2020 State of the Ecosystem

New England

Total commercial fishery landings were scaled to ecosystem productivity. The proportion of total primary production required to support commercial landings has been declining since 2000 in both the Gulf of Maine and on Georges Bank.

Engagement in commercial fishing has increased since 2004 for moderately engaged New England fishing communities. New England commercial fisheries remain dependent on single species (Gulf of Maine lobster and Georges Bank scallops) for a majority of catch and revenue.

2018 commercial catch and revenue increased in both New England ecosystems, primarily due to lobster and scallops. Presently, 2019 lobster catch is down substantially compared with previous years, so a drop in revenue with potential ripple effects is expected.

Habitat modeling indicates that Atlantic herring, little skate, winter skate, windowpane, and winter flounder are among fish species highly likely to occupy wind energy lease areas. Habitat conditions have become more favorable over time for most of these species within wind lease areas.

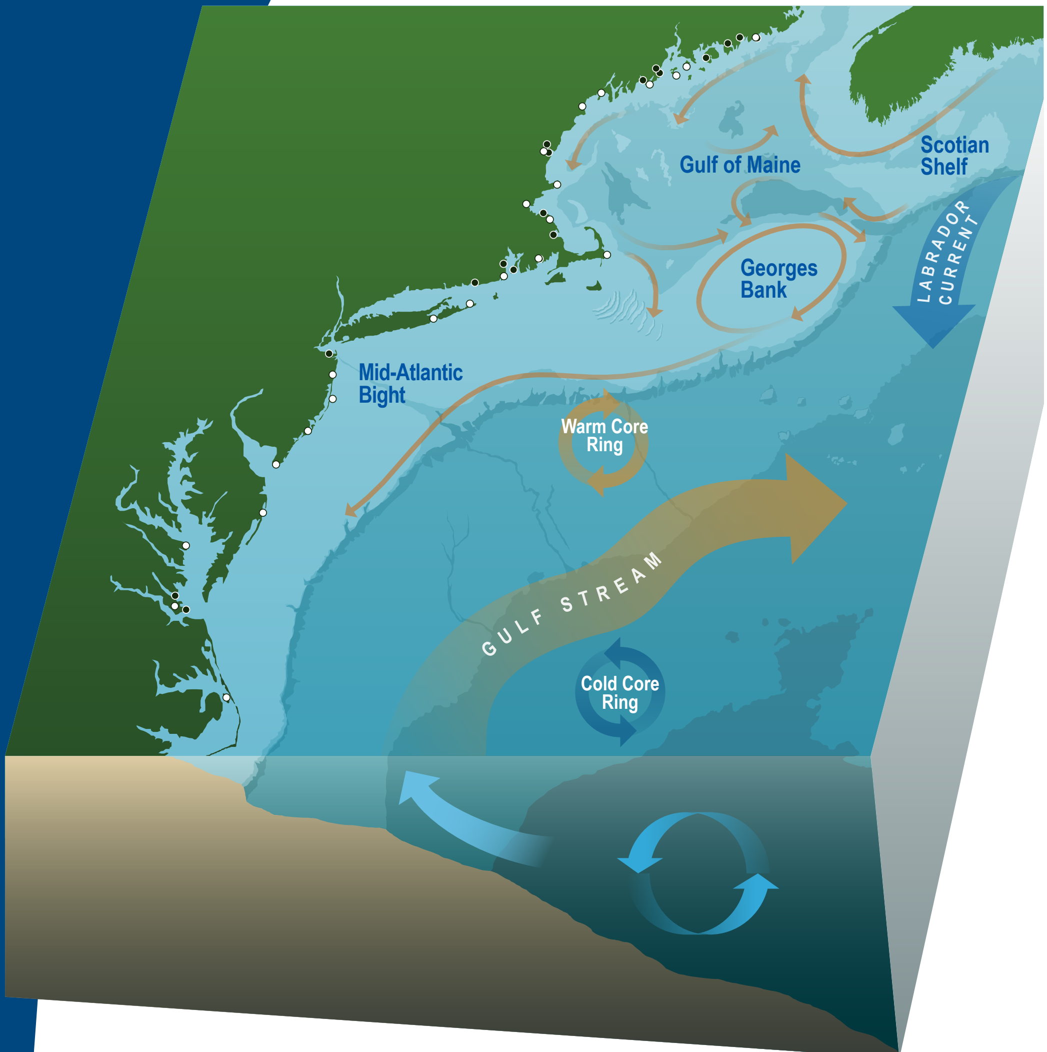
There are few apparent trends in aggregate biomass of predators, forage fish, bottom feeders, and shellfish sampled by trawl surveys, but haddock biomass is high. We continue to see a northward shift in aggregate fish distribution along the Northeast US shelf and a tendency towards distribution in deeper 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.

The Northeast US shelf ecosystem continues to experience changes in ocean circulation. The Gulf Stream is increasingly unstable, with more warm core rings resulting in higher likelihood of warm salty water and associated oceanic species coming onto the shelf. Almost no cold Labrador slope water has entered the Gulf of Maine for the past 3 years.

The Gulf of Maine has been markedly different in the past decade than in the 2000s. Deep water and surface temperatures are high, and marine heat waves have been much more common since 2010. Small bodied zooplankton are now more abundant than large fatty zooplankton favored by North Atlantic right whales. Spring blooms have been below average since 2013.

Georges Bank has also experienced warming and marine heat waves over the past decade. In 2019, a number of warm core rings surrounded the Georges Bank in summer, resulting in above average temperatures at the edge of the bank. Georges Bank phytoplankton biomass was average in 2019. Georges has also been dominated by small-bodied zooplankton for the past decade.



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 Council, 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. 45a), categorization of fish and invertebrate species into feeding groups (Table 4), and definitions of ecological production units (EPUs, including the Gulf of Maine (GOM) and Georges Bank (GB); Fig. 45b) are provided at the end of the document.

Table 1: Established ecosystem-scale objectives in New England

Objective Categories	**Indicators reported here**
Seafood Production	Landings by feeding group
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 group from surveys
Productivity	Condition and recruitment of managed species, Primary productivity
Trophic structure	Relative biomass of feeding groups, Zooplankton
Habitat	Continental shelf 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 the GOM and GB ecological production units separately where possible.

Fisheries remove a proportion of the total energy available to the ecosystem (primary production; see details below). Since 2000, the proportion of energy removed by fisheries has been declining in New England (Fig. 1), because commercial landings have been steady while primary production has increased slightly.

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

The periodicity in the PPR index (Fig. 1) reflects both the periodicity in primary production (see Fig. 39) and the periodicity in the closed areas for scallop harvest.

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

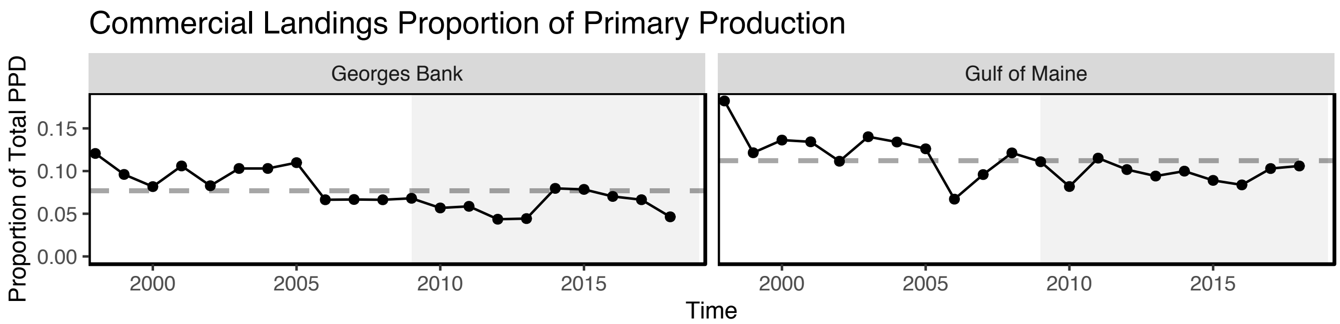


Figure 1: Proportion of primary production required (PPR) to support the commercial landings on Georges Bank (left) and in the Gulf of Maine (right). Included are the top species accounting for 80% of the landings in each year, with 15% transfer efficiency assumed between trophic levels.

Gulf of Maine

Although the demand of fisheries in terms of total ecosystem energy is decreasing, the social-ecological system is becoming more reliant on a smaller number of species, inducing system risk through a secondary pathway. A long term significant decrease in NEFMC managed species revenue was offset by non-NEFMC managed species (Fig. 2), primarily lobster, as indicated by the focal component-level Bennet Volume Indicator for benthivores (Fig. 3). Presently, 2019 lobster catch is down substantially compared with previous years, so a drop in revenue is expected.

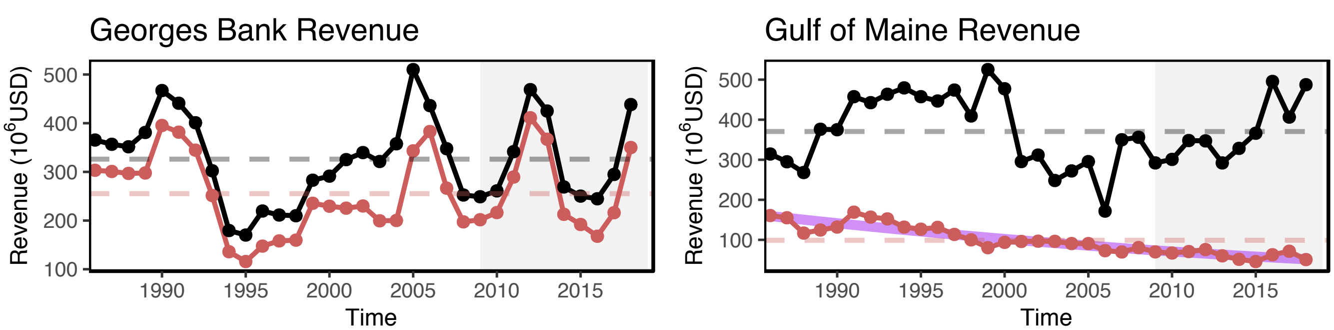


Figure 2: Total commercial revenue (black) and revenue from NEFMC managed species (red) on Georges Bank (left) and in the Gulf of Maine (right).

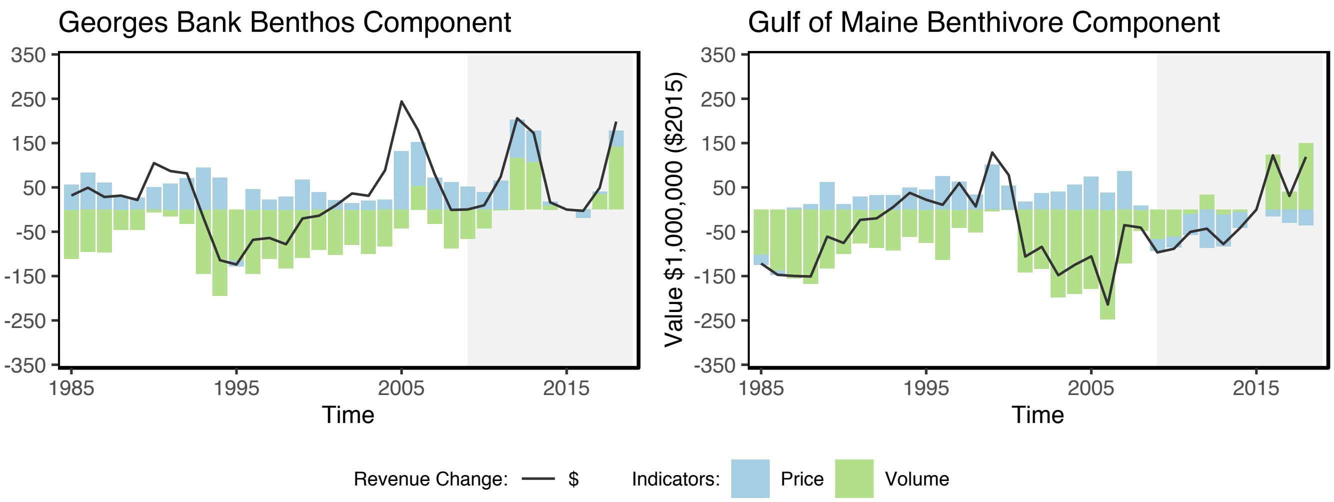


Figure 3: Revenue change from the 2015 base year in 2015 dollars (black), Price (PI), and Volume Indicators (VI) for commercial benthos landings on Georges Bank (left) and for commercial benthivore landings in the Gulf of Maine (right)

There is a concurrent significant decrease in NEFMC-managed commercial seafood production (non-bait landings; Fig. 4), with piscivores, planktivores, and NEFMC-managed benthivores also showing long term negative trends (Fig. 5). The opposite trends of non-NEFMC managed benthivores (increasing) and NEFMC managed benthivores (decreasing) is notable in the GOM (Fig. 5). The overall benthivore increase is driven by state-managed fisheries, with highly dependent and thus highly vulnerable ports in Maine relying on lobster. This trend is a continuation on the reliance on a small number of species, which could induce additional risk in the social system. Given the previously highlighted drop in lobster landings to date in the 2019 fishing year, there are likely to be substantial impacts on the horizon, particularly on fishermen in the Gulf of Maine.

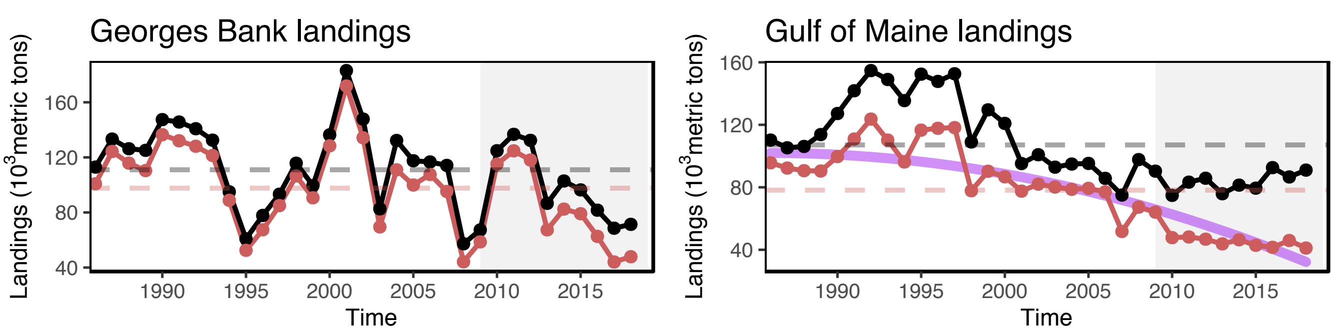


Figure 4: Total commercial seafood landings (black) shown with NEFMC managed seafood landings (red) on Georges Bank (left) and in the Gulf of Maine (right).

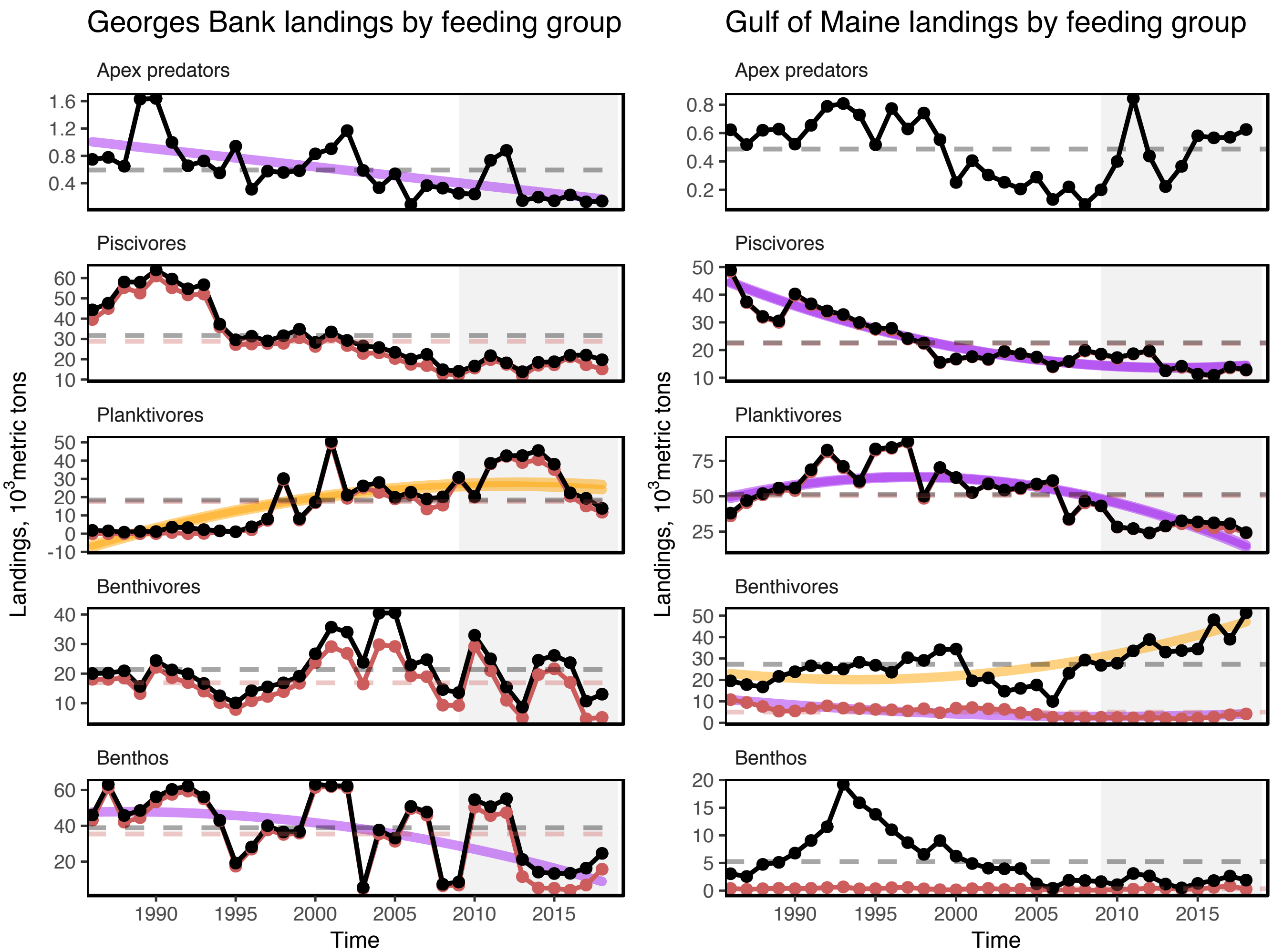


Figure 5: NEFMC managed species landings (red) and total commercial landings (black) by feeding group on Georges Bank (left) and in the Gulf of Maine (right).

Georges Bank

In contrast with the GOM, GB total landings and revenue have no long term trends for NEFMC-managed species (Fig. 4). Rather, fluctuations in GB total revenue and in particular benthos landings (Fig. 5) may be associated with rotational management for scallops altering effort between the GB and MAB ecological production units. Benthos landings have declined over the long term on GB, though they have increased since 2015 and include both scallops (NEFMC managed) and clams (MAFMC managed; Fig. 5). Planktivore landings on GB have increased over the long term (mainly reflecting Atlantic herring), but have returned to the long term average in 2016-2018. Scallop revenue continues to play an oversized role in Georges Bank dynamics. 2018 revenue was above the long term mean, driven mainly by volume of benthos landings revenue (Fig. 3).

New England-wide

Reliance on single species likely represents heightened risk to fishing communities, particularly along the coast of Maine and the South Coast in MA in ports which are highly engaged and/or reliant on commercial fishing. This risk is heightened by the moderate to high climate vulnerability of crustaceans and shellfish, which face risks from ocean acidification as well as increased temperature [1]. The decrease in lobster landings to date in 2019 thus has the potential for substantial impacts on these communities.

Commerical fishery engagement measures the number of permits, dealers, and landings in a community[3]. The trend in the number of New England fishing communities that were moderately to highly engaged (blue, green and red bars) has shown an increase since 2004 (Fig. 6). Significant changes in engagement scores have been observed in medium-highly engaged communities. The average engagement score for medium-highly engaged communities decreased from 2004 to 2011, and then has bounced back since 2011. These changes may be driven by the changes in value landed for primary species such as sea scallops and lobsters in this group of communities.

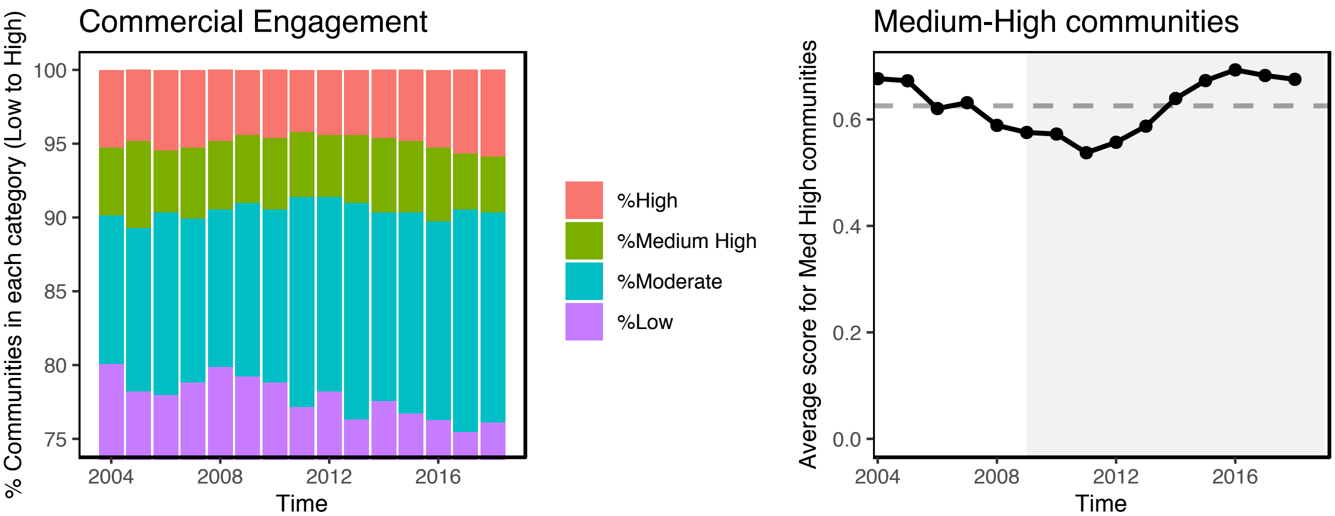


Figure 6: Commercial engagement scores (total pounds landed, value landed, commercial permits, and commercial dealers in a community) for New England fishing communities, 2004-2018.

Commercial fleet diversity indices were updated with 2018 data and remain near the long term average[4].

Similar to commercial fisheries, indicators show no significant trends in diversity of recreational species caught in New England, and recreational fleet effort diversity has not changed over the long term (Fig. 7).

[3] https://www.fisheries.noaa.gov/national/socioeconomics/social-indicator-definitions#fishing-engagement-and-reliance-indices
[4] https://noaa-edab.github.io/ecodata/human_dimensions#new_england

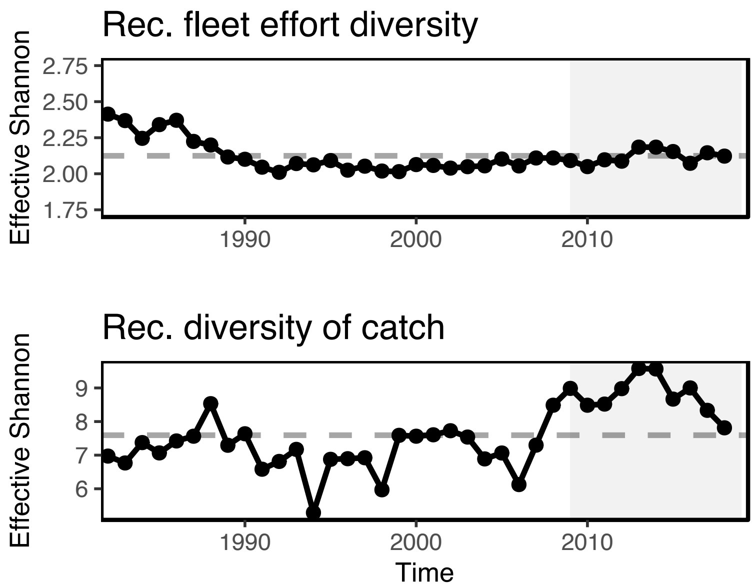


Figure 7: Recreational effort diversity and diversity of recreational catch in New England.

Recreational seafood production (kept fish) decreased in 2018 to the lowest level since 1996, with the drop primarily driven by decreases in Atlantic mackerel, striped bass, haddock, bluefish, and cod (Fig. 8)).

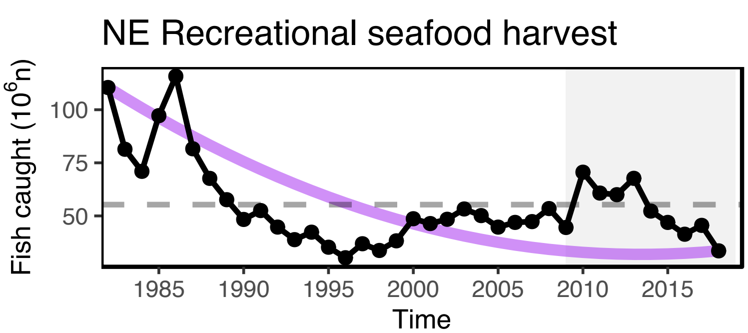


Figure 8: Total recreational seafood harvest in New England.

Updated indicators for recreational opportunities (effort days) show general increases since the 1990s, peaking in the early 2010s and declining since then. This is similar to previously reported trends (Fig. 9).

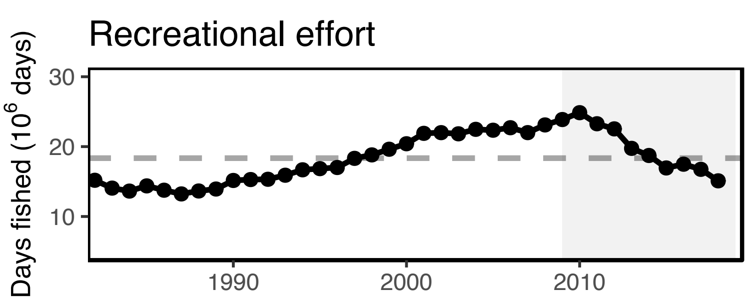


Figure 9: Recreational effort in the New England.

Additional social indicators for New England communities are available online[5].

Fish habitat overlap with offshore wind lease areas (coastwide)

Fish habitat modeling based on NEFSC bottom trawl surveys [2] indicates that Atlantic herring, little skate, winter skate, windowpane, and winter flounder are among fish species highly likely to occupy wind energy lease areas (Fig. 10). Habitat conditions for most species have become more favorable over time within wind lease areas (increasing trend in probability of occupancy). However, some species probability of occupancy has tended to decline, for example Atlantic herring. 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 Mid-Atlantic Bight, 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/

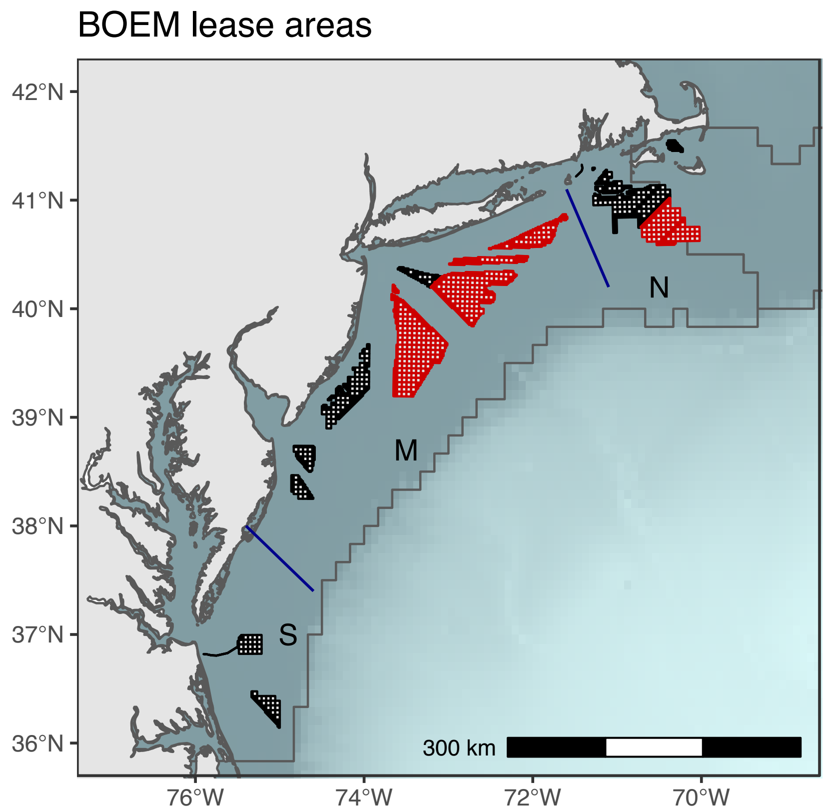


Figure 10: Map of BOEM existing (black) and proposed (red) lease areas in North (N), Mid (M) and South (S) portions of the coast as of February 2019.

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 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

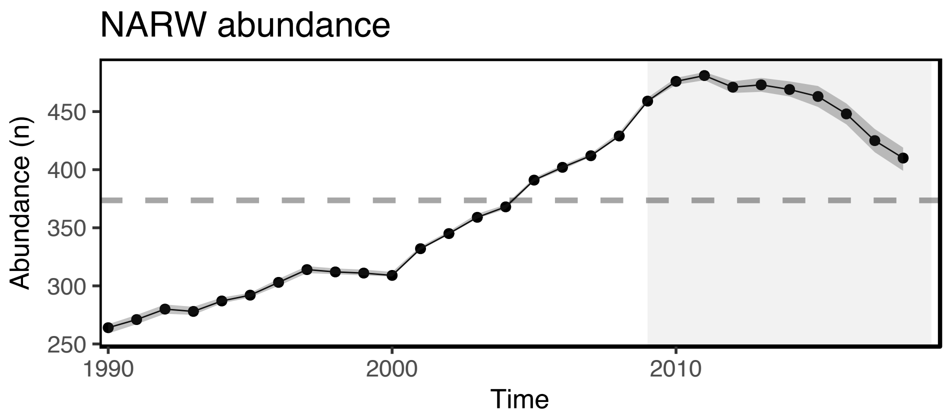


Figure 11: 1990-2018 right whale abundance estimates with 95% credible intervals. These values represent the estimated number of animals alive sometime during the year referenced and NOT at the end of the year referenced. Three known deaths were recorded in 2018, but these deaths were not reflected in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

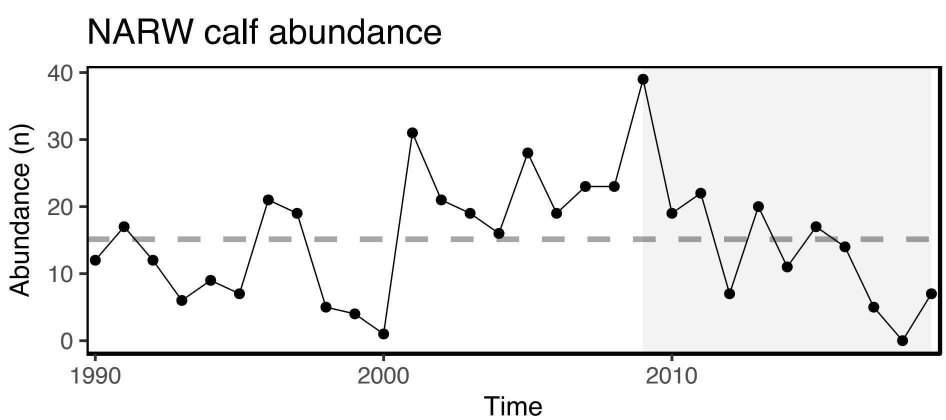


Figure 12: Number of North Atlantic right whale calf births, 1990 - 2019.

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.

Common terns (GOM)

Seabird breeding colonies in the GOM are monitored and managed to promote recovery of formerly harvested species. Common terns are well-monitored and are considered good nearshore ecosystem indicators due to their wide distribution and generalist diet. Common terns breed on islands throughout the Gulf of Maine, feeding on a wide range of invertebrates and fish including Atlantic herring, juvenile (mainly white) hakes, and sand lance (Fig. 13). As surface feeding birds, terns are sensitive to vertical distribution of prey as well as nearshore conditions in general, with a foraging distance of 10-20 km from a nesting colony.

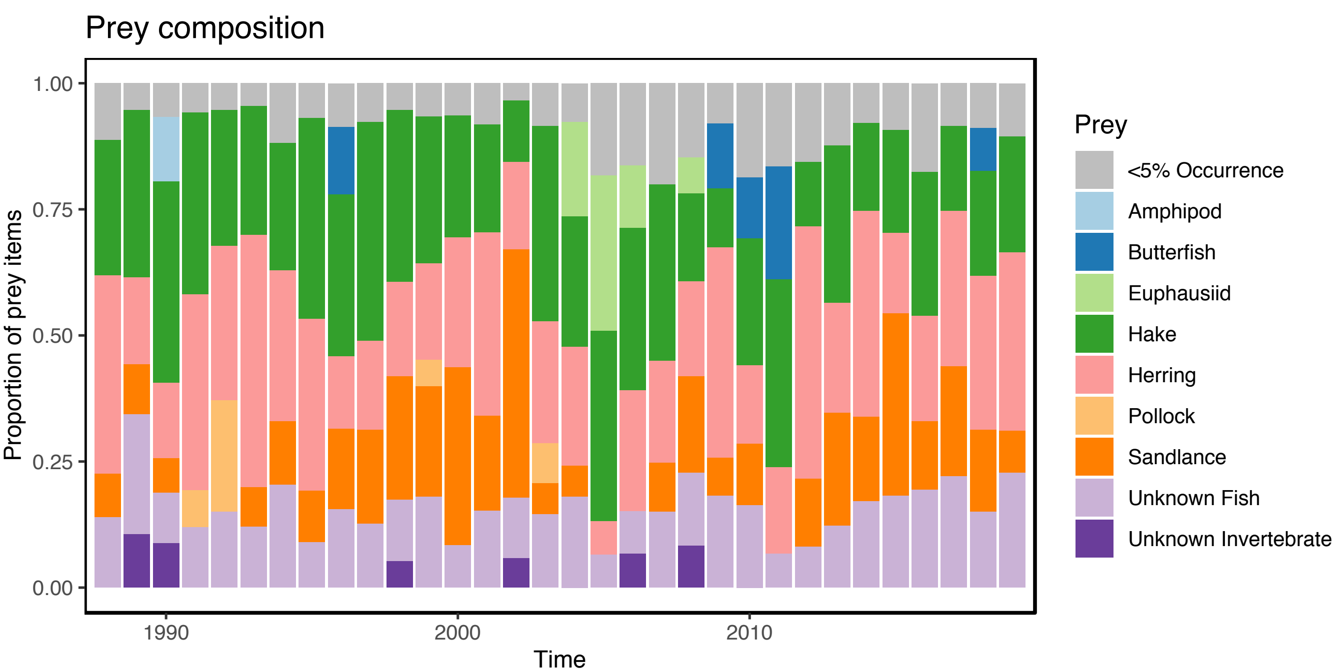


Figure 13: Prey frequencies in the diets of common tern observed across the seven colonies in Gulf of Maine. Prey occurring in <5 percent of common tern diets were aggregated for clarity.

GOM common tern average productivity (fledglings per nest) across 7 colonies has varied over time (Fig. 14). The pattern is similar to that observed for fish condition (high before 2000, lower 2001-2009, higher/variable since 2010; Figs. 22-23). Productivity is affected by both food and predation mortality. While data on predation is lacking, productivity lows in 2004-2006 were associated with euphausiids (Fig. 13), and the 2018 productivity low with

[9]https://www.fisheries.noaa.gov/new-england-mid-atlantic/marine-life-distress/2018-2019-pinniped-unusual-mortality-event-along

butterfish in tern diets (Fig. 13). The presence of butterfish in tern diets reflects the extension of this warm water species into GOM. Due to their thin, deep body form, butterfish are often difficult for small seabird chicks to ingest and swallow, causing chicks to starve and/or parent birds to increase foraging effort.

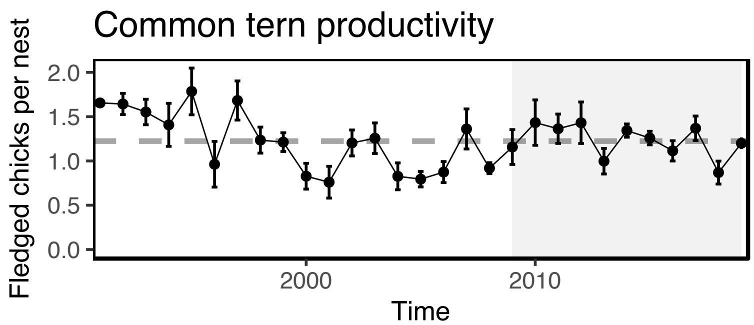


Figure 14: Mean common tern productivity at nesting sites in Gulf of Maine. Error bars show +/- 1 SE of the mean.

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)

Fishery management objectives are being met for 20 (including 6 skate) stocks at the single species level. Stocks in Fig. 15 which are above the F threshold (horizontal line) are experiencing overfishing (F > Fmsy). Stocks in Fig. 15 which are below the B threshold (dashed vertical line) are overfished (B < 0.5Bmsy). For the stocks with either missing F or B values in Fig. 15, additional information has been used to determine overfishing and overfished status. Official stock status for New England stocks[10] lists 4 stocks subject to overfishing (GOM cod, GB cod, southern red hake, and GB yellowtail flounder), and 14 stocks as overfished (GOM cod, GB cod, southern red hake, GOM/GB white hake, Atlantic halibut, Atlantic wolffish, ocean pout, thorny skate, GOM/GB windowpane flounder, southern New England/mid-Atlantic winter flounder, GB winter flounder, witch flounder, GB yellowtail flounder, and southern New England yellowtail flounder).

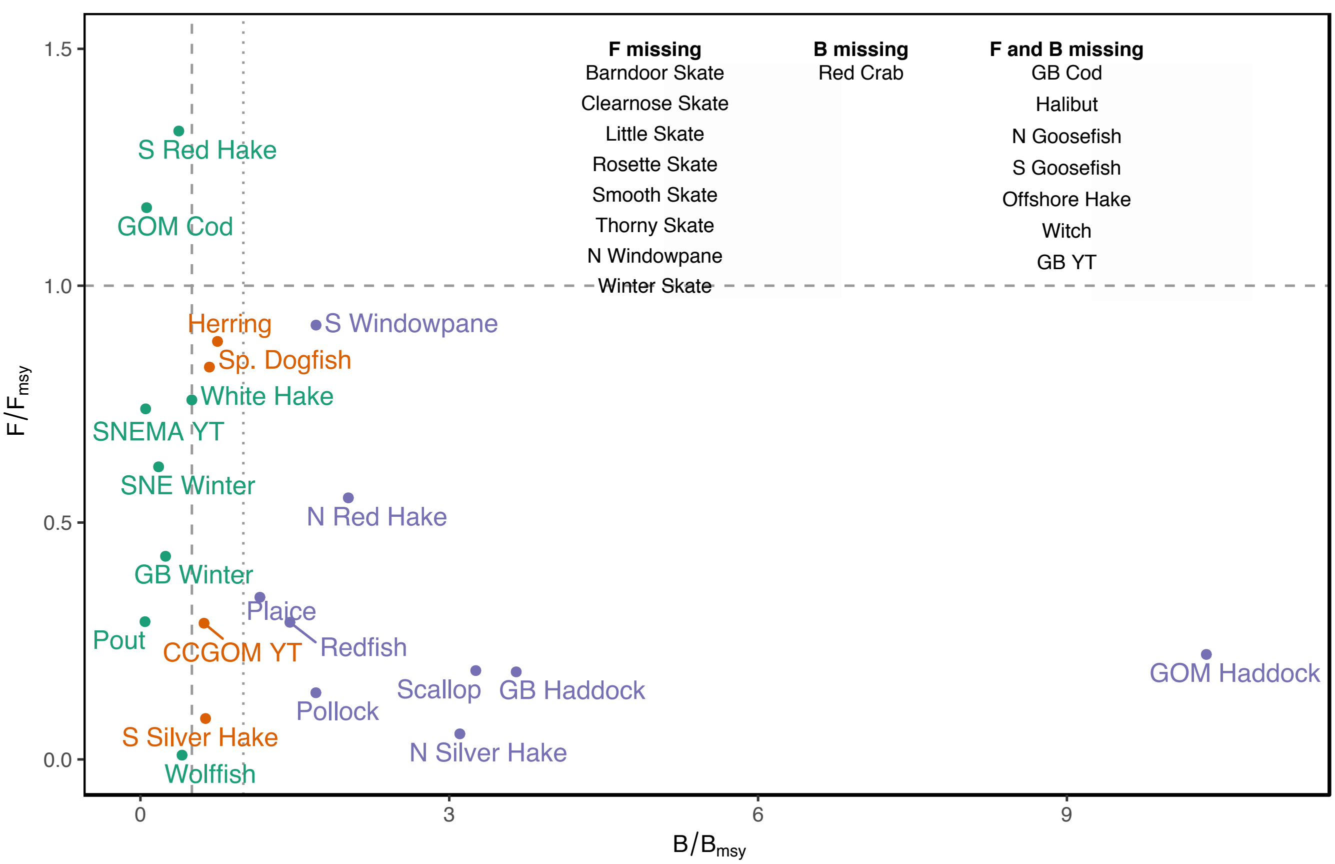


Figure 15: Summary of single species status for NEFMC and jointly managed stocks (goosefish and spiny dogfish).

[10] https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates

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. 16). These shifts will place increasing pressure on a management system based around stable species distributions. We hope to expand analysis beyond fish. Marine mammal distribution maps are available online[11]; updated maps and trends are currently being developed.

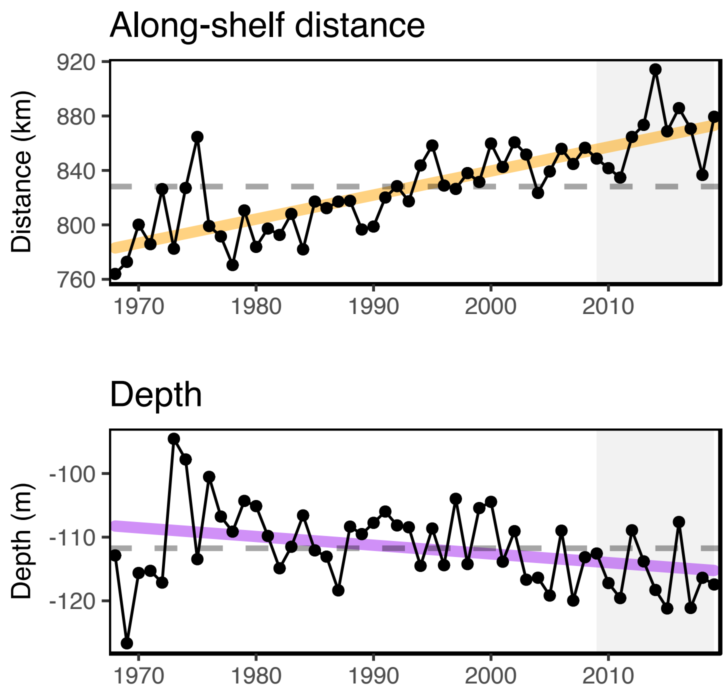


Figure 16: Aggregate species distribution metrics for fish in the Northeast Large Marine Ecosystem. Along-shelf distance measures the center of biomass along an axis oriented from the southwest to the northwest generally following the slope of coastline.

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. 17). 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 (Fig. 13). As temperature and ocean circulation indicators trend toward extremes (next section), fishery management will likely face continued changes in species distribution.

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

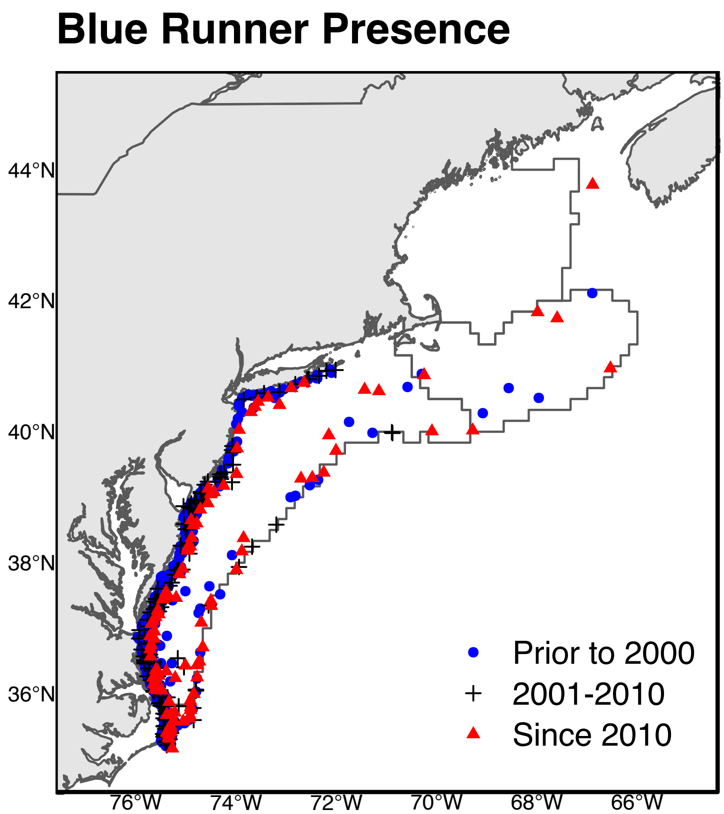


Figure 17: Blue runner presence on Northeast Shelf

Survey biomass (GOM and GB)

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. Biomass across trophic levels shows similar patterns between the Gulf of Maine and Georges Bank offshore, but nearshore patterns differ for some groups. 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 (Figs. 18-20), 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 benthos had a positive trend in both region's fall NEFSC surveys and the GB spring NEFSC survey. However, including sampling variability suggests that this trend is driven by uncertain estimates late in the time series. NEFSC survey biomass estimates for GB fall planktivores and GOM spring planktivores and fall piscivores show a similar pattern. The remaining potential trends to be investigated further in the coming year are increasing trends over time for GB piscivores in the fall and GOM planktivores in the fall (Figs. 18, 19).

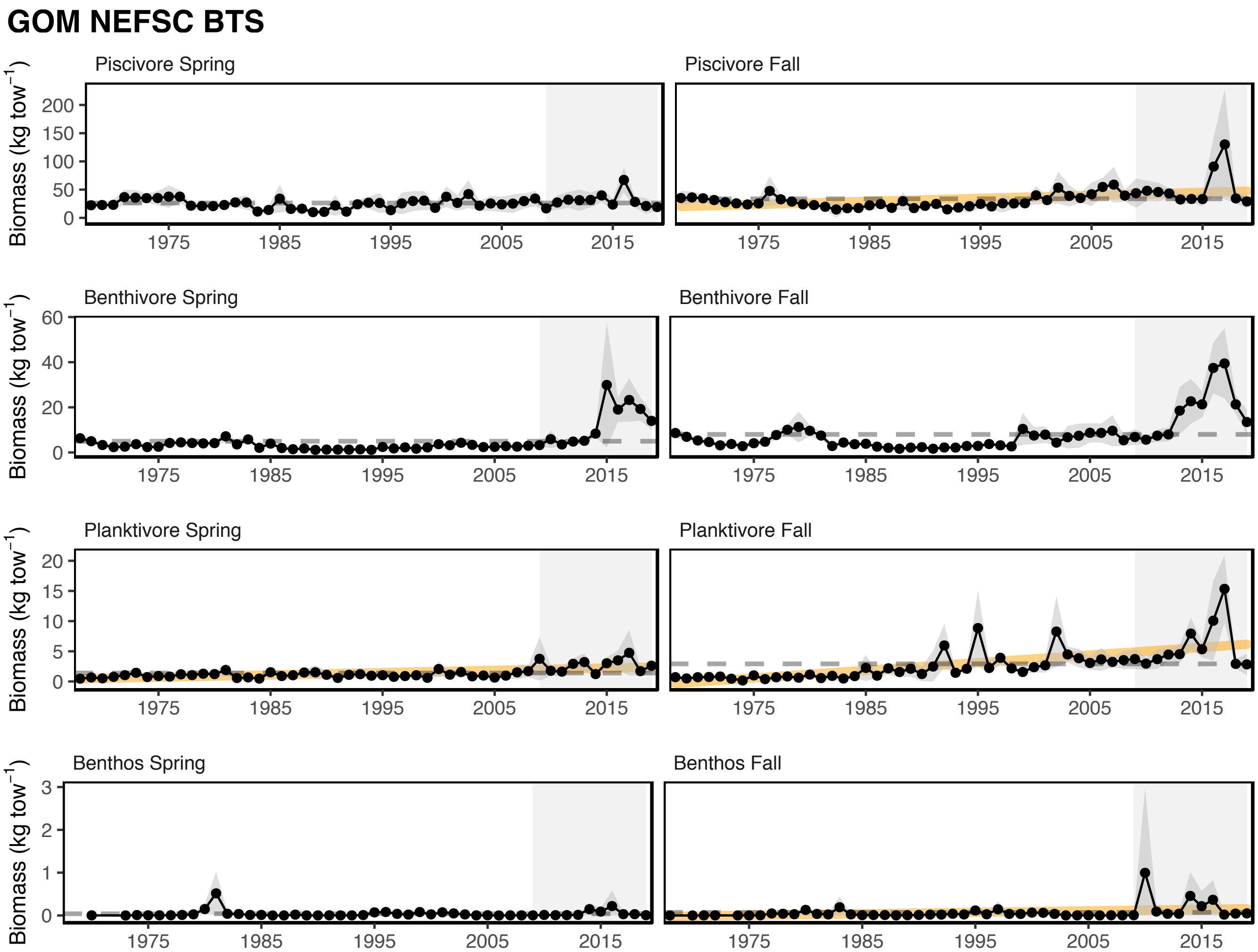


Figure 18: Spring (left) and fall (right) NEFSC surveyed biomass in the Gulf of Maine. The shaded area around each annual mean represents 2 standard deviations from the mean.

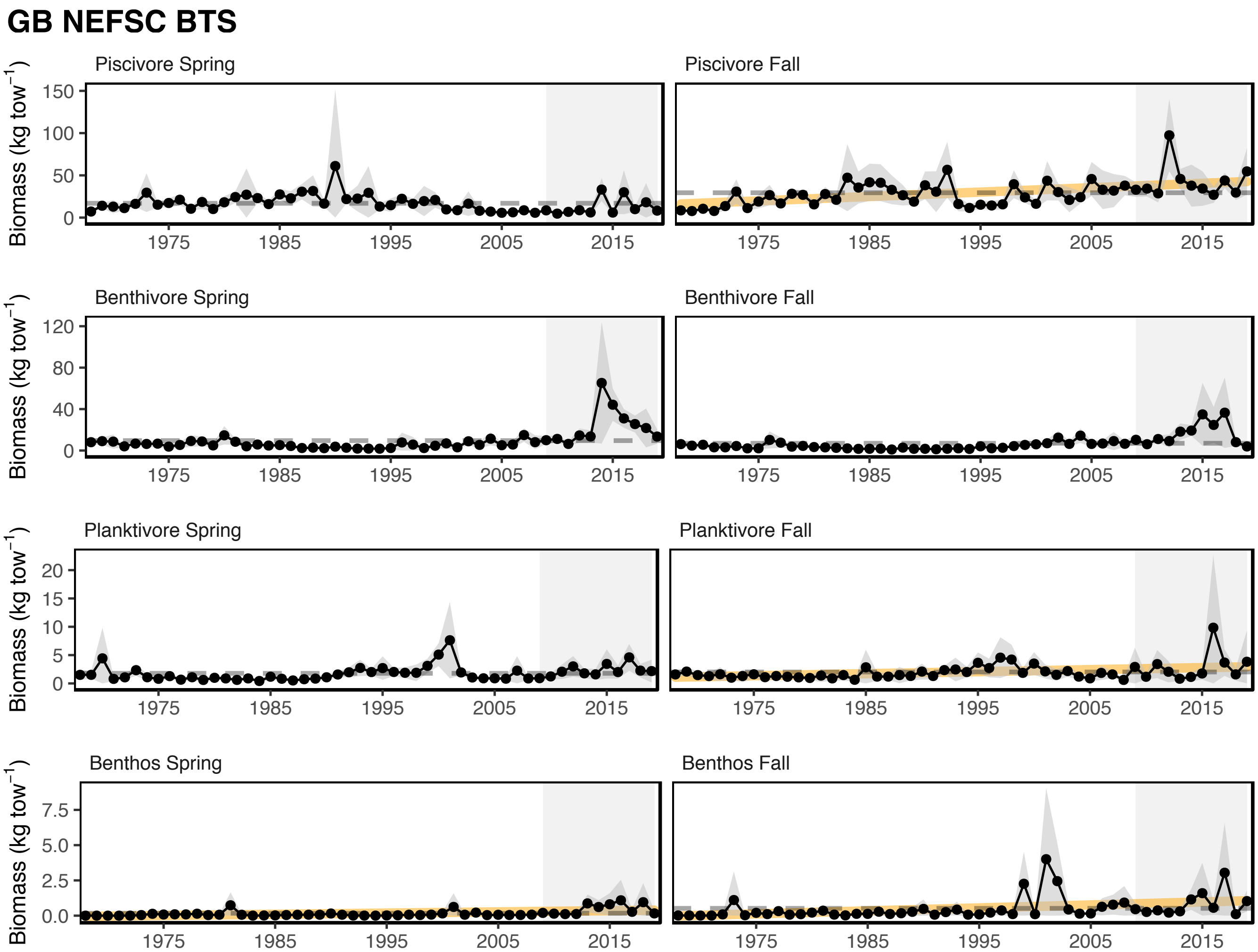


Figure 19: Spring (left) and fall (right) NEFSC surveyed biomass on Georges Bank. The shaded area around each annual mean represents 2 standard deviations from the mean.

Stability in biomass for these aggregate groups would suggest no major disturbances to overall trophic structure in the GOM and GB. There is little evidence of ecologically significant long term biomass trends in NEFSC spring surveys in either region. There are notable short term increases in benthivore biomass in both seasons and both regions that are apparent in the NEFSC as well as the inshore surveys, even when uncertainty is considered (Figs 18-21). This is largely driven by changes in haddock biomass. Further, there is some evidence of a long term decline in piscivores nearshore in the MA survey (Fig. 20). Given the wide range of stock status for managed fish in New England, with haddock in a high biomass state (Fig. 15) more detailed investigation into trophic structure is warranted. These patterns will be explored in more detail using spatio-temporal analyses that include both inshore and offshore surveys at once.

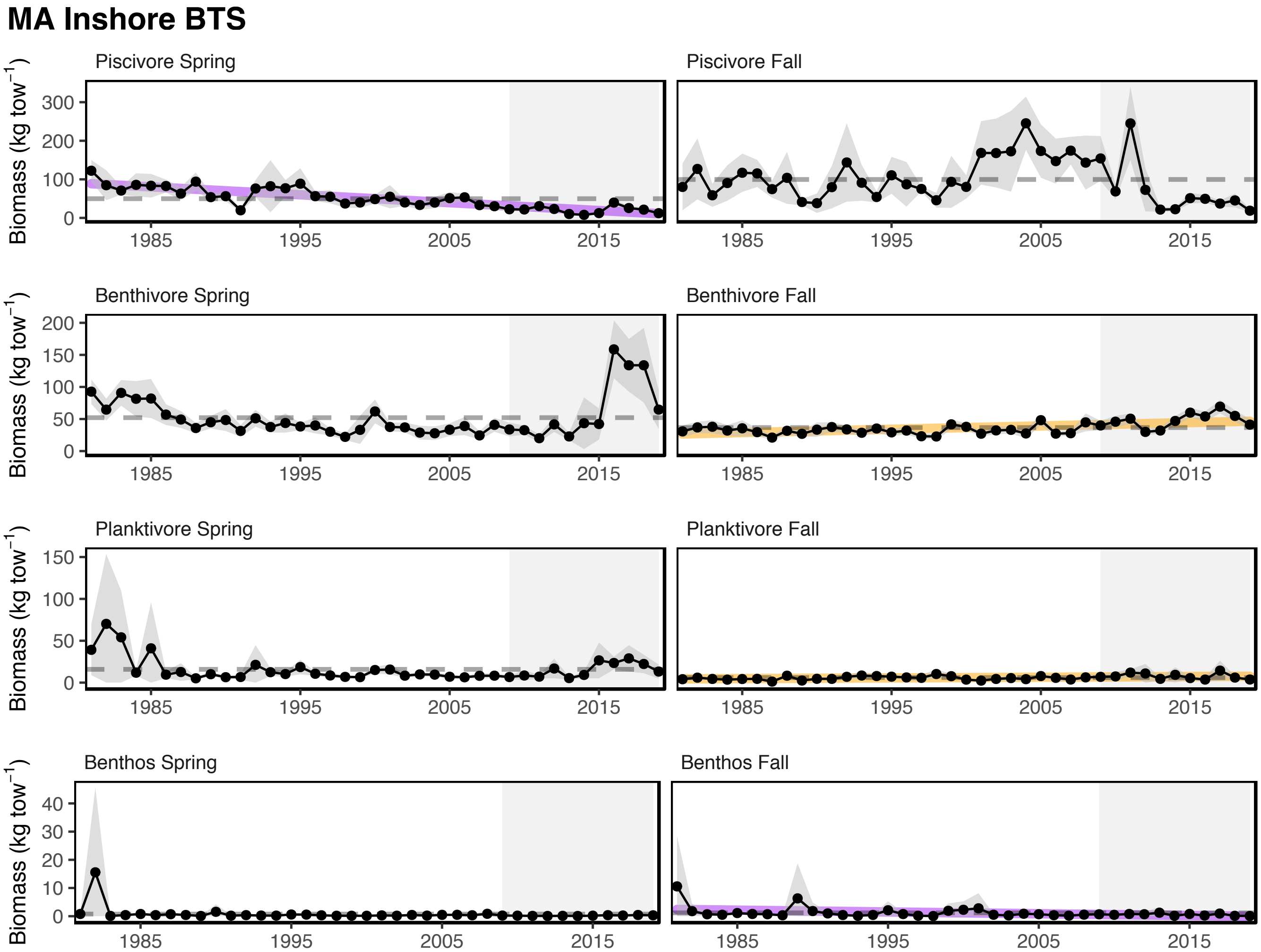


Figure 20: Spring (left) and fall (right) surveyed biomass from the MA state inshore bottom trawl survey. The shaded area around each annual mean represents 2 standard deviations from the mean.

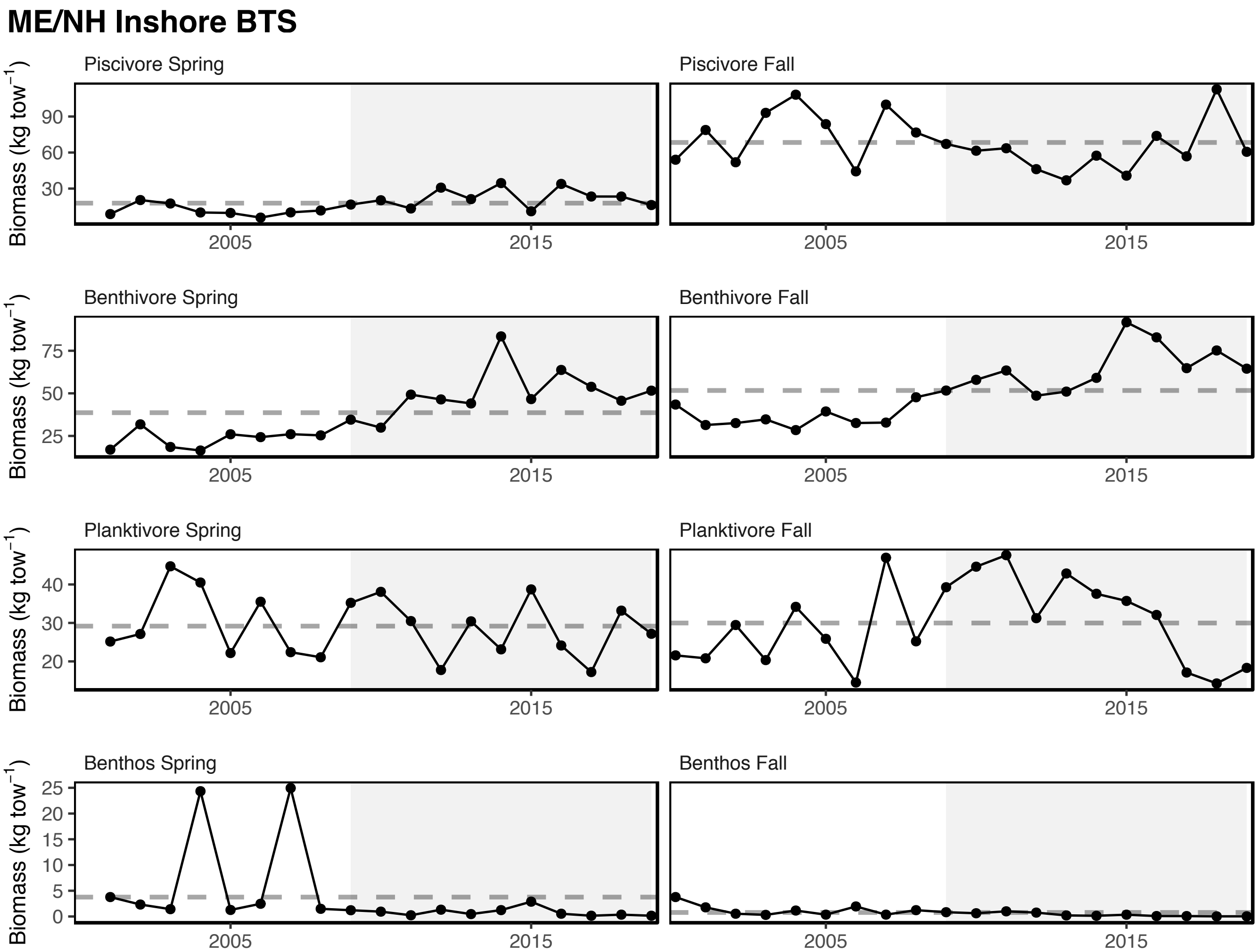


Figure 21: Spring (left) and fall (right) surveyed biomass from the ME/NH state inshore bottom trawl survey.

Fish condition (coastwide, NEFMC managed stocks)

Fish condition, a measure of 'fatness' as an indicator of fish health and a factor that influences fecundity, is measured as the weight at a given length relative to the average. For this report, females of all species with adequate sampling in the Gulf of Maine and Georges Bank portions of the fall NEFSC bottom trawl surveys were analyzed (rather than both sexes of NEFMC managed species across the full Northeast US Shelf as in past years). Overall, condition factor has improved for many species since 2012, similar to overall high condition prior to 2000, and in contrast to overall lower condition between 2001-2010 (Figs. 22-23). The timing of these shifts is similar to shifts in the small-large zooplankton indicator (Fig. 39). Condition factors were generally better on Georges Bank than in the Gulf of Maine in 2019, and were especially high on Georges Bank for winter flounder, windowpane flounder and ocean pout (Fig. 23). Atlantic mackerel, white hake, pollock and Atlantic herring had particularly low condition factors in the Gulf of Maine in 2019 (Fig. 22).

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).

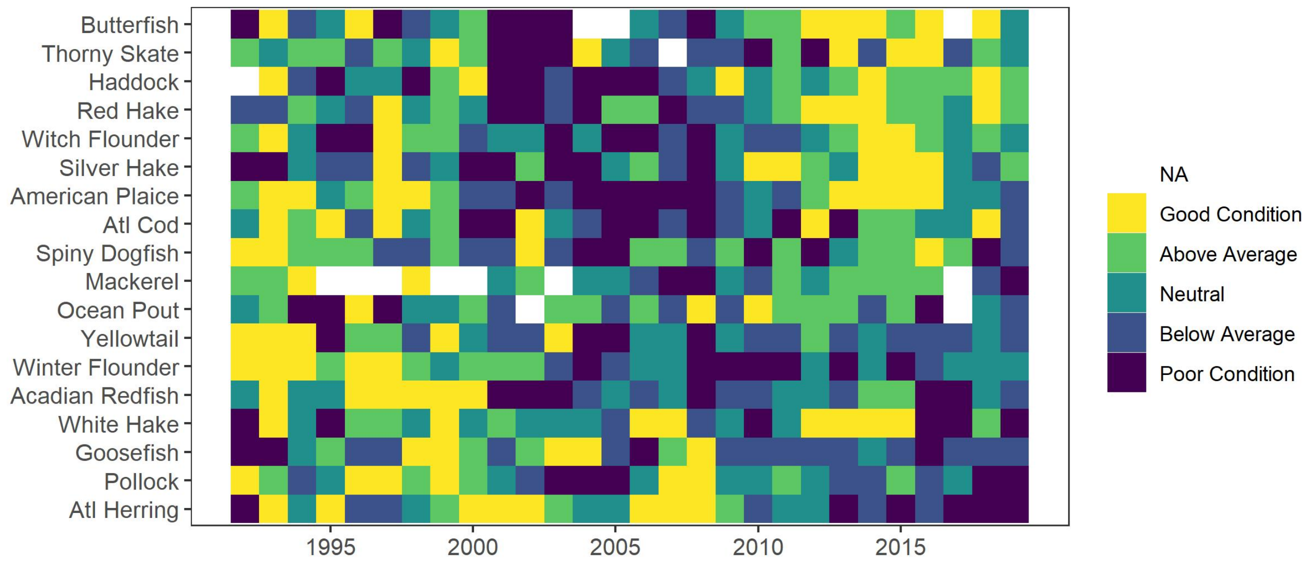


Figure 22: Condition factor for fish species in the Gulf of Maine.

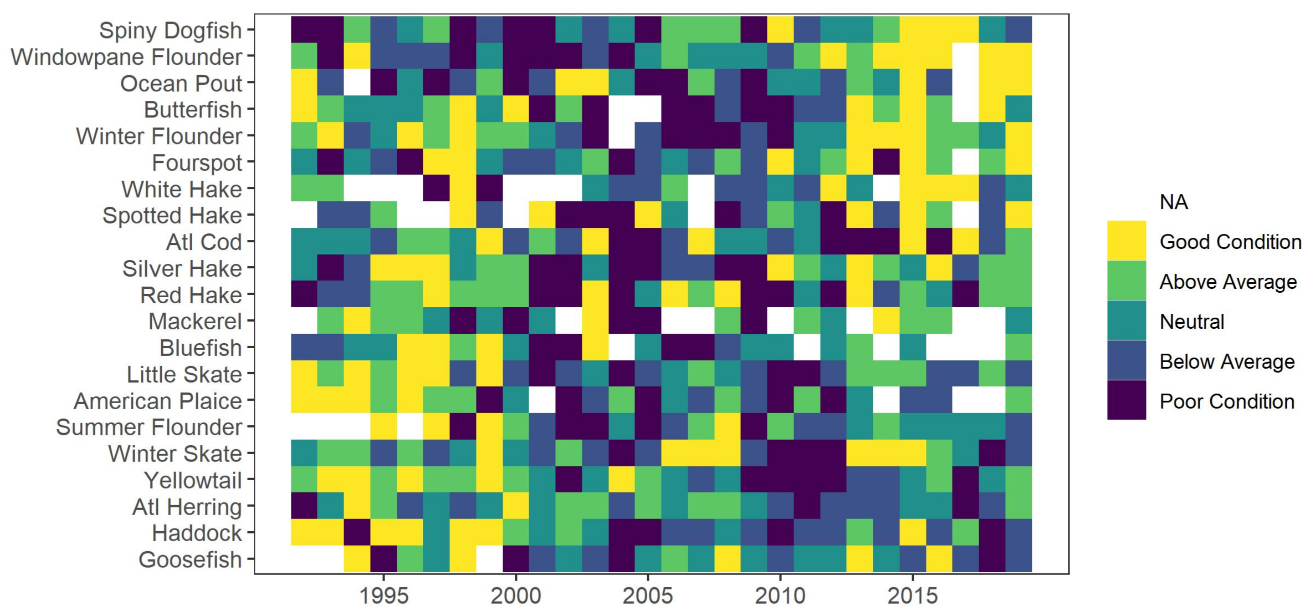


Figure 23: Condition factor for fish species on Georges Bank.

Fish productivity (GOM and GB)

We describe patterns of aggregate fish productivity in New England with the small fish per large fish anomaly indicator derived from NEFSC bottom trawl survey data (Figs. 24-25). The indicator shows that fish productivity has been fluctuating in this region since 2010, although productivity across all species was relatively high in 2018. In 2017, Mid-Atlantic managed species accounted for most of the above average productivity with Summer flounder the only species above average in the Gulf of Maine, and butterfish one of two above average on Georges Bank (yellowtail was the other) based on this indicator. In 2018, it was mainly New England managed species with above average productivity in the New England systems, in particular yellowtail and windowpane flounder on Georges Bank, and Acadian redfish in the Gulf of Maine. Species with above average 2018 productivity in the Mid-Atlantic are New-England managed: witch flounder, silver hake, and red hake[12].

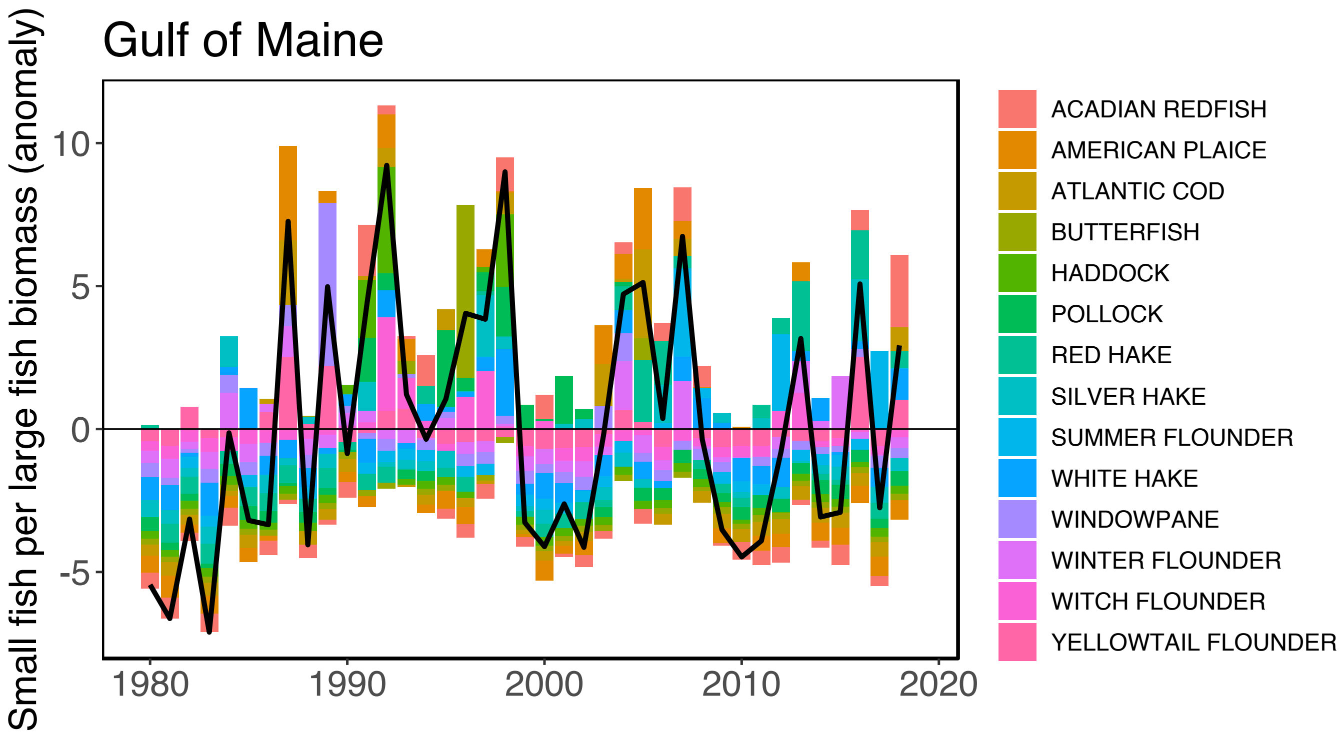


Figure 24: Small fish per large fish biomass anomaly in the Gulf of Maine.

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

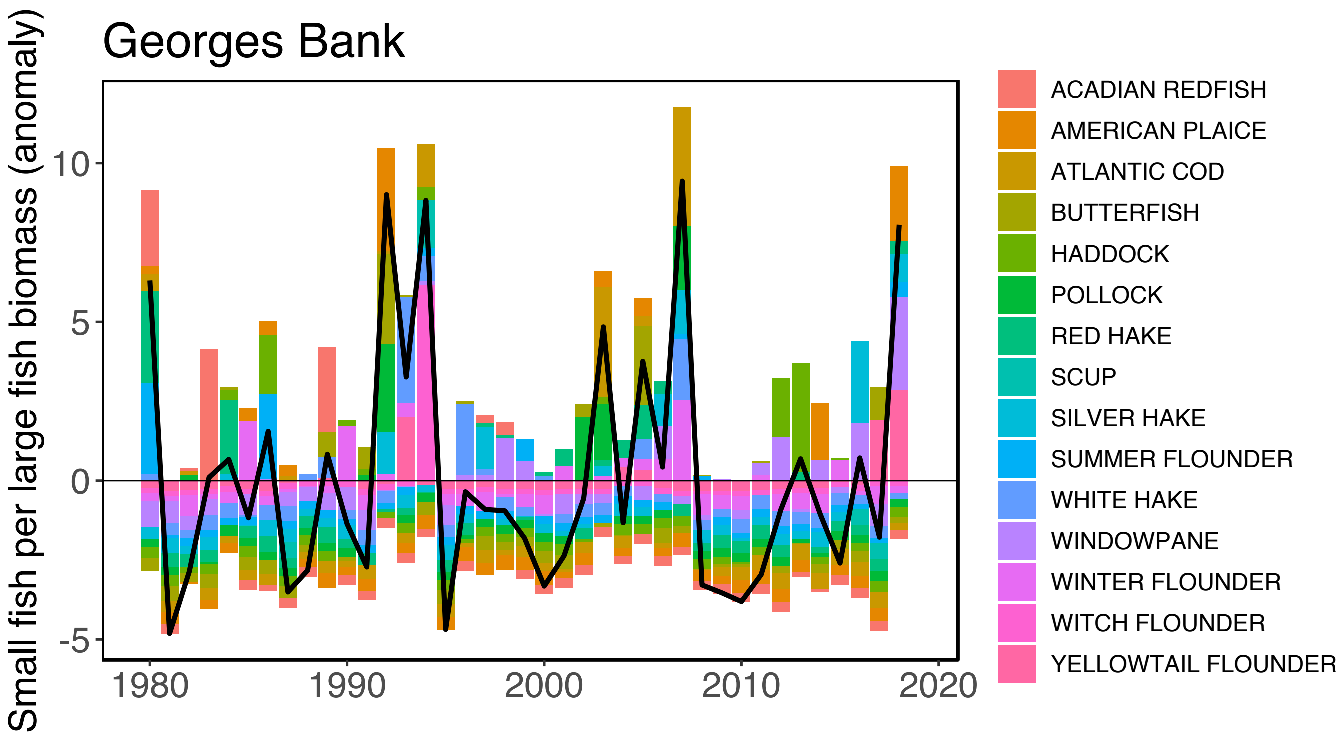


Figure 25: Small fish per large fish biomass anomaly in Georges Bank.

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 [3,4]. 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. Habitat encompasses physical, chemical, and biological factors, including 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. Ultimately, a better understanding of these ecological drivers may permit proactive management in a changing system.

Ocean temperatures in coastal and offshore habitats are at or near 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.

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[13].

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. 26). 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].

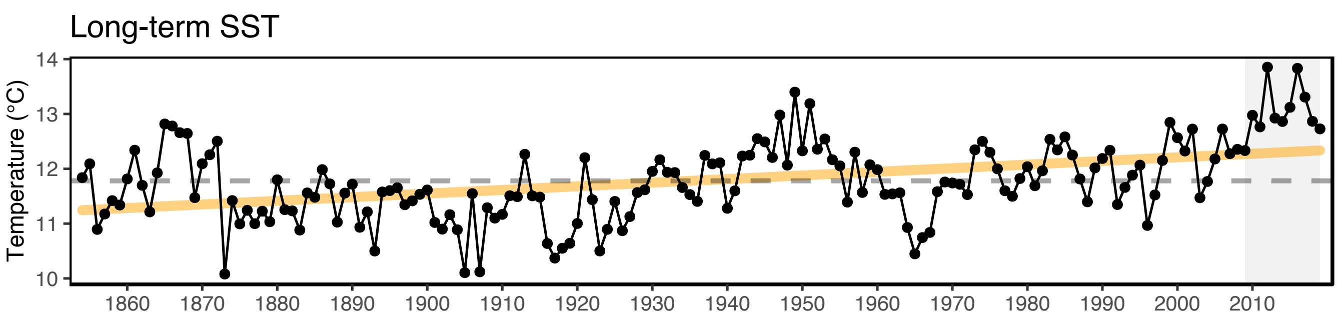


Figure 26: Average annual sea surface temperature (SST) over the Northeast US Shelf

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. 27). 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].

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

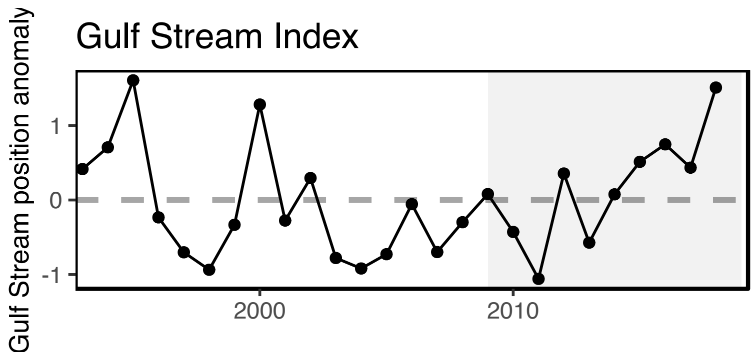


Figure 27: Index representing changes in the location of the Gulf Stream. Positive values represent a more northerly Gulf Stream position.

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 28; [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].

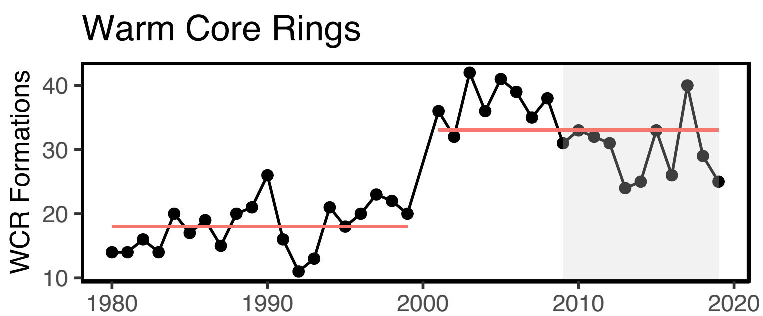


Figure 28: Interannual variability of warm core ring (WCR) formation between 1980 and 2019. The regime shift (denoted by the split in the red solid line) is significant at the turn of the century. Figure reproduced with permission from Gangopadhyay, et al. (2019). 2018 and 2019 data points based on personal communication with A. Gangopadhyay (2020).

Gulf of Maine Sourcewater (Northeast Channel)

The changing position of the Gulf Stream north wall described above directly influences oceanic conditions in the 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. 29), the highest estimated in the time series. The changing proportions of source water affect the temperature, salinity, and nutrient inputs to the system.

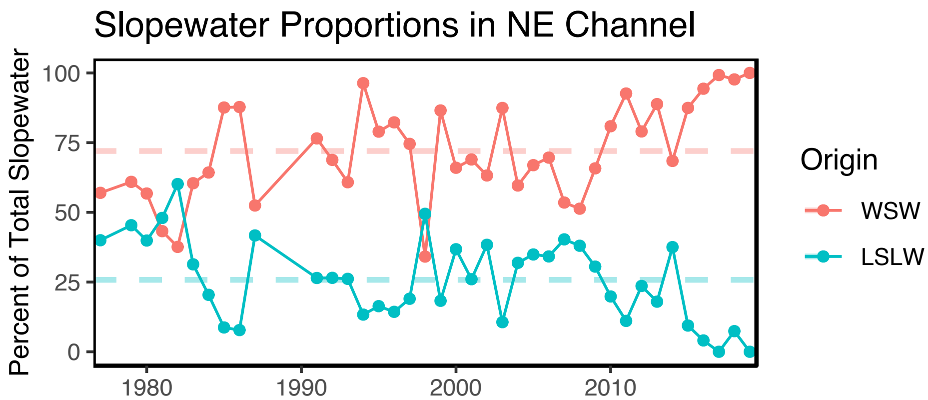


Figure 29: Proportion of Warm Slope Water (WSW) and Labrador slope water (LSLW) entering the GOM through the Northeast Channel.

Ocean temperature, surface and bottom (GOM and GB)

The regional ocean is warming. Annual surface and bottom temperatures (Figs. 31, 30) in the GOM and GB have trended warmer since the early 1980s. GOM bottom temperature was nearly 1°C warmer than average in 2019. Seasonal surface temperatures have trended warmer in spring, summer, and fall throughout New England. The 2018 summer sea surface temperatures were the highest on record in the GOM with temperature moderating slightly in 2019. Surface temperatures during the other seasons were near or slightly below average (Figs. 31, 32). In contrast, 2019 seasonal temperatures in the core portions of Georges Bank were at or below average, while at the outer edge were above average partially due to the influence of a number of Gulf Stream warm core rings surrounding the Bank (personal communication G. Gawarkiewicz and A. Gangopadhyay, 2020).

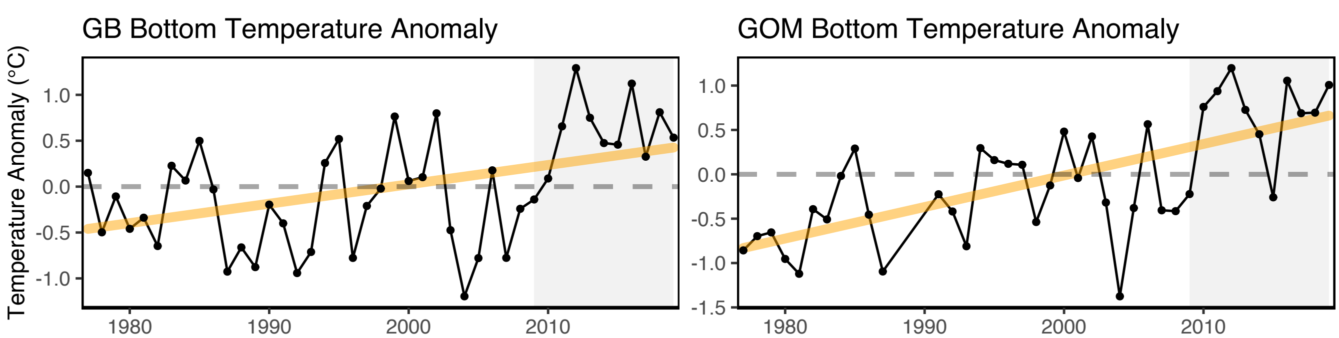


Figure 30: GOM and GB annual bottom temperature anomalies.

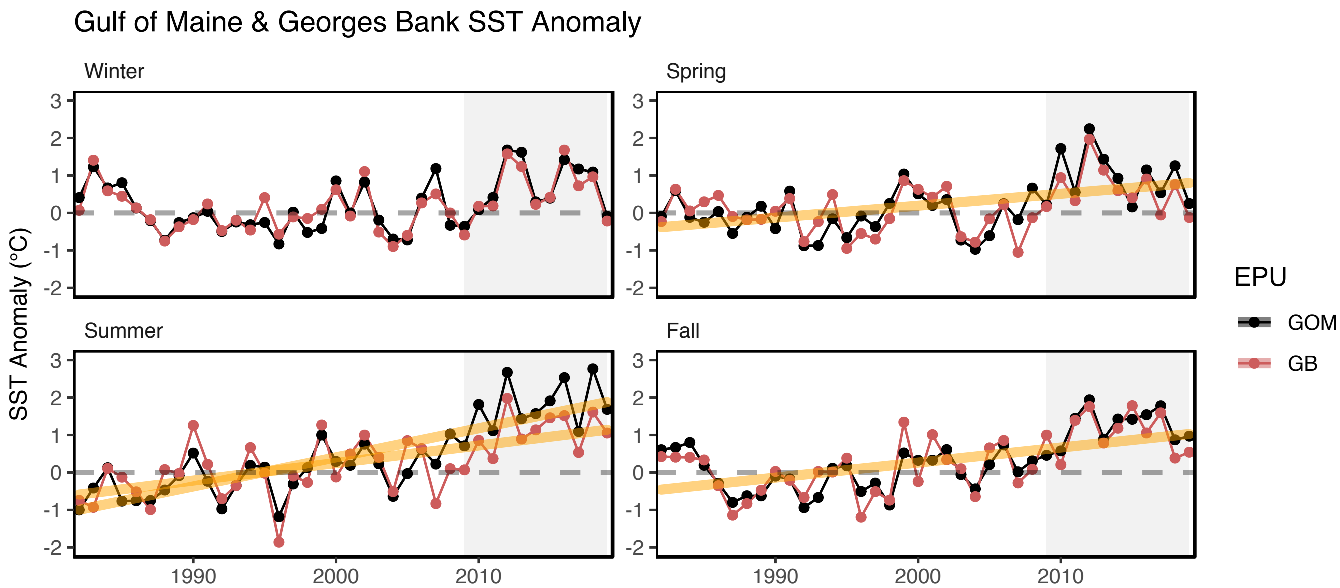


Figure 31: GOM and GB seasonal sea surface temperature anomaly time series.

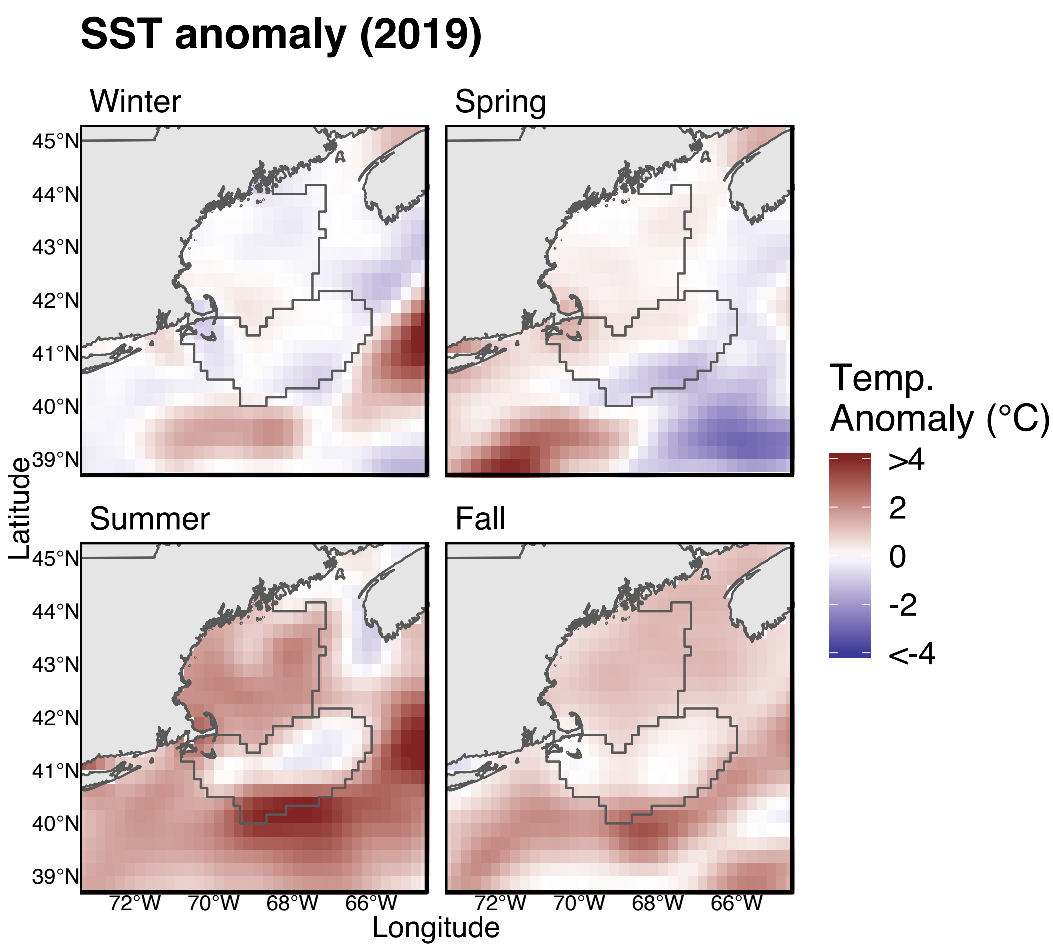


Figure 32: GOM and GB 2019 seasonal sea surface temperature spatial anomalies.

Marine heat waves (GOM and GB)

Marine heatwaves reflect 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) [10].

In 2019, the Gulf of Maine experienced four distinct marine heatwaves in the summer and fall with the strongest event beginning on July 3 and lasting 53 days (Figs. 33, 34). Relative to prior years, this marine heatwave ranked 12th on record in terms of maximum intensity (+3.27 °C above average on Aug 1) and 12th on record in terms of cumulative intensity (112 °C-days) (Fig. 35). The strongest heatwaves on record in the Gulf of Maine occurred in the summer of 2010 in terms of maximum intensity (+4.83 °C above average) and in the summer of 2012 in terms of cumulative intensity (630 °C-days). The impacts of the 2012 marine heatwave in the Gulf of Maine have been well documented within the lobster fishery [11].

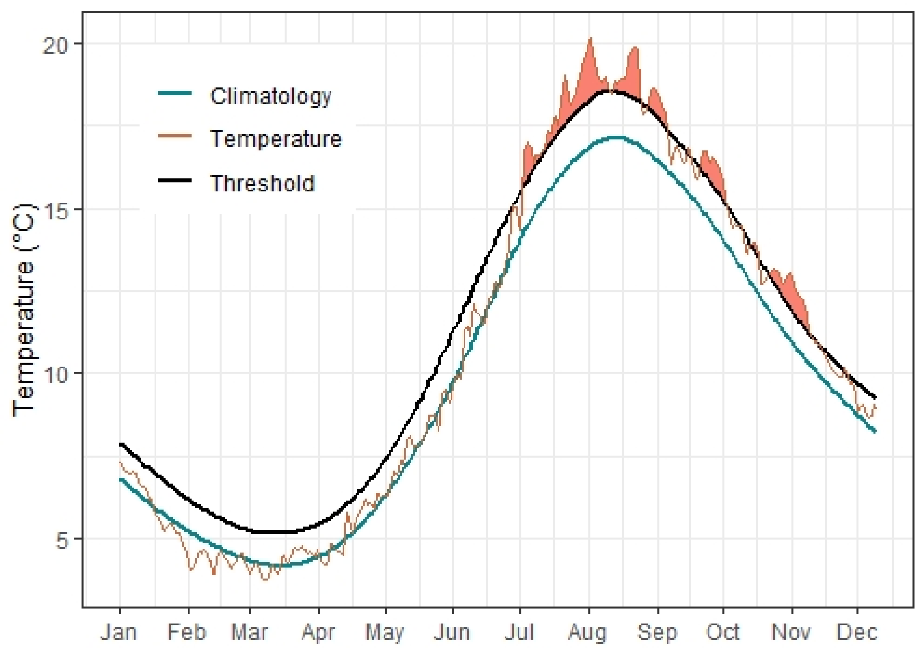


Figure 33: Marine heatwave events (red shading above black threshold line) in the Gulf of Maine occurring in 2019.

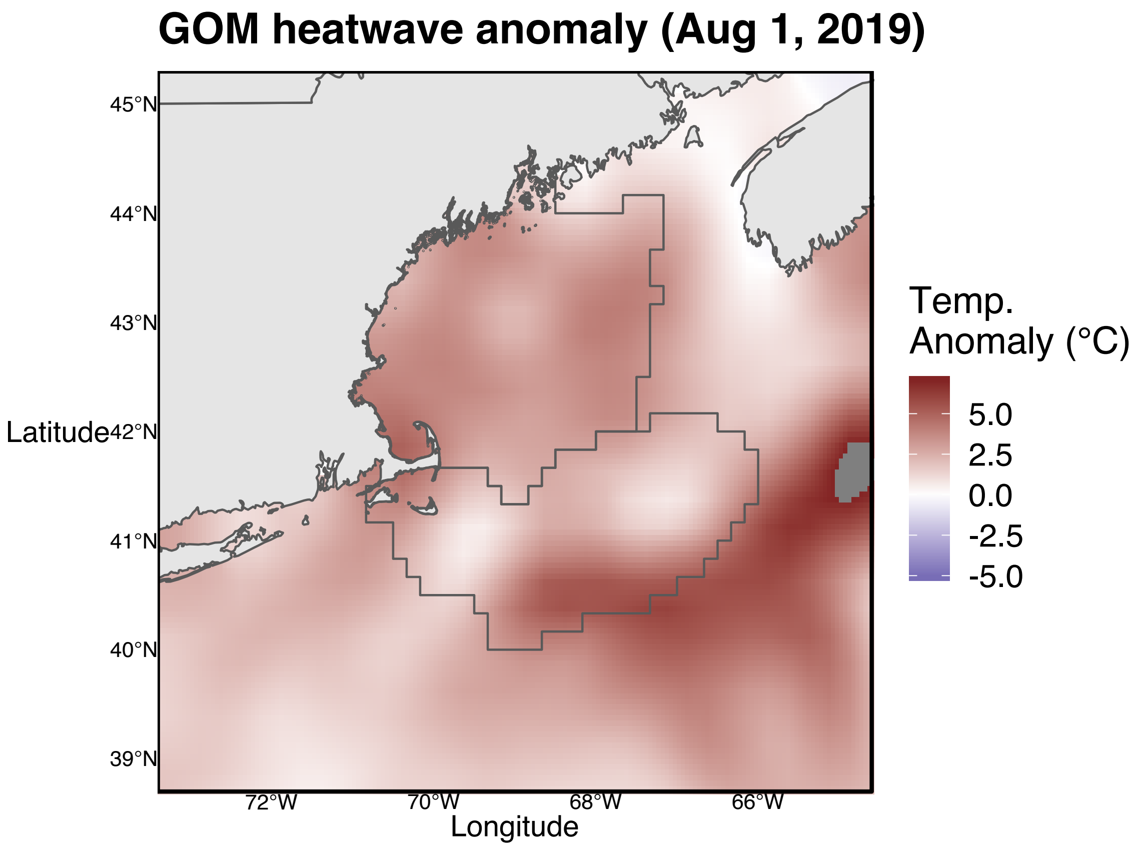


Figure 34: Maximum intensity heatwave anomaly in Gulf of Maine occurring on August 1, 2019.

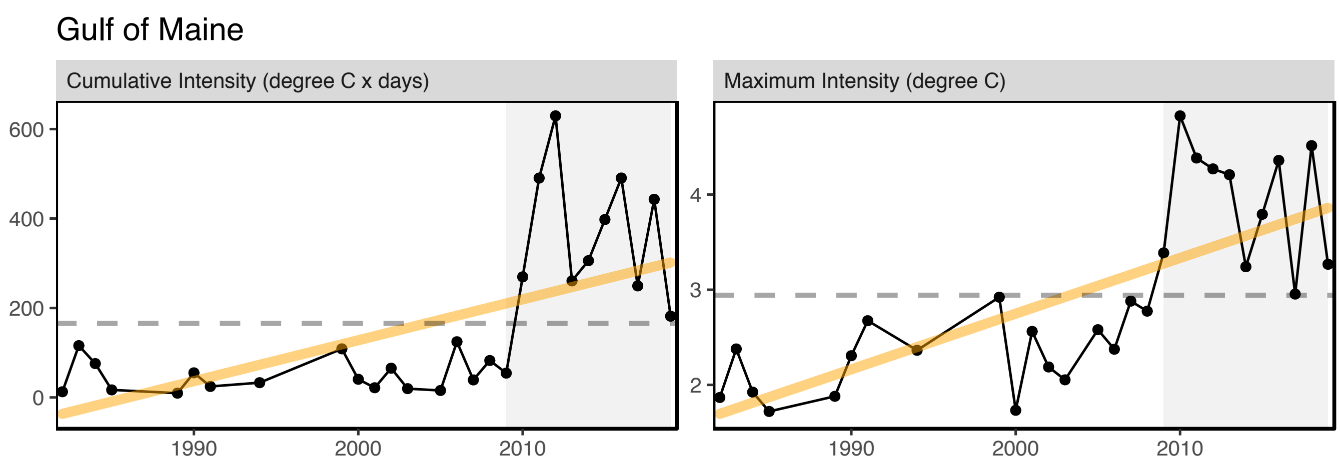


Figure 35: Marine heatwave cumulative intensity (left) and maximum intensity (right) in the Gulf of Maine .

In 2019, Georges Bank experienced three distinct marine heatwaves in the summer and fall with the strongest event beginning on August 17 and lasting 20 days (Figs. 36, 37). Relative to prior years, this marine heatwave ranked 15th on record in terms of maximum intensity (+3.14 °C above average on Aug 23) (Fig. 38). The strongest heatwaves on record in the Georges Bank occurred in the summer of 2016 in terms of maximum intensity (+4.06 °C above average) and in the winter/spring/summer of 2012 in terms of cumulative intensity (485 °C-days).

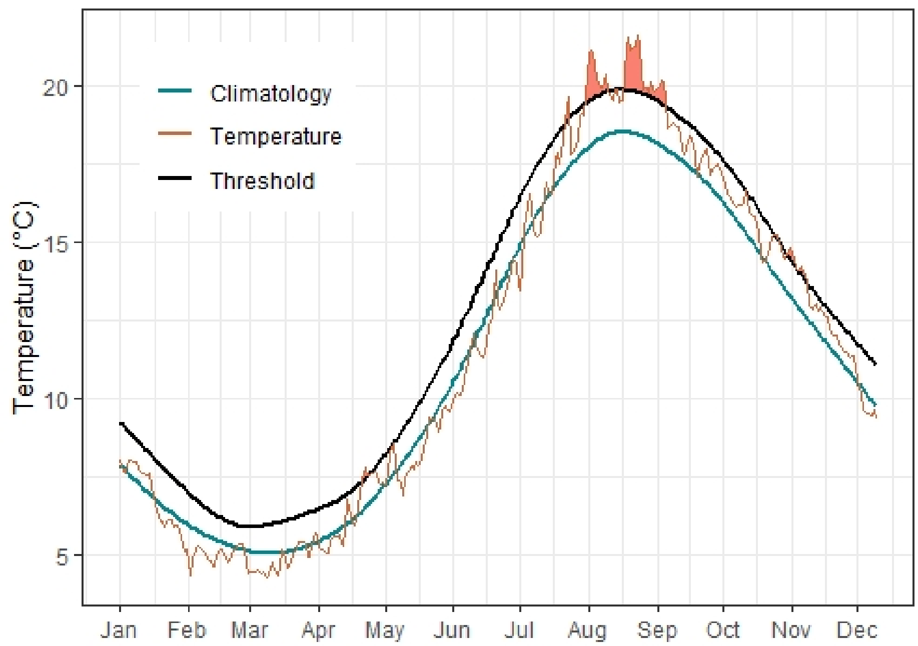


Figure 36: Marine heatwave events (red shading above black threshold line) on Georges Bank occurring in 2019.

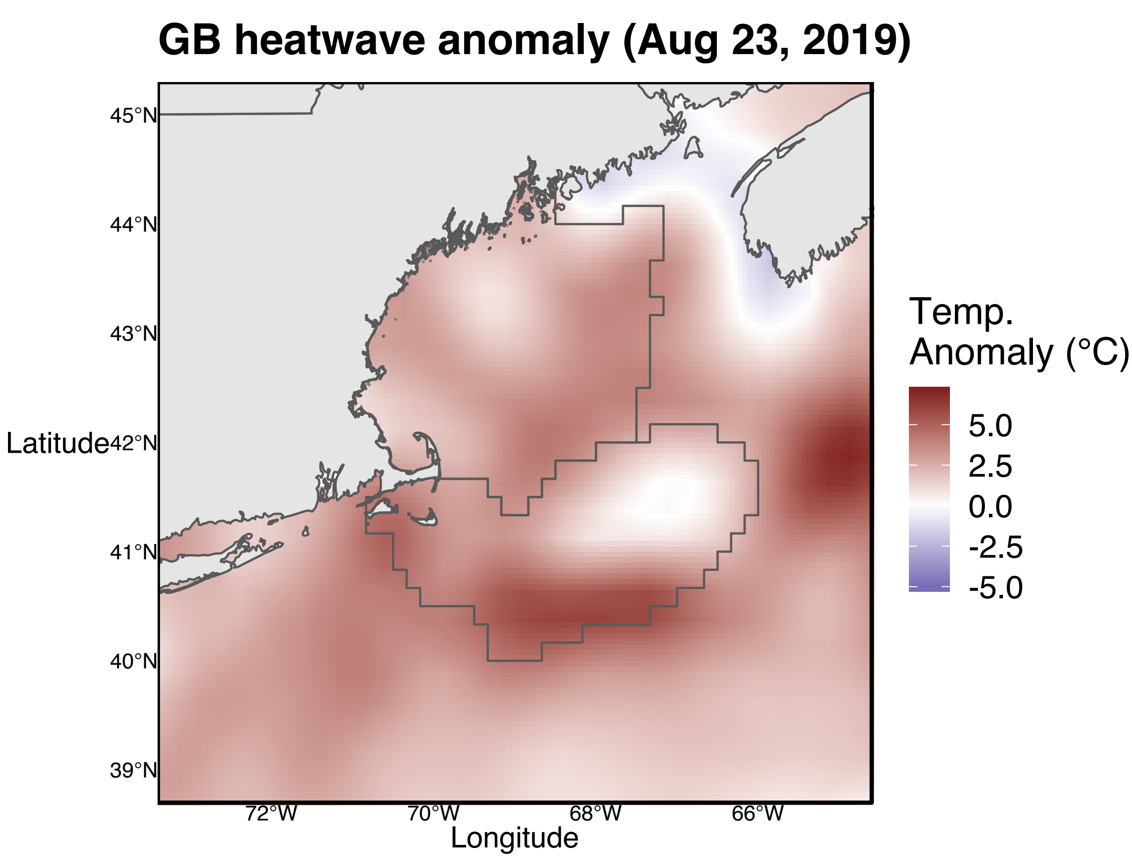


Figure 37: Maximum intensity heatwave anomaly on Georges Bank occurring on August 23, 2019.

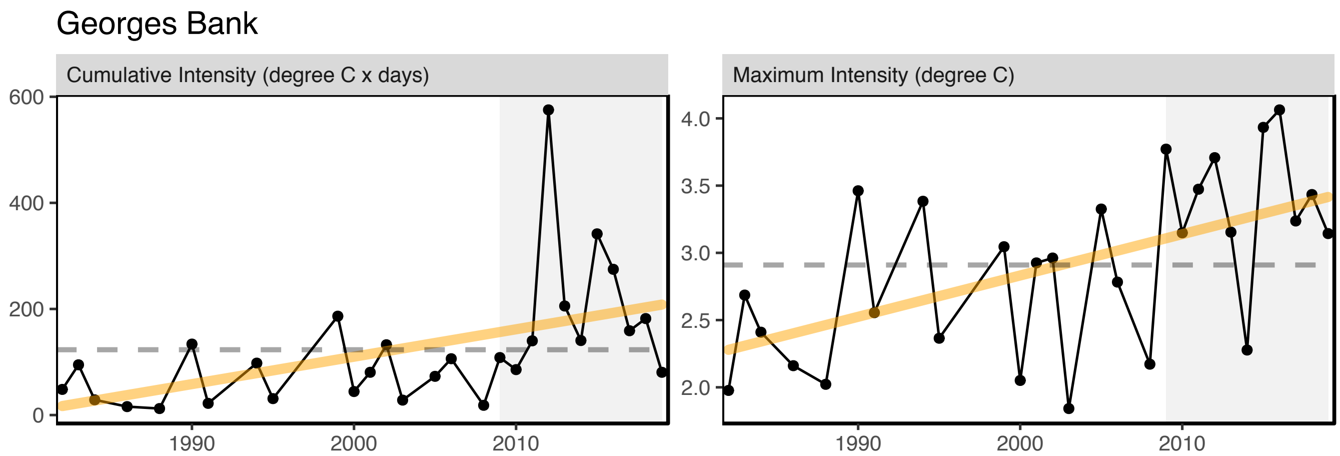


Figure 38: Marine heatwave cumulative intensity (left) and maximum intensity (right) on Georges Bank.

Primary production (GOM and GB)

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 are recent increases in primary production (Fig. 39) in both New England systems, primarily driven by increased summer production, which is due to warmer temperatures and increased bacterial remineralization and nutrient recycling (Fig. 40). This increased productivity is most likely from smaller-celled species that contribute less to fish production compared to larger phytoplankton. The 2019 winter-spring phytoplankton bloom, comprised primarily of larger diatoms, was average in both the GOM and GB, however the timing in the GOM was later than normal (Fig. 41). The spring bloom period was below average for both GOM and GB, while the fall bloom was near average for both regions, but varied spatially (Fig. 42).

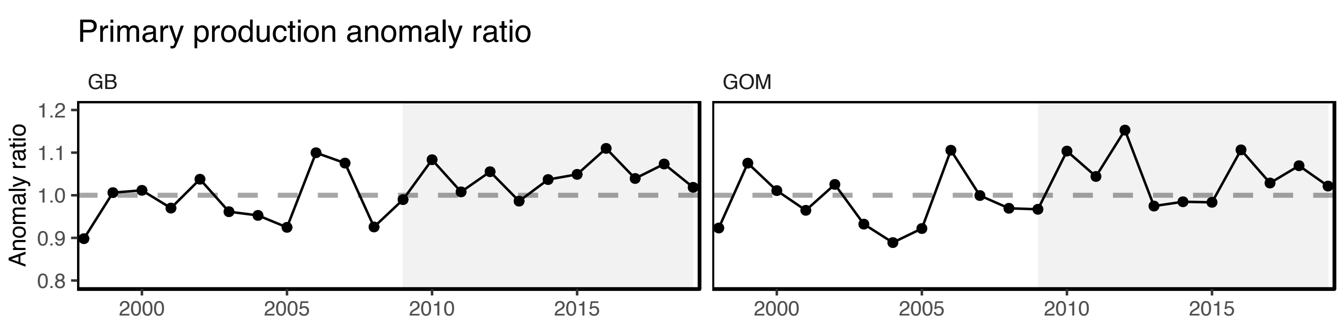


Figure 39: GB and GOM annual primary production anomaly.

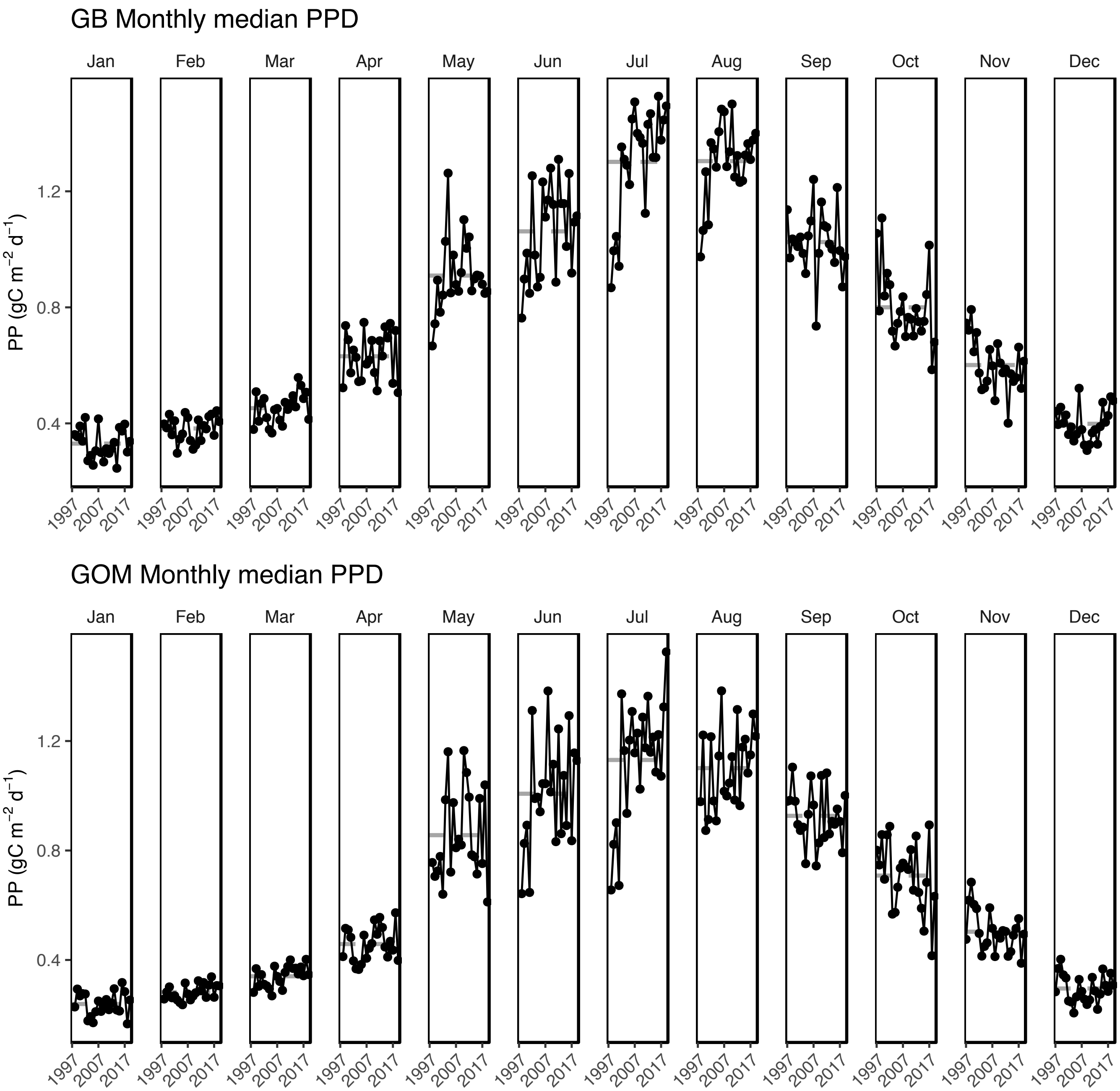


Figure 40: Monthly primary production trends show the annual cycle (i.e. the peak during the summer months) and the changes over time for each month.

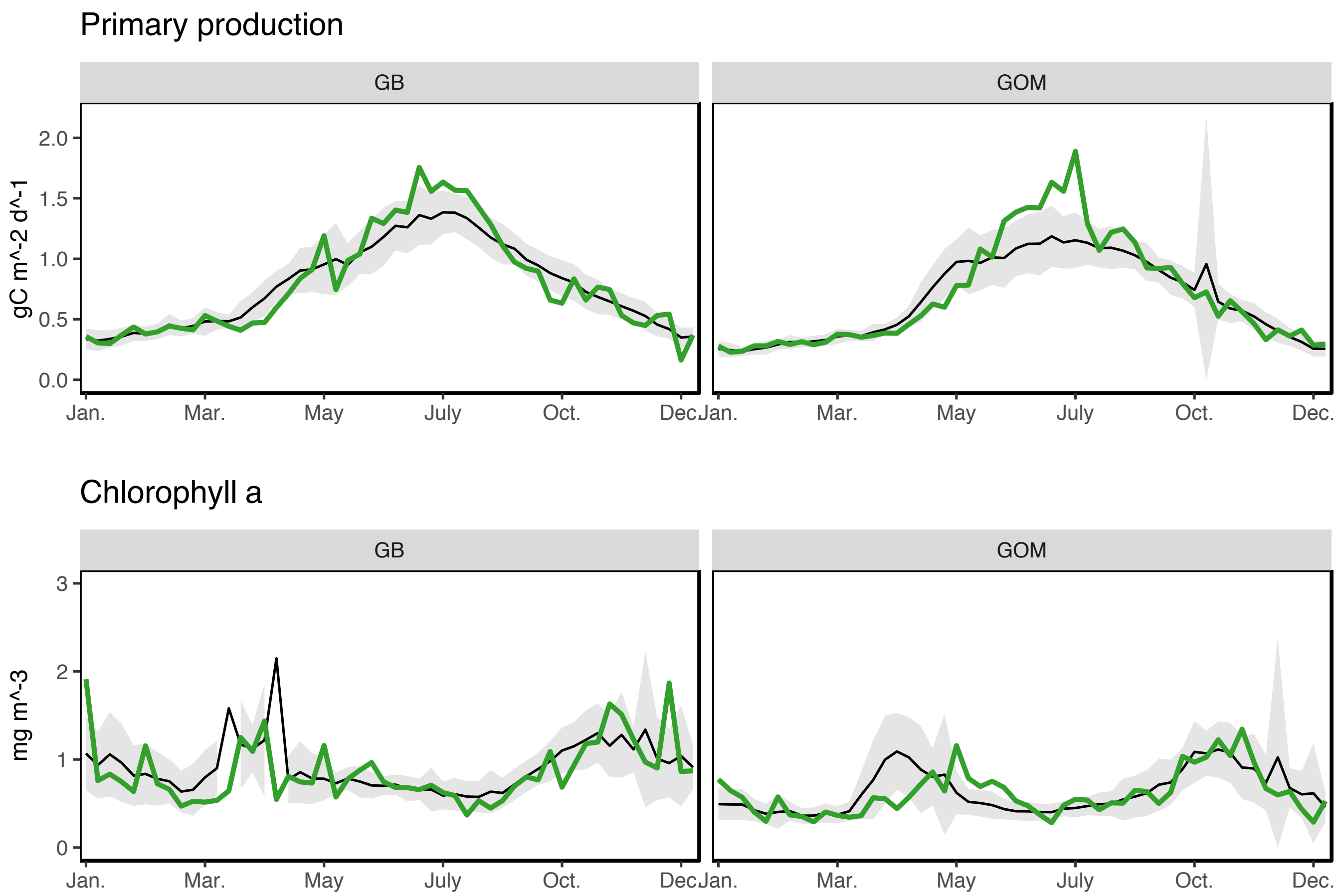


Figure 41: Weekly chlorophyll concentrations and primary productivity for 2019 in Gulf of Maine and Georges Bank are shown by the colored lines in the above figures. The long-term mean is shown in black and shading indicates +/- 1 sample SD.

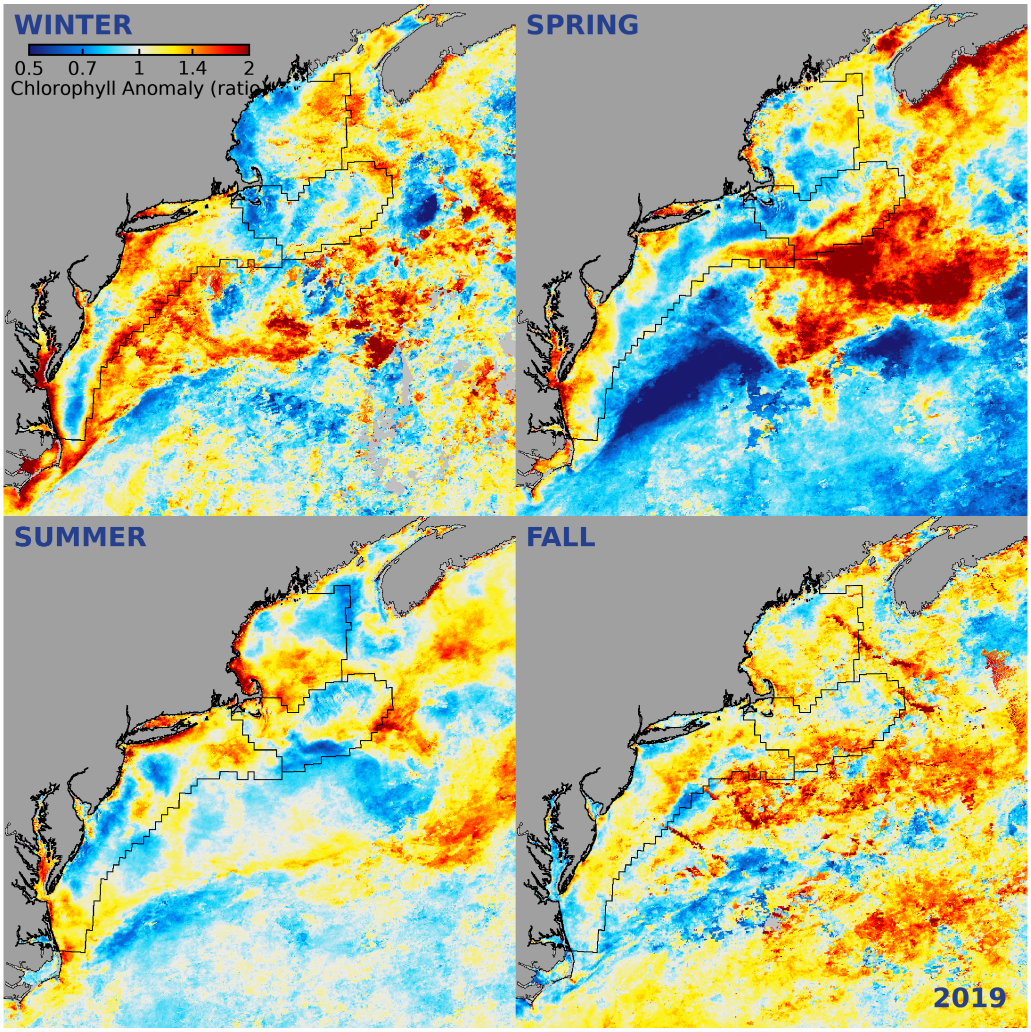


Figure 42: Seasonal chlorophyll a anomalies in 2019.

Fluctuations in primary production over time (Fig. 39) may relate to observed patterns in copepod size structure (Fig. 43). This period also corresponds with regime shifts in fish recruitment [12].

Zooplankton (GOM and GB)

The most abundant zooplankton species in the GOM are the large-bodied *Calanus finmarchicus* (an important prey for larval fish and the north Atlantic right whale), and the small-bodied *Centropages typicus* and *Pseudocalanus* spp. [13]. *Calanus finmarchicus* had low overall abundance in the GOM from 2010-2014, with higher than normal abundance in 2015-2016, normal levels in 2017, and higher abundance in 2018 (Fig. 43). On GB, *Calanus finmarchicus* annual abundance has been lower than normal from 2010-2017 with slightly higher than normal values in 2018.

The mean abundance anomaly of the small-bodied copepod taxa shows a distinct pattern of higher than normal abundance during the period from 1989-2001 for both GB and GOM, followed by a low period from 2002-2010 for the GOM and 2002-2012 for GB (Fig. 43). In recent years, this index has trended up again with higher values from 2012-2018 for the GOM and during 2014-2017 for GB, with 2018 falling right at the mean value. This was driven by lower abundance of *Centropages hamatus* and higher values for both *Temora longicornis* and *Centropages typicus* in 2018. The abundance of both *Temora longicornis* and *Centropages typicus* was the highest value observed in the time series in both GOM and on GB in 2018.

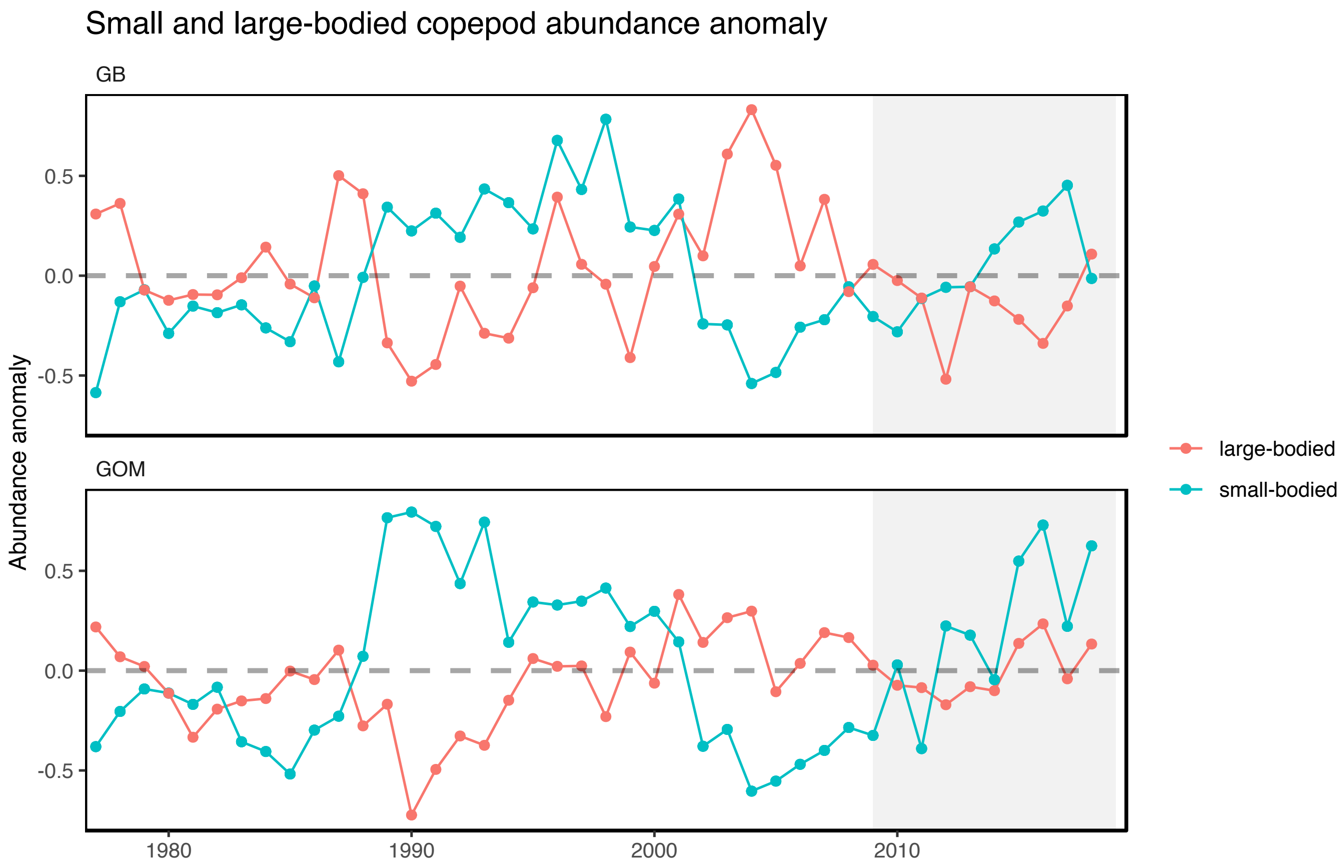


Figure 43: Abundance anomaly time series for copepod size groups found in the GOM and GB.

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. 44). Euphausiids (krill), important prey items for many fish species, also exhibit a long term increasing trend in abundance in the GOM and GB (Fig. 44).

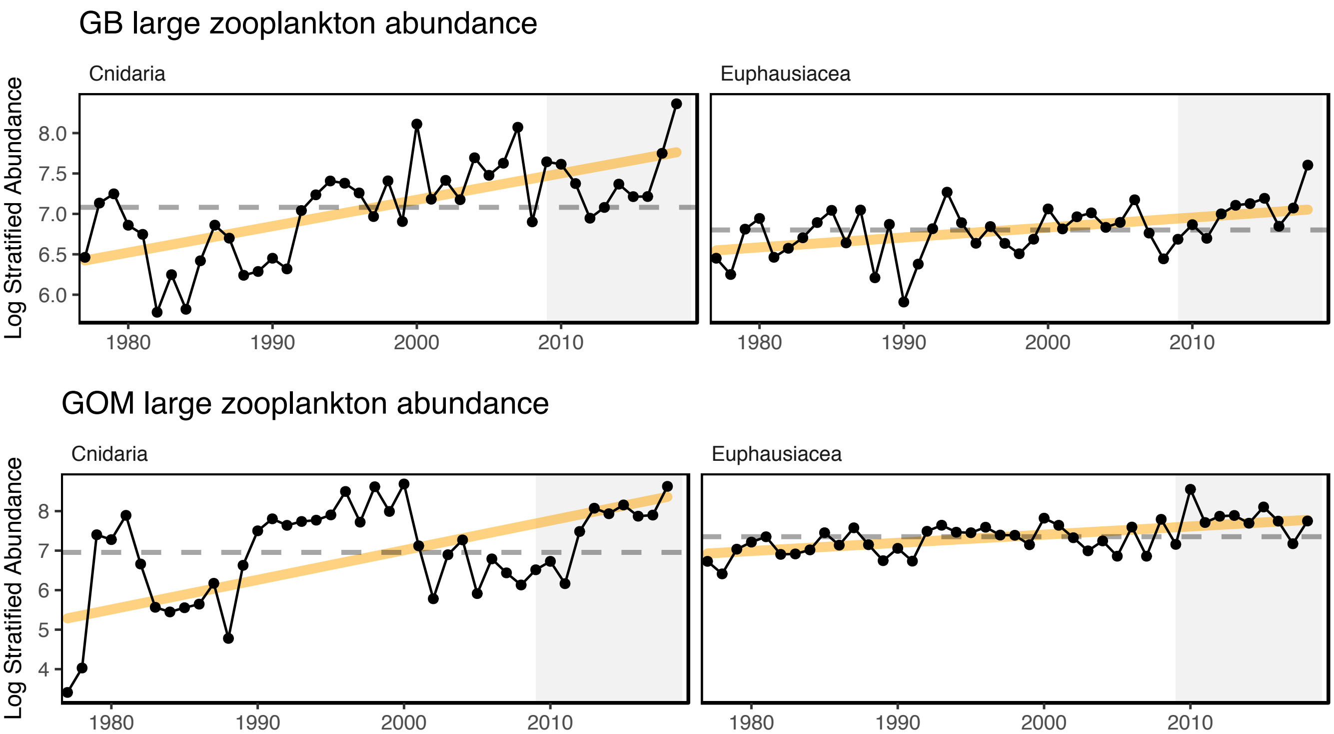


Figure 44: Stratified abundance of cnidarians and euphausiids in New England.

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 45a. 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, New England states (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut), or at the Gulf of Maine (GOM) and Georges Bank (GB) Ecosystem Production Unit (EPU, Fig. 45b) level.

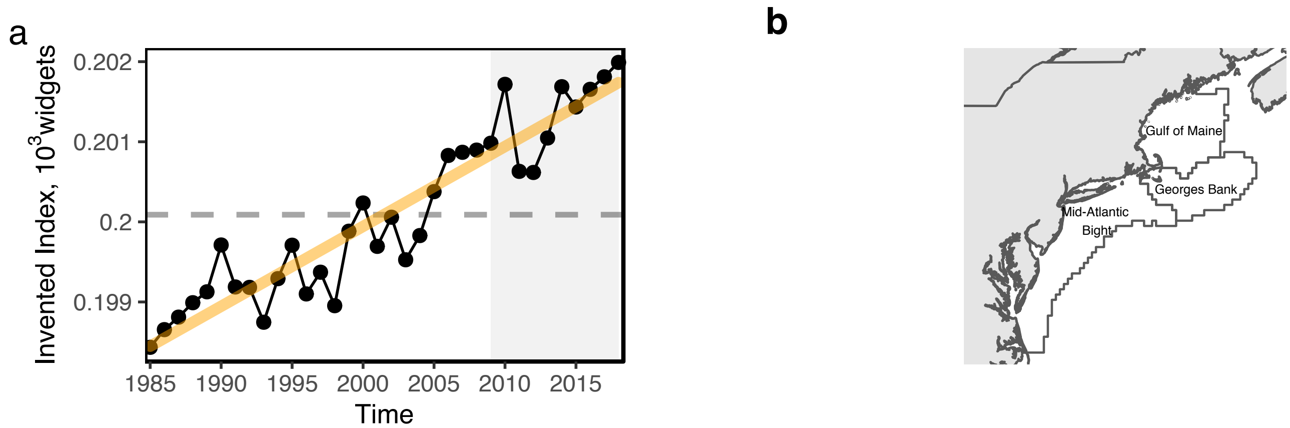

Figure 45: Document orientation. a. Key to figures. b.The Northeast Large Marine Ecosystem.

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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