# State of the Ecosystem - Gulf of Maine and Georges Bank

*Northeast Fisheries Science Center*

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## Introduction

The purpose of this report is to provide **ecosystem-scale information for fishery managers** to consider along with existing species-scale analyses. An overview of ecosystem relationships as represented by **a conceptual model helps place more detailed species-level management in context** by highlighting relationships between focal species groups organized by New England Fishery Management Council (NEFMC) Fishery Management Plan (FMP), managed human activities, environmental drivers, habitats, and key ecological links (Fig. 1). Here, human activities link to high level strategic management objectives. Many components of the conceptual model are represented by indicators in this report, and key paths connecting components and objectives are highlighted.

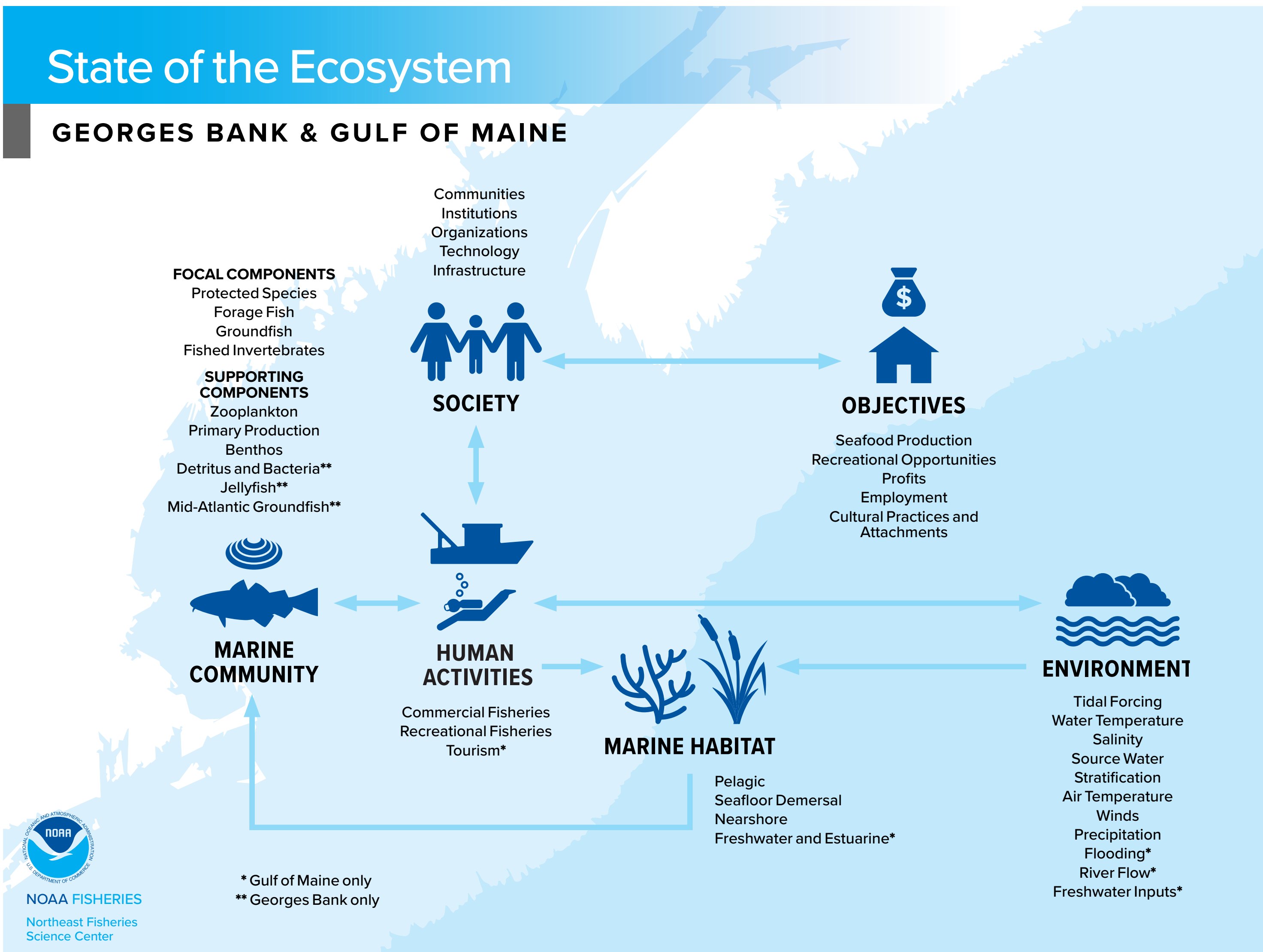


Figure 1: Gulf of Maine and Georges Bank Ecosystem

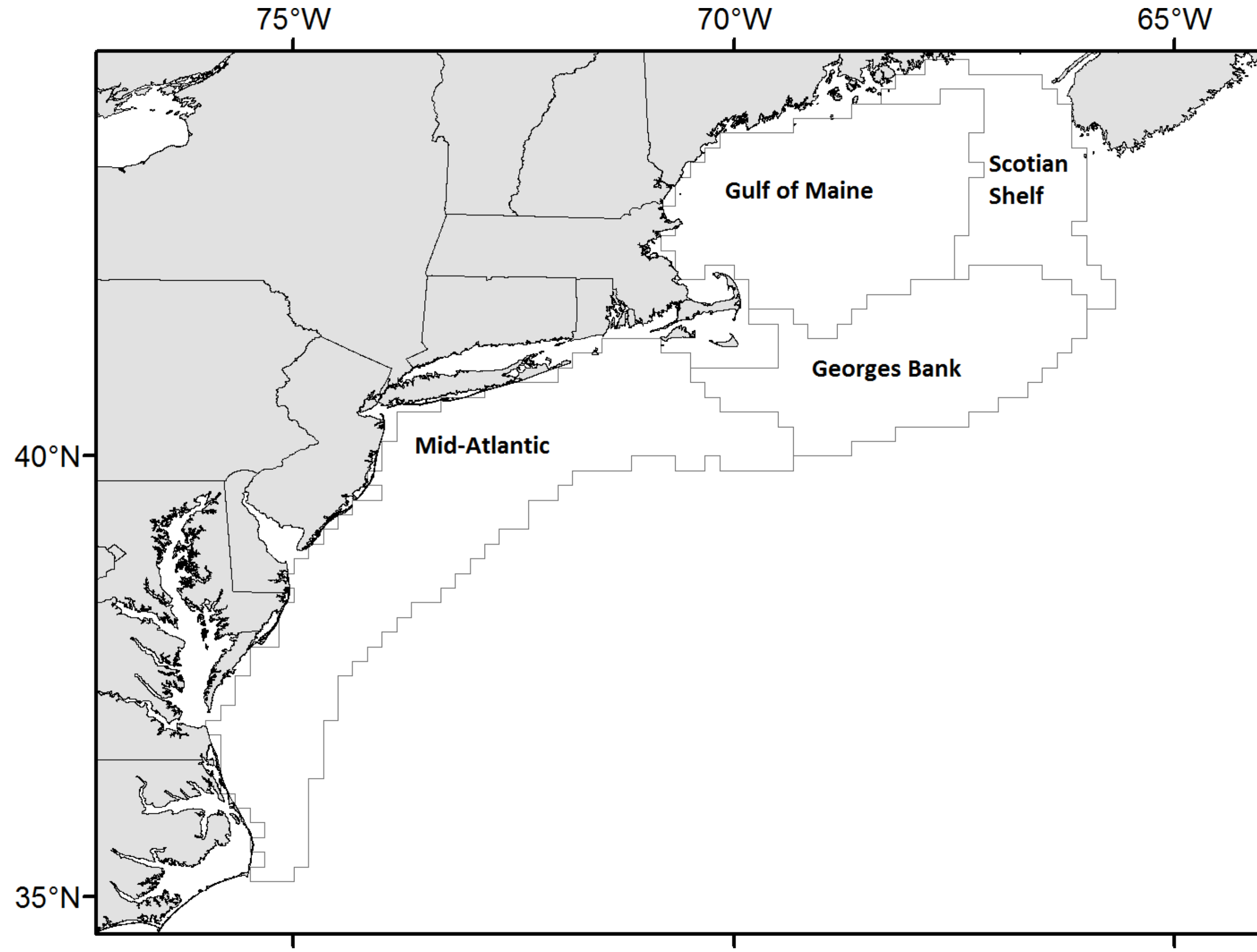


Figure 2: Gulf of Maine (GOM) and Georges Bank (GB) spatial extent

## Executive Summary

We have organized this report using a proposed set of **ecosystem-scale objectives** derived from US legislation and current management practices (Table 1). We take a place-based approach and report indicators separately where possible and relevant for the two ecosystems under New England Council management: Georges Bank (GB) and Gulf of Maine (GOM; Fig. 2). Given that not all indicators refer specifically to Gulf of Maine or Georges Bank, we further specify the scope of the indicators in respective section headings as referring to all of New England or the US Northeast coastwide.

**Table 1**: New England ecosystem objectives

| Objective Categories | Indicators reported here |
|---|---|
| Seafood production | Landings by feeding guild |
| Profits | Revenue by feeding guild |
| Recreation | Number of anglers and trips; recreational catch |
| Stability | Diversity indices (fishery and species) |
| Social-Cultural | Commercial and recreational reliance; social vulnerability |
| Biomass | Biomass or abundance by feeding guild from surveys |
| Productivity | Condition and recruitment of NEFMC managed species |
| Trophic structure | Relative biomass of feeding guilds, primary productivity |
| Habitat | Thermal habitat projections, estimated habitat occurrence |

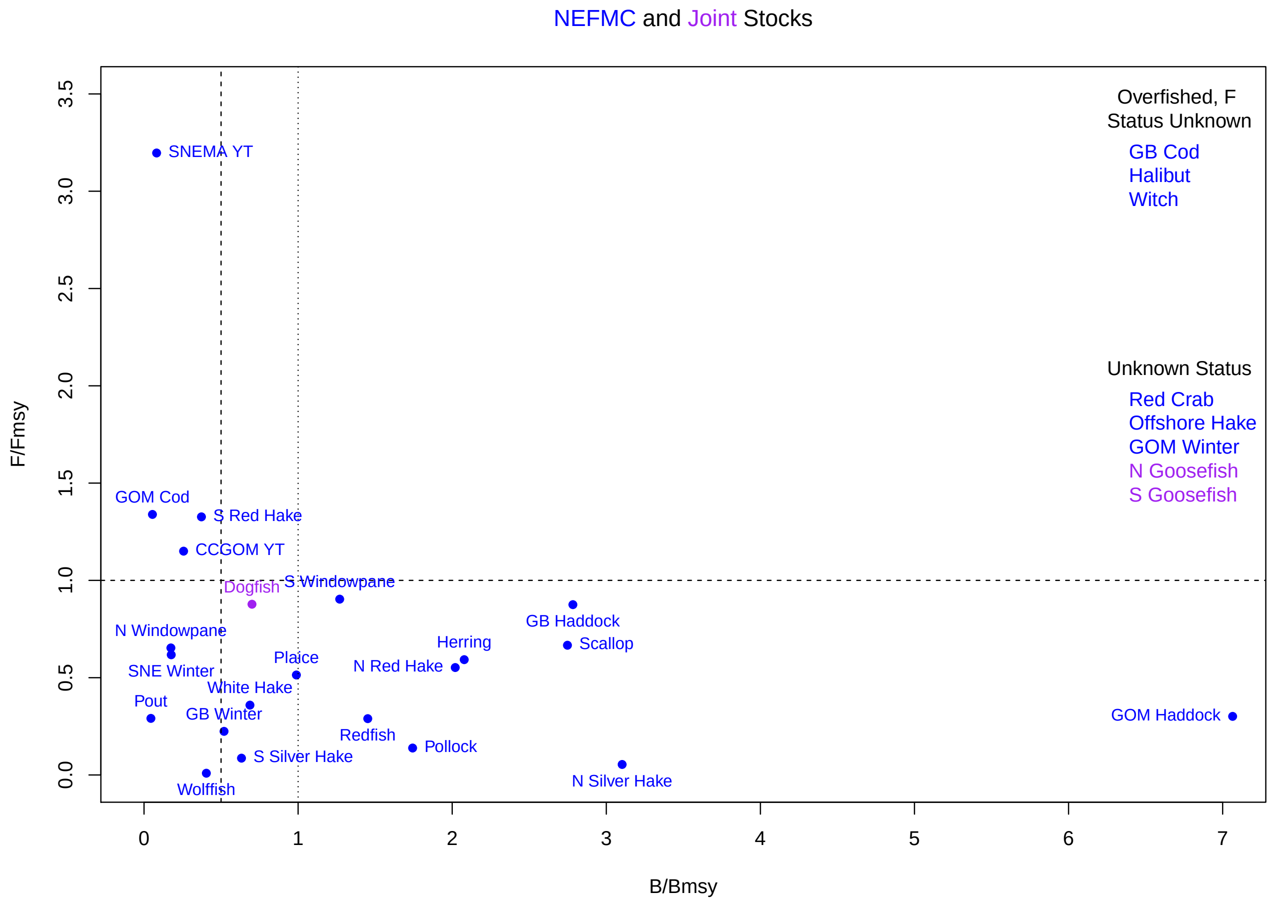


Figure 3: Summary of single species status for NEFMC stocks

**We also report single-species status relative to established objectives and reference points**. The New England Council (NEFMC) is meeting objectives at the managed species level for fishing mortality (F) rates and biomass (B) levels for 20 of 38 stocks relative to established reference points (Fig. 3; note that barndoor, clearnose, little, rosette, smooth, and winter skate stocks have good B and F status according to index based methods, but fishing mortality rates cannot be calculated for this plot). Five stocks have low B status but good F status: thorny skates, Atlantic wolfish, ocean pout, Southern New England winter flounder and Northern windowpane flounder. Another three stocks have low B status with indeterminate F status: GB Atlantic cod, halibut, and witch flounder. Four stocks have F rates exceeding the limits and low B status: GOM cod, southern red hake, Southern New England and Cape Cod/GOM yellowtail flounders. Assessment-based status for GB yellowtail flounder is unknown, but NMFS-determined stock status is overfished with overfishing ocurring. The remaining five stocks have unknown status for B and F.

**Performance against human dimensions objectives is mixed, with declines in seafood production, recreational opportunities, and revenue diversity**. Benthivores have driven recent revenue volatility in both GOM and GB. On GB, this coincides with a flip from benthivore to benthos dominated revenue stream, along with a decline in seafood production. In GOM, total seafood production has been relatively stable. Recreational participation and commercial fleet diversity in NE has seen a continuing decline, and commercial species diversity at the permit level is near an all-time low. Overall, the increasing dominance of benthos could indicate issues in diversity and resilience of the biological system. **Low diversity and reduced resilience threatens high-value port communities like New Bedford, the port with the highest valued landings in the US, primarily composed of climate-vulnerable benthos**.

**Fisheries are currently meeting objectives with respect to protected species bycatch reduction, but climate and ecosystem changes may upset this balance**. Fisheries interactions with harbor porpoise have decreased due to management measures, but have increased with grey seals as that population has increased. Further, climate driven distribution changes for sea turtles may lead to future fishery interactions and potential regulations. In addition, the most endangered species in the system (North Atlantic right whale) may be declining over the most recent few years after a slow but steady increase. **Ecosystem conditions combined with changing distributions may**

**be contributing to the decline and observed unusual mortality event for right whales in 2017**.

Survey biomass trends for aggregated trophic groups are similar across spring and fall and between the Gulf of Maine and Georges Bank. At the lowest trophic level, both **forage fish and benthos, including commercial shellfish, show long term biomass increases** in both seasons. Both **benthivores and piscivores at higher trophic levels have stable or increasing trends** depending on the season sampled, in particular during the most recent decade. However, these **biomass increases are largely driven by non-commercial species**. Species diversity has increased in the Gulf of Maine, but remained stable or decreased on Georges Bank depending on the season sampled.

**Additional indicators in this report suggest a note of caution for the aggregate productivity of fish species in the region** (fish condition declined and recovered for some species). These changes in fish productivity may be linked to observed patterns in plankton communities, to changes in habitat, or both. While there are few clear long-term trends at the bottom of the food web in New England, changes in species composition and shifts in seasonal timing may have a greater impact on upper trophic levels. Temperature is increasing in long term sea surface records as well as surface and bottom measurements from surveys. The seasonal temperature signal also shows sustained warming. **Warming waters have impacts on the ecosystem that can be complex due to differential impacts at the species level, including observed shifts in species distribution and changes in productivity as thermal habitats shift.**

## Changes for 2018

Indicators throughout the report have been updated with the most recent data, and in some cases replaced with more management-relevant indicators based on Council feedback from the 2017 report. In particular, new sections on species-specific habitat status and trends and climate projections of thermal habitat for key species have replaced last year's more general physical environment and climate sections. This report draws on a wider range of expertise and attempts to further link information across indicators to give an integrated overview of ecosystem status relevant to fishery management decision making.

Many metrics aggregate species by similar functional groups. Species that comprise the functional groups are listed below. Relative to the 2017 report, these categories have been aggregated into fewer groups for simplification and clarity (Table 2).

**Table 2**: New England feeding guilds.

| Group | N species | Major species in the group |
|---|---|---|
| A: **Apex predator** (Highest trophic level) | 4 | shark (Unc.), swordfish, yellowfin and bluefin tuna |
| B: **Piscivore** (Eat fish) | 23 | monkfish, winter and thorny skates, silver and offshore hake, Atlantic cod, halibut, fourspot flounder, spiny dogfish, summer flounder, bluefish, striped bass, weakfish |
| C: **Planktivore** (Eat plankton) | 16 | Atlantic herring, butterfish, Atlantic mackerel, menhaden, river herrings, shad, white hake, longfin and shortfin squids, searobins, sculpin, lumpfish |
| E: **Benthivores** (Eat bottom dwellers) | 25 | lobster, haddock, yellowtail, winter, and witch flounders, barndoor skate, ocean pout, black sea bass, scup, tilefish, tautog, cunner, blue crab, red crab, other crabs |
| F: **Benthos** (Filter feeders) | 9 | scallops, surfclam, quahog, mussels, whelks, conchs, sand dollars and urchins |

Our assessment of indicator trends has changed this year. In the 2017 time series plots, monotonic (but not necessarily linear) trends were assessed for both the full time series and the most recent 10 years (shaded dark grey background). Recent simulation analysis suggest that statistical significance tests are unreliable for short time series, but reliable for longer ones. Therefore, similar to 2017, we indicate significant increasing long term trends with orange lines, while significant decreasing long term trends have purple lines. However, we no longer indicate significant trends for the most recent period but rather discuss recent/current status and trend of each indicator relative to the full time series. Time series mean is indicated with a dashed line and the final ten years of the time series are highlighted through a grey background.

## Human Dimensions

### Seafood production (GOM and GB)

Seafood production is a stated goal of optimal fishery management as part of the definition of "benefits to the nation" under MSA. Both commercial and recreational fishing contributes to seafood production, the latter for personal consumption, and indicators for each of these human activities track management performance against this objective.

Commercial landings include all seafood landings in the region, including species not managed by NEFMC. For example, category D, Benthivores, includes lobsters, which are a substantial portion of the landings and drive increases in landings and revenue. In 2016, NEFSC managed stocks made up from 5%-98% of total landings by category, as detailed below (Table 3).

Table 3: Proportion managed by NEFMC

| Groups | GOM Landings | GB Landings | GOM Revenue | GB Revenue |
|---|---|---|---|---|
| Piscivore | 0.98 | 0.98 | 0.93 | 0.91 |
| Planktivore | 0.88 | 0.90 | 0.89 | 0.26 |
| Benthivore | 0.05 | 0.42 | 0.03 | 0.77 |
| Benthos | 0.30 | 0.30 | 0.71 | 0.85 |

Figure 4 shows the removals for human consumption both at the entire EPU level as well as those removals managed by the NEFMC. Landings of piscivores have decreased over the long term in both systems. Benthos landings show no long term trends in either system. Other groups have a decreasing landings trend in either GOM or GB.

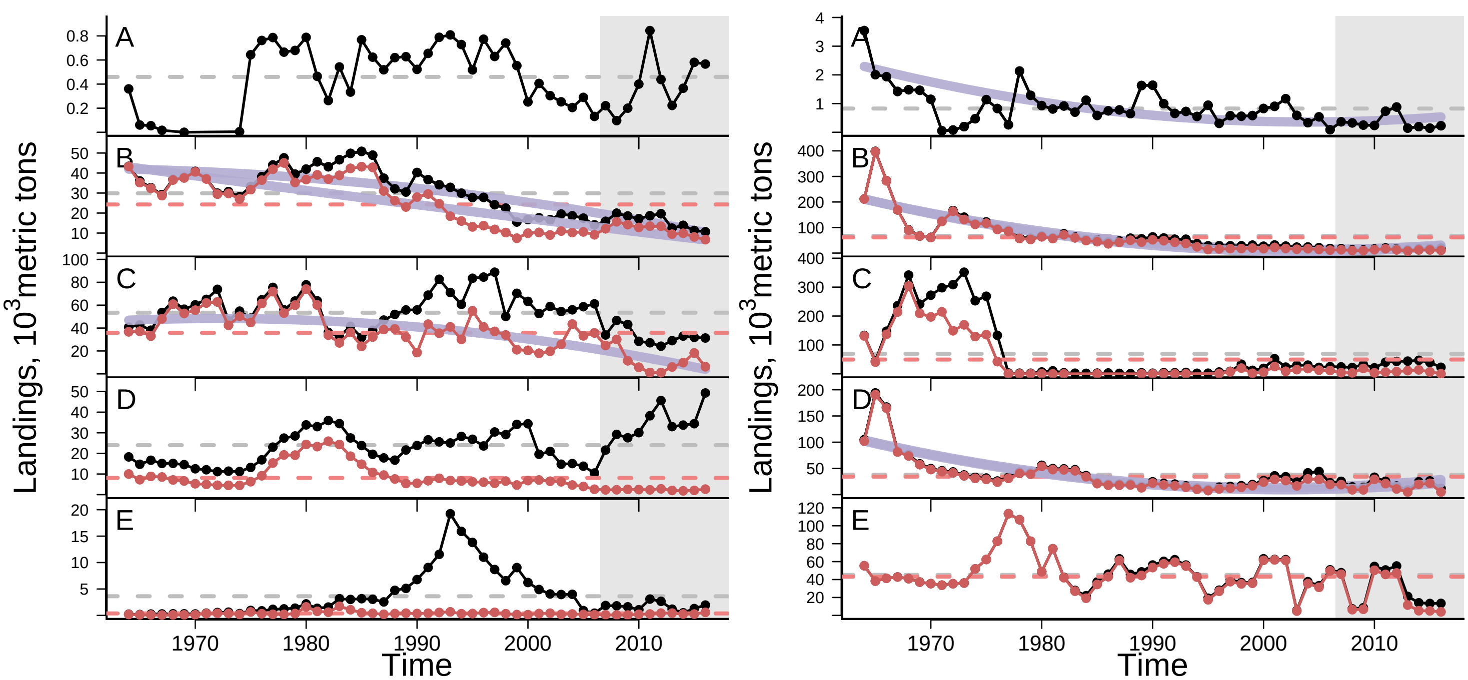


Figure 4: Total landings (black) and total seafood specific landings managed by NEFMC (red) in Gulf of Maine (left) and Georges Bank (right) (A: Apex predators, B: Piscivore, C: Planktivore, D: Benthivore, E: Benthos).

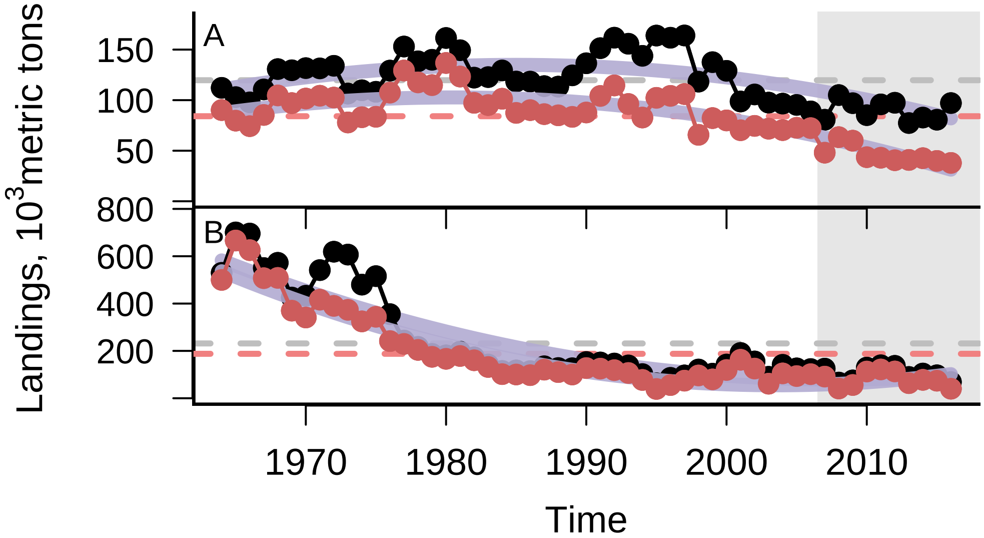


Figure 5: Total landings (black) and total landings managed by NEFMC (red) in Gulf of Maine (A) and Georges Bank (B).

Total commercial seafood landings from all species and from NEFMC managed species indicate total seafood production in the GOM and GB, which has declined over the long term.

Recreational seafood landings (as opposed to total landings which include catch and release that are captured under other risk elements/indicators) were used to assess food use of recreationally caught fish. This trend is also declining.

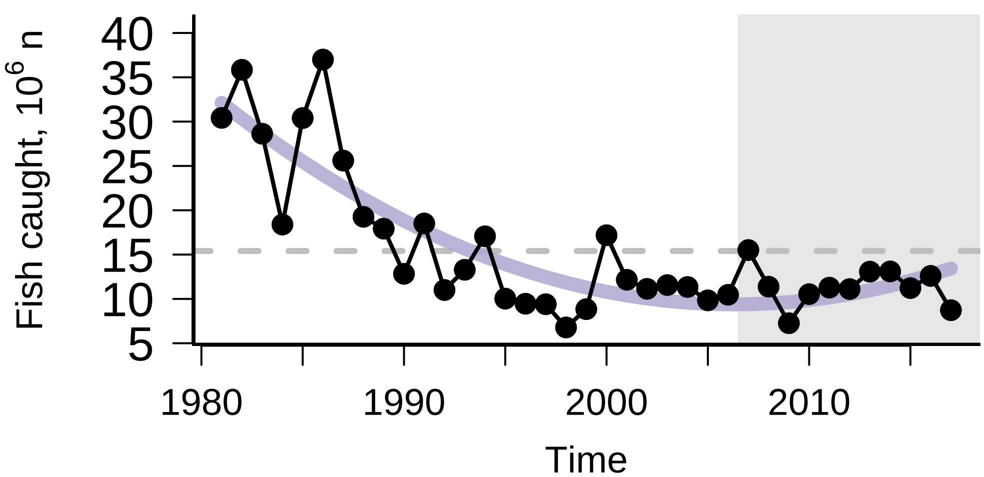


Figure 6: Recreational seafood landings in New England.

### Commercial Fishery Revenue (GOM and GB)

This indicator links the human activity of commercial fishing to the profits objective. The Bennet indicator is used to compare differences in revenue caused by changing quantities of landings and prices during the time period 1964-2016. Each year in the series is compared to an "average" year based on revenue during the entire period. Average revenue, landings and an implicit price (revenue/landings) is calculated for the time period. The volume indicator measures the contribution of changing quantities to revenue change and the price indicator measures the contribution of changing prices. The overall Bennet index is the sum of the volumen and price indicators in each year.

In the years between 1970 and 1990, Gulf of Maine revenue was generally below average (Fig. 7A), and this was due to either lower volumes or lower prices depending on the year. After 1990, revenue was higher than average, before declining dramatically after 2000 mostly due to lower volumes. Revenue then fluctuated between 2008 and 2016, with some years being above average and some below. During most of these yearly cycles, changes in volume of Benthivores

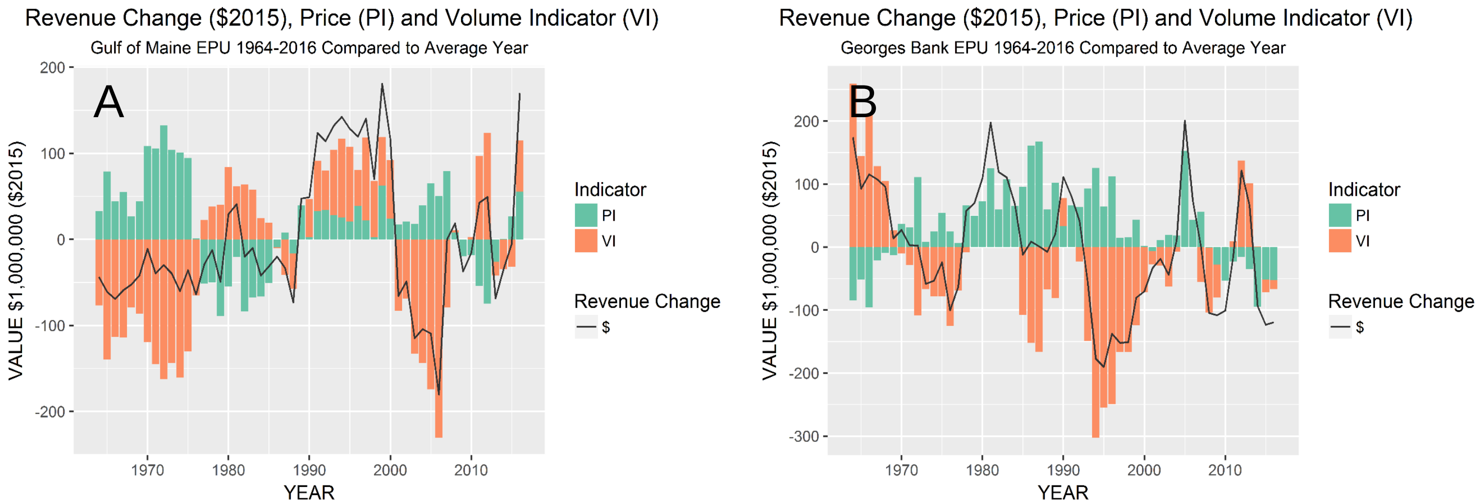


Figure 7: Revenue change in Gulf of Maine (A) and Georges Banks (B) shown through aggregated price and volume indicators.

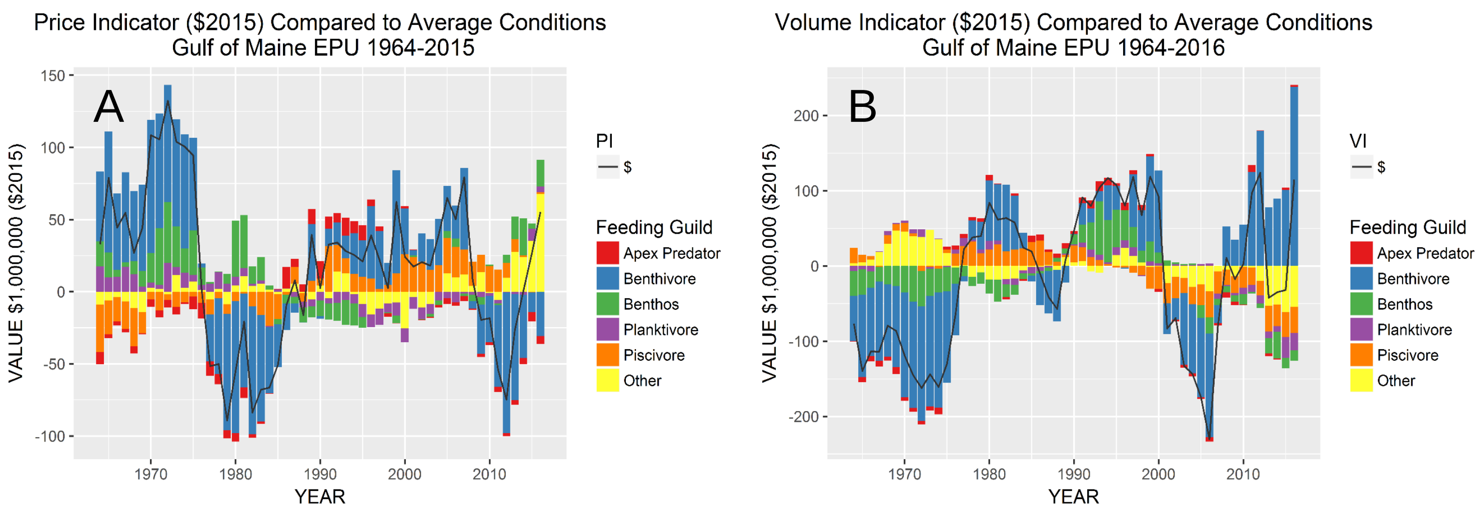


Figure 8: Gulf of Maine Bennet indicator, price component (A) and volume component (B) by functional group.

were responsible for the changes in overall volume (Fig. 8A). Benthivores were also the group whose price difference was the primary reason for the changes in the overall price (Fig. 8B).

On Georges Bank, revenue showed a cyclical pattern which alternated between a positive and negative deviation from average revenue between 1964 and 2016 (Fig. 7B) During periods of negative revenue growth, the decline was caused by lower volumes rather than lower prices. In most years, positive price growth helped offset any negative volume change. Before the 1980's positive Benthivore and Planktivore volumes were offset by negative Benthos volumes (Fig. 9B). The 1990's time period showed declining volumes of virtually all groups. Shortly after 2000, the Benthos group contributed positively to revenue, while the Benthivore group was a negative contributor, a reversal of the trend which existed prior to 1980. The price indicator showed a different trend (Fig. 9A). Until the mid-1980's the Benthos group prices contributed positively to revenue gains compared to the average. The price trend for the Benthos group then turned negative, while the Benthivore group contributed positively to the price indicator.

### Ecosystem-wide and Managed Species Total Revenue (GOM and GB)

Average total revenue from NEFMC managed species ranges from 3-93% of total revenue from commercial fishing in the region in 2016 (Fig. 10).

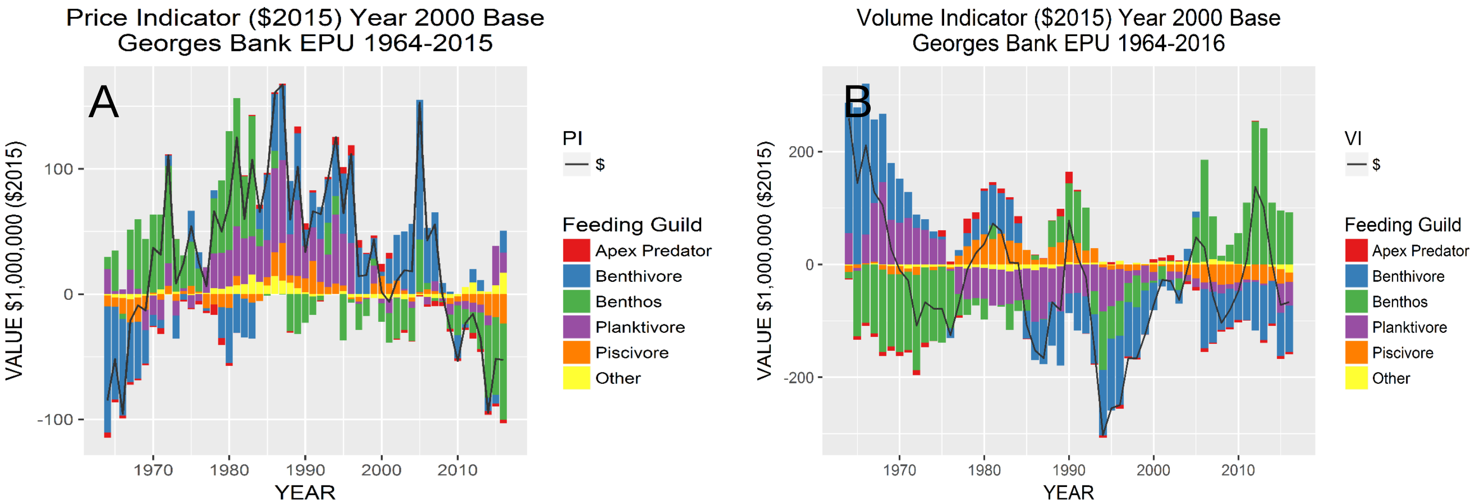


Figure 9: Georges Bank Bennet indicator, price component (A) and volume component (B) by functional group.

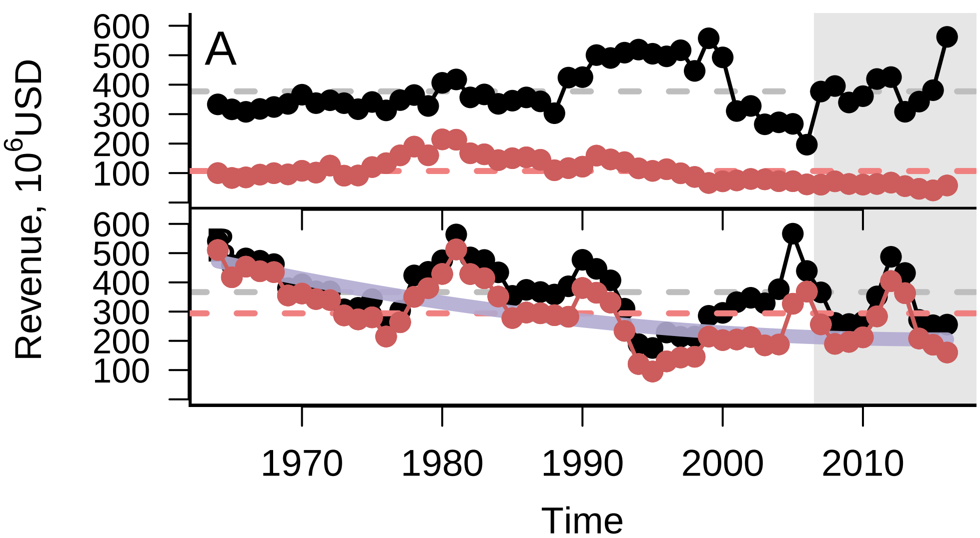


Figure 10: Total revenue by region and NEFMC managed species.

## Commercial fleet diversity (coastwide, New England permits)

Maintaining diversity can provide the capacity to adapt to change at the ecosystem level for dependent fishing communities, and can address objectives related to stability. Diversity estimates have been developed for fleets and species landed by vessels with New England species permits. A fleet is defined here as the combination of gear code (Scallop Dredge, Other Dredge, Gillnet, Hand Gear, Longline, Bottom Trawl, Midwater Trawl, Pot, Purse Seine, or Clam Dredge) and vessel length category (Less than 30 ft, 30 to 50 ft, 50 to 75 feet, 75 ft and above). The metric presented assesses the diversity of the overarching fleet, in terms of all revenue generated. This is coastwide rather than GOM or GB specific.

The fleet revenue diversity for individuals landing NEFMC FMP species shows a consistent downward trend across the entire time series. A declining trend in diversity indicates reliance on either a smaller number of resources, or a less diverse pool of resources but cannot distinguish whether specialization (by choice), or alternatively stovepiping (constrained choices), is occurring in New England. A count of the number of fleets actively landing NEFMC FMP species in each year is relatively consistent with the revenue diversity metric, with a consistent downward trend throughout the time series.

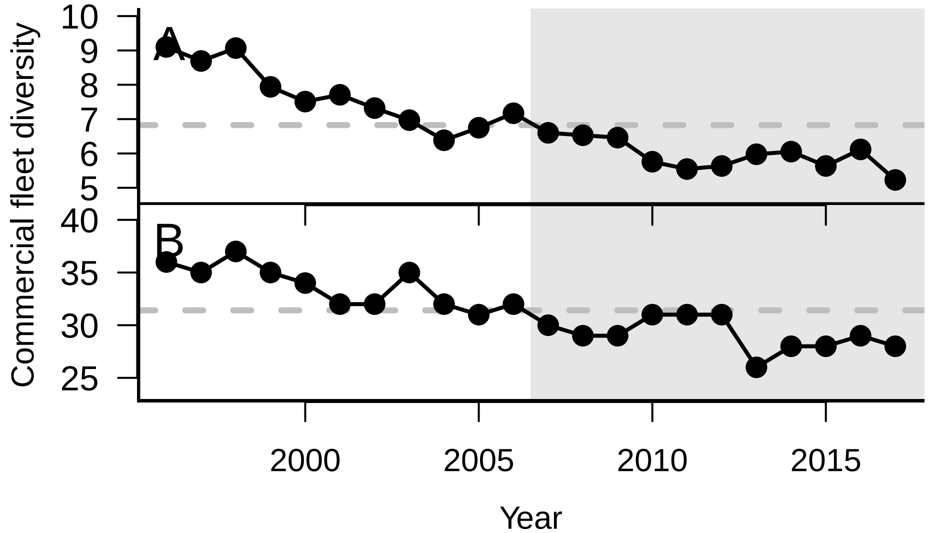


Figure 11: New England commercial fleet diversity (A) and fleet count (B).

### Revenue diversity (New England)

Another diversity index is the average effective Shannon index for species revenue at the permit level, for all permits landing any amount of NEFMC FMP species within a year (including both Monkfish and Spiny Dogfish). Although the exact value of the effective Shannon index is relatively uninformative, the major change in diversity seems to have occurred in the late 1990's, with much of the recent index relatively stable.

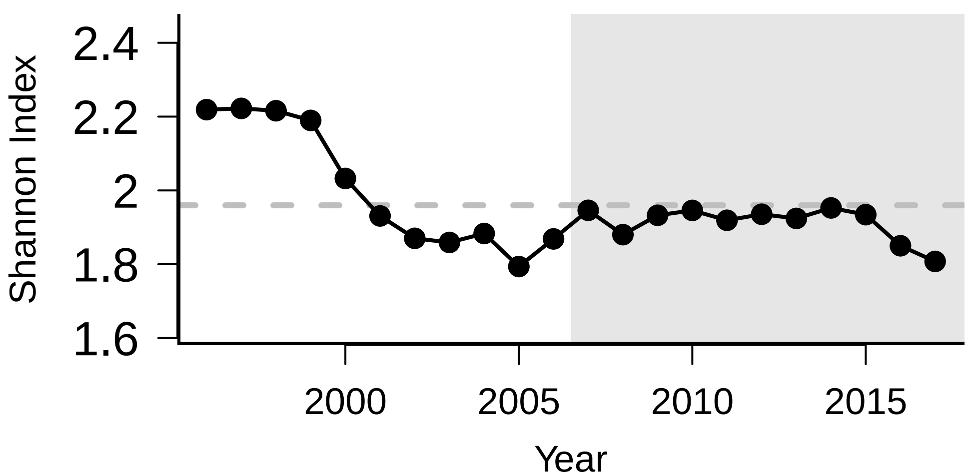


Figure 12: New England species revenue diversity.

### Recreational opportunities (New England)

Providing recreational opportunities is a stated goal of optimal fishery management as part of the definition of "benefits to the nation" under MSA. Recreational fishing is important in the New England region, with many coastal communities from Cape Cod southward having high recreational dependence. Although there is a long-term trend of increasing recreational fishery participation in terms of number of anglers, the most recent 10 years has shown a striking decline in both recreation indices.

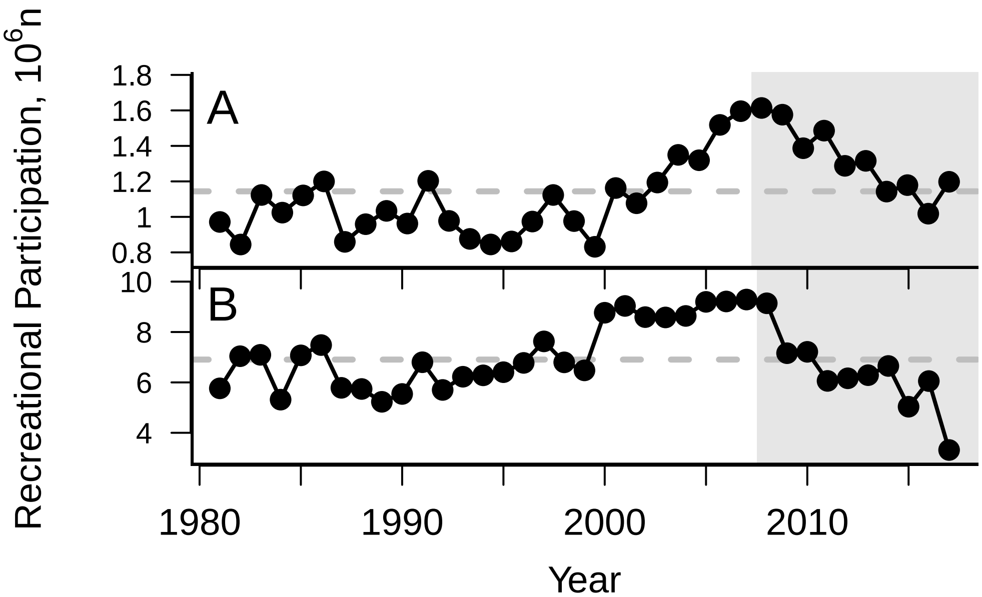


Figure 13: Recreational participation (A) and number of angler trips (B) in New England.

### Harmful Algal Blooms (New England)

The seasonal occurrence of harmful algal blooms (HABs) in New England is responsible for fluxes of saxitoxin and domoic acid into shellfish beds, which can result in paralytic shellfish poisoning (PSP) and amnesic shellfish poisoning (ASP) respectively. Blooms of *Alexandrium fundyense* cause regular closures of shellfish beds from Maine to Massachusetts due to saxitoxin contamination, with at least 30 PSP-related closures occurring between 2007-2016 (Fig. 14). Average blue mussel saxitoxin content in Maine waters increased from 2014 to 2017, although the change was driven by anomalously high values at 2 of 18 sampling sites in 2017. The prevalence of saxitoxin in Maine blue mussel beds exhibits high interannual variability with evidence suggesting a decadal cycle of toxicity.

Blooms of *Pseudo-nitzchia* species that produce domoic acid have become more common in the past decade. In fall 2016, *Pseudo-nitzchia* blooms caused closures of shellfish beds in Maine and Rhode Island. An unprecedented late-season *Pseudo-nitzchia* bloom resulted in the closure of shellfish harvesting in Casco Bay, ME in December 2017. Blooms of the dinoflagellate *Dinophysis* could also pose a threat to New England waters, with the first ever *Dinophysis* related waterway closure in Massachusetts occurring in 2015.

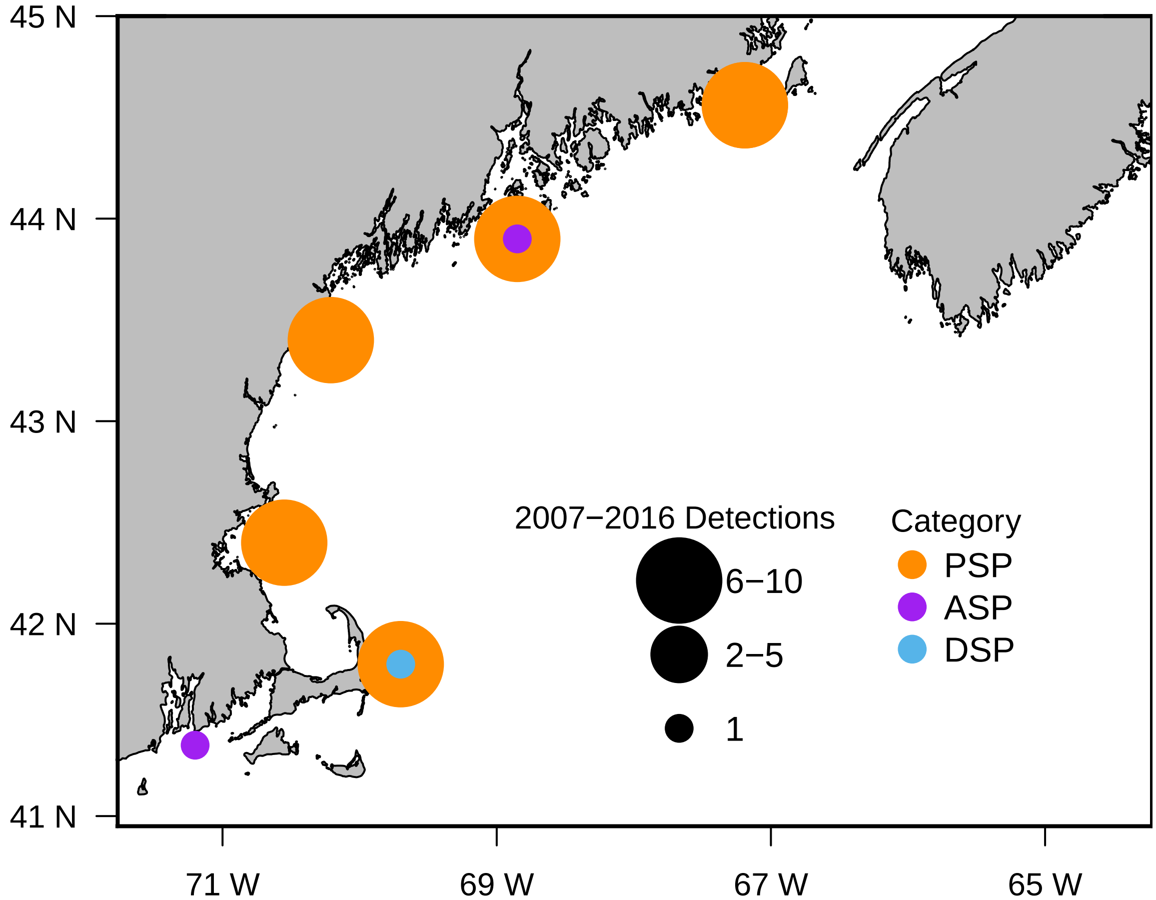


Figure 14: Regional HAB-related shellfish bed closures in New England (2007-2016).

### Community social vulnerability, engagement and dependence on commercial fisheries (New England)

The NOAA Fisheries Community Social Vulnerability Indicators (CSVIs) are statistical measures of the vulnerability of communities to events such as regulatory changes to fisheries, wind farms, and other ocean-based businesses, as well as to natural hazards, disasters, and climate change. The CSVIs currently serve as indicators of social vulnerability, gentrification pressure vulnerability, commercial and recreational fishing reliance and engagement, sea level rise risk, species vulnerability to climate change, and catch composition diversity.

Here, we look at the extent to which commercial and recreational fishing reliance intersect with community social vulnerability in the New England region. Commercial fishing reliance is a measure of per capita pounds landed, value landed, commercial permits and commercial dealers in a community. Recreational reliance is a per capita measure of shore, private vessel and for-hire recreational fishing in a community. Social vulnerability represents social factors that can shape either an individual or community's ability to adapt to change. There are many socially vulnerable communities in the New England region, but with varying degrees of commercial and/or recreational fishing reliance. While there are some communities that are both moderate to highly socially vulnerable and moderate to highly reliant on commercial fishing in Northern New England (Fig.15), there are different communities in Southern New England that are both moderate to highly vulnerable and moderate to highly reliant on recreational fishing (Fig. 15).

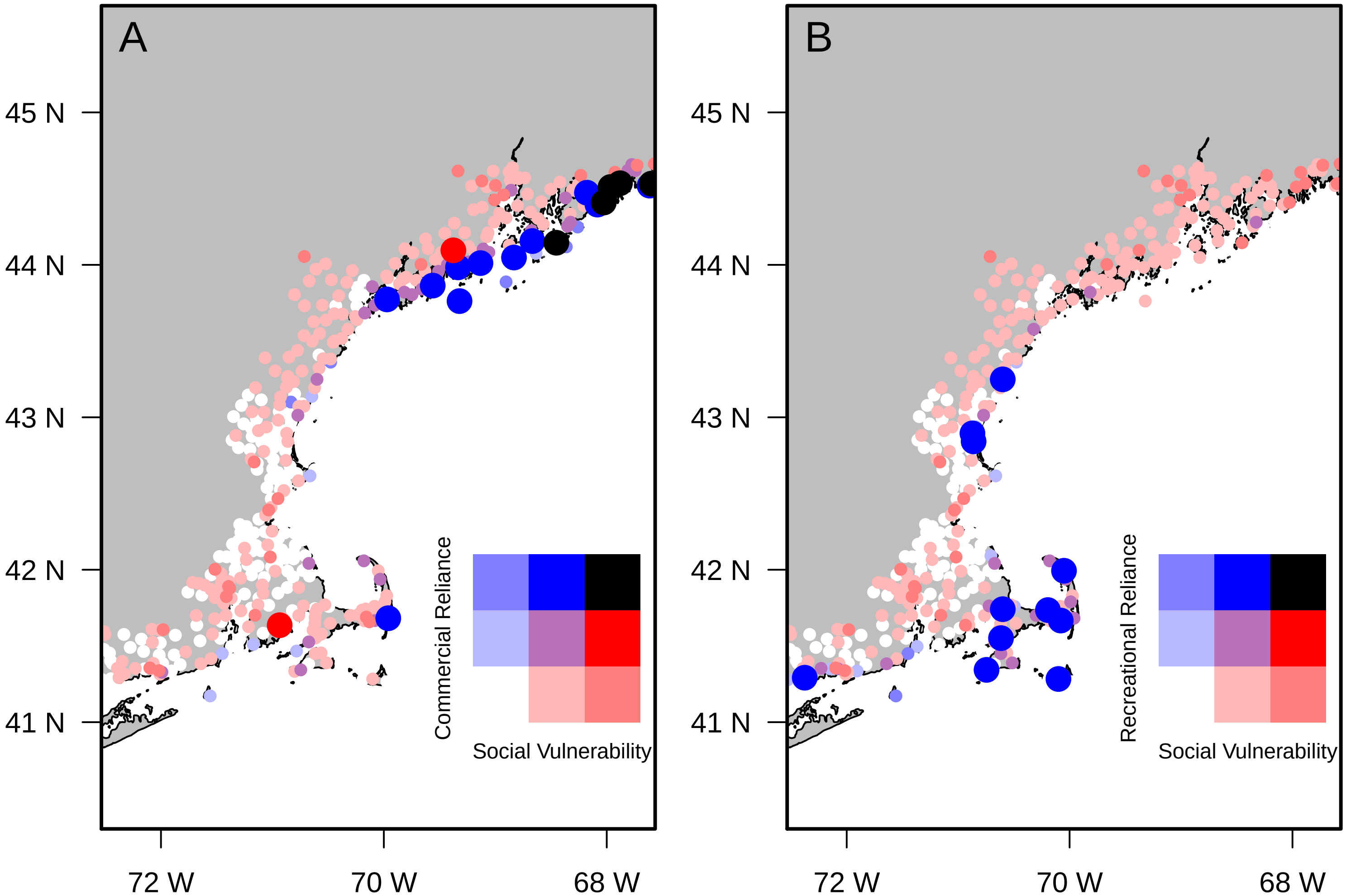


Figure 15: Commercial (A) and recreational (B) reliance and social vulnerability in New England

### Climate Vulnerability of Coastal Fishing Communities (New England)

Assessment of the potential impacts of climate change on recreational and commercial fishermen and their communities has begun by linking social and economic indicators of community vulnerability and resilience to the climate vulnerability assessments of biological and ecological change expected to result from climate change New Bedford, the largest commercial fishing port in US (in terms of revenue) is heavily dependent on benthic species which are in turn highly vulnerable to climate change. Four of the top ports are dependent on an array of species, the majority of which are ranked as low to moderately vulnerable to climate change.

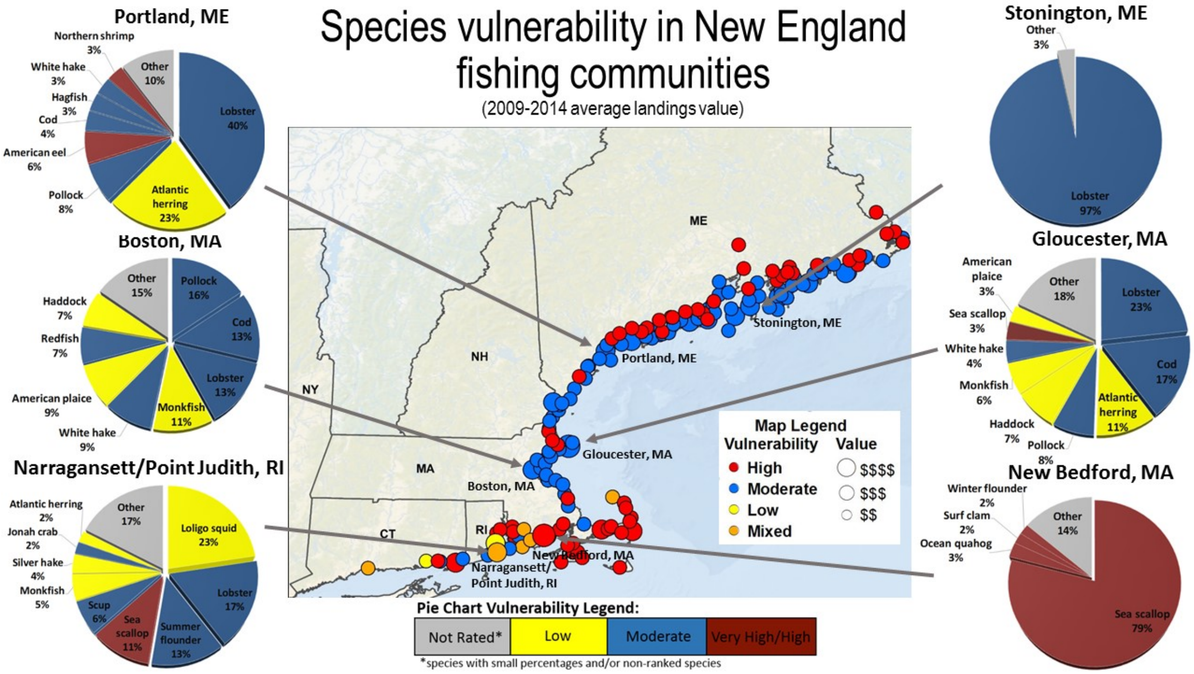


Figure 16: Species vulnerability in Mid-Atlantic fishing communities

## Protected species-fishery interactions

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 interactions between resource and protected species; here we report on the current status of these interactions as well as indicating the potential for future interactions driven by observed and predicted ecosystem changes in the New England region.

### Harbor porpoise (coastwide)

Harbor porpoise bycatch has resulted in fisheries closures in the past, but current bycatch levels demonstrate that management measures have been effective, reducing this fishery interaction. The 5-year mean bycatch has been below the maximum permitted level (Potential Biological Removal, PBR) since 2011 (Fig. 17), and the most recent annual bycatch estimate is one of the lowest in the time series. Increased compliance and reduced fishing effort are thought to contribute to low bycatch estimates. There should be an updated harbor porpoise abundance estimate this year. Recent analyses have examined regional harbor porpoise diet, however, the impact of ecosystem changes on bycatch, population, or distribution remain unclear.

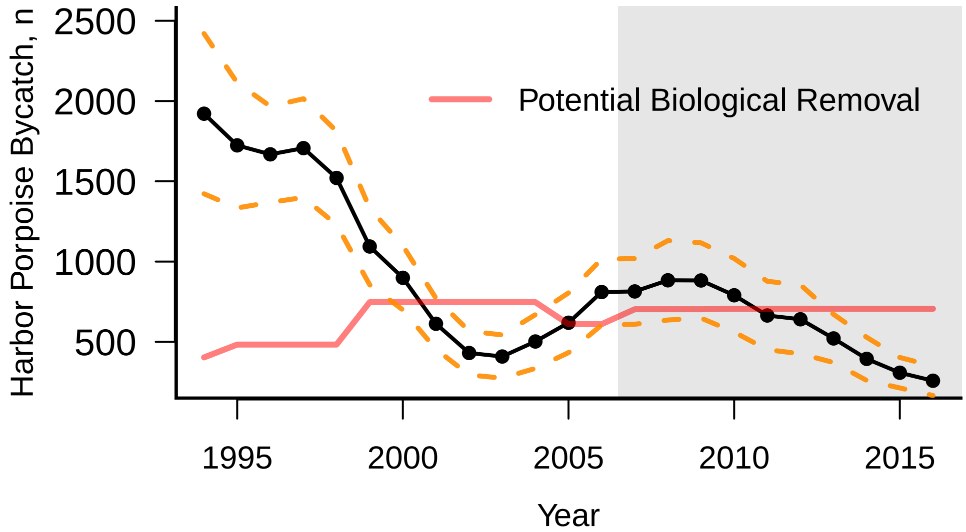


Figure 17: Harbor porpoise bycatch estimated compared with PBR

### Grey seals (coastwide)

The number of grey seals (*Halichoerus grypus*) in U.S. waters has risen dramatically in the last 2 decades, with few being observed in the early 1990s to at least 25,000 on a single Massachusetts beach in 2016. 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. Pups born on Muskeget Island, currently the largest pupping site for gray seals in the U.S., were first observed in 1988 and now number over 3,500. Trends in pup production at U.S. colonies appear to be increasing, and it is likely that U.S. pup production is being supplemented each year by animals from Canada. Fisheries interactions have increased over the past 2 decades, with fewer than 10 total estimated grey seal interactions in 1993, to over 1000 in 2014.

### Sea Turtles (coastwide)

Sea turtles are known to be susceptible to climate and ecosystem changes, and their distribution is influenced by water temperature. Sea turtle diets contain a considerable amount of gelatinous zooplankton, which are also influenced by changes in the pelagic ecosystem. At present, management measures to reduce sea turtle-fishery interactions are limited to the regions with historical observations of sea turtles and based on historical ocean temperature distributions. However, changes in climate may cause turtles to shift northward into areas with heavy fishing, possibly resulting in increased bycatch, and necessitating new management measures.

### Right whale (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. From Pace et al 2017: “The probability that the population’s trajectory post-2010 was a decline was estimated at 99.99%.” Reduced survival rates of adult females and diverging abundance trends between sexes have also been observed. Further, right whale distribution has changed since 2010. The reasons for these changes is unclear, but changes in climate and primary prey (Calanus finmarchicus) are suspected. Not yet reflected in this trend are the 17 right whale deaths observed in 2017, 5 due to vessel strike (1 in US waters, 4 in Canadian waters), 3 from entanglement (2 in Canadian gear, 1 in unknown gear), and the rest from unknown causes.

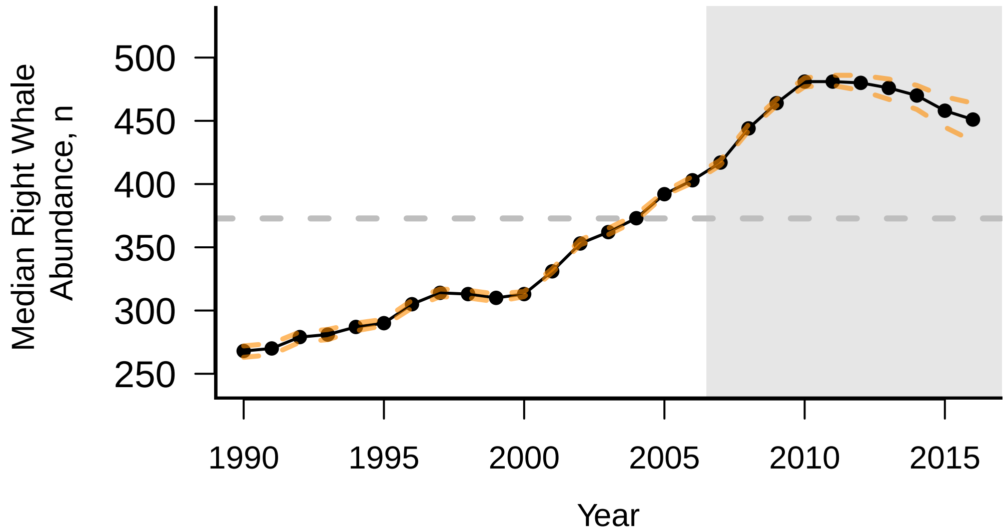


Figure 18: Right whale population estimate

## Resource Species

Patterns for groups of species that feed on similar prey can indicate how overall ecosystem conditions are changing, and provide context for individual species stock assessments. This information is from NEFSC bottom trawl surveys in spring and fall.

### Trends in Biomass (GOM and GB)

Biomass across trophic levels shows similar trends between the Gulf of Maine and Georges Bank. In the Gulf of Maine, forage fish (including herring), show long term increases in both seasons. Fall surveys show increasing trends for all groups (Fig. 19). On Georges Bank, all groups other than piscivores show increasing trends in survey biomass for both seasons (piscivores have an increasing trend only during the fall; Fig. 20).

These survey biomass trends are in contrast with the long term decreasing landings trends shown above. Survey biomass includes non-commercial species, while landings do not. Landings are also affected by management as well as underlying biomass of stocks.

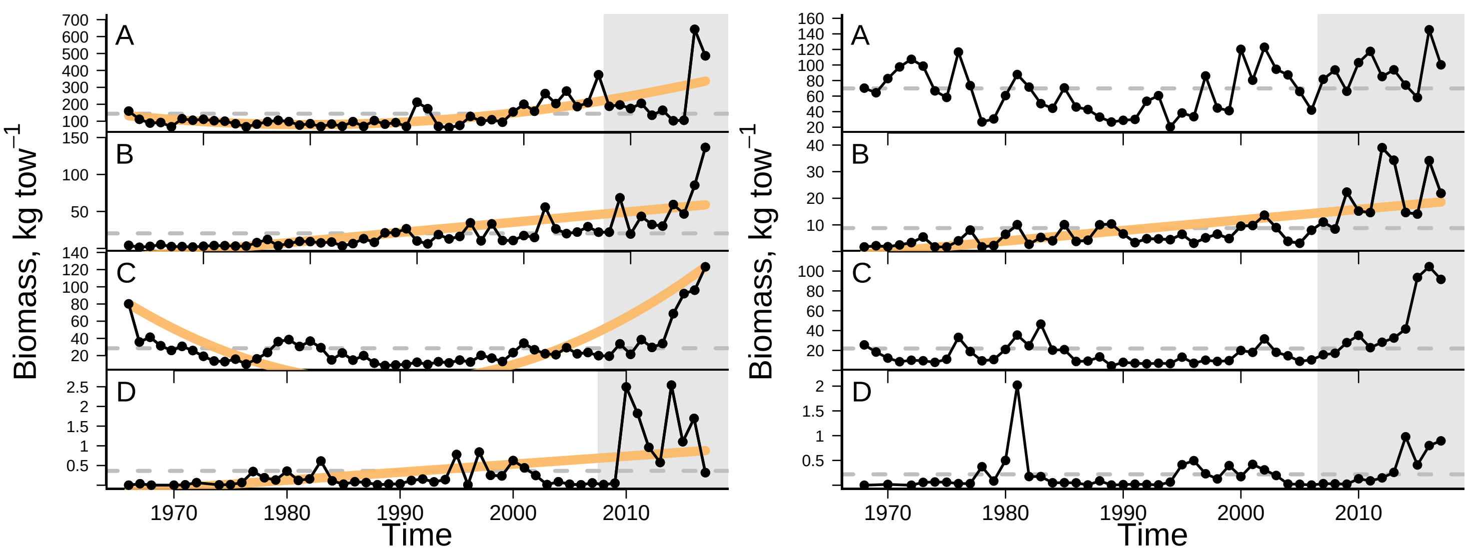


Figure 19: Fall (left) and Spring (right) Gulf of Maine survey biomass (A: Piscivore, B: Planktivore, C: Benthivore, D: Benthos)

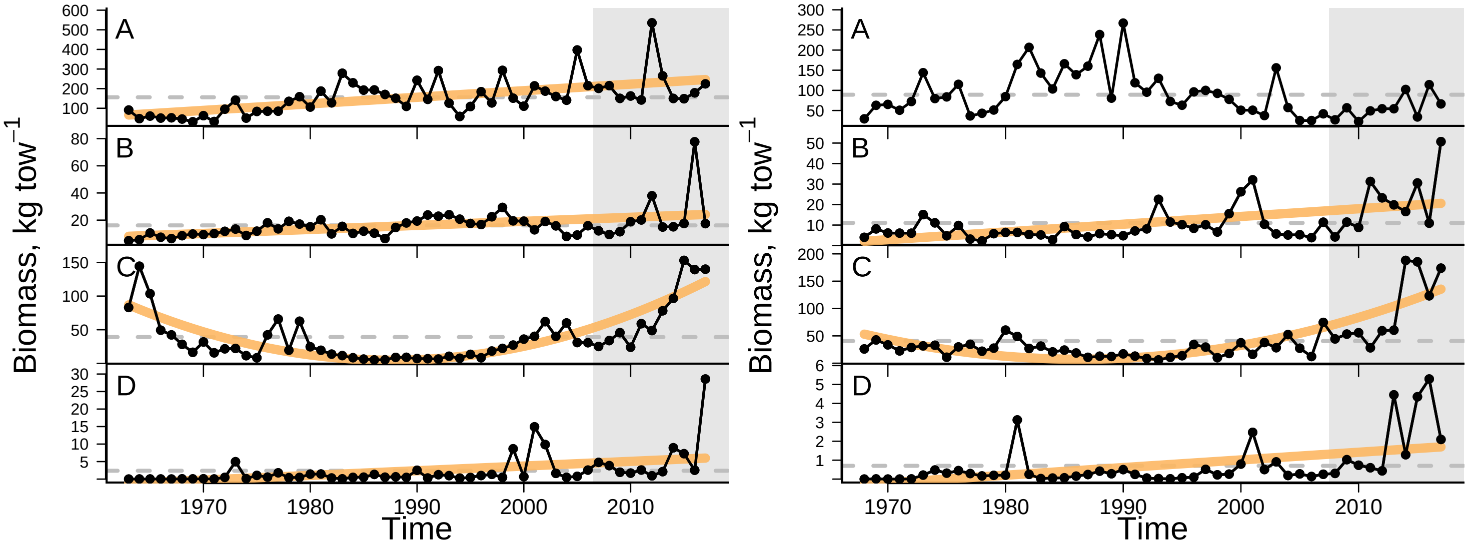


Figure 20: Fall (left) and Spring (right) Georges Bank survey biomass (A: Piscivore, B: Planktivore, C: Benthivore, D: Benthos)

### Species composition (coastwide)

Diversity in species composition mainly addresses objectives related to ecosystem structure and stability; maintaining diversity can provide the capacity to adapt to change at the ecosystem level and for dependent fishing communities. Diversity (here estimated using data from NOAA NEFSC Oceans and Climate branch public dataset for 45 abundant and well-identified ichthyoplankton taxa shows a decrease for one season (spring), suggesting that survey timing may be interacting with changes in spawn timing or migration of adult fish (see above) as well as a potential change in ichthyoplankton availability due to adult fish distribution shifts (see below). The decrease in spring ichthyoplankton diversity coincides with an increase in the spring abundance of sand lance (*Ammodytes* spp.) larvae, an important prey species. Researchers documented a significant seasonal shift from winter to spring based on annual relative proportions from 1977-1987 to 1999-2008.

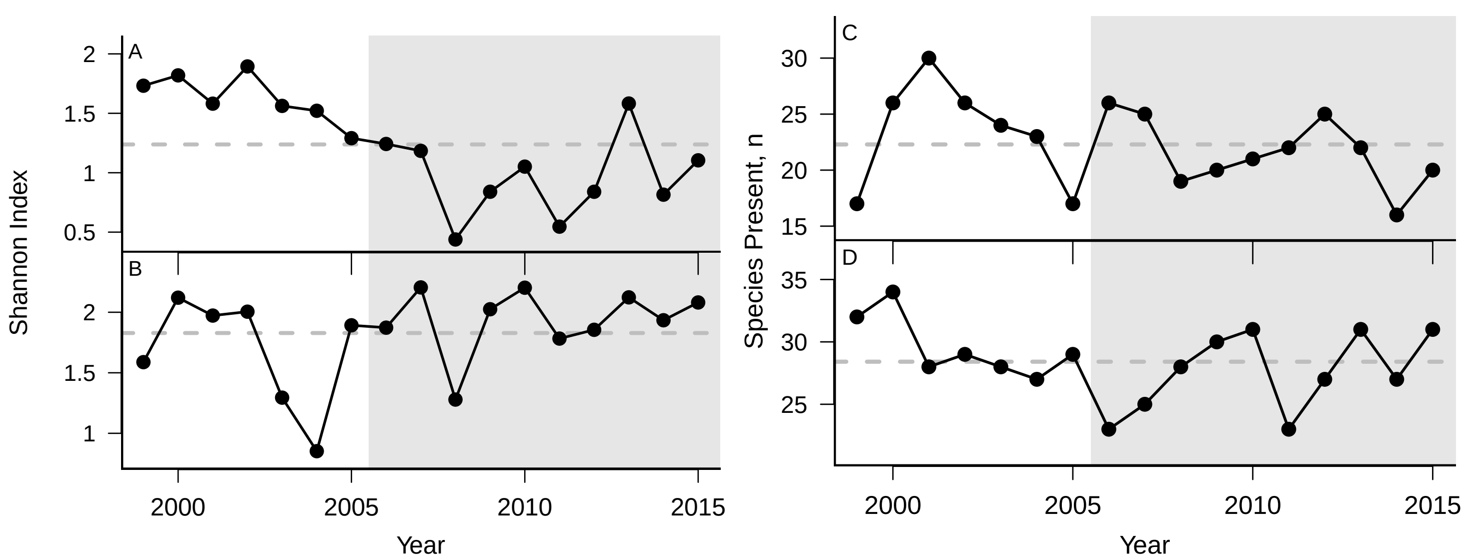


Figure 21: Ichthyoplankton Shannon diversity and species counts in the Spring (Top row) and Fall (bottom row)

### Species distribution (coastwide)

Spatial distribution can change for a variety of different reasons. In the U.S. Northeast Shelf, species distributions have changed over time but the direction and rate of movement is not consistent among some of the key species. Two species of particular interest to the NEFMC are sea scallops and Atlantic cod. Sea scallops show no clear trend in average along-shelf distance or depth in surveys, indicating a generally stable distribution (Fig. 22). In contrast, Atlantic cod average depth and along shelf distance has been increasing (Fig. 23), indicating shifting distribution. Information for more species is available at http://www.nefsc.noaa.gov/ecosys/current-conditions/species-dist.html.

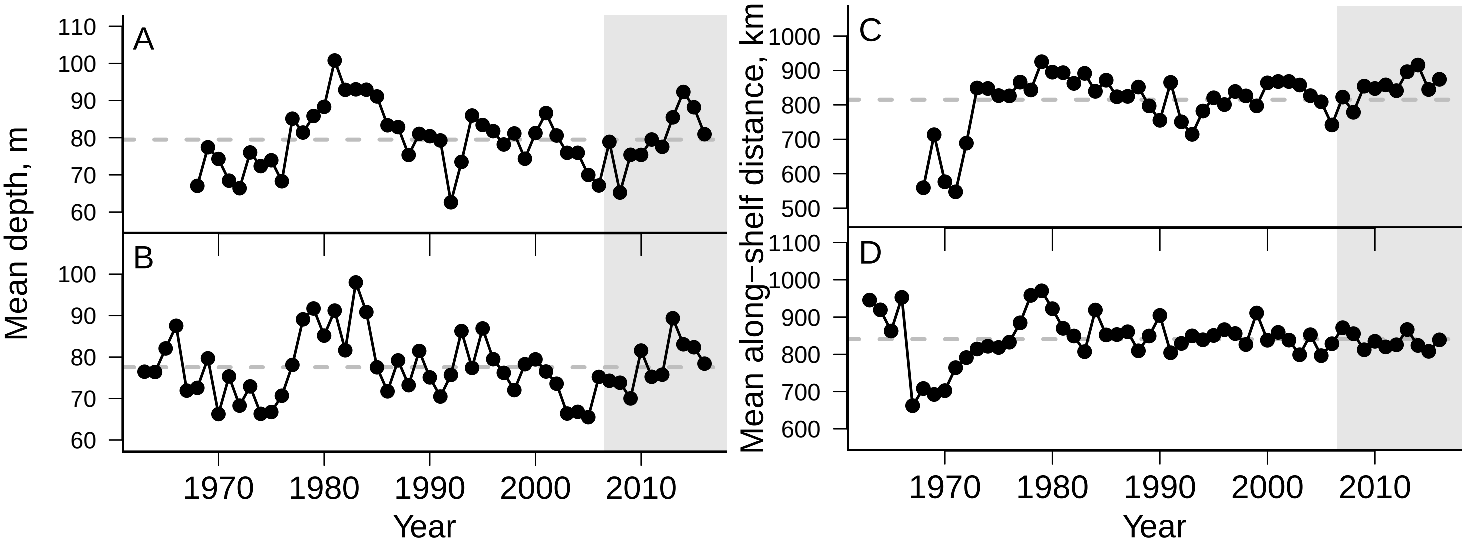


Figure 22: Sea scallop mean depth and along shelf distance trends (Top row: Spring, bottom row: Fall)

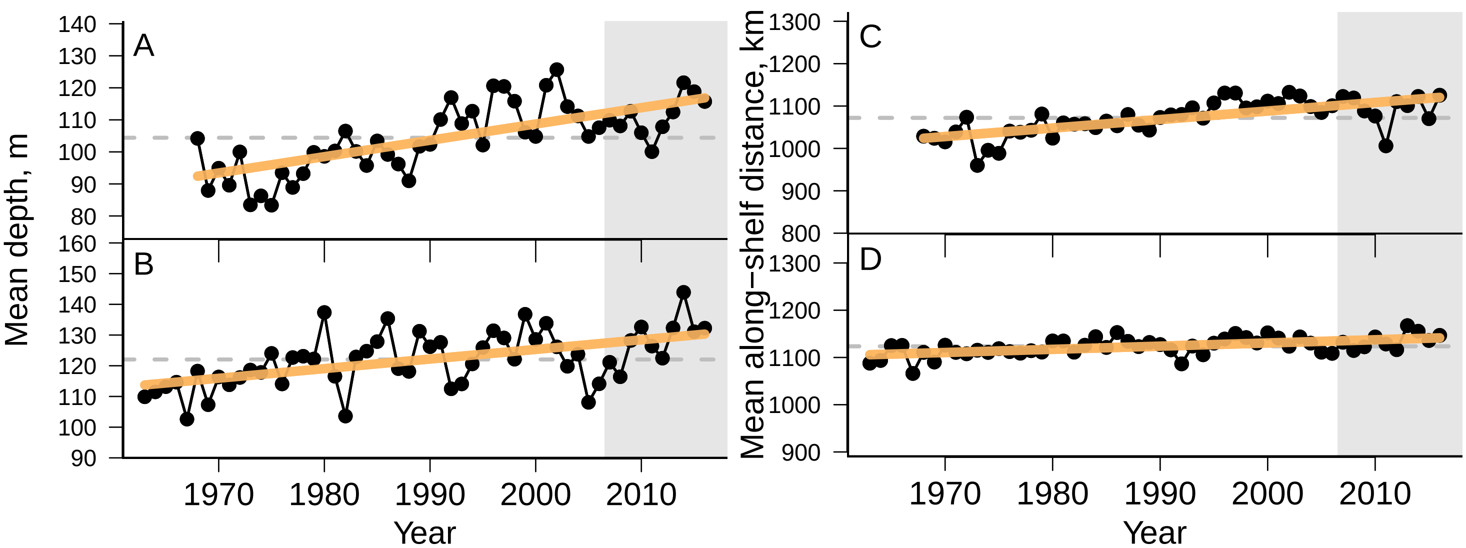


Figure 23: Atlantic cod mean depth and along-shelf distance trends (Top row: Spring, bottom row: Fall)

Looking in more detail at the NEFSC bottom-trawl data, sea scallops have shifted away from the northern flank of Georges Bank and are now more abundant along the Great South Channel (Fig. 24A). Cod abundance has shifted into the southwestern Gulf of Maine and is now nearly absent in southern New England waters off the coastlines of Long Island, Connecticut, and Rhode Island (Fig. 24D).

Other work using temperature data from the NEFSC trawl survey developed thermal habitat preference for these resource species. Thermal habitat for individual species can then be projected using global climate models. While thermal habitat is only part of the picture, and species may adapt to new thermal regimes, these projections indicate the potential for key species to thrive or not over the coming decades where further ocean warming is expected. Thermal habitat area for both sea scallops and cod is projected to decline over the next 40 years of continued ocean warming (Fig. 24B-C and D-F). However, the projected thermal habitat area decline is much more substantial for cod than for sea scallops. It is important to note that these projections do not account for changes in other critical factors such as ocean acidification (scallops), fisheries mortality, new species interactions, and bottom-up

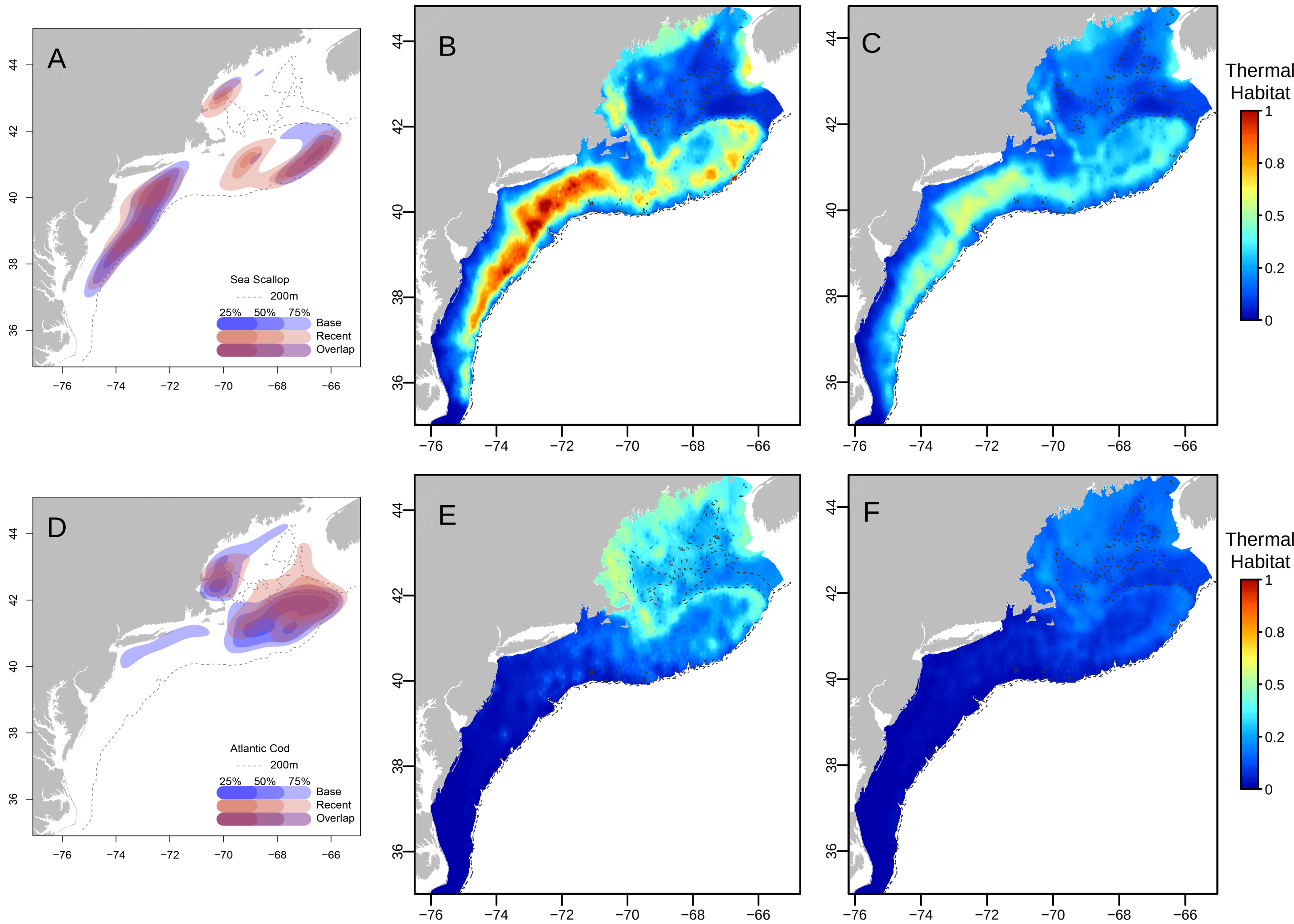


Figure 24: Current and historical abundance estimates (left), current thermal habitat estimate (center), and 20-40 year thermal habitat projection (right) for sea scallop (A-C) and Atlantic cod (D-F).

forcing (i.e. changes in lower trophic levels). The projections shown here are for fall only but spring projections are also available. Observed distribution maps for more species are available at http://www.nefsc.noaa.gov/ecosys/current-conditions/ kernel-density.html. Animations of thernal habitat projections for more species are available at https://www.nefsc.noaa.gov/ecosys/climate-change/projected-thermal-habitat/.

# Ecosystem Conditions and Productivity

Productivity of the system can be influenced by many factors. Temperature affects the behavior and physiology of marine organisms while changes in productivity and species composition at the base of the food web can influence juvenile survival. In this section we report temperature and lower trophic level production trends and annual cycles for the most recent year. We also look at fish productivity through recruitment and fish condition.

## Observed ocean conditions

### Long-term ocean temperature (coastwide)

Sea surface temperature (SST) measurements have been collected on the Northeast Continental Shelf since the mid-1800s. The highest mean annual temperature in this time series was recorded in 2012, as the ecosystem warmed above the levels last seen in the late 1940s. The 2017 datum is the sixth highest temperature in the time series. The positive trend over the full time series (1856-2016) is significant, and the trend over the most recent decade of the time series is even greater.

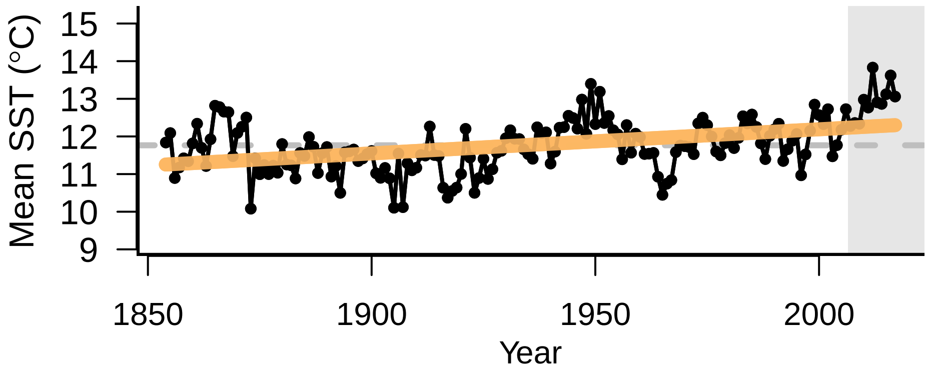


Figure 25: Long-term sea surface temperatures on the Northeast Continental Shelf

Relative to the 1981-2017 mean, the Gulf of Maine experienced above average sea surface temperatures (SSTs) throughout most of 2017 (particularly in the summer) with the exception of the spring when SSTs were only slightly above average (Figure 25). However, Georges Bank SSTs were substantially cooler than average in the spring and summer. Georges Bank also had slight cooling in the winter whereas fall SSTs were predominately above average (Figure 25). In figures 26A and 27A, the long term daily mean SST (1981-2016) is shown as a black line with gray shaded areas representing plus and minus one standard deviation from the long term daily mean. The SSTs for 2017 that were above the mean are shown in red and below the mean in blue. Last winter was characterized by well above average temperatures in both areas, however, the Gulf of Maine remained warm into the summer months where Georges Bank was relatively cool. Both areas experienced extremely warm fall temperature conditions, where SST was close to 2°C above average.

### Patterns in the lower trophic levels

Zooplankton provide a critical link between phytoplankton at the base of the food web, and higher trophic organisms such as fish, mammals, and birds. Changes in the species composition and biomass of the zooplankton community have a great potential to affect recruitment success and fisheries productivity, and climate change may be the most important pathway for these changes to manifest. Therefore these indices are relevant to both productivity and trophic structure objectives.

Chlorophyll a (CHL), an index for phytoplankton biomass, was below average in 2017, including during the spring bloom period in both GB and GOM (Figs. 27 and 28). Conversely, primary production (PP) was at or above average during most of 2017 and there has been an upward in annual trend PP since 2004. The above average PP rates in the fall could be due to the above average temperatures supporting increased remineralization of nutrients and regenerated production by smaller phytoplankton species. This suggests that while overall PP may be increasing, not all of excess PP may be available to higher trophic levels.

Spatial patterns in primary production and chlorophyll for 2017 are shown as difference from the long term mean (Fig. 29).

There are coherent patterns between the primary production anomaly and the copepod size index for both GB and GOM (Fig. 30). While the trends were in opposite direction early in the time series (1998-2002), increasing PP generally led to an increase in the copepod size index after 2002, when an anomalous period of high abundance of small copepods ended. This period of high abundance of small copepods began in the early 1990's and was attributed to a prolonged influx of Scotian shelf waters affecting productivity in the GOM, and can be seen in the time series of *Pseudocalanus* spp. in the GOM (Fig. 31).

The copepod size index relates the abundance anomaly of small bodied copepods to the abundance of a large bodied copepod, *Calanus finmarchicus*. The small copepods are most important during the autumn while *Calanus finmarchicus* dominates early in the year following the spring phytoplankton bloom. *Pseudocalanus* spp., an important copepod

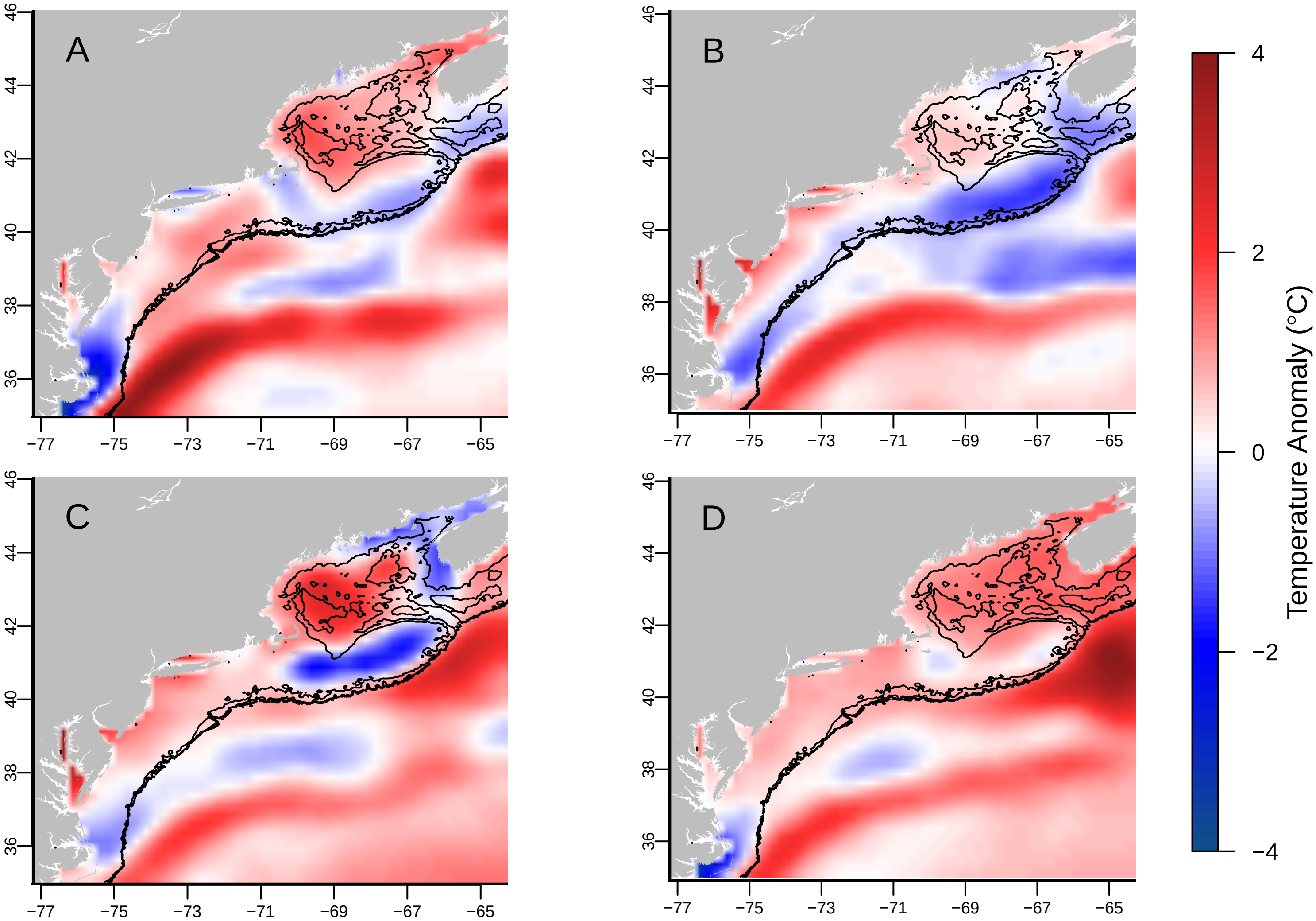


Figure 26: Sea surface temperature anomalies in Winter (A), Spring (B), Summer (C), and Fall (D) 2017.

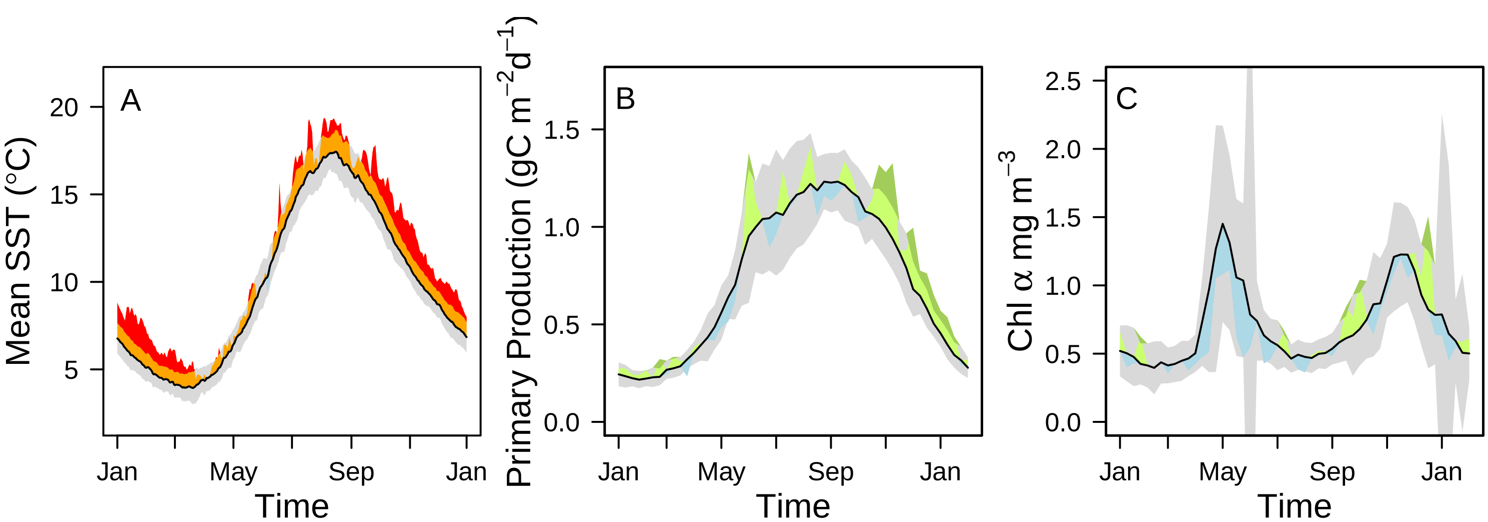


Figure 27: Sea-surface temperature (A), primary production (B), and Chl a (C) over 2017 (colored polygons) compared against the long-term mean (black line) and +/- 1 standard deviation (grey polygon) in Gulf of Maine

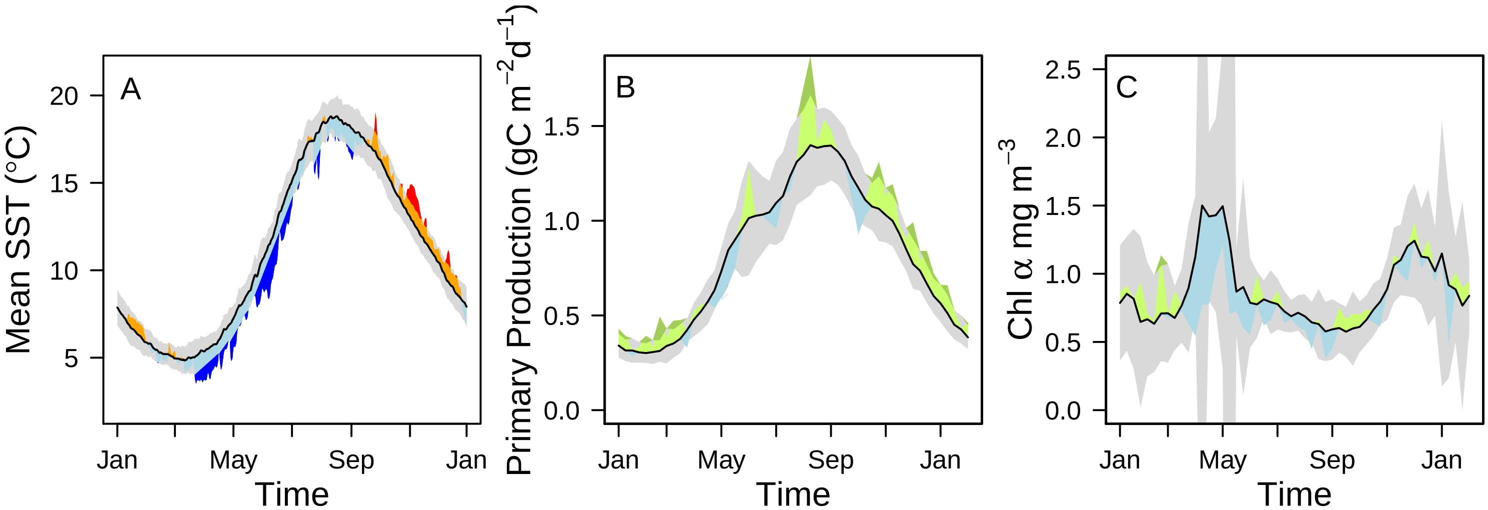


Figure 28: Sea-surface temperature (A), primary production (B), and Chl a (C) over 2017 (colored polygons) compared against the long-term mean (black line) and +/- 1 standard deviation (grey polygon) in Georges Bank

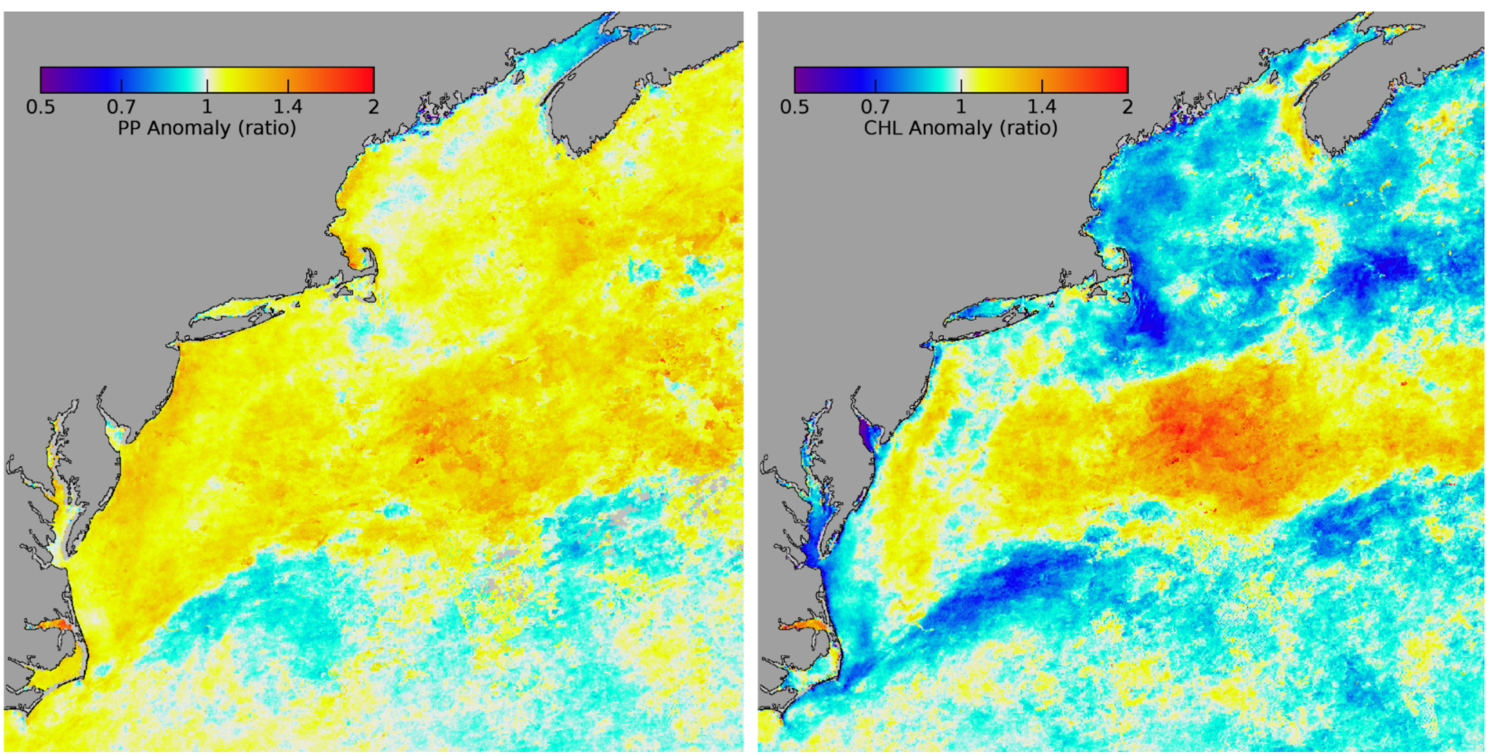


Figure 29: Primary production (left) and chlorophyll (right) anomalies along the Northeast Shelf

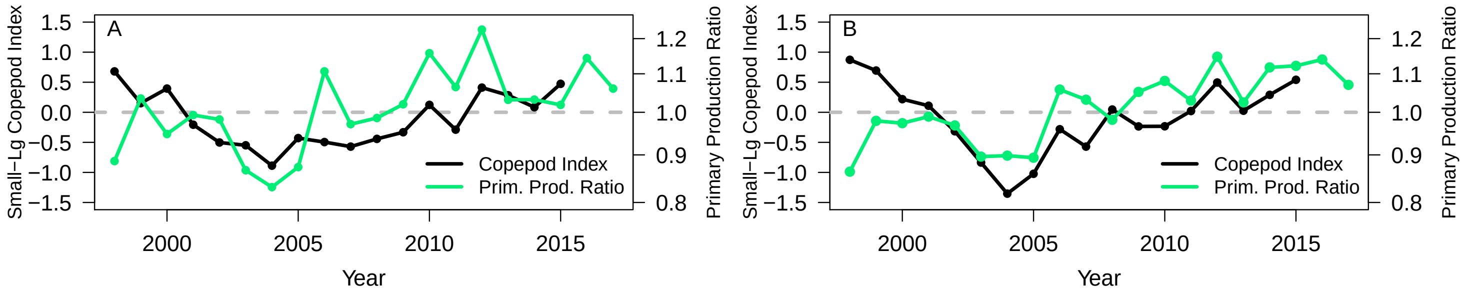


Figure 30: Small-large copepod index with primary productivity anomaly in Gulf of Maine (A) and Georges Bank (B).

genus linked to early stage survival of cod and haddock, exhibits a long-term decline in abundance on GB as well as low abundance from 2002-2014 in the GOM (Fig. 31). In the GOM, *Calanus* abundance was at or below average between 2009-2014, and the most recent data for 2015 show an above average abundance level. On GB, *Calanus* abundance has been below average since 2008. *Calanus* are the principal prey of North Atlantic right whales; reductions in *Calanus* populations potentially impact the most vulnerable protected species in our region as well as key forage fish that feed on them, with implications throughout the food web.

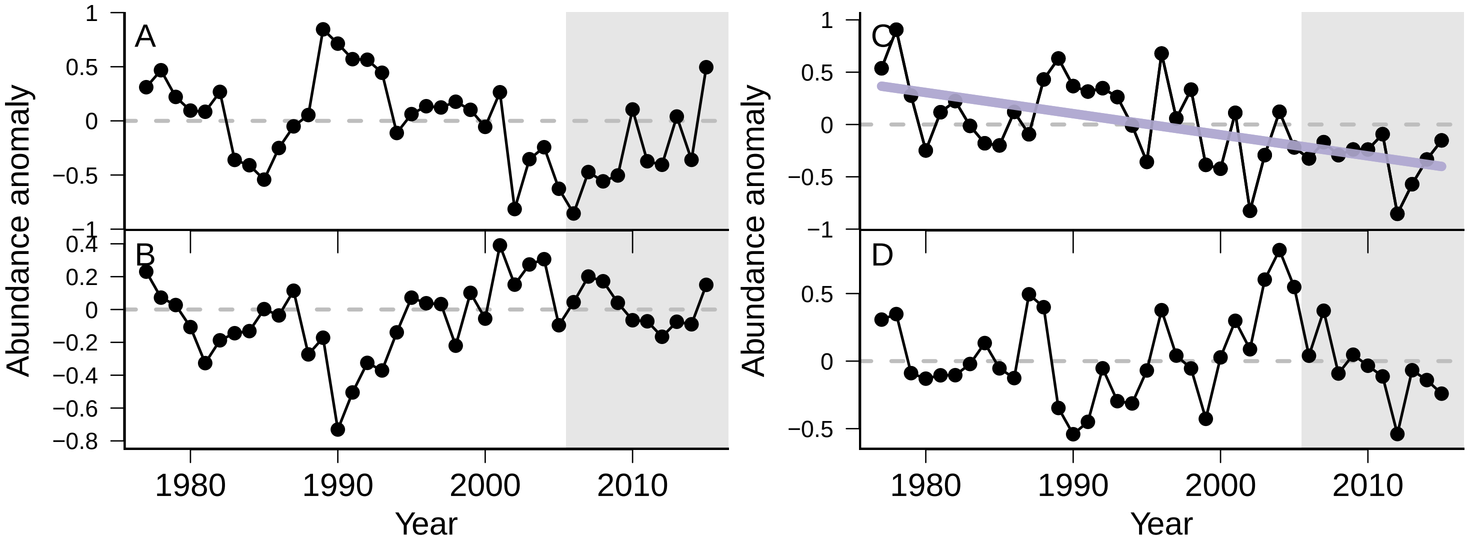


Figure 31: *Pseudocalanus spp.* (top row) and *C. finmarchicus* (bottom row) abundance anomalies in Gulf of Maine (left) and Georges Bank (right)

### Groundfish condition (coastwide)

Fish condition is measured as the weight per length–a measure of "fatness". This information is from NEFSC bottom trawl surveys and shows a change in condition across all species at around 2000. Around 2010-2013 many species started to have better condition, while yellowtail flounder remain thinner for their length on average. This matches the trend in small-large copepods, perhaps reflecting changing nutrition across many species contributing to changes in condition.

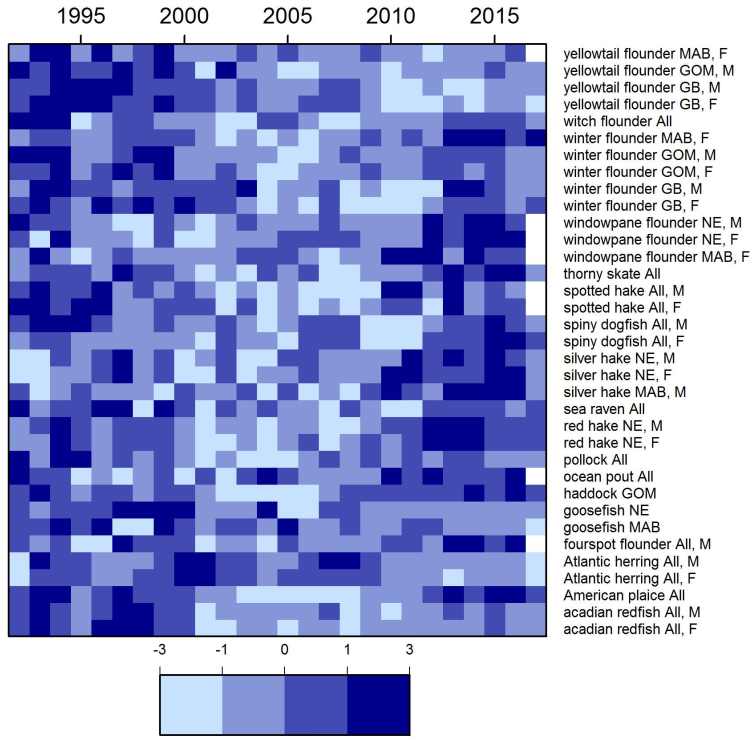


Figure 32: Condition, or weight per length, of New England groundfish species

### Groundfish productivity (GOM and GB)

The amount of small fish relative to larger fish of the same species from the NEFSC surey is a simple measure of productivity, intended to complement model-based stock assessment estimates of recruitment for commercial species. There are no clear long term trends in this indicator when aggregated across all species in the Gulf of Maine and Georges Bank.

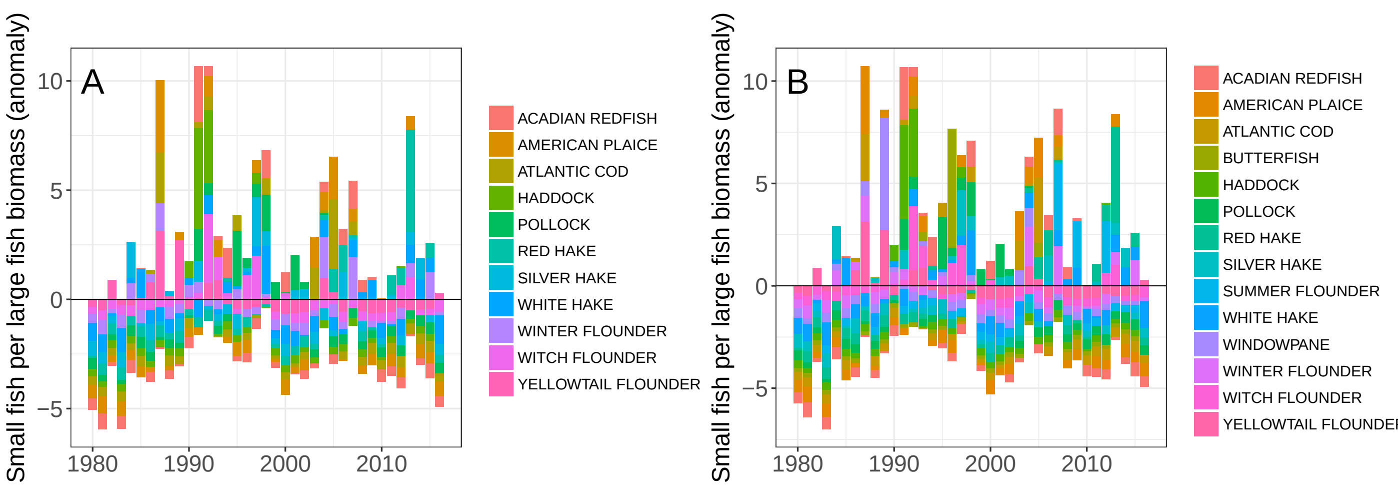


Figure 33: Groundfish productivity (A: NEFMC managed species, B: Commercial Species in New England)

## Work in Progress

### Forage fish energy content (coastwide)

Work is in progress to address changes in forage fish energy content, which links observed changes in the plankton to resource and protected species condition, reproductive success, and population dynamics. A collaborative project between UMASS Dartmouth Biology Department (Dr. Ken Oliveira, M.S student Kelcie Bean) and NEFSC Population Biology Branch (Mark Wuenschel) is underway to evaluate energy content of forage species. The study focuses on the following species; Atlantic herring, alewife, silver hake, butterfish, round herring, northern sandlance, menhaden, Atlantic mackerel, longfin squid, and northern shortfin squid. Samples are being analyzed from the 2017 spring bottom trawl survey (n=1200), 2017 fall bottom trawl survey (n=1000), and from NEFSC study Fleet (n=400). The percentage dry weight (water content) will be measured, as a predictor of energy density, and subsamples are being analyzed to determine remaining proximate composition (lipid, protein, ash) from which total energy can be calculated. Samples from multiple seasons, and regions will enable evaluation of spatial and temporal patterns in energy content of forage. These current estimates will also be compared to historical estimates of forage energy content in the region (where available), to evaluate if long-term changes have occurred. This study is more of an up to date 'snapshot' on the energy content of forage fishes, and not a time series per se; however, we hope the results will provide justification for and establish practical methods (e.g. % dry weight) to monitor energy content of key species on a routine basis.

### Management Complexity (New England)

Constituents have frequently raised concerns about the complexity of fishery regulations and the need to simplify them to improve their efficacy. Complex regulations may lead to non-compliance and/or impact other fisheries. This could be evaluated by quantifying the number of regulations and/or the frequency of regulatory changes (based on evaluation of the code of federal regulations).

## Research recommendations

The Mid-Atlantic Fishery Management Council SSC reviewed a draft of the State of the Ecosystem report for the Mid-Atlantic Bight, and requested that clearer definitions of regional components be included. Those changes are reflected in the New England version of the document, including a regional ecosystem map and section headings reflecting the scope of indicators. The SSC noted prior work between the US and Canada assembling survey data on continental shelf species across the international border and suggested that this information be examined and included if available and relevant. *This will be taken up as possible over the coming year.*

The SSC commented that the indicators presented in the report for the Mid-Atlantic, which are nearly identical to those in the New England document, generally align with the overall objectives, that the objectives are the right ones to look at, and that this is a good starting point. However, there may be better indicators than the ones presented. For example, gross revenue is just a proxy for economic performance, which could be refined. Similarly, recreational participation is driven by both management and other influences well outside council management, such as availability of leisure time and competing recreational opportunities. As such, the MAFMC SSC encourages more in-depth analysis of the social and economic indicators in the report. *This will be taken up as possible over the coming year.*

## Acknowledgements

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