Annual State of the Northeast Continental Shelf Ecosystem

A report of the NMFS Northeast Fisheries Science Center

1 Introduction

National and international efforts are now underway to establish an integrated framework for fisheries management accounting for ecosystem factors. A critical element of this overall approach involves an assessment of ecosystem status and trends. The NEFSC Ecosystem Status Report is intended to meet this need for the Northeast Continental Shelf Ecosystem Large Marine Ecosystem (NES LME). Here, we provide a synopsis of selected sections of the overall report.

We first provide observations on climate forcing and hydrographic conditions. We next document changes at the base of the food web (including the production of the phytoplankton that fuel the system and the small planktonic animals that graze on these microscopic plants and serve as prey for fish and other species). We further report on the status of fish and shellfish of commercial and recreational importance that provide high quality food resources. Humans are an integral part of marine ecosystems; accordingly we provide metrics related to human well-being and the status of certain uses of the ocean in addition to fishing. Finally, we describe several pressures and stressors affecting the status of the system. The highlights of this report are summarized in Box 1.

Box 1: State of the Ecosystem 2016 Highlights

- The North Atlantic Oscillation, a major ecosystem driver in the North Atlantic Basin, underwent a strong reversal in 2010, but is currently increasing
- Sea surface temperatures on the Northeast Continental Shelf reached record levels in 2012 and have remained high
- Production of microscopic plants at the base of the food web has declined over the last three years
- Evidence for changes in the abundance of small and large zooplankton points to decadal-scale regime shifts in the region
- Elasmobranch and small pelagic fish biomass has increased over the last several decades
- Shifts in the center of distribution of a number of fish species have been documented as environmental conditions change
- Fish condition (weight at a given length) declined in many managed species since 2000; some have recovered
- Landings for commercial and recreational fish have declined but commercial scallop and lobster landings remain strong
- No Mid-Atlantic fish stocks are currently classified as overfished and one is experiencing overfishing
- Composite indices that integrate many variables point to decadal-scale shifts in the state of the system

Many figures in this report describe recent and long-term trends and follow a common format for indicating status and trend. The data in the most recent five years (the green shaded area) may have a status above (+), below (-), or within (·) the long term variability, and may show an increasing (↗), decreasing (↘), or no (↔) trend. Inadequate recent data to determine status or trend is indicated by (x).

2 Basin Scale Climate Drivers

Weather and climate patterns off the Northeastern United States are strongly influenced by processes operating over the entire North Atlantic Basin. Large-scale atmospheric pressure cells play a dominant role in these processes.

The North Atlantic Oscillation (NAO) has been associated with changes in physical and biological components of the North Atlantic, including the U.S. Northeast Continental Shelf. The NAO index is based on the difference in the strength of the Icelandic low pressure atmospheric system and the Bermuda-Azores high pressure system. The NAO has largely been in a positive phase (indicating a dominance of the high pressure system) over the last several decades. Negative NAO indices have been observed only a few times in the most recent decade (Fig. 2.1) with a very low observed NAO value in 2010. During negative NAO conditions, the probability of incursions of the Labrador Current onto the NES LME increases, bringing fresher, less productive waters into our region. The NAO has been correlated with changes in recruitment of a number of fish species on the Northeast Shelf.

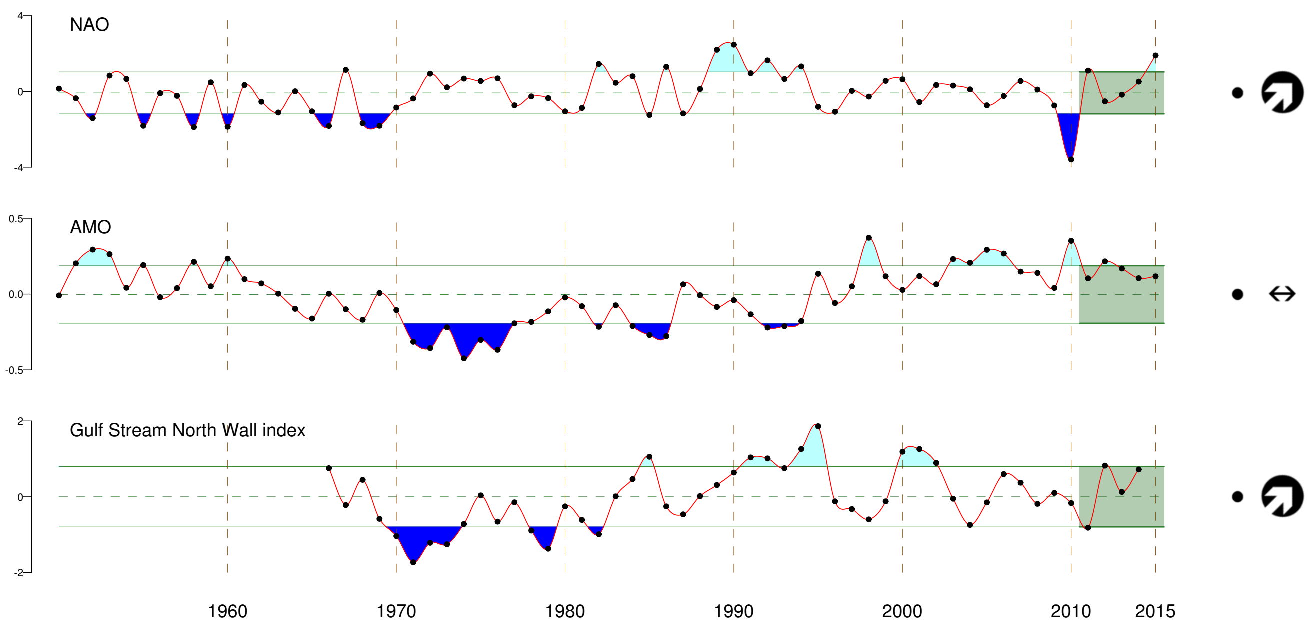


Figure 2.1: North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) indices smoothed using a 10-year moving average, and Gulf Stream North Wall index.

The Atlantic Multidecadal Oscillation (AMO) is a second major basin-scale indicator of climatic conditions in the region, reflecting patterns of sea surface temperature (SST). The warm and cool phases of the AMO have been associated with Atlantic hurricane activity, North American and European summer climate, and changes in the abundance and distribution of North Atlantic biota ranging from phytoplankton to fish. The AMO is currently in a positive (warm) phase, persisting since the shift from a negative (cool) phase in the late 1990s (Fig. 2.1). While the mean annual SST for the year 2012 in the U.S. NES LME was the warmest on record (see Section 3), the 2012 mean AMO index did not reflect this event.The NES has historically warmed more quickly than the rest of the North Atlantic during positive phase of the AMO.

Interannual shifts in the position of the Gulf Stream are correlated with atmospheric fluctuations over the North Atlantic, including the NAO. An index of the position of the North Wall of the Gulf Stream, available since 1966, reveals a shift in the early 1980s from low to high index values (Fig. 2.1), reaching a peak in the early-1990s, and characterized by subsequent multiyear reversals related to changes in the NAO index. The Gulf Stream North Wall index has been related to changes in zooplankton communities in the Northeast Atlantic, but the connection in the Northwest Atlantic appears to be weaker. Interestingly, the relationship between NAO and Gulf Stream position is not as clear after year 2000. Around this time, the character of the NAO changes, shifting away from prolonged periods of high or low toward a weaker higher-frequency oscillation.

3 Regional Climate Indicators

3.1 Temperature

Temperature is one of the most important governing environmental factors for marine organisms. Marine organisms have minimum and maximum temperatures beyond which they cannot survive. They also have preferred temperature ranges, within which temperature influences metabolism, growth, consumption, and maturity. Thus, changes in temperature will have far-reaching impacts on species within the ecosystem, and on the ecosystem itself.

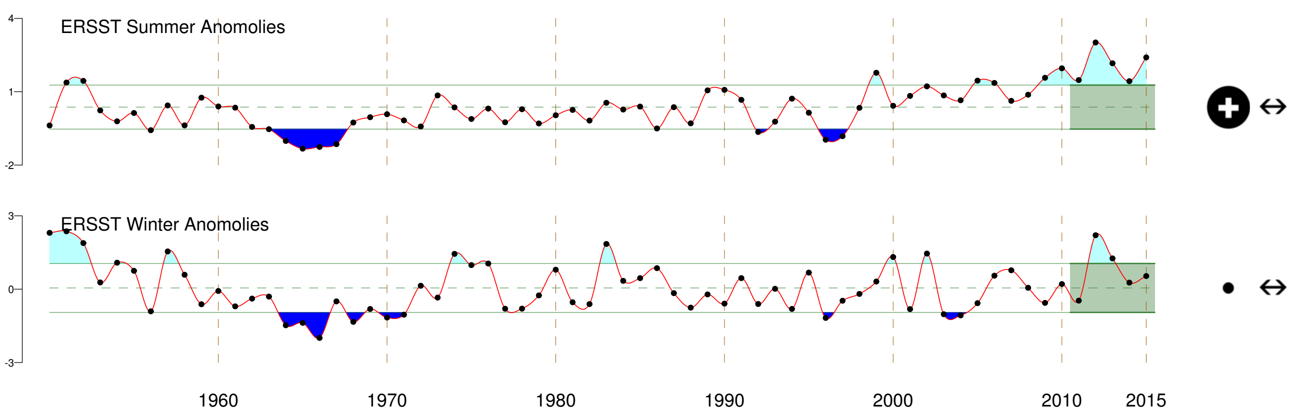


Figure 3.1: Long-term sea surface temperatures averaged over the northeast U.S. continental shelf and adjacent waters.

Temperature in the NES has varied substantially over the past 150 years. The late 1800s to the early 1900s was the coolest period on record, followed by a period of warm temperatures from 1945-1955. There was a rapid drop in temperatures through the 1960s followed by a steady increase to the present. Sea surface temperatures were the warmest on record in 2012. Temperatures moderated somewhat in 2013-2014 but have remained well above average, particularly during the summer (Fig. 3.1). The overall seasonal increase in temperatures has been accompanied by a number of ecosystem changes including shifts in the distribution patterns of fish populations (see Section 5). A significant number of important fishery species including cod, haddock, and yellowtail flounder are at the southern extent of the range in our area and are projected to experience changes in recruitment and distribution. Conversely, certain subtropical-temperate species such as croaker are predicted to increase in abundance and expand their range in the mid-Atlantic Bight if climate projection scenarios hold.

3.2 Stratification

During much of the year, portions of the northeast U.S. shelf are stratified. Stratification refers to the vertical stacking of layers of water having different densities due to differences in temperature and salinity at different depths within the water column. Stratification is important because surface dwelling primary producers need to stay in sunlit waters, but deeper waters are often nutrient rich. Increased stratification makes it harder for these nutrient rich waters to be mixed to the surface where they are available to primary producers, potentially resulting in lower overall productivity in the systems. While the NES has experienced above average conditions for most of the past decade, stratification has returned to near or below average in the last few years (Fig. 3.2). In general, vertical temperature differences (warm water overlaying cold water) tend to be more important than vertical salinity differences (fresh water over salty water) in determining stratification almost everywhere on the NES. The exception is the Scotian Shelf region where the coldest/freshest water first enters the Gulf of Maine and temperature and salinity contribute equally to the stratification.

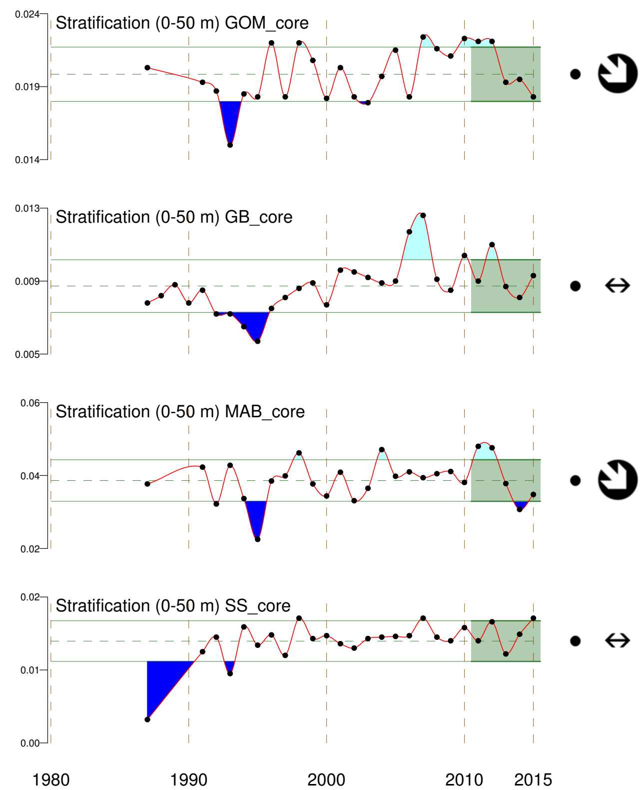


Figure 3.2: Stratification (density layering) of the upper 50m of the water column for the Gulf of Maine (GOM), Georges Bank (GB), the Mid-Atlantic Bight (MAB), and the Scotian Shelf (SS).

4 The Base of the Food Web

4.1 Phytoplankton

Ecosystem productivity ultimately depends on the amount of production at the base of the food web. Single-celled algae, known as phytoplankton, are responsible for nearly all of the primary production in marine ecosystems and almost half of the total photosynthesis on the planet. Measurements of the primary photosynthetic pigment, chlorophyll a (CHL), taken from satellites, are commonly used as a proxy for phytoplankton biomass. Both smaller and larger phytoplankton have shown no long term trend in the NES LME, but have shown a declining trend over the last three years (Fig. 4.1).

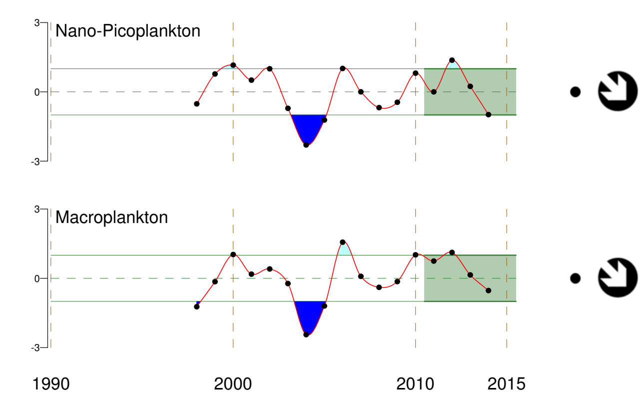


Figure 4.1: Annual trends in small (top) and large (bottom) phytoplankton on the Northeast US shelf.

4.2 Zooplankton

Zooplankton (small animals inhabiting the water column) graze on the phytoplankton and in turn are preyed on by larger animals. One simple indicator of zooplankton abundance is the volume (or biovolume) of material collected in specially designed plankton nets. The time series of zooplankton biovolume in the Gulf of Maine, Mid-Atlantic and Georges Bank ecoregions have been relatively consistent, suggesting large scale coherence in zooplankton throughout much of NES.

The composition of the zooplankton community has changed over time, which is reflected in changes at higher ecosystem levels as well. Specifically, small copepods increased in abundance in the 1990s, but shifted to larger bodied copepod species around 2000 (Fig. 4.2). There is evidence of a more recent shift, with smaller zooplankton becoming more abundant again over the last several years. The small copeods are most important during the autumn while the larger species (including *Calanus finmarchicus*) dominate early in the year following the spring bloom of large phytoplankton. Adult *Calanus* is the principal prey of right whales; any reduction in *Calanus* populations potentially impacts the most vulnerable protected species in our region.

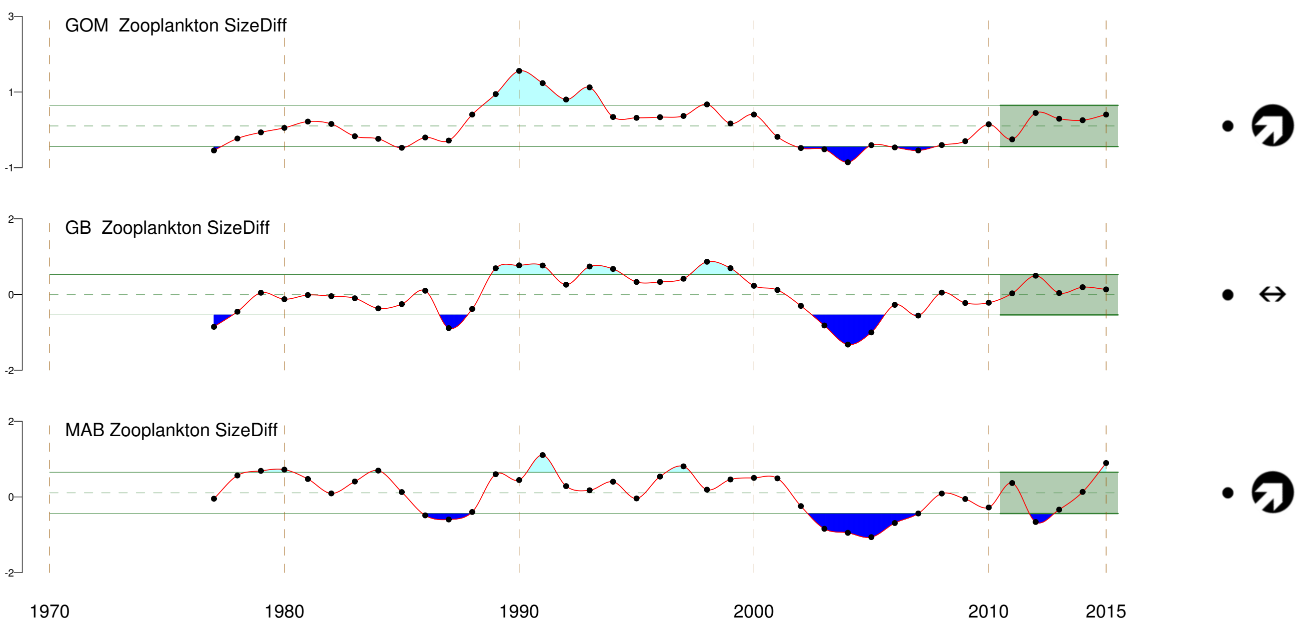


Figure 4.2: Trends in copepod species composition measured as the difference in abundance of small and large-bodied species.

5 Fish and Shellfish

5.1 Fish Communities

Trends in broadly defined taxonomic groups which are targeted by different components of the fishing fleet can reveal shifts in community structure not visible from single species trends. Here we consider groundfish, small elasmobranchs, small pelagic fishes, and other fish. The small elasmobranchs were primarily caught incidentally in groundfish fisheries until markets for these species were further developed in the 1980's. The small pelagic fishes have long supported important commercial fisheries (including some of the oldest in the United States). Many of the species included in the other fish category are taken as incidental catch but some, notably monkfish, have emerged as extremely valuable components of the overall fishery.

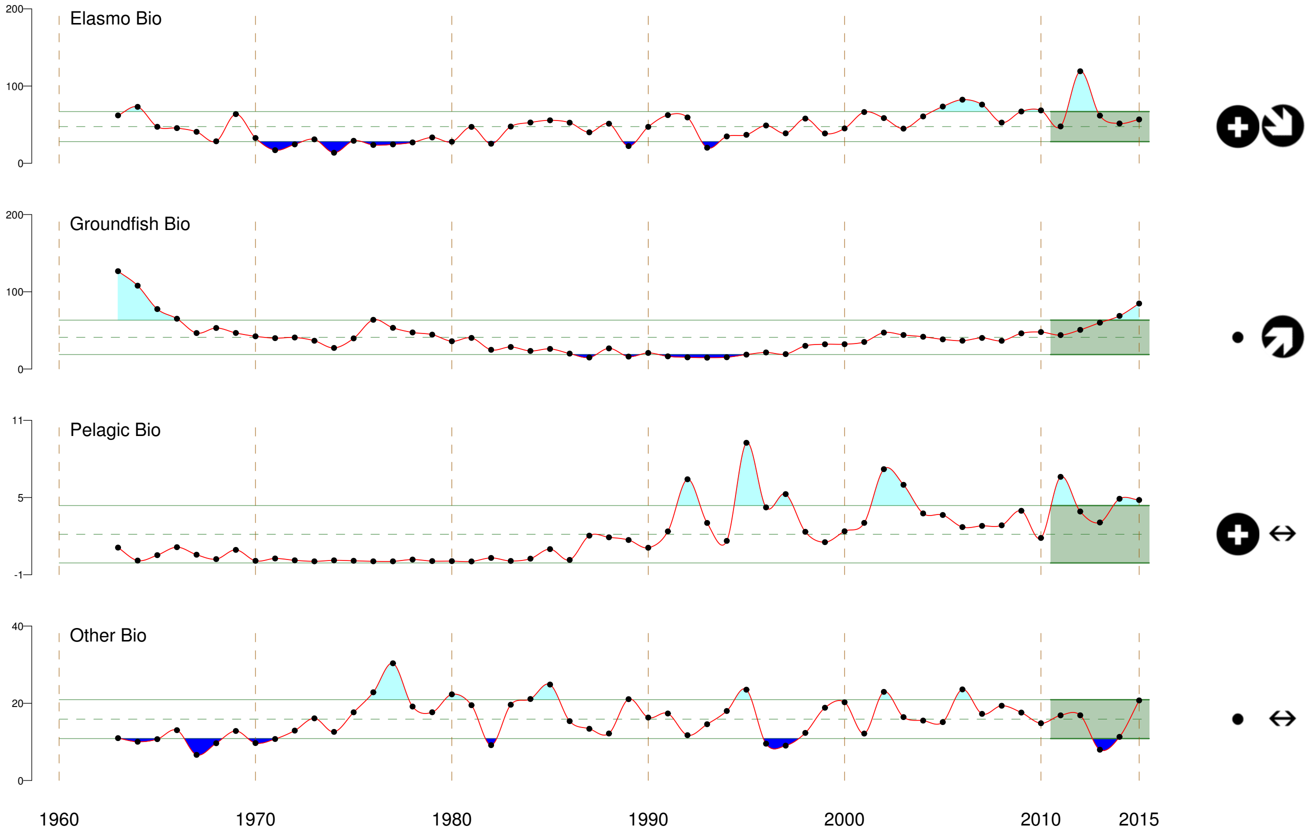


Figure 5.1: Trends in biomass (mean weight per tow) in autumn NEFSC bottom trawl surveys for major fish groups including elasmobranchs (dogfish and skates), groundfish, small pelagic fish (herring, mackerel, etc.) and other finfish.

Based on NEFSC autumn bottom trawl surveys, the small elasmobranch and pelagic fish groups have increased over time. In contrast, an initial decline and subsequent recovery is evident for the groundfish category, while other fish have remained stable or decreased (Fig. 5.1). These patterns are related to harvesting practices that resulted in sharp declines in bottom-dwelling fish, and subsequent implementation of management measures in the 1990s which resulted in recovery of at least some of the groundfish.

Forage species trends were also examined using research vessel survey indices for ten forage fish species that were consistently represented in survey catches. The selected forage species included round herring, Atlantic herring, alewife, bluback herring, shad, mackerel, butterfish, sand lance, shortfin squid, and longfin squid. We constructed a combined forage index by first developing a total biomass index for each species (adjusting for area swept by the gear and survey catachability) and weighting the biomass indices using published estimates of the energy content (kiloJoules per kilogram body weight) for each species and summing over all 10 species. We have seen a general increase in the forage index since the low point in the 1960s when the distant water fleet decimated many species on the Northeast shelf (Fig. 5.2). The energetic content of Atlantic herring is particularly high and this species has increased substatially in biomass over the last several decades.

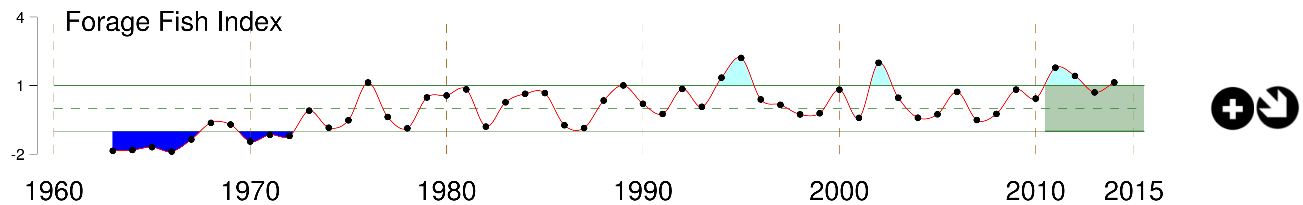


Figure 5.2: Forage fish aggregate index estiamted from trawl surveys of the Northeast Shelf.

Changing patterns of biodiversity – the mix of species within the ecosystem – can reflect fishing effects as well as climate change impacts on ecosystem structure. We track the number of species observed over time after correcting for sampling effort. Biodiversity as measured in NEFSC Spring Bottom Trawl surveys recently declined in the Gulf of Maine but increased in the Mid-Atlantic Bight (Fig. 5.3). On Georges Bank, spring biodiversity showed declines from a recent peak in 2009. Increases in biodiversity in the Mid-Atlantic Bight reflect, in part, increased representation of subtropical species in this region with increasing temperatures.

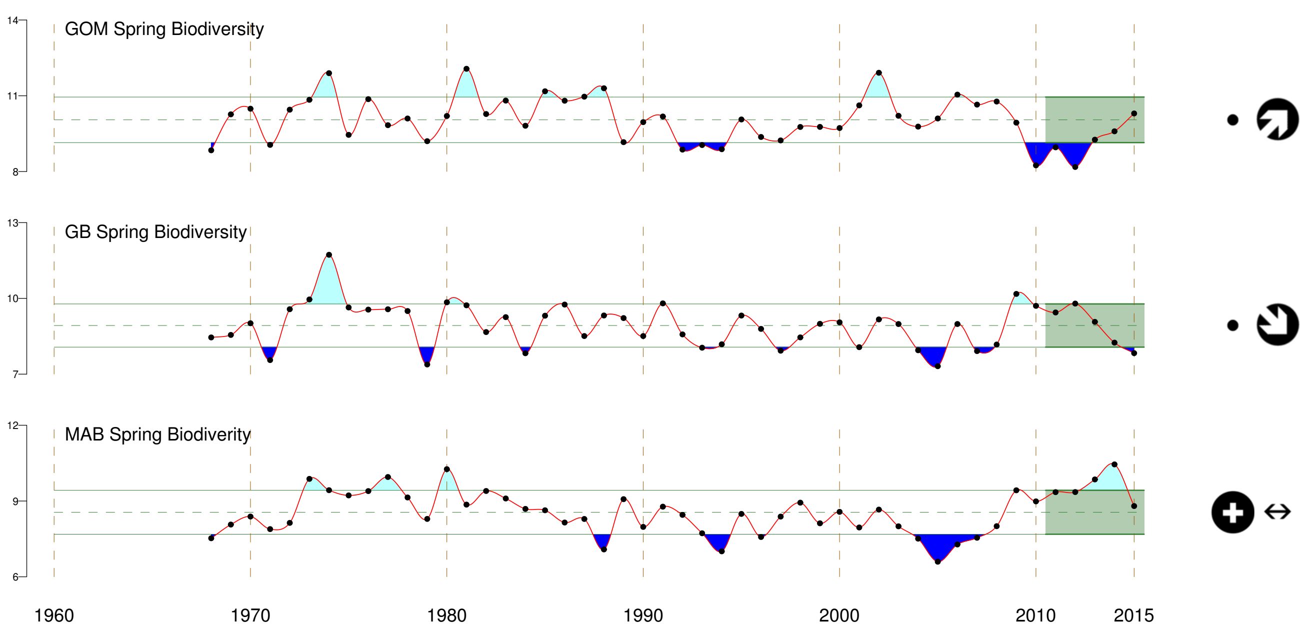


Figure 5.3: Trends in biodiversity in NEFSC Spring Bottom Trawl surveys.

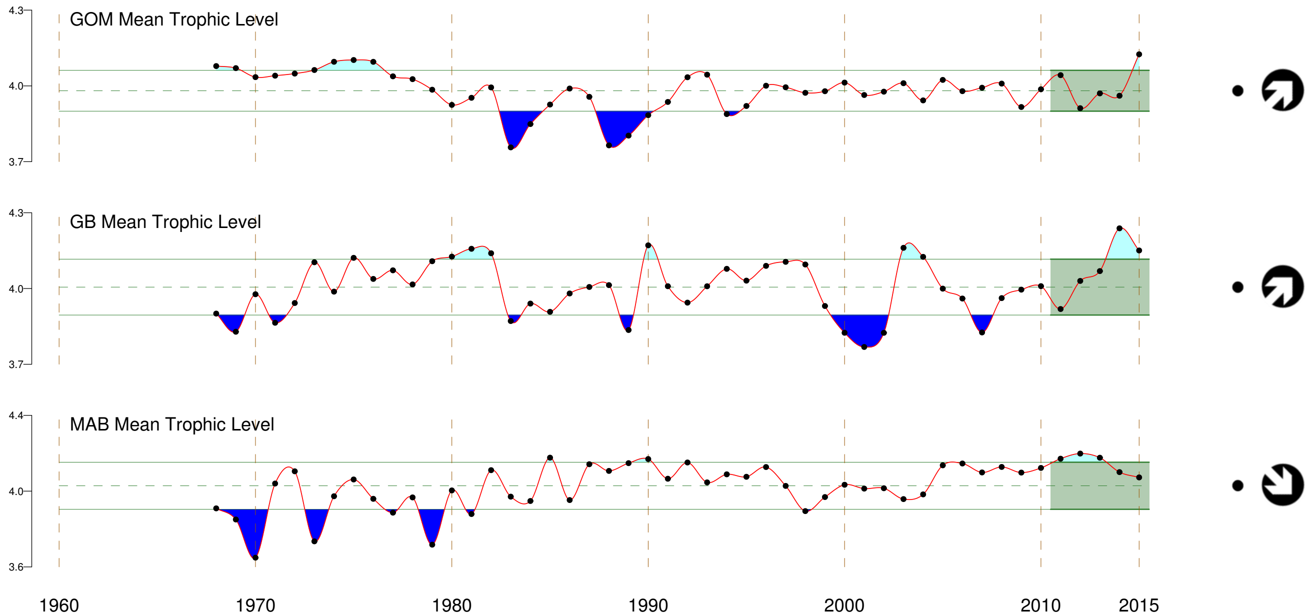


Figure 5.4: Trends in mean trophic level of fish communities in NEFSC Spring Bottom Trawl surveys.

5.2 Mean Trophic Level

The trophic level (TL) of a species (its place in the food web) reflects its role in ecosystem energy transfer.Trophic level is derived from food habits data for each species. Mean trophic level for the sampled fish community is a biomass weighted average of the individual species TLs. Reduction in fishing pressure on top predators such as cod and silver hake can contribute to increases in mean trophic level. The mean trophic level of fish species captured during the NEFSC autumn bottom trawl surveys has remained relatively stable over time (Fig. 5.4), and has increased in the Mid Atlantic Bight.

5.3 Fish Distribution Patterns

With a changing ocean climate on the Northeast US shelf, fish populations have responded with time-varying shifts in distribution and regional productivity. Habitats characterized by a particular community structure may have lost key species or have new additions to the community, usually species associated with regions located to the south. Many species have shifted north or to higher latitude locations on the Northeast Shelf as a whole. Interestingly, we do see differences on a regional basis in the direction of movement. Species distributed along the Mid-Atlantic/Georges Bank region tended to have shifted to the northeast, possibly in an attempt to maintain preferred temperatures. In contrast, in the Gulf of Maine, the dominant direction of movement was southwest, to a region that has remained cooler than other areas of the Gulf.

In order to explore observed shifts in species distributions over the time series, we quantified the distribution of the species in the first and last quarters of the survey time series (1968–1978, and 2001–2012). The average latitude and longitude weighted by biomass was used to calculate the center of the distribution of each species. Then the distance and bearing between the centers of distribution were calculated for each species in each region, seasonally. Figure 5.5 illustrates the average bearing and direction of movement of the center of the distributions of each of the species sampled by the bottom trawl survey in

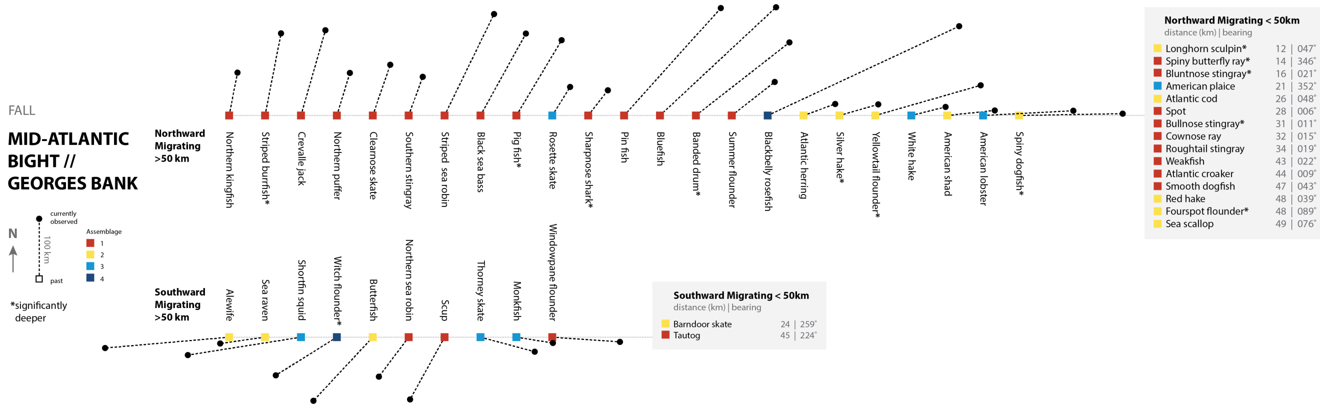


Figure 5.5: Average along shelf position for a group of 50 species resident on the Northeast US Continental Shelf. Distance is along a transect running from Cape Hatteras, North Carolina to Cape Sable, Nova Scotia, so increasing distance reflects net movement to the Northeast along the transect.

the fall for the Mid-Atlantic Bight and Georges Bank regions combined.

5.4 Condition Factor

Declines in condition factor, or individual fish weight at length, have been observed for numerous fish stocks in the Northeast US. Trends in condition factor were analyzed for 40 finfish stocks caught in the NEFSC autumn bottom trawl survey (1992-2015), and sexes were analyzed separately for species whose growth rate differ by sex. Most of fish stocks and sexes (45 of the 64 combinations) were found to have significant trends in condition factor over the time series, and of these, only 10 showed a significant increase in condition factor (both sexes of Northern silver hake, Southern silver hake males, GOM haddock, both sexes of Norther red hake, fourspot flounder, both sexes of Northern windowpane flounder, and Southern windowpane flounder females) (Fig. 5.6).

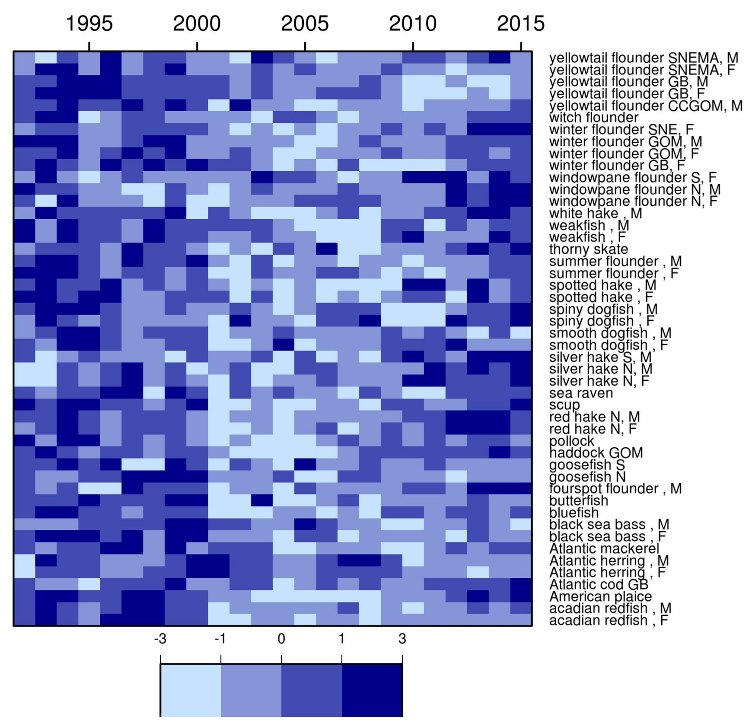


Figure 5.6: Change in condition presented as normalized time series from high (dark blue) to low (light blue) condition.

Changes in condition factor can be due to fishing pressure, competition, or environmental changes, but further analysis showed that abundance or bottom temperatures did not appear to be driving the observed decreases in fish weight. Similar changes in condition have been noted for fish in Atlantic Canada. The overall change in fish condition is important because the productivity of fish stocks and expected yield depend on growth and condition. Further, the reproductive output of fish stocks is linked to their condition, potentially affecting egg production and recruitment. This view of changes in condition factor for a large number of species suggests broad changes in productivity in the system with important implications for management.

5.5 Groundfish Recruitment

Estimates of groundfish recruitment (the number of young fish surviving to a specified age) and the overall weight of the adult population producing this recruitment since 1985 are available for twenty stocks on the Northeast Continental Shelf. We examined the estimated number of recruits divided by the spawning stock that produced this recruitment. To compare this metric for all stocks together, we standardized each ratio relative to its average value and its standard deviation (a measure of the variability of the ratio). We do see periods of apparently favorable and unfavorable recruitment levels (Fig. 5.7). Many of these stocks had poor recruitment index values starting in 2000. In addition to environmental drivers that can affect the recruitment survival index, it is possible that other factors such changes in age-structure of the stocks and related changes in egg and larval survival can come into play. There is increasing evidence that the viability of the progeny from older and larger female spawners is higher.

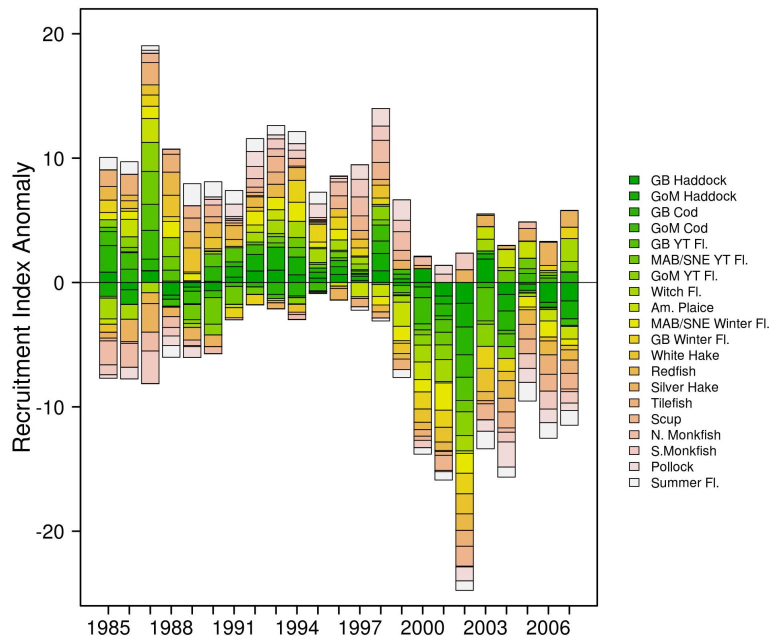


Figure 5.7: Change in recruits per spawner presented as normalized time series for 20 groundfish stocks 1985-2010 from NEFSC stock assessment reports).

5.6 Shellfish

Some of the more prominent benthic biomass trends throughout the NES LME include increases in American lobster and sea scallop populations, and decreases in ocean quahog and Atlantic surf clam populations, especially in recent years. Sea scallops are currently the highest valued fishery in the NES LME, and have increased dramatically in biomass over the last decade on both Georges Bank and in the Mid-Atlantic Bight, as seen in the expanded biomass estimates from the 2010 assessment (Fig. 5.8). This dramatic increase is related to the implementation of effective management measures including reductions in fishing effort, constraints on crew size, and gear restrictions. Sea scallop populations have also benefitted from the establishment of long-term closed areas on Georges Bank in late 1994 and rotational closures in the Mid-Atlantic Bight over the past decade. During the mid-2000s, biomass trends for sea scallops became more variable, with declines on Georges Bank during the period of increased fishing access (Fig. 5.8). Since then, recruitment has improved, biomass has accumulated, and sea scallop biomass is currently at a high level.

The NEFSC autumn bottom trawl survey indicates that American lobster biomass has increased dramatically in the Gulf of Maine. The lobster biomass index for Georges Bank has also increased somewhat in recent years, although the increase is not of the same magnitude or consistency over time as in the Gulf of Maine (Fig. 5.9). In the mid-Atlantic Bight however, lobster populations have declined precipitously as temperatures have increased and the incidence of shell disease has concomitantly increased. Evidence for increasing levels of shell disease in the Gulf of Maine is being carefully monitored.

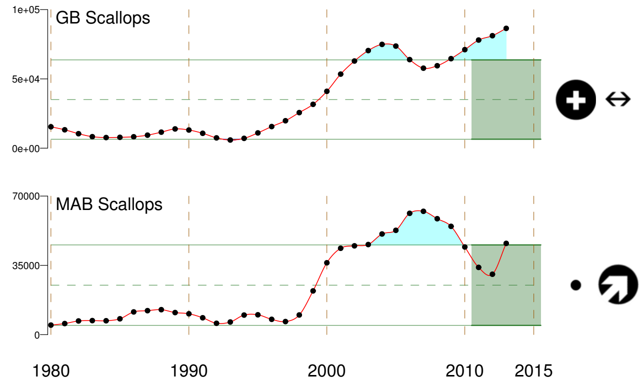
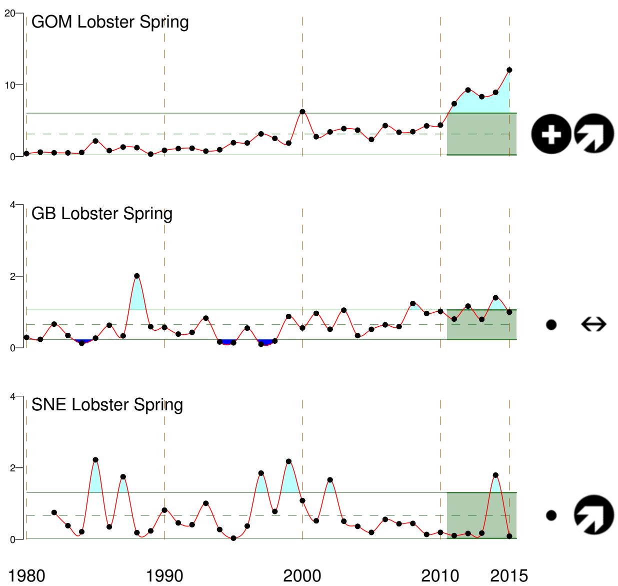
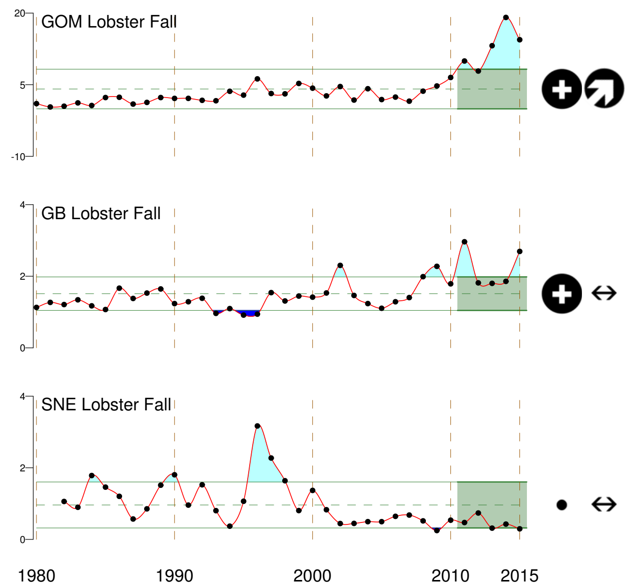


Figure 5.8: Trends in sea scallops for Georges Bank (GB) and the Mid Atlantic Bight (MAB) based on assessments.



(a) Spring lobster trends



(b) Fall lobster trends

Figure 5.9: Lobster trends in the Gulf of Maine (GOM), Georges Bank (GB) and Southern New England (SNE).

Recent declines in biomass for both ocean quahogs and Atlantic surf clams have been most pronounced in the southernmost region of the NES LME.

6 Ecosystem Services

Marine ecosystem services are the benefits human derive from healthy and productive oceans and coasts. Ecosystem services can be partitioned according to four major categories: (1) provisioning services (e.g. food, energy, transportation, natural products), (2) supporting services (e.g. primary production, habitat, shoreline protection), (3) regulating services (e.g. carbon storage, filtration) and (4) cultural services (e.g. recreation, aesthetic appreciation of nature, ecotourism, spiritual connections). Here we will focus on provisioning services related to capture fisheries and mariculture.

6.1 Capture Fisheries

The commercial fisheries of the NES LME have recently displayed some important trends in landings (Fig. 6.1). In the Gulf of Maine, the total biomass extracted peaked between the late 1970's and 1990's. However, the maximum annual removal of crustaceans occurred in 2012, driven primarily by landings of American lobster and landings of pelagics are near the time series' average. Mollusc landings are also near long-run averages in Georges Bank. Although the landings composition has shifted dramatically, the total biomass removed from the Mid-Atlantic is very close to the series average. The shift towards mollusc landings highlights the importance of Atlantic surf clams, ocean quahogs, and Atlantic sea scallops to the Mid-Atlantic, while crustacean landings in this ecoregion are composed primarily of blue crab. Recent landings are however substantially below historical levels.

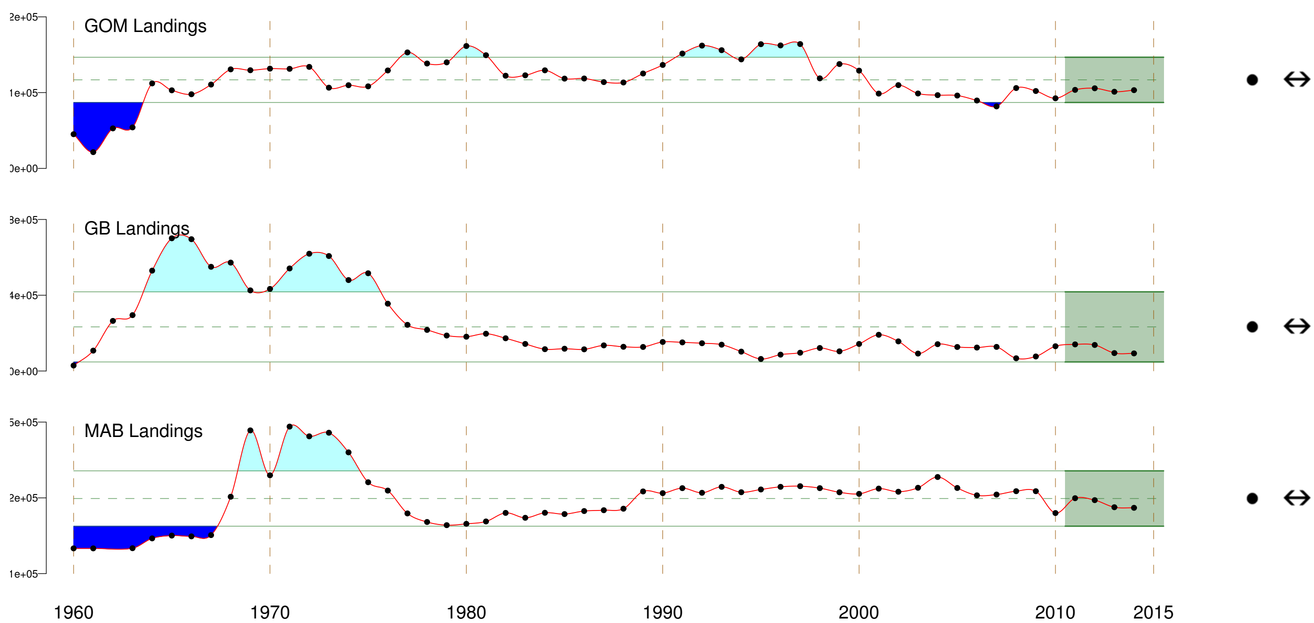


Figure 6.1: Total landings for the Gulf of Maine (GOM), Georges Bank (GB) and the Mid-Atlantic Bight (MAB).

Since 1990, total U.S. revenues from federally permitted commercial fishing vessels in the NES LME waters have fluctuated around an average of $1.66 billion, ending with a 2012 total revenue of just over $1.46 billion (Fig. 6.2).

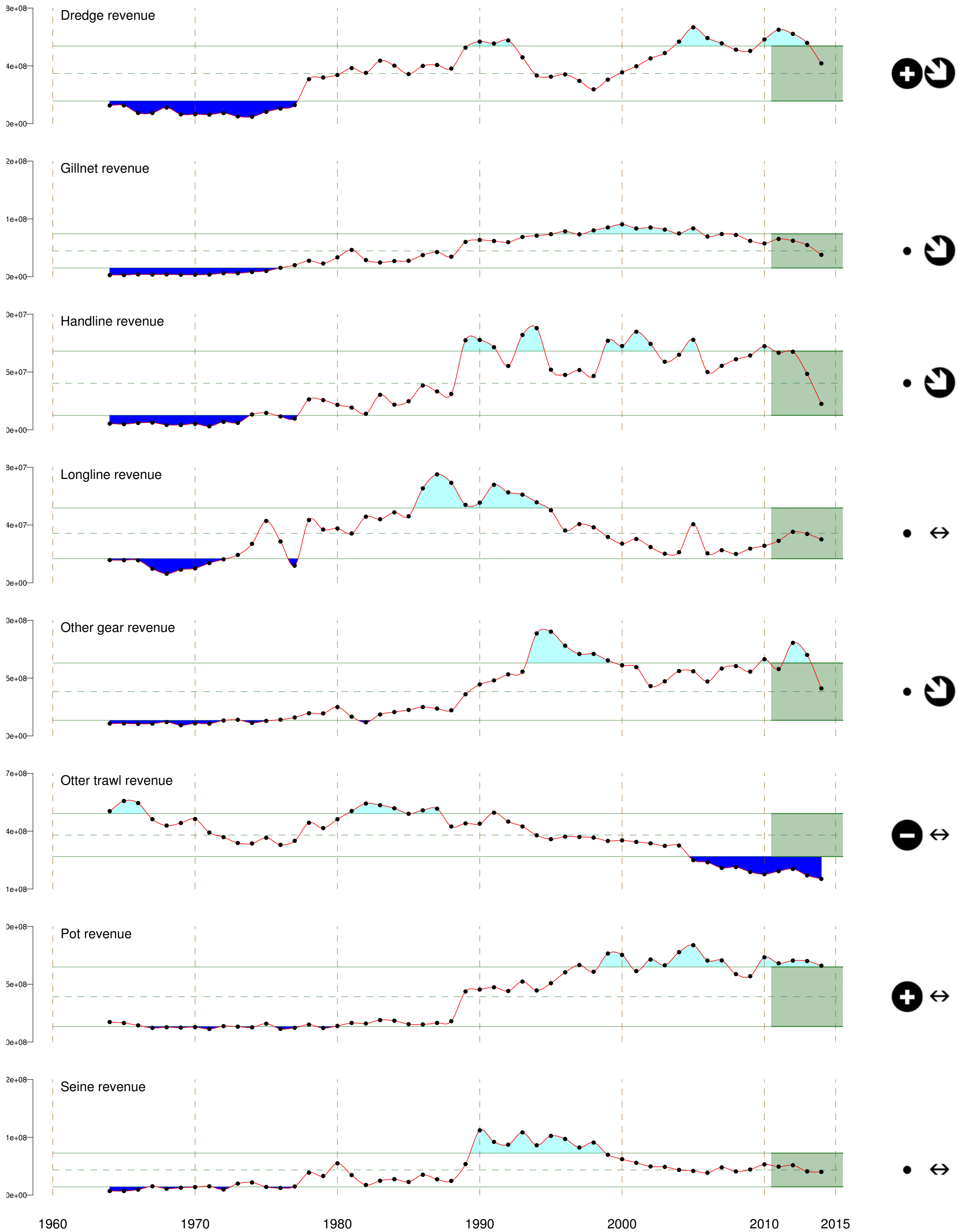


Figure 6.2: Trends in fishery revenues by gear type on the Northeast Shelf.

In 2012 these revenues were dominated by dredge gear, consisting primarily of Atlantic sea scallop, Atlantic surf clam, and ocean quahog landings, and pot and trap gears, 87% of which are explained by lobster landings. These results continue to highlight the shifting economic dependence on both lower trophic levels and a less diversified species mix.

6.2 Recreational Fisheries

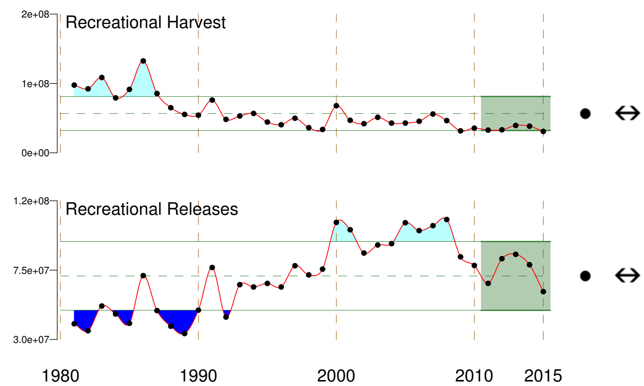


Figure 6.3: Trends in recreational harvest (fish taken for consumption) and caught and released fish.

Providing food is an important dimension of the recreational fishing experience, as reflected in the magnitude of the catch taken for consumption. Recreational fishing is also an aesthetic pursuit and an important cultural service as well. Here we focus on recreational catch statistics. Recreational fish harvest is currently below the time series average, down from a peak in the mid-1980s (Fig. 6.3). Attributing the trend to a single cause is problematic, as recreational fisheries are a complex amalgam of for-profit party and charter vessels together with private boat and shore fishing more purely characterized as leisure and/or subsistence activities. The recent recession and lethargic economic recovery likely explain a portion of the recent trend, as individuals slow expenditures on recreational activities or substitute less expensive leisure activities for fishing. The recreational fishery also depends on many of the same depleted fish stocks as some of the most contracted commercial fisheries in the Northeast, and these depletions likely account for a portion of the longer trends in landings observed. It is worth noting that the number of recreational species caught and released has increased over time but has leveled off over the last 5 years. This may reflect changing regulations affecting sizes and numbers of fish that can be retained.

6.3 Mariculture

Marine aquaculture, or mariculture, conducted in coastal and estuarine waters in the Northeast region, is a growing industry. The value of harvests from aquaculture – primarily oysters and clams, region wide, and salmon in Maine ($161M) – is ranked third in dollar value after scallops and lobsters and currently exceeds the collective value of all groundfish landings ($80M). It is difficult to inventory the full spatial and economic extent of commercial aquaculture in the Northeast region because of inconsistent reporting among states. Regional production of Atlantic salmon in Maine in 2010 was estimated at $74M dollars and was conducted on approximately 250 ha. Shellfish aquaculture is conducted on approximately 61 thousand ha (150,000 acres) from Maine through Virginia, with annual production of about 349 million hard clams and 100 million oysters. This represents an estimated annual value of about US $98 million dollars. Steady growth in East Coast oyster culture has led to a doubling of production in the last five years. Presently, there are over 1000 farms and 28 bivalve hatcheries in the region. Growth in leased acreage and production is projected for the shellfish aquaculture industry.

7 Status Determinations and Species of Special Concern

7.1 Fishery Resource Status

Currently, no MAFMC stocks are classified as overfished (biomass less than one half of their biomass at maximum sustainable yield) (Fig. 7.1). Overfishing is occurring for 1 species (Summer flounder, a.k.a. Fluke). Enhanced management effectiveness since 1997 has resulted in a steady decline in the number of stocks classified as overfished on the Northeast Continental Shelf. However, one quarter of the assessed stocks in the Northeast region tracked in the NOAA Fisheries Fish Stock Sustainbability Index are still classified as overfished. The greatest problem exists in the New England mixed species trawl fisheries where bycatch is a significant issue and fishing rates cannot be fully controlled on all parts of the species complex simultaneously.

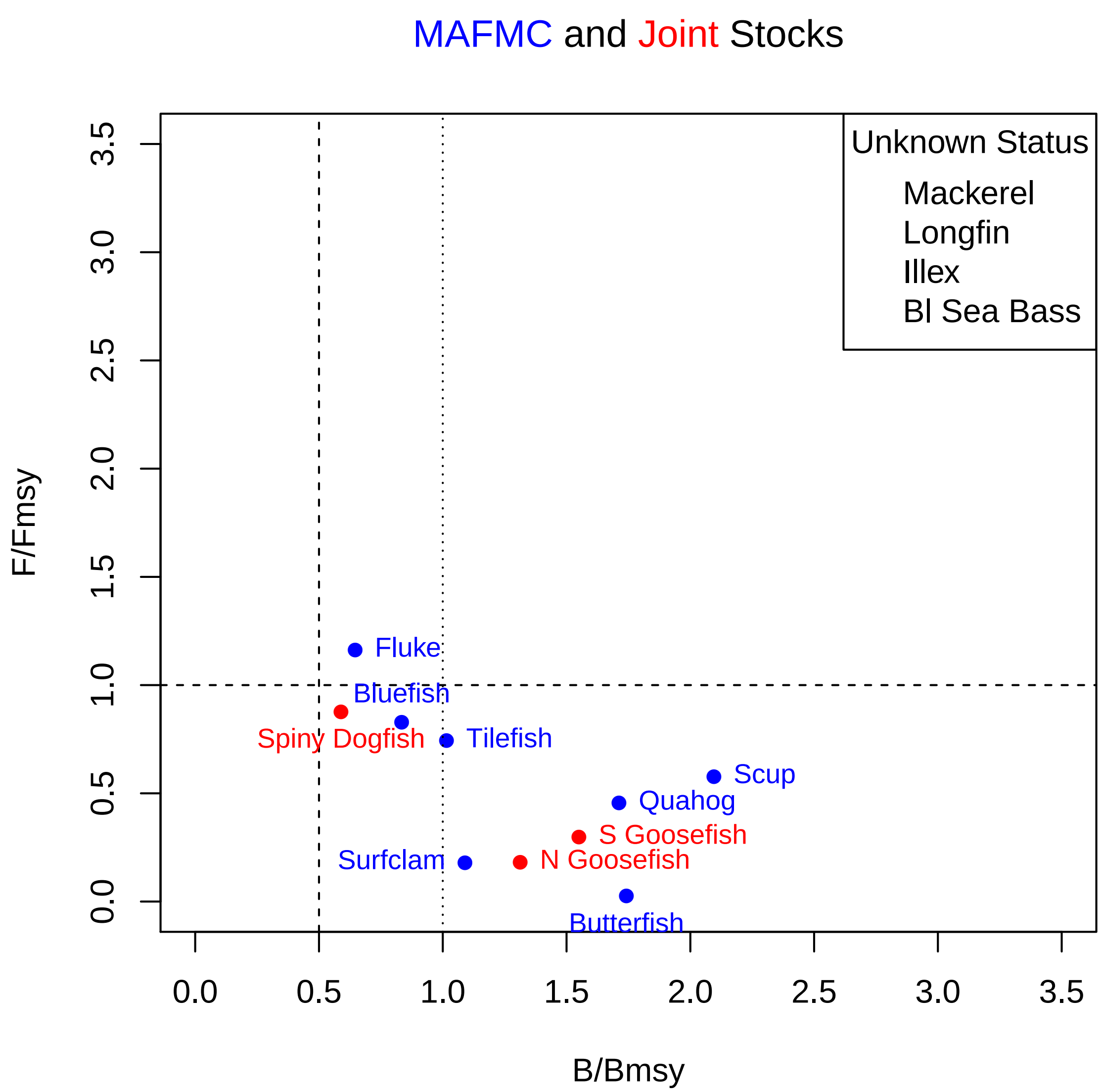


Figure 7.1: Fishing mortality (F) relative to Fmsy and Biomass (B) relative to Bmsy for Mid-Atlantic stocks.

7.2 Protected Species

Protected species inhabiting the U.S. Northeast Shelf Large Marine Ecosystem include fish, marine mammals, sea turtles, and seabirds. Human-caused threats to protected species include accidental commercial and recreational fishery bycatch, boat collisions, exposure to contaminants, and ocean noise.

7.2.1 Marine Mammals

The NES is an important habitat for a number of marine mammal species. The Gulf of Maine and Georges Bank shelf regions in particular are essential summer feeding grounds for large whales including humpback, fin, sei, minke, and North Atlantic right whales; smaller toothed whales including harbor porpoise, short-beaked common dolphin, Atlantic white-sided dolphin, offshore bottlenose dolphin, short-finned and long-finned pilot whales, and seal species including harbor and gray seals. The numbers of harbor and gray seals on the U.S. NES LME have increased in recent years where some seals are present year-round (Fig. 7.2), though they migrate within and outside of the NES. These seal populations eat a wide variety of fish and invertebrates, and despite controversy over consumption of Atlantic cod, they tend to primarily consume small pelagic fish, hakes and flatfish. Other seal species such as the harp and hooded seals primarily use the region as a feeding ground during winter months. All of the above species found in the U.S. NES LME are protected under the Marine Mammal Protection Act, and all of the large whales (excluding minke whales) are listed as endangered under the Endangered Species Act (ESA). The North Atlantic right whale is one of the most endangered populations of large whales in the world. Because of the ESA status of North Atlantic right whales, specific monitoring programs are in place including annual counts of right whale calves. The best estimate of the total North Atlantic right whale population size shows an increase in the population from 261 in 1990 to 476 in 2011 (Fig. 7.2).

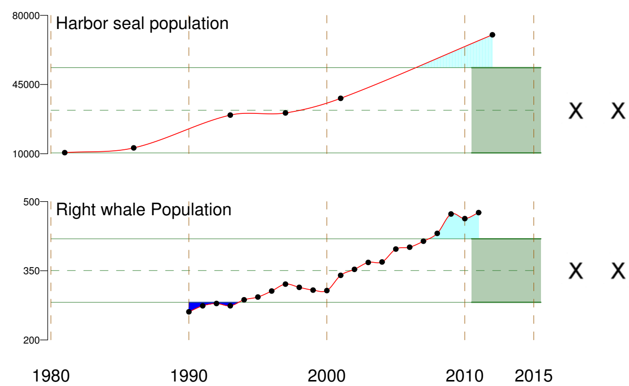


Figure 7.2: Trends in harbor seal and right whale population size on the Northeast Shelf.

7.2.2 Sea Turtles

Sea turtles are commonly observed in the U.S. NES LME in the late spring, summer, and early fall months when ocean temperatures are warmer. Of the four species that typically occur in this region, loggerhead turtles are the most abundant. Other species present in the region include leatherback, green, and Kemp's ridley turtles. All sea turtles are protected under the U.S. Endangered Species Act and those that occur in the U.S. NES LME are listed as threatened (loggerhead and green) and endangered (leatherback and Kemp's ridley). Population abundances and trends have typically been estimated using nesting female count data from the primary nesting beaches. Aerial surveys of in-water turtles are also useful for population estimates but are subject to a much higher level of uncertainty due to temporal inconsistencies in the survey, variability in turtle surfacing behavior, perception bias, and the previous small spatial coverage of surveys.

7.2.3 Seabirds

Atlantic Puffins (*Fratercula fratercula*) and Artic terns (*Sterna paradisaea*) have seen a decline in their breeding productivity related to diet change and SST increase (Fig. 7.3). Atlantic puffin was close to extinction in North America until 1980s. A program of chick translocation was organized by the Audubon Society (Puffin Project) and since then the numbers have increased steadily. In 2012, the lowest breeding productivity was observed. In 2012, Atlantic puffins fed their juveniles with more butterfish relative to Atlantic herring. Chicks have difficulty swallowing the deeper bodied butterfish. Artic tern adults also fed their chicks with more butterfish, and a decline in their breeding success has also been observed (Fig. 7.3) but Artic terns can feed on a wider range of prey items.

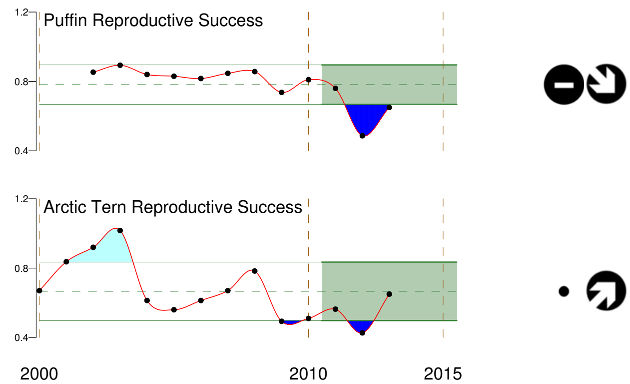


Figure 7.3: Trends in fledging success of puffins and arctic terns on nesting colonies on islands in the Gulf of Maine.

8 Risk Assessment

Understanding the vulnerabilities and risks to populations, ecosystems, and society resulting from both anthropogenic and natural forcing factors is essential for the development of effective management strategies. In the following, we will provide examples of risk assessments for marine fish and shellfish populations affected by climate change and to fishing communities as a result of dependence on commercial and recreational fishing.

8.1 Climate Vulnerability and Risk Assessement

A climate vulnerability assessment was conducted for a total of 82 marine fish and invertebrate species that commonly occur in the Northeast U.S. Shelf. These included exploited species, protected fish species and ecologically important species. The 82 species were nearly equally split among the different climate vulnerability ranks: very high (27%), high (23%), moderate (24%) and low (26%) (Fig 8.1). Climate exposure scores for all 82 species were high or very high, indicating the magnitude of climate change relative to the variability of past conditions is high. Biological sensitivity ranged from low to very high. The certainty in the score of the majority of species exceeded 90% based on the bootstrap analysis. Approximately 27% of species had certainty scores between 66–90%. Approximately 12% of species had certainty scores <66%.

Based on expert opinion of the directional effect of climate change, approximately half of the species were assessed to be negatively affected by climate change in the Northeast U.S. Shelf (Fig 8.1). Overall climate vulnerability is denoted by color: low (green), moderate (yellow), high (orange), and very high (red). Certainty in score is denoted by text font and text color: very high certainty (>95%, black, bold font), high certainty (90–95%, black, italic font), moderate certainty (66–90%, white or gray, bold font), low

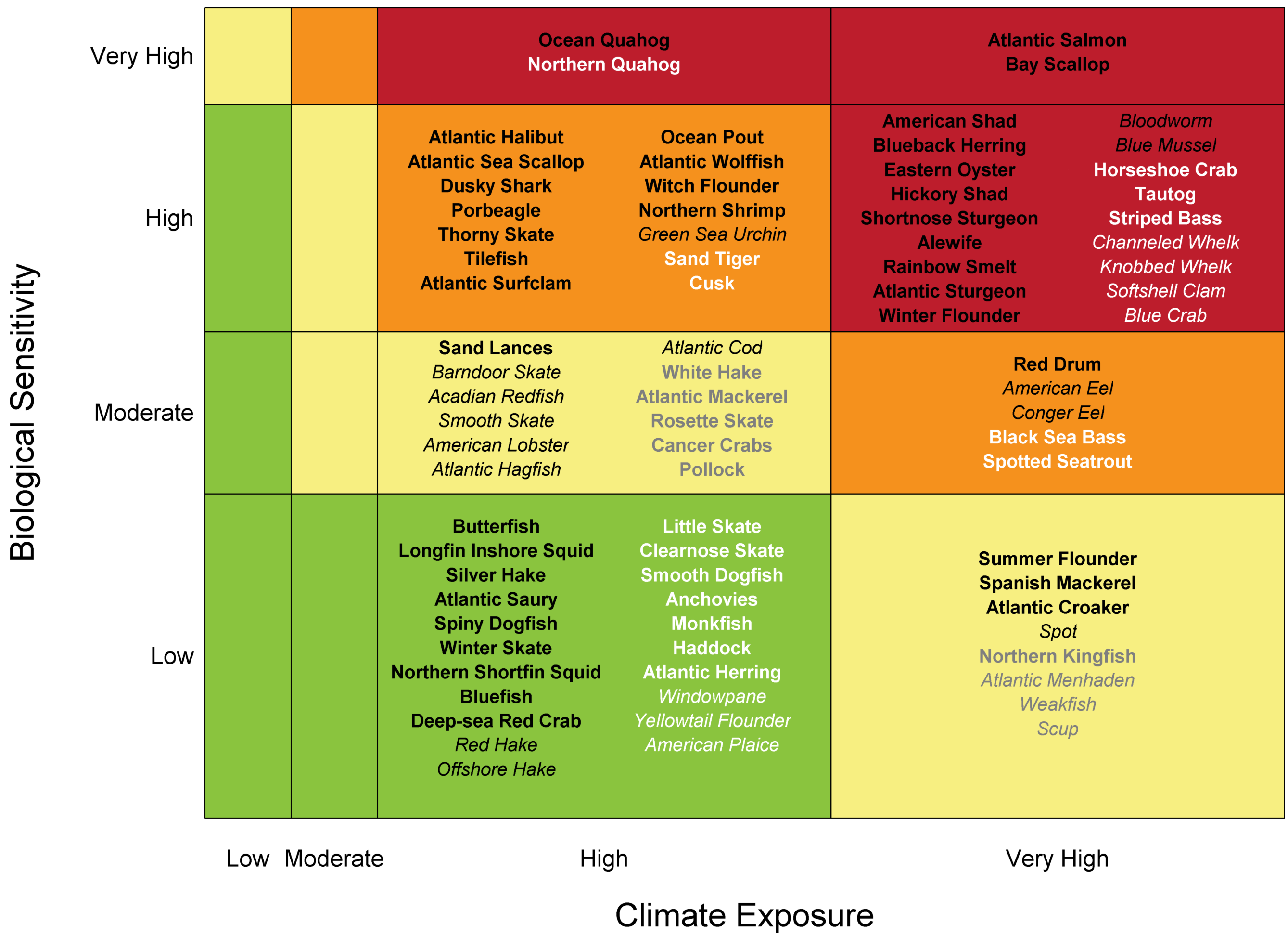


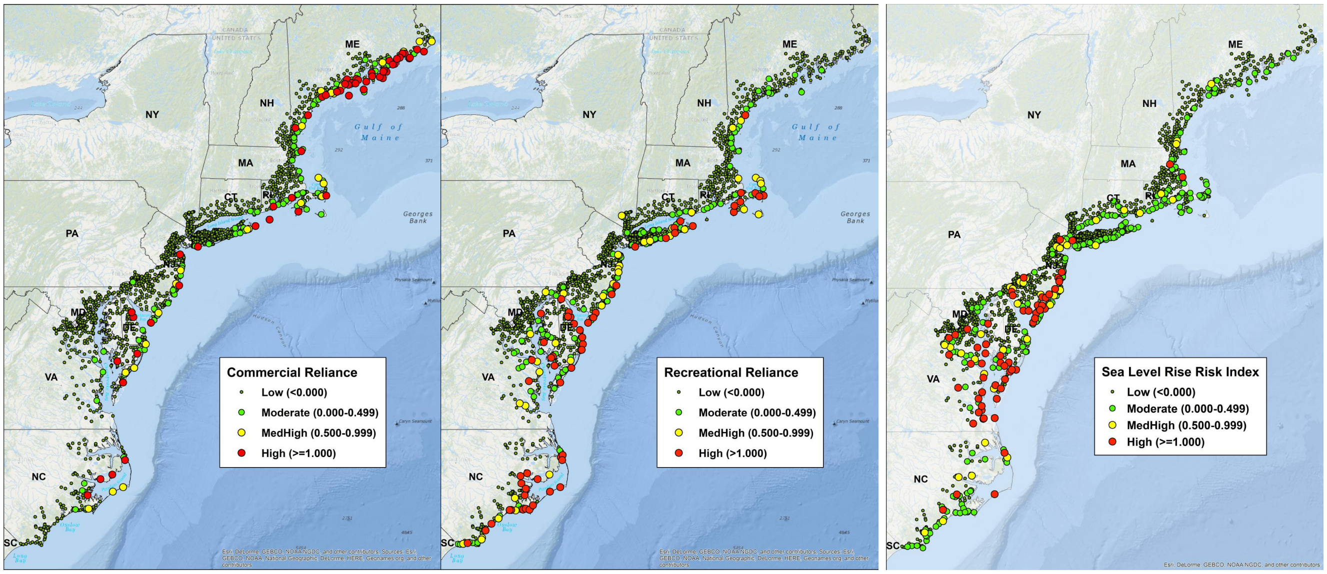
Figure 8.1: Climate Risk, from http://dx.doi.org/10.1371/journal.pone.0146756.

certainty (<66%, white or gray, italic font). Negative effects are anticipated for many benthic invertebrate and groundfish species. However, positive effects are anticipated for 17% of species considered.

8.2 Social Vulnerability and Risk Assessment

Community Social Vulnerability Indicators include 13 indices of social vulnerability and fishing dependence that were developed for nearly 4,000 coastal communities in United States. These indicators fall into four categories: 1) social vulnerability, representing factors such as poverty and population composition that can affect an individual or community's ability to respond and adapt to change or disruptions; 2) gentrification pressure, characterizing factors such as changing population demographics in coastal areas that may compromise sustainability of a commercial or recreational fishing working waterfront; 3) community engagement and reliance on commercial and recreational fishing; and 4) climate change vulnerability related to aspects of sea level rise risk. We focus on the latter two categories here.

Commercial fisheries dependence is very high along the Gulf of Maine (Fig 8.2a). In contrast, the coastal communities in Southern New England and the Mid-Atlantic are highly dependent on recreational fishing and its associated businesses (Fig 8.2b). The projected sea level rise risk to coastal communities, which varies spatially due to coastal subsidence, is highest in the Mid-Atlantic (Fig 8.2c).

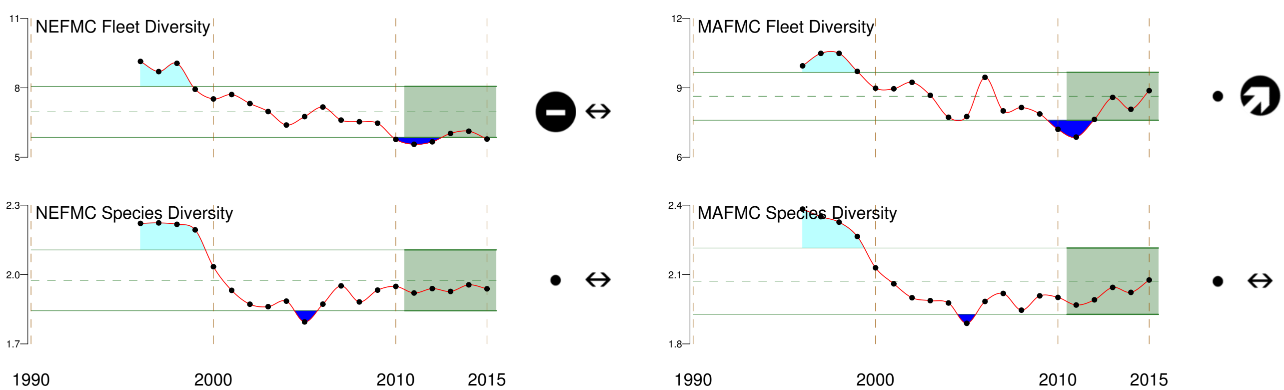


(a) Commercial (b) Recreational (c) Sea Level Rise

Figure 8.2: Coastal community fishery reliance and sea level rise risk from Colburn et al., 2016.

8.3 Fleet Diversity

Diversity can buffer against risk. Here we examine trends in fleet diversity and species diversity for vessels landing species managed by the New England and Mid-Atlantic Fishery Management Councils. These measures look to quantify the extent to which fleet composition has changed, and assess the extent to which stovepiping, or conversely specialization, is occurring. Ultimately, these diversity measures look to situate discussions arising from management actions such as Amendment 18 of the Northeast Multispecies FMP in the historical picture. Ultimately diversity can be measured in numerous ways (for example, in numbers of vessesl in each fleet component as opposed to the current revenue metric) and feedback from the Councils as to how this should be defined is welcomed.



(a) New England (b) Mid-Atlantic

Figure 8.3: Trends in fleet diversity and catch diversity as measured by revenue for each regional Fishery Managemnet Council

9 Have there been ecosystem shifts?

We constructed a composite index of many of the variables provided in our Ecosystem Status Report to provide an overall NES Ecosystem Index. We restricted our analysis to variables with a continuous record of observation from 1977 to the present (some important ecosystem indicators derived from the NEFSC MARMAP and EcoMon surveys were not available prior to 1977). We used a common multivariate statistical procedure, principal components analysis, to construct the index. This technique involves the construction of a set of mutually independent linear combinations of the original variables. This method has been frequently used as a data reduction technique in analyses of ecological indicators in the NES. This method however does not explicitly consider the time-order of the observations and it cannot be used with variables containing missing values. To directly address the time series nature of the observations and to test for evidence of change-points throughout time period examined, we employed another multivariate approach, chronological cluster analysis, which seeks to identify contiguous blocks of time with similar characteristics and points at which statistically significant change occurs.

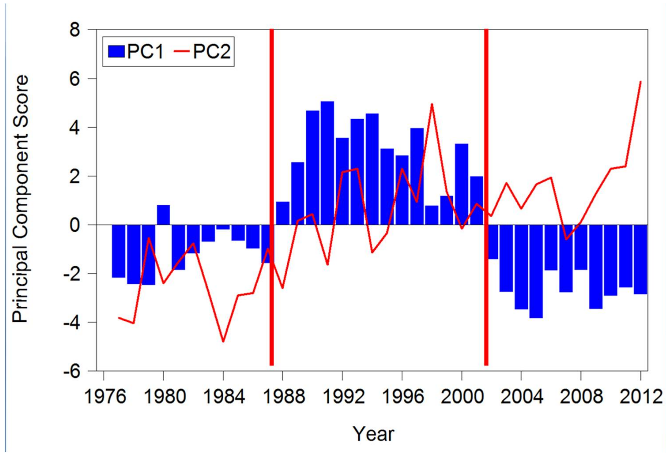


Figure 9.1: Composite index values for the Northeast U.S. Continental Shelf Large Marine Ecosystem. The first composite index is shown in the blue bars. The second composite index is shown in the red lines. The composite indices are based on climate, oceanographic, and ecological indicators but do not include fishery-related indicators.

This analysis reveals some important changes in the Northeast Continental Shelf over the last several decades (Fig. 9.1). Our first composite index, shown in blue bars in the accompanying figure, suggests that the overall characteristics of the system changed in the late 1980s and remained in a different state until the early 2000s. These change points are consistent with ones shown in other analyses focusing on parts of the ecosystem in more restricted geographical areas, principally in the Gulf of Maine. Our system-wide analysis shows that these changes are much broader in scope and more pervasive throughout the system. The second composite index, shown in the red line, reveals an additional component of change indicating a trend related to factors such as steadily increasing temperatures over the last several decades. Understanding that these ecological changes occur and persist on decadal time scales is important in understanding changes we see in our fisheries over time. In turn, this understanding can help inform management decisions if we detect persistent increases or decreases in productivity over time.

Research into composite indicators and ecosystem shifts remains active at the NEFSC, so we expect to develop these analyes more fully in the future.

10 More Information

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