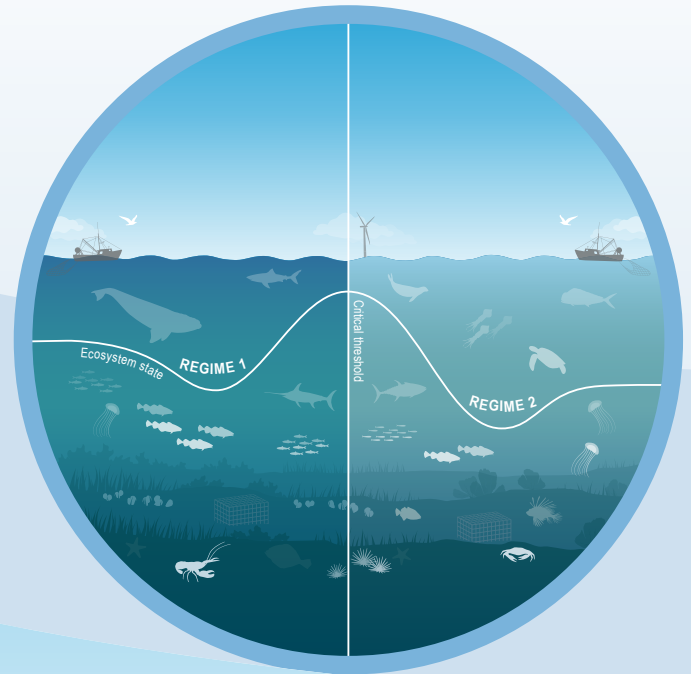
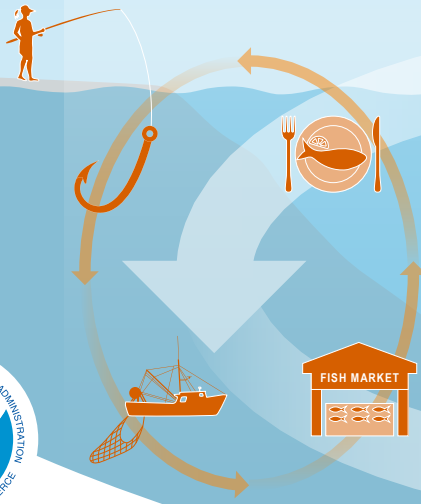


2024 State of the Ecosystem

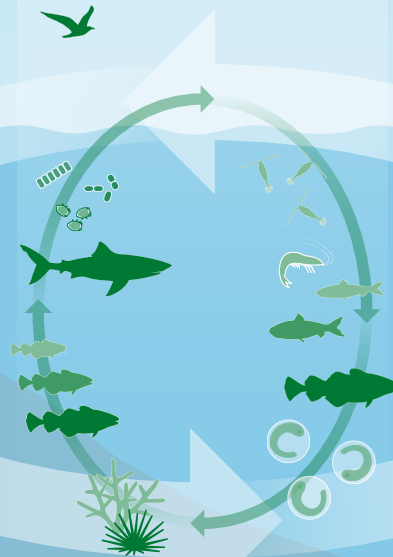
New England



SOCIETAL ACTIVITIES & BENEFITS



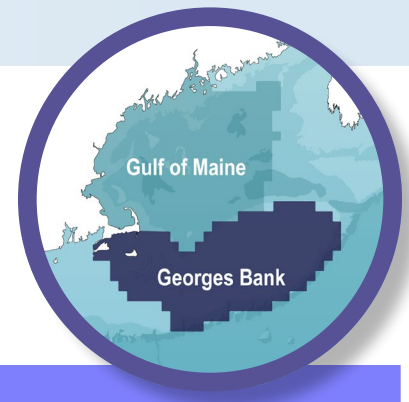
BIOLOGICAL



PHYSICAL & CHEMICAL



NOAA
FISHERIES

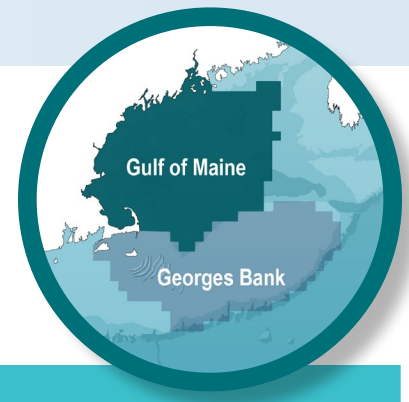


Performance Relative to Fishery Management Objectives

Trends and status of indicators related to broad ecosystem-level fishery management objectives, with implications for the New England Fishery Management Council (NEFMC)

GEORGES BANK (GB)

OBJECTIVE (Indicator)	30 YEAR TREND	CURRENT STATUS	IMPLICATIONS
Seafood production (Total and NEFMC managed landings)	No trend Decline	TOTAL Below long-term average MANAGED Below long-term average	New England managed species seafood production is significantly declining and currently below the long-term average. Total U.S. seafood production is also below the long-term average. Recreational harvest in New England is slightly above the low observed in 2020, but still well below the long-term average. Both the commercial and recreational landings status are driven in part by management to address mandated rebuilding of depleted stocks.
Commercial profits (Total and managed revenue)	No trend	Above long-term objective	Despite high landings of scallop, lower prices drew total revenue down in 2022. Inflation-adjusted revenue on GB has only exceeded 1982 levels twice in the time series, with price effects driving dynamics over the past decade.
Recreational opportunities (Effort and fleet diversity)	No trend No trend	EFFORT Near long-term average DIVERSITY Near long-term average	Recreational opportunities in the region are relatively stable, with respect to the types of trips (i.e., shore, private boat, charter/party) and numbers of species landed.
Stability (Fishery and ecosystem diversity maintained over time)	No trend Mixed trends	FISHERY Commercial Below long-term average Recreational Near long-term average ECOSYSTEM Near long-term average	Commercial: Commercial fleets continue to shift towards a reliance on fewer species, with 2022 near historic low species diversity levels. Recreational: Species diversity is increasing due to increases in southerly species and lower catch limits on traditional regional species. Ecosystem: Adult fish diversity indices are stable while zooplankton diversity is increasing, indicating potential instability. Several climate and oceanography metrics are changing and should be monitored as warning signs for potential regime shift or ecosystem restructuring.
Social and cultural (Community fishery engagement, reliance, and environmental justice vulnerability)	Status only indicator	Environmental justice status for top commercial and recreational communities	The specific issues facing communities with environmental justice concerns in New England vary widely. New Bedford, MA, is the only community in New England that scored medium-high for all three environmental justice indicators. Boston, MA scored medium-high for population composition and poverty. By contrast, communities in Maine scored medium to medium-high for poverty and personal disruption, but had lower population composition scores.
Protected species (Coastwide bycatch, population numbers, mortalities)	Mixed trends Mixed trends	BYCATCH Harbor porpoise Meeting objectives Gray seal Meeting objectives POPULATIONS NARW Below long-term average Gray seal Above long-term objective	Bycatch objectives are being met for harbor porpoise and gray seals. Mixed bycatch trends through 2021 are related to fishery management, shifts in porpoise distribution combined with fishery shifts, and population increase for gray seals. Population drivers for North Atlantic Right Whales (NARW) include combined fishery interactions/vessel strikes and distribution shifts related to prey abundance and quality. Management measures to reduce adult mortality are reflected in more stable population numbers. Unusual mortality events continue for 3 large whale species.



Performance Relative to Fishery Management Objectives

Trends and status of indicators related to broad ecosystem-level fishery management objectives, with implications for the New England Fishery Management Council (NEFMC)

GULF OF MAINE (GOM)

OBJECTIVE (Indicator)	30 YEAR TREND	CURRENT STATUS	IMPLICATIONS
Seafood production (Total and NEFMC managed landings)	Decline	Below long-term average	Seafood production from New England managed species is near the lowest levels observed with a long-term declining trend. Total U.S. seafood production also shows a significant long-term decreasing trend. Recreational harvest in New England is up slightly from its lowest point in 2020, but is still well below the long-term average. Both the commercial and recreational landings status are driven in part by management to address mandated rebuilding of depleted stocks.
Commercial profits (Total and managed revenue)	No trend	TOTAL Above long-term objective	Total GOM revenue exceeded 1982 baseline levels in all but 4 years. High prices and landings of lobster continue to drive total regional revenue. However, revenue from New England managed species is near the all-time low.
	Decline	MANAGED Below long-term average	
Recreational opportunities (Effort and fleet diversity)	No trend	EFFORT Near long-term average	Recreational opportunities in the region are relatively stable, with respect to the types of trips (i.e., shore, private boat, charter/party) and numbers of species landed.
	No trend	DIVERSITY Near long-term average	
Stability (Fishery and ecosystem diversity maintained over time)	No trend	FISHERY Commercial: Below long-term average Recreational: Near long-term average	Commercial: Commercial fleets continue to shift towards a reliance on fewer species, with 2022 near historic low species diversity levels. Recreational: Species diversity is increasing due to increases in southerly species and lower catch limits on traditional regional species. Ecosystem: Fish species richness is increasing while zooplankton diversity is stable, indicating potential instability. Several climate and oceanography metrics are changing and should be monitored as warning signs for potential regime shift or ecosystem restructuring.
	Mixed trends	ECOSYSTEM Near long-term average	
Social and cultural (Community fishery engagement, reliance, and environmental justice vulnerability)	Status only indicator	Environmental justice status for top commercial and recreational communities	The specific issues facing communities with environmental justice concerns in New England vary widely. New Bedford, MA, is the only community in New England that scored medium-high for all three environmental justice indicators. Boston, MA scored medium-high for population composition and poverty. By contrast, communities in Maine scored medium to medium-high for poverty and personal disruption, but had lower population composition scores.
Protected species (Coastwide bycatch, population numbers, mortalities)	Mixed trends	BYCATCH Harbor porpoise: Meeting objectives Gray seal: Meeting objectives	Bycatch objectives are being met for harbor porpoise and gray seals. Mixed bycatch trends through 2021 are related to fishery management, shifts in porpoise distribution combined with fishery shifts, and population increase for gray seals. Population drivers for North Atlantic Right Whales (NARW) include combined fishery interactions/vessel strikes and distribution shifts related to prey abundance and quality. Management measures to reduce adult mortality are reflected in more stable population numbers. Unusual mortality events continue for 3 large whale species.
		POPULATIONS NARW: Below long-term average Gray seal: Above long-term objective Salmon: Below long-term average	

Risks to Meeting Fishery Management Objectives

Climate and Ecosystem Risks

Climate and ecosystem change can directly and indirectly create risks to meeting fisheries management objectives by affecting the distribution, seasonal timing, productivity, and physiology of marine species.

Risks to Spatial Management: Species distribution shifts can complicate quota allocation because historical distributions may not reflect current availability and catch. Changing spatial overlap of species and fisheries can alter bycatch patterns. Species availability to surveys can change.

- **Observations:** Species distributions are trending to the northeast along the continental shelf and into deeper water for many fish and marine mammals.
- **Drivers:** Increasing temperature, changing oceanography, and the decreasing seasonal cold pool can alter the spatial distribution of suitable habitat for managed species and the availability of their prey.

Risks to Seasonal Management: Changes in seasonal life-cycle events may not align with fishing seasons or area openings/closings, potentially reducing effectiveness of management measures. Changes in species and fisheries temporal overlap can alter bycatch and availability to surveys.

- **Observations:** Seasonal timing of spawning has changed for some managed species. Migration timing of some tunas and large whales has changed.
- **Drivers:** Later transition to fall conditions, a shorter seasonal cold pool, changing timing of fall phytoplankton blooms, seasonal community shifts in zooplankton, and changes in timing of food availability affect the timing of life-cycle events.

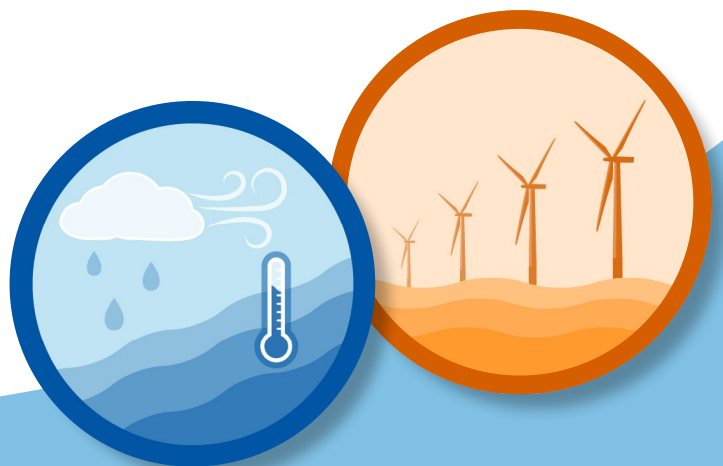
Risks to Quota Setting/Rebuilding: Environmentally driven changes in growth, reproduction, and natural mortality can complicate short-term stock projections. Stock reference points may not reflect prevailing environmental conditions.

- **Observations:** Changes in fish productivity and condition have been observed for multiple species.
- **Drivers:** Warmer temperatures increase metabolic demands and alter the availability and quality of prey. Episodic extreme temperatures, ocean acidification, and low oxygen events are multiple stressors that can affect growth rates and cause mortality.

Other Ocean Uses: Offshore Wind Risks

There are 30 offshore wind energy projects proposed for construction on the Northeast shelf, covering more than 2.3 million acres by 2030, with additional large areas under consideration. Impacts at the wind project, local ocean, and regional scales are likely. Negative effects are possible for species that prefer soft bottom habitat, while species that prefer hard structured habitat may benefit. Wind energy updates include:

- Two projects are under construction in southern New England (South Fork Wind and Vineyard Wind 1).
- The first draft wind energy area within the Gulf of Maine has been proposed for floating offshore wind, with lease sales anticipated for late 2024.
- 1–34% of New England port revenue (2008–2022) came from existing leased and proposed offshore wind areas. Some of these communities score medium-high to high in environmental justice concerns and gentrification vulnerability.
- 3–54% and 4–53% of annual commercial revenue and landings, respectively, for NEFMC managed species between 2008–2022 occurred within existing and proposed wind energy areas and may be displaced. Individual operators may depend on lease areas for even larger proportions of their annual landings or revenue.
- An Integrated Ecosystem Assessment is ongoing for offshore wind and fisheries interactions in the Gulf of Maine.
- Ongoing construction areas and planned future wind areas overlap with one of the only known winter right whale foraging habitats, and altered local oceanography could affect right whale prey availability. Development also increases vessel strike risk and the potential impacts of pile driving noise.



2023 Highlights

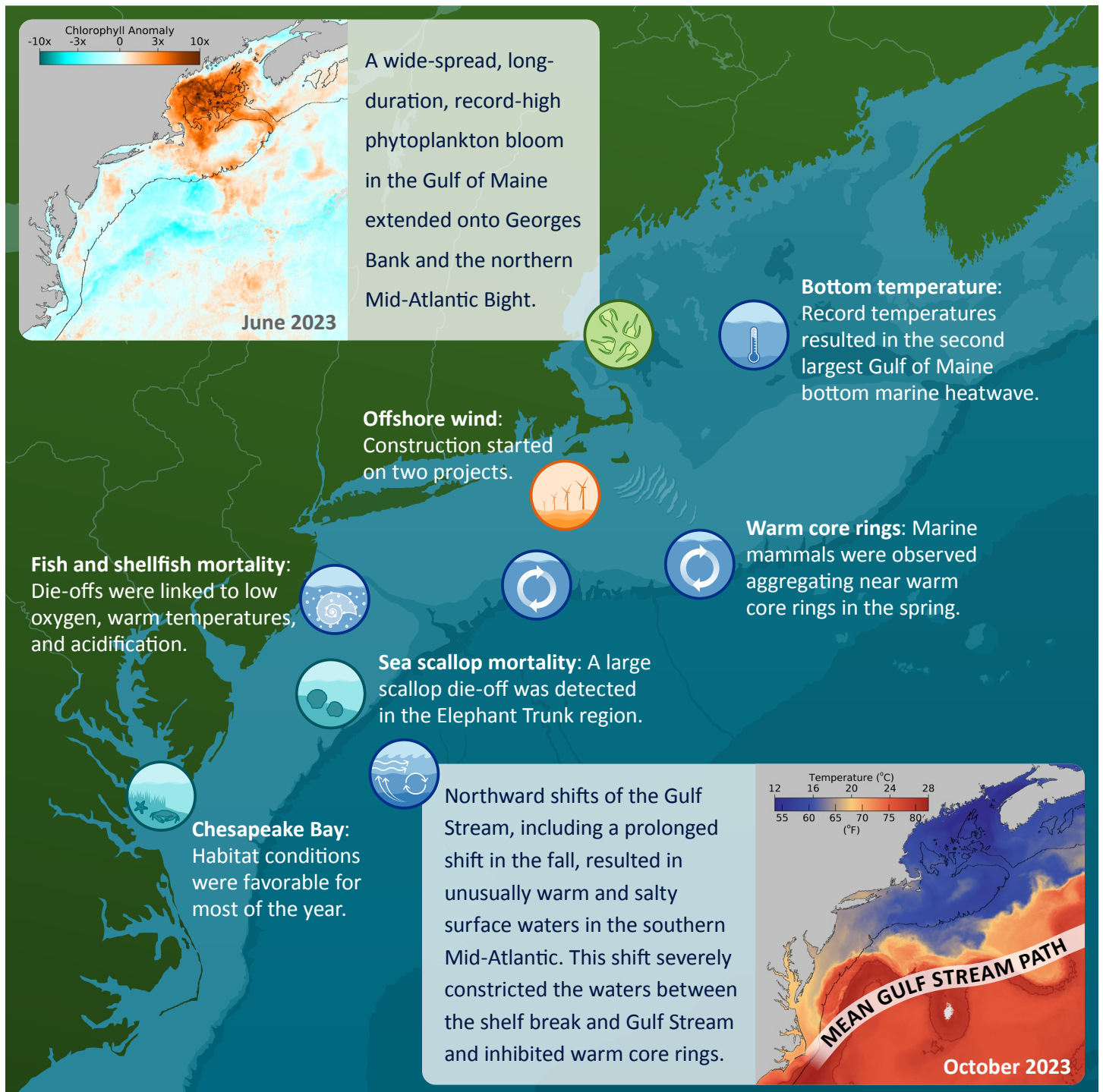
Multiple anomalous conditions and extreme events were observed in 2023 that could have brief local effects and/or widespread long-term ecosystem, fishery, and management implications. Anomalous events describe unusual or remarkable observations and can lead to increased uncertainty and unpredictable management outcomes.

Sea Surface Temperature

2023 global and North Atlantic sea surface temperatures were the warmest on record. However, Northeast U.S. shelf temperatures were more variable, with near record highs in winter and near average in other seasons.

El Niño Conditions

The 2020–2022 La Niña conditions ended in late winter and shifted to strong El Niño conditions in late spring 2023. The current El Niño is expected to gradually weaken and transition to neutral conditions in spring 2024.



Introduction

About This Report

This report is for the New England Fishery Management Council (NEFMC). The purpose of this report is to synthesize ecosystem information to allow the NEFMC to better meet fishery management objectives. The major messages of the report are synthesized on pages 1-3, with highlights of 2023 ecosystem events on page 4. The information in this report is organized into two main sections; **performance measured against ecosystem-level management objectives** (Table 1), and potential **risks to meeting fishery management objectives** (climate change and other ocean uses). A final new section introduced this year highlights **notable 2023 ecosystem observations**.

Report structure

We recommend new readers first review the details of standard figure formatting (Fig. 56a), categorization of fish and invertebrate species into feeding guilds (Table 4), and definitions of ecological production units (EPUs, including the Gulf of Maine (GOM) and Georges Bank (GB); Fig. 56b) provided at the end of the document.

The two main sections contain subsections for each management objective or potential risk. Within each subsection, we first review indicator trends, and the status of the most recent data year relative to a threshold (if available) or relative to the long-term average. Second, we synthesize results of other indicators and information to outline potential implications for management (i.e., connecting indicator(s) status to management and why an indicator(s) is important). For example, if there are multiple drivers related to an indicator trend, we examine which drivers may be more or less supported by current information, and which, if any, are affected by management action(s)? Similarly, we examine which risk indicators warrant continued monitoring to evaluate whether regime shifts or ecosystem reorganization are likely? We emphasize that these implications are intended to represent testable hypotheses at present, rather than “answers,” because the science behind these indicators and syntheses continues to develop.

A glossary of terms¹, detailed technical methods documentation² and indicator data³, and detailed indicator descriptions⁴ are available online.

Table 1: Example ecosystem-scale fishery management objectives for the New England region

Objective categories	Indicators reported
Provisioning and Cultural Services	
Seafood Production	Landings; commercial total and by feeding guild; recreational harvest
Profits	Revenue decomposed to price and volume
Recreation	Days fished; recreational fleet diversity
Stability	Diversity indices (fishery and ecosystem)
Social & Cultural	Community engagement/reliance status
Protected Species	Bycatch; population (adult and juvenile) numbers, mortalities
Supporting and Regulating Services	
Biomass	Biomass or abundance by feeding guild from surveys
Productivity	Condition and recruitment of managed species, Primary productivity
Trophic structure	Relative biomass of feeding guilds, Zooplankton
Habitat	Estuarine and offshore habitat conditions

Performance relative to fishery management objectives

In this section, we examine indicators related to broad, ecosystem-level fishery management objectives. We also provide hypotheses on the implications of these trends—why we are seeing them, what’s driving them, and potential

¹<https://noaa-edab.github.io/tech-doc/glossary.html>

²<https://NOAA-EDAB.github.io/tech-doc>

³<https://github.com/NOAA-EDAB/ecodata>

⁴<https://noaa-edab.github.io/catalog/index.html>

or observed regime shifts or changes in ecosystem structure. Identifying multiple drivers, regime shifts, and potential changes to ecosystem structure, as well as identifying the most vulnerable resources, can help managers determine whether anything different needs to be done to meet objectives and how to prioritize upcoming issues/risks.

Seafood Production

Indicator: Landings; commercial and recreational

This year, we present updated indicators for total [commercial landings](#), U.S. seafood landings, and Council-managed U.S. seafood landings. Total commercial landings within New England show no long-term trend on GB, and a long term decline in the GOM (Fig. 1). There exist long-term declines in commercial seafood landings and NEFMC managed seafood landings for both the GOM and GB, but over the last decade GOM landings appear to be relatively stable.

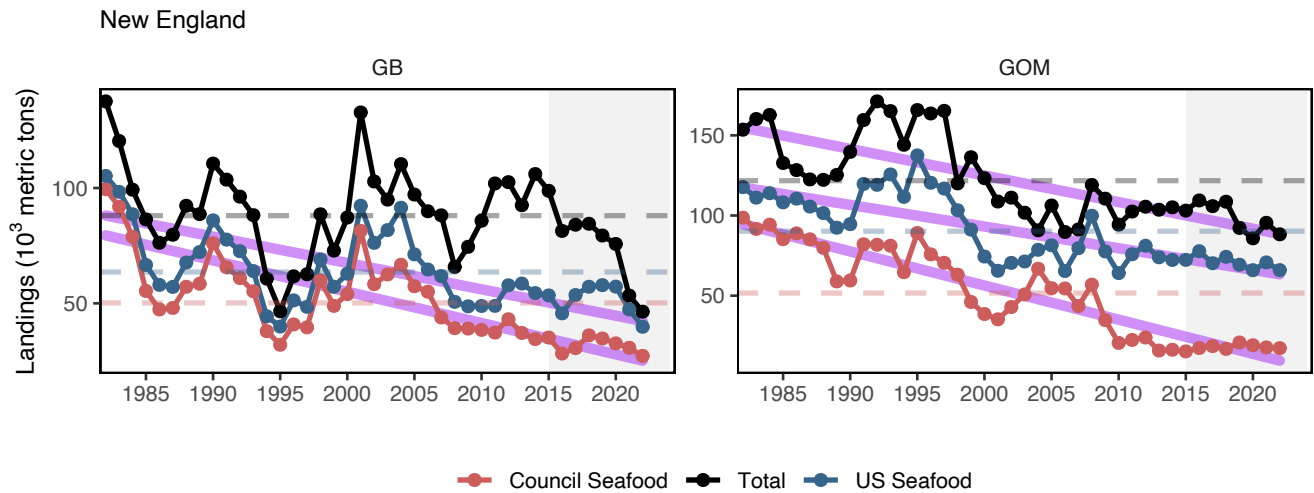


Figure 1: Total commercial landings (black), total U.S. seafood landings (blue), and New England managed U.S. seafood landings (red) for Georges Bank (GB) and the Gulf of Maine (GOM).

Commercial landings by guild include all species and all uses, and are reported as total for the guild and the NEFMC managed species within the [guild](#). As reported in previous years, downward trends persist for a number of guilds in both regions. Current high total landings for benthivores (GOM) are attributable to American lobster, and a significant long term increase in benthos landings (GB) is attributable to clams and scallops (Fig. 2). Current landings of planktivores are near historic lows.

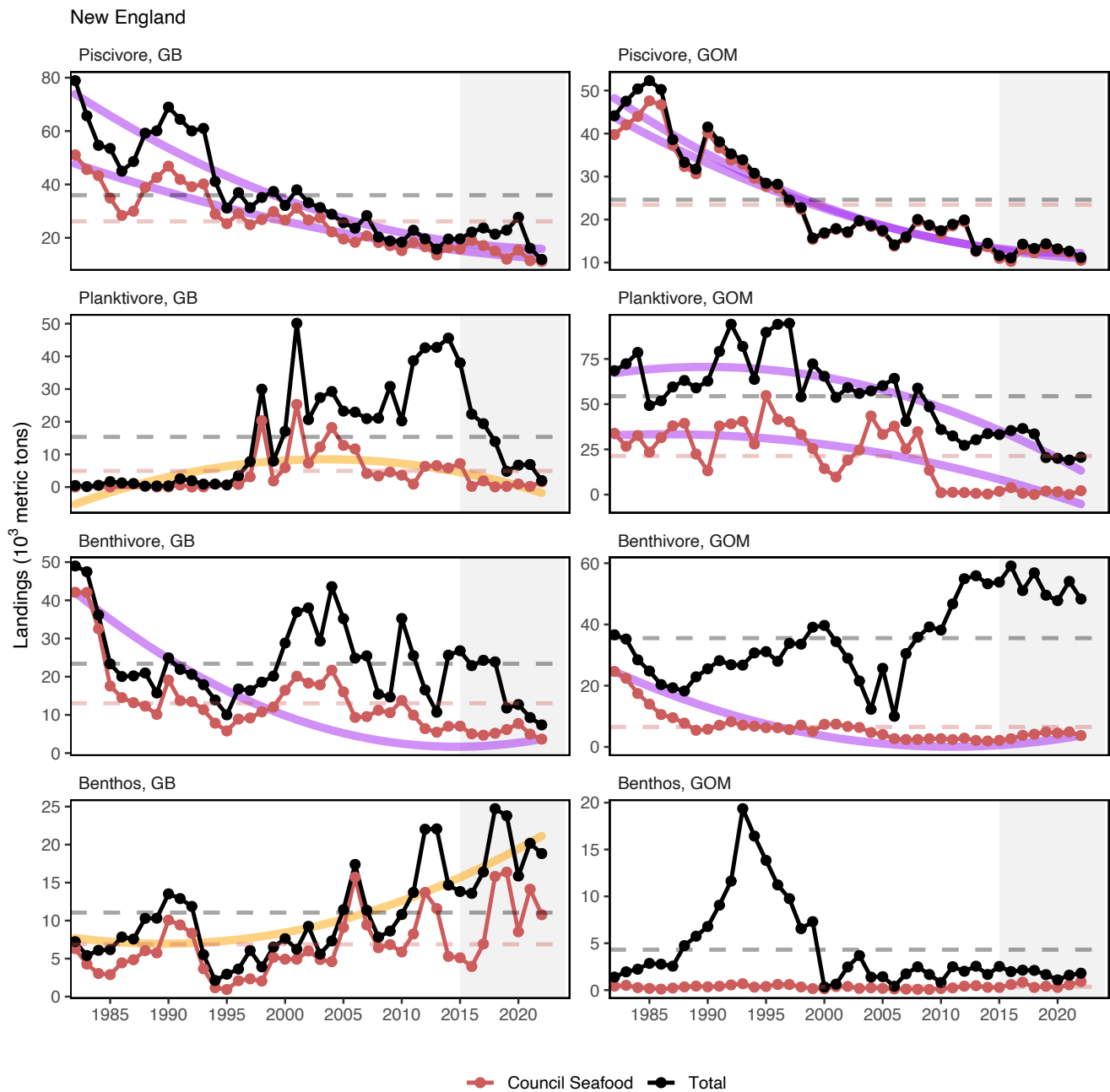


Figure 2: Total commercial landings (black) and NEFMC managed U.S. seafood landings (red) by feeding guild for the Gulf of Maine (GOM, right) and Georges Bank (GB, left).

Overall, [recreational harvest](#) (retained fish presumed to be eaten) has also declined in New England (Fig. 3). However, harvest has rebounded somewhat from the historical low level in 2020. Recreational [shark landings](#) of pelagic and prohibited sharks have declined since 2018 (Fig 4), likely influenced by regulatory changes implemented in 2018 intended to rebuild shortfin mako stocks.

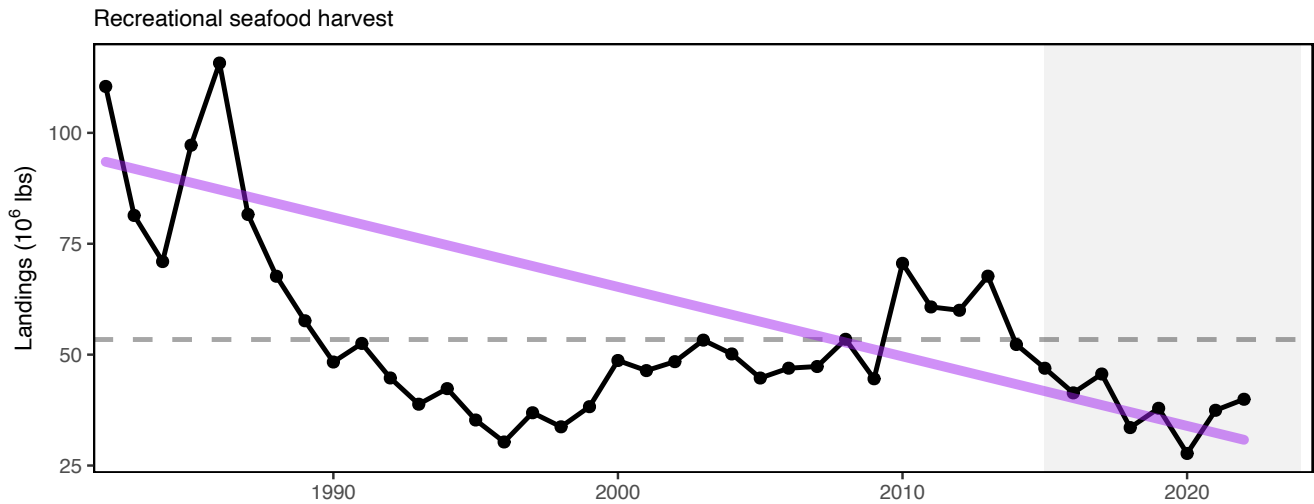


Figure 3: Total recreational seafood harvest (millions of pounds) in the New England region.

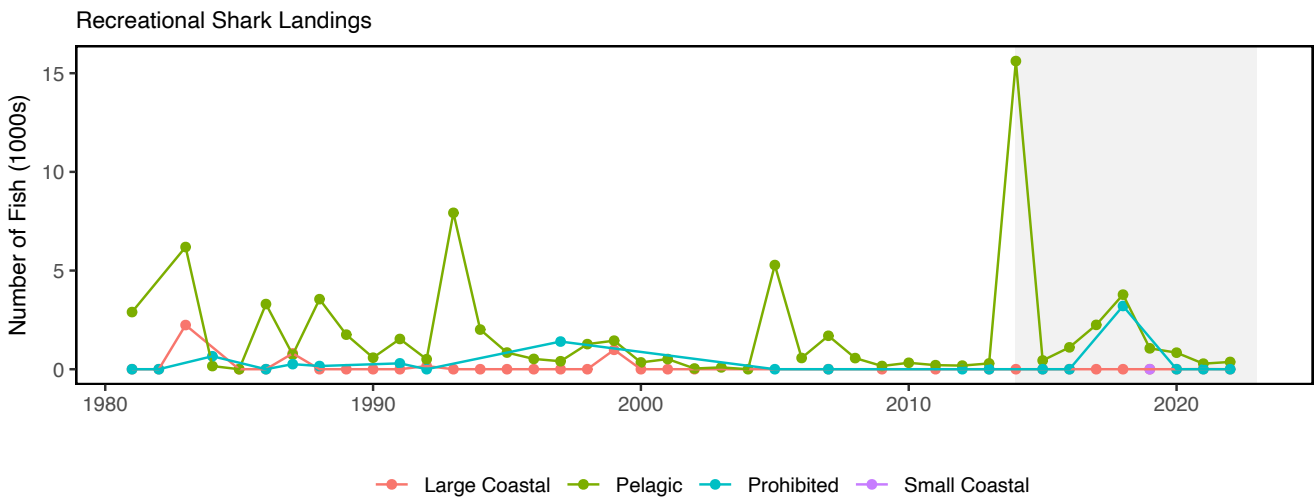


Figure 4: Recreational shark landings from Large Pelagics Survey.

[Aquaculture production](#) is not yet included in total seafood landings.

Implications

Declining commercial seafood and recreational landings are driven by many interacting factors, including combinations of ecological and stock production, management actions, market conditions, and environmental changes. While we cannot evaluate all possible drivers at present, here we evaluate the extent to which stock status and changes in system biomass play a role.

Stock Status Single species [management objectives](#) (1. maintaining biomass above minimum thresholds and 2. maintaining fishing mortality below overfishing limits) are not being met for some NEFMC managed species. Thirteen stocks are currently estimated to be below B_{MSY} , while status relative to B_{MSY} could not be assessed for 13 additional stocks (Table 2). Therefore, stock status and associated management constraints are likely contributing

to decreased landings. To better address the role of management in future reports, we could examine how the total allowable catch (TAC) and the percentage of the TAC taken for each species has changed through time.

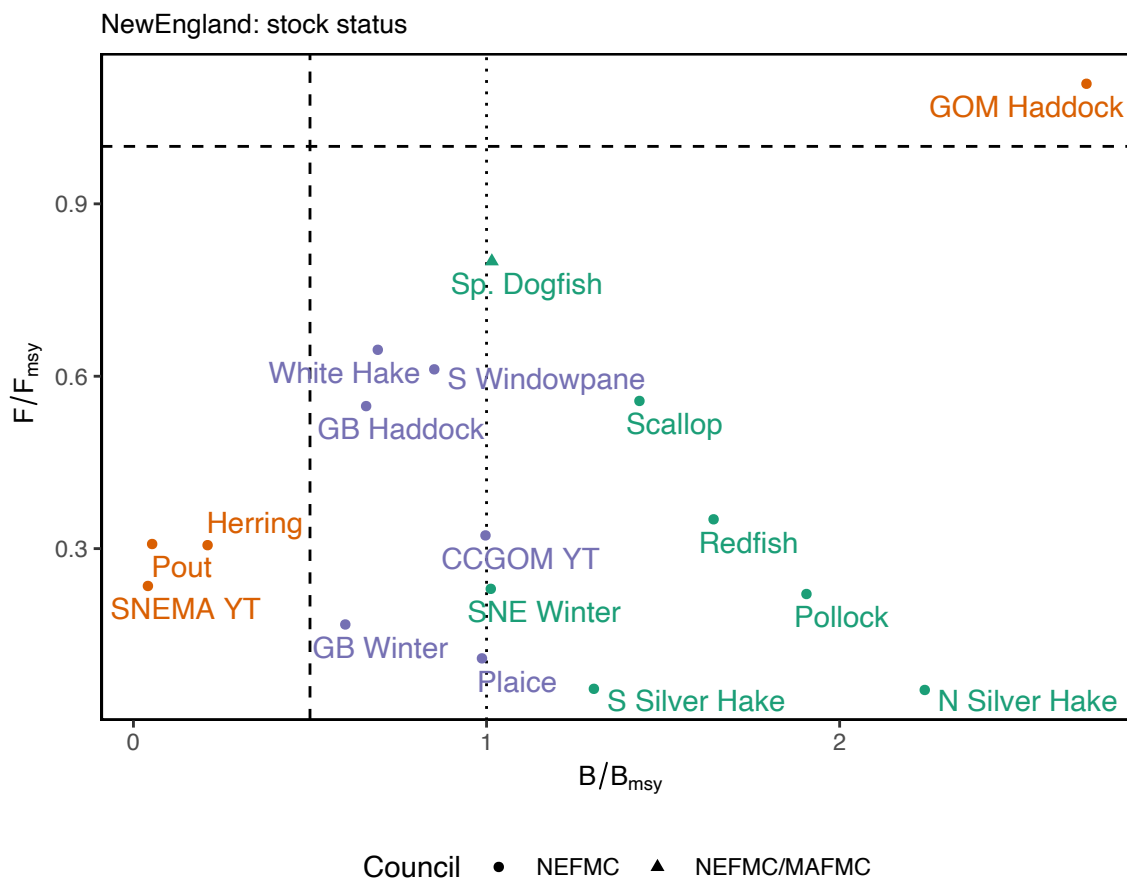


Figure 5: Summary of single species status for NEFMC and jointly federally managed stocks (goosefish and spiny dogfish). The dotted vertical line at one is the target biomass reference point of B. The dashed lines are the management thresholds of B (vertical) or F (horizontal). Colors denote stocks with $B/B_{MSY} < 0.5$ or F/F_{MSY} (orange), stocks $0.5 < B/B_{MSY} < 1$ (blue), and stocks $B/B_{MSY} > 1$ (green). CCGOM = Cape Cod Gulf of Maine, GOM = Gulf of Maine, GB = Georges Bank, SNEMA = Southern New England Mid Atlantic

System Biomass Aggregate biomass trends derived from scientific resource surveys have been stable to increasing in both regions (Fig. 6 & Fig. 7). The benthivores group spiked during the last decade, due to a large haddock recruitment, but appears to be returning to average levels. Planktivore biomass on GB continues to rise with the highest fall biomass observed since 1968. There are also increasing trends in piscivores, and planktivores in at least one season in both regions, and benthos on Georges Bank in both seasons. The New Hampshire/Maine state survey time series is too short to estimate trends, while the Massachusetts state survey shows the increasing trend in benthivores in the spring and planktivores in the fall but a decrease in piscivores in the spring and benthos in both seasons (Fig. 8). While managed species comprise varying proportions of aggregate biomass, trends in landings are not mirroring shifts in the overall trophic structure of survey-sampled fish and invertebrates. Therefore, major shifts in feeding guilds or ecosystem trophic structure are unlikely to be driving the decline in landings.

Table 2: Unknown or partially known stock status for MAFMC and jointly managed species.

Stock	F/F _{msy}	B/B _{msy}
Atlantic cod - Georges Bank	-	-

Stock	F/Fmsy	B/Bmsy
Atlantic cod - Gulf of Maine	-	-
Atlantic halibut - Northwestern Atlantic Coast	-	-
Barndoor skate - Georges Bank / Southern New England	-	0.968
Clearnose skate - Southern New England / Mid-Atlantic	-	1.667
Little skate - Georges Bank / Southern New England	-	0.662
Offshore hake - Northwestern Atlantic Coast	-	-
Red deepsea crab - Northwestern Atlantic	-	-
Red hake - Gulf of Maine / Northern Georges Bank	-	-
Red hake - Southern Georges Bank / Mid-Atlantic	-	-
Rosette skate - Southern New England / Mid-Atlantic	-	1.208
Smooth skate - Gulf of Maine	-	0.741
Thorny skate - Gulf of Maine	-	0.027
Windowpane - Gulf of Maine / Georges Bank	-	-
Winter flounder - Gulf of Maine	-	-
Winter skate - Georges Bank / Southern New England	-	1.714
Witch flounder - Northwestern Atlantic Coast	-	-
Yellowtail flounder - Georges Bank	0.09	-
Goosefish - Gulf of Maine / Northern Georges Bank	-	-
Goosefish - Southern Georges Bank / Mid-Atlantic	-	-

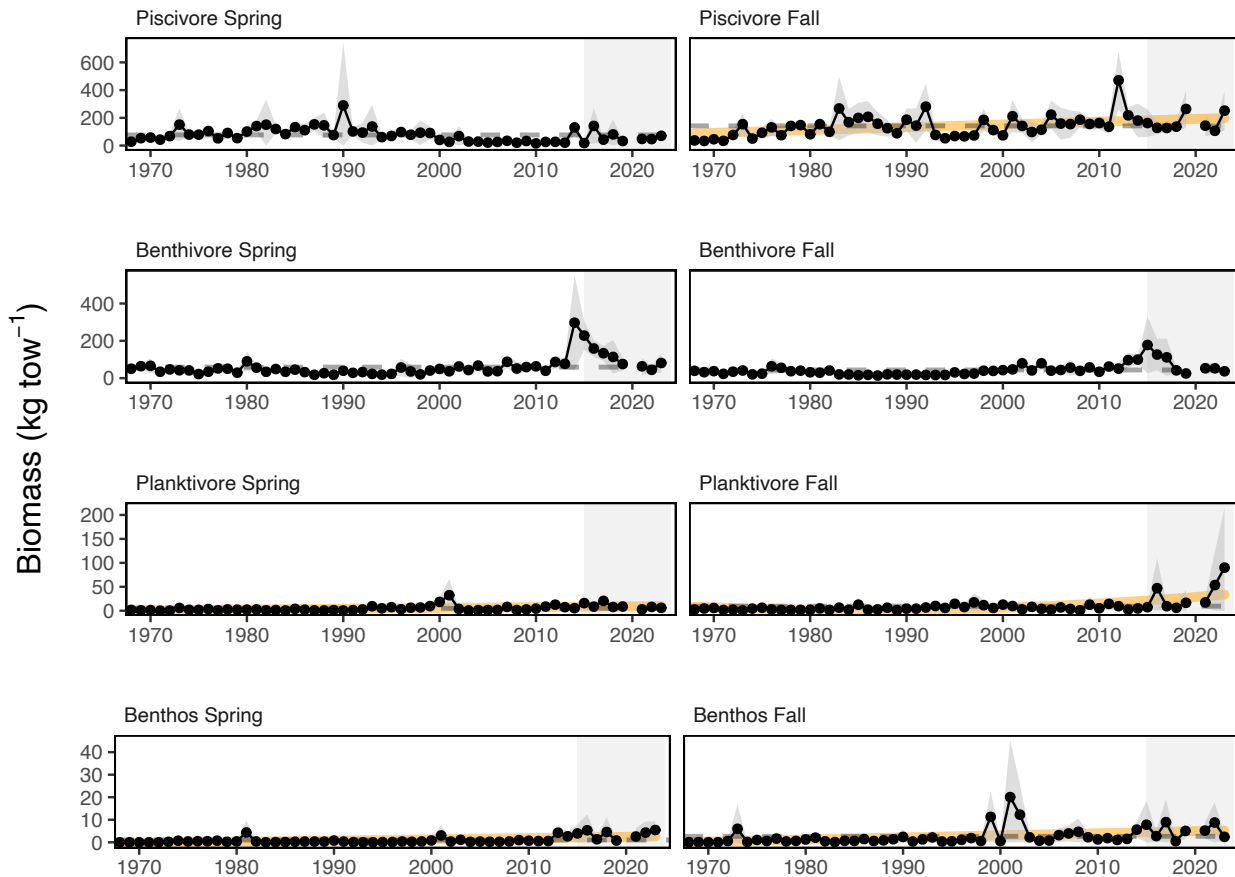


Figure 6: Spring (left) and fall (right) surveyed biomass on Georges Bank. The shaded area around each annual mean represents 2 standard deviations from the mean.

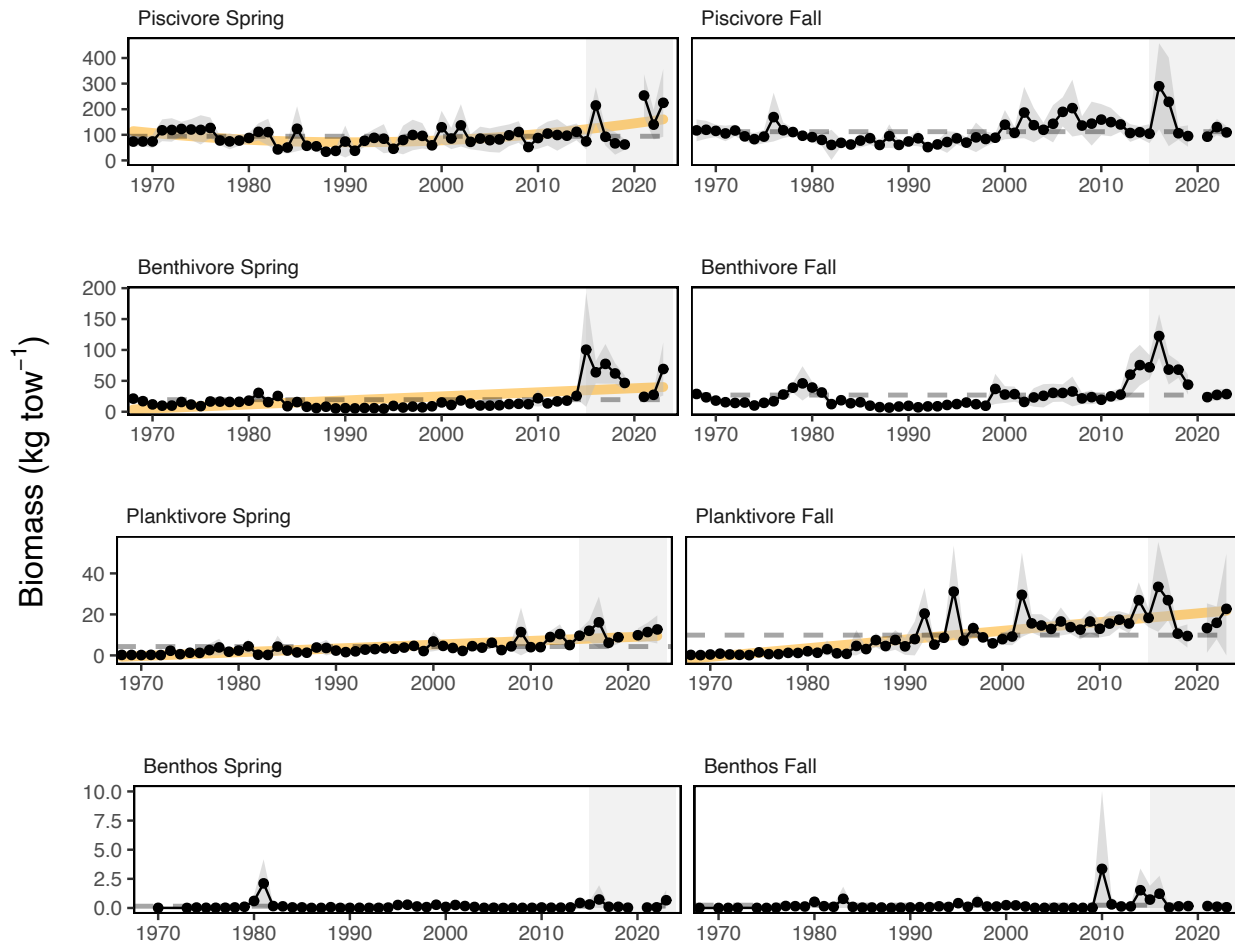


Figure 7: Spring (left) and fall (right) surveyed biomass in the Gulf of Maine. The shaded area around each annual mean represents 2 standard deviations from the mean.

Effect on Seafood Production With the poor or unknown stock status of many managed species, the decline in commercial seafood landings in the Gulf of Maine most likely reflects lower catch quotas implemented to rebuild overfished stocks, as well as market dynamics.

The decline in recreational seafood harvest stems from multiple drivers. Some of the decline, such as for recreational shark landings, continues to be driven by tightening regulations. However, changes in demographics and preferences for recreational activities likely play a role in non-HMS (Highly Migratory Species) declines in recreational harvest, with current harvests well below the time series average.

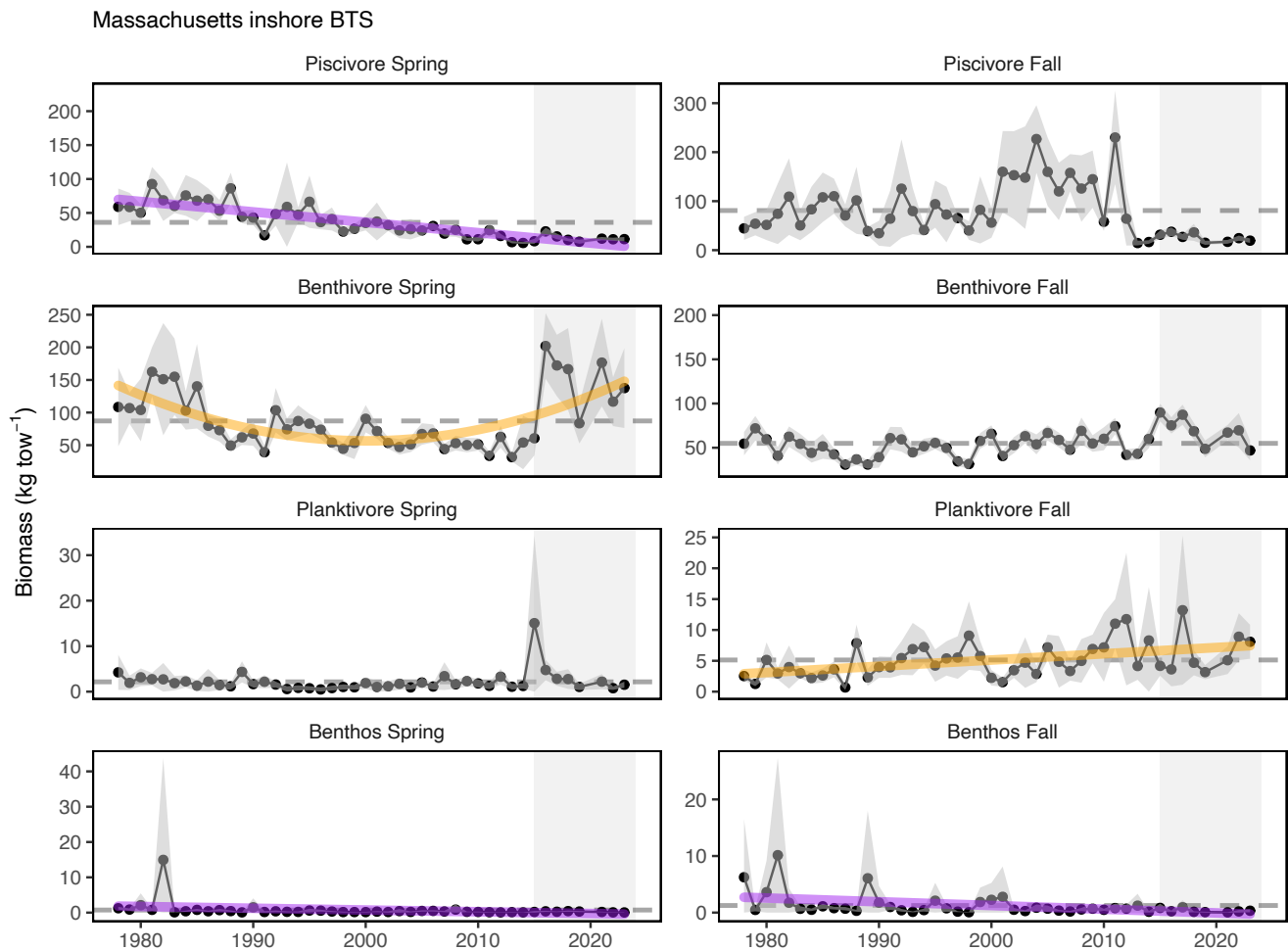


Figure 8: Spring (left) and fall (right) surveyed biomass from the state of Massachusetts inshore survey. The shaded area around each annual mean represents 2 standard deviations from the mean.

Other environmental changes require monitoring as they may become important drivers of future landings:

- Climate is trending into uncharted territory. Globally, 2023 was the warmest year on record⁵ (see [Climate Risks section](#)).
- Stocks are shifting their distribution, moving towards the northeast and into deeper waters throughout the Northeast US Large Marine Ecosystem (Fig. 29).
- Ecosystem composition and production changes have been observed (see [Stability section](#)).
- Some fishing communities are affected by environmental justice vulnerabilities (see [Environmental Justice and Social Vulnerability section](#)).

⁵https://noaa-edab.github.io/catalog/observation_synthesis.html

Commercial Profits

Indicators: revenue (a proxy for profits)

Commercial revenue in the region has been mostly positive with total commercial revenues from all species above the long-term mean for both the GB and GOM regions in 2022 (Fig. 9). However, revenue from NEFMC managed species shows a long-term decline in the GOM. GB continues to exhibit a cyclical nature with regards to revenue, largely driven by rotational management of Atlantic sea scallops.

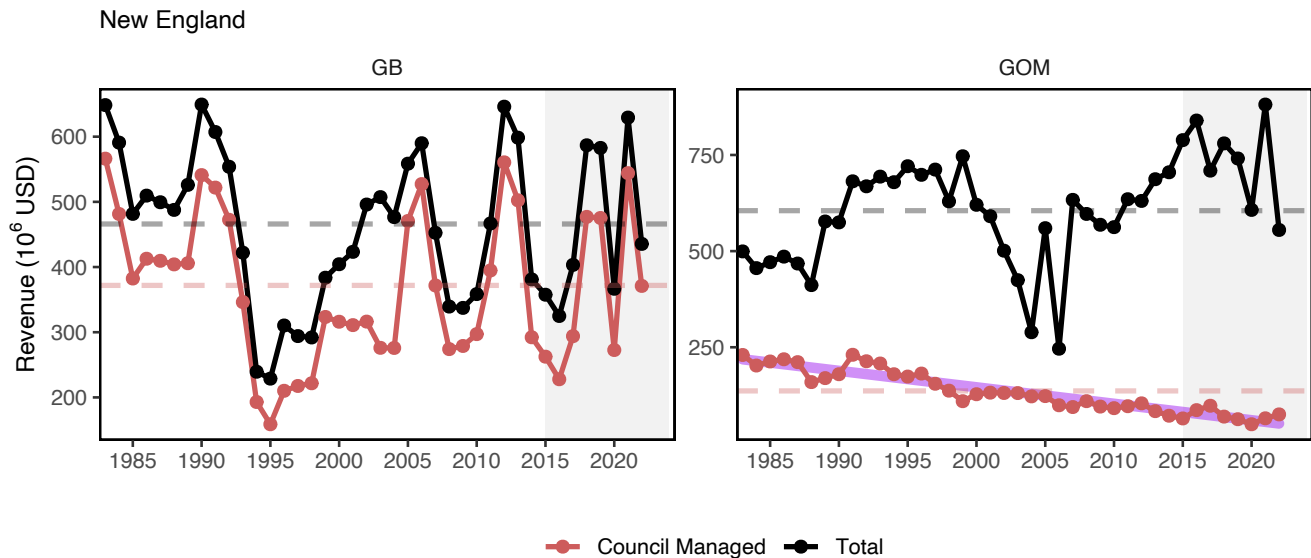


Figure 9: Revenue through 2022 for the New England region: total (black) and from NEFMC managed species (red).

Revenue earned by harvesting resources is a function of both the quantity landed of each species and the prices paid for landings. Beyond monitoring yearly changes in revenue, it is even more valuable to determine what drives these changes: harvest levels, the mix of species landed, price changes, or a combination of these. The [Bennet Indicator](#) decomposes revenue change into two parts, one driven by changing quantities (volumes), and a second driven by changing prices. All changes are in relation to a base year (1982). We note that 2022 Atlantic herring revenue data were incomplete for this report, and will be revised in future reports.

In the GB region, revenues have been consistently lower than the 1982 baseline throughout the time series. The changes in total revenue in GB was primarily driven by volumes prior to 2010, and then by prices (Fig.10). In the GOM, revenues have been above the 1982 baseline in all but four years, largely due to changing prices in most years. Breaking down the revenue by guild (Fig. 11), for GB, both the volume and price trend have been largely driven by benthos (quahogs and surfclams). In the GOM region, increased prices for benthivores drove the year-over-year increases in overall prices. Benthivores also had a large influence on the overall volume indicator in the GOM.

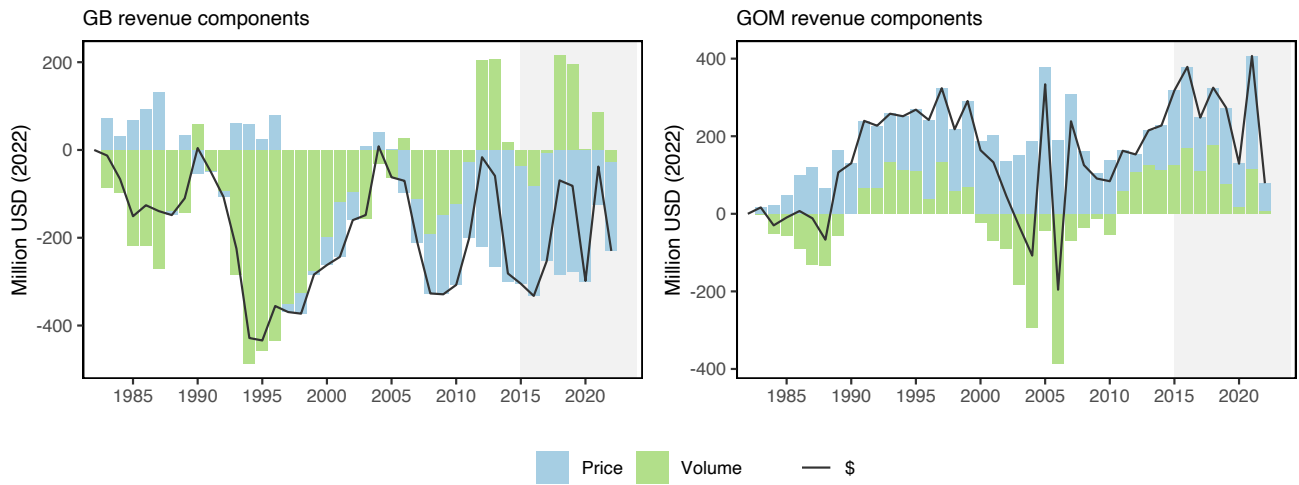


Figure 10: Revenue change from the 1982 baseline in 2022 dollars (black), price, and volume for commercial landings from Georges Bank (GB: left) and the Gulf of Maine (GOM: right)

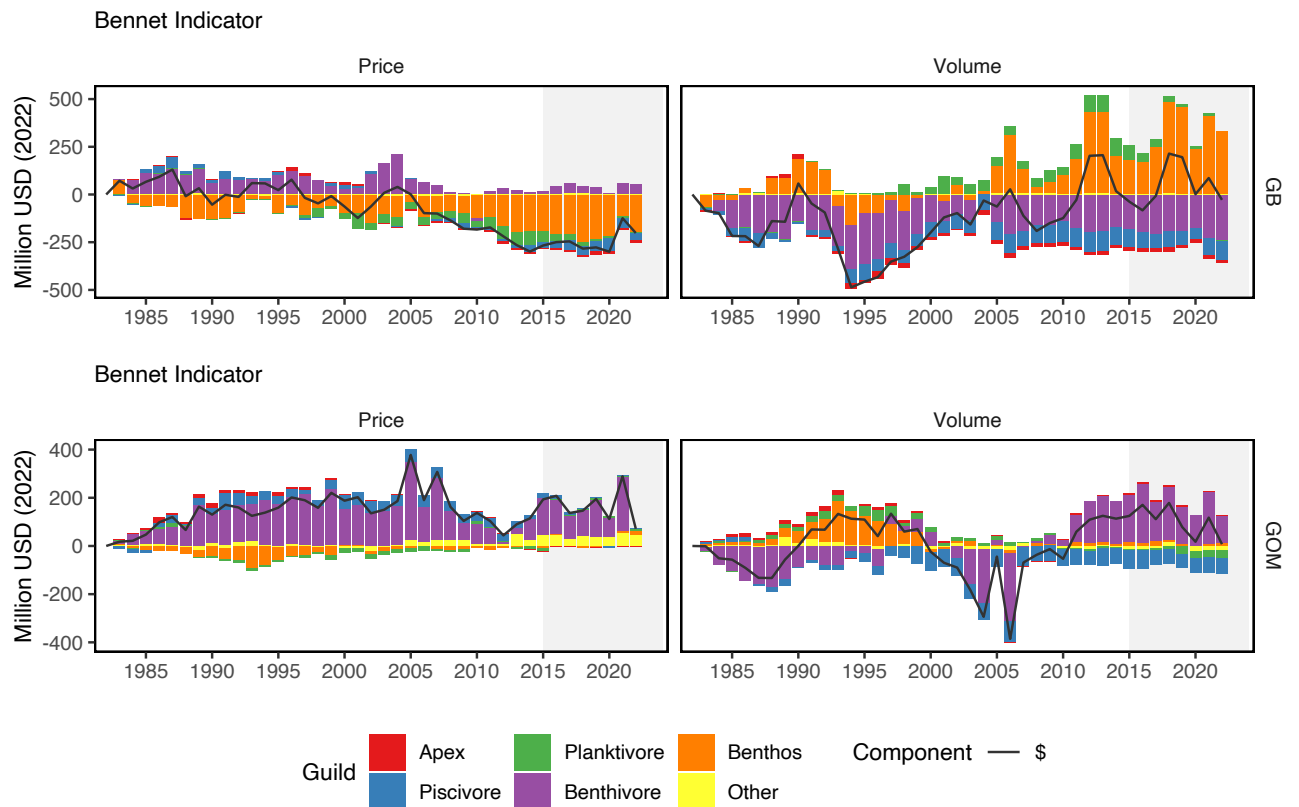


Figure 11: Revenue change from the long-term mean in 2022 dollars (black), price, and volume for commercial landings from Georges Bank (GB: top panels) and the Gulf of Maine (GOM: bottom panels)

Implications

The continued dependence on lobster in the GOM and sea scallops on GB is affected by multiple drivers including resource availability and market conditions. As both species are sensitive to ocean warming and acidification, it is important to monitor these and other climate drivers.

Recreational Opportunities

Indicators: Angler trips, fleet diversity

Recreational effort (angler trips) increased during 1982-2010, but has since declined to the long-term average (Fig. 12). Recreational fleets are defined as private vessels, shore-based fishing, or party-charter vessels. Recreational fleet diversity, or the relative importance of each fleet type, has remained relatively stable over the latter half of the time series (Fig. 13).

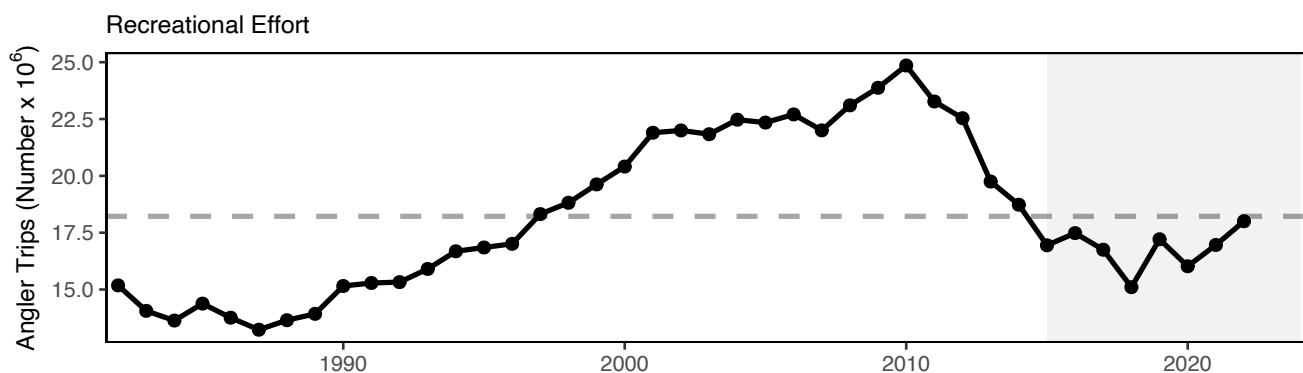


Figure 12: Recreational effort in New England.

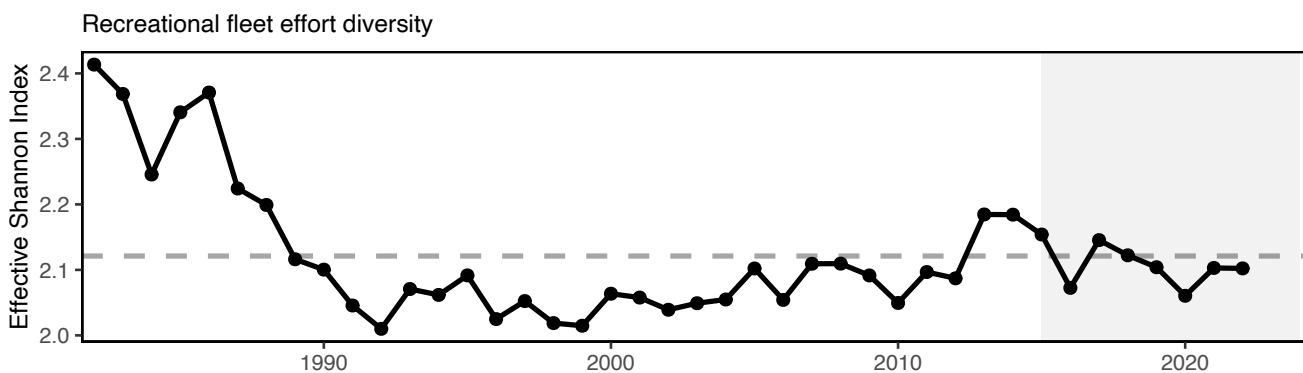


Figure 13: Recreational fleet effort diversity in New England.

Implications

The absence of a long term trend in recreational angler trips and fleet effort diversity suggests relative stability in the overall number of recreational opportunities in the region.

Stability

Indicators: fishery fleet and catch diversity, ecological component diversity, total primary production

While there are many potential metrics of stability, we use diversity indices to evaluate overall stability in fisheries and ecosystems. In general, diversity that remains constant over time suggests a similar capacity to respond to change over time. A significant change in diversity over time does not necessarily indicate a problem or an improvement, but does indicate a need for further investigation. We examine diversity in commercial fleet and species catch, and recreational species catch (with fleet effort diversity discussed above), zooplankton, and adult fishes.

Fishery Stability Diversity estimates have been developed for species landed by commercial vessels with New England permits and fleets landing managed species. Although the effective number of species being landed in the commercial fleet rebounded slightly from the historical low of 2021, the diversity in catch is still well below the series average (Fig. 14). Commercial fishery fleet count is also below the time series average.

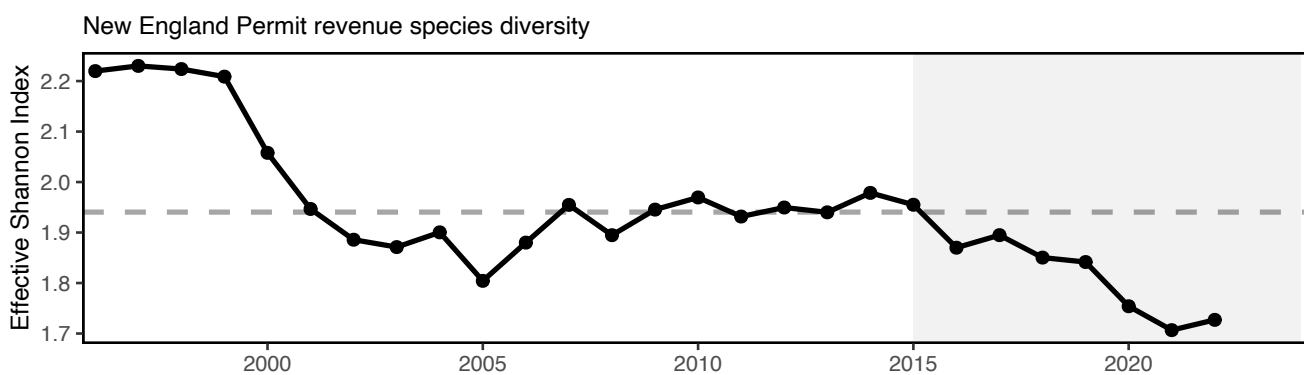


Figure 14: Species revenue diversity in New England.

As noted above, recreational fleet effort diversity is stable. However, recreational species catch diversity has been above the time series average since 2008 with a long-term positive trend (Fig. 15).

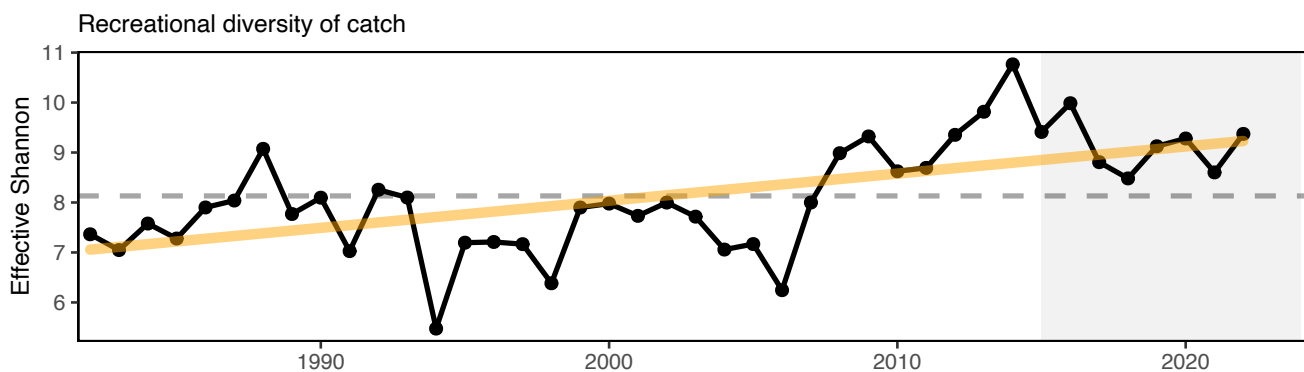


Figure 15: Diversity of recreational catch in New England.

Ecological Stability Total primary production (PP) is a measure of the total energy input into a system per year. 2023 saw record high PP in the GOM, which may indicate a change in system-wide processes.

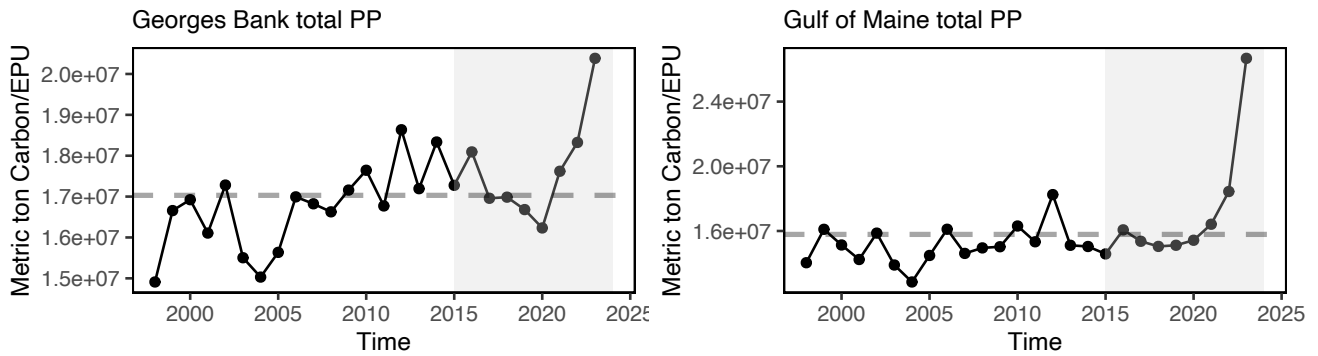


Figure 16: Total areal annual primary production by ecological production unit. The dashed line represents the long-term (1998-2023) annual mean.

Ecological diversity indices show mixed trends. [Zooplankton diversity](#) is increasing on GB, while no trend is evident in the GOM (Fig. 17). However, it is worth noting that the 2021 index for the GOM is the highest observed. [Adult fish diversity](#) shows an increasing trend in the GOM and no trend on GB (Fig. 18). This metric is measured as the expected number of species in a standard number of individuals sampled from the NEFSC bottom trawl survey.

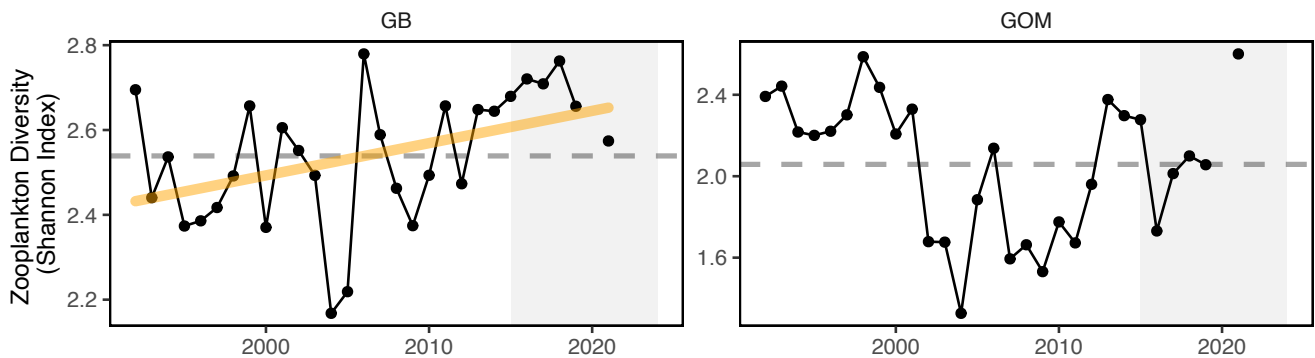


Figure 17: Zooplankton diversity on Georges Bank and in the Gulf of Maine, based on Shannon diversity index. 2020 surveys were incomplete due to COVID-19.

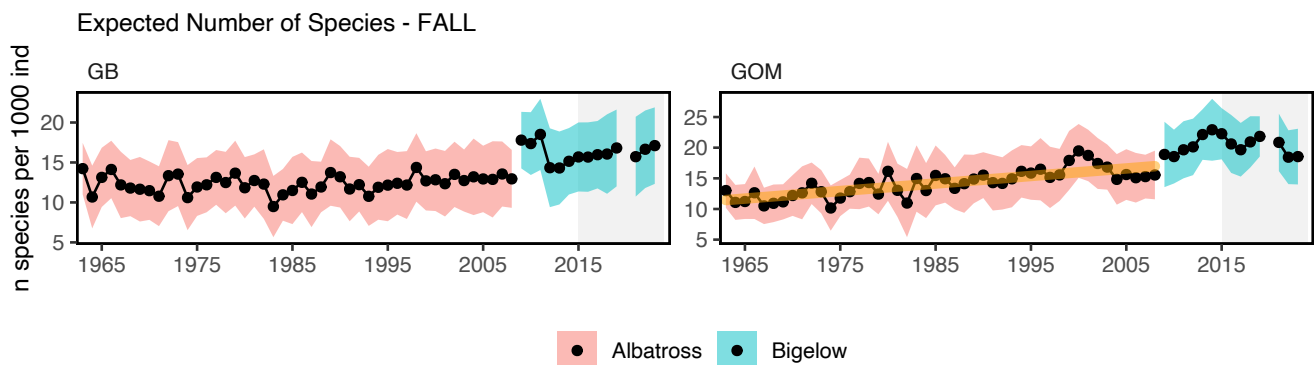


Figure 18: Adult fish diversity for Georges Bank and in the Gulf of Maine, based on expected number of species. Results from survey vessels Albatross and Bigelow are reported separately due to catchability differences.

Implications

Fleet diversity indices can be used to evaluate stability objectives as well as risks to fishery resilience and to maintain equity in access to fishery resources. The relatively low diversity estimates for the commercial fishery are likely driven by the continued reliance on a few species, such as sea scallops and lobster. This trend could diminish the capacity to respond to future fishing opportunities. Meanwhile, the increase in recreational species catch diversity is due to recent increases in Atlantic States Fisheries Management Council (ASFMC) and MAFMC managed species within the region, offsetting decreased limits on more traditional regional species.

Ecological diversity indices can provide insight into ecosystem structure. Changes in ecological diversity over time may indicate altered ecosystem structure with implications for fishery productivity and management. Increasing zooplankton diversity in GB is attributed to an overall increase in zooplankton abundance and the declining dominance of the calanoid copepod *Centropages typicus*. Stable adult fish diversity on GB suggests the same overall number and evenness over time, but does not rule out species substitutions (e.g., warm-water species replacing cold-water ones). Increasing adult diversity in the GOM suggests an increase in warm-water species and should be closely monitored.

As a whole, the examined diversity indicators suggest changes in commercial and recreational fisheries, likely driven by changes in the mix of species landed. However, there seems to be overall stability in ecosystem components. Increasing diversity in the recreational catch, GB zooplankton, and GOM adult fish accompanied by lows in commercial fleet diversity metrics, suggests warning signs of a potential regime shift or ecosystem restructuring and warrants continued monitoring to determine if managed species are affected.

Environmental Justice and Social Vulnerability

Indicators: Environmental Justice and Social Vulnerability in commercial and recreational fishing communities

Social vulnerability measures social factors that shape a community's ability to adapt to change. A subset of these can be used to assess potential environmental justice issues. We report the top ten communities most engaged in, and/or reliant upon, commercial and recreational fisheries and the degree to which these communities may be vulnerable to environmental justice issues (i.e., Poverty, Population Composition, and Personal Disruption) based on 2021 data. The engagement and reliance indices demonstrate the importance of commercial and recreational fishing to a given community relative to other coastal communities in a region. Similarly, the environmental justice indices characterize different facets and levels of social vulnerability in a given community relative to other coastal communities in a region.

Two commercial fishing communities (Stonington and Beals, ME) scored high for both engagement and reliance based on 2021 data (Fig. 19). New Bedford and Boston, MA and Swans Island, ME ranked medium-high or above for one or more of the environmental justice indicators in 2021 (Fig. 20). Swan's Island has considerable unemployment concerns, but does not have the same demographic and age structure concerns as Boston or New Bedford. Port Clyde-Tenants Harbor and Stonington, ME ranked medium for one or more of the environmental justice indicators. Decreased commercial fishing engagement/reliance led to Winter Harbor, ME no longer being listed as a top ten commercial fishing community.

In New England, Dennis and Bourne, MA scored high for both recreational engagement and reliance, whereas no communities did previously (Fig. 21). Seabrook and Newington, NH; Sandwich and Yarmouth, MA; Groton and Clinton, CT have decreased in their recreational engagement/reliance and are no longer listed as top ten recreational communities, replaced by Barnstable Town, Plymouth, Falmouth, and Chatham, MA; Sronington, CT; Tiverton and New Shoreham, RI. There are no communities ranked medium-high or above for environmental justice indicators (Fig. 22). Communities that ranked medium for one or more of the environmental justice indicators including Falmouth and Dennis, MA.

Narragansett/Point Judith, like all of these top recreational communities ranked low for environmental justice vulnerability. In fact, the scores below 0 for all three environmental justice indicators implies a lower than average level of vulnerability, based on recreational engagement and reliance, among the communities included in the analysis.

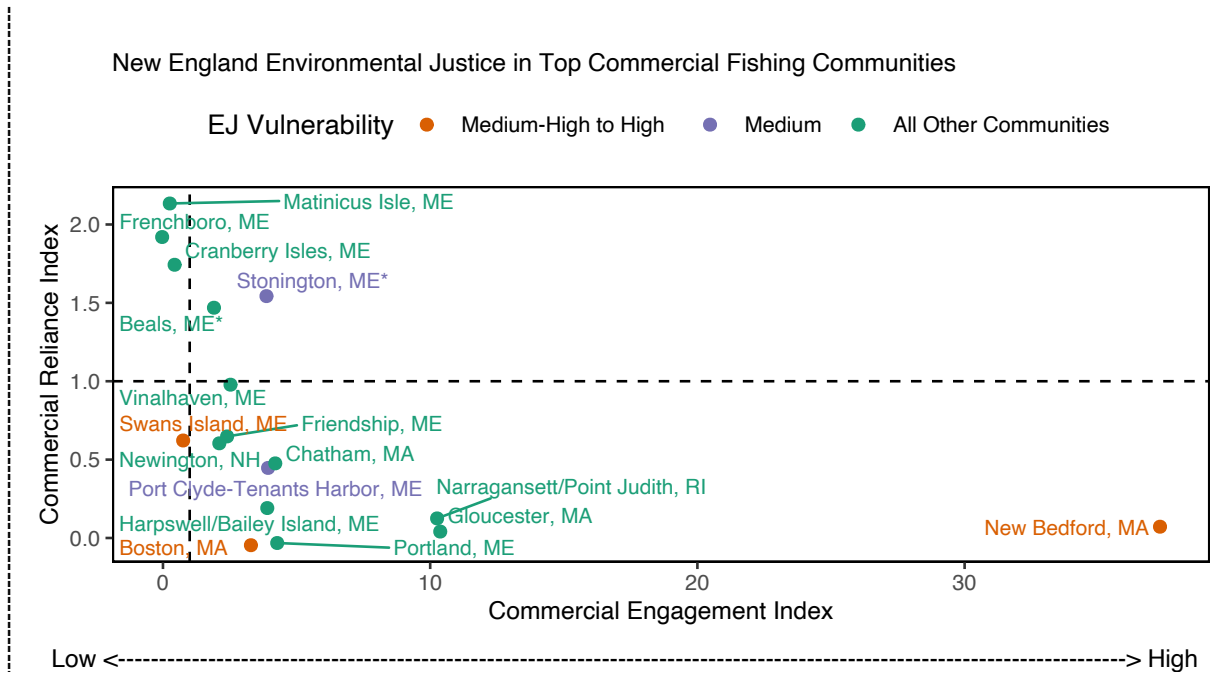


Figure 19: Commercial engagement, reliance, and environmental justice vulnerability for the top commercially engaged and reliant fishing communities in New England. Communities in orange are ranked medium-high or above for one or more of the environmental justice indicators. Communities in purple are ranked medium for one or more of the environmental justice indicators. *Community scored high (1.00 and above) for both commercial engagement and reliance indicators.

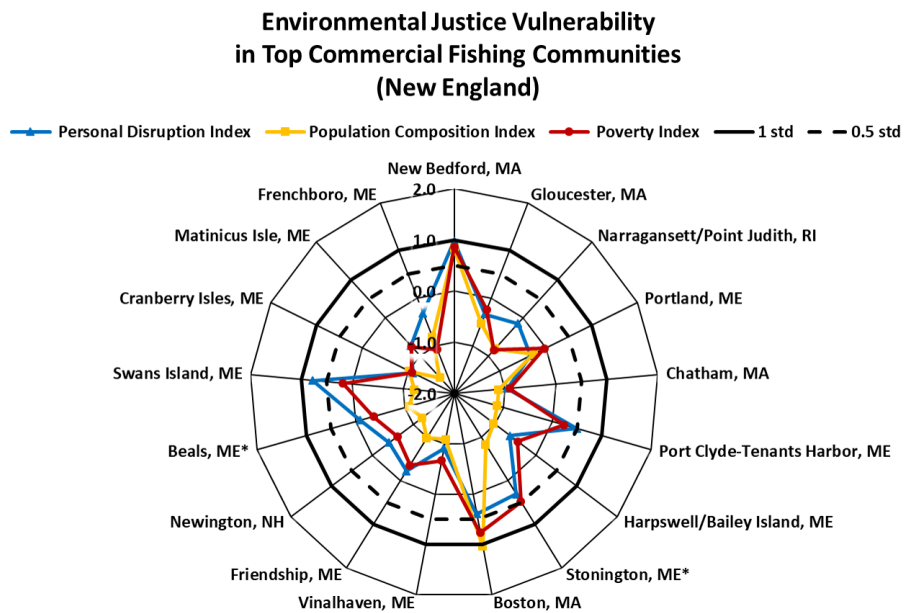


Figure 20: Environmental justice indicators (Poverty Index, population composition index, and personal disruption index) for top commercial fishing communities in New England. *Community scored high (1.00 and above) for both commercial engagement and reliance indicators.

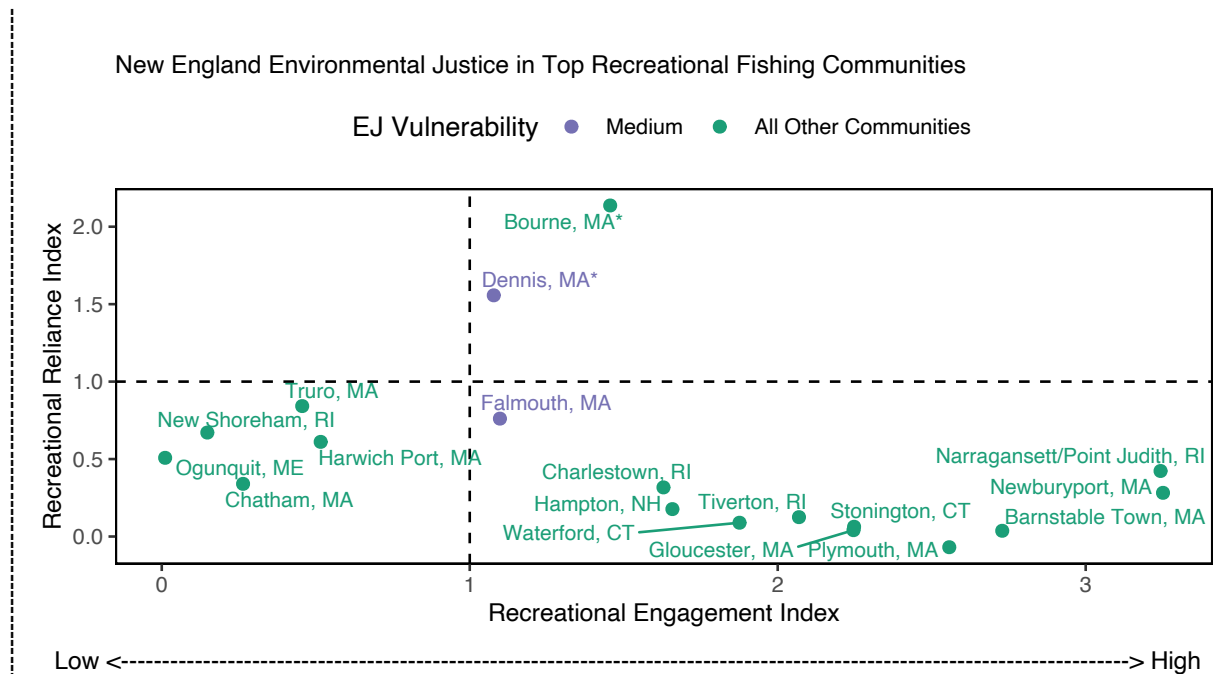


Figure 21: Recreational engagement and reliance, and environmental justice vulnerability, for the top recreationally engaged and reliant fishing communities in New England. None of these communities ranked medium-high or above for one or more of the environmental justice indicators. Communities ranked medium for one or more of the environmental justice indicators are highlighted in purple. *Community scored high (1.00 and above) for both recreational engagement and reliance indicators.

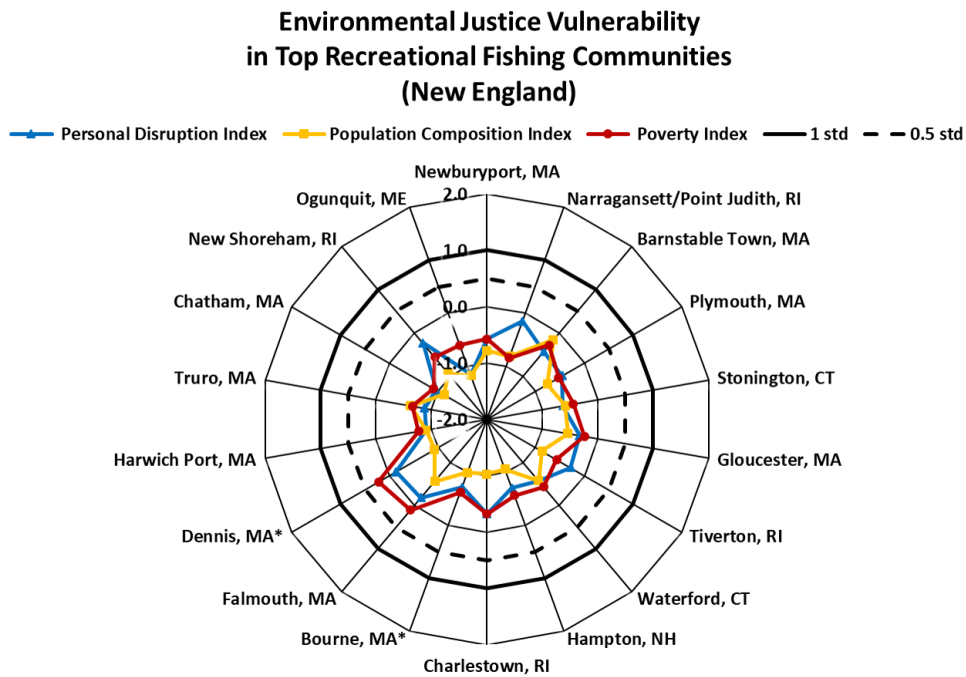


Figure 22: Environmental justice indicators (Poverty Index, population composition index, and personal disruption index) for top recreational fishing communities in New England. *Community scored high (1.00 and above) for both commercial engagement and reliance indicators.

Both commercial and recreational fishing are important activities in Narragansett/Point Judith, RI; Gloucester and Chatham, MA, meaning these communities may be impacted simultaneously by commercial and recreational regulatory changes. These three communities currently score low for all of the three environmental justice indicators, indicating that environmental justice may not be a major concern in these communities at the moment based on the indicators analyzed.

Implications

These indicators provide a snapshot of the presence of environmental justice issues in the most highly engaged and most highly reliant commercial and recreational fishing communities in New England. These communities may be especially vulnerable to changes in fishing patterns due to regulations and/or climate change. A range of environmental justice concerns are found throughout New England fishing communities. However, index scores for these concerns are higher overall in the top commercial communities relative to the top recreational communities. Some changes occurred among the top recreational fishing communities between 2020 and 2021 due to shifts in recreational fishing activities, while the top commercial communities remained stable. A few of these top fishing communities, mostly commercial fishing communities, demonstrated medium to high environmental justice vulnerability, indicating that they may be at a disadvantage responding to change.

Protected Species

Fishery management objectives for protected species generally focus on reducing threats and on habitat conservation/restoration. Protected species include marine mammals protected under the Marine Mammal Protection Act, endangered and threatened species protected under the Endangered Species Act, and migratory birds protected under the Migratory Bird Treaty Act. In the Northeast U.S., endangered/threatened species include Atlantic salmon, Atlantic and shortnose sturgeon, all sea turtle species, and five baleen whales. Protected species objectives include managing bycatch to remain below potential biological removal (PBR) thresholds, recovering endangered populations, and monitoring unusual mortality events (UMEs). Here we report on performance relative to these objectives with available indicator data, as well as indicating the potential for future interactions driven by observed and predicted ecosystem changes in the Northeast U.S.

Indicators: bycatch, population (adult and juvenile) numbers, mortalities

Average indices for both harbor porpoise (Fig. 23) and gray seal bycatch (Fig. 24) are below current PBR thresholds, meeting management objectives.

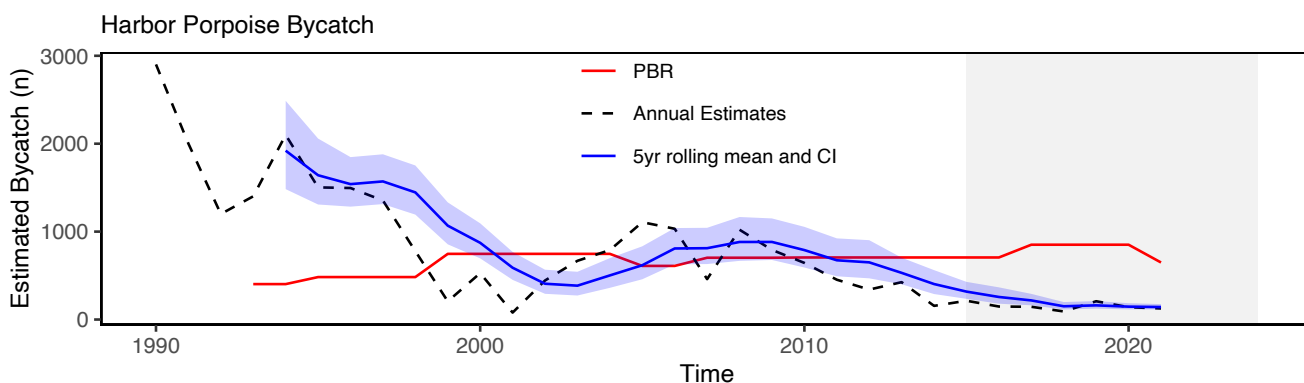


Figure 23: Harbor porpoise average bycatch estimate for Mid-Atlantic and New England gillnet fisheries (blue) and the potential biological removal (red).

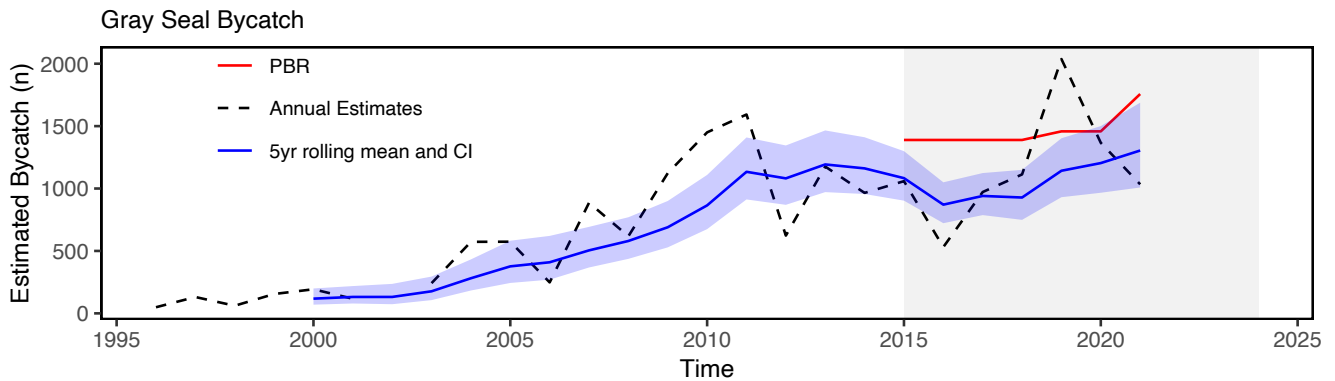


Figure 24: Gray Seal average bycatch estimate for gillnet fisheries (blue) and the potential biological removal (red).

The annual estimate for gray seal bycatch has declined since 2019, in part driven by declining gillnet landings. In addition, estimates since 2019 have greater uncertainty stemming from low observer coverage since 2019. The rolling mean confidence interval remains just below the PBR value.

The [North Atlantic right whale population](#) was on a recovery trajectory until 2010, but has since declined (Fig. 25). The sharp decline observed from 2015-2020 appears to have slowed, although the right whale population continues to experience annual mortalities above recovery thresholds. Reduced survival rates of adult females lead to diverging abundance trends between sexes. It is estimated that there are fewer than 70 adult females remaining in the population.

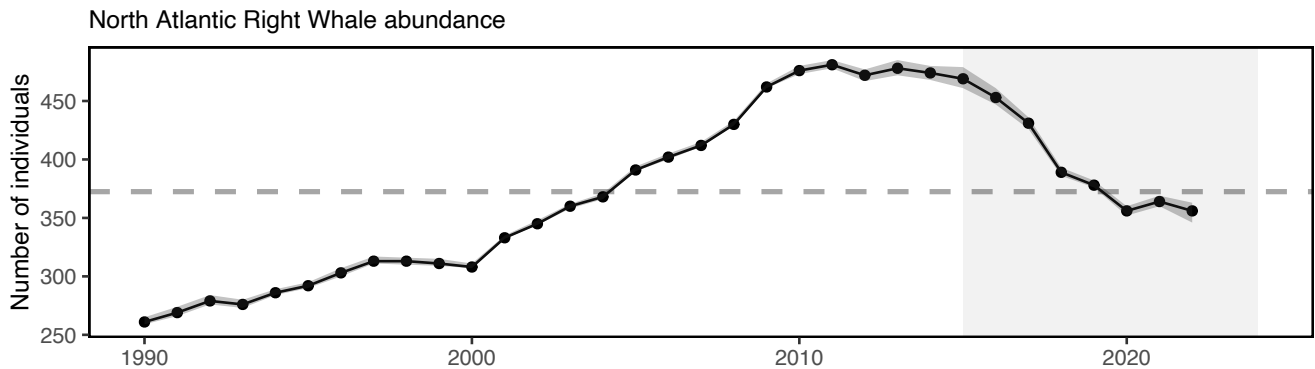


Figure 25: Estimated North Atlantic right whale abundance on the Northeast Shelf.

North Atlantic right whale [calf counts](#) have generally declined after 2009 to the point of having zero new calves observed in 2018 (Fig. 26). However, since 2019, we have seen more calf births each year with 15 births in 2022.

This year, the Unusual Mortality Event (UME) for North Atlantic right whales continued. Since 2017, the total UME right whale mortalities includes 36 dead stranded whales, 15 in the U.S. and 21 in Canada. When alive but seriously injured whales (35) and sublethal injuries or ill whales (51) are taken into account, 122 individual whales are included in the UME. Recent research suggests that many mortalities go unobserved and the true number of mortalities are about three times the count of the observed mortalities. The primary cause of death is “human interaction” from entanglements or vessel strikes.

A UME continued from previous years for humpback whales (2016-present); suspected causes include human interactions. A UME for both gray and harbor seals on the Maine coast was declared in June 2022 due to a high number of mortalities thought to be caused by highly pathogenic avian influenza virus. A UME for minke whales that began in 2017 remains open, but is pending closure as of January 2024.

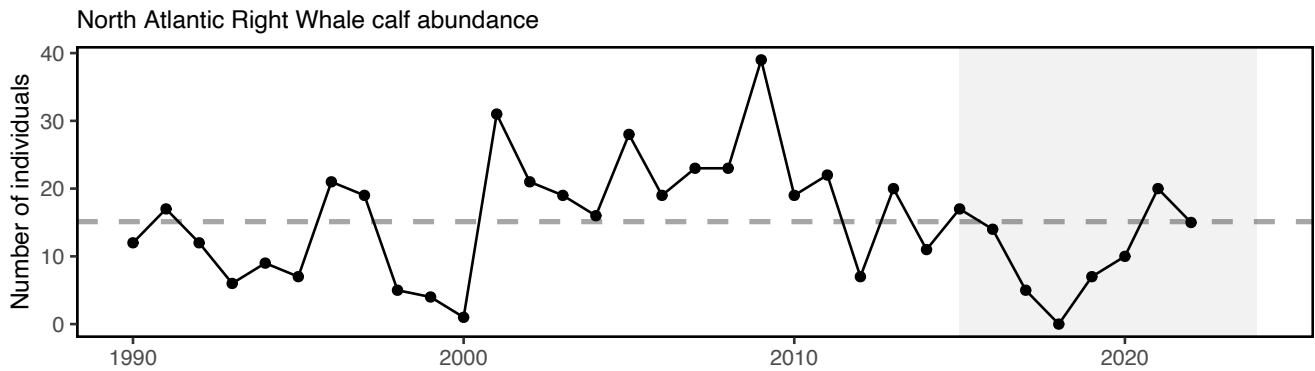


Figure 26: Number of North Atlantic right whale calf births, 1990 - 2021.

Implications

Bycatch management measures have been implemented to maintain bycatch below PBR thresholds. The downward trend in harbor porpoise bycatch can also be due to a decrease in harbor porpoise abundance in U.S. waters, reducing their overlap with fisheries, and a decrease in gillnet effort. The increasing trend in gray seal bycatch may be related to an increase in the gray seal population ([U.S. pup counts](#)), supported by the dramatic rise over the last three decades in observed numbers of gray seal pups born at U.S. breeding sites plus an increase in adult seals at the breeding sites (Fig. 27), some of which are supplemented by Canadian adults.

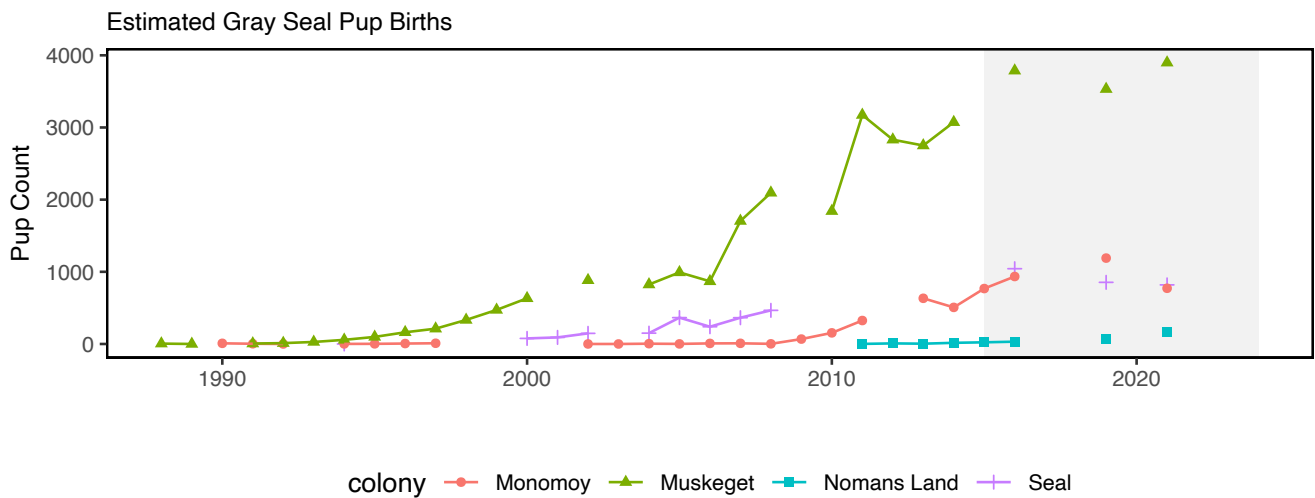


Figure 27: Estimated number of gray seal pups born at four United States pupping colonies at various times from 1988 to 2021. Recreated from Wood et al. 2022 (Figure 5).

Strong evidence exists to suggest that interactions between right whales and both the fixed gear fisheries in the U.S. and Canada and vessel strikes in the U.S. are contributing substantially to the decline of the species. Further, right whale distribution has changed since 2010. [New research](#) suggests that recent climate driven changes in ocean circulation have resulted in right whale distribution changes driven by increased warm water influx through the Northeast Channel, which has reduced the primary right whale prey (*Calanus finmarchicus*) in the central and eastern portions of the Gulf of Maine. Additional potential stressors include offshore wind development, which overlaps with important habitat areas used year-round by right whales, including mother and calf migration corridors and foraging habitat. This area is also a primary right whale winter foraging habitat. Additional information can be found in the [offshore wind risks section](#).

A UME continued from previous years for humpback whales (2016-present) and Atlantic minke whales (2018-present); suspected causes include human interactions. A UME for Northeast pinnipeds that began in 2018 for infectious disease is pending closure as of February 2024.

A climate vulnerability assessment is published for Atlantic and Gulf of Mexico marine mammal populations.

Risks to meeting fishery management objectives

Climate and Ecosystem Change

Regulations and measures designed to meet fishery management objectives are often based on historical information about stocks, their distribution in space and time, and their overall productivity. Large scale climate related changes in the ecosystem can lead to changes in important habitats and ecological interactions, altering distributions and productivity. With large enough ecosystem changes, management measures may be less effective and management objectives may not be met.

This year, we restructured this section to focus on three categories of management decisions and the risk posed to them by climate and ecosystem change: spatial management, seasonal management, and quota setting or rebuilding depleted stocks. In each section, we describe potential risks to the management category, highlight indicators of observed changes that contribute to those risks, and review possible biological and environmental drivers and the ways they may explain the observed indicators.

Risks to Spatial Management

Shifting species distributions (changes in spatial extent or center of gravity) alter both species interactions and fishery interactions. In particular, shifting species distributions can affect expected management outcomes from spatial allocations and bycatch measures based on historical fish and protected species distributions. Additionally, species availability to surveys can change as distributions shift within survey footprints.

Indicator: Fish and protected species distribution shifts As noted in the [landings implications section](#) above, the [center of distribution](#) for a suite of 48 commercially or ecologically important fish species along the entire Northeast Shelf continues to show movement towards the northeast and generally into deeper water (Fig. 29). [Habitat model-based species richness](#) suggests shifts of both cooler and warmer water species to the northeast. Similar patterns have been found for [marine mammals](#), with multiple species shifting northeast between 2010 and 2017 in most seasons (Fig. 28).

Whale and Dolphin Distribution Shifts

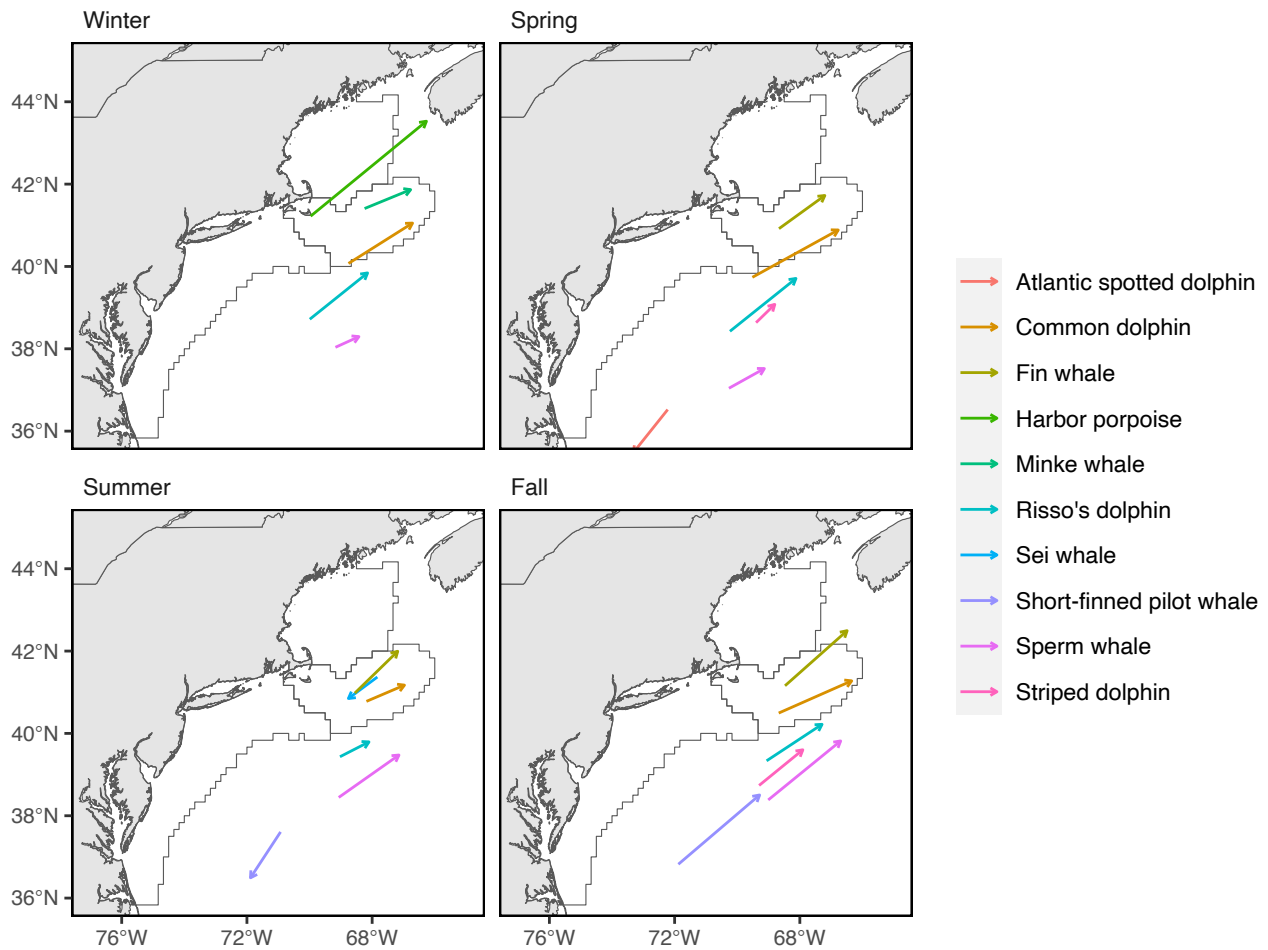


Figure 28: Direction and magnitude of core habitat shifts, represented by the length of the line of the seasonal weighted centroid for species with more than 70 km difference between 2010 and 2017 (tip of arrow).

Drivers Mobile populations are shifting distributions to maintain suitable temperature and prey fields, possibly expanding if new suitable habitat exists. Changes in managed species distribution is related, in part, to the [distribution of forage biomass](#). Since 1982, the fall center of gravity of forage fish (20 species combined) has moved to the north and east. Spring forage fish center of gravity has been more variable over time.

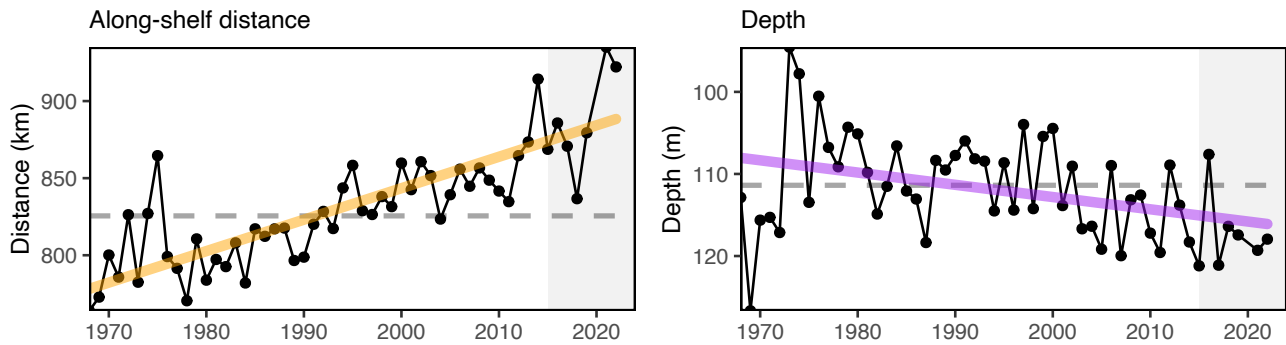


Figure 29: Aggregate species distribution metrics for species in the Northeast Large Marine Ecosystem.

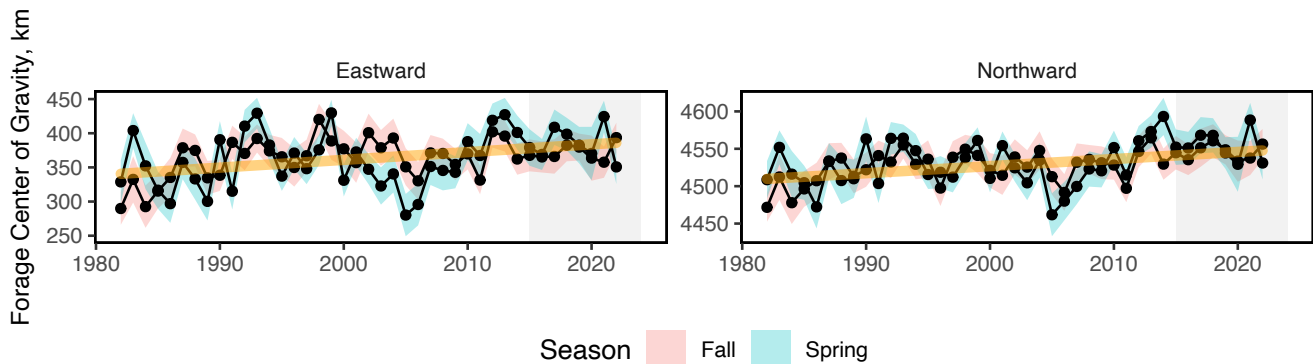


Figure 30: Eastward (left) and northward (right) shifts in the center of gravity for 20 forage fish species on the Northeast U.S. Shelf.

Ocean temperatures influence the distribution, seasonal timing of migrations and spawning, as well as the productivity of managed species (see sections below). New England has experienced a continued warming trend for both the surface (Fig.31) and in all seasons.

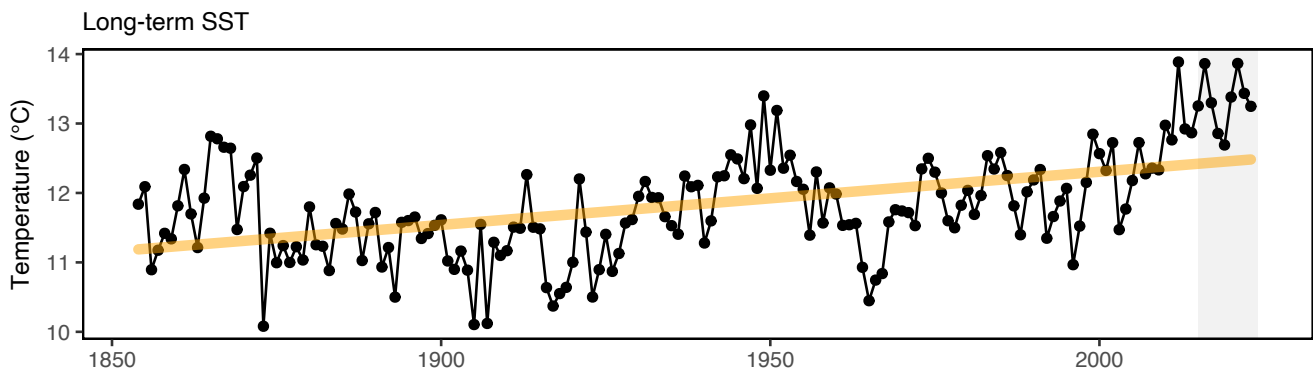


Figure 31: Mean sea surface temperature across the entire Mid-Atlantic shelf.

Species' suitable habitat can expand or contract when changes in temperature and major oceanographic conditions alter distinct water mass habitats. The variability of the Gulf Stream is a major driver of the predominant

oceanographic conditions of the Northeast U.S. continental shelf. As the **Gulf Stream** has become less stable and shifted northward in the last decade (Fig. 32), warmer ocean temperatures have been observed on the northeast shelf and a higher proportion of **Warm Slope Water** has been present in the Gulf of Maine Northeast Channel. Since 2008, the Gulf Stream has moved closer to the Grand Banks, reducing the supply of cold, fresh, and oxygen-rich Labrador Current waters to the Northwest Atlantic Shelf. Nearly every year since 2010, warm slope water made up more than 50% of the annual slope water proportions entering the Gulf of Maine. In 2017 almost no cooler Labrador Slope water entered the Gulf of Maine through the Northeast Channel. The changing proportions of source water affect the temperature, salinity, and nutrient inputs to the Gulf of Maine ecosystem. In 2022, warm slope water was a majority (59.7%) of inputs to the Gulf of Maine.

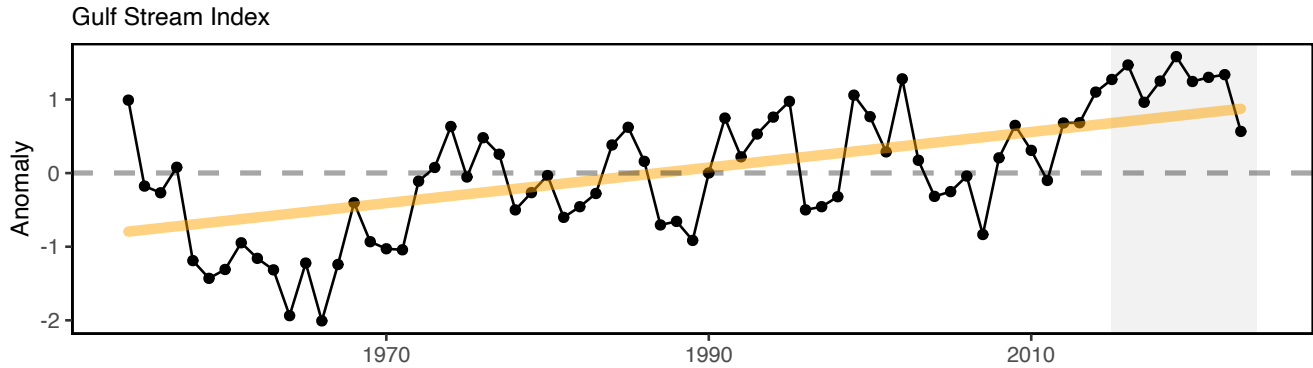


Figure 32: Index representing changes in the location of the Gulf Stream north wall. Positive values represent a more northerly Gulf Stream position.

Future Considerations Distribution shifts caused by changes in thermal habitat are likely to continue as long as long-term temperature trends persist. Near-term oceanographic forecasts are currently in development and may inform how future warming impacts species distributions.

Distribution patterns associated with climate-driven changes in oceanographic circulation patterns are unlikely to be reversed to historical ranges in the short term. Increased oceanographic variability needs to be captured by regional ocean models and linked to species distribution processes to better understand potential future distributions. Species with high mobility or short life spans react differently from immobile or long-lived species.

Adapting management to changing stock distributions and dynamic ocean processes will require continued monitoring of populations in space and evaluating management measures against a range of possible future spatial distributions.

Risks to Seasonal Management

The effectiveness of seasonal management actions (fishing seasons or area opening/closing) depends on a proper alignment with the seasonal life cycle events, also known as phenology, of fish stocks (e.g., migration timing and spawning). Changes in the timing of these biological cycles can reduce the effectiveness of management measures if not accounted for. The timing of seasonal patterns can also change the availability of species to surveys and interactions between fisheries and non-target species thus influencing the amount of bycatch.

Indicators: Timing shifts **Spawning timing** is shifting earlier for multiple stocks, including haddock and yellowtail flounder (Fig. 33). Spawning of both haddock stocks is occurring earlier, as indicated by more resting (post-spawning) stage fish in the 2010s as compared to earlier in the time series. The northern (Cape Cod/GOM) stock shows earlier active spawning in recent years with a decline in pre-spawning resting females. Yellowtail flounder spawning is related to bottom temperature, week of year, and decade sampled for each of the three stocks.

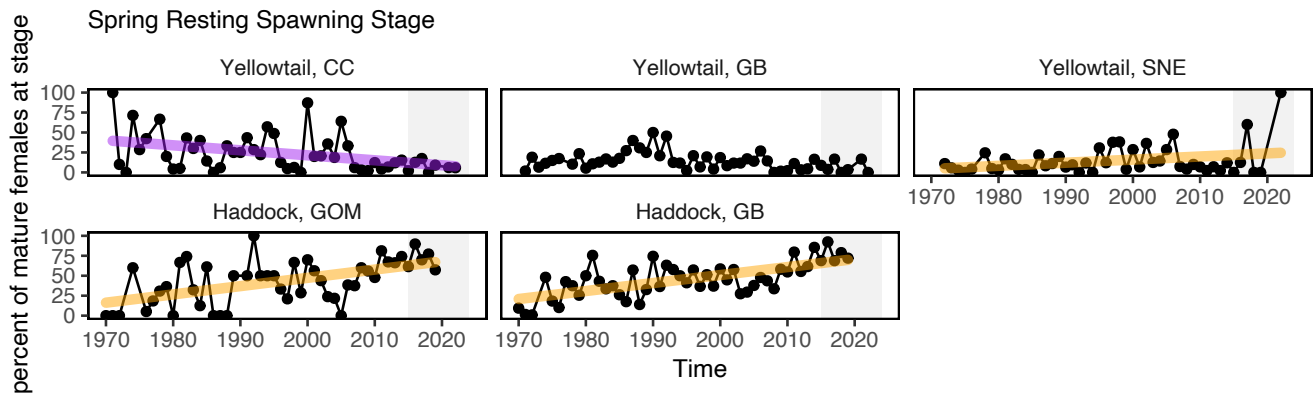


Figure 33: Percent resting stage (non-spawning) fish from two haddock and three yellowtail flounder stocks: CC = Cape Cod Gulf of Maine, GOM = Gulf of Maine, GB = Georges Bank, SNE = Southern New England.

Migration timing of some tuna and large whale migrations has changed. For example, tuna were caught in recreational fisheries 50 days earlier in the year in 2019 compared to 2002. In Cape Cod Bay, peak spring habitat use by right and humpback whales has shifted 18-19 days later over time.

Understanding whether seasonal patterns are changing for stocks requires regular observations during seasonal life history events. Despite the importance of understanding seasonal patterns, we have few indicators that directly assess timing shifts of species. We plan on incorporating more indicators of phenology in future reports.

Drivers The drivers of timing shifts in managed stocks are generally coupled to shifts in environmental or biological conditions, since these can result in changes in habitat quality or food availability within the year. Changes in the timing of fall phytoplankton blooms and seasonal shifts in zooplankton communities are thought to be critical indicators of changes in seasonal food availability to stocks.

Along with the overall warming trends in New England, ocean summer conditions have been lasting longer, as shown by the later **transition** from warm stratified summer conditions to well mixed cool fall conditions (Fig. 34). These transition dates are defined as the day of the year when surface temperatures change from cool to warm conditions in the spring and back to cool conditions in the fall. Changes in the broad seasonal cycles of their environment can lead to changes in species biological processes (migrations, spawning, etc.) that are triggered by seasonal events. Additionally, prolonged fall temperatures have been linked to the increased number of cold-stunned Kemp’s ridley sea turtles found in Cape Cod Bay.

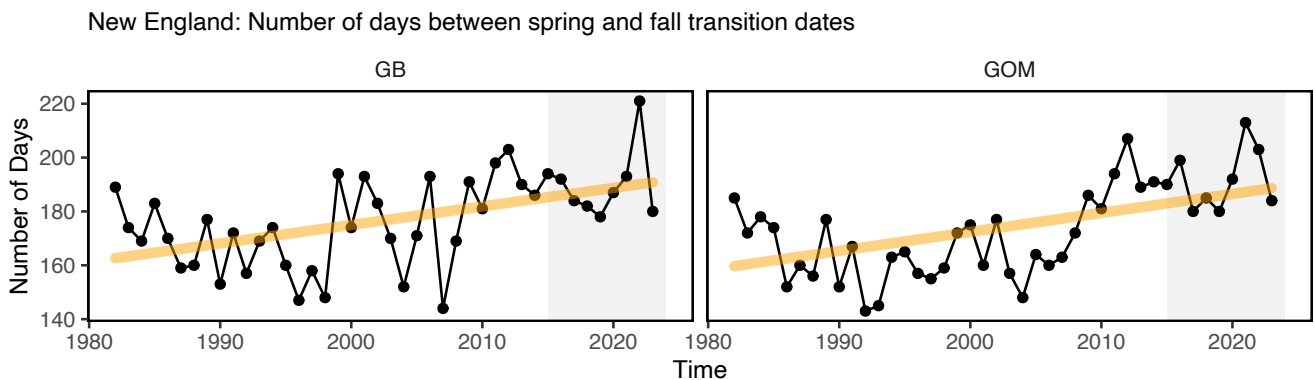


Figure 34: Ocean summer length: the annual total number of days between the spring thermal transition date and the fall thermal transition date.

The **cold pool** is a seasonal feature within the mid-Atlantic bight (MAB) that creates seasonally suitable habitat

for many species, including some managed by the NEFMC. Since the mid-2000s, the cold pool has persisted for a shorter portion of the year (Fig. 35). A change in the timing of the cold pool may impact the recruitment of species that rely on it for seasonal cues. Southern New England-Mid Atlantic yellowtail flounder recruitment and settlement are related to the strength of the cold pool (a factor of extent and persistence). The dependency of pre-recruit settlers within the cold pool represents a bottleneck in yellowtail life history, during which a local and temporary increase in bottom temperature negatively impacts the survival of the settlers. Including the effect of cold pool variations on yellowtail recruitment reproduced retrospective patterns and improved the skill of short-term forecasts in a stock assessment model.

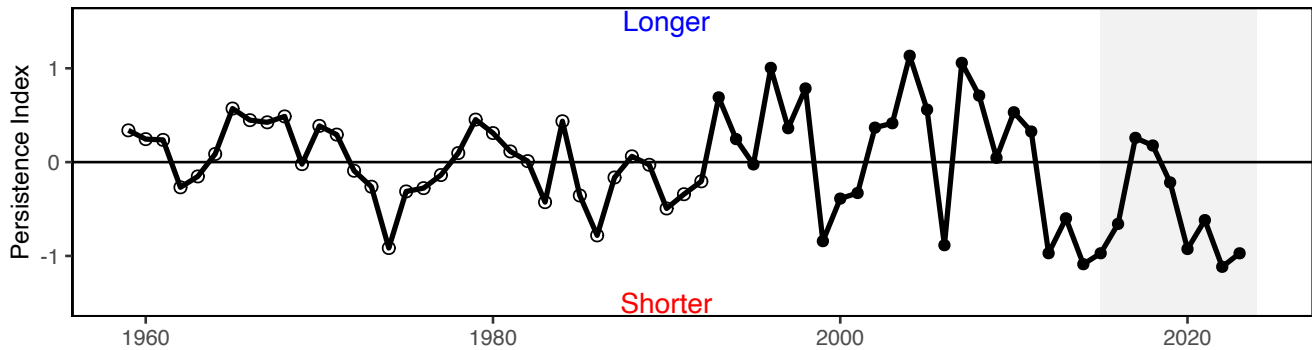


Figure 35: Cold pool persistence index based on bias-corrected ROMS-NWA (open circles) and GLORYS (closed circles).

Future Considerations For stocks reliant on environmental processes to dictate the timing of their behavior (e.g., phytoplankton bloom timing, thermal transition, or the duration of the cold pool), it is possible that some effects will be episodic and have interannual variability, while other effects on timing can change on scales of years to decades. However, other species rely on the general seasonal succession of environmental drivers (e.g., the timing of the fall turnover) to cue biological processes, which rely on long-term trends unlikely to reverse in coming years. Such timing shifts in migration or spawning for those species are expected to continue. Management actions that rely on effective alignment of fisheries availability and biological processes should continue to evaluate whether prior assumptions on seasonal timings still hold, and new indicators should be developed to monitor timing shifts for stocks.

Risks to Quota Setting/Rebuilding

The efficacy of short-term stock projections and rebuilding plans relies on an accurate understanding of processes affecting stock growth, reproduction, and natural mortality. These biological processes are often driven by underlying environmental change. When observed environmental change occurs, there is a risk that established stock-level biological reference points may no longer reflect the current population.

Indicators: Fish productivity and condition shifts Indicators of [fish productivity](#) are derived from observations (surveys) or models (stock assessments). With the exception of two years (2006 and 2013), fish productivity has been below the long-term average in the Gulf of Maine since the early 2000s, as described by the small-fish-per-large-fish anomaly indicator (derived from NEFSC bottom trawl survey)(Fig. 36). This decline in fish productivity is also shown by a similar analysis based on stock assessment model outputs (recruitment per spawning stock biomass anomaly). Other signs of changing productivity in New England are the declines in [common tern chicks](#) per nest (Fig. 37) and declining return rates for [Atlantic salmon](#)(Fig. 38).

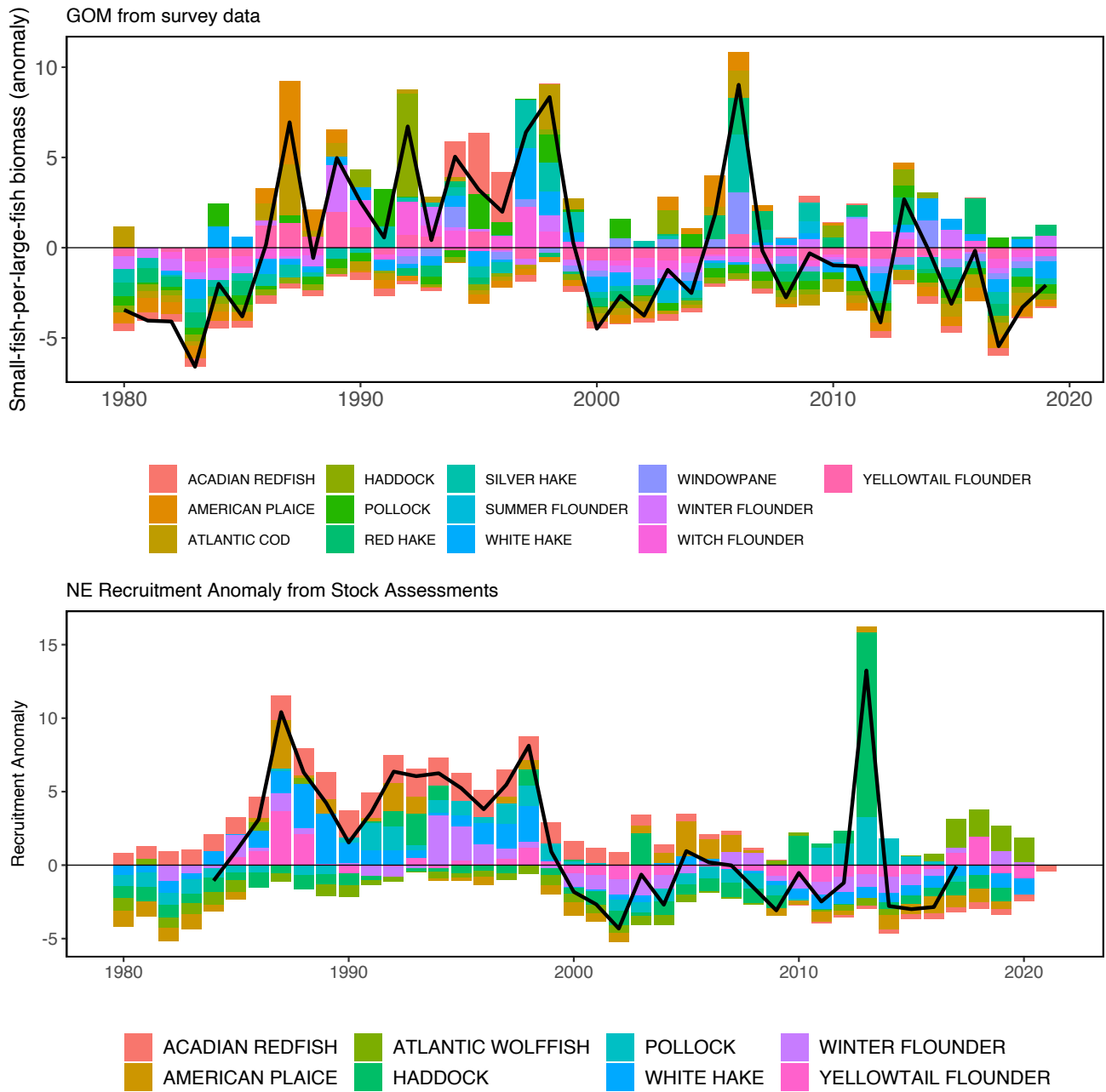


Figure 36: Fish productivity measures. Top: Small-fish-per-large-fish survey biomass anomaly in the Gulf of Maine. Bottom: assessment recruitment per spawning stock biomass anomaly for stocks managed by the New England Fishery Management Council region. The summed anomaly across species is shown by the black line, drawn across all years with the same number of stocks analyzed.

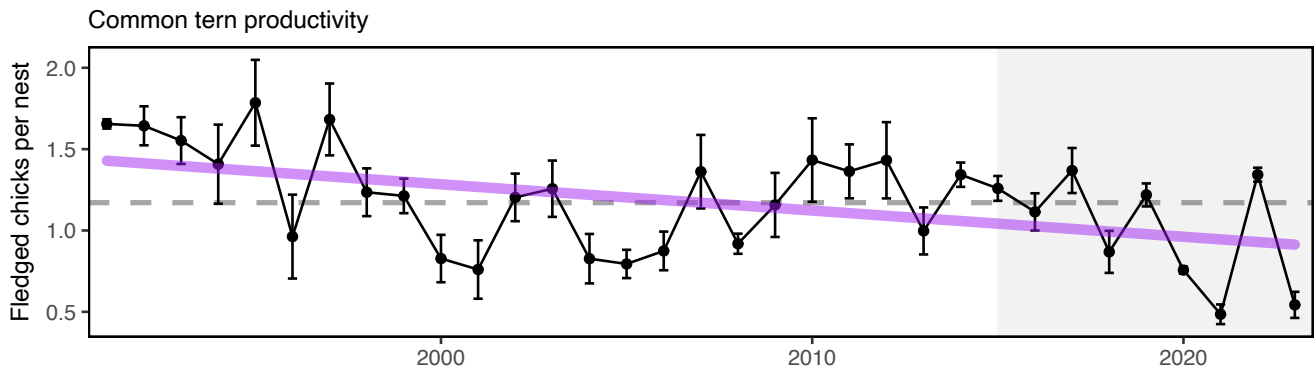


Figure 37: Productivity of Common terns in the Gulf of Maine.

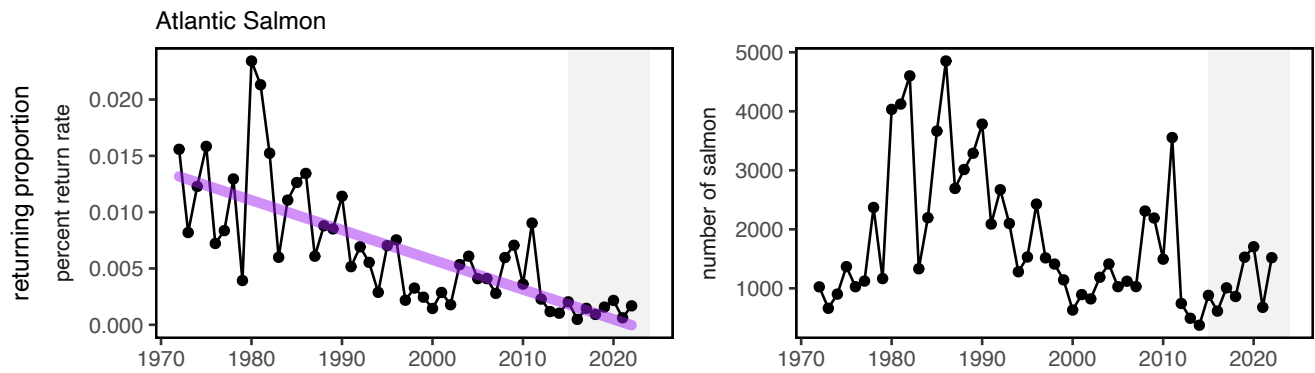


Figure 38: Return rate proportions and abundance of Atlantic salmon.

The health of individual fish (i.e., fish condition) can contribute to population productivity through improved growth, reproduction, and survival. [Fish condition](#) in the Gulf of Maine and Georges Bank regions were generally good prior to 2000, poor from 2001-2010 (concurrent with declines in fish productivity, Fig. 36), and a mix of good and poor since 2011. In 2023, fish condition was mixed, with generally improving condition on Georges Bank, but the highest number of species in poor condition in the Gulf of Maine since 2010 (Fig. 39).

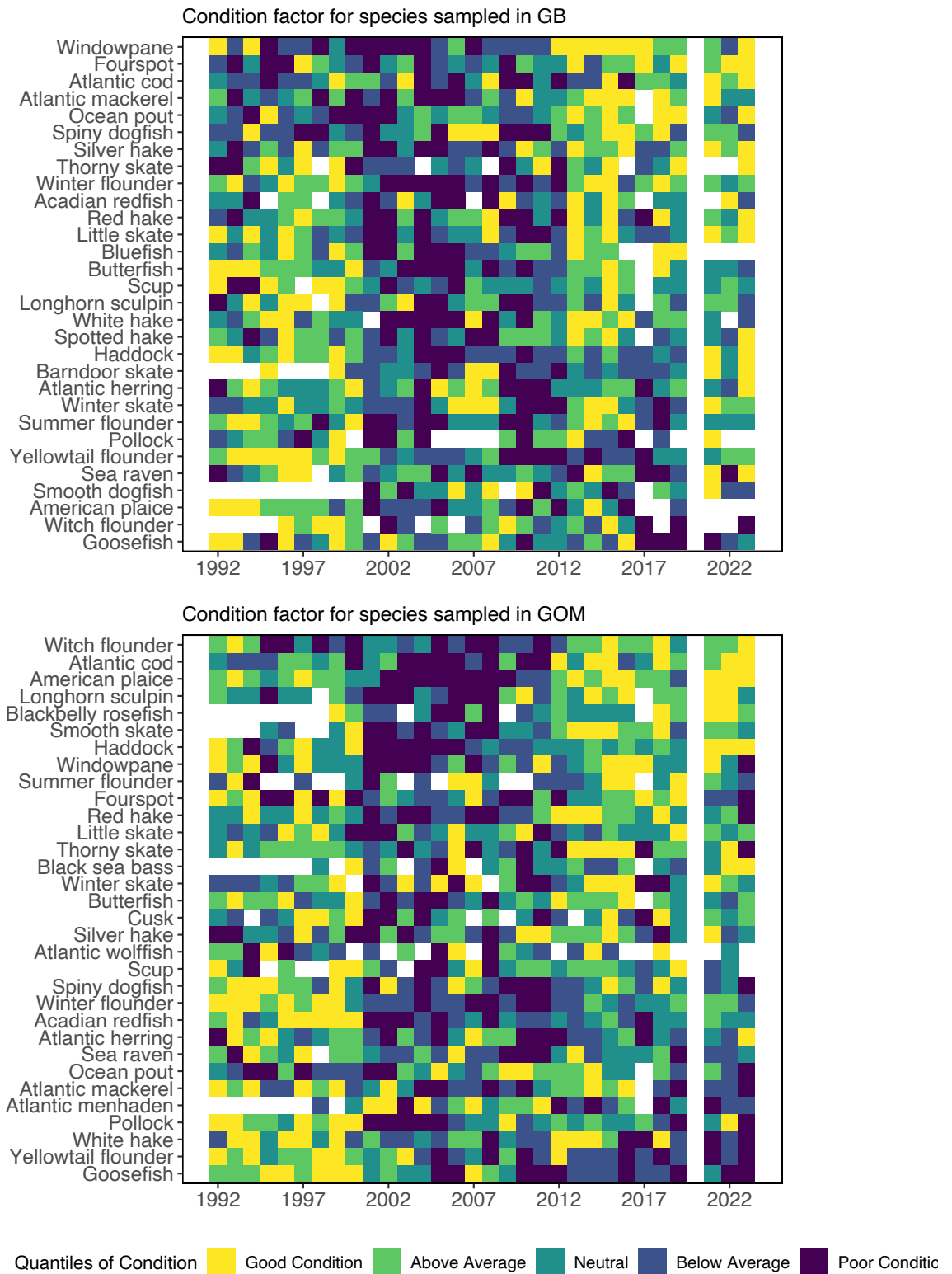


Figure 39: Condition factor for fish species in New England based on fall NEFSC bottom trawl survey data. No survey was conducted in 2020.

Drivers Fish productivity and condition are affected by increasing metabolic demands from increasing temperature, combined with changes in the availability and quality of prey. Long-term environmental trends and episodic extreme temperatures, ocean acidification, and low oxygen events represent multiple stressors that can affect growth rates, reproductive success and recruitment, and cause mortality.

Biological Drivers: Forage quality and abundance Fish productivity is dependent on the energy potentially available to them based on the nutritional value (energy content) and abundance of prey. Changes in the forage fish base can drive managed and protected species production and condition.

The [energy content](#) of juvenile and adult forage fish as prey is related to forage fish growth and reproductive cycles, as well as environmental conditions. The energy content of Atlantic herring from the NEFSC trawl surveys has increased but is still well below observations in the 1980s and 1990s (Fig. 40). Silver hake, longfin squid (Loligo in figure), and shortfin squid (Illex in figure) remain lower than previous estimates.

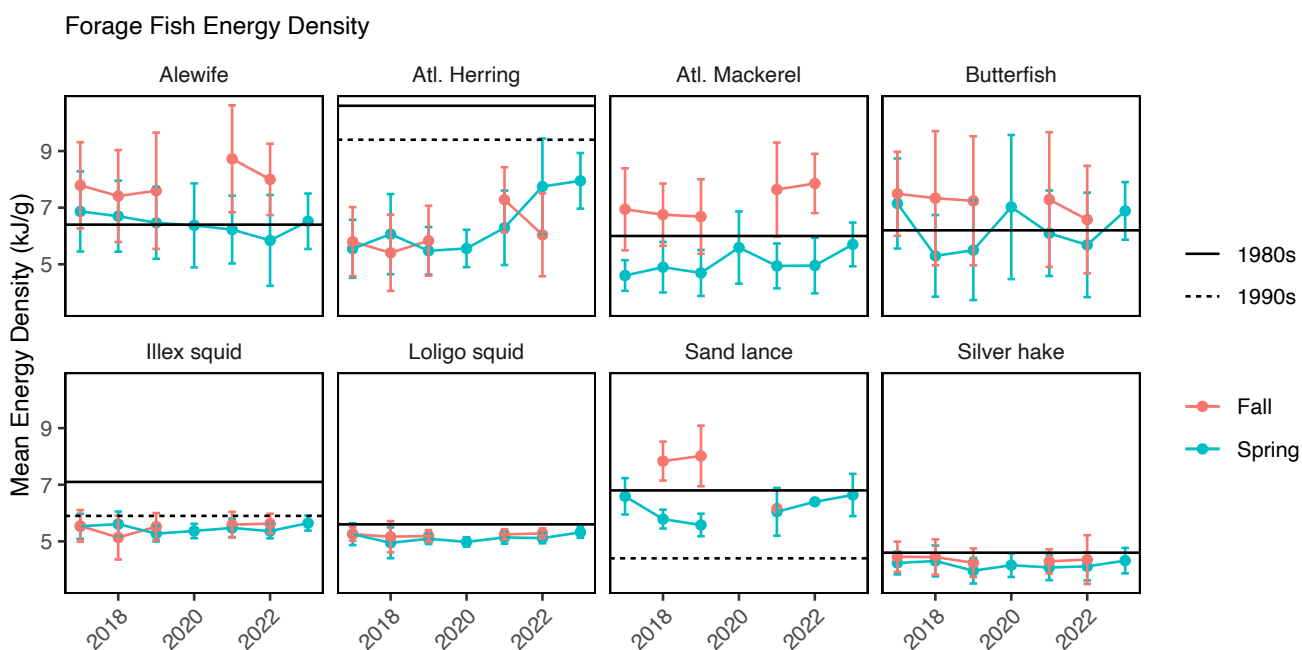


Figure 40: Forage fish energy density mean and standard deviation by season and year, compared with 1980s (solid line; Steimle and Terranova 1985) and 1990s (dashed line; Lawson et al. 1998) values.

Changes in the overall abundance of forage fish can influence managed species productivity as it relates to changes in food availability. New England [fall forage biomass](#) is stable with long-term increases in the spring GOM (Fig. 41). Forage biomass was highest during fall in the 1980s.

Biological Drivers: Lower trophic levels Phytoplankton are the foundation of the food web and are the primary food source for zooplankton and filter feeders such as shellfish. Numerous environmental and oceanographic factors interact to drive the abundance, composition, spatial distribution, and productivity of phytoplankton. While changes in fish productivity (including forage) could result from changing primary productivity, total primary production in New England has no long-term trend, despite anomalous conditions in the GOM in 2023 (Fig. 16).

[Zooplankton communities](#) in the Mid-Atlantic have increasing trends for smaller bodied copepods and gelatinous species (Cnidaria; Fig. Fig 42). Smaller bodied copepods and gelatinous species are less energy-rich than Eupausiids (krill) or the larger-bodied copepod *Calanus finmarchicus*. A changing mix of zooplankton prey can impact forage fish energy content and abundance, as well as the prey field of filter feeding whales.

Since 2010, the abundance of the lipid-rich older stages of *Calanus finmarchicus* in the GOM has declined. Observations from a fixed time series station in Wilkinson Basin indicate that *Calanus* seasonal abundance in late summer-winter between 2020-2022 has declined to 30-40% of its population level in 2005-2008 (Fig. 43), although spring abundances are still the same as 15-20 years ago. The seasonal differences in abundance change reflect differences in influence of primary seasonal drivers:

1. *Calanus* reproductive output is tied to phytoplankton availability in late winter/early spring.
2. Gulf of Maine source waters drive *Calanus* supply (high *Calanus* in Scotian Shelf/Labrador shelf water (LSW) and less in warm slope water (WSW))
3. Predation is likely higher with warmer temperatures

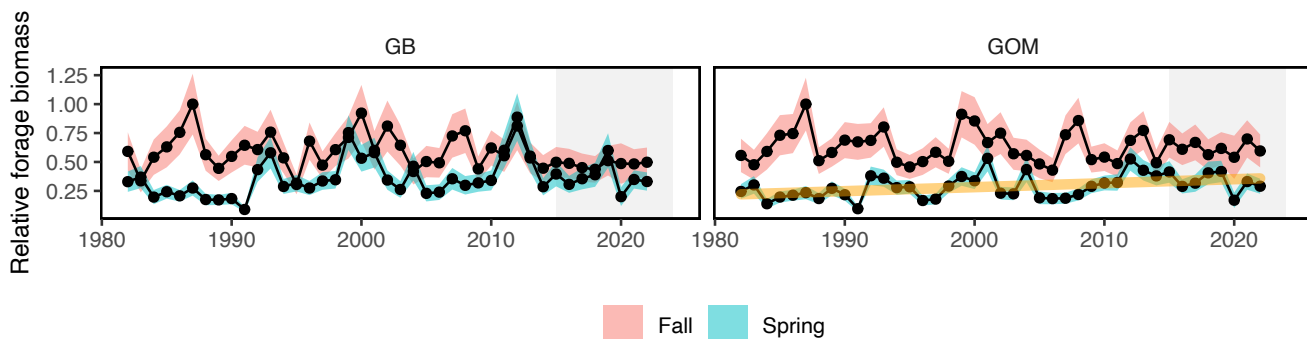


Figure 41: Forage fish index in GB (left) and GOM (right) for spring (blue) and fall (red) surveys. Index values are relative to the maximum observation within a region across surveys.

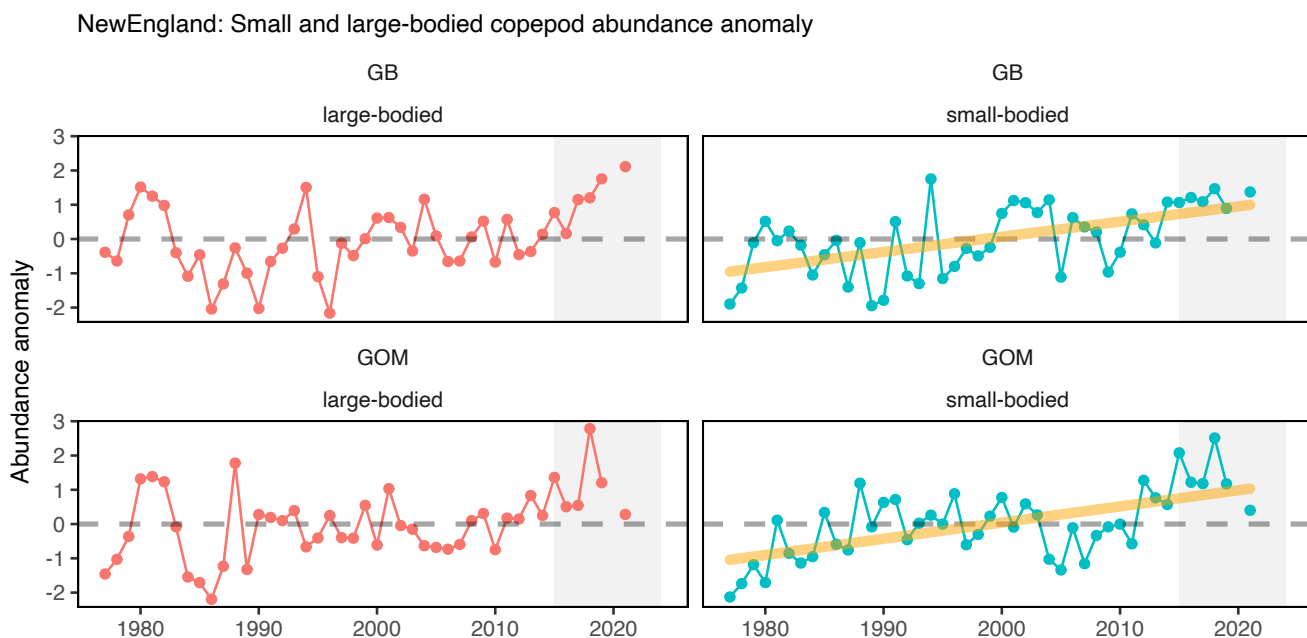


Figure 42: Georges Bank (GB) and Gulf of Maine (GOM) abundance anomalies three dominant zooplankton (*Calanus finmarchicus*, *Calanus typicus*, and *Pseudocalanus* spp.).

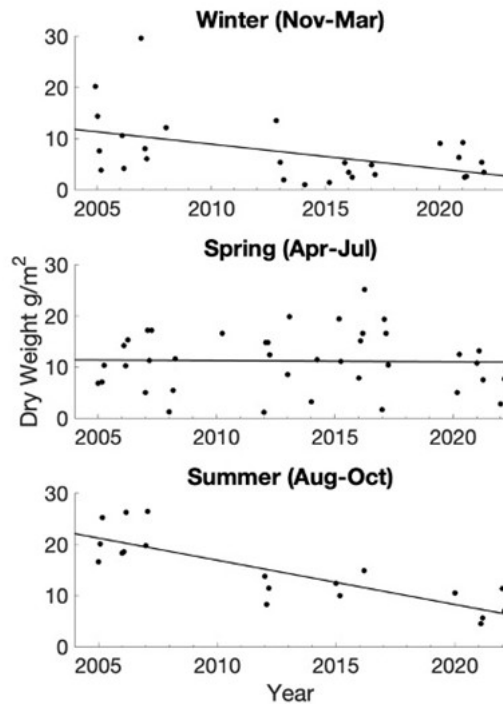


Figure 43: Dry mass of mesozooplankton captured with a 200µm ring net towed from the bottom to surface at a deep time series station in Wilkinson Basin between 2005-2022 (Runge et al. 2023).

Environmental Drivers Fish production can also be directly related to the prevailing environmental conditions by altering metabolic (growth) and reproductive processes. Many species possess thermal tolerances and can experience stressful or lethal conditions if temperatures exceed certain levels. Extreme temperature at both the [surface](#) (Fig. 31) and [bottom](#) can exceed [thermal tolerance](#) limits for some fish. For example, 2012 had among the warmest surface and bottom temperatures in New England. A large proportion of the Georges Bank and Mid-Atlantic regions had bottom temperatures above the 15°C thermal tolerance for most groundfish, with some days exceeding the 24°C potential mortality limit (Fig. 44).

In 2023, the second strongest [bottom marine heatwave](#) since 1982 was observed in the GOM, although it did not exceed this 15°C threshold. Although parts of GB and the inshore GOM exceeded this 15°C threshold, heatwaves are an EPU-wide metric and include areas where bottom temperature is typically far below this threshold.

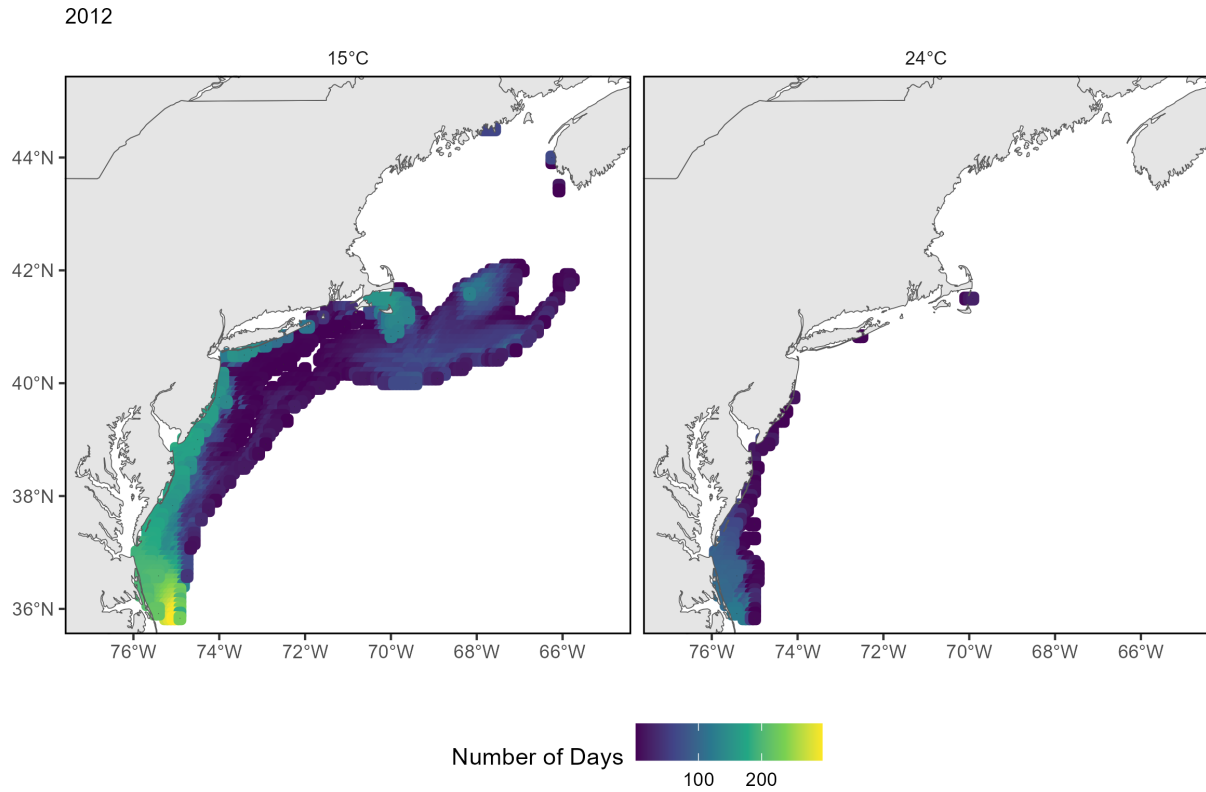


Figure 44: The number of days in 2012 where bottom temperature exceeds 15°C (left) and 24°C (right) based on the GLORYS 1/12 degree grid.

Ocean acidification (OA) risks vary among species and include reduced survival, growth, reproduction, and productivity, where high OA risk indicates potential negative effects to species. High OA risk was observed for Atlantic sea scallop and longfin squid in Long Island Sound and the nearshore and mid-shelf regions of the New Jersey shelf (Fig. 45, right panel) during summer 2016, 2018, 2019, and 2023.

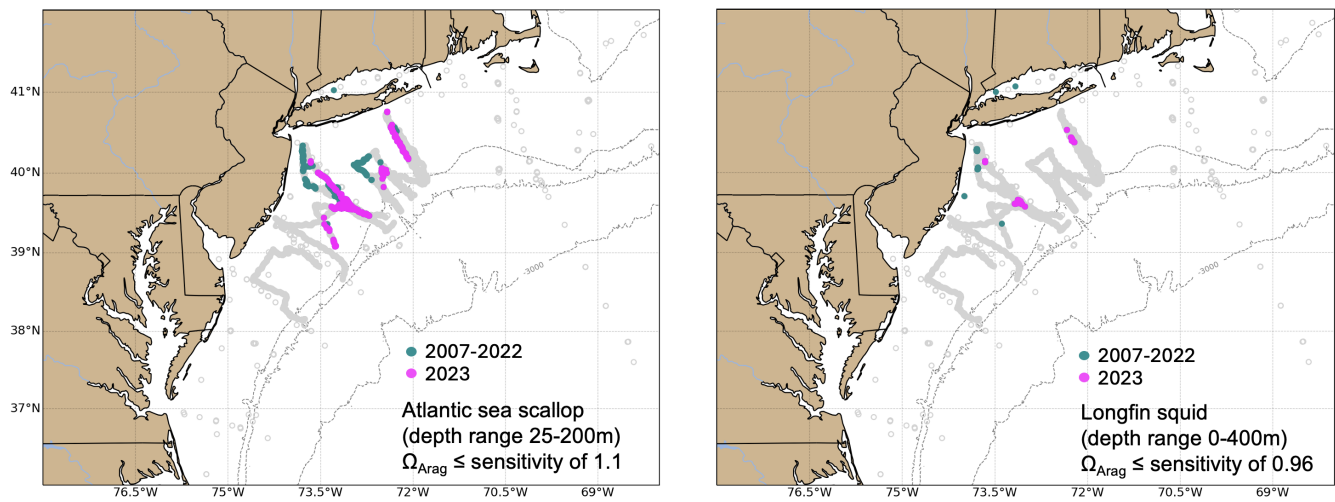


Figure 45: Locations where bottom aragonite saturation state (Ω_{Arag} ; summer only: June-August) were at or below the laboratory-derived sensitivity level for Atlantic sea scallop (left panel) and longfin squid (right panel) for the time periods 2007-2022 (dark cyan) and 2023 only (magenta). Gray circles indicate locations where bottom Ω_{Arag} values were above the species specific sensitivity values.

Biological and oceanographic processes can affect the amount of oxygen present in the water column. During low oxygen (hypoxic) events, species’ growth is negatively affected and very low oxygen can result in mortality. The duration and extent of hypoxic events is being monitored, but long-term shelf-wide observations are not yet available. However, [hypoxic events](#) were detected off the coast of New Jersey in 2023 and were potentially responsible for fish, lobster, and crab [mortalities](#).

Drivers: Predation The abundance and distribution of predators can affect both the productivity and mortality rates on managed stocks. Predators can consume managed species or compete for the same resources resulting in increased natural mortality or declining productivity, respectively. The northeast shift in some [highly migratory species](#) (Fig. 28) indicates a change in the overlap between predators and prey. Since we also observe distribution shifts in both managed and forage species, the effect of changing predator distributions alone is difficult to quantify.

The increase in the [gray seal population](#) suggests predator populations are increasing in the GOM and GB regions. [Stock status](#) is mixed for Atlantic Highly Migratory Species (HMS) stocks (including sharks, swordfish, billfish, and tunas) occurring throughout the Northeast U.S shelf. While there are several HMS species considered to be overfished or that have unknown stock status, the population status for some managed Atlantic sharks and tunas is at or above the biomass target, suggesting the potential for robust predator populations among these managed species. Stable predator populations suggest stable predation pressure on managed species, but increasing predator populations may reflect increasing predation pressure.

Future Considerations The processes that control fish productivity and mortality are dynamic, complex, and the result of the interactions between multiple system drivers. There is a real risk that short-term predictions in assessments and rebuilding plans that assume unchanging underlying conditions will not be as effective, given the observed ecological and environmental process changes documented throughout the report. Assumptions for species’ growth, reproduction, and natural mortality should continue to be evaluated for individual species. With observations of system-wide productivity shifts of multiple managed stocks, more research is needed to determine whether regime shifts or ecosystem reorganization are occurring, and how this should be incorporated into management

Other Ocean Uses: Offshore Wind

Indicators: development timeline, revenue in lease areas, coastal community vulnerability

As of January 2024, 30 offshore [wind development](#) projects are proposed for construction over the next decade in the Northeast (timelines and project data for 2024 are based on the [Ocean Wind 1 Offshore Wind Farm Final Environmental Impact Statement. Volume II: Appendix F](#)). Offshore wind areas are anticipated to cover more than 2.3 million acres by 2030 in the Greater Atlantic region (Fig. 46). It is anticipated that all states will be able to reach their 2030 offshore wind goals with existing lease areas.

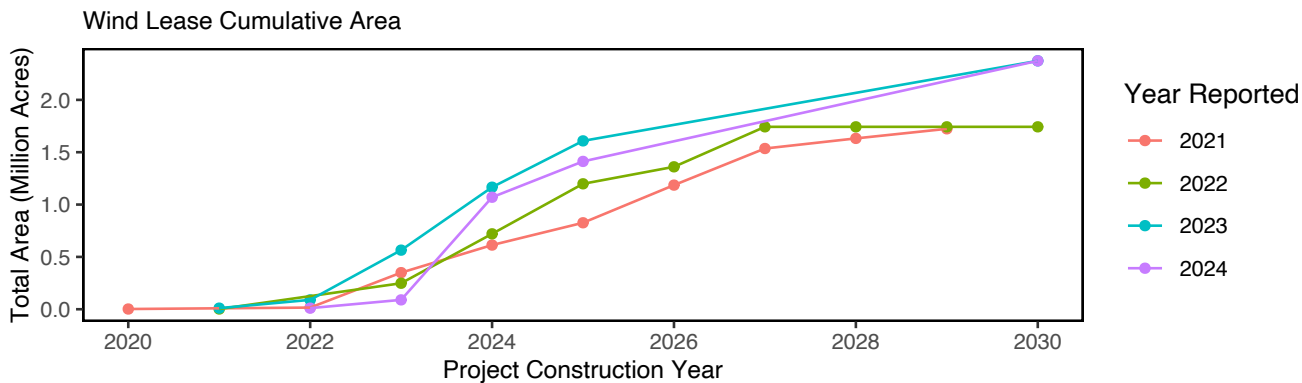


Figure 46: Proposed wind development on the northeast shelf.

Just over 3,300 foundations and more than 12,000 miles of inter-array and offshore export cables are proposed to

date. Since first reporting timeline indicators in 2021, construction years by 2030 have become increasingly uncertain with a wide range of estimated construction years being reported for some projects as reflected in the “Estimated Construction Schedule” column of Fig. 47 below. The areas affected would be spread out such that it is unlikely that any one particular area would experience full development at one time. Construction of two projects in Southern New England (South Fork Wind and Vineyard Wind 1) during 2023 has affected fisheries managed by the New England Fishery Management Council, while construction activities began for Revolution Wind in early 2024. It is likely that construction will begin on other projects in Southern New England and possibly the New York Bight during 2024 that will further affect regional fisheries.

Offshore floating wind is expected to be developed in the GOM. Although no commercial wind lease areas have been proposed, the Bureau of Ocean Energy Management (BOEM) released a draft Wind Energy Area (Fig. 47) on October 19, 2023, which could be refined into future lease areas. BOEM announced that the final wind energy area and proposed commercial lease area designations for the GOM are expected in quarter one of 2024, with lease sales before 2025. BOEM is also reviewing the state of Maine’s application to lease 9,700 acres (15 square miles) for the first floating offshore wind research site in federal waters of the GOM, which could have up to 12 turbines. Leasing for offshore floating wind in the Gulf of Maine will seek to meet the Biden Administration’s proposed goal of 15GW of floating offshore wind by 2035 in the U.S.

NEFSC has partnered with the Responsible Ocean Development Alliance (RODA) and the University of Rhode Island to conduct an Integrated Ecosystem Assessment (IEA) of the interactions between offshore wind, fisheries, and the environment in the Gulf of Maine. The IEA report will be similar to the State of the Ecosystem, but fully dedicated to impacts of offshore wind. Data from the IEA will be suitable for inclusion in the environmental impact statements for any projects in the GOM.

Based on federal vessel logbook data, [commercial fishery revenue](#) from trips in the current offshore wind lease areas, the Central Atlantic Final Lease Areas, and the GOM Draft Wind Energy Area (excluding potential secondary areas), represent 3-54% of the total annual revenue for fisheries managed by the NEFMC from 2008-2022 (Table 3). Fishing revenue affected by offshore wind lease areas varies over time, but has largely declined over time. Maximum annual revenue for the fisheries with the most overlap with wind lease areas peaked at over \$51 million for the sea scallop fishery, \$4.2 million for monkfish, \$2.2 million for skates, \$724,000 for silver hake, and just over \$1 million for Atlantic herring (Fig. 48). The scallop fishery is mainly affected by lease areas in the Mid-Atlantic, as most of the Northern Area scallop fishery is outside of the GOM Draft Wind Energy Area. However, substantially more groundfish landings overlap with the GOM Draft Wind Energy Area, with up to \$15.1 million in annual groundfish revenue caught within potential lease areas. Individual groundfish species are more affected than others, with over 28-53% of annual revenues for redfish (53%), pollock (40%), white hake (34%) and American plaice (28%) overlapping with the GOM Draft Wind Energy Area (Table 3). This potential overlap will decrease once BOEM designates final lease areas for the GOM, which will be substantially smaller than the Draft Wind Energy Area. Future fishery resource overlap with wind leases, especially scallops, may change due to species distribution shifts attributable to climate change and recruitment and larval dispersion pattern changes caused by hydrodynamic flow disruptions from turbine foundations, which could also affect fishery landings/revenue.

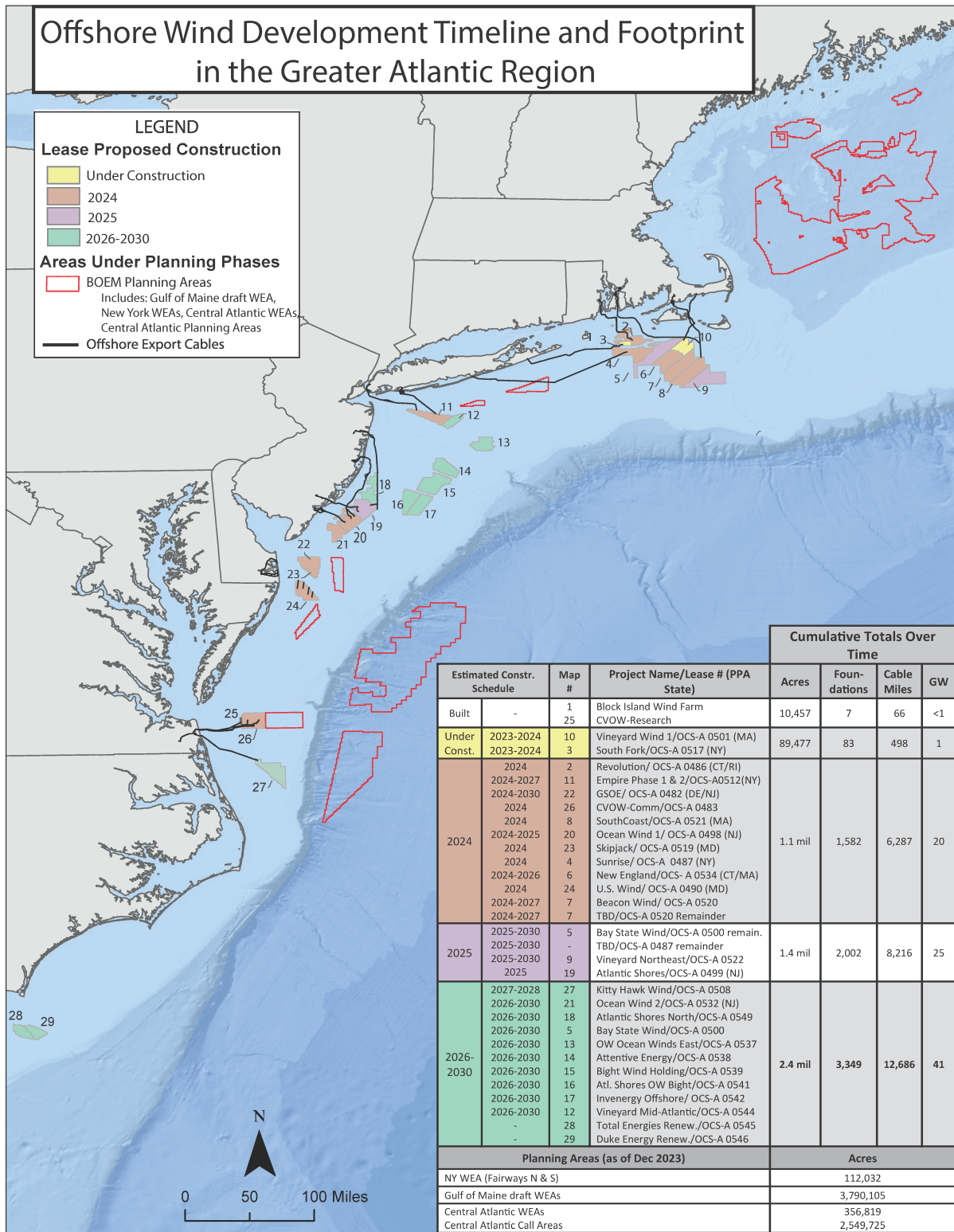


Figure 47: All Northeast Project areas by year construction ends (each project has 2 year construction period).

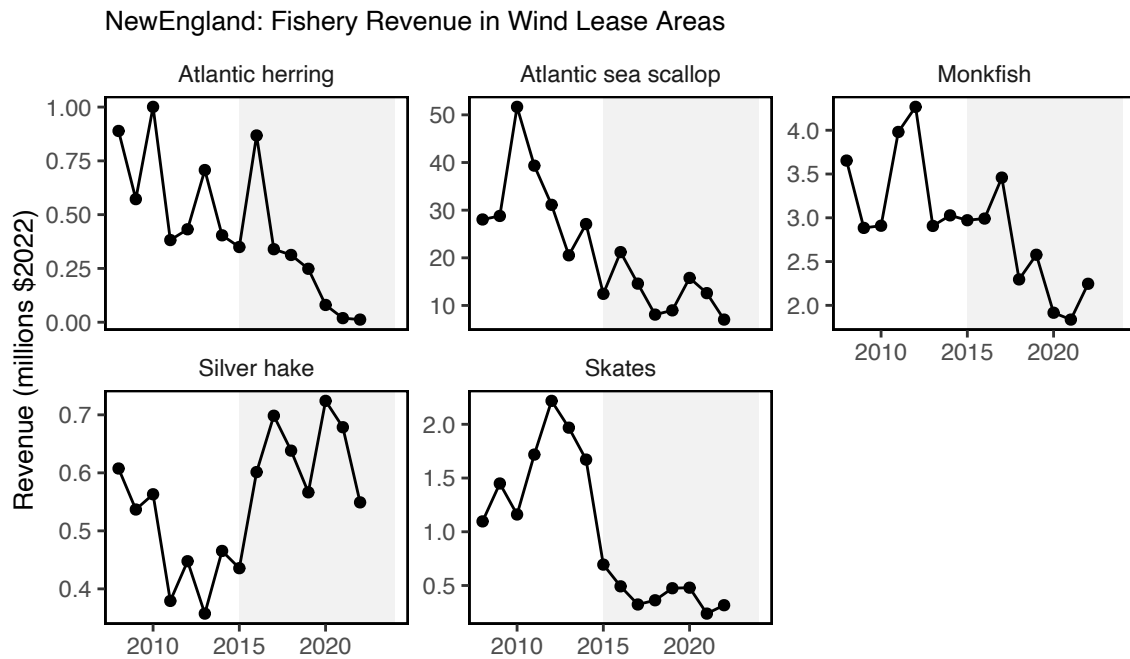


Figure 48: Fishery revenues from NEFMC managed species in the Wind energy lease areas.

Table 3: New England managed species Landings and Revenue from Wind Energy Areas. *Skates includes barndoor, winter, clearnose, smooth, little, and general skates reported in logbooks.

NEFMC, MAFMC, and ASMFC Managed Species	Maximum Percent Total Annual Regional Species Landings	Maximum Percent Total Annual Regional Species Revenue
Redfish	53	54
Skates*	40	51
Pollock	43	40
White hake	34	34
American plaice	26	28
Atlantic halibut	23	24
Haddock	24	23
Witch flounder	25	23
Monkfish	20	20
Yellowtail flounder	15	15
Atlantic cod	15	15
Atlantic sea scallop	10	9
Red hake	11	8
Silver hake	9	7
Winter flounder	5	5
Offshore hake	15	5
Atlantic herring	5	4
Spiny dogfish	4	4
Windowpane flounder	4	3

Equity and environmental justice (EJ) are priority concerns with offshore wind development and fisheries impacts in the Northeast, and the impacts of offshore wind development are expected to differentially [impact specific coastal communities](#). Additionally, impacts of offshore wind development may unevenly affect individual operators, with some permit holders deriving a much higher proportion of revenue from wind areas than the port-based mean.

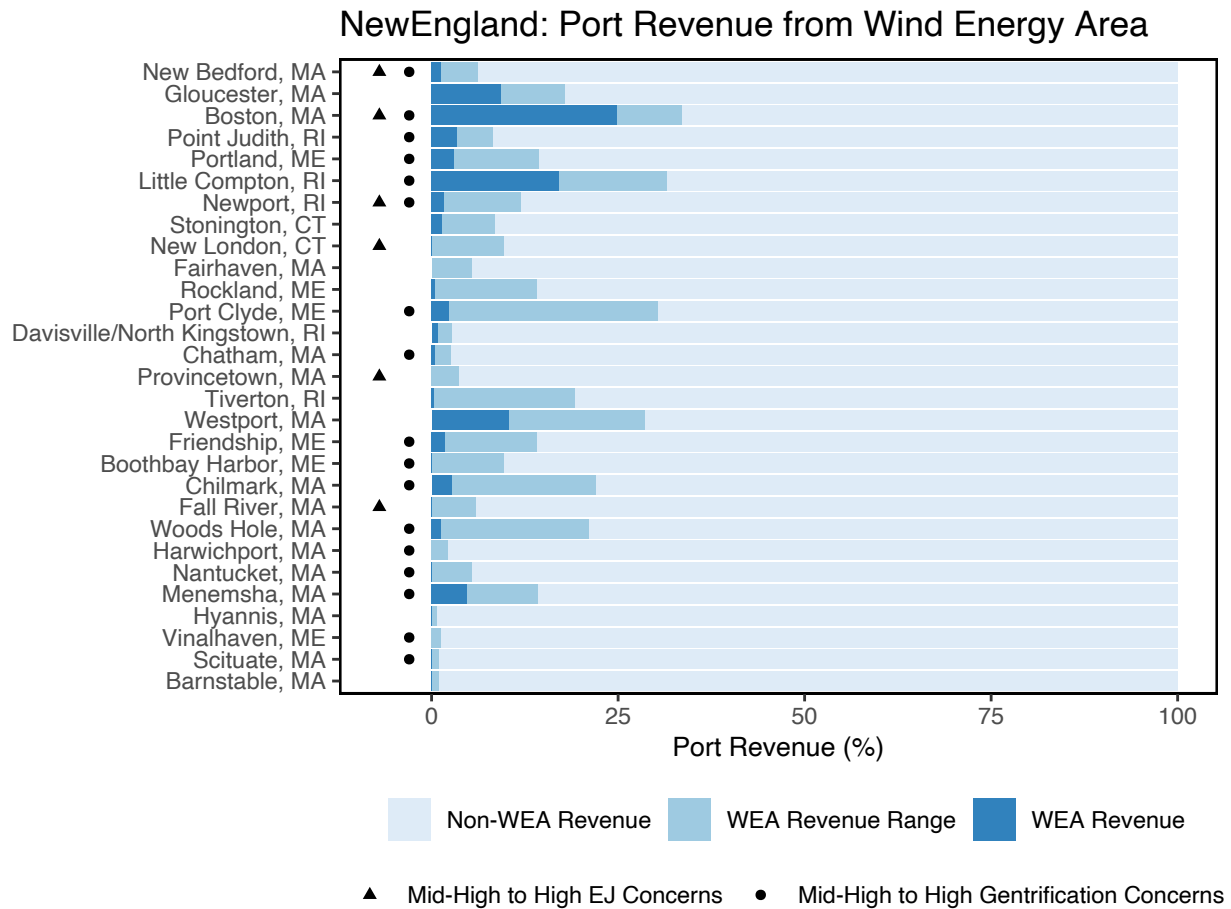


Figure 49: Percent of port fisheries revenue from Wind Energy Areas (WEA) in descending order from most to least port fisheries revenue from WEA. EJ = Environmental Justice.

For example, Little Compton, RI had a minimum of 17% and maximum of 32% overlap of wind energy revenue to the total port revenue between 2008-2022 (Fig. 49). BOEM reports that cumulative offshore wind development (if all proposed projects are developed) could have moderate impacts on low-income members of vulnerable communities who work in the commercial fishing and for-hire fishing industry due to disruptions to fish populations, restrictions on navigation, and increased vessel traffic as well as existing vulnerabilities of low-income workers to economic impacts.

Top fishing communities with high [environmental justice concerns](#) such as New Bedford, MA and New London, CT should be considered in decision making to reduce the social and economic impacts and aid in the resilience and adaptive capacity of underserved communities. These two ports are also undergoing significant changes to support offshore wind development port infrastructure needs. Environmental justice concerns also highlight communities where further resources are needed to reach underserved and underrepresented groups and create opportunities for, and directly involve, these groups in the decision-making process.

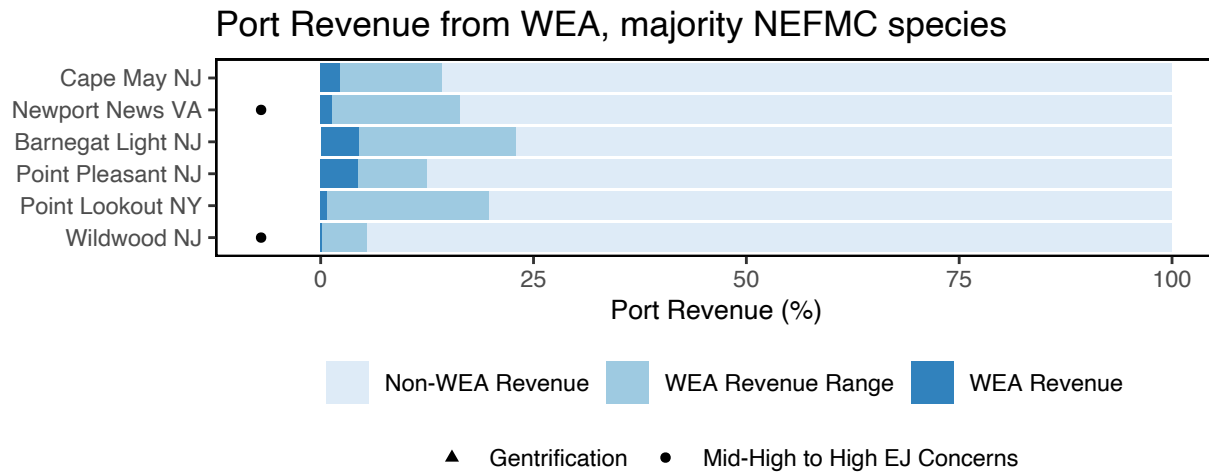


Figure 50: Percent of Mid-Atlantic port revenue with majority NEFMC landings from Wind Energy Areas (WEA) in descending order from most to least port fisheries revenue from WEA. EJ = Environmental Justice.

Implications

Current plans for rapid buildout of offshore wind in a patchwork of areas spreads the impacts differentially throughout the region (Fig. 47).

Up to 12% of total average revenue for major New England commercial species in lease areas could be forgone, or reduced, and associated effort displaced if all sites are developed. Displaced fishing effort can alter historic fishing areas, timing, and methods, which can in turn change habitat, species (managed and protected), and fleet interactions. Several factors, including fishery regulations, fishery availability, and user conflicts affect where, when, and how fishing effort may be displaced, along with impacts to and responses of affected fish species.

Planned development overlaps NARW mother and calf migration corridors and a significant foraging habitat that is used throughout the year in addition to one of the only known winter foraging areas (Fig. 51). Turbine presence and extraction of energy from the system could alter local oceanography and may affect right whale prey availability. For example, persistent foraging hotspots of right whales and seabirds overlap on Nantucket Shoals, where unique hydrography aggregates enhanced prey densities. Wind leases (OCS-A 0521 and OCS-A 0522) currently intersect these hotspots on the southwestern corner of Nantucket Shoals and a prominent tidal front associated with invertebrate prey swarms important to seabirds and possibly right whales. Proposed wind development areas also bring increased vessel strike risk from construction and operation vessels. In addition, there are a number of potential impacts to whales from pile driving and operational noise such as displacement, increased levels of communication masking, and elevated stress hormones.

Proposed wind development areas interact with the region’s federal scientific surveys. Scientific surveys are impacted by offshore wind in four ways:

1. Exclusion of NOAA Fisheries’ sampling platforms from the wind development area due to operational and safety limitations
2. Impacts on the random-stratified statistical design that is the basis for scientific assessments, advice, and analyses;
3. Alteration of benthic and pelagic habitats, and airspace in and around the wind energy development, requiring new designs and methods to sample new habitats
4. Reduced sampling productivity through navigation impacts of wind energy infrastructure on aerial and vessel survey operations

Increased vessel transit between stations may decrease data collections that are already limited by annual days-at-sea day allocations. The total survey area overlap ranges from 1-70% for all Greater Atlantic federal surveys. The Gulf of Maine Cooperative Research Bottom Longline Survey (41%) and the Shrimp Survey (70%) have the largest

percent overlap with the draft Gulf of Maine Wind Energy Areas. The remaining surveys range from 1-16% overlap. Individual survey strata have significant interaction with wind energy development, including the sea scallop survey (up to 96% of individual strata) and the bottom trawl survey (BTS, up to 60% strata overlap). Additionally, up to 50% of the southern New England North Atlantic right whale survey's area overlaps with proposed project areas and a region-wide survey mitigation program is underway

The increase of offshore wind development can have both positive (e.g., employment opportunities) and negative (e.g., space-use conflicts) sociocultural effects. Continued increase in coastal development and gentrification pressure has resulted in loss of fishing infrastructure space within ports. Understanding these existing pressures can help avoid and mitigate negative impacts to our shore support industry and communities dependent on fishing. Some of the communities with the highest fisheries revenue overlap with offshore wind development areas that are also vulnerable to gentrification pressure are Point Judith and Newport, RI; New Bedford, MA; and Port Clyde and Portland, ME.

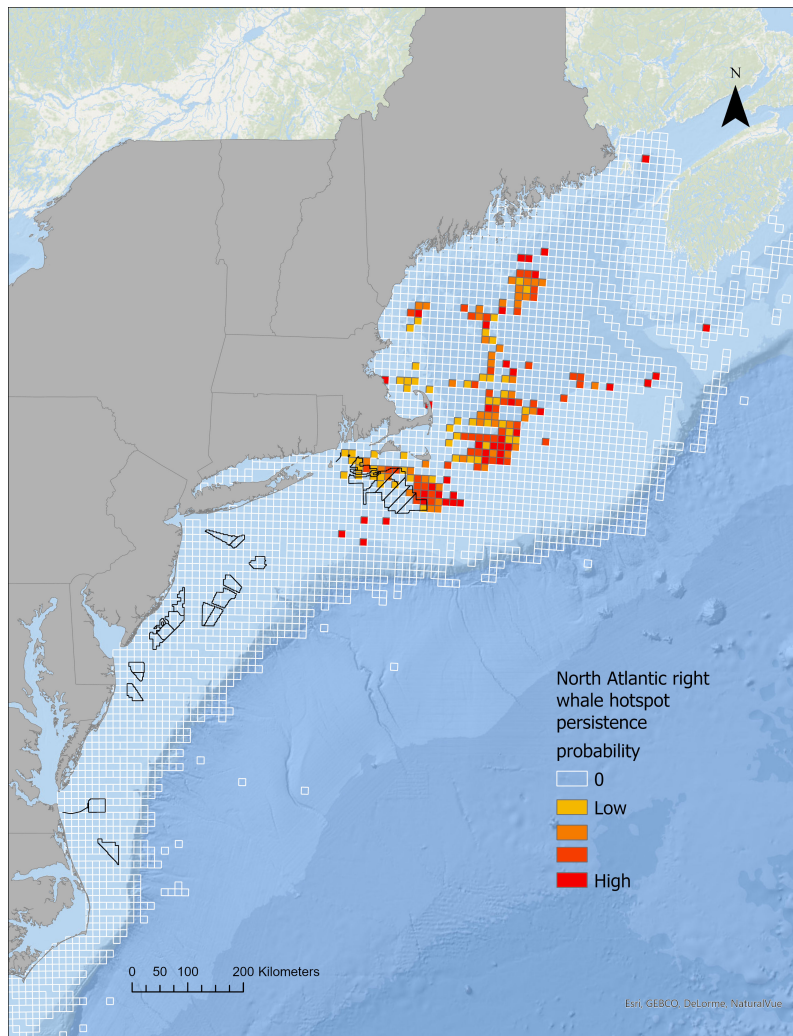


Figure 51: Northern Right Whale persistent hotspots and Wind Energy Areas. Areas outlined in black show active or proposed wind energy leases.

2023 Highlights

Multiple [anomalous conditions](#) and extreme events were observed in 2023 that could have brief local effects and/or widespread long-term ecosystem, fishery, and management implications. This section intends to provide a record of these observations, the implications they may have for other ecosystem processes, and a reflection on how they fit into our understanding of the ecosystem. Many of these observations are being actively studied but should be noted and considered in future analyses and management decisions.

Globally, 2023 was the warmest year on record with record high sea surface temperatures in the North Atlantic. In contrast, Northeast U.S. shelf surface temperatures were more variable, with near record highs in winter and near average conditions in other seasons.

Regional/Coastal Phenomena

There was a documented [die-off of scallops](#) in the Mid-Atlantic Elephant Trunk regions between the 2022 and 2023 surveys. In 2022, Elephant Trunk experienced [stressful temperatures](#) for scallops (17 - 19 °C) for an average of 30 days, (Fig. 52) but ongoing research is being conducted to identify contributing factors. A fish and shellfish mortality event was observed in coastal New Jersey linked to [hypoxia and ocean acidification](#) (Fig. 53).

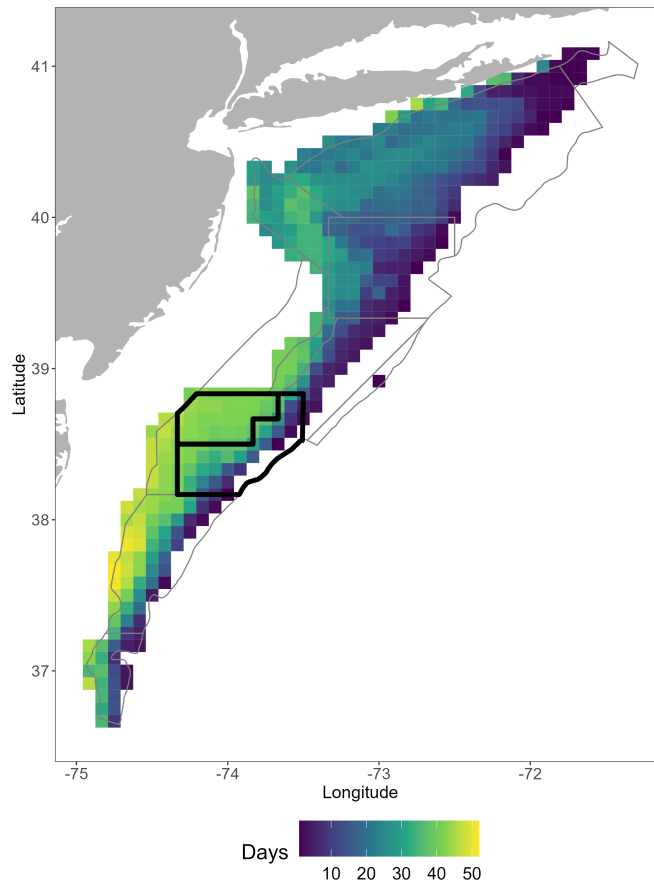


Figure 52: The number of days in 2022 where bottom temperature was between 17 and 19 °C (stressful thermal temperatures for sea scallops) in each GLOFRYS grid cell. The gray lines show the sea scallop estimation areas, with the Elephant Trunk region highlighted in black lines.

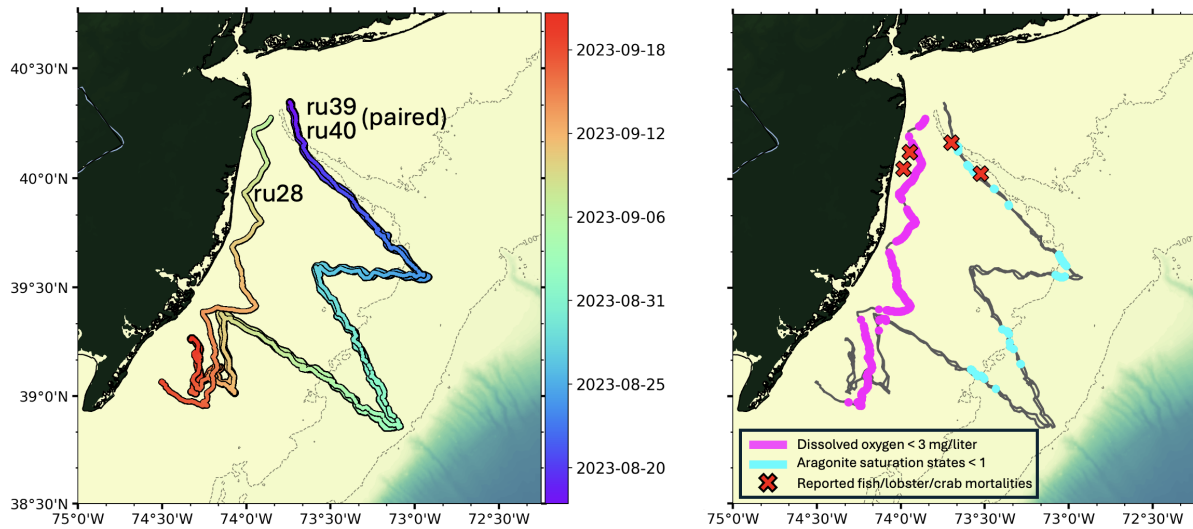


Figure 53: Left: Mission tracks of three gliders deployed off the coast of New Jersey in August and September of 2023. Right: Locations of hypoxic levels of dissolved oxygen (magenta; < 3 mg/liter) and low aragonite saturation state (cyan; < 1) measured along the glider mission tracks and locations of reported fish, lobster, and/or crab mortalities (red X).

Summer [bottom temperatures](#) in the Gulf of Maine were the warmest on record (since 1959) resulting in the second largest [bottom marine heatwave](#). The heatwave started in February, peaked in May and likely continued beyond August (pending data update). 2023 [bottom temperature](#) exceeded the 15°C hreshold for up to 59 days along the shelf break.

A wide-spread, long-duration [phytoplankton bloom](#) of the dinoflagellate *Tripes muelleri* was observed in the GOM and generated [chlorophyll concentrations](#) up to ten times greater than average (a record high since 1998) from March to August (Fig. 54). The bloom severely reduced water clarity, impacting harpoon fishing and likely affecting visual predators. Despite *Tripes* being a similar size to typical large phytoplankton (diatoms), this extra production was not grazed nor did it sink to the bottom. The specific drivers of the bloom and implications to the food web are still under investigation.

The Chesapeake Bay experienced the least amount of [hypoxia conditions](#) on record (since 1995), creating more suitable habitat for multiple fin fish and benthic species. Cooler [Chesapeake Bay water temperatures](#) paired with less hypoxia in the summer suggest conditions that season were favorable for striped bass. Cooler summer temperatures also support juvenile summer flounder growth. However, warmer winter and spring water temperatures in the Chesapeake Bay, along with other environmental factors (such as low flow), may have played a role in low production of juvenile striped bass in 2023.

Higher-than-average [salinity](#) across the Bay was likely driven by low precipitation and increased the area of available habitat for species such as croaker, spot, menhaden, and red drum, while restricting habitat area for invasive blue catfish.

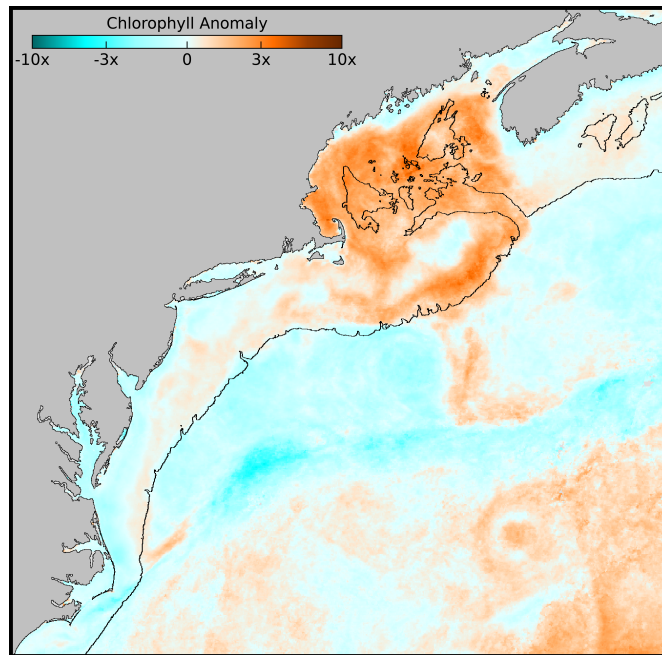


Figure 54: The chlorophyll anomaly for June 2023. Chlorophyll concentrations in the Gulf of Maine were 5-10 times greater than the long-term June average.

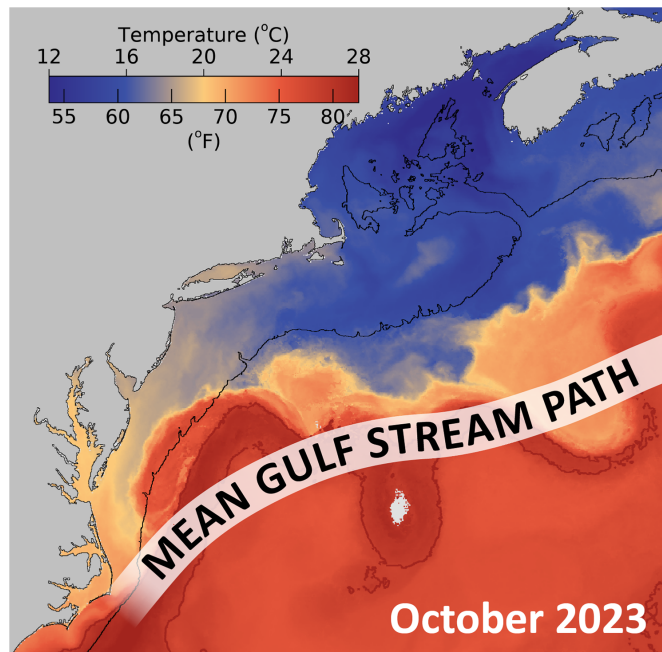


Figure 55: Weekly mean sea surface temperature (October 8-10, 2023) with the long-term mean Gulf Stream position. Red lines represent the 26°C (78.8°F) temperature contour.

Shelf-wide Phenomena

The [Gulf Stream](#) was highly variable in 2023, with northward shifts intermittently throughout the year and a more notable prolonged shift north along the continental shelf break in the southern Mid-Atlantic in the fall (Fig .55). This shift severely constricted the Slope Sea (the waters between the Gulf Stream and continental shelf), inhibited warm

core ring formation and interactions, resulted in unusually warm and salty surface waters, and strong northeastward currents in the southern Mid-Atlantic. Intermittent warm waters like this can be threats to temperature-sensitive species, especially species at the southern end of their range or that are not mobile (e.g. scallops), while also providing suitable habitat for more southern species.

While the total number of [warm core rings](#) in 2023 (18) was below the decadal average (31), there were a few notable events. A large early season ring pulled continental shelf water into the Slope Sea. Events like these can create biological hotspots, aggregating multiple species in small areas, increasing bycatch risks, and marine mammal shipstrike risks. In spring 2023, concentrations of [North Atlantic right whales](#), humpback whales, basking sharks, and other large baleen whales were observed feeding near the edge of warm core rings near the shelf break.

Multiple fall 2023 tropical and coastal storms caused several flash flood events, above-average coastal water levels, strong winds, and high rainfall totals throughout the Northeast. These storms may be related to the shift from 2020-2022 La Niña conditions to strong El Niño conditions in late spring 2023. El Niño winters are associated with more frequent East Coast storms, which can result in increased risk of coastal flooding, increased freshwater runoff into the coastal ocean, and delayed spring transition from a well mixed water column to stratified. In estuaries, increased freshwater flow decreases salinity, reduces the amount of suitable habitat for juvenile marine fish, and is related to increased hypoxia (low oxygen). However, precipitation is not uniform throughout the Northeast U.S., and [Chesapeake Bay 2023 conditions](#) did not align with El Niño expectations. The current El Niño is expected to weaken by spring 2024.

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Document Orientation

The figure format is illustrated in Fig 56a. Trend lines are shown when the slope is significantly different from 0 at the $p < 0.05$ level. An orange line signifies an overall positive trend, and purple signifies a negative trend. To minimize bias introduced by small sample size, no trend is fit for < 30 year time series. Dashed lines represent mean values of time series unless the indicator is an anomaly, in which case the dashed line is equal to 0. Shaded regions indicate the past ten years. If there are no new data for 2020, the shaded region will still cover this time period. The spatial scale of indicators is either coastwide, New England states (Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine), or at one of the two Ecosystem Production Units (EPUs, Fig. 56b) levels in the region, Georges Bank (GB) or Gulf of Maine (GOM).

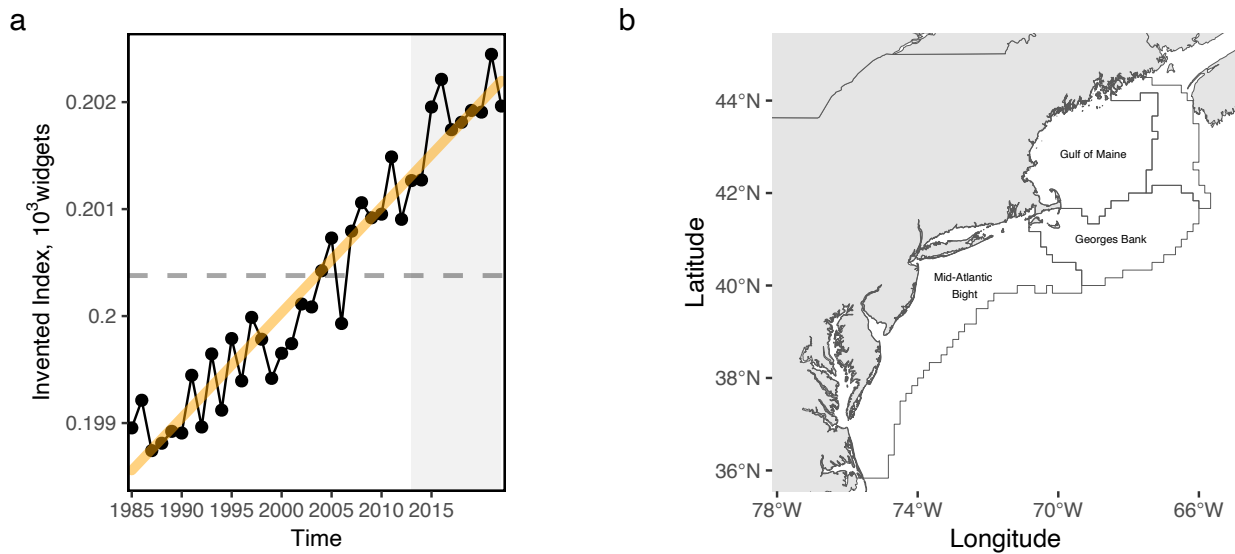


Figure 56: Document orientation. a. Key to figures. b. The Northeast Large Marine Ecosystem.

Fish and invertebrates are aggregated into similar [feeding guild categories](#) (Table 4) to evaluate ecosystem level trends in predators and prey.

Table 4: Feeding guilds and management bodies.

Guild	MAFMC	Joint	NEFMC	State or Other
Apex Predator				shark uncl, swordfish, yellowfin tuna, bluefin tuna
Piscivore	summer flounder, bluefish, northern shortfin squid, longfin squid	spiny dogfish, goosefish	winter skate, clearnose skate, thorny skate, offshore hake, silver hake, atlantic cod, pollock, white hake, red hake, atlantic halibut, acadian redfish	sea lamprey, sandbar shark, atlantic angel shark, atlantic torpedo, conger eel, spotted hake, cusk, fourspot flounder, windowpane, john dory, atlantic cutlassfish, blue runner, striped bass, weakfish, sea raven, northern stargazer, banded rudderfish, atlantic sharpnose shark, inshore lizardfish, atlantic brief squid, northern sennet, king mackerel, spanish mackerel

Guild	MAFMC	Joint	NEFMC	State or Other
Planktivore	atlantic mackerel, butterfish		atlantic herring	harvestfishes, smelts, round herring, alewife, blueback herring, american shad, menhaden, bay anchovy, striped anchovy, rainbow smelt, atlantic argentine, slender snipe eel, atlantic silverside, northern pipefish, chub mackerel, atlantic moonfish, lookdown, blackbelly rosefish, lumpfish, northern sand lance, atlantic saury, mackerel scad, bigeye scad, round scad, rough scad, silver rag, weitzmans pearlsides, atlantic soft pout, sevenspine bay shrimp, pink glass shrimp, polar lebbeid, friendly blade shrimp, bristled longbeak, aesop shrimp, norwegian shrimp, northern shrimp, brown rock shrimp, atlantic thread herring, spanish sardine, atlantic bumper, harvestfish, striated argentine, silver anchovy
Benthivore	black sea bass, scup, tilefish		barndoor skate, rosette skate, little skate, smooth skate, haddock, american plaice, yellowtail flounder, winter flounder, witch flounder, ocean pout, crab, red deepsea	crab, unc, hagfish, porgy, red, sea bass, nk, atlantic hagfish, rougtail stingray, smooth dogfish, chain dogfish, bluntnose stingray, bullnose ray, southern stingray, longfin hake, fourbeard rockling, marlin-spike, gulf stream flounder, longspine snipefish, blackmouth bass, threespine stickleback, smallmouth flounder, hogchoker, bigeye, atlantic croaker, pigfish, northern kingfish, silver perch, spot, deepbody boarfish, sculpin uncl, moustache sculpin, longhorn sculpin, alligatorfish, grubby, atlantic seasnail, northern searobin, striped searobin, armored searobin, cunner, tautog, snakeblenny, daubed shanny, radiated shanny, red goatfish, striped cusk-eel, wolf eelpout, wrymouth, atlantic wolffish, fawn cusk-eel, northern puffer, striped burrfish, planehead filefish, gray triggerfish, shortnose greeneye, beardfish, cownose ray, american lobster, cancer crab uncl, jonah crab, atlantic rock crab, blue crab, spider crab uncl, horseshoe crab, coarsehand lady crab, lady crab, northern stone crab, snow crab, spiny butterfly ray, smooth butterfly ray, snakefish, atlantic midshipman, bank cusk-eel, red cornetfish, squid cuttlefish and octopod uncl, spoonarm octopus, bank sea bass, rock sea bass, sand perch, cobia, crevalle jack, vermilion snapper, tomtate, jolthead porgy, saucereye porgy, whitebone porgy, knobbed porgy, sheepshead porgy, littlehead porgy, silver porgy, pinfish, red porgy, porgy and pinfish uncl, banded drum, southern kingfish, atlantic spadefish, leopard searobin, dusky flounder, triggerfish filefish uncl, blackcheek tonguefish, orange filefish, queen triggerfish, ocean triggerfish
Benthos	atlantic surfclam, ocean quahog		sea scallop	sea cucumber, sea urchins, snails(conchs), sea urchin and sand dollar uncl, channeled whelk, blue mussel