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, 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: Gulf of Maine and Georges Bank Ecosystems](image_url)
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. The objectives and associated indicators are listed in the table below. We also report single-species status relative to established objectives and reference points.

<table>
<thead>
<tr>
<th>Objective Category</th>
<th>Indicators reported here</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seafood production</td>
<td>Landings by functional group, mariculture</td>
</tr>
<tr>
<td>Profits</td>
<td>Revenue by functional group</td>
</tr>
<tr>
<td>Recreation</td>
<td>Numbers of anglers and trips</td>
</tr>
<tr>
<td>Employment</td>
<td>Indicator under development (see p. 3)</td>
</tr>
<tr>
<td>Stability</td>
<td>Diversity indices (fishery and species)</td>
</tr>
<tr>
<td>Social-Cultural</td>
<td>Community vulnerability, fishery engagement and reliance</td>
</tr>
<tr>
<td>Biomass</td>
<td>Biomass or abundance from surveys, biomass relative to reference</td>
</tr>
<tr>
<td>Productivity</td>
<td>Condition and recruitment, fishing mortality relative to reference</td>
</tr>
<tr>
<td>Trophic structure</td>
<td>Relative biomass of trophic groups</td>
</tr>
<tr>
<td>Habitat</td>
<td>Thermal habitat volume, physical properties</td>
</tr>
</tbody>
</table>

40% of New England Council (NEFMC) stocks are meeting objectives at the managed species level. Of 38 managed stocks, 15 are within target ranges for fishing mortality (F) and above the threshold for biomass (B), 9 stocks exceed F rates and/or are below B levels relative to reference points, and the remaining 14 have unknown status.

**NEFMC and Joint Stocks**

Figure 2: Summary of single species status for NEFMC stocks
At the ecosystem scale, commercial Gulf of Maine and Georges Bank seafood production increasingly relies on benthos and benthivores (scallops, lobster), with other groups stable or decreasing in landings (forage fish, piscivores). Aquaculture production has been steady for Maine salmon and increasing in Rhode Island. The majority of Georges Bank commercial fishery revenue is from a single species (scallops), and the majority of Gulf of Maine revenue is from a single species not managed by the Council (lobster), underlining the need to work across jurisdictions to address ecosystem-level objectives.

Recreational opportunities from fishing have 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 fishing communities in New England have generally moderate to low risks from sea level rise, there is moderate to high reliance on species vulnerable to climate. Catch diversity is lowest in eastern Maine. Maine coastal communities have a high reliance on commercial fisheries, while communities from Cape Cod south rely on both recreational and commercial fisheries.

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

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 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 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). 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 New England, smaller less energy dense zooplankton have been increasing while primary production has been average.

Temperature is increasing in long term sea surface records as well as 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, a local mechanism for increased temperature and species redistribution, adding to broader influences of a warming climate.

This report currently lacks indicators for 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. 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 degrees of engagement in and reliance on fishing. Engagement generally measures the amount of fishing activity in terms of landings, permits, and fish dealers in a community, while reliance measures these on a per capita basis. In particular, communities around the Gulf of Maine region have a higher reliance on commercial fishing relative to 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

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 and sea-level rise. Fishing communities in New England have generally moderate to
low risks from sea level rise compared with communities in the Mid-Atlantic. However, there is moderate to high reliance on species vulnerable to climate in New England, and generally low catch diversity for communities in the Gulf of Maine, which may also increase risk.

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 commercial fishing (the human activity) to the seafood production objective. Functional groups based on food habits of species are listed with the codes below.

**Species groupings**

<table>
<thead>
<tr>
<th>Group (Description)</th>
<th>N species</th>
<th>Major species in the group</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Benthos (Bottom dwellers)</td>
<td>7</td>
<td>scallops, surfclam, quahog, mussels, whelks, conchs, sand dollars and urchins</td>
</tr>
<tr>
<td>B: Mesoplanktivores (Eat Copepods)</td>
<td>7</td>
<td>Atlantic herring, butterfish, Atlantic mackerel, menhaden, river herrings and shad</td>
</tr>
<tr>
<td>C: Macroplanktivore (Eat large zooplankton)</td>
<td>6</td>
<td>white hake, longfin and shortfin squids, searobins, sculpin, lumpfish</td>
</tr>
<tr>
<td>D: Macrozoopiscivores (Eat large zooplankton, shrimp, and fish)</td>
<td>12</td>
<td>redfish, windowpane, cusk, pollock, red hake, clearnose, little, and smooth skates, smooth dogfish, buckler dory, blackbelly rosefish</td>
</tr>
<tr>
<td>E: Benthivores (Eat bottom dwellers)</td>
<td>24</td>
<td>lobster, haddock, yellowtail, winter, and witch flounders, barnoo skate, ocean pout, black sea bass, scup, tilefish, tautog, cunner, blue crab, red crab, other crabs</td>
</tr>
<tr>
<td>F: Piscivores (Eat fish)</td>
<td>13</td>
<td>monkfish, winter and thorny skates, silver and offshore hake, Atlantic cod, halibut, fourspot flounder, spiny dogfish, summer flounder, bluefish, striped bass, weakfish</td>
</tr>
</tbody>
</table>
Commercial landings include all landings in the region, including species not managed by NEFMC. For example, category E, Benthivores, includes lobsters, which are a substantial portion of the landings and drive increases in landings and revenue. Over the most recent 5 years, NEFSC managed stocks made up from 5%-100% of total landings by category, as detailed in the table below. This indicator is being refined to eventually distinguish landings sold for human consumption versus other uses.

Table 3: Proportion managed by NEFMC

<table>
<thead>
<tr>
<th>Group</th>
<th>GOM landings</th>
<th>GOM value</th>
<th>GB landings</th>
<th>GB value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benthos</td>
<td>0.15</td>
<td>0.55</td>
<td>0.61</td>
<td>0.92</td>
</tr>
<tr>
<td>Mesoplanktivore</td>
<td>0.98</td>
<td>0.99</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>Macroplanktivore</td>
<td>0.94</td>
<td>0.97</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Macrozoopiscivore</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Benthivore</td>
<td>0.05</td>
<td>0.03</td>
<td>0.64</td>
<td>0.37</td>
</tr>
<tr>
<td>Piscivore</td>
<td>0.65</td>
<td>0.62</td>
<td>0.82</td>
<td>0.72</td>
</tr>
</tbody>
</table>

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: Macrozoopiscivores, E: Benthivores, F: Piscivores
Commercial Fishery Revenue

This indicator links commercial fishing (the human activity) to the profits objective. The overwhelming majority of Gulf of Maine revenue is from lobster (within benthivores here). The majority of Georges Bank revenue is currently from benthos (scallops). Revenue from piscivores has decreased in both the Gulf of Maine and Georges Bank over the past decade. We note that time series at the Gulf of Maine 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.

Figure 6: Commercial revenue from A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoopiscivores, 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 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.

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.

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.

This trend contrasts with the species diversity trends for the Gulf of Maine 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 both the fall and spring survey data). However, Georges Bank survey species diversity trends differ from Gulf of Maine in both seasons with less contrast between the mid-1990’s and the present.

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 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 9: A: number of anglers, B: number of trips](image)

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 the state of Maine is available for the Gulf of Maine region.
In Rhode Island, the total value of aquaculture production has been steadily increasing. The number of oysters sold is similarly increasing.

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 similar trends between the Gulf of Maine and Georges Bank. At the lowest trophic levels, benthos and forage fish, groups including commercial shellfish and herring, show long term increases in both seasons. Benthos also have recent short term increases in spring and forage fish have short term increases in fall surveys. Interestingly, predators of benthos (benthivores) are also show long term increases and short term increases in fall surveys (and spring in the Gulf of Maine), perhaps supported by the observed increase in benthos. In contrast, although forage fish (mesoplanktivores) show long term increases in all surveys, piscivores at higher trophic levels have significant long term increasing trends only during fall surveys.
Figure 12: Fall survey trends for A: Benthos, B: Mesoplanktivores, C: Macroplanktivores, D: Macrozoo-piscivores, E: Benthivores, F: Piscivores

Figure 13: 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 Gulf of Maine and Georges Bank portions of NEFSC surveys) can provide the capacity to adapt to change at the ecosystem level and for dependent fishing communities. Unlike total biomass trends by trophic group, trends in species diversity differ between Gulf of Maine and Georges Bank. The number of species has steadily increased in the Gulf of Maine over the long term in the spring, and over the most recent decade in both the fall and spring surveys.

![Graph showing species diversity trends in the Gulf of Maine and Georges Bank](https://www.nefsc.noaa.gov/ecosys/current-conditions/species-dist.html)

Figure 14: A-Fall, B-Spring

Species distribution

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 the depth of occurrence. 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. Depth ranges from 0 to 260, which relates to depth of occurrence in meters. The mean along shelf distance for several NEFMC species by year is shown below; most show a northeastward change along the shelf, aside from herring. However, herring has a long term deeper distribution trend. Cod has a long term shift towards deeper distribution, but a more recent return to shallower distributions (along with winter flounder and haddock). 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: Yellowtail flounder, B: Winter flounder, C: Cod, D: Haddock, E: Atlantic herring, F: Acadian redfish

Spatial distribution has changed over time for some species more than for others. Lobster, yellowtail flounder, and haddock distributions measured by NEFSC surveys have shifted northward relative to historical distributions. However, Acadian redfish distributions in the Gulf of Maine have remained relatively stable. A full suite of these maps is available at http://www.nefsc.noaa.gov/ecosys/current-conditions/kernel-density.html.
Figure 16: Shifts in species distribution, 1970s (blue), recent (red) and overlap (purple)

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 yellowtail flounder remain thin for their
length on average.

**Figure 17: Fish Condition (weight/length anomaly)**

**Groundfish productivity**

The amount of small fish relative to larger fish of the same species from the NEFSC survey 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 18: Fish productivity: Anomalies of recruit abundance per spawner biomass for species in the Gulf of Maine (GOM) and Georges Bank (GB), 1980-2015. Annual anomalies shown (small fish numbers per large fish biomass anomaly, y axis) 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 attributable to survey methods and/or 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.
Seabirds

Seabird breeding colonies in the Gulf of Maine are monitored and managed to promote recovery of formerly harvested species. Common and Arctic terns both breed on islands throughout the Gulf of Maine, feeding on a wide range of invertebrates and fish including Atlantic herring, juvenile hakes, and sand lance. Data compiled from the Gulf of Maine Seabird Working group show mixed trends for seabirds with high variability at particular colonies. However, common terns have a long term increasing trend across 13 Gulf of Maine colonies, while Arctic terns have decreased in the same region during the past decade.

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 21: 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 22: Primary production, Gulf of Maine (left) and Georges Bank (right)
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 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.

Seasonal trends in major species

Zooplankton represent intermediate levels of the Gulf of Maine and Georges Bank food webs, which have undergone shifts in recent decades. 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 for spring (combined February, March and April samples) and fall (September, October, November) suggest that overall secondary production has not changed in the spring but has declined in the fall. This decline can be attributed to the decline in key zooplankton species, in particular *Pseudocalanus* spp., which has declined during fall in both the Gulf of Maine and Georges Bank, in contrast to an absence on long-term trend in the spring for both ecoregions. Similarly, the zooplankton *Calanus finmarchicus* shows no spring trends, but a long-term decline in the fall on Georges Bank as well as a short term decline in both regions over the past decade. Adult *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 23: A: *Pseudocalanus* spring, B: *Pseudocalanus* fall, C: *Calanus finmarchicus* spring, D: *Calanus finmarchicus* fall

Aggregate zooplankton trends

One simple indicator of overall zooplankton biomass is the volume of material collected in plankton nets, which has been relatively consistent, suggesting large scale coherence in zooplankton throughout much of NES. While the anomalies show no significant long or short term trends, the composition of the zooplankton community shows shifts over time. Specifically, small copepods increased in abundance in
the 1990s, but shifted to larger bodied copepod species around 2000. There is evidence of a more recent shift, with both smaller zooplankton and *Calanus finmarchicus* becoming more abundant again over the last several years. The small copepods are most important during the autumn while *Calanus finmarchicus* dominates early in the year following the spring phytoplankton bloom.

![Graph](image1)

**Figure 24:** A: Calanus, B: zooplankton biomass, C: small copepods

### Physical Environment

**Annual sea surface temperature cycle**

The Gulf of Maine and Georges Bank ecoregions experienced above average sea surface temperatures (SSTs) during 2016. In each 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 were moderate on Georges Bank at temperature levels often matching the mean. Both ecoregions warmed dramatically from late summer into fall. The Gulf of Maine ecoregion remained at above average temperature through the end of the year, whereas Gorges Bank saw temperatures moderate at the end of December.

![Graph](image2)

**Figure 25:** Annual sea surface temperature cycle for Gulf of Maine (A) and Georges Bank (B) in 2016. Center line is the longterm mean. Dark red color indicates temperature was above 1 standard deviation of the mean while light red indicates the temperature was above the mean. The grey shaded area is plus or minus 1 standard deviation.
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.

![Graph showing long-term sea surface temperature trends](image)

Figure 26: 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 Gulf of Maine and Georges Bank suggest no trend over time, whereas the October temperatures steadily increased over the past half century in both regions.

![Graph showing interpolated survey bottom temperature trends](image)

Figure 27: 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 km² 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 greater model agreement in the forecasts for the Gulf of Maine versus the Gorges Bank forecast, both suggesting that sea surface temperature will remain approximately 1.2°C above average conditions. Skill of these forecasts for our specific region requires further evaluation.

Stratification and Salinity

Stratification shows a decreasing trend for the last decade in the Gulf of Maine, but a long term increasing trend on Georges Bank. Changing stratification can potentially affect system productivity by altering the nutrient supply to the primary producers in the surface layer.

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. Salinity shows no significant trends over time in the Gulf of Maine or on Georges Bank.

Figure 28: Stratification

Figure 29: 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.

![Gulf Stream Index Graph](image)

Figure 30: 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 Gulf of Maine and Georges Bank, system variability has increased as evidenced by the increase in the annual standard deviation of sea surface temperature, going from approximately 4.0 to 5.0 over the time period, indicating organisms have experienced greater day to day temperature excursions.
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.

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 circulation 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

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/

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