State of the Ecosystem - Mid-Atlantic

Ecosystem Dynamics and Assessment Branch, Northeast Fisheries Science Center

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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 highighting relationships between focal species groups organized by Mid Atlantic Fishery Management Council (MAFMC) Fishery Management Plan (FMP), managed human activities, environmental drivers, habitats, and key ecological links. The activities link to high level strategic management objectives (described next). Many components of the conceptual model are represented by indicators in this report, and key paths connecting components and objectives are highlighted.

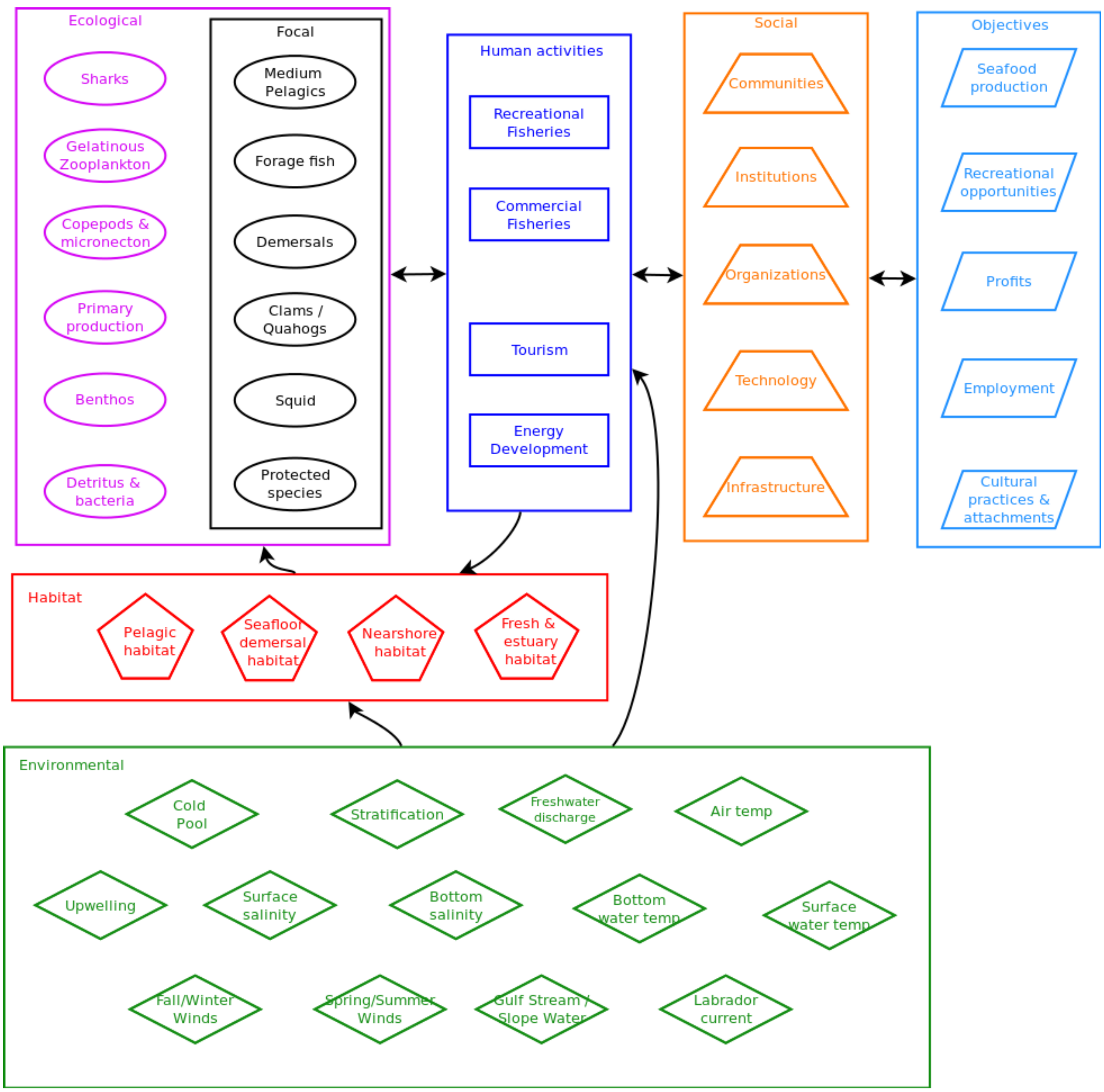

Figure 1: Mid-Atlantic Ecosystem

Ecosystem status: Executive summary

We have organized this report using a proposed set of **ecosystem-scale objectives** derived from US legislation and current management practices. We also report single-species status relative to established objectives and reference points.

Objective Category	Indicators reported here
Seafood production	Landings by functional group, mariculture
Profits	Revenue by functional group
Recreation	Numbers of anglers and trips
Employment	Indicator under development (see p. 4)
Stability	Diversity indices (fishery and species)
Social-Cultural	Community vulnerability, fishery engagement and reliance
Biomass	Biomass or abundance from surveys, biomass relative to reference
Productivity	Condition and recruitment, fishing mortality relative to reference
Trophic structure	Relative biomass of trophic groups
Habitat	Thermal habitat volume, physical properites

The Mid Atlantic Council (MAFMC) is meeting objectives at the managed species level for fishing mortality (F) rates and biomass (B) levels relative to established reference points, with the exception of F rates for summer flounder. This has been a focus of management.

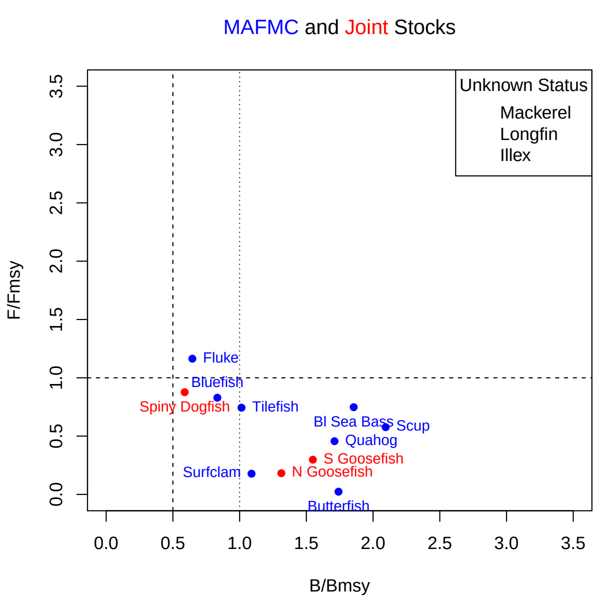

Figure 2: Summary of single species status for MAFMC stocks

At the ecosystem scale, trends in commercial **seafood production** indicate generally **long term increases with recent stability across trophic levels**, with the exception of forage fish (mackerel are at a historic low; menhaden are not included here). The single state (Virginia) with aquaculture production information similarly shows steady production of oysters and increasing production of hard clams. Similarly, **commercial revenues** in the region mainly **show long-term increases**. **However, these increases are only partially driven by MAFMC managed species, underlining the need to work across jurisdictions to address ecosystem-level objectives.**

Recreational opportunities from fishing have also **increased over the long term**, according to numbers of angler trips and anglers. However, there has been a **significant decline over the past 10 years** which may have started with the 2008 economic collapse, though recovery of recreational indices has not matched recovery in the wider economy.

Community vulnerability assessments suggest that although species managed by the MAFMC have lower vulnerability to climate impacts than species managed by NEFMC, many of the **fishing communities in the region are vulnerable to sea level rise**, for which exposure is expected to increase. **Mid Atlantic coastal communities have a high reliance on both commercial and recreational fisheries.**

Stability is addressed with indices of **commercial fleet and species revenue diversity**. These **show long term declines** in the Mid-Atlantic, which may raise a caution flag for stability within the industry, but requires further investigation into mechanisms.

Survey **biomass trends for aggregated trophic groups differ** in the fall and spring, with few significant fall trends and many significant spring trends. Species diversity also has a significant recent increase only during the spring survey (athough patterns are similar between seasons). At the lowest trophic level, **benthos, including commercial shellfish, show long term increases in both seasons**. In contrast, **piscivores at higher trophic levels have conflicting long term trends depending on the season** sampled. Seasonally divergent aggregate trends require further investigation.

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 while survey-based aggregate "recruitment" has declined overall). In addition, while there are few time series for protected species, **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. Further, signals from the wider northwest Atlantic suggest a **decrease in forage fish energy content**. While there are no clear long-term trends at the bottom of the food web in the Mid Atlantic, **abundance of the major zooplankton species may have shifted seasonally, and the seasonal timing of primary production may have changed**.

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. Regional climate indices show a northward movement of the Gulf Stream north wall which can be a local mechanism for increased temperature and species redistribution, in addition the to broader influences of a warming climate.

This report currently lacks indicators for general objectives related to employment (information exists and can be updated) and habitat quality, quantity, and diversity. Risks to habitat including frequency and intensity of harmful algal blooms (HABs) in the region are being investigated, although information is in multiple locations with a range of accessibility. Data for cultural practices and attachments (e.g., number of generations of individual families involved in fishing, length of residence in individual fishing communities, use of kin as crew) require more investigation.

Human Dimensions

Community engagement and dependence on fisheries

Coastal communities have varying degress of engagement in and reliance on fishing. Engagement generally measures amounts of fishery infrastructure and production in a community, while reliance measures these on a per capita basis. In particular, communities in the Mid-Atlantic region have a more balanced reliance on recreational and commercial fishing than do other regions of the Northeast US shelf.

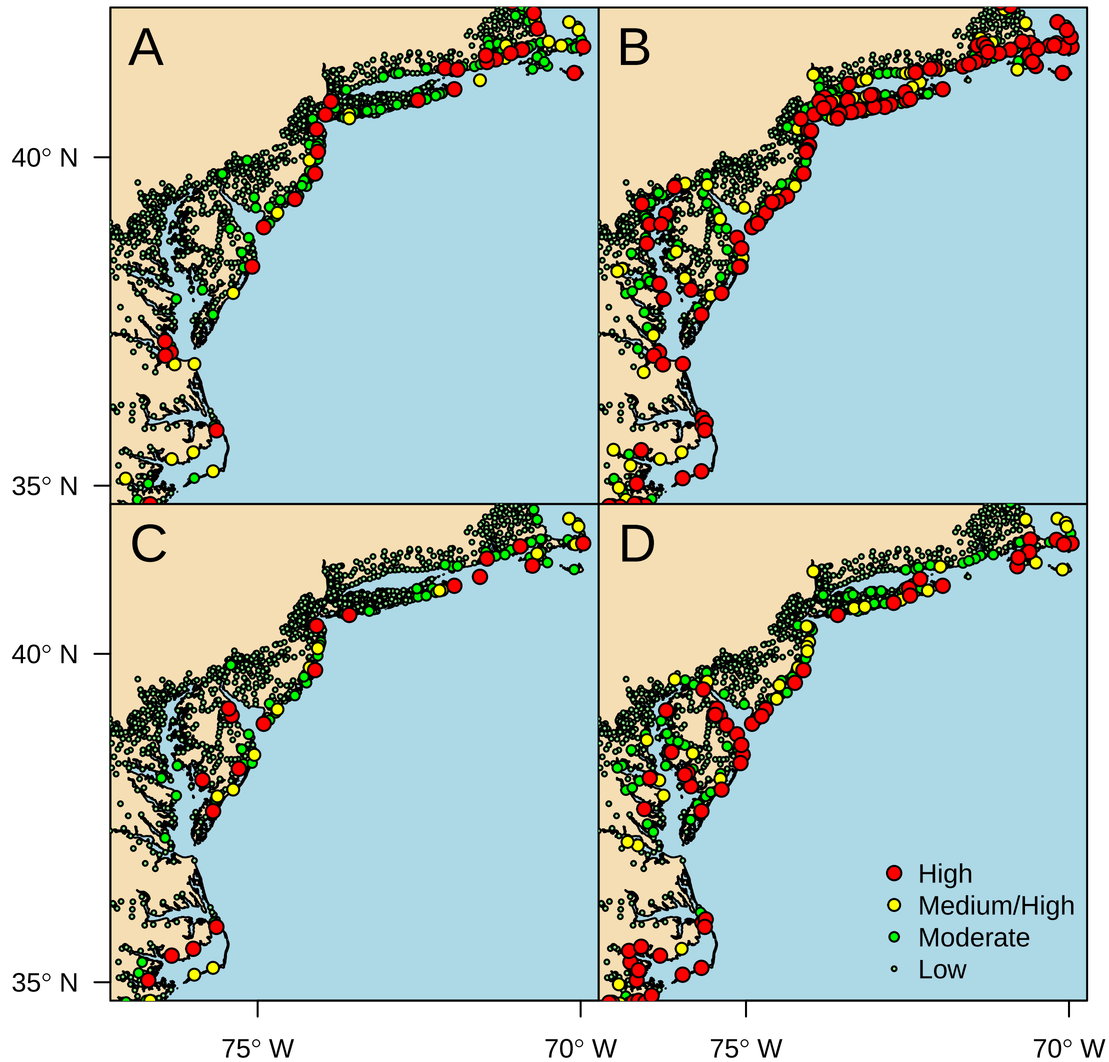

Figure 3: Community engagement (A: Commercial, B: Recreational) and reliance (C: Commercial, D: Recreational) on fishing

Climate Risk to Coastal Communities

Mid-Atlantic communities clustered around the Chesapeake Bay area and the New Jersey shore have especially high vulnerability to sea level rise. These vulnerabilities include infrastructure (docks, marinas, bait shops, gear storage) and access to shore-based facilities due realignment of coastal communities.

Mid-Atlantic fishing communities with total landings value of $100,000 or more were mapped for their dependence on species vulnerable to climate change and catch composition diversity (Simpson Reciprocal Index). A number of communities in southern New Jersey, Maryland and Virginia are highly dependent on species such as clams that are highly vulnerable to climate change while displaying low catch composition diversity.

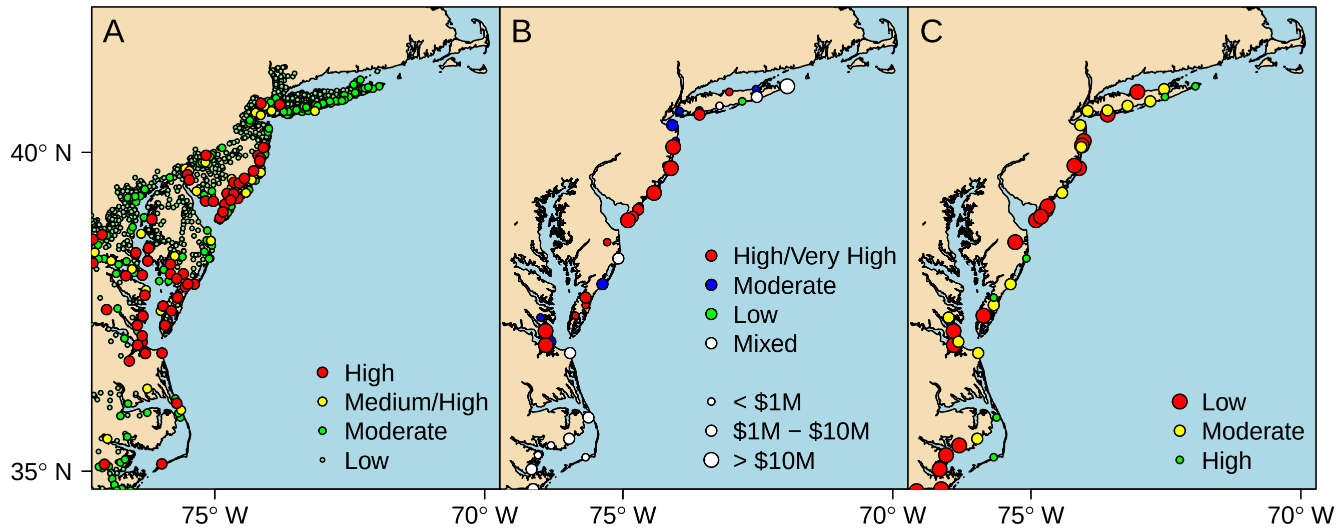

Figure 4: Risks from sea level rise (A), reliance on climate-vulnerable species (B), and catch diversity (C)

Seafood Production

Seafood production is a stated goal of optimal fishery management as part of the definition of "benefits to the nation" under MSA. This indicator links the human activity commercial fishing to the seafood objective. Functional groups of species are listed with the codes below, and these groups are also used to organize trawl survey data.

Species groupings

Group	N species	Major species in the group
A: Benthos	7	scallops, surfclam, quahog, mussels, whelks, conchs, sand dollars and urchins
B: Mesoplanktivores	6	Atlantic mackerel, butterfish, Atantic herring, river herrings and shad
C: Macroplanktivore	6	longfin and shortfin squids, white hake, searobins, sculpin, lumpfish
D: Macrozoo-piscivores	12	clearnose, little, and smooth skates, smooth dogfish, buckler dory, blackbelly rosefish, redfish, windowpane, cusk, pollock, red hake, cancer crabs
E: Benthivores	24	black sea bass, scup, tilefish, tautog, cunner, blue crab, red crab, lobster, ocean pout, haddock, yellowtail winter and witch flounders, barnoor skate, other crabs
F: Piscivores	13	spiny dogfish, summer flounder, bluefish, striped bass, weakfish, monkfish, winter and thorny skates, silver and offshore hake, Atlantic cod and halibut, fourspot flounder

Commercial landings include all landings in the region, including species not managed by MAFMC, with the notable exception of Atlantic menhaden. For example, category E, Benthivores, includes blue crabs, which are a substantial portion of the landings. In 2015, Benthos was 68% MAFMC managed, Macro-planktivores 100% (this would be much reduced with menhaden landings included), Mesoplanktivores 84%, Macrozooplanktivores 0%, Benthivores 17%, Piscivores 59%.

In these and subsequent time series plots, trends are assessed for both the full time series and the most recent 10 years (shaded dark grey background). Significant increasing trends have orange lines, while significant decreasing trends have purple lines. Dotted white horizontal lines indicate +- 1 standard deviation from the long term time series mean.

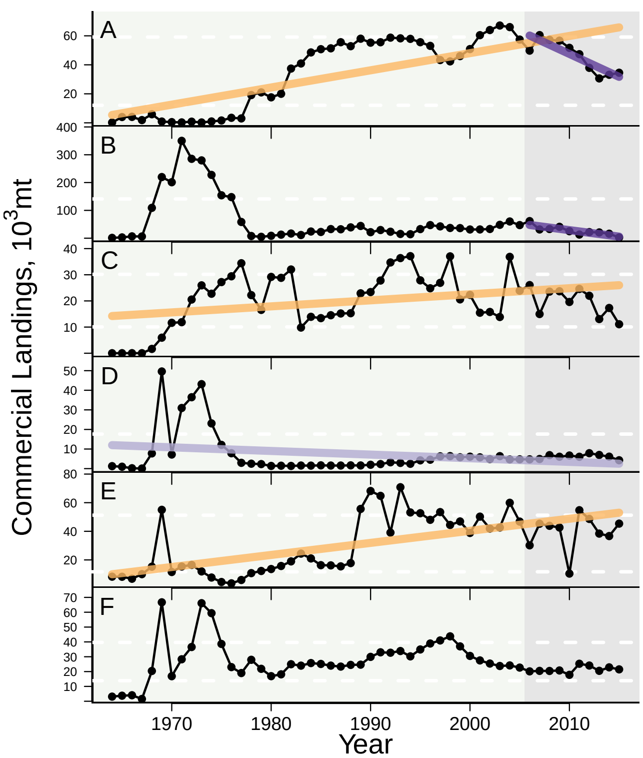

Figure 5: Commercial landings of A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoo-piscivores, E: Benthivores, F: Piscivores

We note that time series at the Mid-Atlantic regional scale may not include all state landings prior to 1994. This indicator is being refined to distinguish landings sold for human consumption versus other uses, and to include landings of menhaden.

Commercial Fishery Revenue

This indicator links the human activity commercial fishing to the profits objective. We note that time series at the Mid-Atlantic regional scale may not include all states landings prior to 1994, which affect revenue calculations. Similarly, 2006 and 2010 were missing some revenue data for some species.

Average total revenue from MAFMC managed species ranges from 17-21% of total revenue from commercial fishing in the region over the last 5 years. By species group, in 2015, Benthos revenue was from 11% MAFMC managed species, Macroplanktivores 100% (would be reduced if including menhaden), Mesoplanktivores 97%, Macrizooplanktivores 0%, Benthivores 14%, Piscivores 67%.

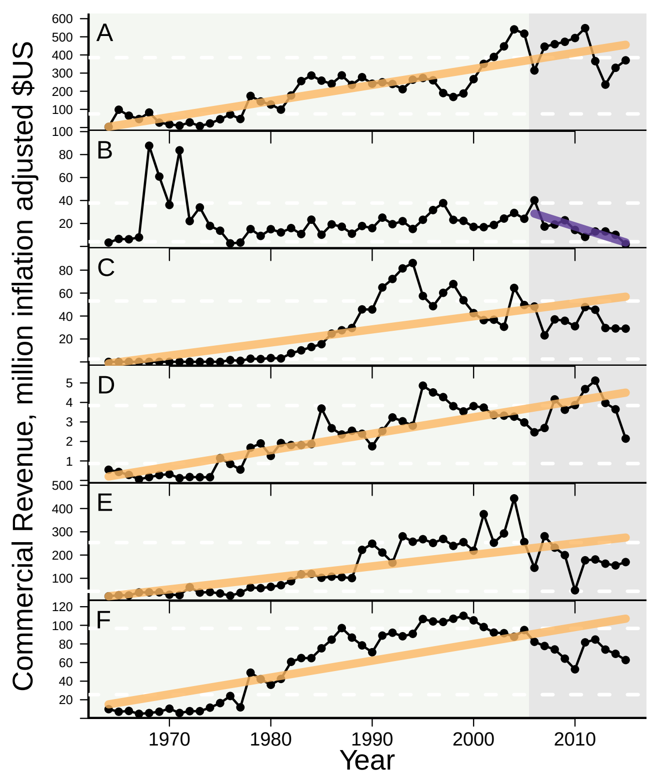

Figure 6: Commercial revenue from A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoo-piscivores, E: Benthivores, F: Piscivores

Commercial Fleet Diversity

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 Mid-Atlantic 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.

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 the Northeastern Large Marine Ecosystem.

The number of fleets in the Mid-Atlantic seems to be negatively correlated to the revenue diversity metric in the most recent five years, which indicates that the latter results are being dominated by changes in the distribution of revenue across fleets, as opposed to the number of active fleets.

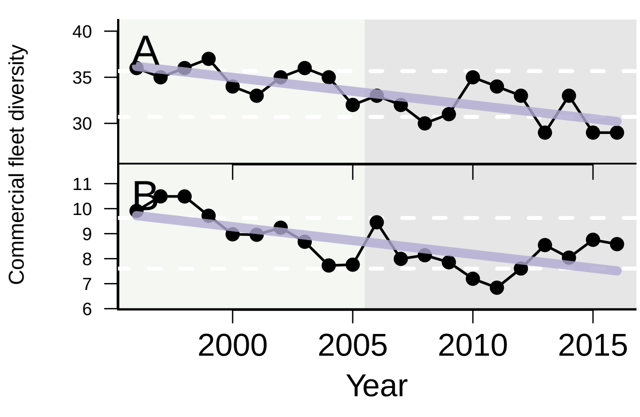

Figure 7: A: fleet count, B: average fleet diversity

Another diversity index is the average effective Shannon index for species revenue at the permit level, for all permits landing any amount of MAFMC 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.

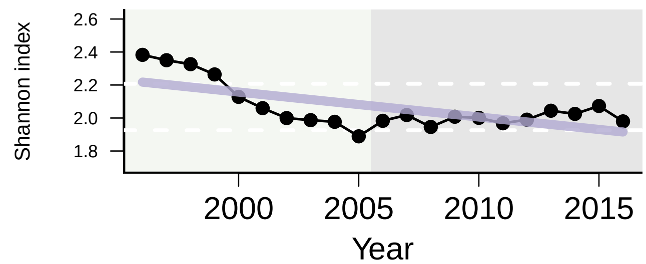

Figure 8: Diversity in species revenue

This trend contrasts with the species diversity trends from survey data presented below, which indicate relatively low diversity during the mid-1990's and higher diversity now (with a significantly increasing recent trend in the spring survey data).

Ultimately diversity can be measured in numerous ways (for example, in numbers of vessels in each fleet component as opposed to revenue) and feedback from the Council as to how this should be defined is welcomed.

Recreational opportunities

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 Mid-Atlantic region with many coastal communities having high recreational dependence. Although there is an overall 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.

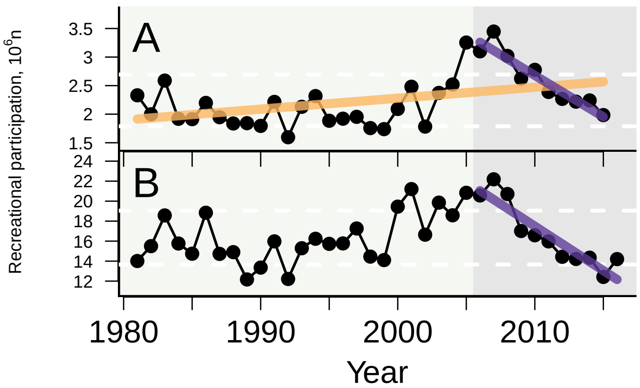

Figure 9: A: number of anglers, B: number of trips

Mariculture

Aquaculture indicators addresses both seafood production and possibly habitat objectives in that planted bivalves such as oysters may provide both habitat structure and contribute to improved water quality at sufficient numbers (we cannot evaluate that function here yet). Individual states collect and publish aquaculture production differently; at this time only information reported by VIMS is available for the Mid-Atlantic region. Virginia leads the Nation in hard clam production, and oyster culture is increasing steadily.

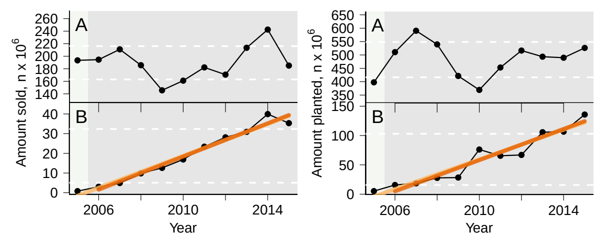

Figure 10: Aquaculture stats from VA. A - hard clams, B - oysters

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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

Biomass across trophic levels shows different trends between the fall and spring NEFSC trawl surveys, with few significant fall trends and many significant spring trends. At the lowest trophic level, benthos, including commercial shellfish, show long term increases in both seasons. In contrast, piscivores at higher trophic levels have conflicting long term trends depending on the season sampled.

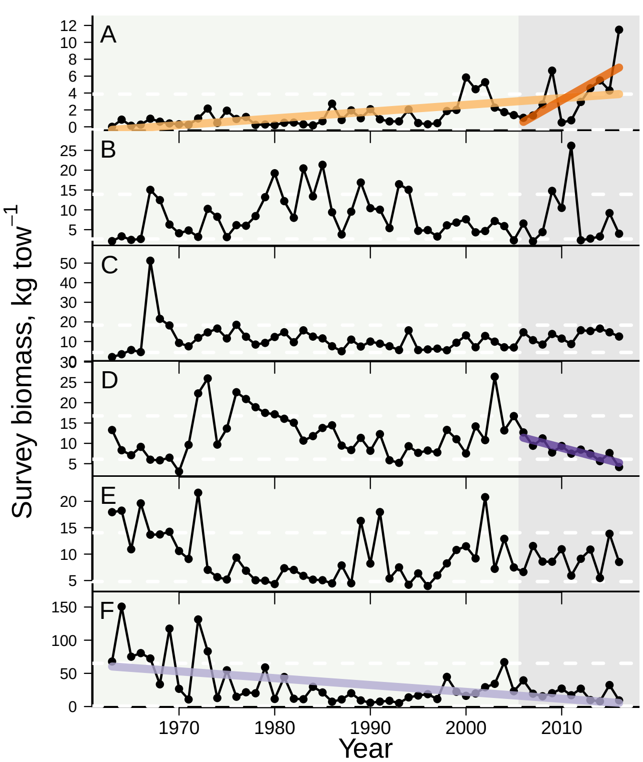

Figure 11: Fall survey trends for A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoo-piscivores, E: Benthivores, F: Piscivores

Seasonally divergent aggregate biomass trends require further investigation. They could indicate the trends of different fish communities with seasonal differences that are the result of regular seasonal migrations, or they could indicate movement of new species into/out of the region on a seasonal basis, or both. These trends across trophic levels point to the potentially complex and dynamic trophic structure of the Mid-Atlantic ecosystem.

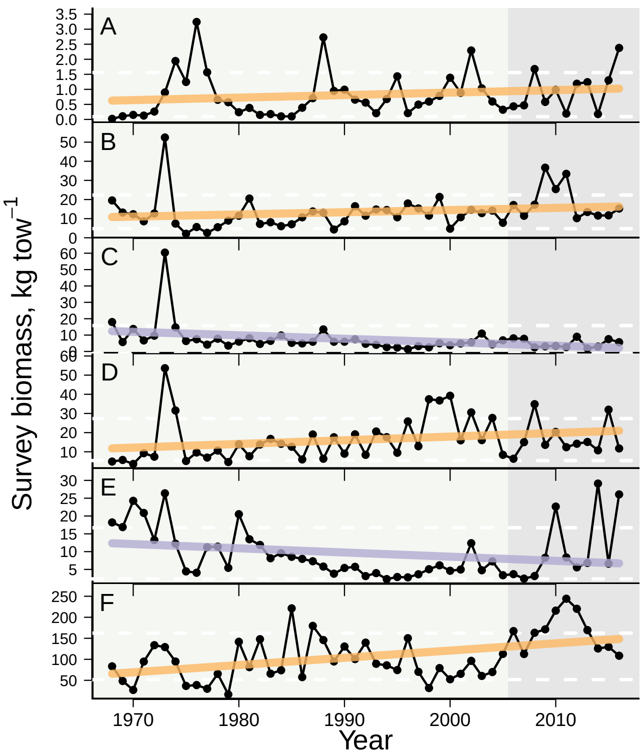

Figure 12: Spring survey trends for A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoo-piscivores, E: Benthivores, F: Piscivores

Species composition

Diversity in species composition mainly addresses objectives related to ecosystem structure and stability; maintaining diversity (here estimated as the mean number of species found in a random sample of 100 fish at a station for the Mid-Atlantic portion of NEFSC surveys) can provide the capacity to adapt to change at the ecosystem level and for dependent fishing communities.

Diversity shows a signficant increase for one season in the Mid-Atlantic, suggesting that survey timing may be interacting with changes in the seasonal movement of fish (see above) as well as a potential change in species availability due to distribution shifts (see below).

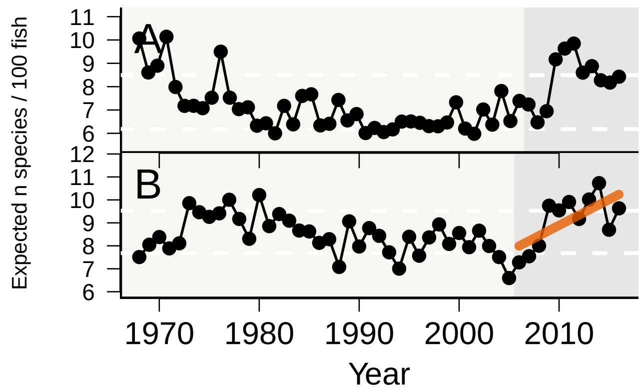

Figure 13: A-Fall, B-Spring

Species distribution

Spatial distribution has changed over time for some species more than for others. Black sea bass distributions measured by NEFSC surveys have shifted northward relative to historical distributions. In contrast, longfin squid distributions in the Mid-Atlantic have remained relatively stable.

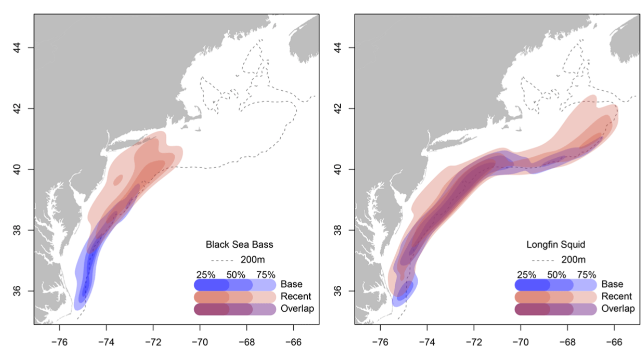

Figure 14: Shifts in species distribution, 1970s (blue), recent (red) and overlap (purple)

A full suite of these maps is available at http://www.nefsc.noaa.gov/ecosys/current-conditions/kernel-density.html.

Species distribution on the NE Shelf can be characterized by the position in the ecosystem along an axis oriented from the southwest to the northeast, referred to as the along shelf distance, and by depth. Along shelf distances range from 0 to 1360, which relates to positions along the axis from the origin in the southwest to the northeast in kilometer units. The mean along shelf distance for several MAFMC species by year is shown below; most show a northeastward change in distribution aside from shortfin squid. Mean depth has not changed significantly for these species. Information for more species is available at http://www.nefsc.noaa.gov/ecosys/current-conditions/species-dist.html.

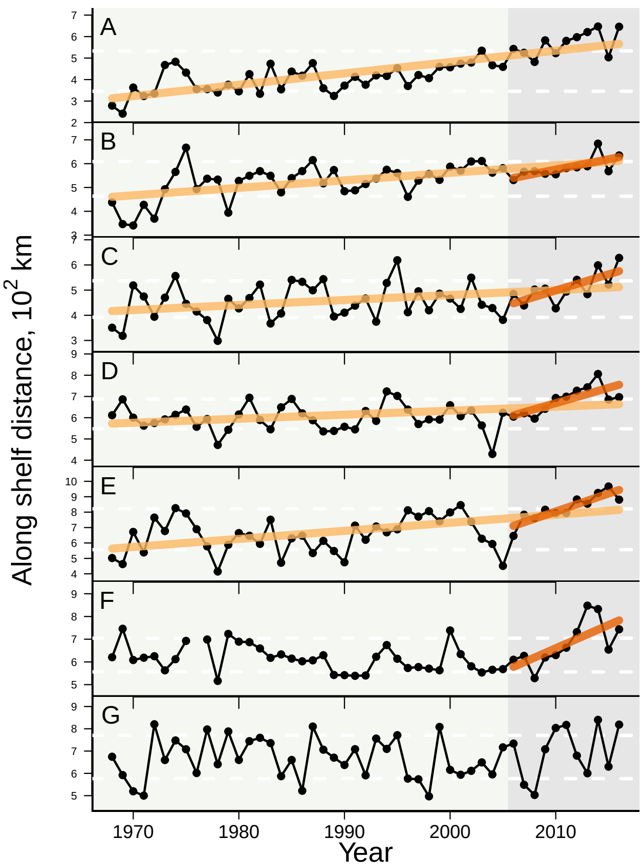

Figure 15: Shifts in species distribution over time; A: Black sea bass, B: Summer flounder, C: Scup, D: Butterfish, E: Atlantic mackerel, F: Longfin squid, G: Shortfin squid

Species condition

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 black sea bass remain thinner for their length on average.

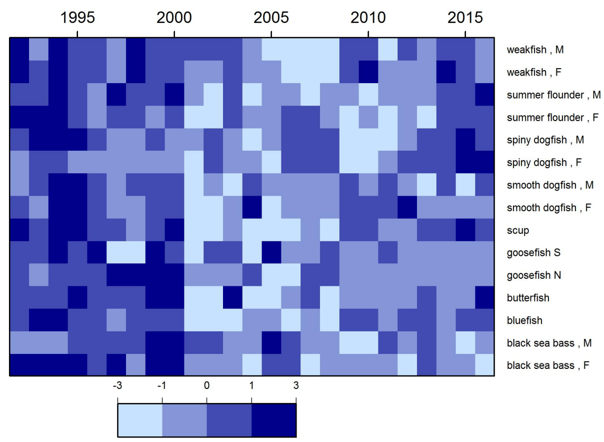

Figure 16: Fish Condition (weight/length)

Groundfish productivity

The number of small fish relative to the biomass of 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 is a general decrease in this indicator when aggregated across managed species in the Mid-Atlantic.

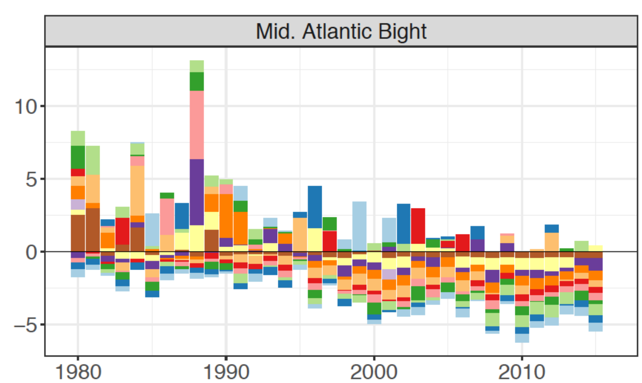

Figure 17: Fish productivity: Anomalies of recruit abundance per spawner biomass for species in the MAB. Annual anomalies shown are the average of spring and fall anomalies.

Species of concern

Marine mammals

North Atlantic right whales are among the most endangered large whale populations in the world. Although the population increased steadily from 1990 to 2011, it has decreased recently. This is fully discussed in an upcoming assessment, but may be linked to both ecosystem conditions and human activities. Changes in right whale trends can have implications for fisheries management where fisheries interact with these whales.

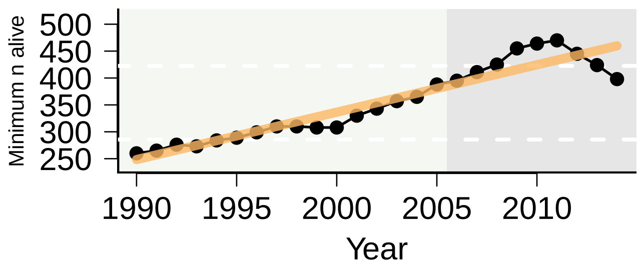

Figure 18: North Atlantic right whale estimated population

Endangered Fish

Despite diverse population structures and management regimes, concurrent abundance declines in disparate North American and European Atlantic salmon populations suggest that marine feeding conditions may be poor. Diet analysis of Atlantic salmon sampled off the coast of West Greenland demonstrated that they are consuming slightly less capelin by weight, but more lower quality prey (amphipods and squid) recently compared to 1960-1970. Further, the energy density of capelin, their primary prey item at Greenland (~40-90% annually), decreased by almost 34% recently. This coincides with an approximate 66% reduction in Atlantic salmon marine productivity. The influence of declining resource quality is not unique to Atlantic salmon, as some populations of Atlantic cod, bluefin tuna, seabirds, and marine mammals are either of lower body condition and/or not as productive as they once were in the region pre-1990. This may partially be a response to reduced prey quality caused by changes in bottom-up processes. Determining and understanding the mechanisms that influence marine food-webs is necessary to fully evaluate survival and productivity trends, and to establish realistic management targets for commercial, recreational, and protected species.

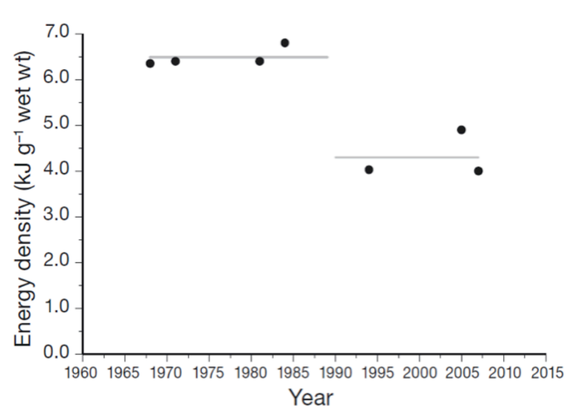

Figure 19: Energy content of capelin

Lower Trophic Levels

Phytoplankton production

Primary production has fluctuated recently with current conditions near average. This suggests that ecosystem production overall is relatively stable, although the trends in higher trophic levels reported above suggest that the uptake of primary production through benthic channels may be increasing over the long term, leading to the steady increase in benthos biomass over time.

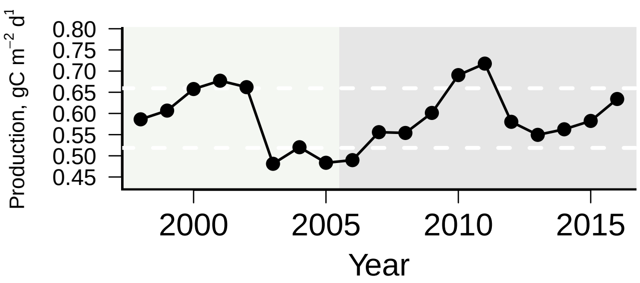

Figure 20: Primary production

The observed stability in system productivity is in contrast to an apparent shift in the timing of the bloom cycle in the Mid-Atlantic. Comparing remote sensing information from the 1970-80s to recent information suggest that winter productivity was higher in the MAB and that the spring bloom we see today was not as prominent. This change in phytoplankton seasonal biomass may be related to the changes seen in the zooplankton community (see below) suggesting a grazing effect; but, whatever the mechanism associated with these changes, shifts in timing of low trophic level production can affect resource fish species and their early life history stages that feed on zooplankton.

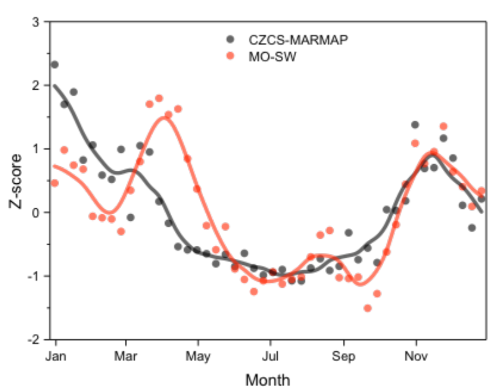

Figure 21: Comparison of 1970-80s annual primary productivity cycle (black) with 1997-present (orange)

Harmful algal blooms

Harmful algal bloom (HAB) data on the continental shelf of the Mid-Atlantic region is sparse. In the lower Chesapeake Bay, annual blooms of the dinoflagellate *Cochlodinium polykrikoides* have been observed for several decades and more recently, blooms of *Alexandrium monilatum*, a toxin-producing dinoflagellate common to the Gulf of Mexico, has invaded the region. Both dinoflagellate species have been associated with fish kills either directly or indirectly, due to hypoxic events following a bloom. Blooms of *C. polykrikoides* have also occurred on a nearly annual basis in the Long Island Sound region. Other major HAB events have been observed along the Eastern Shore of Maryland and Virginia, and in and around Narragansett Bay, but typically not on an annual basis.

Zooplankton

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 compostion 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.

Zooplankton surveys have been conducted since the 1970s and have been most consistently executed in the spring and fall seasons coinciding with the NEFSC bottom trawl survey. The time series of zooplankton biovolume suggest that overall zooplankton production has not changed over time. However, the dominant species of zooplankton in the MAB, *Centropages typicus* shows a seasonal shift in abundance, suggesting a change in timing of zooplankton reproductive cycles, which may be impacting fish species such as mackerel.

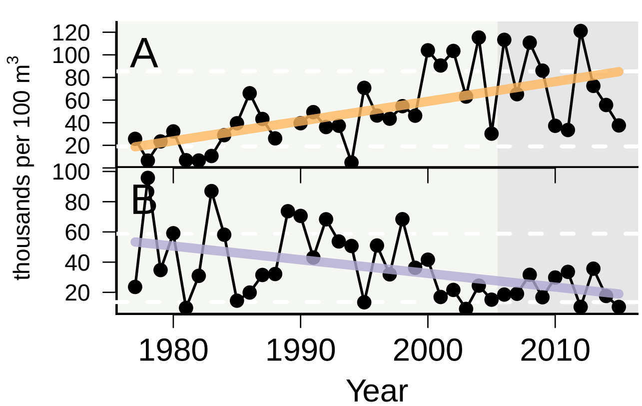

Figure 22: A: Centropages typicus spring, B: Centropages typicus fall

Physical Environment

Annual sea surface temperature cycle

The Mid-Atlantic experienced above average sea surface temperatures (SSTs) during 2016. In the graph, the long term mean SST is shown as a dark gray line with areas representing plus and minus one and two standard deviations of the mean as progressive shades of gray, respectively. SSTs for 2016 that were above the mean are shown in red and below the mean in blue. Spring conditions moderated in the Mid-Atlantic to below average temperature conditions in June and July. The region warmed dramatically from late summer into fall and remained above average temperature through the end of the year.

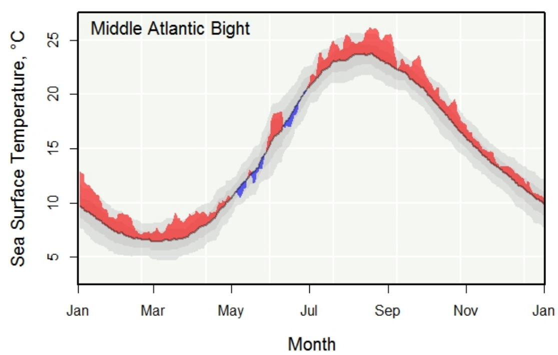

Figure 23: Annual sea surface temperature cycle, 2016

Long-term shelfwide sea surface temperature

Long-term sea surface temperature measurements have been collected off the Northeast Continental Shelf since the mid-1800s. The highest annual temperature in this time series was recorded in 2012, as the ecosystem warmed above the levels last seen in the late 1940s. The 2016 datum is the third highest temperature in the time series. The trend over the period 1856-2016, the full time series, was significant and positive, as is the trend over the most recent decade of the time series.

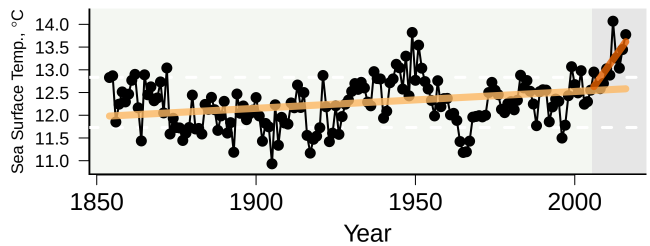

Figure 24: Long term sea surface temperature, Northeast US continental shelf

Regional bottom temperature

The thermal conditions at the bottom of the water column are extremely important in defining the habitats for the majority of resource species. Unlike sea surface temperatures that can be measured synoptically with satellite telemetry, bottom temperatures must be measured directly from ship surveys and other means. Thus, we often have incomplete spatial and temporal sample coverage to describe bottom temperature conditions. Recently, scientists at the NEFSC developed an interpolation approach that provides a more accurate depiction of spring and fall bottom temperatures. The time series of April bottom temperature in the Mid-Atlantic suggest no trend over time, whereas the October temperatures steadily increased over the past half century. This seasonal difference may be linked to the seasonally different trends observed in resource species biomass and species diversity above.

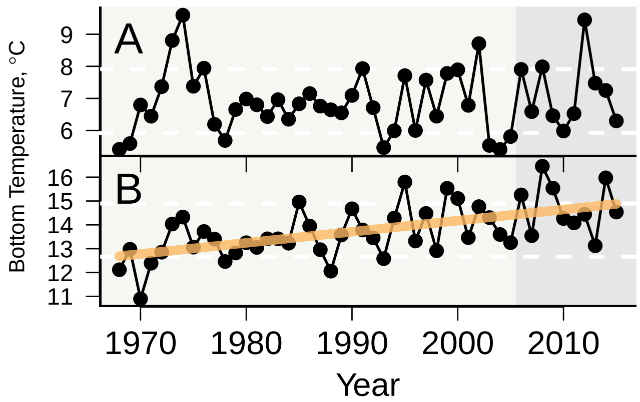

Figure 25: Interpolated survey bottom temperature, A: April, B: October

Species thermal habitat trends coastwide

Temperature affects the behavior and physiology of marine organisms, thus it is a key determinant of habitat within the ecosystem. Cool water habitats (5-15°C), which are the core resident habitats of the ecosystem, show a negative trend over time declining on the order of 460 km 2 yr -1 , which is matched by a corresponding increase in warm water habitats (16-27°C) at a rate of 560 km2 yr-1. The trend on warm water habitats over the past decade is also significant, reflecting the occurrence of the four largest warm thermal habitat values during the last five years.

Sea surface temperature forecast

Seasonal sea surface temperature forecasts are made from an ensemble of seven models over the period starting in February 2017 and ending in August 2017. There was relatively good model agreement in the forecasts for the Mid-Atlantic suggesting that sea surface temperature will rebound in the coming months to an ensemble mean of approximately 0.9°C above average. Skill of these forecasts for our specific region requires further evaluation.

Stratification and Salinity

Stratification shows no clear trend in the Mid-Atlantic. Similarly, surface salinity has no clear trend. However, salinity at the bottom has significantly increased over the most recent 10 years.

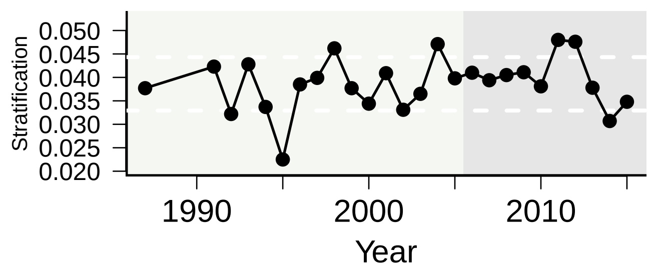

Figure 26: Stratification

Salinity structures habitat for living resources, however the effects of increased salinity on marine organisms are currently less clear than the effects of increased temperature. This significant increasing trend in bottom salinity warrants further investigation.

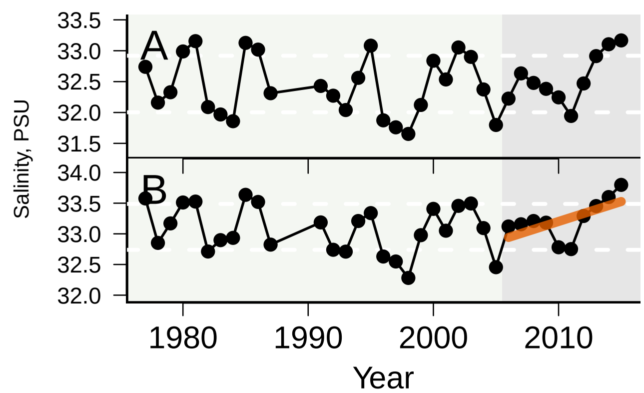

Figure 27: Survey measured salinity; A: Surface, B: Bottom

Climate Indices

Gulf Stream North Wall

Interannual and decadal shifts in the position of the Gulf Stream's Northern Wall are associated with both deep ocean circulation and atmospheric fluctuations over the North Atlantic. An index of the position of the North Wall of the Gulf Stream (15 °C isotherm at 200 m depth), measured in degrees latitude, reveals a shift in the early 1980s from a low (more southerly) to a high (more northerly) index values, reaching a peak in the early-1990s. The Gulf Stream Index has been related to the spatial distribution and recruitment of certain U.S. NES commercial fish, phytoplankton blooms along the Shelf Break, and sea surface temperature in the Gulf of Maine such that a more northern Gulf Stream (positive index) is associated to warmer ocean temperature.

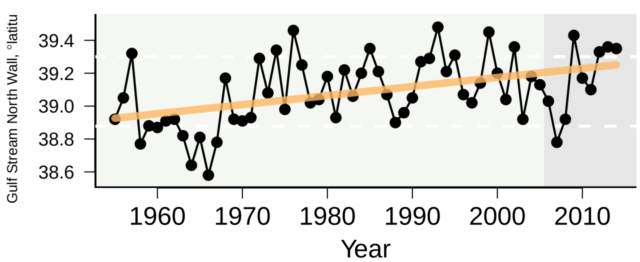

Figure 28: Gulf Stream Index

Daily temperature variability

Climate change involves not only the change in level of climate parameters, it also involves change in system variability that can be seen in more dramatic shifts in weather in terrestrial systems and in ocean parameters on the Northeast Shelf. In an examination of daily sea surface temperatures in the Mid-Atlantic, system variability has increased as evidenced by the increase in the annual standard deviation of sea surface temperature, going from approximately 5.8 to 6.4 over the time period, indicating organisms have experienced greater day to day temperature excursions.

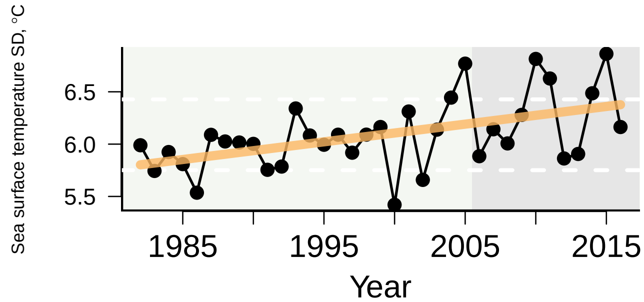

Figure 29: Standard deviation of annual sea surface temperature

Inundation

Sea level change occurring in the Northeast Shelf Ecosystem and on global scales reflects increased thermal expansion of the world's ocean and an increase in ocean water volume resulting from the accelerated melting of glaciers and ice on land and at sea. Sea level has risen by nearly 0.35m in the southern states bordering the Northeast Shelf Ecosystem and on the order of 0.25m in the northern states; the data from these gauging stations is set relative to the most recent mean sea level established by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). The rate of sea level change is expected to increase in the coming decades. With expectations of rising sea level, coastal communities face the likelihood of more frequent flooding of coastal structures and land habitats.

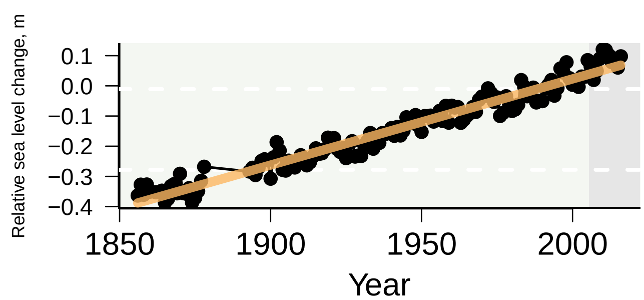

Figure 30: Sea level change, all Northeast States

Deep Ocean Circulation

The upper ocean flow of warm, salty water to the high latitude North Atlantic where it cools and sinks to form North Atlantic Deep Water, which flows to the south is a primary driver of the global ocean conveyor belt (thermohaline circulation). Measurements of this flow in the Atlantic began in 2004. Since measurements began over 10 years ago, the ciruclation appears to have weakened. When this circulation is weaker than average, the Gulf Stream Northern Wall is typically further north and sea level along the U.S. east coast is higher than average. Climate change projections from global models suggest that this deep ocean circulation will weaken under continued increases of greenhouse gas concentrations in the atmosphere. This weakening may also lead to a northern shift of the Gulf Stream and a higher proportion of warmer Slope water entering the U.S. NES leading to an enhanced warming of the Shelf's waters under climate change. Regional indicators reported here show that warming and sea level rise is already happening.

Research recommendations

The MAFMC SSC requested more information regarding activities not managed by the Council that may interact with fisheries management, such as energy development. One way to address this could be through habitat indicators. We are actively working towards development and integration of multispecies habitat quantity and quality indicators in this report, and potentially habitat vulnerability assessment in concert with Council EAFM and EFH efforts.

The MAFMC SSC requested more information on fleet diversity and stability metrics, and suggested including portfolio analyses (already in progress at NEFSC) as well as some metric of volatility that would speak to the temporal variation of revenue streams. We will bring examples forward for the next SSC review in 2018.

We are in the process of applying a suite of indicator evaluation criteria to the set of indicators presented here (as well as others not presented here) to provide more information on indicator performance.

Incorporating information on ecosystem processes at multiple scales is a priority. We welcome collaboration with fishery participants and actively seek collaboration with investigators throughout the region.

More Information

http://www.nefsc.noaa.gov/ecosys/

Acknowldegements

We are grateful for the contributions of many workers throughout the Northeast US region that are represented by the indicators. The structure and framework of this report is based on best practices for Integrated Ecosystem Assessment (IEA) developed through the ICES Working Group for the Northwest Atlantic Regional Sea (WGNARS), a joint working group of the US and Canada. Finally, funding and intellectual support from the NOAA NMFS Integrated Ecosystem Assessment Program was essential to the production of this report.