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# Relevance of the Northeast Integrated Ecosystem Assessment for Stellwagen Bank NMS Condition Report (2007-2017)



PREPARED BY NOAA NCCOS MARINE SPATIAL ECOLOGY DIVISION  
BIOGEOGRAPHY BRANCH

# Relevance of the Northeast Integrated Ecosystem Assessment for Stellwagen Bank NMS Condition Report (2007-2017)

NCCOS Marine Spatial Ecology Division Biogeography Branch

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## 1. Background

NOAA is conducting a multi-Line Office data synthesis initiative (FY16-18) called the Integrated Ecosystem Assessment Program (IEA) for the Northeast U.S. Continental Shelf (Cape Hatteras to the northern Gulf of Maine). The Program has assembled an extensive body of physical, ecological, and social-economic indicators and a wide range of ecosystem models for this region with the purpose of enabling regional ecosystem-based management (EBM). The IEA process is an iterative and flexible stepwise approach involving the following steps: defining ecosystem goals, assessing the status of ecosystem indicators and attributes, analysing risk, and evaluating the likely outcomes and trade-offs among alternative management strategies (Fig. 1). As such, the IEA framework was designed to provide a more holistic approach to assimilate scientific knowledge in a format suitable for providing advice to inform marine EBM (Harvey et al. 2017). One of the key strengths of the IEA process in practice is its role in assimilating, standardizing, and maximizing the value of the vast amount of available information about a marine ecosystem (Levin et al. 2009).

The data analysed through the Northeast IEA process are of interest to the Stellwagen Bank National Marine Sanctuary (SBNMS) because the Sanctuary is located within the Gulf of Maine subregion of the NE IEA focus area (Fig. 2). It is becoming increasingly clear that strong linkages exist between water conditions, nutrient cycling and biological population dynamics across the Gulf of Maine region suggesting that the entire Gulf varies as a cohesive interconnected ecological unit within which Stellwagen Bank National Marine Sanctuary is a significant management area. The Sanctuary recognize the strategic importance of assessing the conditions and trends within Sanctuary waters relative to the conditions and trends observed at broader geographical scales i.e. the surrounding Gulf of Maine region. This information need was specifically recognized (Goal 1; Objective 5) in the Northeast IEA proposal with the aim of providing IEA data and products to support development of quantitative metrics for the SBNMS Condition Report. The Condition Report poses questions related primarily to water quality, habitat quality and living resources, followed by identification of human activities that influence condition (Table 1).

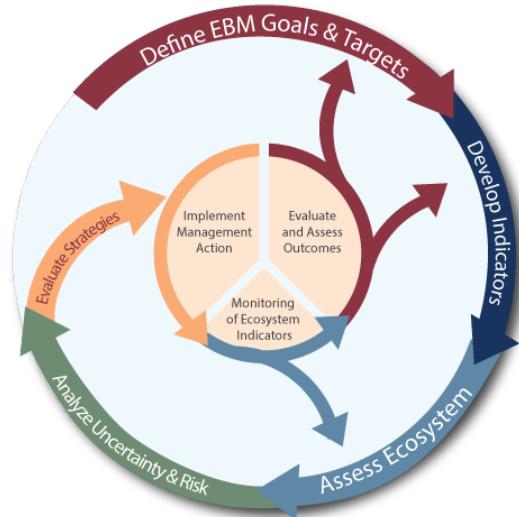


Figure 1. Conceptual model for the IEA process.

In April 2017, NOAA NMFS Northeast Fisheries Science Center released a data synthesis emerging from the NE IEA process in the report ‘State of the Ecosystem- Gulf of Maine and Georges Bank. The purpose of the report was to provide ecosystem-scale information for fishery managers through tracking of trends and reporting of interconnections in a diverse set of indicators.

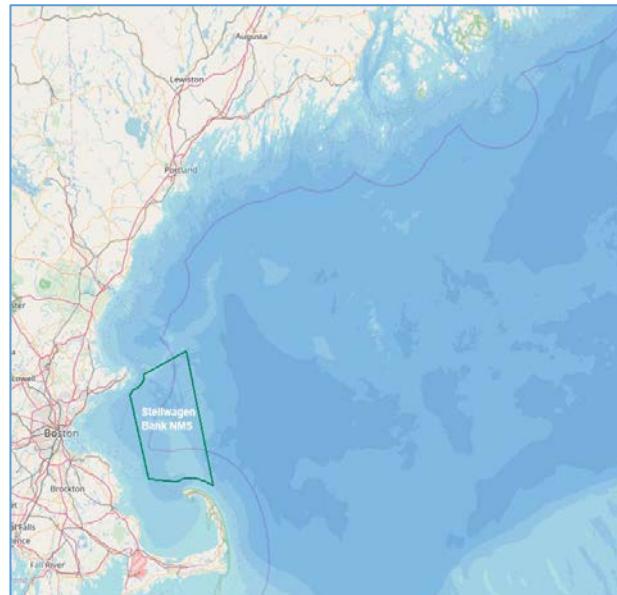
On August 10<sup>th</sup> 2017, scientists from NOAA NCCOS Biogeography Branch and NOAA Office of National Marine Sanctuaries met to discuss the data needs for the next SBNMS Condition Report. The following tasks emerged from the discussion:

#### **Tasks of the initial report:**

- Task 1:** Identify and document IEA data relevant to each question of the Condition Report focusing primarily on changes to water quality, habitat and living resources since the last Condition Report (2006)
- Task 2:** Identify any regional trends in biophysical conditions detected, or forecast
- Task 3:** Identify and document any relevant knowledge gaps and potential caveats in the IEA data

#### **Acknowledgements:**

The majority of the information summarized in this report was gained from the ‘State of the Ecosystem - Gulf of Maine and Georges Bank’ report produced by the Ecosystem Dynamics and Assessment Branch, NOAA Northeast Fisheries Science Center (April 06, 2017). The State of the Ecosystem report was 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. Funding and intellectual support from the NOAA NMFS Integrated Ecosystem Assessment Program was essential to the production of this report. We thank Sean Lucey (NOAA NEFSC) for guidance on additional data sources as well as the MDAT project team. Where IEA data did not provide sufficient information to address Condition Report questions then other NOAA NMFS and NCCOS reports were reviewed together with summaries provided by the State of the Gulf of Maine report. The [Northeast Ocean Data](#) portal was also a source of regional information.



**Figure 2.** The location of Stellwagen Bank National Marine Sanctuary within the Gulf of Maine sub-region of the Northeast Integrated Ecosystem Assessment focus area.

**Table 1. Questions addressed by the Condition Report.** In placing the Sanctuary within a broader regional context this report replaces the word sanctuary with *regional* in the following questions. NB: Maritime archaeological resources were not adequately addressed by IEA data.

Section	2017 Question
Water Quality	<p>Q1 – What is the eutrophic condition of <i>regional</i> waters and how is it changing?</p> <p>Q2 - Do <i>regional</i> waters pose risks to human health and how are they changing?</p> <p>Q3 - Have recent changes in climate altered water conditions and how are they changing?</p> <p>Q4 - Are other stressors, individually or in combination, affecting water quality, and how are they changing?</p> <p>Q13 - What are the levels of human activities that may adversely influence water quality and how are they changing?</p>
Habitat Quality	<p>Q5 - What is the integrity of major habitat types and how is it changing?</p> <p>Q6 - What are contaminant concentrations in <i>regional</i> habitats and how are they changing?</p> <p>Q14 - What are the levels of human activities that may adversely influence habitats and how are they changing?</p>
Living Resources	<p>Q7 – What is the status of keystone and foundation species and how is it changing?</p> <p>Q8 – What is the status of other focal species and how is it changing?</p> <p>Q9 – What is the status of non-indigenous species and how is it changing?</p> <p>Q10 - What is the status of biodiversity and how is it changing?</p> <p>Q15 - What are the levels of human activities that may adversely influence living resource quality and how are they changing?</p>
Maritime Archaeological Resources	<p>Q11 – What is the archaeological integrity of known maritime archaeological resources and how is it changing?</p> <p>Q12 - Do known maritime archaeological resources pose an environmental hazard and how is this threat changing?</p> <p>Q16 - What are the levels of human activities that may adversely influence maritime archaeological resource quality and how are they changing?</p>
Human Dimensions	<p>(other Human Dimensions questions integrated into relevant topical section...)</p> <p>Q17 - What are the states of influential human drivers and how are they changing?</p>

## Water quality

### Q1 - What is the eutrophic condition of *regional* waters and how is it changing?

Eutrophication is an ecosystem response to increases in nutrient inputs such as nitrogen and phosphorus typically from human sources. Nearshore coastal waters of the Gulf of Maine receive nutrients from land-based sources, aquaculture, atmospheric deposition and oceanic upwelling and circulation. Nutrients influence the growth of benthic plants, phytoplankton, other bloom forming organisms such as dinoflagellates and bacteria with consequences through the food chain. Upwelled waters mix with Scotian Shelf waters and with runoff and riverine plumes to form the Maine Coastal Current, which make the region highly productive (GOMC 2010). Fluxes of offshore water masses and their nutrient loads are the major source of nutrients for phytoplankton production in the region, including annual blooms of the toxic dinoflagellate *Alexandrium fundyense*. Since the 1970s, the Gulf of Maine has been experiencing a changing nutrient regime thought to be influenced by increasing colder and fresher water from the Arctic with lower nitrate ( $\text{NO}_3$ ) but higher silicate ( $\text{Si(OH)}_4$ ) concentrations (Townsend et al. 2010) affecting the magnitude of blooms (Townsend et al. 2014). Therefore, through water circulation and nutrient recycling the conditions at the scale of the Gulf of Maine will influence the water nutrient and productivity patterns observed within the Stellwagen Bank NMS.

Using methods described by Hak & Comer (2017) coastal landscape condition was evaluated and mapped by NatureServe for the Gulf of Maine revealing an area of relatively low condition index value for coastal watersheds in the southwest Gulf of Maine. The index reflects the extensive level of human-altered landscape and source of pollution in the terrestrial coastal areas closest to Stellwagen Bank NMS. In 2012, the State of the Gulf of Maine report (Chapter on Eutrophication), however, water quality sampling conducted in nearshore waters indicated that the southern Gulf of Maine waters (using National Coastal Assessment methods) are classified as good-fair quality for Dissolved Inorganic Nitrogen (DIN), Dissolved Inorganic Phosphorous (DIP) and Chlorophyll *a* concentrations. When frequency of occurrence and spatial coverage are also integrated with concentration as an indicator of eutrophication then Casco Bay, Maine, Plum Island Sound, Massachusetts, Massachusetts Bay and Cape Cod Bay are considered to have a high level of chlorophyll *a* that has increased since 1999. Cape Cod Bay has also experience an increase in macroalgae since 1999 (GOMC 2012). In Great Bay, macroalgae have replaced 6% of seagrass meadows between 1996 and 2007 specifically in areas of high nitrogen concentrations (NHDES 2009). The summary of combined information from the NOAA and EPA assessments for hypoxic conditions between 2000 and 2006 show no to low occurrence of low dissolved oxygen in the bays and estuaries of the southwest Gulf of Maine.

## **Q2 - Do regional waters pose risks to human health and how are they changing?**

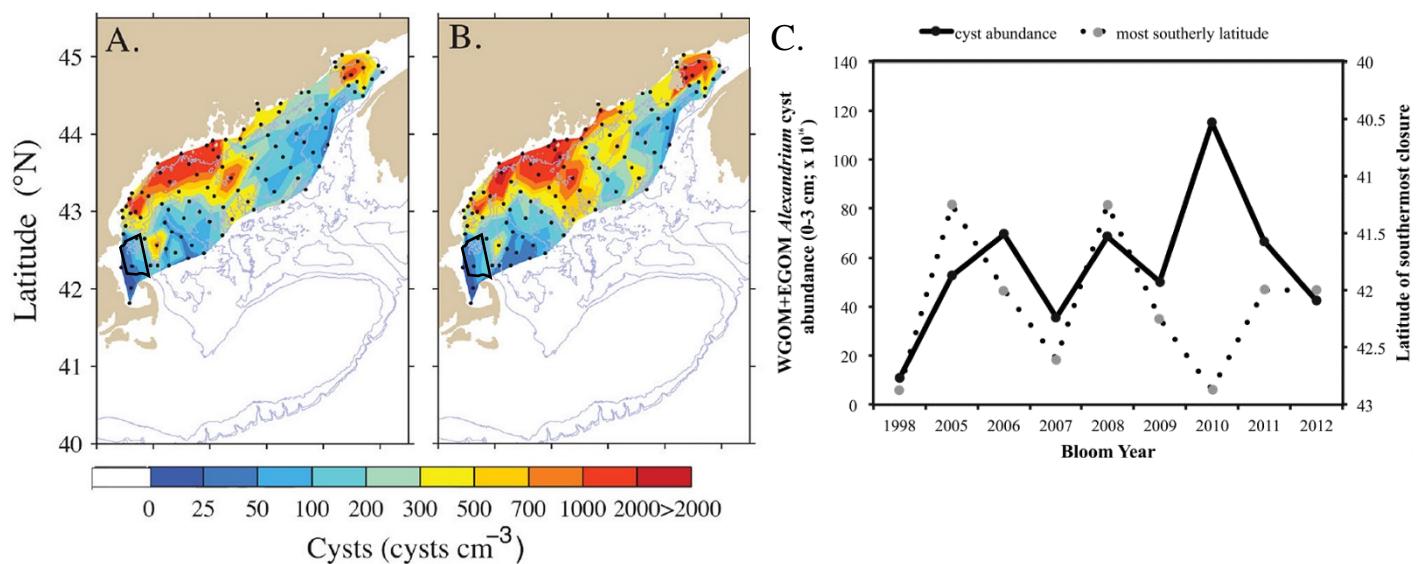
### ***Harmful algal blooms***

Several harmful algal bloom (HAB) species occurring within the Gulf of Maine system are known to produce neurotoxins that have the potential to threaten human and ecosystem health (Li et al. 2011). Much progress has been made in forecasting and monitoring harmful algal blooms (HABs) in the Gulf of Maine. Annual forecasts (weekly in spring & summer) are issued based on the distribution of cysts of nuisance toxic dinoflagellate species, *Alexandrium fundyense*, a primary cause of paralytic shellfish poisoning (PSP) in the Gulf of Maine (Thomas et al. 2010). In 2008, the first seasonal forecast for PSP in the Gulf of Maine was issued and correctly predicted a large toxic bloom resulting in closures for shellfish harvesting in the western Gulf of Maine as far south as Cape Cod. Compiled maps of historical shellfish harvesting closures and duration of closures are also a valuable source of data to understand the spatial and temporal trends in toxic bloom events (Kleindinst et al. 2014).

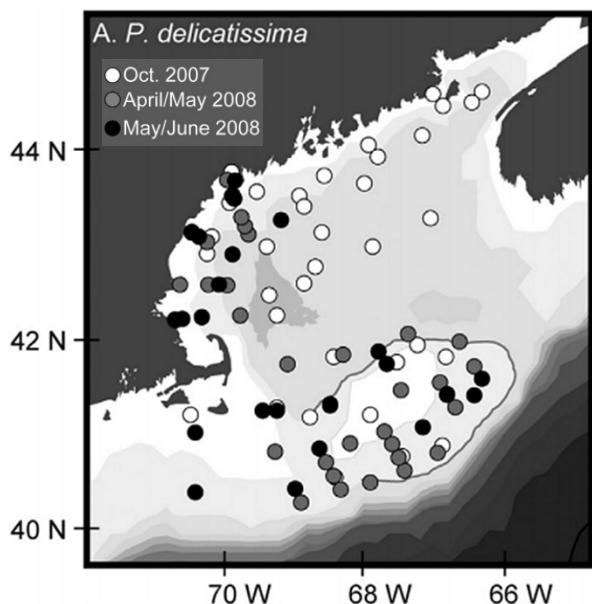
Between 1978 and 2011, records for the entire Gulf of Maine indicate a combined total of closure days amounting to over 13 years duration. Closure records for the Western Gulf of Maine during the five years prior (2001-2005) to the publication of the Stellwagen Bank NMS Condition Report (2006) an estimated 872 km of coastline was closed to shellfish harvesting and a total summed closure duration of 585 days, compared with the following five years (2007-2011) with an estimated 1260 km of coastline closed and a total duration of 493 days (Kleindinst et al. 2014).

Surveys of *A. fundyense* cysts in surface sediments ('seedbeds') reveal that a major expansion of the mid-coast Maine seedbed occurred in 2009 following an intense red tide bloom (Anderson et al. 2014) that impacted the southwestern Gulf of Maine as far south as Stellwagen Bank NMS (Figure 3A&B). Changes in regional-scale water conditions, however, suppressed the magnitude of the bloom in 2010 (Figure 3C) as near-surface waters were warmer, fresher, and more stratified with lower nutrients than expected and a weaker-than-normal coastal current lessened *A. fundyense* transport into the western Gulf of Maine and Massachusetts Bay (McGillicuddy et al. 2011). This highlights the importance of considering changes to Gulf of Maine wide oceanographic processes in understanding the conditions within the Stellwagen Bank NMS.

Blooms of the toxic marine diatom *Pseudo-nitzschia* spp. have also increased in the Gulf of Maine including in the region of Stellwagen Bank and Cape Cod (Figure 4). More than 14 *Pseudo-nitzschia* species have been identified in the Gulf of Maine of which seven are known to produce the neurotoxin domoic acid (DA) which accumulates in filter-feeding bivalves and fish and can cause amnesic shellfish poisoning (ASP) in humans or domoic acid poisoning (DAP) in marine mammals, seabirds and some fish (Fernandes et al. 2014).



**Figure 3.** Multi-year (2004–2011) mean cyst abundance (*A. fundyense*) in: (A) surface (0–1 cm) sediment layer, and (B) 1–3 cm sediment layer. (C) Time-series of cyst abundance (cysts  $\times 10^{16}$ ) in the western Gulf of Maine (WGOM) and the latitude of southernmost closure the following year (note axis reversal). Source: Anderson et al. (2014).



**Figure 4.** Samples collected (2007–2008) with presence of toxic diatom *Pseudo-nitzschia delicatissima*. Source: Fernandes et al. (2014).

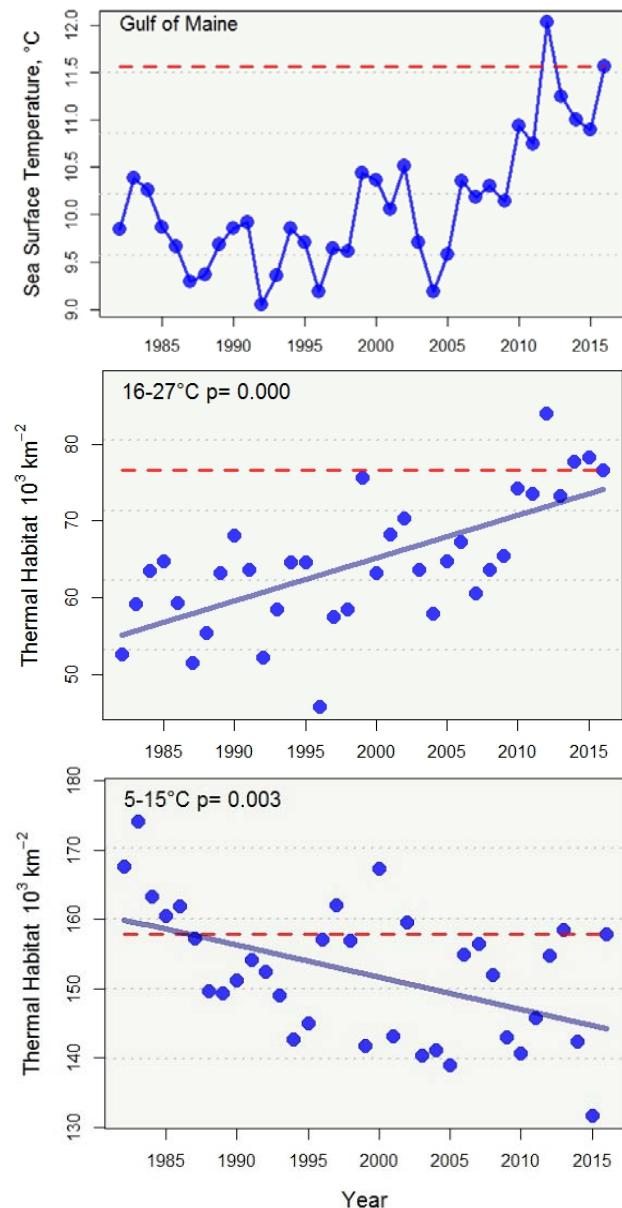
### **Q3 - Have recent changes in climate altered water conditions and how are they changing?**

#### **Water temperature**

The 2017 summary of conditions for the Northeast Continental Shelf provided by NOAA's Northeast Fisheries Science Center (NMFS NEFSC) concludes that sea surface temperatures (SSTs) continue to be above average with 2016 being the second warmest year on record after 2012 (Fig 5a). A trend of increasing area of warm ( $16\text{-}27^{\circ}\text{C}$ ) water habitat in recent years has been estimated and decreasing area of cool ( $5\text{-}15^{\circ}\text{C}$ ) water has occurred since 1980 (Fig 5b & c). A 33-year (1982-2014) time series of sea surface temperature data indicates an increase trend of warming ( $>0.4^{\circ}\text{C decade}^{-1}$ ) waters in the Gulf of Maine (Nye et al. 2017).

Temperature strongly influences both the physical conditions in the region (driving ocean circulation) and biological distributions through the influence of temperature on biological rates. In response to warming, many fish and invertebrate species have moved to cooler northern waters and cooler deeper waters (see Living Resources). High-resolution climate models predict further substantial changes to the distribution of suitable thermal habitat for many marine species.

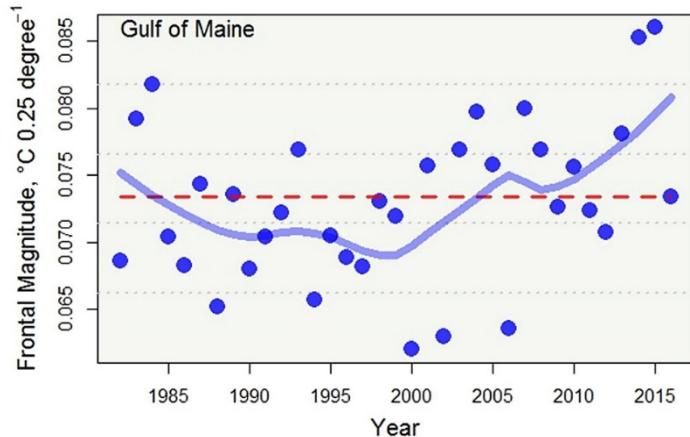
At broader temporal scales, the effect of NAO on surface waters appear to exhibit a four-year time lag, whereas a two-year time lag has been observed for deeper waters entering the Gulf of Maine (Xu et al. 2015). Furthermore, although decadal fluctuations are well-documented, the late 1980s experienced an abrupt warming resulting in the reported climate regime shift (Lo & Hsu 2010)



**Figure 5.** (a) Thermal change in the waters of the Gulf of Maine region (1980 – 2016); (b) increase in area of warm waters; (c) decrease in area of cool waters. Source: [Ecosystems Dynamics & Assessment](#), NOAA NMFS NEFSC.

representing a major change in the Earth's biophysical systems from the upper atmosphere to the depths of the ocean (Reid et al. 2016).

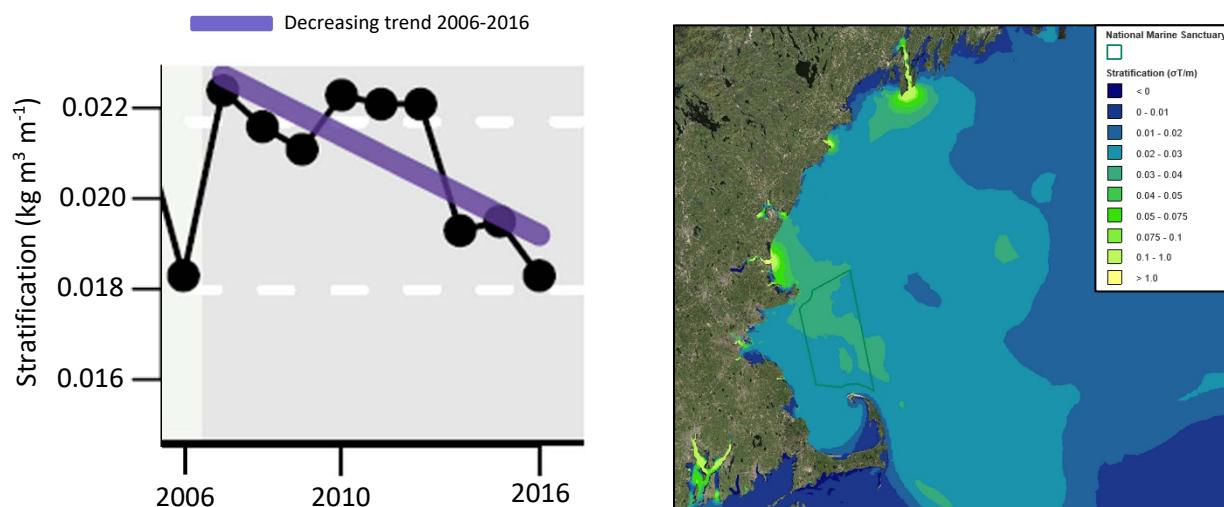
The strength of temperature fronts has increased in the Gulf of Maine since 2009 (Figure 6).



**Figure 6.** Frontal magnitude in the Gulf of Maine. Blue line is a smoothed time series fitted trend. Red dashed line indicates the 2016 data. Source: [Ecosystems Dynamics & Assessment](#), NOAA NMFS NEFSC.

### Stratification

Stratification refers to the vertical stacking of layers of water having different densities at different depths within the water column. Variations in the timing and magnitude of stratification play a role in driving changes in the seasonal cycles of nutrients, plankton, and higher-trophic-level consumers (Greene et al. 2012). Hydrographic measurements made by NOAA NMFS NEFSC represent the most comprehensive ongoing, shelf-wide record of hydrographic measurements on the Northeast U.S. continental shelf.



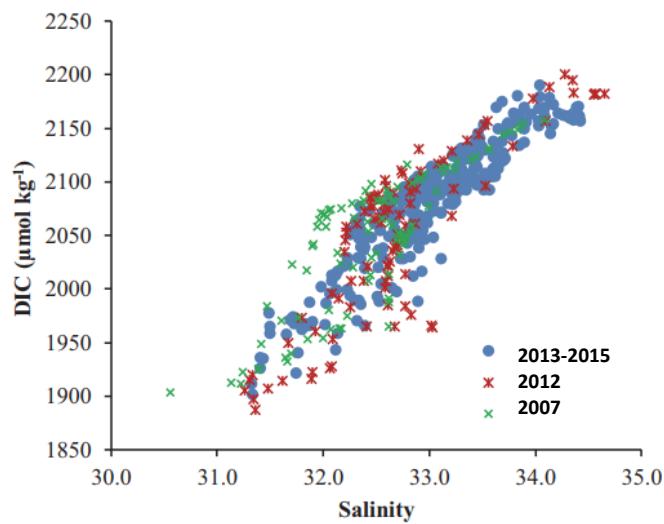
**Figure 7.** (a) Annual mean density stratification in the Gulf of Maine from 2006 to 2016 calculated between the surface and 50 meters depth. Source: (b) Modelled long-term (1978-2013) annual mean stratification calculated between the surface and 20 meters and divided by the difference in depth between the two observations. Source: Northeast Ocean Data portal.

These measurements show that stratification of the water column in the Gulf of Maine has fluctuated around the long-term mean since the late 1980s with no significant trend until 2007 after which stratification weakened significantly (2007-2015) (Figure 7). This may be caused by warming and decreased influence of freshwater (Li et al. 2017). Decreased stratification can potentially affect system productivity by increasing the nutrient supply from bottom waters to the phytoplankton in the surface layers that can result in extensive blooms. Stratification has been identified as a driver of zooplankton community composition and is linked to ecosystem regime shifts in the Gulf of Maine (Morse et al. 2017).

### **Ocean acidification**

Chemical changes in seawater as a result of the uptake of CO<sub>2</sub> include increasing concentrations of dissolved inorganic carbon (DIC), the production of carbonic acid (lowering of pH), an increase in the partial pressure of seawater CO<sub>2,sw</sub> (pCO<sub>2,sw</sub>), and a decrease in the availability of carbonate ion (Gledhill et al. 2015). Nutrients from land-based sources also affect the local carbonate chemistry. The Gulf of Maine is especially vulnerable to ocean acidification due to naturally low pH and aragonite saturation states ( $\Omega_{AR}$ ). Aragonite saturation state in the US Northeast coastal waters on average is close to a border line value of 1, below which seawater chemical conditions would favor dissolution of aragonite shell (Wang et al. 2017).

In laboratory experiments, negative impacts of declining pH and aragonite saturation ( $\Omega_{AR}$ ) have been demonstrated for American lobster, soft shell clam, hard clam and Eastern oyster, Bay scallop, longfin squid and summer flounder (reviewed by Gledhill et al. 2015) and predicted to impact food webs and ecosystem structure (Fay et al. 2017). The pCO<sub>2</sub> and aragonite concentrations show decadal cycles, however, the natural variability of the carbonate system in the Gulf of Maine has not yet been adequately characterized to understand the drivers of the temporal trends. Comparison of the change in dissolved inorganic carbon (DIC) and total alkalinity between samples from the southern Gulf of Maine in summer of 2007, 2012 and 2014/2015 revealed higher DIC, but with a strong linear relationship with salinity and highly variable with depth (Wang et al. 2017) (Figure 8). Between 2013 and 2015, annual mean  $\Omega_{AR}$  was 1.86 in water less than 60 m; 1.43 between 60-160 m and 1.34 in water deeper than 160 m over Wilkinson Basin and it has been predicted that mean  $\Omega_{AR}$  of the subsurface and bottom water in Wilkinson Basin will approach under-saturation in 30–40 years (Wang et al. 2017).



**Figure 8.** Comparison of DIC and salinity measurements from 2013-15 and the GOMECC 1 (2007) and GOMECC 2 (2012) studies. GOMECC data include all stations in the Gulf of Maine. Source: Wang et al. (2017).

**Q4 - Are other stressors, individually or in combination, affecting water quality, and how are they changing?**

*See section on contaminants Q6*

**Q13 - What are the levels of human activities that may adversely influence water quality and how are they changing?**

*See section on contaminants Q6*

## **Habitat quality**

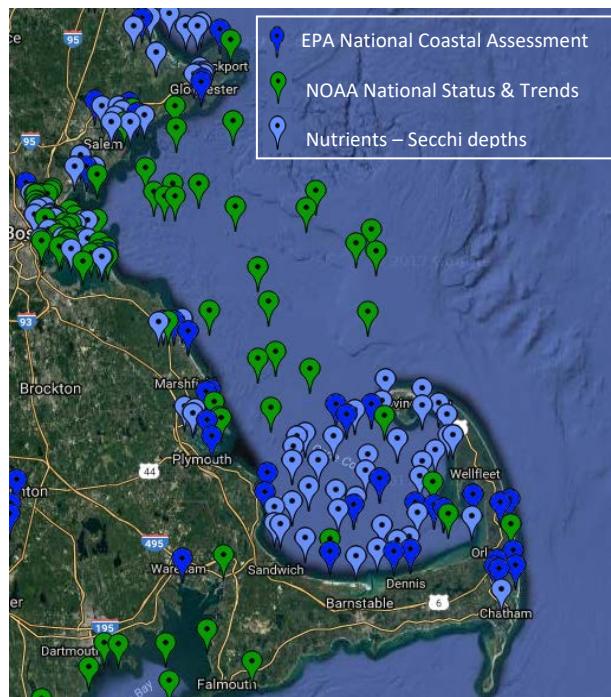
**Q5 - What is the integrity of major habitat types and how is it changing?**

Water masses with distinct physical and biological characteristics form pelagic habitat types for many marine species. On the seafloor, substrate types and the complexity of the ocean floor determine the major benthic habitat types. Changes to the water mass that impact the integrity of pelagic habitat types are mentioned in Water Quality Q3 and Living Resources Q7. Impacts to the structural integrity of the seafloor are largely attributed to mobile fishing gear, especially bottom trawling and dredging which can have a direct negative impact to biogenic structure (e.g., sponges, hydrozoans, bryozoans, amphipod tubes, holothurians, shell aggregates) (Auster et al. 1996, Jennings & Kaiser 1998) and the species which depend on those benthic communities. Changes are occurring in the distribution of coastal vegetated habitat types with documented losses and fragmentation reported. In 2010, the State of the Gulf of Maine Report (Coastal Ecosystems and Habitats) classified the status and trends for the extent and distribution of salt marsh and seagrass in the Gulf of Maine as poor condition due to human impacts. There is currently insufficient data available within the IEA data to determine trends in habitat condition for benthic habitat types.

**Q6 - What are contaminant concentrations in sanctuary habitats and how are they changing?**

IEA data does not at this point have any synthesis products for contaminants. Information on contaminants can be found in the State of the Gulf of Maine Report ([Microbial Pathogens and Biotoxins](#) September 2011) and the chapter [Toxic Chemical Contaminants: Review](#) (2013) . The trends for harmful algal blooms, fecal-borne microbial pollution and pathogenic vibrios are all increasing in the Gulf of Maine. In 2011, a well-documented raw sewage discharge event occurred in the southern Gulf of Maine releasing 300,000 tonnes of untreated sewage. Gulfwatch sites using contaminants in the tissue of blue mussels (*Mytilus edulis*) indicate that Massachusetts state waters have a high level of dichlorodiphenyltrichloroethane (DDT), chlordanes (CHLs),

polychlorinated biphenyls (PCBs), dieldrin and lead (Pb) between 1993 and 2008. NOAAs [Mussel Watch Program](#) provides contaminant data for the Gulf of Maine from 1986 to 2012 (Figure 9).



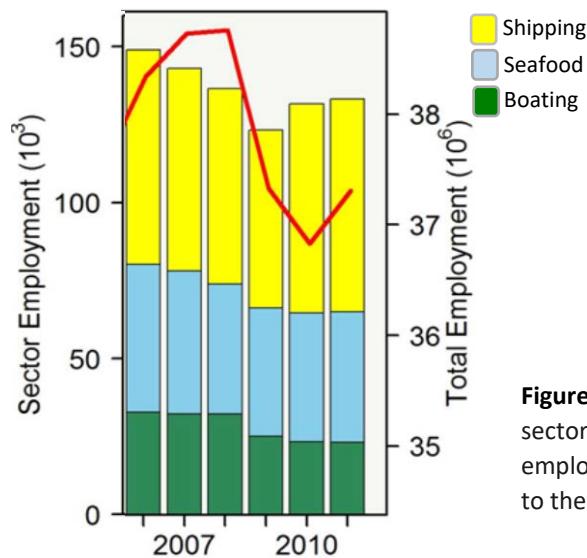
**Figure 9.** Water quality and contaminant sampling sites within the southwest Gulf of Maine region.

#### **Q14 - What are the levels of human activities that may adversely influence habitats and how are they changing?**

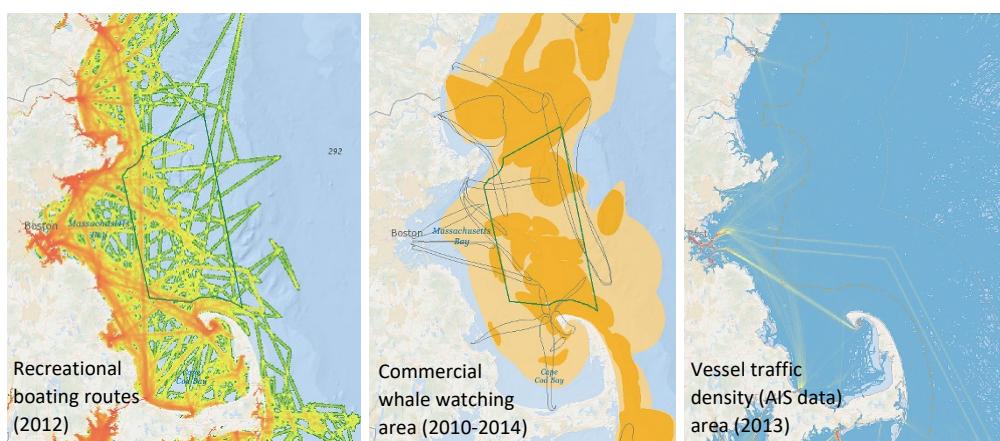
Clearly, commercial shipping, boating-based activities such as whale watching and fisheries provide an extremely important benefit to the region in terms of employment, revenues, and as a source of high quality food. Since the last Condition Report in 2006, employment in the three main marine sectors (shipping, seafood and boating) declined due to the economic recession but show an upturn in 2011 (Figure 10). Data on patterns of human activities at sea is available to support impact assessments linking changing human pressures and habitat condition (Figure 11). More recent data is required to examine the trends to 2017.

Incidental environmental impacts are associated with the provision of these important services. Fishing removes marine fauna intentionally through harvesting (and via bycatch) and bottom trawling and dredging fishing gear can have adverse effects on geological features and associated benthic faunal assemblages (Auster et al. 1996, Jennings & Kaiser 1998). From 2007 to 2011, relative to other regions of the Gulf, the southwest region experienced intermediate levels of scallop and clam dredging; low levels of otter trawling; low-intermediate levels of potting; and intermediate-high levels of gill and seine netting based on the spatial distribution of landings (NEFSC Ecosystem Assessment Program). The Swept Area Seabed Impact (SASI) method for

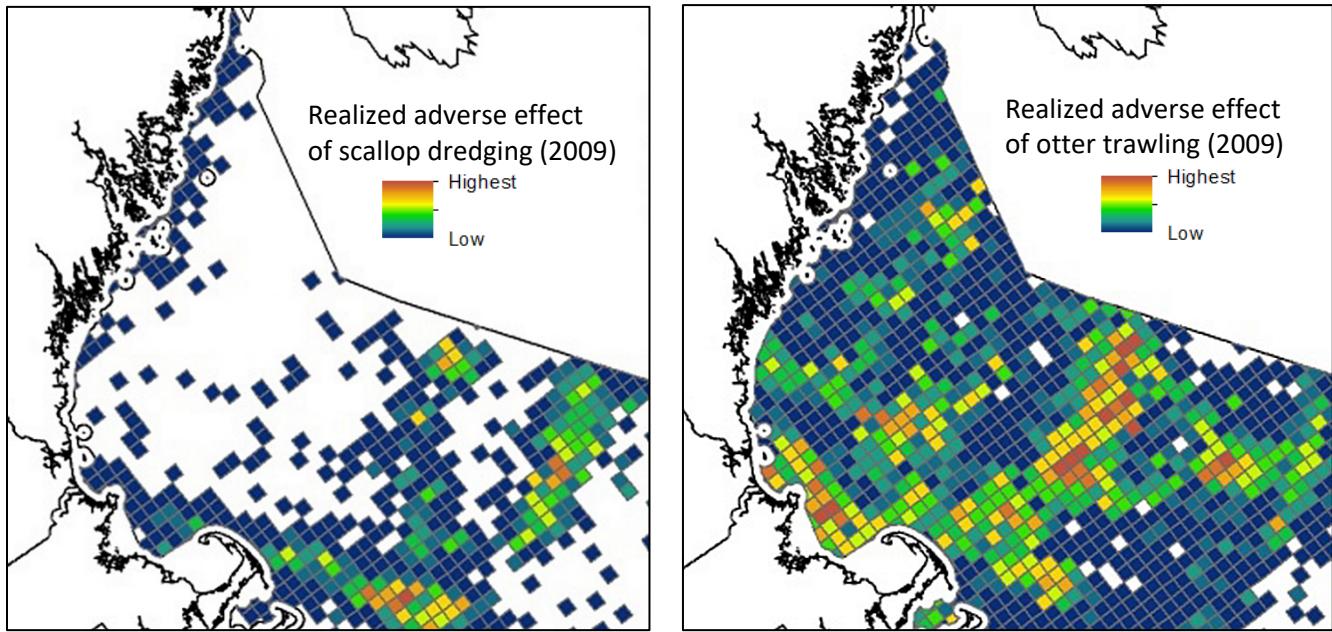
analysing the effects of fishing was applied by New England Fishery Management Council (NEFMC Habitat Plan Development team) using susceptibility and recovery scores assigned individually for each combination of habitat and gear type for both physical habitat and their associated benthic communities (Figure 12). The primary assumption of SASI is that area swept, when adjusted for gear contact with the seabed, is a proxy for seabed impact. Further, seabed impact as modified to account for the vulnerability of habitat features encountered is taken as a suitable proxy for the adverse effect of fishing on fish habitat.



**Figure 10.** Employment in boating, seafood, and shipping sectors of the economy (2006-2011). Red line indicates total employment in states abutting the NES LME, and corresponds to the right y-axis. Source: NMFS NEFSC.



**Figure 11.** Data on patterns of human activities at sea is available to support impact assessments linking changing human pressures and habitat condition.



**Figure 12.** Modelled realized adverse effects on seafloor structure and biological communities for scallop dredging and otter trawling in 2009. Source: NEFMC 2011

## Living resources

### Q7 – What is the status of keystone and foundation species and how is it changing?

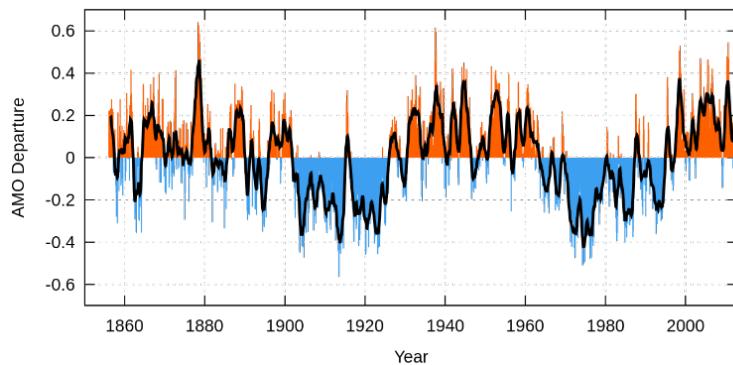
#### Fish

Distribution models developed by NEFSC (Kleisner et al. 2017) have projected a future loss in suitable thermal habitat for key northern species including Acadian redfish, American plaice, Atlantic cod, haddock, and thorny skate, but potential gains for some species including spiny dogfish and American lobster. Geographical ranges of 48 species recorded from trawls in 1970s (baseline) and again from 2013-2015 (recent) were mapped using kernel density estimation methods. Kernel density maps were used to spatially characterize distributions for a species based on the probability of a species being found at a location. Of the 48 species modeled, 24 species had shifted northeasterly into deeper water, 18 species shifted their distribution northeasterly into shallower water, and six species had moved along the shelf to the southwest, mostly into shallower water. The northward shift of fish species, as well as predicted negative and positive effects is now well-reported in the scientific literature (Nye et al. 2009, Lucey & Nye 2010, Hare et al. 2016).

Thirty-one of these species showed mapped distributions in the Stellwagen Bank NMS region (Table 2). Eleven species exhibited high overlap showing no clearly discernible change in

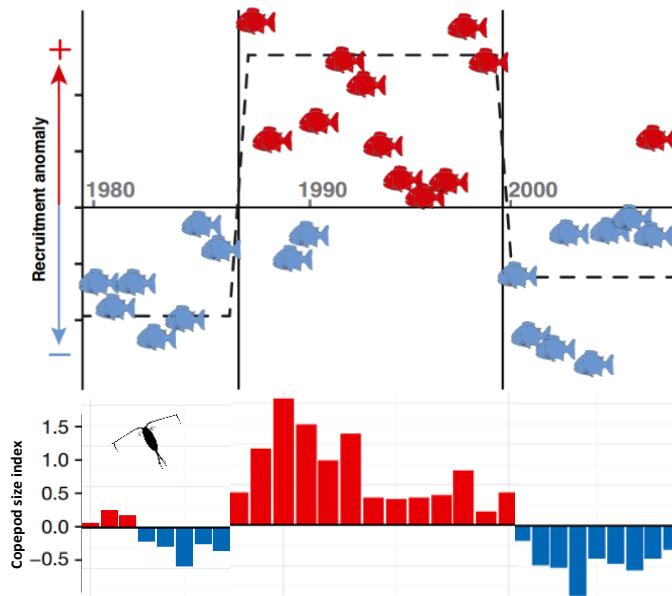
geographical range for the SBNMS; eight species showed range expansion (gains) in the SBNMS area in 2014/15 compared with the 1970s; twelve species showed a contraction in their geographical range in 2013–2015 compared with their distribution in the 1970s (Figures 13, 14 & 15).

Broader scale changes in the composition of communities and species interactions such as predator-prey relationships are expected with as-yet unknown socio-ecological consequences. Anticipation of these changes has important implications for industries and resource management linked directly or indirectly to fish distributions. Analyses of multi-decadal fish and zooplankton populations revealed a general pattern of approximate decadal rise and fall in species abundance (Pershing et al. 2005, Perretti et al. 2017). The high faunal productivity phase began in 1987 and returned to lower than average around 2000 (Figure 16). In the Gulf of Maine, the high copepod abundance phase began in 1991 and ended in 2001. It is likely that increased primary and secondary productivity in the planktonic and/or benthic food of fish drive the observed cyclical patterns in fish population dynamics. Research suggests that the productivity cycles and trophic cascades are linked to the dynamics of the North Atlantic Oscillation (NAO) whereby copepod abundance is higher in years with higher NAO index (Conversi et al. 2001, Greene et al. 2012). At broader time scales, the Atlantic Multi-decadal Oscillation (AMO) will also influence biological patterns through changes to temperature, salinity, and the effects on water stratification (Nye et al. 2014) (Figure 17).



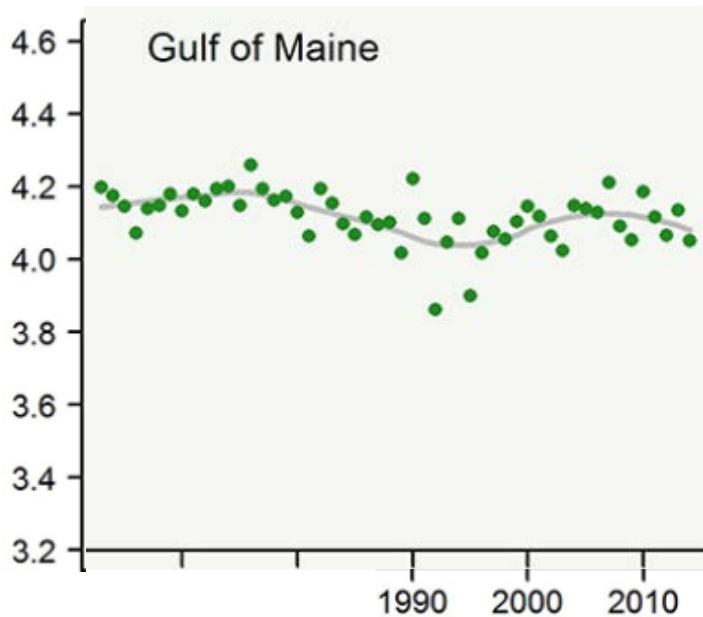
**Figure 17.** Atlantic Multi-decadal Oscillation (AMO) time series (1856–2013) with a 12-month moving average (black line). Source: NOAA, USGS

This broad spatio-temporal pattern is important context for assessments of condition for Stellwagen Bank NMS where reporting periods may fall somewhere in one decadal regime, or data may span parts of two different regimes. Analyses of trends in biological populations must therefore be interpreted within this broader temporal context of regime dynamics. In addition, determining the relative importance of fishing pressure and climate forcing in biological dynamics and the strength of interaction between the two ecosystem drivers is still under investigation for the Gulf of Maine, but is likely to be very significant for ecosystem functioning (Nye et al. 2013). For example, analyses led by NEFSC found that human pressures, especially high fishing pressure, in the Northeast Atlantic region were able to explain considerably more of the variation in ecological indicators of ecosystem health than environmental pressures (Large et al. 2015) suggesting that human activities have significantly altered the ecosystem structure and functioning of the Northeast U.S. shelf ecosystem.



**Figure 16.** (top) Fish recruitment success regimes on the Northeast US Continental Shelf (1980 to 2008). (bottom) Average annual anomaly in the copepod size index (small copepod anomaly – large copepod anomaly). Source: Perretti et al. 2017).

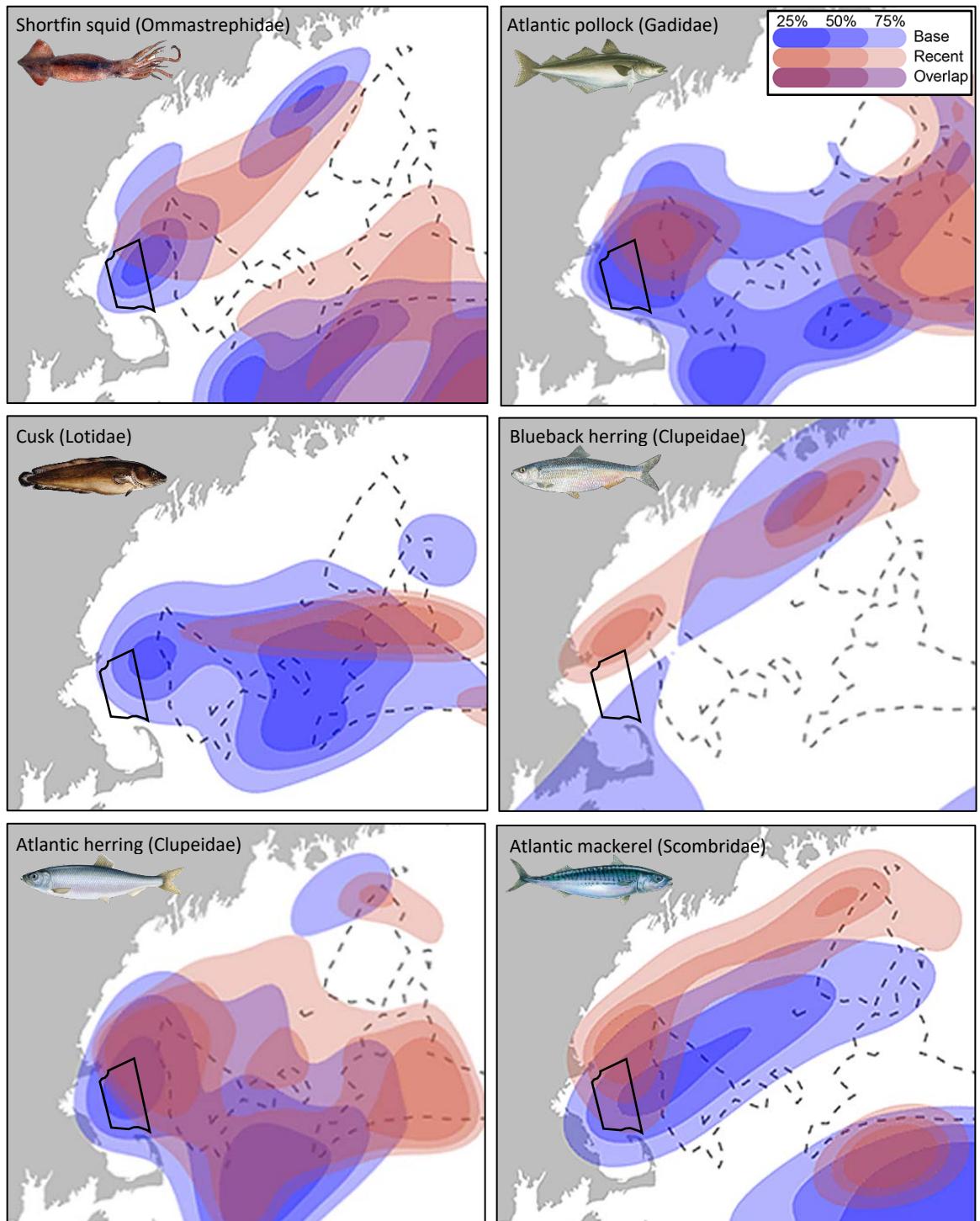
Another potential ecological indicator is the trophic level of a species. The trophic level (TL) of a species is a measure of its relative position in the food web and is an important aspect of understanding not only the implied size of species in an ecosystem, but also the transfer of energy in the system. Based on its diet we can determine the trophic level of a species from examining its diet. The mean trophic level is an indicator of how much energy is transferred to species feeding higher up in the food web and is a component of ecological integrity that can be disrupted by fishing activity or other disturbances. Mean trophic level for all fish from the bottom trawl surveys has remained relatively stable in the Gulf of Maine between 2006 and 2014 (Figure 17).



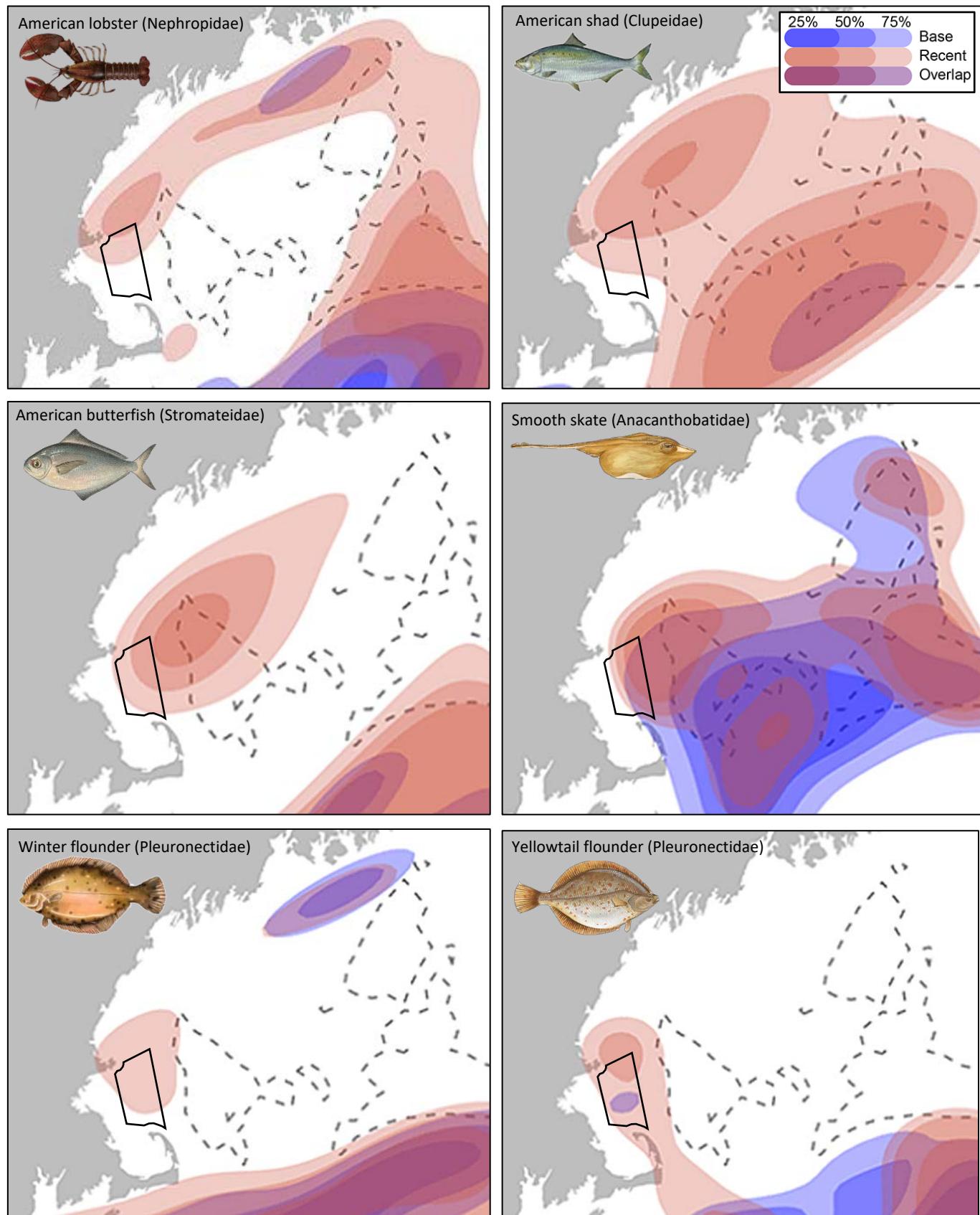
**Figure 17.** Mean trophic level of all finfish species caught in fall bottom trawl surveys. Source: NEFSC.

**Figures 13-15.** Kernel density plots. Three levels of probability contours were mapped (25%, 50% and 75%) for species distributions recorded in the 1970s trawl data (blue shading=base) and for the 2013-2015 data (orange=recent) whereby the 25% kernel defines the core area of the distribution and the 75% defines the broader outlying extent of the distribution. Overlap between the 1970s and recent years is colored with purple. Spatial uncertainty in models were not reported at the source. <https://www.nefsc.noaa.gov/ecosys/current-conditions/kernel-density.html>

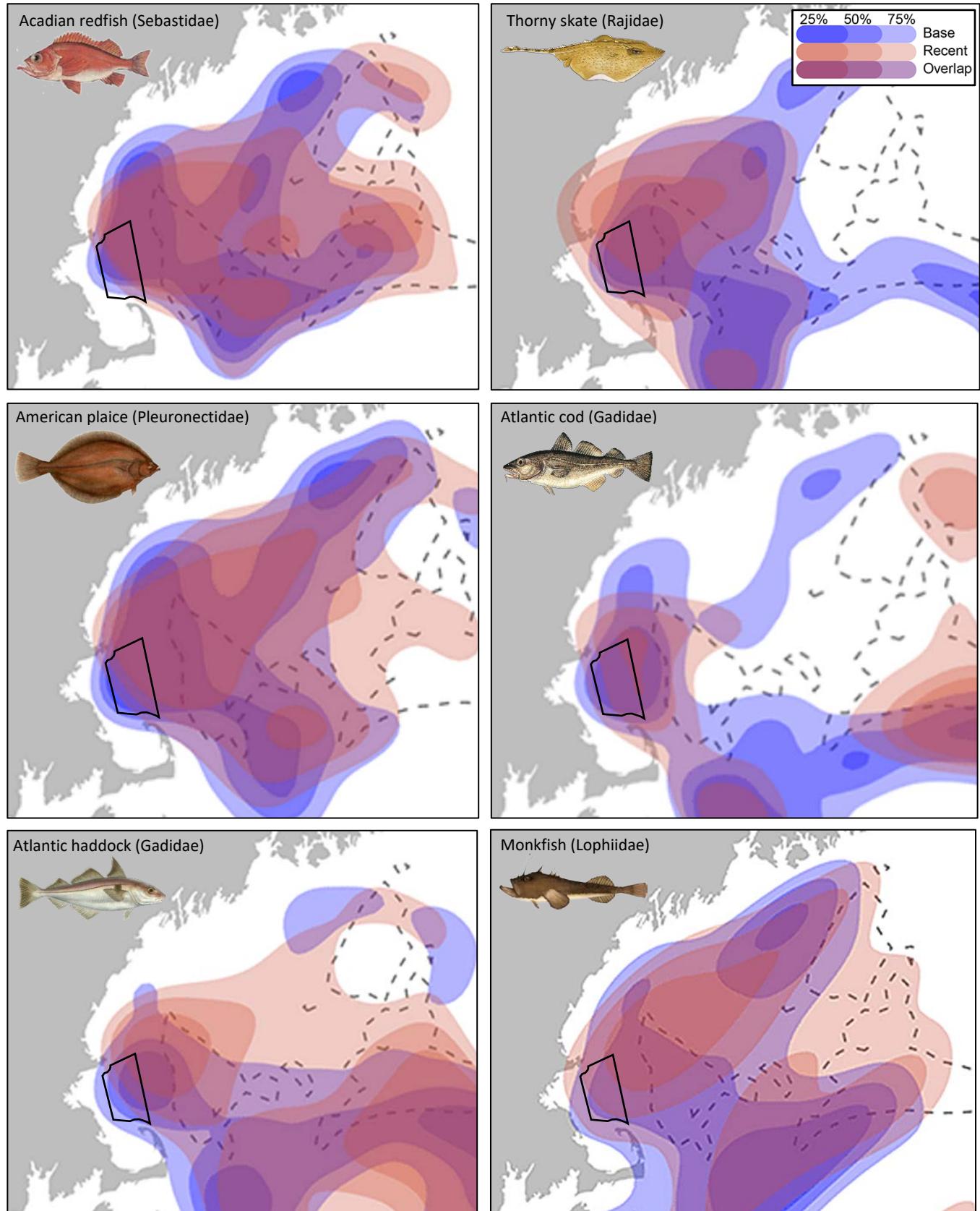
**Figure 13. Contraction of species distribution away from Stellwagen Bank NMS from 1970s to 2015.**



**Figure 14. Expansion of species distribution into Stellwagen Bank NMS region from 1970s to 2015.**



**Figure 15. High overlap in species distributions in the Stellwagen region between 1970s and 2015.**

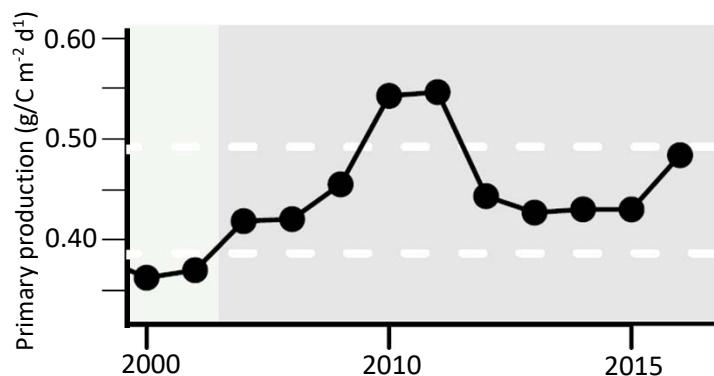


**Table 2.** Changes in distribution patterns for 31 species recorded in the Stellwagen Bank NMS region in the southern Gulf of Maine. Descriptions are visual interpretations of the kernel density maps. Species are hyperlinked to the original web-based graphic at <https://www.nefsc.noaa.gov/ecosys/current-conditions/kernel-density.html>

Species	Changes in distribution in Southern Gulf of Maine ( 1970s to 2015)	Stellwagen Bank NMS
	<i>Regional geographical patterns</i>	
<a href="#">Acadian redfish</a>	Slight northward shift, high overlap	High overlap
<a href="#">Alewife</a>	High overlap	High overlap
<a href="#">American lobster</a>	No overlap, new range extended into western GoM and Stellwagen region	Gain
<a href="#">American plaice</a>	High overlap	High overlap
<a href="#">American shad</a>	No overlap, new range extended into western GoM and Stellwagen region	Gain
<a href="#">Atlantic cod</a>	High overlap, core area range contraction & fragmented core areas in GofM	High overlap
<a href="#">Atlantic herring</a>	Overlap but northeastward shift to include deeper waters	Overlap/loss
<a href="#">Atlantic mackerel</a>	Overlap but northwestward shift to shallower waters	Overlap/loss
<a href="#">Blueback herring</a>	No overlap, but shift to northwestern shallower waters	No overlap/loss
<a href="#">Butterfish</a>	No overlap, new range extended into western GoM and Stellwagen region	No overlap/gain
<a href="#">Cunner</a>	No overlap, possible contraction of range out of GoM	No overlap/loss
<a href="#">Cusk</a>	No overlap, retraction of range and shift to deeper GoM waters	No overlap/loss
<a href="#">Haddock</a>	High overlap, range expansion and slight northward shift	High overlap/loss
<a href="#">Longhorn sculpin</a>	Overlap, range shift westward into southern GoM	High overlap/gain
<a href="#">Monkfish</a>	High overlap, expansion into deeper central GoM	High overlap
<a href="#">Ocean pout</a>	High overlap little change	High overlap
<a href="#">Pollock</a>	Reduced overlap with range contraction and core area shifting northwards	Overlap/loss
<a href="#">Red hake</a>	Overlap range expansion north and northeast to deeper waters	High overlap/loss
<a href="#">Sand lance</a>	No overlap dramatic range contraction and shift to offshore waters	No overlap/loss
<a href="#">Sea raven</a>	High overlap with range contraction and slight northward shift	High overlap/loss
<a href="#">Sea scallop</a>	Small overlap in central and northern Stellwagen region	Overlap/gain
<a href="#">Shortfin squid</a>	Slight overlap northward shift	Overlap/loss
<a href="#">Silver hake</a>	High overlap	High overlap
<a href="#">Smooth skate</a>	Slight overlap, northwest shift to shallower waters	Overlap/gain
<a href="#">Spiny dogfish</a>	High overlap, slight northward shift of core area	High overlap
<a href="#">Thorny skate</a>	High overlap, range contraction to shallower waters in the southern GoM	High overlap
<a href="#">White hake</a>	High overlap	High overlap
<a href="#">Winter flounder</a>	No overlap recent expansion to southwestern GofM including Stellwagen	Gain
<a href="#">Witch flounder</a>	High overlap	High overlap
<a href="#">Wolffish</a>	High overlap, range contraction with slight northward shift of core habitat	High overlap/loss
<a href="#">Yellowtail flounder</a>	Low overlap, expansion into shallower southwest GoM including Stellwagen	Overlap/gain

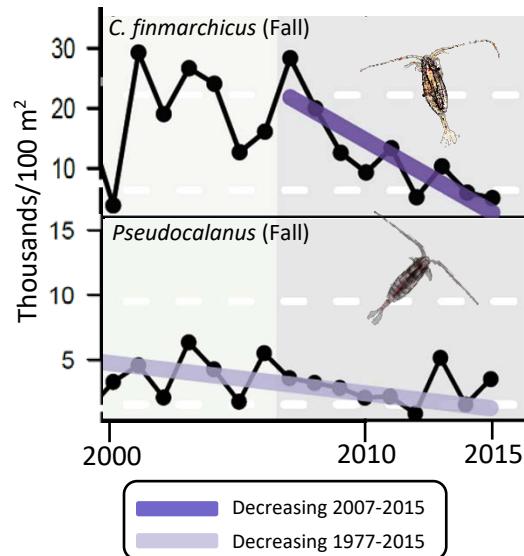
## Plankton

From 2006 phytoplankton (primary production) in the Gulf of Maine exhibited an increase above the long-term average ( $\pm 1$  SD) to 2011 and then declined to relatively stable average conditions between 2012 and 2016 (Figure 18). This is likely to be driven by inter-decadal patterns in local and regional water conditions.



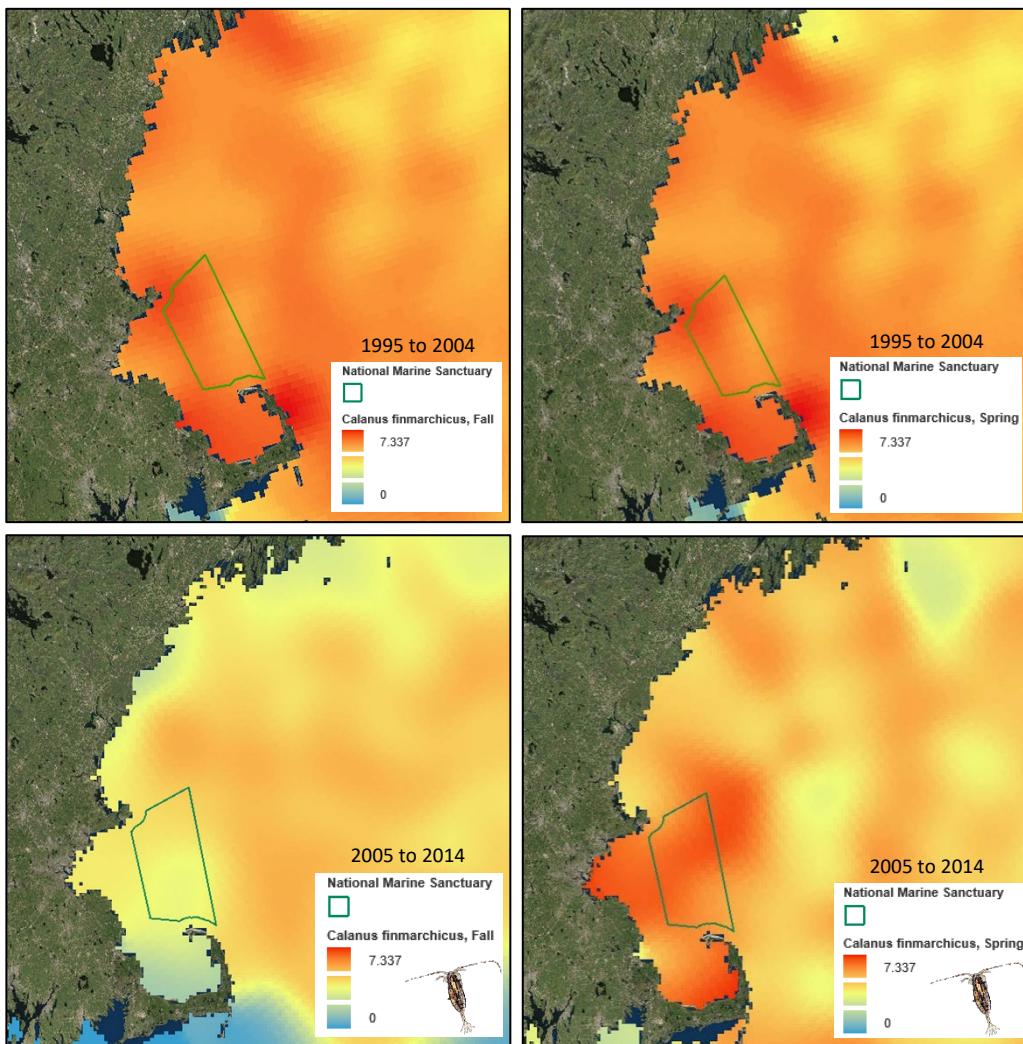
**Figure 18.** Phytoplankton productivity in the Gulf of Maine from 2000 to 2016. Dashed white horizontal lines indicate  $\pm 1$  standard deviation from the long-term time series mean. Source: State of the Ecosystem report, NOAA NMFS NEFSC.

Several species of zooplankton such as *Calanus* spp. are important components of the North Atlantic food web and a primary prey for vulnerable North Atlantic right whales (Mayo & Marx 1990, Meyer-Gutbrod & Greene 2014) and many species of forage fish such that changes in zooplankton abundance will have important ecological consequences for the Gulf of Maine ecosystem. *Calanus finmarchicus* is one of the most commonly found species of zooplankton in the Gulf of Maine and several species of harvested fish depend on the lipid rich calanoid copepods and their eggs as prey including cod, herring, haddock, mackerel and red fish. Other key predators are seabirds such as Leaches storm petrel as well as planktonic invertebrates such as siphonophores and euphausiids. IEA analyses revealed a recent significant decline in the abundance of both *Calanus finmarchicus* and *Pseudocalanus* in the fall sampling season, but no significant trend was detected for spring abundance which is the time when right whales begin feeding in the Gulf of Maine (Figure 19). Interpolated maps of *C. finmarchicus* (Figure 20) suggest a contraction in the regional abundance in spring 2005 to 2014 compared with the previous decade (1995 to 2004) and a considerable broad geographical reduction in density through the southern Gulf in fall 2005 to 2014 compared with 1995 to 2004. Models by NOAA NMFS NEFSC (Grieve et al. 2017) forecast



**Figure 19.** Declining (fall season) abundance of calanoid copepods in the Gulf of Maine. Source: State of the Ecosystem report, NOAA NMFS NEFSC.

that future temperature and salinity conditions will result in a gradual decrease in *C. finmarchicus* densities, with a high greenhouse gas emissions scenario decreasing density of this species by as much as 50 % by the end of this century. Mapped predictions indicate that the Stellwagen region will experience less decline than the deeper central and northern Gulf waters. In Wilkinson Basin in the western Gulf of Maine, *C. finmarchicus* has persisted in large concentrations despite recent significant warming (Ji et al. 2017).

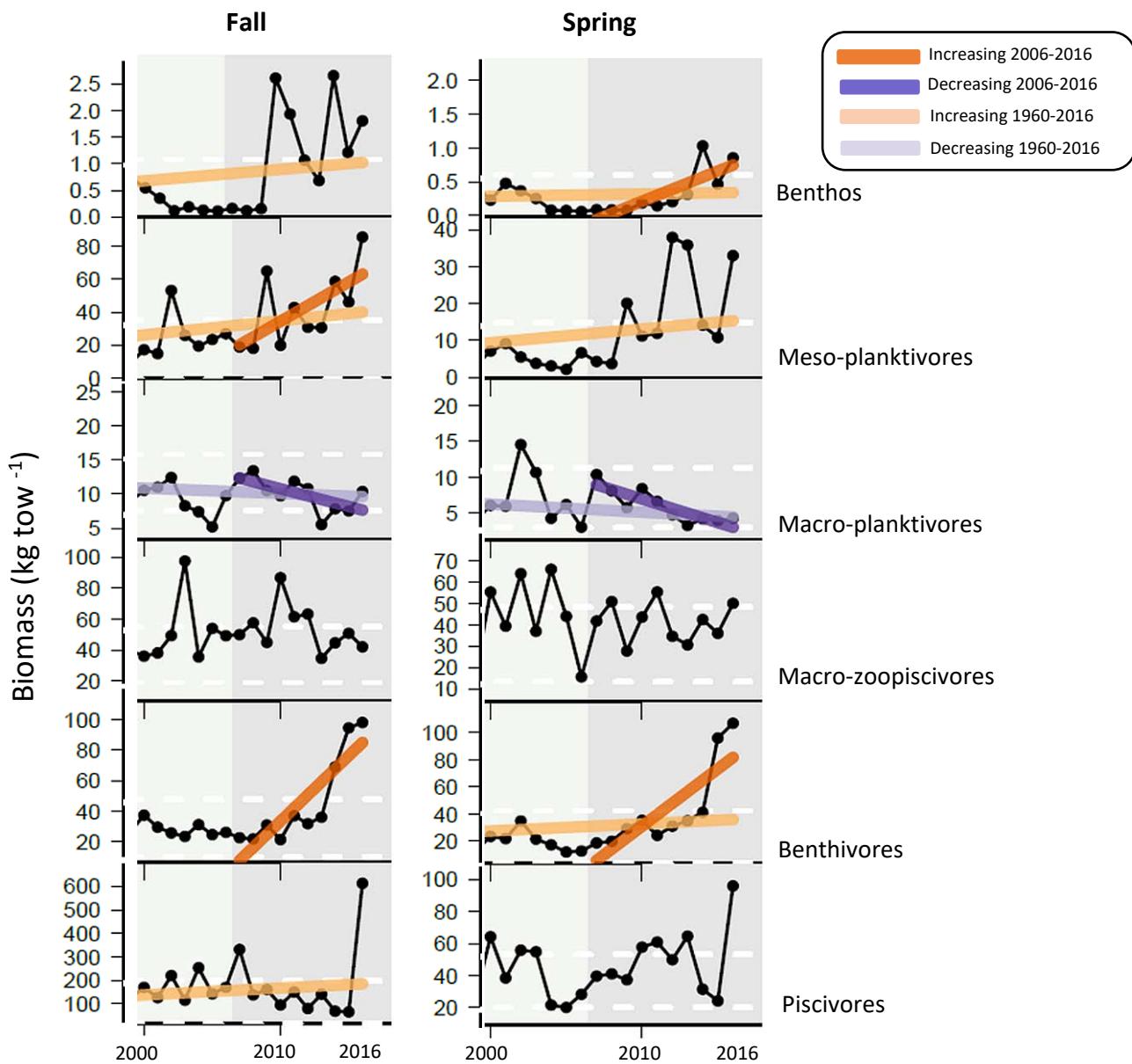


**Figure 20.** *Calanus finmarchicus* abundance (per cubic meter log-transformed) in fall and spring surveys in the southern Gulf of Maine in the survey period 1995-2004 (top) and 2005-2014 (bottom). Source: NEFSC & TNC Northeast Ocean Data.

Further analyses is required to understand the ecological consequences for the spatio-temporal changes that are represented in Figure 20.

Biomass for six major trophic (functional) groups for the Gulf of Maine show long-term increases in both seasons for benthos and meso-planktivores and statistically significant recent (2006–2016) increases for spring benthos, fall meso-planktivores and benthivores in both spring and fall sampling seasons (Figure 21). Only macro-planktivores experienced statistically significant declines in both seasons since 2006. IEA data showing an increase in benthic biomass and benthivore biomass has led researchers to suggest that the benthic influence on food webs may be increasing relative to the pelagic productivity.

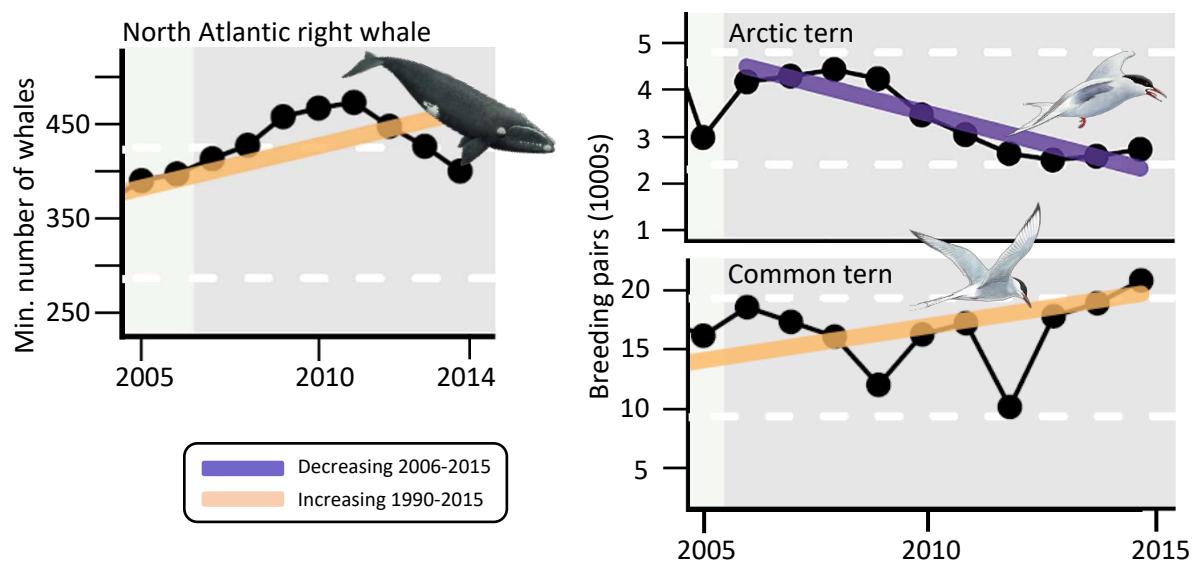
Group (Description)	N species	Major species in the group
<b>Benthos</b> (bottom dwellers)	7	scallops, surfclam, quahog, mussels, whelks, conchs, sand dollars and urchins
<b>Meso-planktivores</b> (eat copepods)	7	Atlantic herring, butterfish, Atlantic mackerel, menhaden, river herrings and shad
<b>Macro-planktivore</b> (eat large zooplankton)	6	white hake, longfin and shortfin squids, searobins, sculpin, lumpfish
<b>Macro-zoopliscivores</b> (eat large zooplankton, shrimp, and fish)	12	redfish, windowpane, cusk, pollock, red hake, clearnose, little, and smooth skates, smooth dogfish, buckler dory, blackbelly rosefish
<b>Benthivores</b> (eat bottom dwellers)	24	lobster, haddock, yellowtail, winter, and witch flounders, barndoor skate, ocean pout, black sea bass, scup, tilefish, tautog, cunner, blue crab, red crab, other crabs
<b>Piscivores</b> (eat fish)	13	monkfish, winter and thorny skates, silver and offshore hake, Atlantic cod, halibut, fourspot flounder, spiny dogfish, summer flounder, bluefish, striped bass, weakfish



**Figure 21.** Fall and Spring trends in biomass for key trophic groups sampled from the Gulf of Maine fisheries-independent (NEFSC) bottom trawls (2000 – 2016). Dashed white horizontal lines indicate  $\pm 1$  standard deviation from the long term time series mean. Gray shaded time period is the most recent decade (2006–2016). Source: State of the Ecosystem report, NOAA NMFS NEFSC.

## Q8 – What is the status of other focal species and how is it changing?

North Atlantic right whales (*Eubalaena glacialis*) are among the most endangered large whale populations in the world and has been listed as endangered under the Endangered Species Act since 1970. The population increased steadily from 1990 to 2010, but by 2014 the population is estimated to have decreased back to the population size estimated in 2006 (Figure 22). Latest NMFS model estimates for 2015 predict 458 individuals (Pace et al. 2017). Terns are important indicators of the state of the environment and iconic bird species in the Gulf of Maine. Arctic tern (*Sterna paradisaea*) have experience a significant decline in population size in the Gulf of Maine region while Common tern (*S. hirundo*) have been steadily increasing since 2005 (Figure 22).



**Figure 22.** North Atlantic right whale estimated population (2005 to 2014) and tern breeding population size (2005-2015). Dashed white horizontal lines indicate  $\pm 1$  standard deviation from the long term time series mean. Gray shaded time period is the most recent years (2007-2014). Source: State of the Ecosystem report, NOAA NMFS NEFSC.

## **Q9 – What is the status of non-indigenous species and how is it changing?**

More than sixty non-native marine species that cause or are likely to cause harm to ecosystems, economies, or public health have been reported in the Gulf of Maine (Table 3). These species have mostly come from Europe, Asia and the Pacific Ocean transported inadvertently through commercial shipping (Brawley et al. 2009). It is thought that human activity is leading to an increase in the number and abundance of invasive species in the Gulf of Maine. Some species may proliferate with warming waters, however, for most invasive species it is not yet clear how climate change will influence their population dynamics and extent although some invasive species are shifting northward. Introduced seaweeds in Maine have increased particularly in the Casco Bay area. Colonial ascidians, Asian shore crab, Mitten crab, a red alga (*Grateloupia turuturu*) and lionfish may become more abundant in the region. Sites in New Hampshire and Maine have experienced 27-fold increases of the green alga *Codium fragile* over a 22-year period along with its associated epiphyte *Neosiphonia harveyi* (Mathieson et al. 2008).

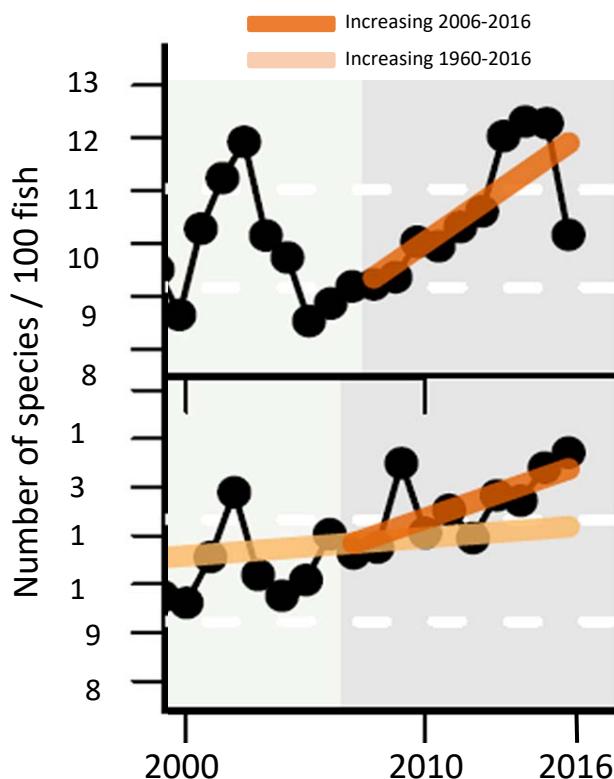
TAXONOMIC GROUP	NUMBER
Crustacea	13
Rhodophyceae	11
Tunicata	7
Mollusca	6
Phaeophyceae	5
Hydrozoa	3
Bryozoa	3
Protista	3
Cnidaria	2
Polychaeta	2
Platyhelminthes	2
Diatomacea	2
Kamptozoa	1
Nematoda	1
Porifera	1
Cholorophyceae	1
Virus	1
<b>TOTAL</b>	<b>64</b>

**Table 3.** Marine invasive species in the Gulf of Maine. Source: State of the Gulf of Maine report 2010.

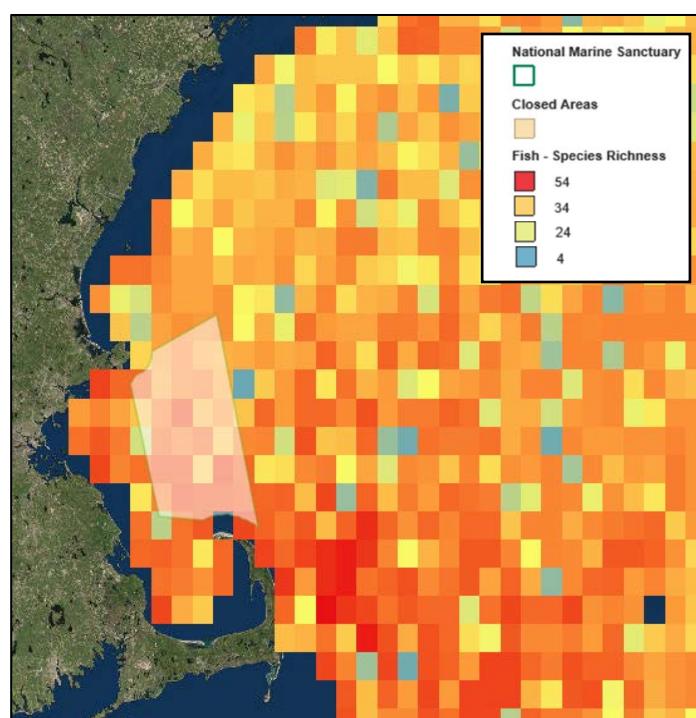
## Q10 - What is the status of biodiversity and how is it changing?

### Fish

The best example of a well-documented pattern of distribution and abundance at Gulf-wide scale is for the fishes, which have been sampled by fishery-independent assessment surveys for more than 40 years (Incze et al. 2010) (Figure 24). There are four sources for fisheries trawl data: the NEFSC, North East Areas Monitoring and Assessment Program (NEAMAP), Massachusetts Division of Marine Fisheries (MDMF), and Maine & New Hampshire state trawls (ME/NH). Each set of data sources have used standardized survey designs and data collection methodologies. Results were normalized to account for vessel and gear differences within each data source. According to IEA analyses, 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 (Figure 23). Comparing fish species richness from trawl samples may provide a useful surrogate for patterns of ecosystem biodiversity, but further studies will be needed to determine trends in benthic species diversity. Recent synthesis by the Census of Marine Life may provide a reliable baseline for future studies.



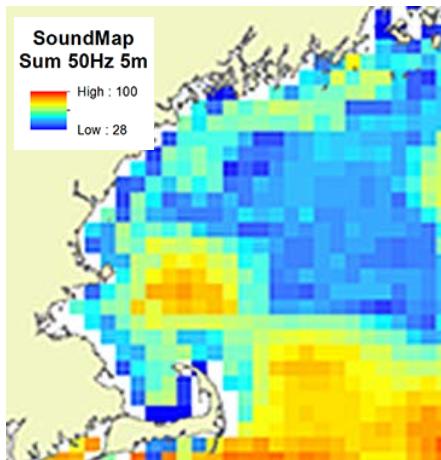
**Figure 23.** Fish species richness estimated as the mean number of species found in a random sample of 100 fish at a station for the Gulf of Maine portions of NEFSC surveys. Dashed white horizontal lines indicate  $\pm 1$  standard deviation from the long term time series mean. Source: State of the Ecosystem report, NOAA NMFS NEFSC.



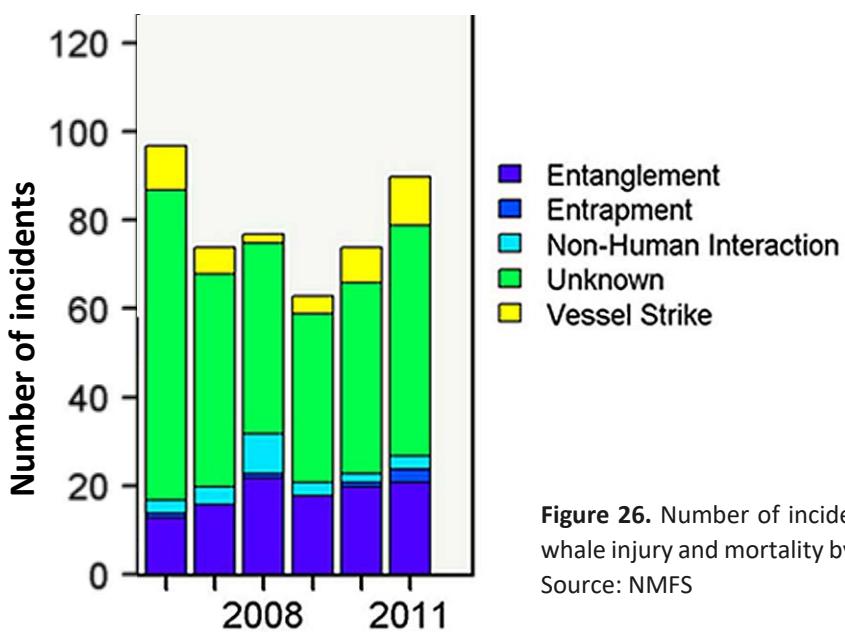
**Figure 24.** Number of fish species from all NEFSC fisheries-independent bottom trawls (1970-2014). For all fish species together (82 species) total species richness maps are calculated in a GIS by summing the number of individual species present in each cell. A species was considered present in a cell if its biomass in that cell was greater than 1.5 kg. Each map cell is 10 km x 10 km. Source: Marine-life Data & Analysis Team (MDAT) data described by Curtice et al. (2016) and Fogarty & Perretti (2016).

## **Q15 - What are the levels of human activities that may adversely influence living resource quality and how are they changing?**

Shipping and boating introduce noise pollution (Figure 25) and occasionally ships strike large marine animals such as whales. There is some evidence that recently introduced (2008) vessel speed restrictions have reduced the incidence of mortality by ship strike (Figure 26). Fishing gear also account for an increasing number of incidents of injury and mortality to cetaceans.

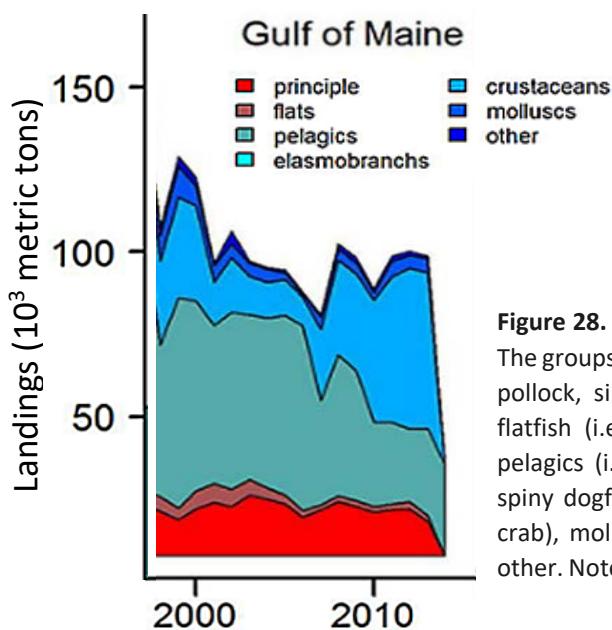


**Figure 25.** Modeled sound levels as a function of vessel traffic for different vessel types at 5 m depth and 50 Hz. Source: NOAA CetSound Program.



**Figure 26.** Number of incidents involving large whale injury and mortality by incident category. Source: NMFS

Commercial fishing is a major factor in structuring the biological communities in the Gulf of Maine and takes place over a considerable area and more intensively near densely populated urban centers (Figure 27) in the southwest region of the Gulf. Based on the weight of landings since 2006, the catch from the Gulf of Maine commercial fishery has declined for pelagics and increased for crustaceans while remaining relatively stable for all principle species combined (Figure 28). Change in catch for individual species is beyond the scope of this paper, but the data are available (NEFSC).

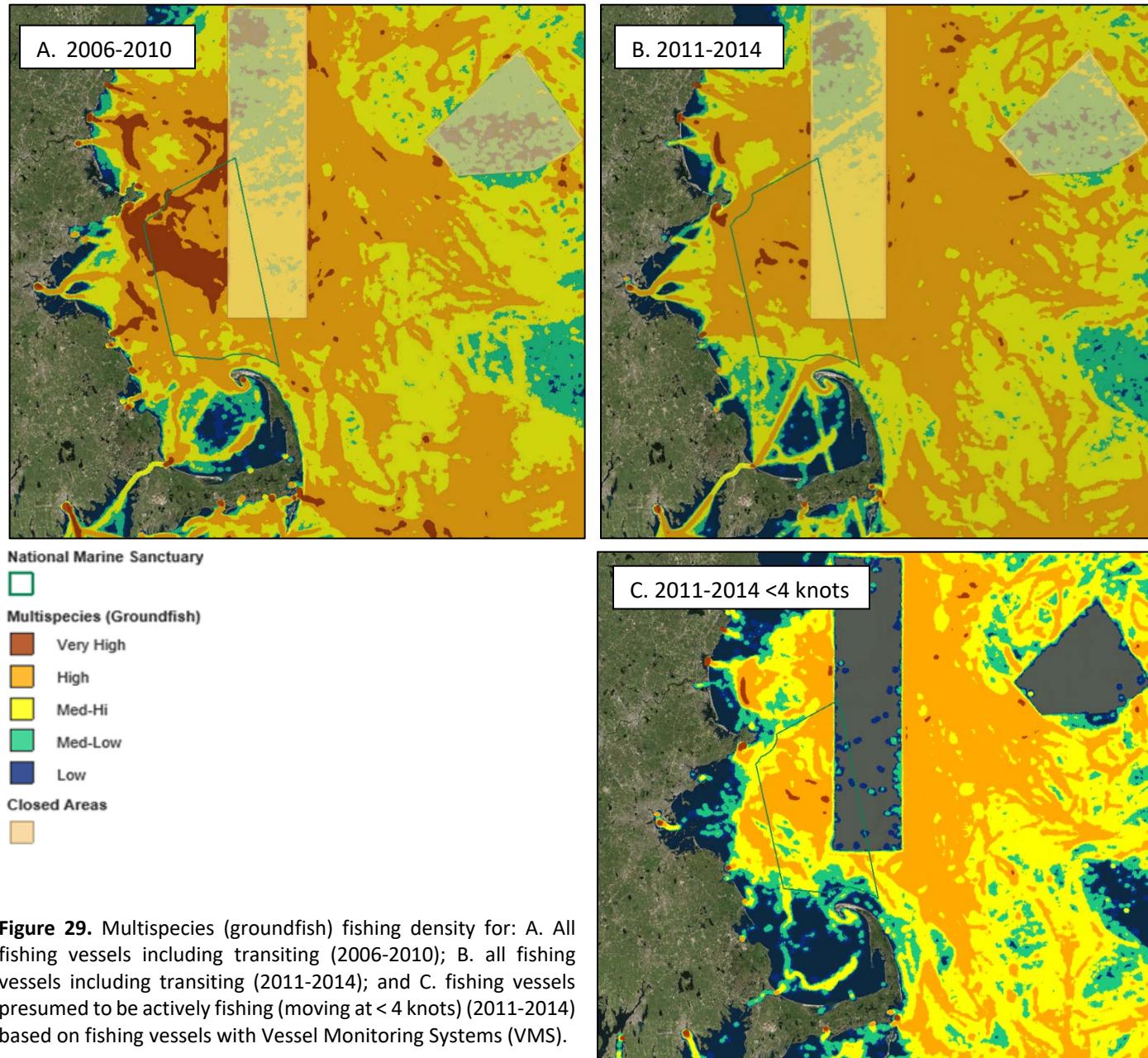


**Figure 27.** Concentration of fishing days for fixed-area fishers.

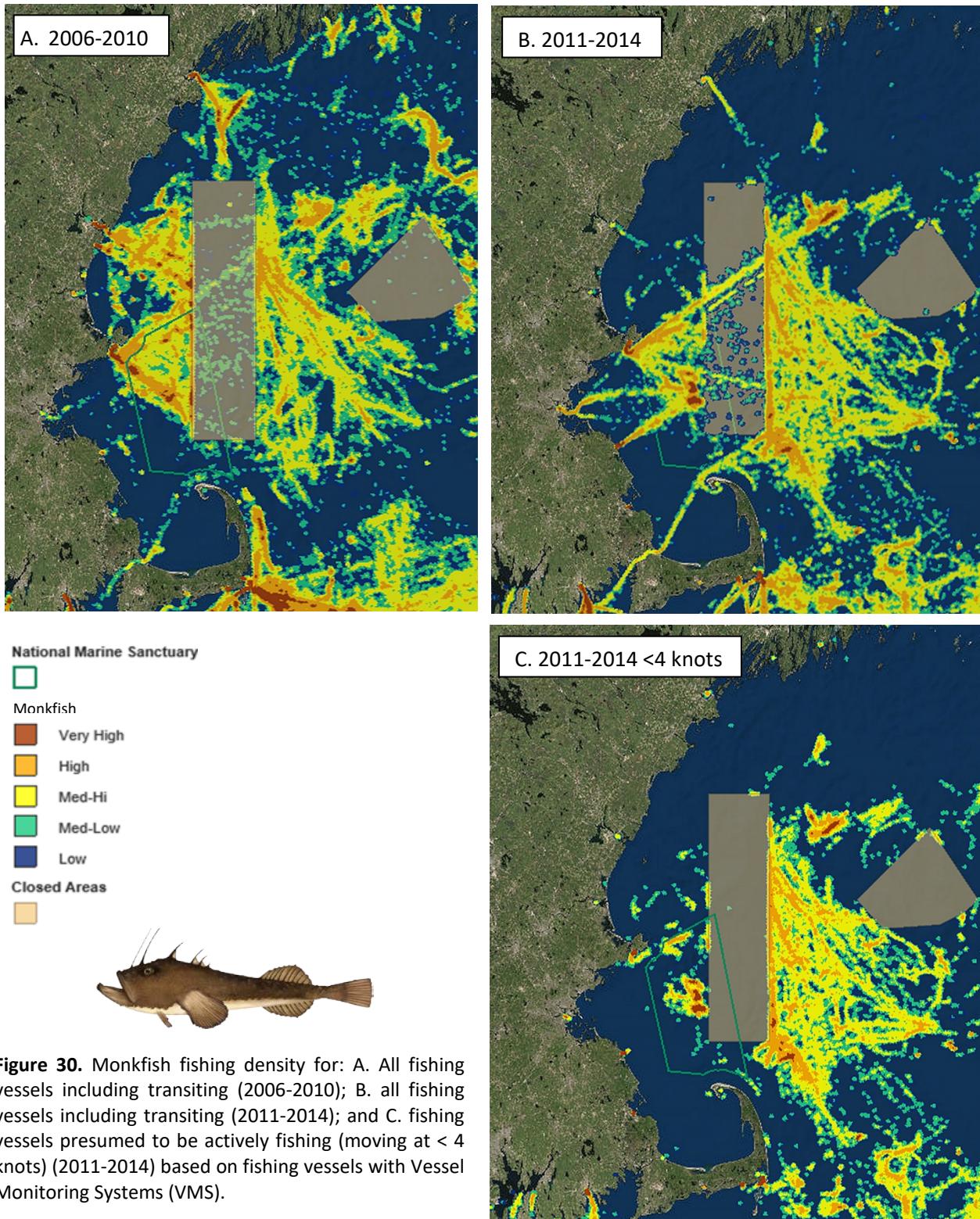
**Figure 28.** Landings (live weight) for the Gulf of Maine production unit. The groups represented are: principal groundfish (Atlantic cod, haddock, pollock, silver hake, red hake, white hake, red fish, and monkfish), flatfish (i.e. summer flounder, winter flounder, yellowtail flounder), pelagics (i.e. Atlantic herring, Atlantic mackerel), elasmobranchs (i.e. spiny dogfish, winter skates), crustaceans (i.e. American lobsters, red crab), molluscs (i.e. Atlantic scallops, ocean quahogs, surfclams), and other. Note: landings of lobster are underrepresented in the time series.

Comparison of the fishing boat at-sea traffic between the 2006-2010 period and the 2011-2014 based on vessel monitoring system location data indicate a reduction in the fishing boat activity in the region of Stellwagen Bank NMS. When the boat traffic density data are refined to only show the density of fishing boats that are travelling more slowly than 4 knots (the speed associated with deployed gears) 2011-2014 patterns are similar suggesting that the uncorrected data do also provide a reliable picture of the spatial patterns of relative fishing intensity (Figure 29). The data also suggest a relatively high level of compliance with fishery closures (Northeast Multispecies Closed Areas). However, there are special programs that allow some fisheries, including groundfish, herring, surfclam/ocean quahog, and scallop to access some parts of these closed areas under certain conditions. Vessels may transit the areas that are closed provided that their fishing gear is stowed according to regulations. Visual comparison for scallop fishing intensity suggests that fishers are not exploiting the offshore grounds as much in the 2011-2014

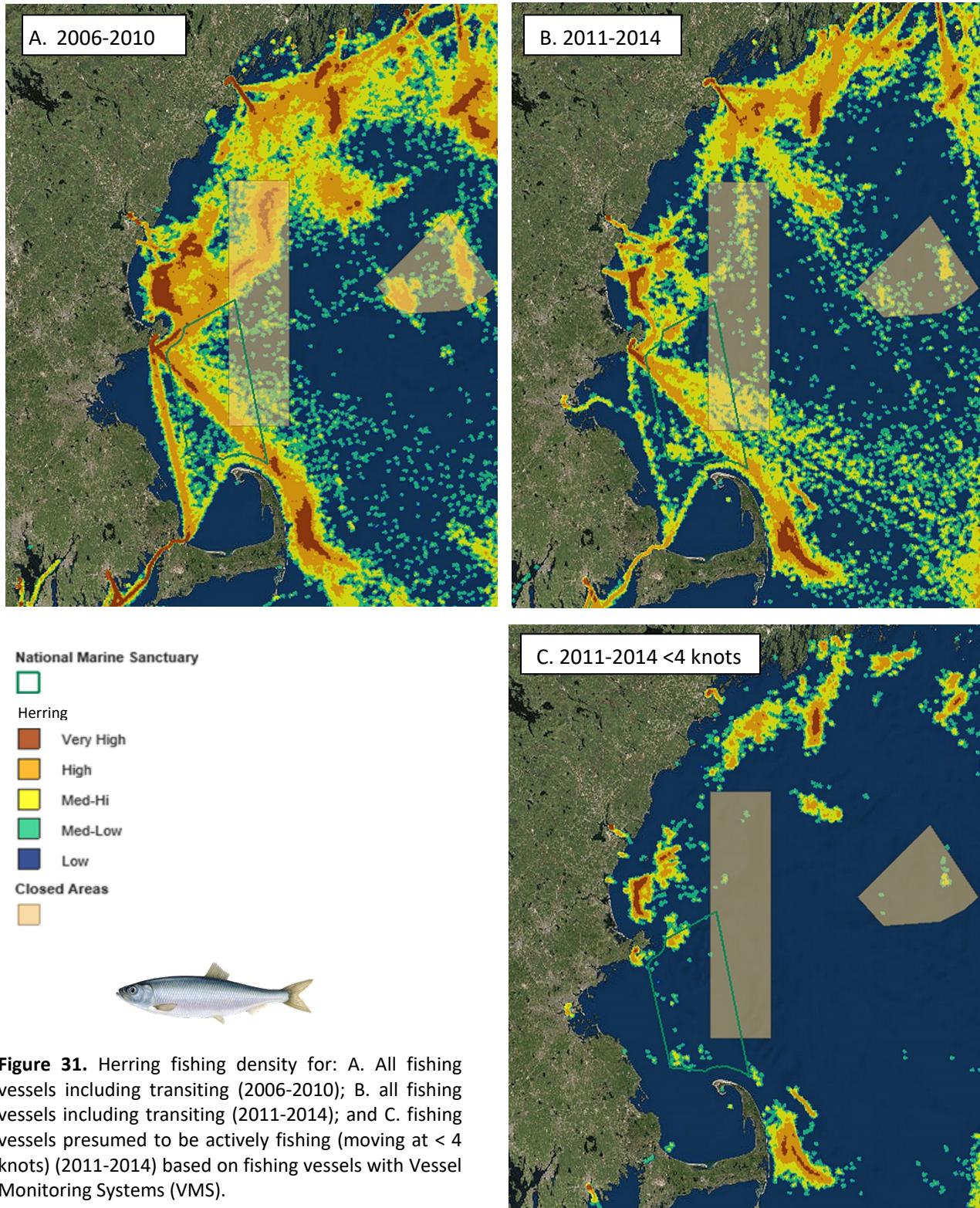
period compared with 2006-2010 (Figure 32) whereas for monkfish fishers are working more intensively on offshore grounds (Figure 30).

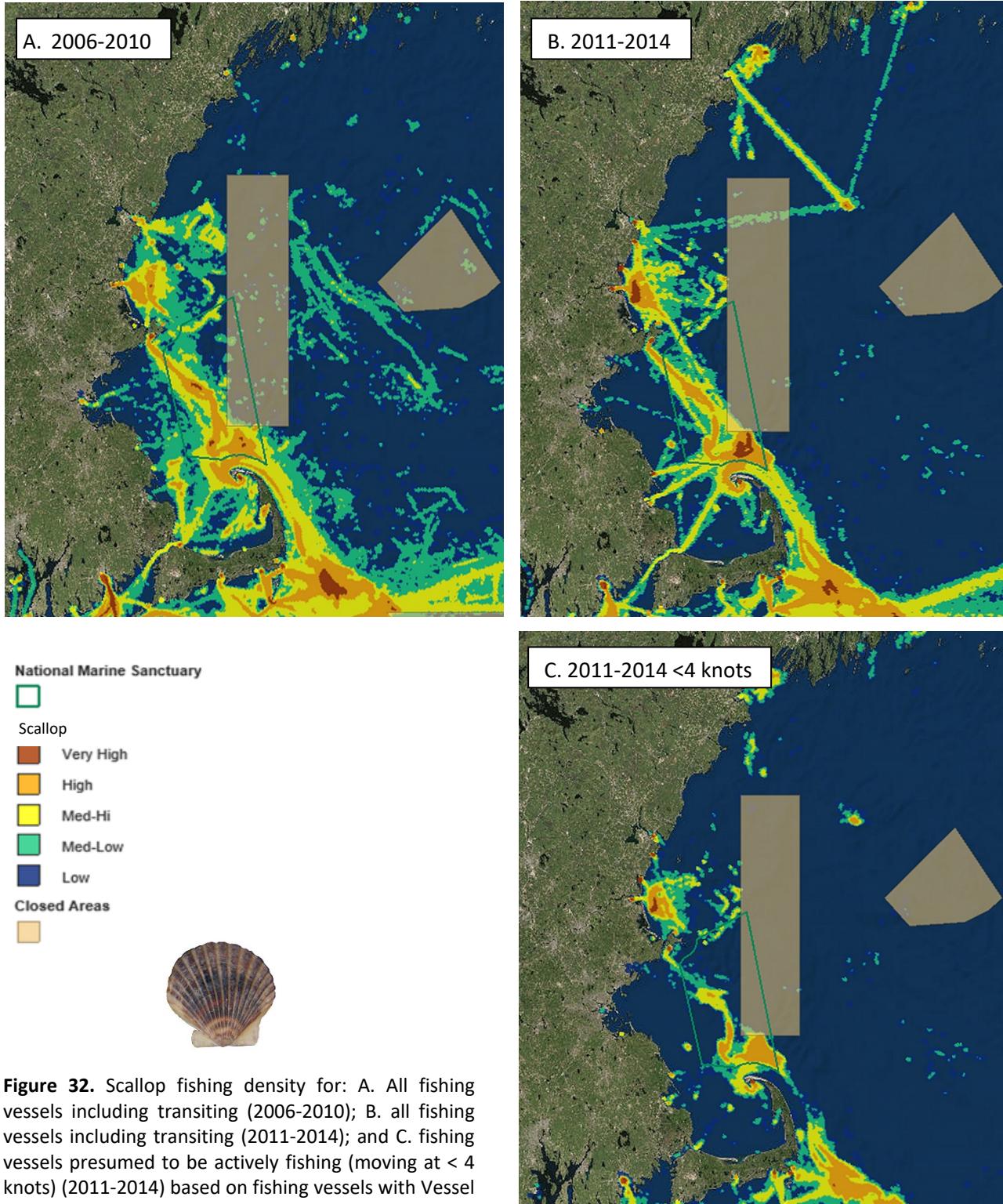


**Figure 29.** Multispecies (groundfish) fishing density for: A. All fishing vessels including transiting (2006-2010); B. all fishing vessels including transiting (2011-2014); and C. fishing vessels presumed to be actively fishing (moving at < 4 knots) (2011-2014) based on fishing vessels with Vessel Monitoring Systems (VMS).



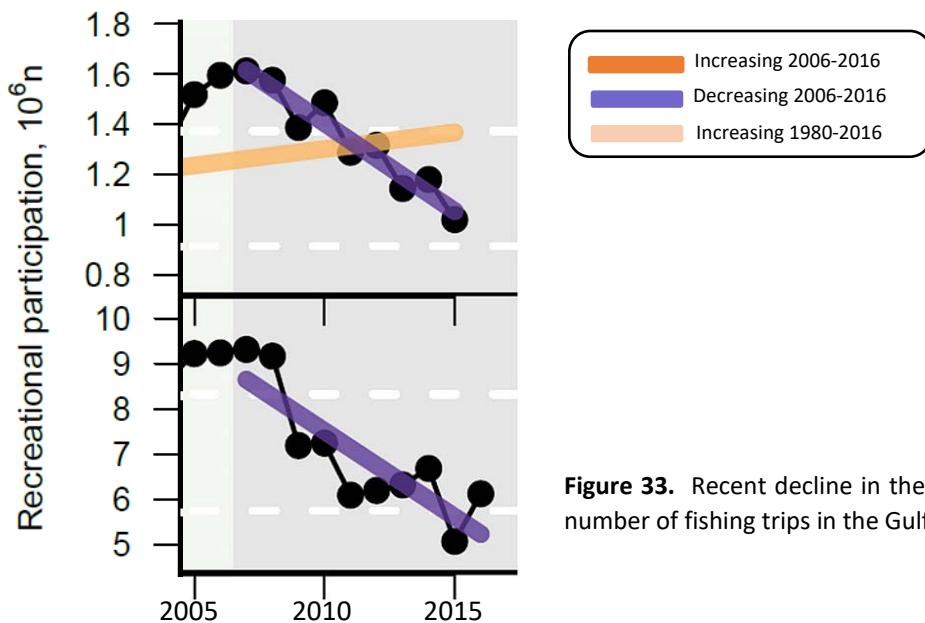
**Figure 30.** Monkfish fishing density for: A. All fishing vessels including transiting (2006-2010); B. all fishing vessels including transiting (2011-2014); and C. fishing vessels presumed to be actively fishing (moving at < 4 knots) (2011-2014) based on fishing vessels with Vessel Monitoring Systems (VMS).



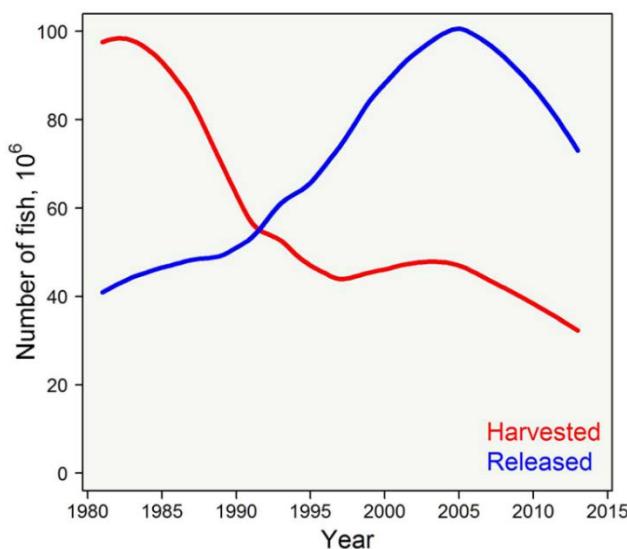


**Figure 32.** Scallop fishing density for: A. All fishing vessels including transiting (2006-2010); B. all fishing vessels including transiting (2011-2014); and C. fishing vessels presumed to be actively fishing (moving at < 4 knots) (2011-2014) based on fishing vessels with Vessel Monitoring Systems (VMS).

Recreational fishing has 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 (Figure 33). Surveys also suggest an increase in the number of caught fish being released rather than harvested (Figure 34).



**Figure 33.** Recent decline in the number of : A. anglers and B. number of fishing trips in the Gulf of Maine recreational fishery.



**Figure 34.** Trends in the number of fish caught and released in the recreational fishery (1980-2015). Source: NEFSC

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