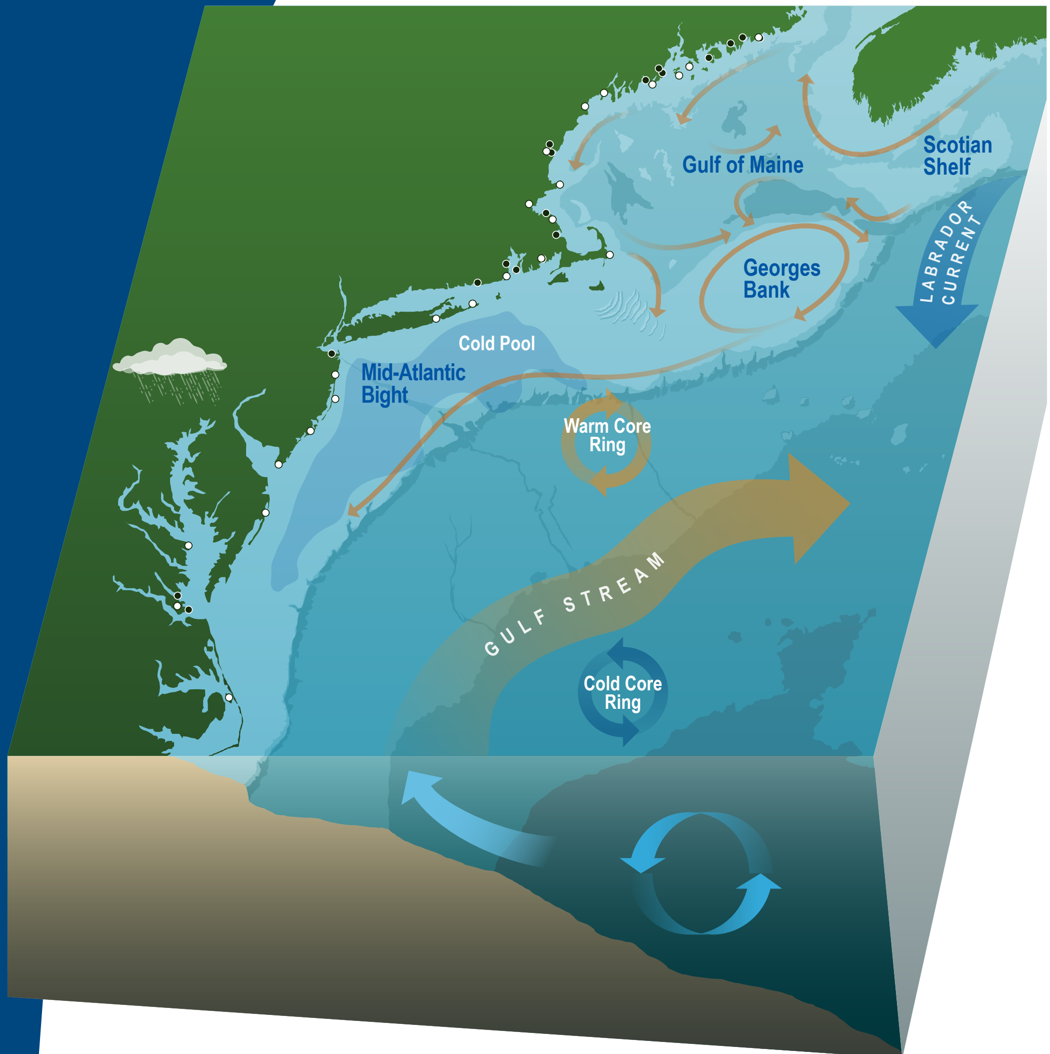
There are no apparent trends in aggregate biomass of predators, forage fish, bottom feeders, and shellfish sampled by trawl surveys, implying a stable food web. However, we continue to see a northward shift in aggregate fish distribution along the Northeast US shelf and a tendency towards distribution in deeper waters.

Forage fish energy content is now being measured regularly, revealing both seasonal and annual variation in energy of these important prey species due to changing ecosystem conditions. Notably, Atlantic herring energy content is half what it was in the 1980-90s.

Nearshore habitats are under stress. Heavy rains in 2018-2019 resulted in unprecedented fresh water and high nutrient flow into the Chesapeake Bay, driving low oxygen, increased oyster mortality, and spread of invasive catfish in this critical Mid-Atlantic nursery habitat. Sea level rise is altering coastal habitats in the Mid-Atlantic, driving declines in nesting seabirds on Virginia islands.

The Northeast US shelf ecosystem continued to experience warm conditions in 2019, with changes in ocean circulation affecting the shelf. The Gulf Stream is increasingly unstable, with more warm core rings resulting in higher likelihood of warm salty water and associated oceanic species such as shortfin squid coming onto the shelf.

The intensity and duration of marine surface heatwaves are increasing, and bottom temperatures both in the seasonal Mid-Atlantic cold pool and shelfwide are increasing. Warmer temperatures increase nutrient recycling and summer phytoplankton productivity.



The Northeast US Shelf is one of the most productive marine ecosystems in the world. Changes in climate, nearshore, and oceanographic processes as well as human uses affect productivity at all trophic levels and impact fishing communities and regional economies.

Research Spotlight

Fish condition, “fatness”, is an important driver of population productivity. Condition is affected by changing habitat (e.g. temperature) and ecosystem productivity, and in turn can affect market prices. We are investigating potential factors influencing fish condition to better inform operational fishery management decisions.

Report Structure

The major messages of the report are synthesized in the 2-page summary, above. The information in this report is organized around general ecosystem-level management objectives (Table 1), and indicators related to these objectives are grouped into four general categories in the four sections below: economic and social, protected species, fish and invertebrates, and habitat quality and ecosystem productivity. Each section begins with a summary of main messages with links to other sections, including any new information added at the request of the Fishery Management Councils, and includes figures with brief descriptions of all current indicators. Detailed technical methods documentation[1] and indicator data[2] are available online. The details of standard figure formatting (Fig. 37a), categorization of fish and invertebrate species into feeding groups (Table 4), and definitions of ecological production units (EPUs, including the Mid-Atlantic Bight, MAB; Fig. 37b) are provided at the end of the document.

Table 1: Established ecosystem-scale objectives in the Mid-Atlantic Bight

Objective Categories	Indicators reported here
Seafood Production	Landings by feeding guild
Profits	Revenue decomposed to price and volume
Recreation	Days fished; recreational catch
Stability	Diversity indices (fishery and species)
Social & Cultural	Commercial engagement trends
Biomass	Biomass or abundance by feeding guild from surveys
Productivity	Condition and recruitment of managed species, Primary productivity
Trophic structure	Relative biomass of feeding guilds, Zooplankton
Habitat	Estuarine and offshore habitat conditions

Economic and Social

The objectives of U.S. federal fishery management include providing benefits to the Nation in terms of seafood production and recreational opportunities, while considering economic efficiency and effects on coastal communities. The indicators in this section consider these objectives for commercial and recreational fishing sectors separately where possible.

Despite mostly meeting fishery management objectives at the single species level (Fig. 14), long term declines in total seafood production and commercial revenue remain apparent. Indicators highlight a declining diversity of recreational opportunities (fishing modes and species). Further, coastal communities with high fishery engagement and reliance are dependent on a smaller number of species than historically, these species are predominantly high valued shellfish vulnerable to increased ocean temperature and acidification. New analysis of wind energy lease areas and modeled habitat occupancy highlights which species are most likely to be found in wind development areas seasonally (Fig. 10).

Commercial sector (MAB)

The amount of potential yield we can expect from a marine ecosystem depends on the amount of production entering at the base of the food web, primarily in the form of phytoplankton; the pathways this energy follows to reach harvested species; the efficiency of transfer of energy at each step in the food web; and the fraction of this production that is removed by the fisheries. Species such as scallops and clams primarily feed directly on larger phytoplankton species and therefore require only one step in the transfer of energy. The loss of energy at each step can exceed 80-90%. For many fish species, as many as 2-4 steps may be necessary. Given the trophic level and the efficiency of

[1] https://NOAA-EDAB.github.io/tech-doc
[2] https://github.com/NOAA-EDAB/ecodata

energy transfer of the species in the ecosystem the amount phytoplankton production required (PPR) to account for the observed catch can be estimated.

Primary production required has declined over the past 20 years (Fig. 1). There is also an apparent cyclical pattern. The overall trend is largely driven by the decrease in landings with an increase in primary production over the same period. The landings in many of the years are dominated by species at lower trophic levels (scallops and clams). The periodicity in the PPR index reflects both the periodicity in primary production (see Fig. 36) and the periodicity in the closed areas for scallop harvest.

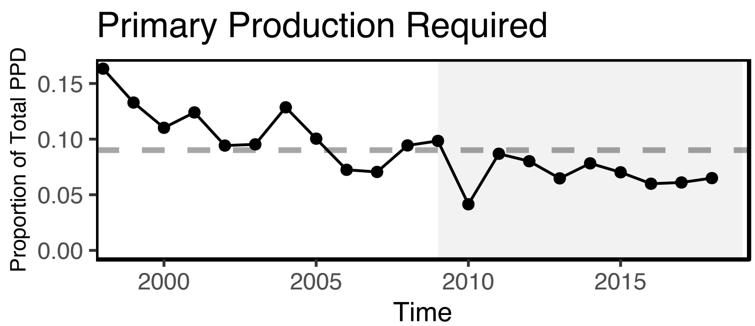


Figure 1: Primary production required to support MAB commercial landings. Included are the top species accounting for 80% of the landings in each year, with 15% transfer efficiency assumed between trophic levels.

Total seafood landings and MAFMC managed species seafood landings have declined over the long term (Fig. 2) with a slight increase 2016-2018. Seafood landings for feeding guilds are also stable or declining overall (Fig. 3), although landings of piscivores and planktivores increased in the MAB. Recent increased landings of *Illex* squid are apparent in the piscivores guild (attributed to the planktivores guild in previous reports). Landings of apex predators are available for 2016-2018 but trends are not detectable in this short time series.

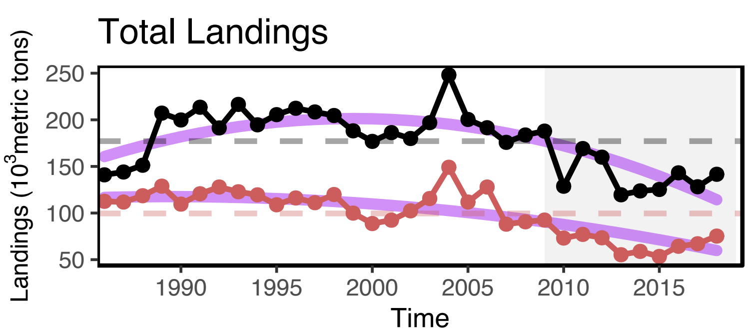


Figure 2: Total commercial seafood landings (black) and Mid-Atlantic managed seafood landings (red).

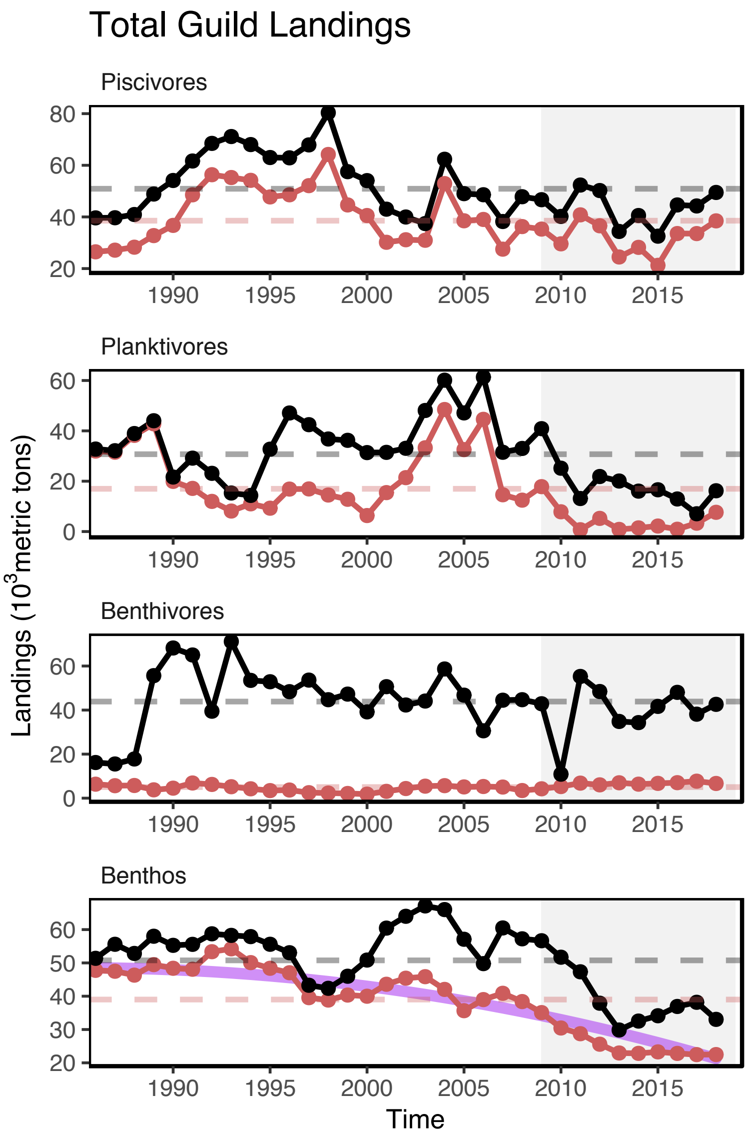


Figure 3: MAFMC managed species landings (red) and total commercial landings (black) by feeding guild.

Revenue for MAFMC managed species has also declined over the long term (Fig. 4), with recent decreases in total revenue driven by decreased prices compared to the 2015 baseline (Fig. 5).

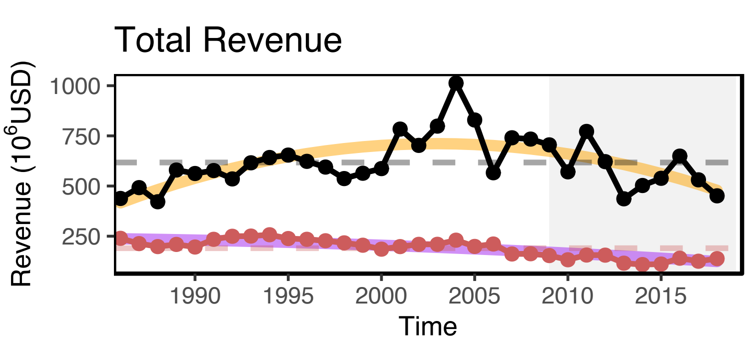


Figure 4: Total revenue for the region (black) and revenue from MAFMC managed species (red).

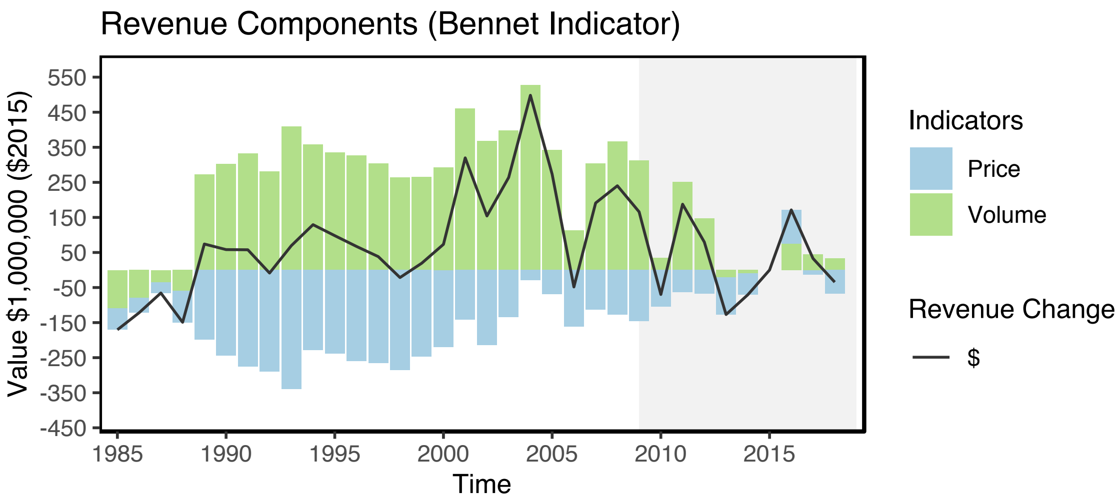


Figure 5: Revenue change from the 2015 base year in 2015 dollars (black), Price (PI), and Volume Indicators (VI) for commercial landings in the Mid-Atlantic.

Commercial fleet diversity indices were updated with 2018 data and remain near the long term average[3].

Commerical fishery engagement measures the number of permits, dealers, and landings in a community[4]. The trend in the number of Mid-Atlantic fishing communities that were highly engaged (red bar) in commercial fishing has shown a decrease since 2004 (Fig. 6). Some of the communities that were highly engaged have moved into the moderate (blue bar) or medium-high (green bar) category, and thus the number of moderately to medium-highly engaged communities have increased. Significant changes in engagement scores have also been observed in medium-highly engaged communities. The average engagement score has decreased since 2004. These changes may be driven by the decline in value landed by primary species such as sea scallops in this group of communities.

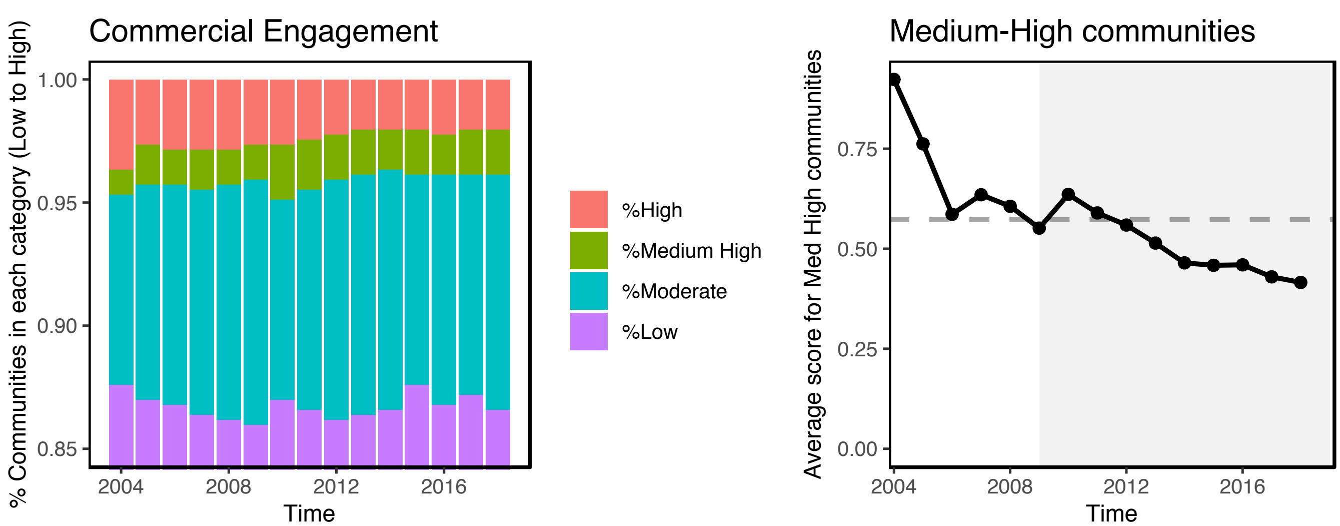


Figure 6: Commercial engagement scores (total pounds landed, value landed, commercial permits, and commercial dealers in a community) for Mid-Atlantic fishing communities, 2004-2018.

[3] https://noaa-edab.github.io/ecodata/human_dimensions#mid-atlantic

[4] https://www.fisheries.noaa.gov/national/socioeconomics/social-indicator-definitions#fishing-engagement-and-reliance-indices

Recreational sector (Mid-Atlantic states)

Indicators for recreational diversity are presented in this report at the request of the MAFMC. In contrast to the commercial seafood production trends, recreational seafood production has been stable since the mid-1990s with the updated MRIP data (Fig. 7). However, 2018 recreational seafood landings were the lowest observed since 1982, with a 47% drop year over year. This drop involved multiple species, including black sea bass, scup, spot, and bluefish, among others and though accompanied by lower recreational effort in 2018, is not fully explained by changes in effort alone. The survey methodology behind these numbers was updated in 2018, and additional years worth of data is needed to understand whether these declines are driven by changes in the precision or other statistical properties of the data.

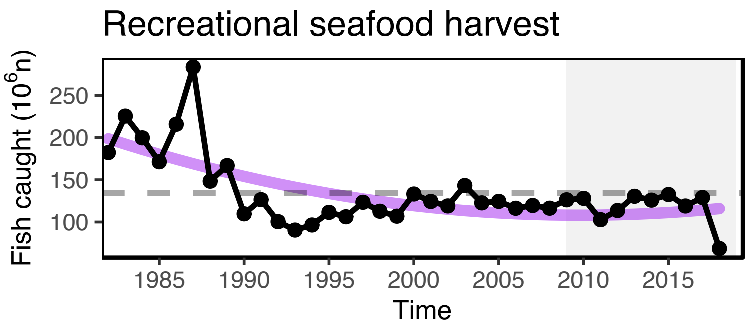


Figure 7: Total recreational seafood harvest in the Mid-Atlantic region.

Updated indicators for recreational opportunities (effort days) show general increases since the 1990s, peaking in the late 2000s and declining since then. This is similar to previously reported trends (Fig. 8).

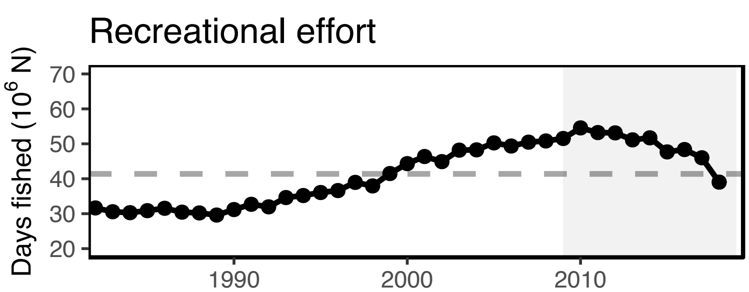


Figure 8: Recreational effort in the Mid-Atlantic.

Indicators for the diversity of recreational effort (i.e. access to recreational opportunities) by mode (party/charter boats, private boats, shore-based), and diversity of catch (NEFMC, MAFMC, SAFMC, and ASMFC managed species) show different trends. The downward effort diversity trend is driven by party/charter contraction (from a high of 24% of angler trips to 7% currently), with a shift towards shorebased angling. Effort in private boats remained stable between 36-37% of angler trips across the entire series. The long-term decrease in species catch diversity in the Mid-Atlantic states reported last year resulted from aggregation of SAFMC and ASMFC managed species into a single group. With SAFMC and ASMFC species considered individually, there is no long term trend in recreational catch diversity. This implies that recent increases in catch of SAFMC and/or ASMFC managed species is helping to maintain diversity in the same range that MAFMC and NEFMC species supported in the 1990s (Fig. 9).

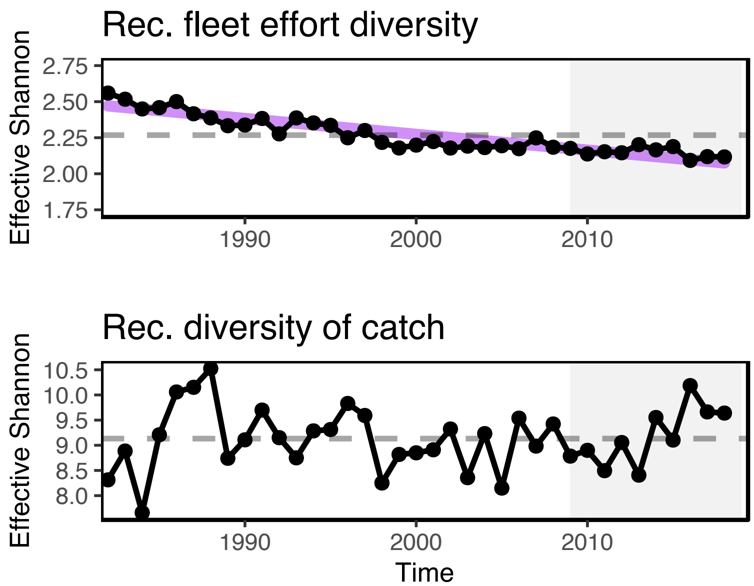


Figure 9: Recreational effort diversity and diversity of recreational catch in the Mid-Atlantic.

Additional social indicators for Mid-Atlantic communities are available online[5].

Fish habitat overlap with offshore wind lease areas (coastwide)

Fish habitat modeling based on NEFSC bottom trawl surveys [1] indicates that summer flounder, butterfish, longfin squid, and spiny dogfish are among fish species highly likely to occupy wind energy lease areas (Fig. 10). Habitat conditions for many of these species have become more favorable over time within wind lease areas (increasing trend in probability of occupancy). Table 2 lists the top 5 species in each season most likely to occupy the wind lease areas in the northern, central, and southern portions of the MAB, along with observed trends in probability of occupancy.

Table 2: Species with highest probability of occupancy species each season and area, with observed trends

	Existing - North		Proposed - North		Existing - Mid		Proposed - Mid		Existing - South	
Season	Species	Trend	Species	Trend	Species	Trend	Species	Trend	Species	Trend
Spring	Little Skate	↗	Atlantic Herring		Little Skate	↗	Spiny Dogfish	↗	Spiny Dogfish	↗
Spring	Atlantic Herring	↘	Little Skate	↗	Atlantic Herring	↘	Atlantic Herring	↘	Longfin Squid	↗
Spring	Windowpane	↗	Longhorn Sculpin	↗	Spiny Dogfish	↗	Little Skate	↗	Summer Flounder	↗
Spring	Winter Skate	↗	Windowpane	↗	Windowpane	↗	Alewife	↘	Clearnose Skate	↗
Spring	Longhorn Sculpin	↗	Alewife	↘	Winter Skate	↗	Silver Hake	↗	Spotted Hake	↗
Fall	Butterfish	↗	Butterfish	↗	Summer Flounder	↗	Longhorn Sculpin	↗	Longfin Squid	↘
Fall	Longfin Squid	↗	Fourspot Flounder		Longfin Squid	↗	Little Skate	↗	Northern Searobin	↗
Fall	Summer Flounder	↗	Longhorn Sculpin	↘	Butterfish	↗	Butterfish	↗	Clearnose Skate	↗
Fall	Winter Flounder	↘	Summer Flounder	↗	Smooth Dogfish	↗	Sea Scallop	↗	Butterfish	↗
Fall	Spiny Dogfish	↘	Spiny Dogfish	↘	Windowpane	↗	Fourspot Flounder	↗	Spiny Dogfish/Spotted Hake	↗

[5] https://www.st.nmfs.noaa.gov/humandimensions/social-indicators/

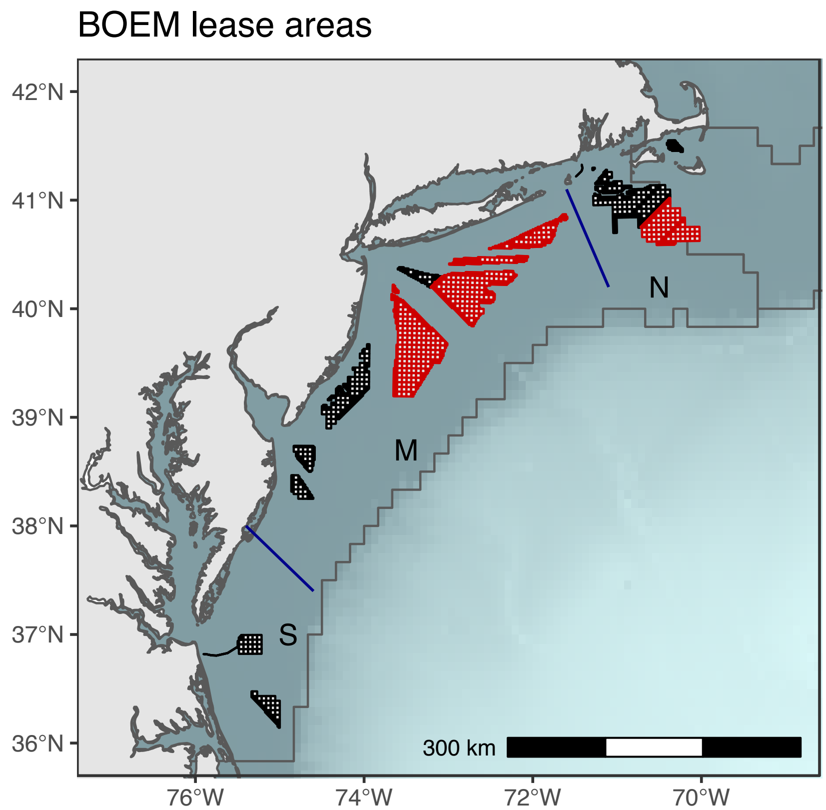


Figure 10: Map of BOEM existing (black) and proposed (red) lease areas in North (N), Mid (M) and South (S) portions of the coast as of February 2019.

Protected Species

Protected species include marine mammals (under the Marine Mammal Protection Act), endangered and threatened species (under the Endangered Species Act), and migratory birds (under the Migratory Bird Treaty Act). In the Northeast US, endangered/threatened species include Atlantic salmon, Atlantic and shortnose sturgeon, all sea turtle species, and 5 baleen whales. Fishery management objectives for protected species generally focus on reducing threats and on habitat conservation/restoration; here we report on the status of these actions as well as indicating the potential for future interactions driven by observed and predicted ecosystem changes in the Northeast US region. Also, a marine mammal climate vulnerability assessment is currently underway and for Atlantic and Gulf of Mexico populations and will be reported on in future versions of this report.

While harbor porpoise bycatch continues to be quite low as reported previously, this year saw the continuation of four Unusual Mortality Events (UMEs) for three large whale species and four seal species, with several mortalities attributed to human interactions. Strong evidence exists to suggest that the level of interaction between right whales and the combination of offshore lobster fishery in the US and snow crab fishery in Canada is contributing substantially to the decline of the species.

Whales (coastwide)

North Atlantic right whales are among the most endangered large whale populations in the world. Changes in right whale trends can have implications for fisheries management where fisheries interact with these whales. Additional management restrictions could have a large impact on fishing times, gears, etc. Although the population increased steadily from 1990 to 2011, it has decreased recently (Fig. 11). Reduced survival rates of adult females and diverging abundance trends between sexes have also been observed. It is estimated that there are only about 100 reproductive adult females remaining in the population. In 2018 there were no new calves observed, and a drop in annual calf production roughly mirrors the abundance decline (Fig. 12), however seven new calves were born in 2019. Right whale distribution has changed since 2010. New research suggests that recent climate driven changes in ocean circulation has resulted in right whale distribution changes driven by increased warm water influx through the Northeast Channel, which has reduced the primary right whale prey (*Calanus finmarchicus*) in the central and eastern portions of the Gulf of Maine.

Three large whale Unusual Mortality Events (UMEs) are ongoing for North Atlantic right whales, humpback whales (117 dead to date since January 2016[6]), and minke whales (80 dead to date since January 2017[7]). In all three cases human interaction appears to have contributed to increased mortalities, although investigations are not complete. Since 2017, 30 right whale mortalities have been documented, 9 in the US and 21 in Canada[8]. During 2019, 9 dead right whales have been documented in Canada and one in the US. Three of these mortalities were determined to have been due to vessel strike while the remainder are undetermined at this time.

[6] https://www.fisheries.noaa.gov/national/marine-life-distress/2016-2020-humpback-whale-unusual-mortality-event-along-atlantic-coast

[7] https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2020-minke-whale-unusual-mortality-event-along-atlantic-coast

[8] https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2020-north-atlantic-right-whale-unusual-mortality-event

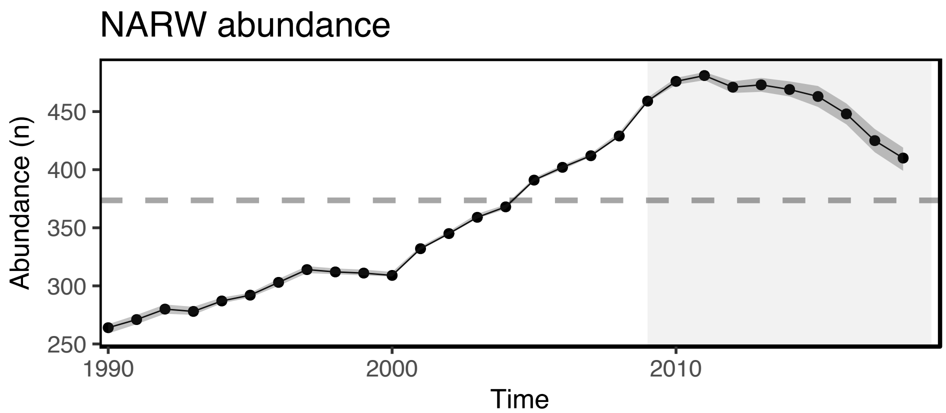


Figure 11: 1990-2018 right whale abundance estimates with 95% credible intervals. These values represent the estimated number of animals alive sometime during the year referenced and NOT at the end of the year referenced. Three known deaths were recorded in 2018, but these deaths were not reflected in the 2018 estimate because those animals were alive sometime during the year. An additional 10 known deaths occurred in 2019.

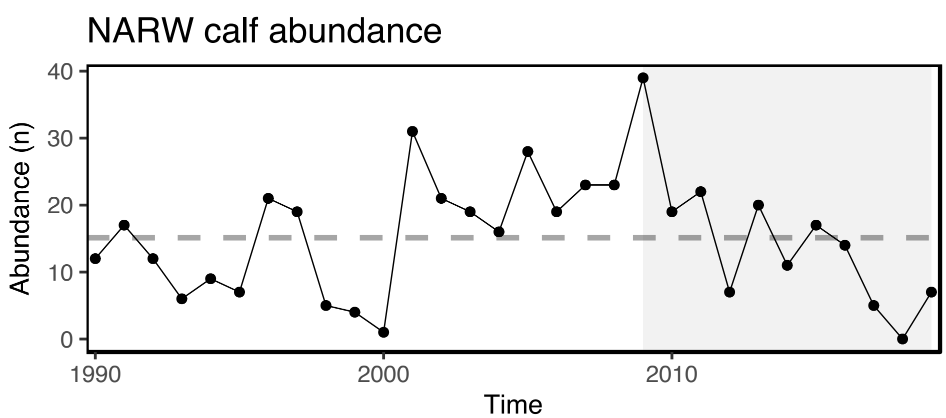


Figure 12: Number of North Atlantic right whale calf births, 1990 - 2019.

Seals (coastwide)

The best current abundance estimate of harbor seals (*Phoca vitulina*) is 75,834 (CV = 0.15), based on a survey conducted during the pupping season in 2012. A population survey was conducted in 2018 to provide updated abundance estimates and these data are in the process of being analyzed, as part of a larger trend analysis. Tagging studies of both gray and harbor seals demonstrate long-range movements throughout the Gulf of Maine and mid-Atlantic.

The number of grey seals (*Halichoerus grypus*) in U.S. waters has risen dramatically in the last 2 decades, with few observed in the early 1990s to roughly 24,000 observed in southeastern Massachusetts in 2015. Roughly 30,000 - 40,000 gray seals were estimated in southeastern Massachusetts in 2015, using correction factors applied to seal counts visible in Google Earth imagery. As of 2016, the size of the grey seal population in Canada, which is part of the same stock as the grey seals in the U.S., was estimated to be roughly 425,000, and increasing by 4% a year. In U.S. waters, the number of pupping sites has increased from 1 in 1988 to 9 in 2019. Mean rates of increase in the number of pups born at various times since 1988 at 4 of the more data-rich pupping sites (Muskeget, Monomoy, Seal, and Green Islands) ranged from -0.2% (95%CI: -2.3 - 1.9%) to 26.3% (95%CI: 21.6 - 31.4%). These high rates of increase provide further support that seals from Canada are continually supplementing the breeding population in U.S. waters. Fisheries interactions have also increased over the past 2 decades, with fewer than 10 total estimated grey seal interactions in 1993, to more than 1000 annually in four out of the last 5 years; this is the highest bycatch of any US marine mammal species.

A UME for both gray and harbor seals was declared in 2018, triggering an investigation into the cause of this event. Tests so far suggest phocine distemper virus as a potential cause, although the investigation is not yet complete. Several cases of phocine distemper in harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*) have been identified recently, and these two species have been added to the UME[9].

Current information suggests that gray seals eat primarily sand lance, hakes and flatfish, and squids, while harbor seals consume a variety of groundfish (hakes, cod, haddock, flatfish), redfish, herring and squids, however much of this information comes from juvenile animals and more research is needed on animals at other life stages. Additional analysis of gray and harbor seal diet is currently underway at the NEFSC using a variety of techniques (analysis of stomach contents, fatty acids, and DNA). This information can eventually be coupled with estimates of population abundance and consumption rates to estimate total biomass removals of fish due to pinniped predation.

Nesting waterbird abundance (Virginia)

Many nesting waterbird species on Virginia barrier islands have declined over the last 20-25 years[10]. Between 1993 and 2018, Common Terns declined by 80.6% in coastal Virginia. Considerable declines have been documented in all 3 geographic regions that supported colonies in 1993. These declines have been attributed to habitat loss linked to sea level rise. All functional groups have declined since 1993 (Fig. 13).

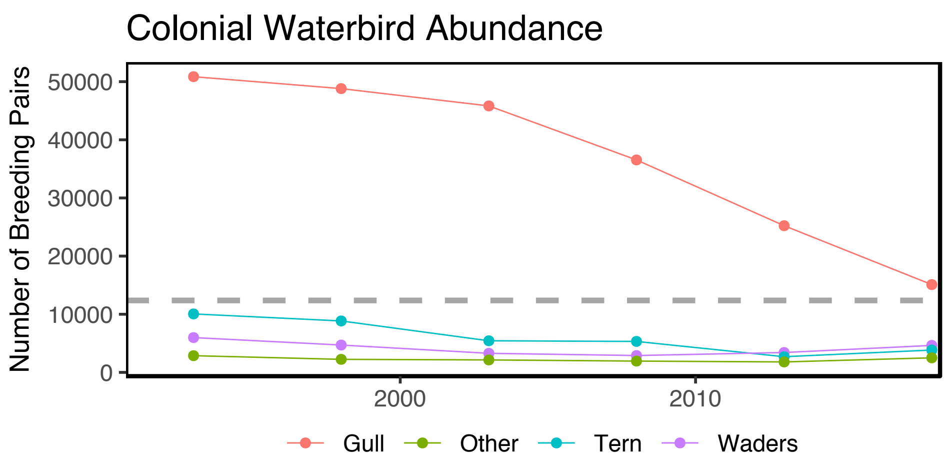


Figure 13: Functional group population estimates derived from Table 4 of Watts, B. D., B. J. Paxton, R. Boettcher, and A. L. Wilke. 2019. Status and distribution of colonial waterbirds in coastal Virginia: 2018 breeding season. Center for Conservation Biology Technical Report Series, CCBTR-19-06. College of William and Mary and Virginia Commonwealth University, Williamsburg, VA. 28 pp.

[9] https://www.fisheries.noaa.gov/new-england-mid-atlantic/marine-life-distress/2018-2019-pinniped-unusual-mortality-event-along
[10] https://ccbbirds.org/wp-content/uploads/CCBTR-19-06_Colonial-waterbirds-in-coastal-Virginia-2018.pdf

Fish and Invertebrates

Fishery management aims to keep individual harvested species within population ranges where productivity is maximized over the long-term. However, these managed species represent a subset of the full ecosystem, interacting with a wider range of predators and prey and relying on diverse habitats. Indicators in this section summarize single species status as well as tracking trends for broad categories of fish within the ecosystem, including changes in biomass, distribution, condition, and productivity. Changes in overall predator and prey levels as well as distribution have implications for managed fish productivity, fishing operations, and regional fishery management.

Stock status and aggregate distribution (coastwide)

Single species management objectives of maintaining biomass above minimum thresholds and fishing mortality below limits are being met for all but one MAFMC managed species, though the status of four stocks is unknown (Fig. 14). Bluefish biomass is below the threshold, but fishing mortality was below the limit, while mackerel biomass was below the threshold and fishing mortality was above the limit.

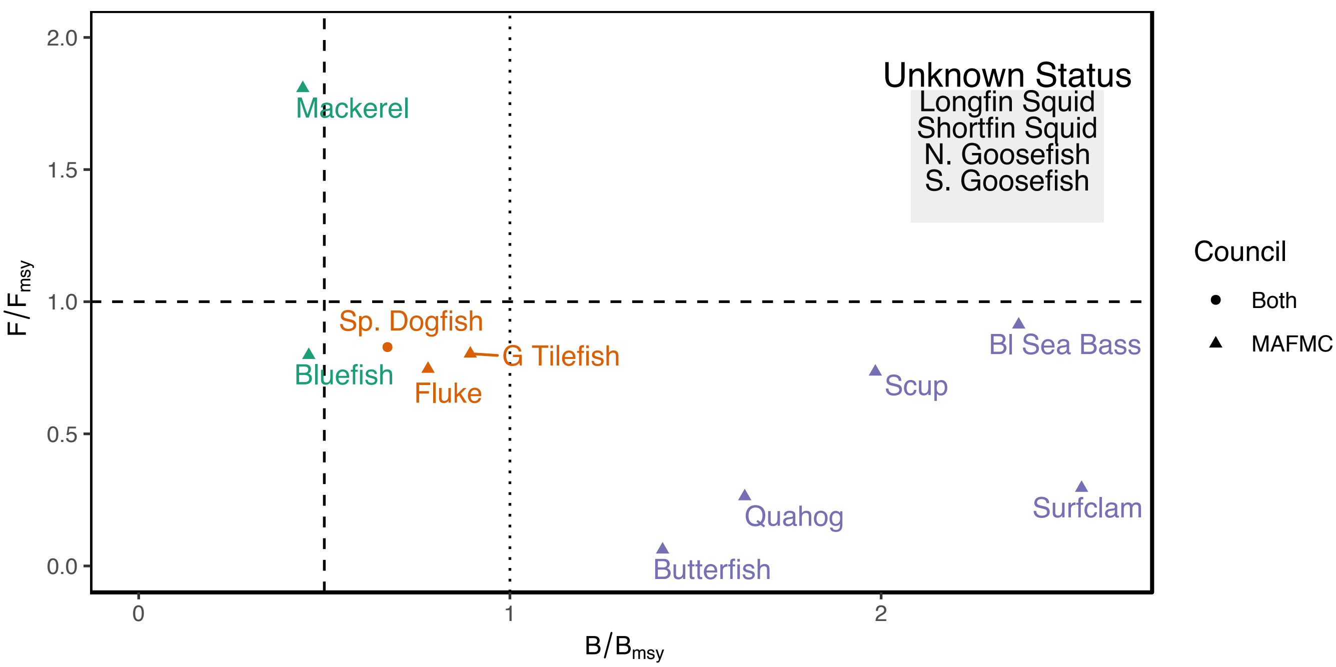


Figure 14: Summary of single species status for MAFMC and jointly managed stocks (Goosefish and Spiny dogfish).

Trends for a suite of 48 commercially or ecologically important fish species along the entire Northeast Shelf continue to show movement towards the northeast and generally into deeper water (Fig. 15). We hope to expand analysis beyond fish. Marine mammal distribution maps are available online[11]; updated maps and trends are currently being developed.

[11] https://www.nefsc.noaa.gov/AMAPPSviewer/

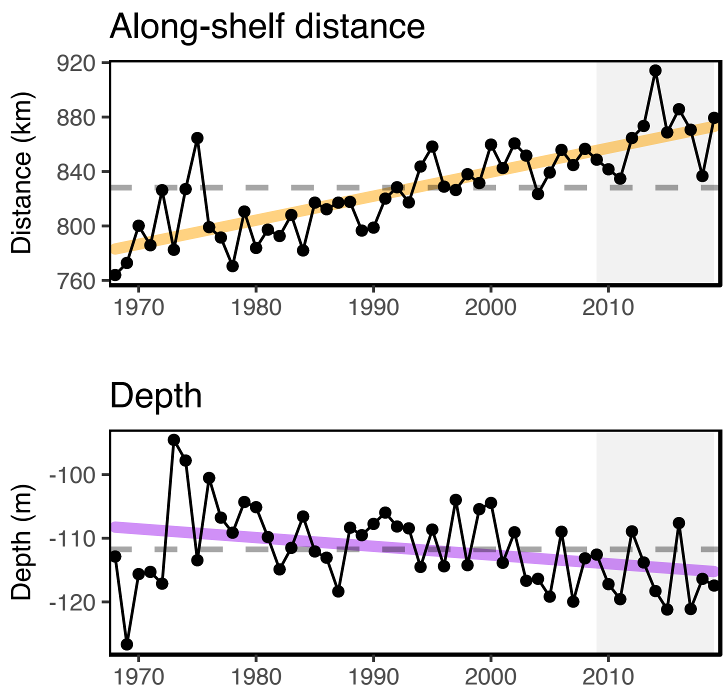


Figure 15: Aggregate species distribution metrics for fish in the Northeast Large Marine Ecosystem. Along-shelf distance measures the center of biomass along an axis oriented from the southwest to the northwest generally following the slope of coastline.

Southeast US fish occurrence (coastwide)

Preliminary analysis of NEFSC trawl survey data shows limited occurrence of South Atlantic Fishery Management Council (SAFMC) managed species groups during the fall, but almost never in spring. Lack of these species on spring surveys suggests that they are not overwintering in our region. There is no detectable trend in fall frequency of occurrence of SAFMC managed species as a group over time, nor are there detectable trends for the most common southeast US shelf species in the trawl surveys: blue runner, Spanish mackerel, chub mackerel, cobia.

Blue runner (*Caranx crysos*) was the southeast US shelf species with the highest frequency of occurrence over time. While there were no detectable trends, recent warm years have led to some observations of blue runner further north within the timing of the fall survey (Fig. 16). Four of the five the most northerly catches have happened since 2010, with the furthest north in 2012 in GOM and 3 on GB in 2018. Other indicators corroborate these observations. For example, butterfish have been observed in Gulf of Maine common tern fledgling diets between 2009-2011 and again in 2018 (New England Report Fig. 13b). As temperature and ocean circulation indicators trend toward extremes (next section), fishery management will likely face continued changes in species distribution.

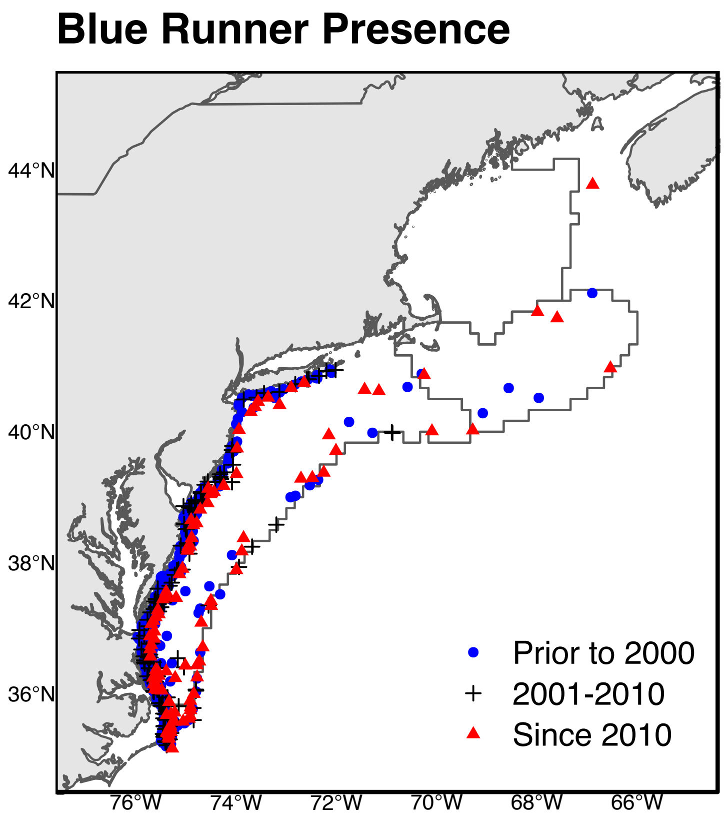


Figure 16: Blue runner presence on Northeast Shelf

Survey biomass (MAB)

Examining trends in biomass by aggregate groups rather than individual species reveals the overall stability of the trophic structure within the system. In past reports we noted several trends in aggregate biomass which might suggest an instability in this structure. This year we include information on survey biomass uncertainty as well as the mean trend. When considering variable catch between survey stations within strata for each year (Fig. 17), several previously identified trends are no longer significant, and others are unlikely to be ecologically significant. For example, our statistical analysis based on annual means suggests that benthivores had a positive trend in spring surveys. However, including sampling variability suggests that this trend is driven by uncertain estimates late in the time series.

Stability in biomass for these aggregate groups would suggest no major disturbances to overall trophic structure in the MAB. Both shelfwide and inshore surveys show stability over time for benthivores and planktivores. Similarly, piscivores and benthos are stable over time in the fall and spring, respectively. Including biomass uncertainty also demonstrates the similarity of trend and often magnitude of estimates between the NEFSC and NEAMAP surveys. These patterns will be explored in more detail using spatio-temporal analyses that include both surveys at once.

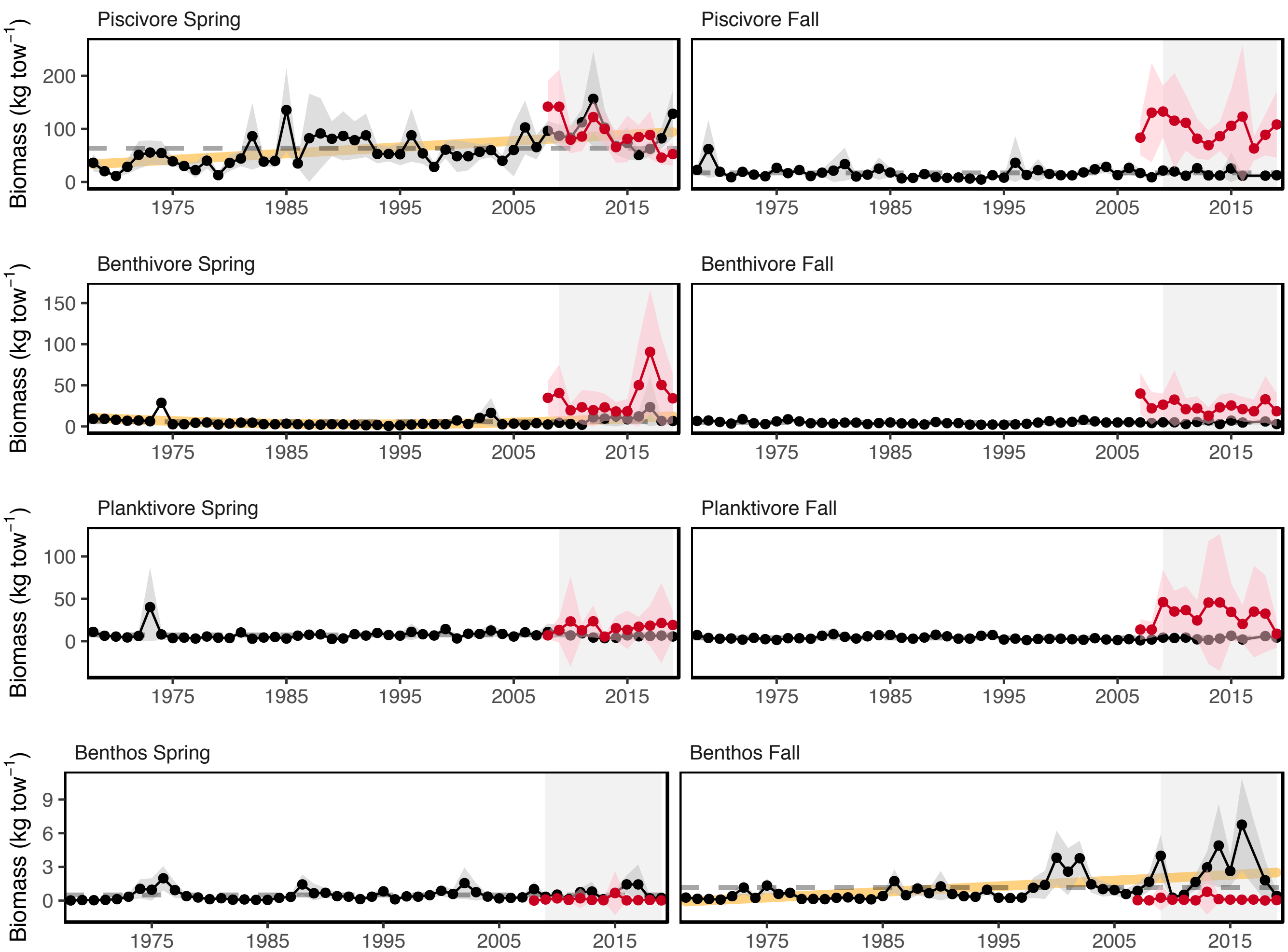


Figure 17: Spring (left) and fall (right) surveyed biomass in the Mid-Atlantic Bight. Data from the NEFSC Bottom Trawl Survey are shown in black, with NEAMAP shown in red. The shaded area around each annual mean represents 2 standard deviations from the mean.

Fish condition (MAB)

Fish condition, a measure of 'fatness' as an indicator of health and a factor that influences fecundity, is measured as the weight at a given length in relation to the average. For this report, females of all species adequately sampled in the Mid-Atlantic Bight portion of the fall NEFSC bottom trawl survey were analyzed (rather than both sexes of MAFMC managed species across the full Northeast US Shelf as in past years). Overall, condition factor has been mixed for the past decade, in contrast to overall high condition up to 2000 and overall lower condition for 2001-2010 (Fig. 18). The timing of these shifts is similar to shifts in the small-large zooplankton indicator (Fig. 36). Condition factor for some MAFMC managed species (bluefish, butterfish) were high in the MAB in 2018-2019. Black sea bass and goosefish have had generally poor condition in the MAB since 2015. Summer flounder condition has varied considerably 2016-2019 in the MAB.

Statistical analyses indicate that these trends in condition may be related to temperature changes and copepod size structure, but are not likely related to density dependence for most species. Fish condition is an important driver of population productivity as well as market prices, so we will investigate these potential links to changing habitat (temperature) and ecosystem productivity to evaluate whether they can inform decisions on annual catch limits. Work will continue over the coming year to explore relationships between fish condition and other indicators in this report (Research Spotlight, p. 2).

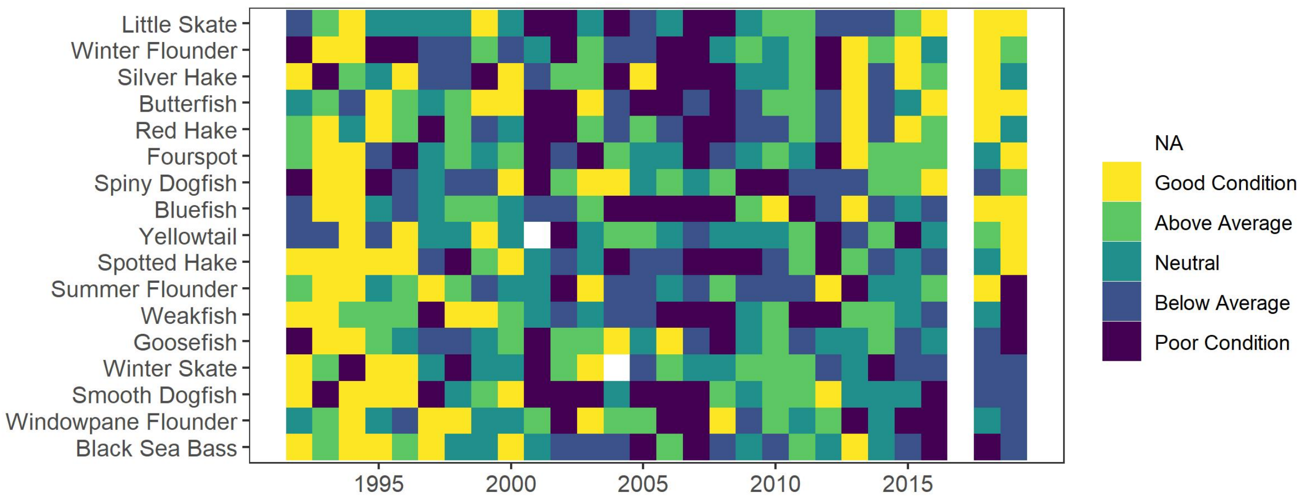


Figure 18: Condition factor for fish species in the MAB. MAB data are missing for 2017 due to survey delays.

Fish productivity (MAB)

We describe patterns of aggregate fish productivity in the Mid-Atlantic with the small fish per large fish anomaly indicator derived from NEFSC bottom trawl survey data (Fig. 19). The indicator shows that fish productivity has been relatively low in this region since 2010, although productivity across all species is trending back up towards average. Species with above average 2018 productivity in the Mid-Atlantic include witch flounder, silver hake and red hake. As for MAFMC managed species in other regions, in 2017 Summer flounder had above average production in the Gulf of Maine while butterfish had above average production on Georges Bank based on this indicator[12]. However, for 2018, it was mainly New England managed species with above average productivity in the New England systems.

[12]https://noaa-edab.github.io/ecodata/InteractiveSOE

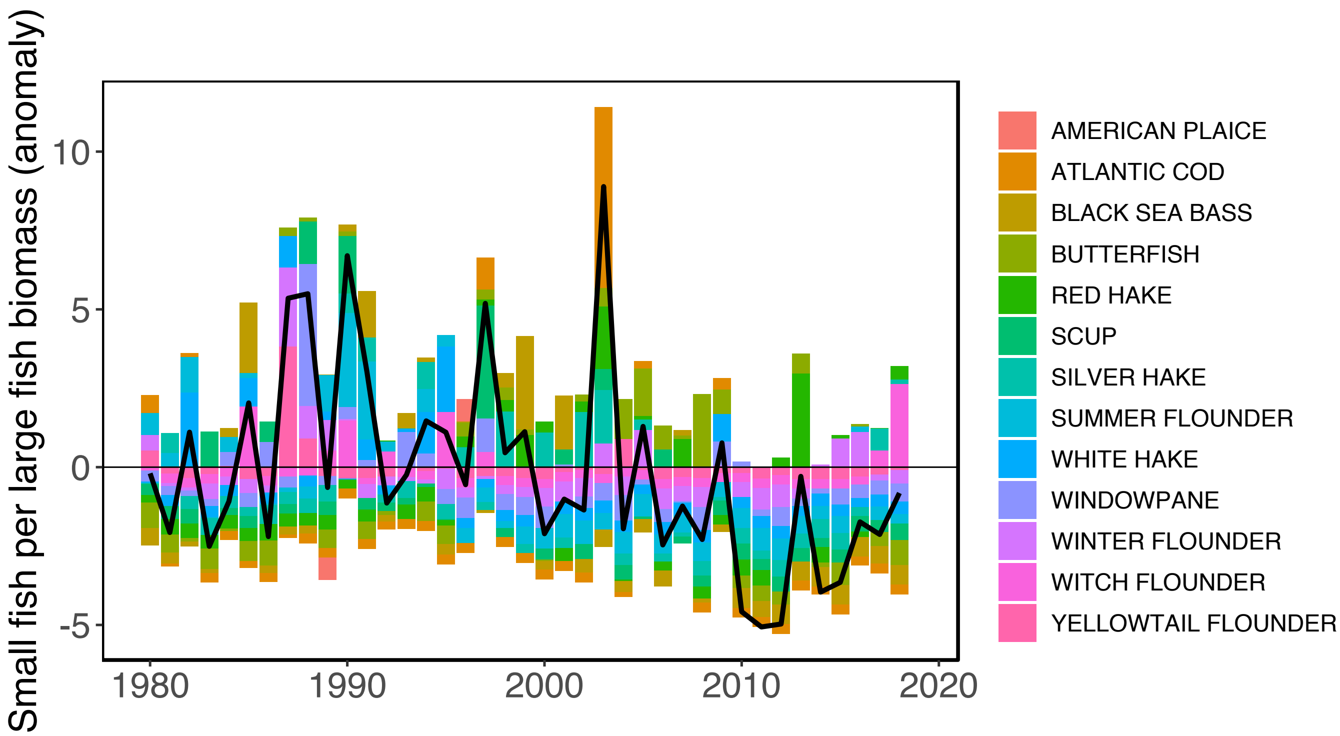


Figure 19: Small fish per large fish biomass anomaly in the Mid-Atlantic Bight. The summed anomaly across species is shown by the black line.

Forage fish energy content (coastwide)

Nutritional value of forage fishes as prey (energy content) is related to both environmental conditions and fish growth and reproductive cycles. Energy content is now being measured systematically on NEFSC trawl surveys, revealing both seasonal and interannual variation as well as differences from older measurements (Table 3). Notably, the energy density of Atlantic herring was almost half the value (5.69 +/- 0.07 kJ/g wet weight) reported in earlier studies (10.6-9.4 kJ/ g wet weight). Silver hake, sandlance, longfin squid (*Loligo* below) and shortfin squid (*Illex* below) were also lower than previous estimates [2,3]. Energy density of Alewife, butterfish and Atlantic mackerel were higher than earlier estimates. Sampling and laboratory analysis is ongoing, with the goal of continuing routine monitoring of energy density of these species.

Table 3: Forage fish mean energy density (ED) mean and standard deviation (SD) by season and year, compared with 1980s (Steimle and Terranove 1985) and 1990s (Lawson et al. 1998) values. N = number sampled.

	2017				2018				Total		1980s	1990s
	Spring		Fall		Spring		Fall					
Species	ED (SD)	N	ED (SD)	N	ED (SD)	N	ED (SD)	N	ED (SD)	N	ED	ED (SD)
Alewife	6.84 (1.62)	128	8.12 (1.46)	50	6.45 (1.21)	47	7.41 (1.6)	42	7.1 (1.62)	267	6.4	
Atl. Herring	5.34 (0.94)	122	5.77 (1.31)	52	6.69 (0.85)	51	5.41 (1.34)	50	5.69 (1.19)	275	10.6	9.4 (1.4)
Atl. Mackerel		NA	7.24 (1.13)	50	5.33 (0.86)	51	6.89 (1.07)	50	6.48 (1.32)	151	6.0	
Butterfish	7.13 (1.59)	65	7.31 (1.45)	89	4.91 (1.12)	53	8.1 (2.7)	50	6.92 (2.04)	257	6.2	
Illex	5.54 (0.4)	77	5.43 (0.51)	52	5.5 (0.52)	50	4.76 (0.79)	50	5.33 (0.63)	229	7.1	5.9 (0.56)
Loligo	5.22 (0.36)	83	5.24 (0.26)	60	4.84 (0.63)	52	4.6 (0.72)	50	5.02 (0.56)	245	5.6	
Sand lance	6.66 (0.54)	18		NA	5.78 (0.34)	60	7.99 (0.74)	8	6.17 (0.81)	86	6.8	4.4 (0.82)
Silver hake	4.25 (0.39)	189	4.42 (0.45)	50	4.19 (0.39)	50	4.55 (0.63)	50	4.31 (0.46)	339	4.6	

Habitat Quality and Ecosystem Productivity

Productivity of harvested fish and protected species, and therefore sustainability of fisheries, depends on adequate habitat, which encompasses physical and chemical conditions and biological productivity at the base of the food web. Many harvested and protected species on the Northeast US shelf occupy several distinct habitats throughout their life cycle, including estuaries, nearshore coastal, and offshore environments. The indicators in this section provide information on the changing conditions encountered by managed species in different seasons and across habitats, which may explain observed changes in species distribution and productivity. New for this year, habitat models were used to determine which species are most likely to occupy offshore wind energy development lease areas. Ultimately, a better understanding of these ecological drivers may permit proactive management in a changing system.

While management limiting nutrient inputs has significantly improved water quality in Chesapeake Bay [4], extremely high precipitation in late 2018-early 2019 led to reduced water quality. Temperature in coastal and offshore habitats continues to trend towards unprecedented levels, accompanied by alterations in ocean circulation patterns. Observed changes at the base of the food web, including timing of production and plankton community composition, affect productivity of protected and managed species in ways we do not yet fully understand.

Estuarine habitat quality (Chesapeake Bay)

Many important MAFMC managed species use estuarine habitats as nurseries or are considered estuarine and nearshore coastal-dependent (summer flounder, scup, black sea bass, and bluefish), and interact with other important estuarine-dependent species (e.g., striped bass and menhaden).

The Chesapeake Bay experienced below average salinity, caused by the highest precipitation levels ever recorded for the watershed throughout 2018 and 2019. Shifts in physical conditions changed the salinity dynamics throughout the Chesapeake Bay environment, impacting habitat conditions and biological responses for multiple species of interest, including eastern oysters, blue crab, striped bass, shad and herring, invasive blue catfish, and underwater seagrasses. Low salinity levels recorded by NOAA Chesapeake Bay Office's Chesapeake Bay Interpretive Buoy System (CBIBS) at Stingray Point showed below-average levels starting in summer 2018 and continuing through spring of 2019 (Fig. 20).

High flows during the winter and spring of Water Year (WY) 2019 came during a critical time of year when the nutrients delivered to the Bay fuel algal blooms, which can cause low dissolved oxygen in the summer. Low dissolved oxygen levels less than 2.0 mg/l (or hypoxia) are harmful to oysters, crabs and fish. The high flows, and associated nutrient loads, during WY 2019 contributed to summer dissolved-oxygen levels in the Bay that were the 3rd lowest recorded in Maryland waters, according to the Maryland Department of Natural Resources[13].

In Maryland, the Spatfall Intensity Index, a measure of oyster recruitment success and potential increase in the population, was 15.0 spat/bu, well below the 34-year median value of 39.8. Blue catfish, an invasive species in the Chesapeake, spread over the last two summers due to the lower salinity levels.

[13] https://www.usgs.gov/center-news/september-hypoxia-report

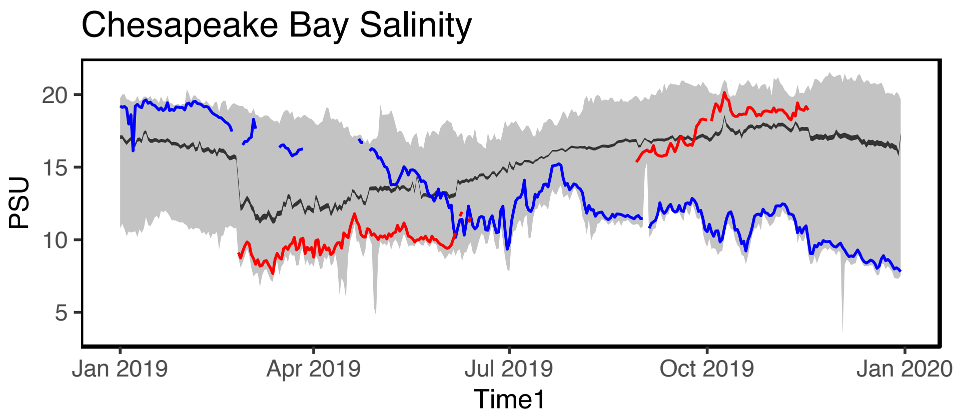


Figure 20: Salinity in Chesapeake Bay throughout 2018 (blue) and 2019 (red) as well as the daily average 2008-2019 (black) and the full observed range 2008-2019 (gray shading).

Estuarine water quality is measured in many other locations coastwide. Work is in progress to evaluate dissolved oxygen, chlorophyll, and nitrogen in NOAA-monitored estuaries throughout the Northeast US to get a better picture of important fishery nursery habitat in the region.

Oceanographic conditions (coastwide)

Globally, 2019 was the 2nd warmest year on record and the last five years have been the warmest in the last 140 years[14].

Since the 1860's, the Northeast US shelf sea surface temperature (SST) has exhibited an overall warming trend, with the past decade measuring well above the long term average (and the trendline; Fig. 21). Changes in the Gulf Stream, increases in the number of warm core ring formations and anomalous onshore intrusions of warm salty water are affecting the coastal ocean dynamics with important implications for commercial fisheries [5].

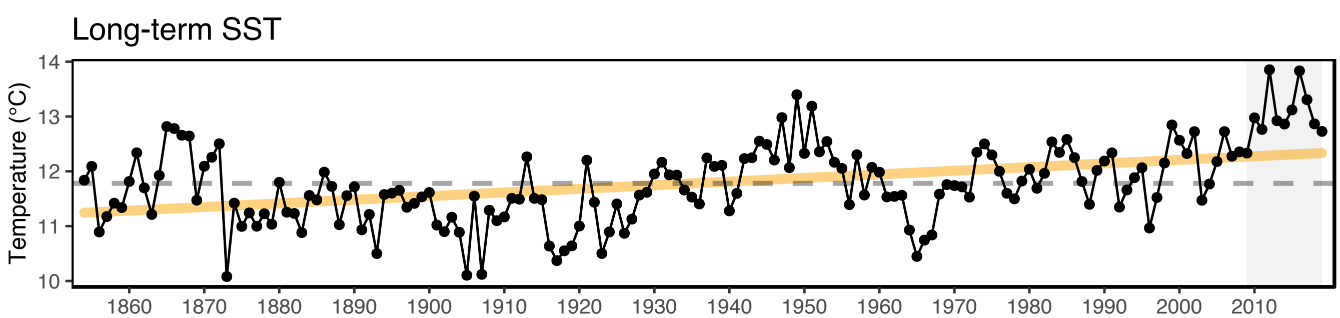


Figure 21: Average annual sea surface temperature (SST) over the Northeast US Shelf

Gulf Stream and Warm Core Rings (coastwide)

The Gulf Stream is shifting further northward and becoming more unstable. Over the last decade, the Gulf Stream Index (GSI) has an increasing trend indicating a northward shift in the Gulf Stream. In 2018, the GSI was at its most northerly position recorded since the year 1995 (Fig. 22). A more northerly Gulf Stream position is associated with warmer ocean temperature on the Northeast US shelf [6], a higher proportion of Warm Slope Water in the Northeast Channel, and increased sea surface height along the U.S. east coast [7].

[14] https://www.nasa.gov/press-release/nasa-noaa-analyses-reveal-2019-second-warmest-year-on-record

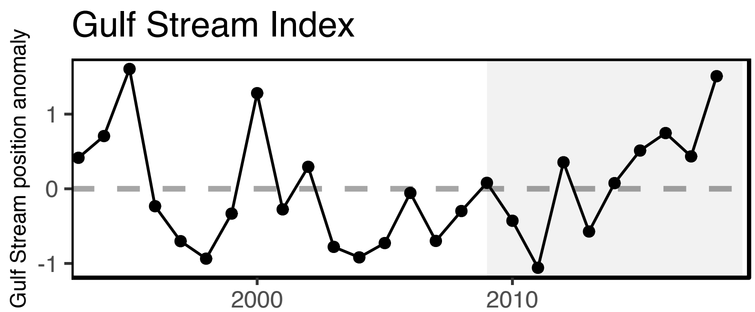


Figure 22: Index representing changes in the location of the Gulf Stream north wall. Positive values represent a more northerly Gulf Stream position.

Concurrently, large amplitude Gulf Stream meanders are forming more frequently further west [8]. There has also been a regime shift since 2000 after which there has been a significant increase in the number of warm core rings formed each year (Fig 23; [9]. The greater number of warm core rings increases the probability of intrusions of warm/salty Gulf Stream water onto the continental shelf. Any resulting accumulation of warmer water will add to the long term warming already occurring on the shelf. This in turn may lead to a response in species distributions [9].

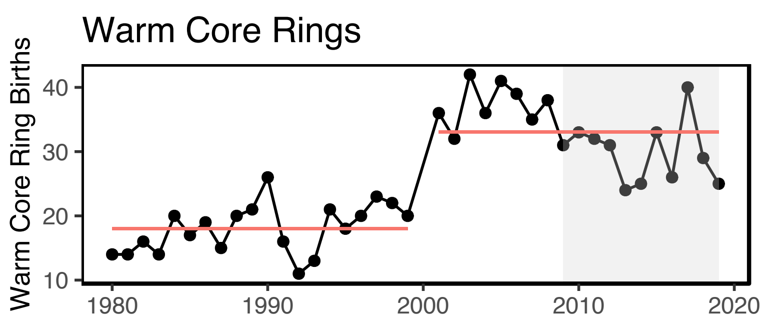


Figure 23: Interannual Variability of the WCR formation between 1980 and 2019. The regime shift (denoted by the split in the red solid line) is significant at the turn of the century. Figure reproduced with permission from Gangopadhyay, et al. (2019). 2018 and 2019 data points based on personal communication with A. Gangopadhyay (2020).

Gulf Stream Index and Labrador Slope Water (Northeast Channel)

The changing position of the Gulf Stream north wall described above directly influences oceanic conditions in the Gulf of Maine (GOM). Since the mid-2000's, warmer, saltier slope water associated with the Gulf Stream has dominated the input into the GOM at the Northeast Channel, with 2017 and 2019 consisting of 99% warm slope water (Fig. 24), the highest estimated in the time series. The changing proportions of source water affect the temperature, salinity, and nutrient inputs to the Gulf of Maine ecosystem.

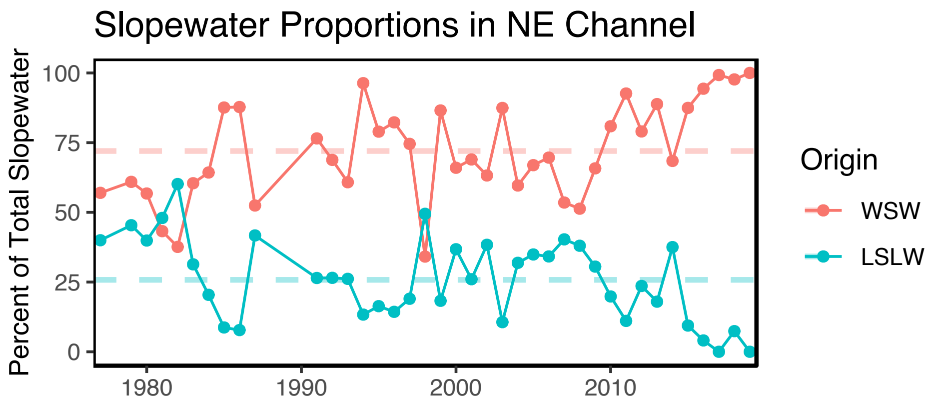


Figure 24: Proportion of Warm Slope Water (WSW) and Labrador slope water (LSLW) entering the GOM through the Northeast Channel.

Ocean temperature, surface and bottom (MAB)

The regional ocean is warming. Annual surface and bottom temperature in the MAB has trended warmer since the early 1980s; while seasonal temperatures have trended warmer in spring, summer, and fall. The 2019 winter MAB temperatures were below average, while the temperatures in spring and summer were among the top six during the satellite data record (1982-2019) and fall was above average (Fig. 25). 2019 MAB bottom temperature was just above the time series average (Fig. 26).

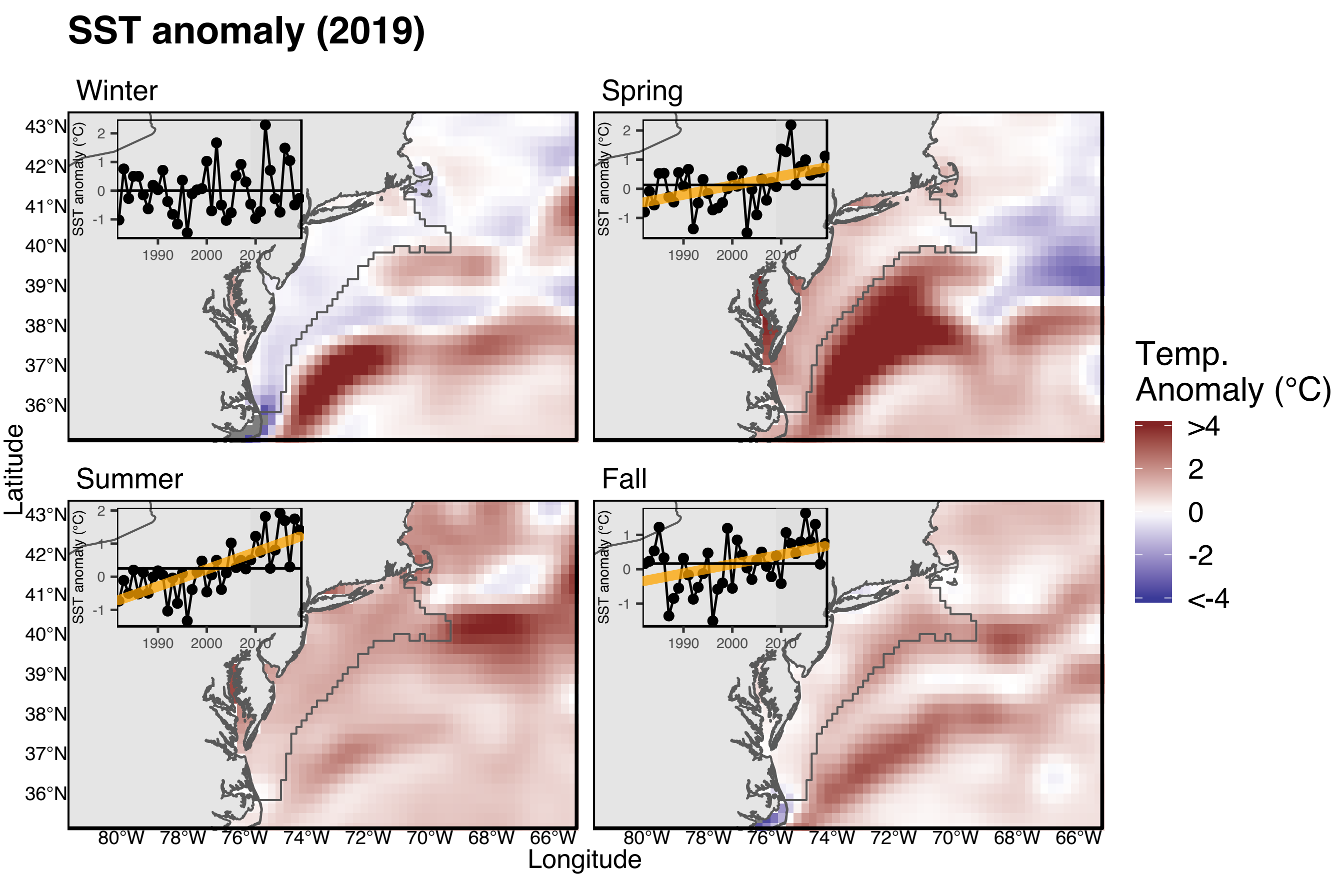


Figure 25: MAB seasonal sea surface time series overlaid onto 2018 seasonal spatial anomalies.

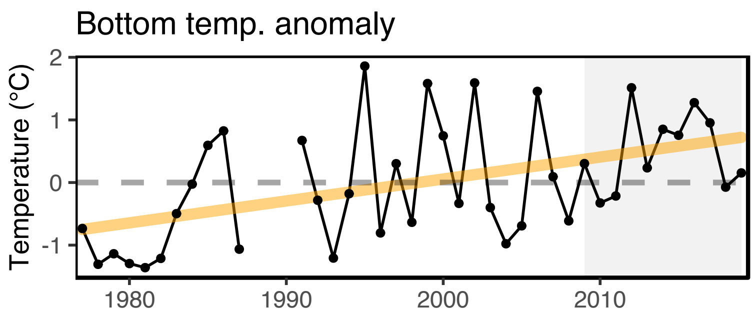


Figure 26: Annual bottom temperature in the Mid-Atlantic Bight.

Cold pool index (MAB)

Changes in ocean temperature and circulation alter habitat features such as the cold pool, a 20–60 m thick band of cold, relatively uniform near-bottom water that persists from spring to fall over the mid-shelf and outer shelf of the Middle Atlantic Bight (MAB) and Southern Flank of Georges Bank [10]. The cold pool plays an essential role in the structuring of the MAB ecosystem. It is a reservoir of nutrients that feeds phytoplankton productivity, is essential fish spawning and nursery habitat, and affects fish distribution and behavior [10]. The average temperature of the cold pool has been getting warmer over time (Fig. 27, calculated based on [11]) and the area of the cold pool is shrinking. These changes can affect distribution and migration timing for species that depend on the cold pool habitat.

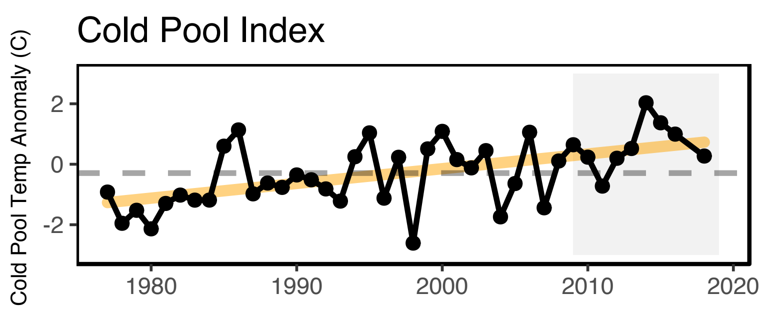


Figure 27: Temperature anomaly in cold pool region, defined as the area with a mean September-October bottom temperature <12°C from 1963 to 2013.

Marine heat waves (MAB)

Marine heatwaves measure not just temperature, but how long the ecosystem is subjected to the high temperature. They are driven by both atmospheric and oceanographic factors and can have dramatic impacts on marine ecosystems. Marine heatwaves are measured in terms of intensity (water temperature) and duration (the cumulative number of degree days) using satellite measurements of daily sea surface temperature. Plotted below are maximum intensity and cumulative intensity, which is intensity times duration. Here we define a marine heatwave as a warming event that lasts for five or more days with sea surface temperatures above the 90th percentile of the historical daily climatology (1982-2010) [12].

The strongest heatwaves on record in the Middle Atlantic Bight occurred in the winter of 2012 in terms of maximum intensity (+5.13 °C above average) and in the winter/summer of 2012 in terms of cumulative intensity (515 °C-days; Fig. 28). In 2019, the Middle Atlantic Bight experienced six distinct marine heatwaves in the spring, summer, and fall with one of the strongest events beginning on July 3 and lasting 21 days (Figs. 29, 30). Relative to prior years, this marine heatwave ranked 17th on record in terms of maximum intensity (+2.88 °C above average on Jul 22). Another strong marine heatwave began on Aug 1 and lasted 24 days, which was 20th on record in terms of cumulative intensity (46 °C-days).

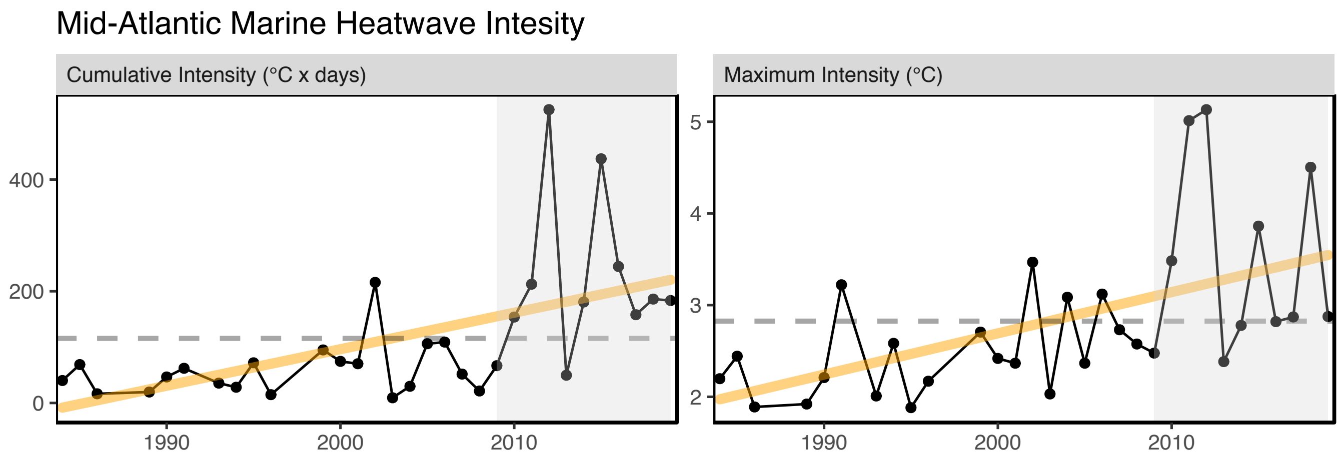


Figure 28: Marine heatwave cumulative intensity (left) and maximum intensity (right) in the Mid-Atlantic Bight.

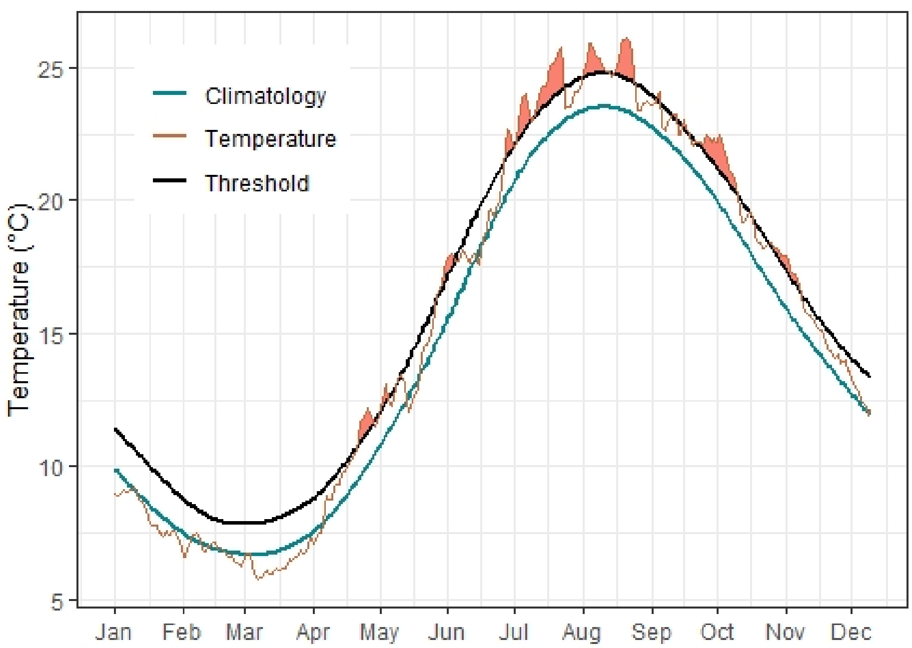


Figure 29: Marine heatwave events (red shading above black threshold line) in the Mid-Atlantic occurring in 2019.

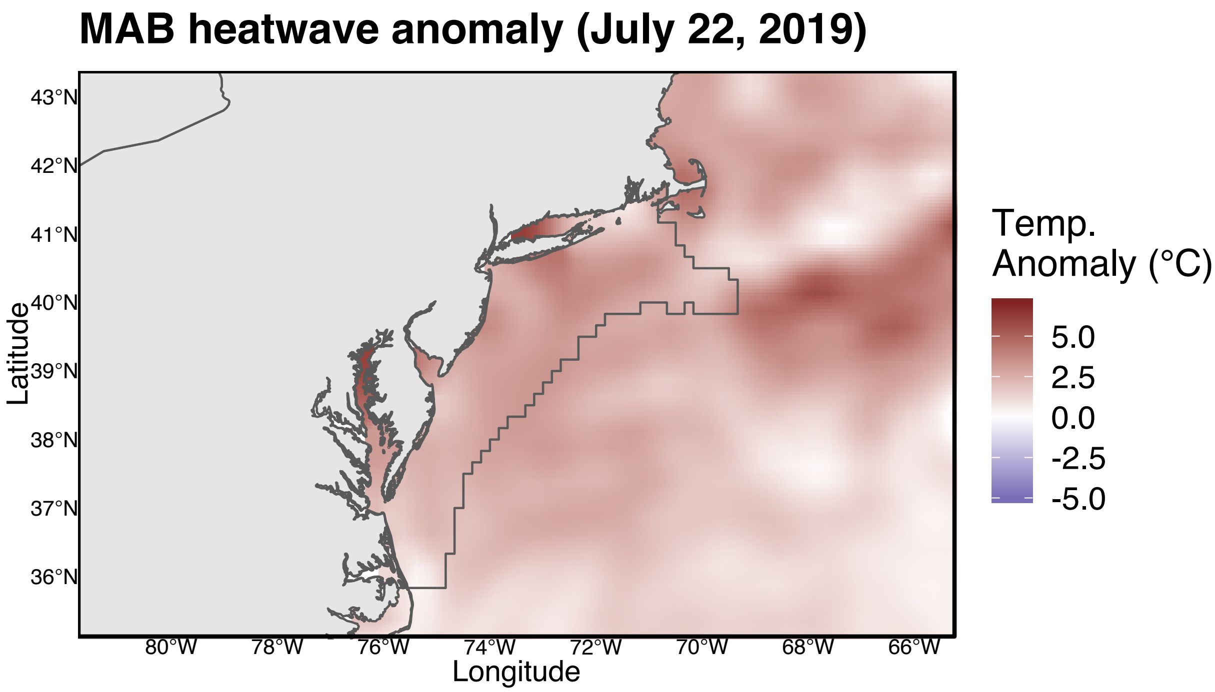


Figure 30: Maximum intensity heatwave anomaly in the Mid-Atlantic Bight occurring on July 22, 2019.

Primary production (MAB)

Phytoplankton primary production is a function of biomass, light, and temperature, and sets the overall level of potential fish and fishery productivity in an ecosystem. All primary production and chlorophyll estimates presented here are satellite-derived. There is a trend of increasing primary production in the Mid-Atlantic, primarily driven by increased summer production, which is due to warmer temperatures and increased bacterial remineralization and nutrient recycling (Fig. 31). This increased productivity is most likely from smaller-celled species that contribute less to fish production compared to larger phytoplankton. The fall of 2019 had an early above average phytoplankton bloom (Fig. 32), most likely comprised of larger diatom species, with above average blooms in the central portion of the shelf (Fig. 33).

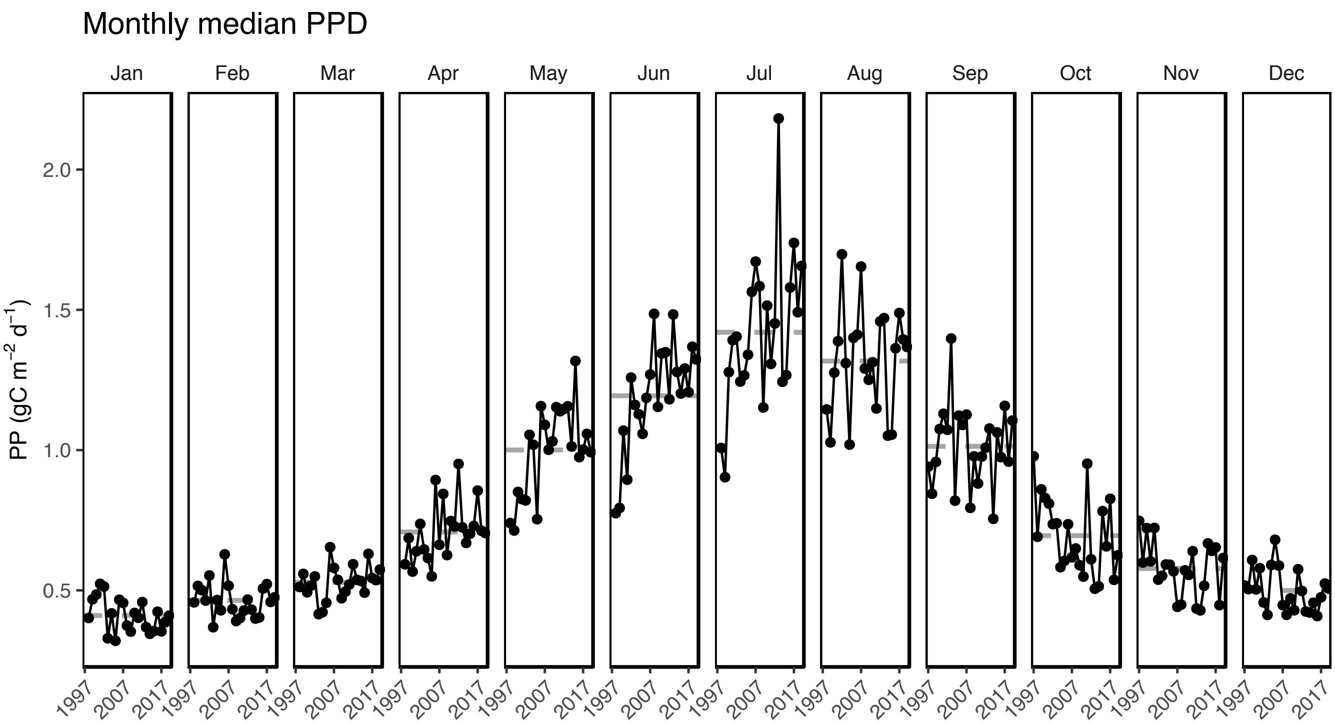


Figure 31: Monthly primary production trends show the annual cycle (i.e. the peak during the summer months) and the changes over time for each month.

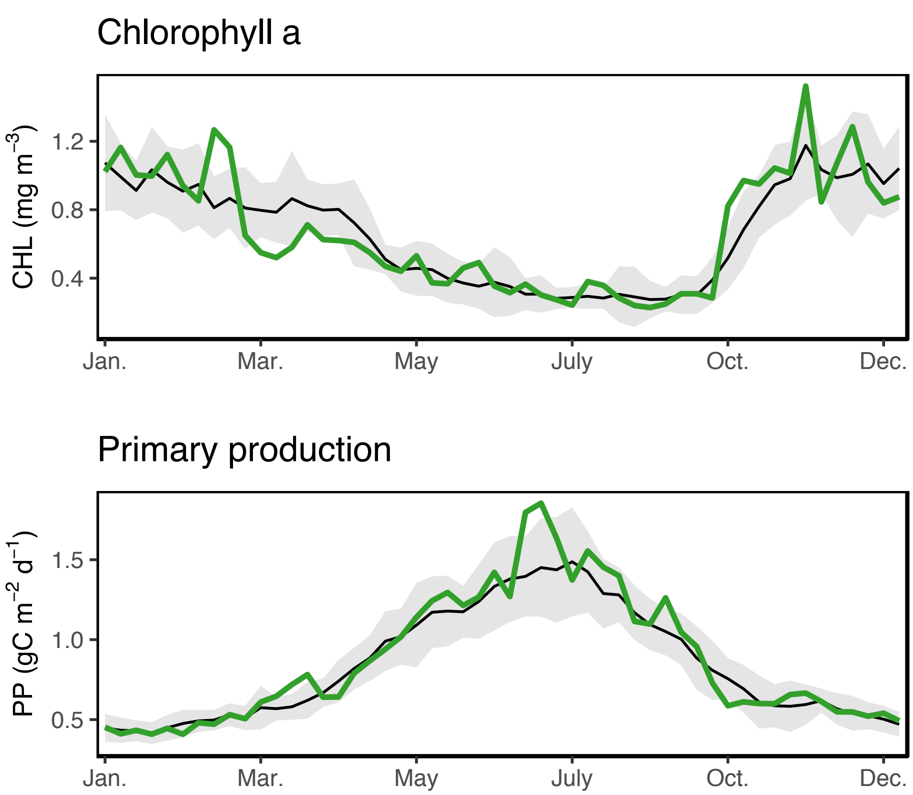


Figure 32: Weekly chlorophyll concentrations in the Mid-Atlantic are shown by the colored line for 2019. The long-term mean is shown in black, and shading indicates +/- 1 sample SD.

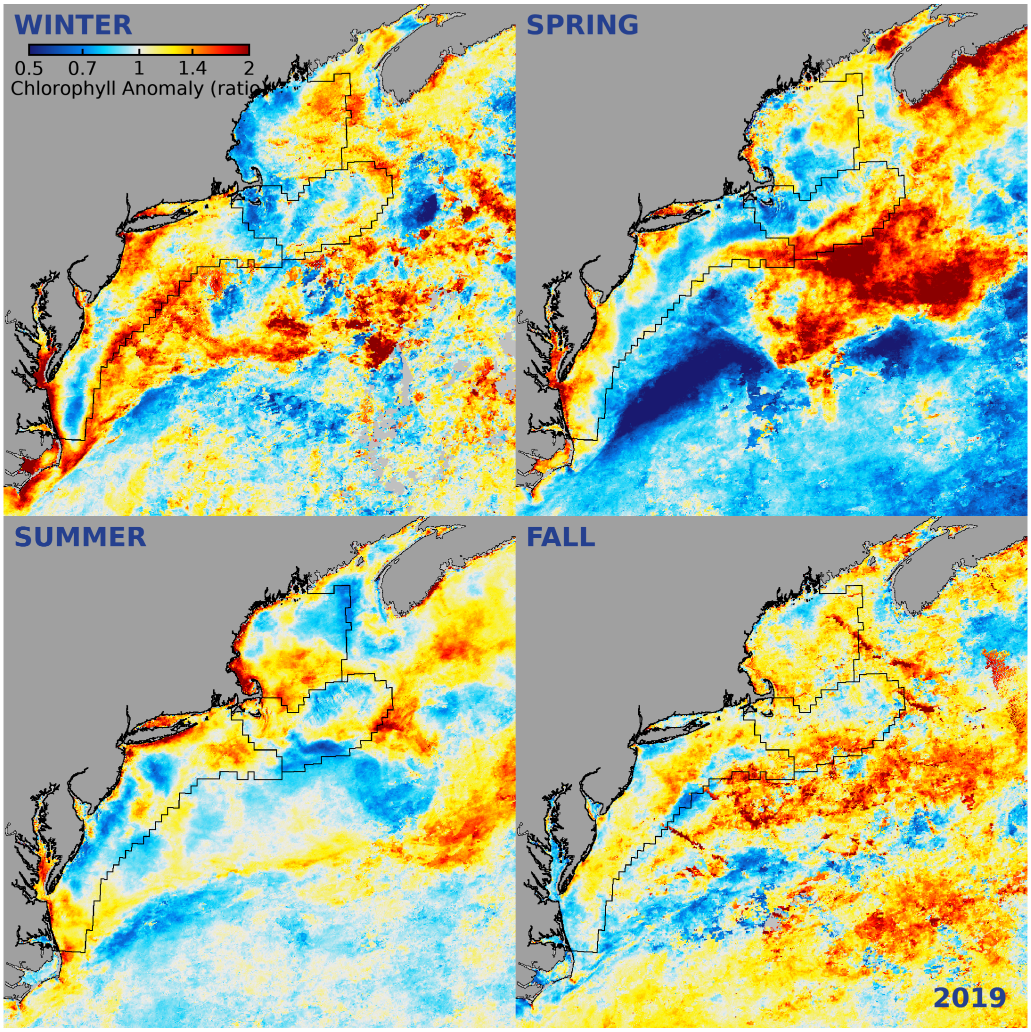


Figure 33: Seasonal chlorophyll a anomalies in 2019.

Zooplankton (MAB)

The most abundant zooplankton species in the MAB are the small-bodied species *Centropages typicus*, *Psuedocalanus* spp., and *Temora longicornis* [13]. The large-bodied species *Calanus finmarchicus* is also abundant in the MAB and is an important prey for larval fish and the North Atlantic right whale. The mean abundance of small-bodied copepods was slightly above average in 2018 (Fig. 34). This increase in abundance from the previous year was driven by all members of the small-bodied taxa above in addition to *Centropages hamatus*. While the long term trend in *Psuedocalanus* abundcance remains significantly negative in the MAB, 2018 abundance values were slightly above the long term mean and were the highest abundance values in the MAB since 1998 for this species. *Calanus finmarchicus* abundance was also higher in 2018 than in the previous 10 years, following a period of lower abundance between 2014-2017 (Fig. 34).

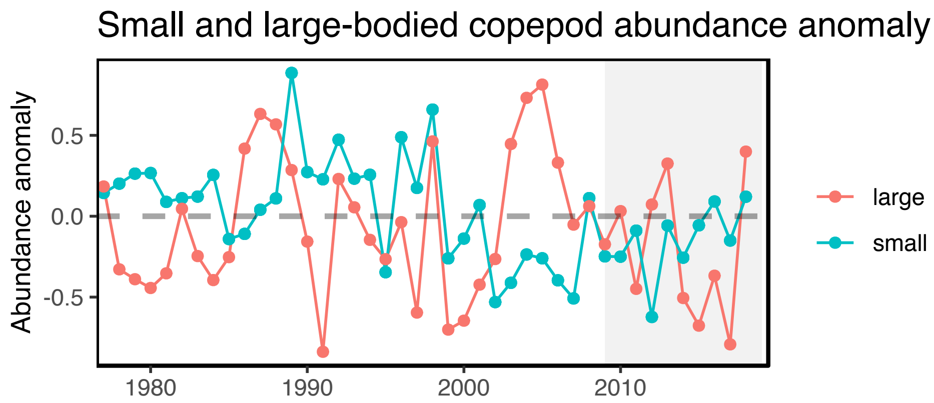


Figure 34: Abundance anomaly time series for copepod size groups found in the MAB.

Cnidarians (jellyfish) exhibit an increasing trend in abundance over the long term record, and higher than normal abundance during the 1990's when the abundance of small-bodied copepods was highest (Fig. 35). Euphausiids (krill), important prey items for many fish species, also exhibit a long term increasing trend in abundance in the MAB (Fig. 35).

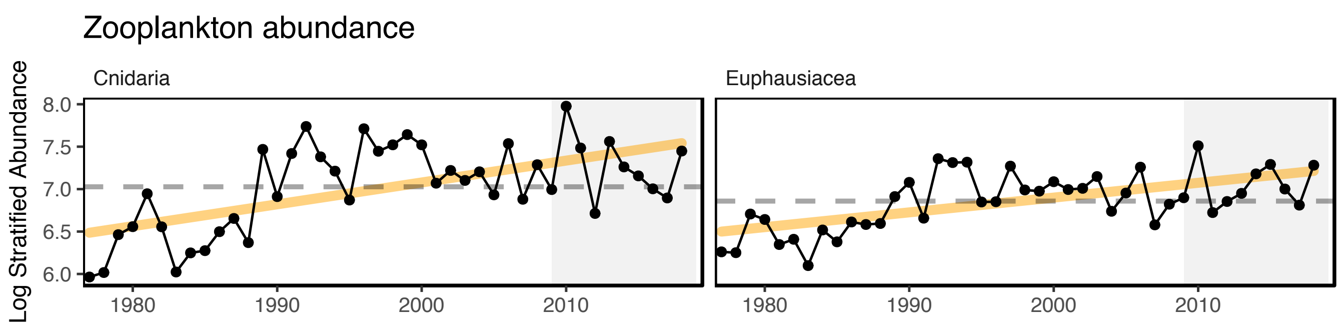


Figure 35: Stratified abundance of cnidarians and euphausiids in Mid-Atlantic Bight.

Fluctuations in primary production over time (Fig. 36) may relate to observed patterns in copeopod size structure (Fig. 34). This period also corresponds with regime shifts in fish recruitment [14].

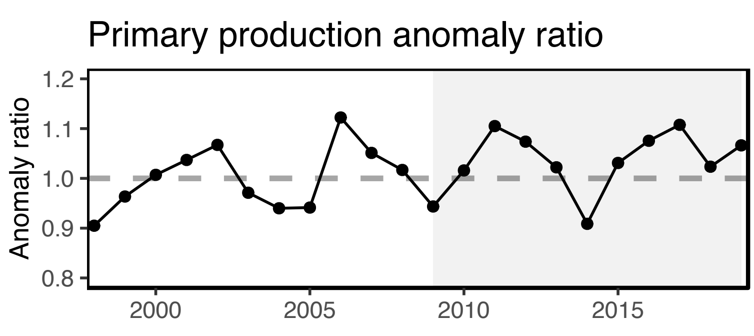


Figure 36: MAB annual primary production anomaly.

Changes in primary productivity, phytoplankton and zooplankton composition and abundance affect the food web and may be related to observed changes in fish condition, recruitment patterns, and forage fish energy content. However, more research and analyses are needed to directly link these connections. Any attempt to predict how the ecosystem will respond to changes in climate and fishing patterns ultimately will depend on understanding these connections. Our objective is to shed light on these fundamental issues and to document changes affecting human communities and the fishery ecosystem on which we depend.

Contributors

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Document Orientation

The figure format is illustrated in Fig 37a. Trend lines are shown when slope is significantly different from 0 at the p < 0.05 level. An orange line signifies an overall positive trend, and purple signifies a negative trend. To minimize bias introduced by small sample size, no trend is fit for < 30 year time series. Dashed lines represent mean values of time series unless the indicator is an anomaly, in which case the dashed line is equal to 0. Shaded regions indicate the past ten years. If there are no new data for 2018, the shaded region will still cover this time period. The spatial scale of indicators is either coastwide, Mid-Atlantic states (New York, New Jersey, Delaware, Maryland, Virginia, North Carolina), or at the Mid-Atlantic Bight (MAB) Ecosystem Production Unit (EPU, Fig. 37b) level.

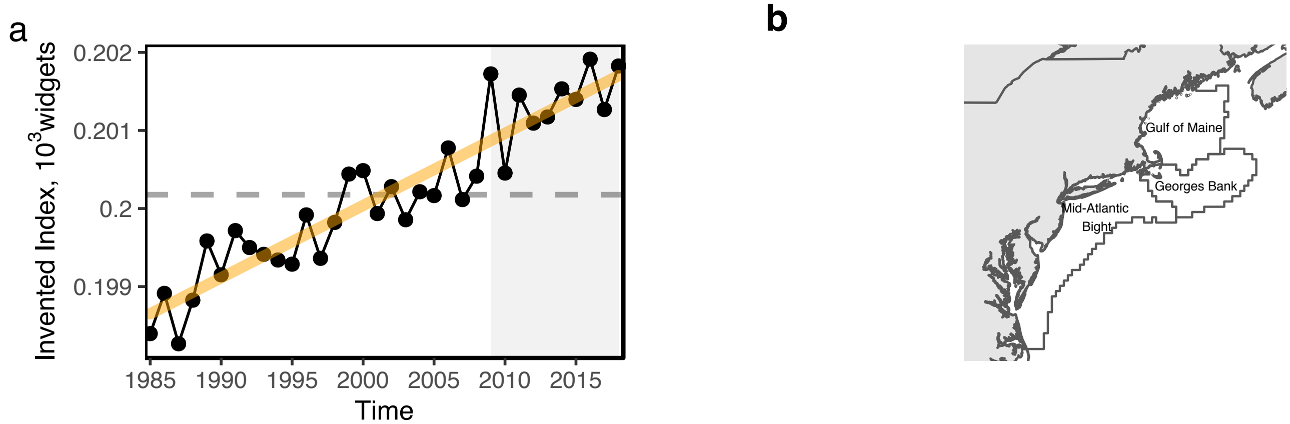

Figure 37: Document orientation. a. Key to figures. b.The Northeast Large Marine Ecosystem.

Fish and invertebrates are aggregated into similar feeding categories (Table 4) to evaluate ecosystem level trends in predators and prey.

Table 4: Feeding guilds and management bodies.

Guild	MAFMC	Joint	NEFMC	State or Other
Apex Predator	NA	NA	NA	bluefin tuna, shark uncl, swordfish, yellowfin tuna
Piscivore	bluefish, longfin squid, northern shortfin squid, summer flounder	goosefish, spiny dogfish	acadian redfish, atlantic cod, atlantic halibut, clearnose skate, little skate, offshore hake, pollock, red hake, silver hake, smooth skate, thorny skate, white hake, winter skate	fourspot flounder, john dory, sea raven, striped bass, weakfish, windowpane
Planktivore	atlantic mackerel, butterfish	NA	atlantic herring	alewife, american shad, blackbelly rosefish, blueback herring, cusk, longhorn sculpin, lumpfish, menhaden, northern sand lance, northern searobin, sculpin uncl
Benthivore	black sea bass, scup, tilefish	NA	american plaice, barndoor skate, crab,red deepsea, haddock, ocean pout, rosette skate, winter flounder, witch flounder, yellowtail flounder	american lobster, atlantic wolffish, blue crab, cancer crab uncl, chain dogfish, cunner, jonah crab, lady crab, smooth dogfish, spider crab uncl, squid cuttlefish and octopod uncl, striped searobin, tautog
Benthos	atlantic surfclam, ocean quahog	NA	sea scallop	blue mussel, channeled whelk, sea cucumber, sea urchin and sand dollar uncl, sea urchins, snails(conchs)

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