Mid-Atlantic Fishery Management Council
Ecosystem Approach to Fisheries Management Guidance Document

Approved by Council August 8, 2016

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1. INTRODUCTION

The Mid-Atlantic Fishery Management Council (Council) has been considering mechanisms to introduce ecosystem considerations into the fishery management process since the late-1990s (MAFMC 2006). In the fall of 2011, the Council hosted the fourth National Scientific and Statistical Committee Workshop, which was convened to provide an opportunity for the eight Council SSCs to discuss incorporation of ecosystem considerations in federal fisheries management (Seagraves and Collins 2012). After a review of the various approaches to incorporating ecosystem considerations into fishery management around the US, the Council adopted the transitional approach being taken by the Pacific Fishery Management Council to introduce ecosystem considerations into Council management actions in a step-wise, evolutionary fashion - herein referred to as an *ecosystem approach to fisheries management* or EAFM (as opposed to EBFM - see Box 1).

Box 1. Definitions - ultimately we are attempting to manage fisheries within a broader ecosystem context compared to traditional single species approaches (see Link 2010 for more in-depth discussion).

Ecosystem based fisheries management or EBFM attempts to manage the ecosystem as an entity to account for species/interactions of interest.

Ecosystem approach to fisheries management or EAFM attempts to manage species while considering the broader interactions within the ecosystem.

This strategy addresses several key elements necessary for the successful implementation of an ecosystem approach to fisheries management. The first is the need to carefully develop a transition strategy to move from the current single-species focused management system to more of a multi-species/ecosystem based one. This transitional approach will allow the Council to meet its current single-species based MSA requirements with respect to the prevention of overfishing and attainment of OY while moving towards a definition of OY which truly takes into account interactions at multiple dimensions of the environment/ecosystem, of which humans are inextricably a major component. Importantly, the approach allows for the growth and development of EAFM policy at a rate commensurate with the availability of the science necessary to support it. The Council recognizes that stakeholder involvement is imperative to success and that EAFM will require engagement of a much broader range of stakeholder interests compared to traditional fisheries management.

This document articulates the Council’s policy with respect to the incorporation of ecosystem considerations into its current management programs through the development of a series of policy statements and other recommendations related to important ecosystem considerations. Based on this guidance, initial implementation of Council management actions with respect to ecosystem considerations will occur in a consistent, coordinated fashion within the context of the current FMP structure. This document was developed as a "how-to" guide to allow the Council to transition to EAFM, but it could potentially be expanded and converted into a regulatory document in the future (i.e., a stand-alone Fishery Ecosystem Plan or FEP). It also important to note that this document represents the articulation of Council policy based on current available scientific data and analyses. As new information and analytical tools become available, the Council fully anticipates that future policy with respect to incorporation of ecosystem considerations into assessment and management will be revised based on the adaptive framework established in this guidance document.

2. PURPOSE AND NEED

The Council embarked on a Visioning Project in 2011 to chart a course for the future of marine fisheries management in the Mid-Atlantic based on extensive stakeholder input. This effort culminated in the development of the Council's Strategic Plan (http://www.mafmc.org/strategic-plan), which established an overarching goal of maintaining sustainable fisheries, ecosystems, and habitats in the Mid-Atlantic through the development of management approaches that minimize adverse ecosystem impacts. This EAFM Guidance Document was developed to specifically address objective 15 of the strategic plan - *Advance ecosystem approaches to fisheries management in the Mid-Atlantic (i.e., through development of EAFM Guidance Document).* This objective will be accomplished by moving beyond single species assessment and management and toward the development and implementation of assessments and management frameworks that incorporate: 1) environmental drivers, 2) habitat and climate change, 3) species interactions, and 4) fleet interactions, into fisheries management (the major sources of ecosystem-related uncertainties identified by stakeholders).

3. EAFM DEFINITION

> *An ecosystem approach to fishery management recognizes the biological, economic, social, and physical interactions among the components of ecosystems and attempts to manage fisheries to achieve optimum yield taking those interactions into account.*

4. EAFM GOAL

To manage for ecologically sustainable[1] utilization of living marine resources while maintaining ecosystem productivity, structure, and function.

5. ECOSYSTEM CONSIDERATIONS OF HIGHEST PRIORITY FOR DEVELOPMENT OF EAFM GUIDELINES

Based on Council and SSC discussions and stakeholder input from the Councils Visioning project, the Council concluded that the EAFM document should focus on the following major ecosystem-related issues[2]:

1. Forage/low trophic level species considerations;

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[1] Ecologically sustainable utilization is defined as utilization that accommodates the needs of present and future generations, while maintaining the integrity, health, and diversity of the marine ecosystem.

[2] Social and economic considerations were integrated throughout the analyses of the four topic areas

2. Incorporation of ecosystem level habitat conservation and management objectives in the current management process;
3. Effects of systematic changes in oceanographic conditions on abundance and distribution of fish stocks and ramifications for existing management approaches/programs; and
4. Interactions (species, fleet, habitat, and climate) and their effects on sustainable harvest policy and achievement of OY.

In response to the issues identified by stakeholders, the Council organized a series of four workshops which brought together scientists, managers and stakeholders to discuss each issue and best management practices to address them. After completion of the workshops, the Council developed white papers (http://www.mafmc.org/eafm/) which provide detailed information and in-depth discussion on issues related to forage fish management, climate change and climate variability, and interactions (synthesizing the incorporation of species, fleet, habitat, and climate interactions into fisheries management in the final white paper). This guidance document builds off that foundation for establishing an EAFM in the Mid-Atlantic Region.

6. DESCRIPTION OF THE NORTHEAST LARGE MARINE ECOSYSTEM

A description of the Northeast Large Marine Ecosystem (NELME) provided by the Northeast Fisheries Science Center is given in Appendix 1. While the jurisdictional boundaries of the Mid-Atlantic Council extend from New York to the North Carolina -Virginia border, the management units specified in Council fishery management plans extend throughout the range of the species under management (the case for all managed species). For example, the management unit for the Atlantic Bluefish Fishery Management Plan extends from the East Coast of Florida to the US Canadian border. Thus, bluefish transcend the boundaries of ecosystems north and south of Cape Hatteras, the southern boundary of the NELME described in appendix i. Additional information describing the ecosystems along the entire Atlantic Coast of the United States was given in the Climate White Paper. From an operational standpoint, guidance provided in this document shall apply to the species under consideration throughout its management unit (which, in many cases, extends well north and south of the boundaries of the NELME).

7. OPERATIONAL TRANSITION TO EAFM

Policy guidelines and recommendations which address incorporation of ecosystem considerations into Council assessment and management programs

7.1 Guidelines for the management of forage species

The Council and its constituent stakeholder groups have expressed strong interest in the development of a policy/approach for managing forage fishes (MAFMC 2012). The role of forage species in Mid-Atlantic ecosystems and potential considerations for their management were evaluated in-depth in the Council’s Forage Fish White Paper (http://www.mafmc.org/eafm/). The debate about best practices for management of forage stocks has continued since the Council held its forage workshop. Essington et al (2015a) present a strong argument that special safeguards protecting heavily exploited forage stocks should be in place due to the important role they play in the transfer of energy in marine food webs. They note that forage fish collapses share a common and unique set of circumstances: high fishing pressure for several years before collapse, a sharp drop in natural population productivity, and a lagged response to reduced fishing pressure. The authors demonstrate that the magnitude and frequency of forage species collapses are greater than expected from natural productivity characteristics (which can likely be attributed to fishing). The authors conclude that a risk-management approach that reduces fishing pressure when populations become scarce should be in place to protect forage stocks and their predators.

Szuwalski and Hilborn (2015) argue that the productivity of forage fish stocks is driven primarily by environmental factors through the regulation of recruitment processes and that fishing plays little, if any role in the collapse of forage stocks. The authors conclude that management should respond to collapses in recruitment by preventing fishing mortality from increasing as biomass declines, rather than waiting for biomass to decline and then reacting. In rebuttal, Essington et al 2015b emphasized that fishing pressure tends to amplify natural troughs in production of forage stocks which can lead to further depletion and have negative consequences for obligate predators within the ecosystem. They argue that fishing strategies need to avoid, to the extent possible, depleting forage fish stocks below critical ecological thresholds. Both papers agree that management should respond to declines in recruitment as an early indicator of decreased productivity. Anticipating recruitment failures through monitoring of these stocks is critical and remains one of the primary challenges in the assessment and management of forage fish stocks.

Hence, a consensus is emerging that forage and/or low trophic level species should be managed more conservatively than the MSY based conservation and management MSA standard because of the important role they play within the ecosystem. To that end, the Council adopted the following policy:

> **It shall be the policy of the Council to support the maintenance of an adequate forage base in the Mid-Atlantic to ensure ecosystem productivity, structure and function and to support sustainable fishing communities.**

7.1.1 Modifications to Biological Reference Points

Special management of forage species can be accomplished through modification to the Council's risk policy and ABC control rule framework in several ways. First, the Council could adopt biological reference points (overfishing levels or OFL) for forage stocks that are more conservative than the required MSA standard of F_{MSY}. We would expect the stock in question to be maintained at biomass levels that exceed B_{msy}. Candidate reference points in this regard include fishing mortality rates that do not exceed the natural mortality rate (i.e., $F<M$) or are specified as some fraction of the natural mortality rate, among others (Box 2).

Box 2. Potential precautionary biological reference points for forage fish fisheries. Empirical mortality- and biomass-based reference points. F is the fishing mortality rate; F_{msy} is the F level to achieve maximum sustainable yield; M is the instantaneous natural mortality; F_{ERP} is an ecological reference point for F; B_{ERP} is an ecological reference point for biomass; and B_0 is virgin biomass.

Mortality-based reference points	**Source**
F = M	Beverton 1990
F = 0.87 M	Zhou et al. 2012
F = 0.67 M	Patterson 1992
F_{ERP} = (0.2, 0.5 or 0.75) F_{MSY}	Pikitch et al. 2012

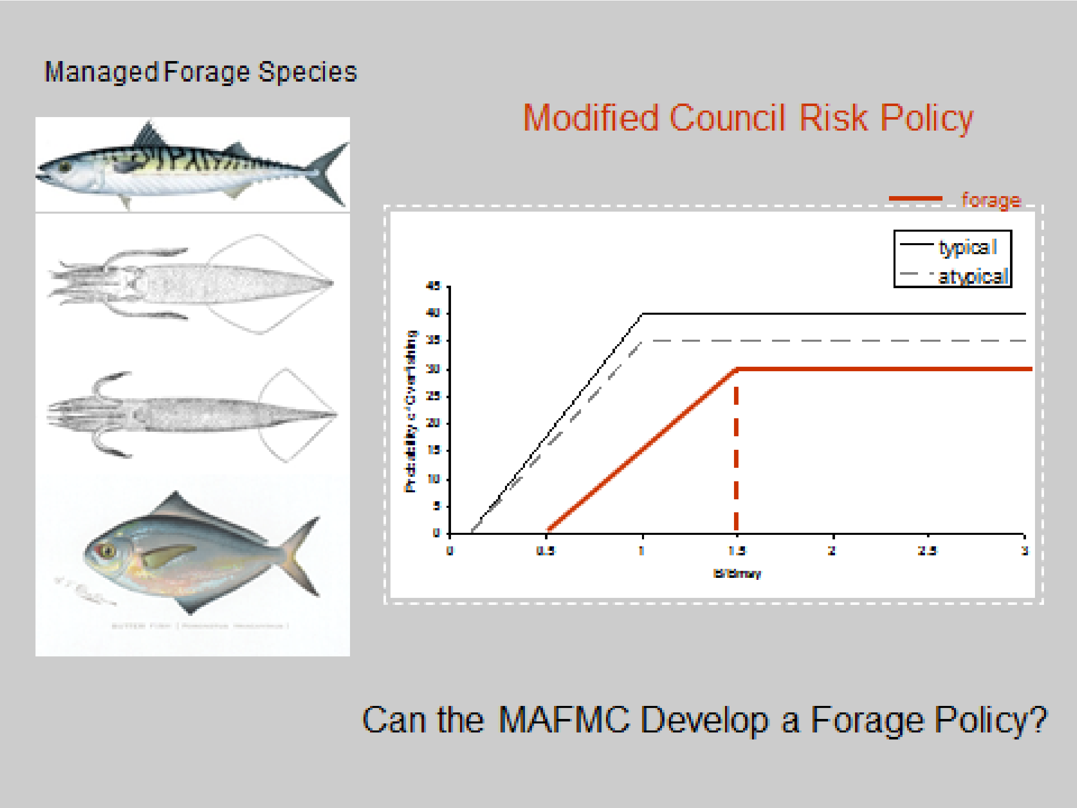
Biomass-based reference points Source	
B_{ERP} = 0.75 B_0	FAO 2003, Smith et al. 2011
B_{ERP} = (0.8, 0.4, or 0.3) B_0	Lenfest 2012

Reference points based on this convention should be considered as a starting point for evaluation of potential biological reference points for managed forage species. For example, the Council adopted an OFL for Atlantic butterfish based on a fishing mortality rate of F=0.67 M (see the Forage White Paper for a more detailed discussion of the reference point issue). This option has the potential to perform as a stand-alone measure when implemented within the existing Council risk policy framework - depending on the life history of the species of interest and the Council's specific objectives relative to the forage species in question.

The potential reference points for forage species described in Box 2 represented the best science available at the time this document was developed. The issue of specification of biological reference points for forage species is the source of ongoing scientific debate and the Council anticipates that the future policies and decisions about how to best manage forage species will continue to be refined as new information becomes available.

7.1.2 Modifications to existing Council Risk Policy

Another option would be to modify the shape of the ABC control rule for forage species through modification of the Council's risk policy. The current default control rule (depicted as the solid black line) and an ***example*** forage control rule (red line) is depicted in Figure 1.



Managed Forage Species

Modified Council Risk Policy

Can the MAFMC Develop a Forage Policy?

Figure 1. Example modification (red line) to the Council's ABC framework and risk policy for forage species.

According to the existing control rule (black line above), the Council’s maximum tolerance for risk of overfishing is specified at 40% (i.e., when the stock is at or above B_{MSY}). Below B_{MSY} the Council’s tolerance for risk of overfishing declines linearly with stock size to a level of 10% of B_{msy} at which point fishing mortality would be reduced to zero to prevent any further stock declines. This functional control rule is designed to automatically trigger required reductions in fishing mortality as stocks decline below B_{msy}, which, in turn, should result in increases in stock biomass and cause stock size to increase.

Modifications to the existing risk policy to accommodate ecosystem level concerns for forage species could be accomplished by reducing the maximum tolerance for risk of overfishing. For example, forage species currently managed by the Council (*Illex* and longfin squid, butterfish, and mackerel) could be managed by maintaining the current OFL fishing mortality rate (F_{msy} based or proxy) and reducing the maximum probability of overfishing to 35% (the default value chosen for atypical species) or some other level below the current maximum of 40%. In addition, as depicted in the example red line in Figure 1, the Council could specify a control rule that reduces fishing mortality more aggressively as forage stock biomass declines (to address the concern that fishing tends to exacerbate environmentally driven declines in forage stocks). It is important to note that the potential modification to the risk policy depicted in Figure 1 (red line) is presented as an *example* only; the final policy adopted by the Council for any given species will depend on the outcome of tradeoff analyses described in the section below.

7.1.3 Establishing forage species management policy - evaluating tradeoffs

As noted above, managing forage species to achieve ecosystem level objectives can be accomplished functionally through modifications to biological reference points and/or the Council's risk policy. However, this approach only addresses ways to maintain (at least theoretically) forage stocks at higher biomass levels to support ecosystem level objectives from a purely biological perspective. Optimal management of forage fish ultimately depends on the trade-off between their indirect in situ value versus their direct harvest market value. Thus, managing these trade-offs requires knowledge of not only the species ecology, but also the uses of and substitutes for these species within the economy. Further, these choices are based not just on ecological preferences and commercial uses, but cultural and social preferences as well.

The data and analyses required to perform these analyses are discussed in detail in the Forage White Paper. That analysis concluded that given adequate information, optimal harvest levels can be derived from bio-socio-economic multispecies models. See Charles (1989) for a theoretical exposition of how these types of models can be operationalized.

Unfortunately, the state of the science is such that these models have yet to be practical. Lacking full bio-socio-economic models, population dynamics, ecology, economics, anthropology, and social sciences can help generate an understanding of the relative trade-offs between these direct and indirect benefits through an understanding of the economic, social, and ecological dependence on the forage fish of interest. Economically, this can be achieved by first developing an understanding of valuable species that predate on, and the preferential targeting of, the forage fish of interest. This helps to ascertain not only which species are likely to benefit from alternative management strategies, but also to identify which strategies are likely to generate the benefits of interest.

The role of forage fish in the economy, in terms of both value and substitutability, must also be understood. Qualitative and, when feasible, quantitative analyses can be conducted to understand the relative impact of choosing more precautionary biological thresholds for forage fish management. Ultimately economic, social and cultural analyses will help understand which forage fish are likely to generate the largest net benefits to society, given changing societal preferences at home and abroad, if and when, more precautionary biological thresholds are adopted.

Given that the current state of the social and economic data to evaluate these trade-offs is lacking, the Council adopted the following policy:

> **The Council, in conjunction with its SSC and the NEFSC, shall promote the timely collection of data and development of analyses to support the biological, economic and social evaluation of ecosystem level tradeoffs including those required to establish an optimal forage fish harvest policy.**

This policy statement is important because, historically, fishery management under the Magnuson Act has focused primarily on the biological aspects of fishery conservation and management. An examination of the state of affairs relative to the incorporation of social and economic analyses in federal fisheries management occurred at the fourth national SSC workshop. The results of that workshop emphasized the need to greatly improve social and economic impact analyses and incorporate them in federal fisheries management (Seagraves and Collins 2012). Little has changed in this regard since that workshop was held in 2011. The Council should consider the formation of a working group comprised of Council and Regional office staff, NEFSC personnel and SSC members with expertise in the social and economic disciplines to address this deficiency. The Council's SSC has recently discussed a desire to engage its members with expertise in the social and economic disciplines, so the environment is favorable for the adoption of this approach. The Council should establish terms of reference for the working group which directs the group to evaluate available information and recommend a prioritized economic and social research plan to address the forage fish tradeoff issue, as well as other ecosystem considerations identified in this document.

7.1.4 Unmanaged Forage Species

Small, mostly planktivorous fishes are some of the most abundant fishes in the Mid-Atlantic region (see Table 3 in Forage White Paper). Some of these fishes, such as bay anchovy and Atlantic silverside, occur predominantly in estuaries, coastal embayments, and the three-mile zone. Others are broadly distributed along the coast and offshore (e.g., sand lance), while still others are found over deeper shelf waters (e.g., round herring). None of these forage species has been assessed and there are no biomass or abundance estimates. Some are species of concern since they may be at low population levels and/or occur as bycatch in fisheries for managed species in the Mid-Atlantic and New England (e.g., river herrings). With climate change, some of the more southern species now supporting small fisheries in the S. Atlantic and Gulf (e.g., thread herring, Spanish sardine), might become abundant enough to warrant fishing in Mid-Atlantic waters. Sand lance, while not fished much historically in the western Atlantic, has had large catches in the Eastern Atlantic and might be targeted. Water quality concerns for some of the nearshore coastal species (e.g., bay anchovy, silverside) are significant, and these species support production of MAFMC-managed species at some life stages (e.g., bluefish). They also play a role in supporting food needs of striped bass and weakfish (ASMFC managed species).

In an effort to proactively protect and conserve currently unmanaged forage species, the Council is considering number of options regarding the protection of currently unmanaged forage species. In December 2014, the Council voted to "initiate a regulatory action to prohibit the development of new, or expansion of existing, directed fisheries on unmanaged forage species until adequate scientific information is available to promote ecosystem sustainability". The Council passed this motion with the intent of protecting the important ecological role that forage species play in the Mid-Atlantic.

The Council conducted a scoping process in the fall of 2015 to solicit input from interested members of the public on the types of management measures which could effectively address this motion. After considering recommendations from the Fishery Management Action Team the Council voted to initiate an omnibus amendment to add unmanaged forage species as Ecosystem Component (EC) species to the relevant Fishery Management Plans (FMPs) for Council-managed stocks.

In August 2016, the Council approved an amendment to protect over 50 previously unmanaged forage species in the Mid-Atlantic. If approved by the Secretary of Commerce, the Unmanaged Forage Omnibus Amendment would prohibit the development of new and expansion of existing directed commercial fisheries on these species in Mid-Atlantic federal waters. The prohibition would continue until the Council has had an opportunity to assess the available scientific information for these species and consider the potential impacts to existing fisheries, fishing communities, and the marine ecosystem.

The amendment establishes an incidental possession limit for all of the species included in the amendment, with the exception of chub mackerel. For chub mackerel, the Council approved temporary measures, including an annual quota and a possession limit, to be implemented while the Council evaluates potentially adding the species as a stock in the Atlantic Mackerel, Squid, and Butterfish FMP. The amendment also requires use of exempted fishing permits (EFPs) prior to allowing any new fisheries or expansion of existing fisheries for unmanaged forage species and establishes a new policy for Council review of EFP applications. In addition, prior to allowing any new fisheries or expansion of existing fisheries for the forage species included in the amendment, the Council will consider whether the species in question should be managed as a stock in the fishery or if other discretionary management measures should be used. Additional information concerning this Council management action can be found on the Council's website at (http://www.mafmc.org/actions/unmanaged-forage).

7.2 Ecosystem-level Habitat Guidance

While habitat is recognized as a fundamental component of marine ecosystems and provides the basis for fisheries production, full integration of habitat management and conservation into the fishery management process has been challenging. The Council considered ways to effectively consider habitat from an ecosystem-level perspective and integrate habitat information into an ecosystem approach to fisheries management at a Habitat Workshop held in Philadelphia, PA in October 2015 (http://www.mafmc.org/workshop/2015/eafm-habitat-considerations). Discussion at the workshop resulted in a number of key points and considerations described below to provide ecosystem-level habitat guidance to the Council.

7.2.1 Demonstrate and communicate the value of habitat to managed fisheries and transition to landscape/ecosystem level habitat descriptions and conservation.

Fish habitats are the places where species live, including the physical, chemical, biological, and geological components of both benthic and pelagic environments (Box 3). Habitats provide ecological benefits to species reproduction, growth, and survival, and play a fundamental role in supporting fishery and ecosystem production (NMFS 2015). There is ongoing work to integrate this critical supporting function in the Northeast Integrated Ecosystem Assessment (IEA); see below. Fish species may use various habitats for each life stage.

Box 3: Habitat Characteristics Important to Marine Species (modified after NMFS 2010)

Seafloor Structure	Vegetation Emergent epifauna Biogenic reefs (e.g. coral, oyster, sponge) Geomorphology (e.g. rocky outcrops, pinnacles) Physiography (e.g. seamount, submarine canyon)
Sediments	Grain size Organic content Rugosity Stability Slope
Hydrodynamic Processes	Currents/boundaries/fronts Tidal dynamics Wave dynamics Upwelling
Hydrology	Depth/bathymetry Salinity/haloclines Temperature/thermoclines Density/pycnoclines Turbidity Nutrients Dissolved oxygen/oxyclines pH
Anthropogenic Alterations	Pollutants/contaminants Artificial structures (e.g. artificial reef, oil platform) Created habitats (e.g. restored salt marsh, planted seagrass bed) Fishery impacts Marine debris

The MSA requires fishery management councils to identify, describe, map, and conserve Essential Fish Habitat (EFH) for each fish species managed under its jurisdiction. EFH is defined in the MSFCMA as "those waters and substrate necessary to fish [and shellfish] for spawning, breeding, feeding or growth to maturity”[3]. The broad definition of EFH has led the Mid-Atlantic and the New England Fishery Management Councils to identify EFH in most, if not all areas in the Northeast U.S. Shelf Ecosystem, ranging from offshore pelagic areas to nearshore wetlands to streams and rivers. At its most basic level, habitat (*sensu* EFH) is defined separately for each managed fisheries species by where that species in any of its life stages has been caught; physical/chemical/geological/biological characteristics are acknowledged, but are secondary to the definition of EFH. However, the broader ecological concept of habitat is based upon characteristics of the water column, benthic structure, and linkages from primary productivity to benthic communities to the pelagic, assuming that these factors dictate fish distribution. The fact that multiple species can inhabit a habitat so defined allows for easier accounting for species interactions and for habitat change.

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[3] 16 U.S.C. 1802 (10)

The Mid-Atlantic Fishery Management Council first identified EFH for thirteen species in 1998, and updated EFH descriptions for tilefish in 2009. The 1998 EFH designations are based on long-term and historic data sets[4] that provide levels 1 (distribution of the species for some or all of the geographic range) and 2 (habitat-related species density) EFH information. Text descriptions for individual species and lifestages include several additional habitat characteristics beyond abundance and distribution, including depth, temperature, and salinity ranges. For benthic life stages, substrate and vegetation associations are also included. The Council has also identified two Habitat Areas of Particular Concern (HAPCs) to highlight habitat types and areas that are especially valuable to summer flounder and tilefish.

Habitat management in an ecological sense is really ecosystem management, it's mainly a difference in the scale at which we consider issues. To date, habitat and EFH designations have been considered on a single species basis by management, and this has proven useful for regulatory purposes, especially regarding potential non-fishing impacts. However, there is a need to consider habitat more broadly from an ecosystem perspective at both regional and global scales that goes hand-in-hand with the need to manage multiple, overlapping and interacting fisheries in a more integrated way. Moving towards ecosystem level habitat description and conservation requires consideration of habitat from new perspectives and at different space and time scales relative to historical practice.

A variety of sources to address this issue are available from NMFS. Essential Fish Habitat Source Documents (http://www.nefsc.noaa.gov/nefsc/habitat/efh/) and the Essential Fish Habitat Mapper (http://www.habitat.noaa.gov/protection/efh/efhmapper/). These resources have been used to compile scientific information on habitat from a variety of sources. However, new data sources could be used to update and refine current habitat information and improve understanding of fish habitat use. Much of this is based on broad trawl survey work, which has the advantage of very extensive coverage but at a coarse scale. Additional focused sampling in habitats at finer scales is needed.

An IEA framework may be helpful for organizing and considering the specific habitat processes detailed below. At the ecosystem level, interactions between both large scale environmental drivers and human activities are mediated by habitat to affect the ecological systems under management. A possible conceptual model demonstrating these linkages shows how healthy habitat supports biological objectives (e.g. healthy biomass levels, production, and trophic structure) for managed species, which in turn support objectives for human well-being (e.g. seafood production, recreational opportunities, profitability, employment, stability, and culture; Fig 2.). At the IEA level, managed fish and invertebrate species could be categorized by habitat type; e.g. mackerel, squids, and butterfish would be in the "pelagics" category in Fig. 2, while surfclams and ocean quahogs would be in the "benthic inverts" category. Alternatively, managed

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[4] Maps of juvenile and adult EFH are based on data from the 1963 - 1997 NMFS bottom trawl survey. Maps of egg and larval EFH are based on data from the NMFS Marine Resources Monitoring, Assessment and Prediction (MARMAP) 1977 - 1987 ichthyoplankton survey. Additional sources of information were used to identify EFH within inshore areas, including data collected during surveys that spanned 1978 – 1997.

species could be classified by warm or cold water habitat preference. Using a framework like this, connections between habitats within and outside MAFMC jurisdiction and MAFMC managed species can be visualized and eventually quantified, if that becomes a priority for the Council. This would complement existing single stock oriented EFH by taking a full system perspective.

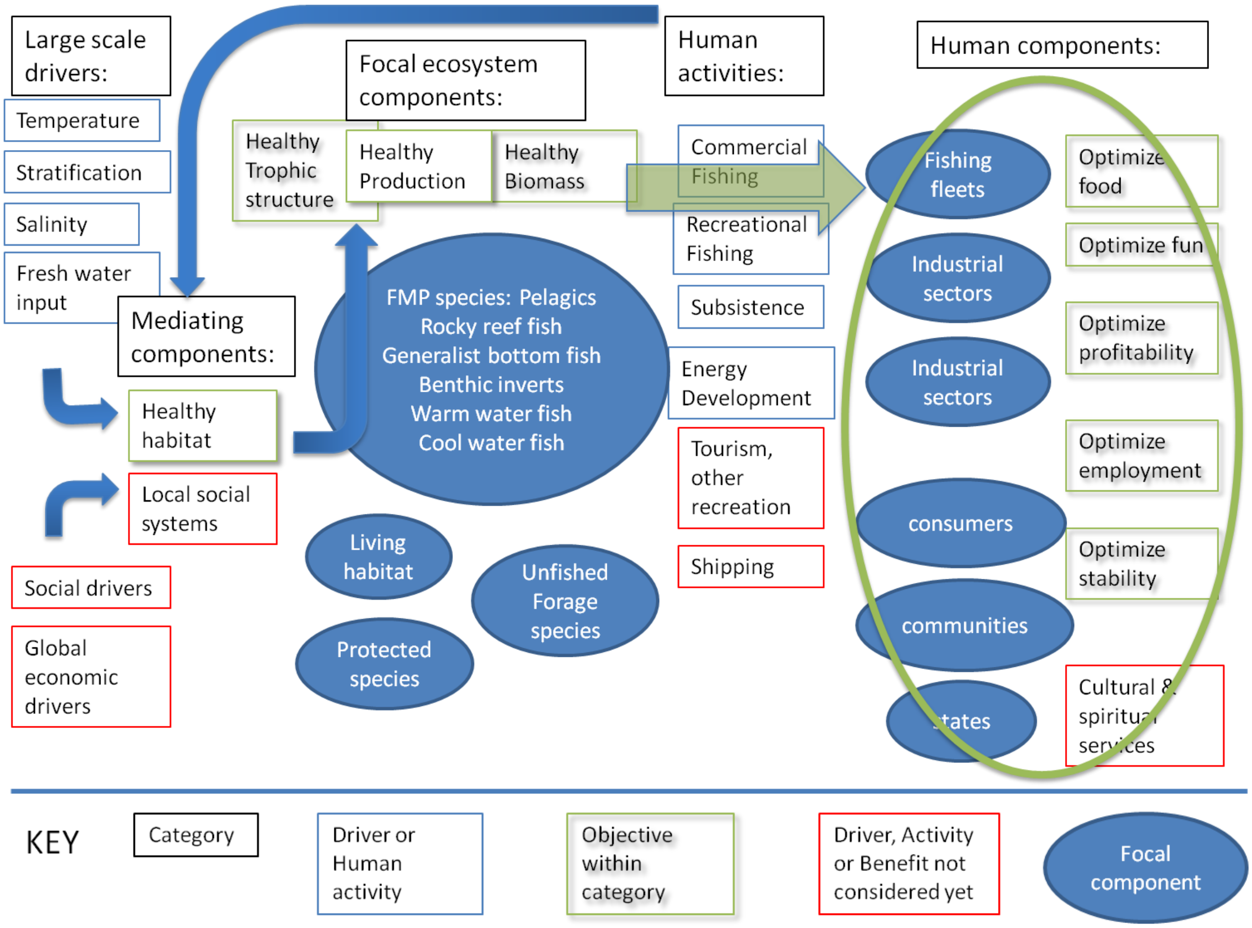

Figure 2. Potential conceptual model for habitat interactions in a Mid-Atlantic IEA (draft suggested as a starting point for further discussion).

In the Northeast IEA, the key habitat types are Freshwater/Estuarine habitat, Nearshore habitat, Pelagic habitat, and Seafloor/demersal habitat. Characterizing habitats in this way permits the selection and analysis of habitat-specific indicators. IEA Indicators for habitat types apply to multiple species associated with or dependent on that habitat type. This is intended to complement the extensive work already done under Essential Fish Habitat, which focuses on individual managed stocks and the habitats that they need for major life stages and processes. Initial Northeast IEA habitat indicators are already compiled within the NEFSC Ecosystem Considerations webpage[5].

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[5] http://www.nefsc.noaa.gov/ecosys/ecosystem-status-report/ecosystem-services.html.

7.2.2 Identify and document the contributions of inshore habitats to offshore fishery productivity

The Mid-Atlantic region is comprised of a mosaic of habitats extending from the rivers and estuaries to continental shelf and deeper waters at the shelf break and beyond. These coastal habitats are used by most species managed by the Mid-Atlantic Fishery Management Council (11 of 13) for spawning activities, nursery habitat, and refuge. Many forage species also use these coastal habitats. Activities occurring in freshwater and terrestrial habitats in the highly developed coastal zone have downstream effects on coastal and estuarine ecosystems and contribute to the natural mortality of fishery species. However, limited information exists to quantify fisheries production resulting from inshore and coastal habitats and this level 4 data is rarely incorporated in EFH identifications, descriptions, or maps across the United States.

Ecosystem models can help quantify the habitat-related effects on fish stocks, including effects on natural mortality, recruitment, growth, and migration. For example, Atlantis and other ecosystem models have been used by NMFS to determine the contribution of marsh and oyster reef habitats in the Chesapeake Bay to summer flounder and black sea bass production, respectively (see http://chesapeakebay.noaa.gov/ecosystem-modeling/chesapeake-bay-fisheries-ecosystem-model).

The EFH Source Documents include information on the coastal habitats used by Mid-Atlantic fisheries. Several additional data sources that can inform such ecosystem models are available from partner organizations, including:

- NOAA/NESDIS – Coastwatch: Satellite images and coast algorithms for chlorophyll, sediments, and sea surface temperature are useful for understanding the dynamics of coastal habitats.
- Telemetry networks (such as Atlantic Cooperative Telemetry (ACT) Network and Mid-Atlantic Acoustic Telemetry Observing System (MATOS): Data on fish movement patterns could be useful for understanding where fish prefer to spend time and movement patterns between inshore and offshore locations.
- Otolith chemistry studies: this type of analysis aims to identify stable isotope or trace element signatures that discriminate between locations where fish resided so information can be gained about the life history and movement of fishes. It provides a chronological record of exposure to habitats during natal and adult stages.
- Research on the effects of stressors on habitat quality at the land/water interface (such as the study in the Chesapeake and coastal bays conducted by regional PIs from The Smithsonian Environmental Research Center, Virginia Institute of Marine Sciences and University of Delaware): This type of work quantifies the connection between land use and shoreline alteration and the influence on estuarine and coastal habitats and ecosystems.

Updates to EFH Source Documents using these sources will improve our understanding of the location and functions of critical habitats. Additional work will be necessary to quantitatively link habitats and fisheries productivity.

7.2.3 Recognize the impact of climate on habitat

Climate change and climate variability will cause changes in physical attributes of habitat that in turn affect their ability to support fisheries. Dynamic properties of the ocean fluid are critical habitat features that have strong effects on metabolic rates that underlie most performance rates determining the growth rates of populations and climate change is expected to increase the dynamic nature of ocean habitats. Ocean acidification – increases in dissolved CO2 and decreases in pH - will continue and will effect physiology, calcification, olfaction and other biological components of individuals. Increases in temperature will also change the distribution of snow accumulation and the timing of snow melt thus changing the timing and magnitude of streamflow. Increases in precipitation will also lead to increases in streamflow and freshwater discharge into coastal systems. These changes in physical habitat will have direct (e.g., physiological) and indirect (e.g., through changes in survey availability) impacts to managed species.

Climate change and variability will also cause changes in biological habitats. Increases in dissolved CO_2 may increase productivity of macroalgae and sea grasses potentially increasing their capacity to provide shelter for managed species and for the prey of managed species. However, increases in turbidity owing to increases in streamflow may decrease macroalgal production. Increased temperatures in the Chesapeake Bay have already contributed to significant die-offs of eelgrass, which provides important nursery habitat for juvenile fish, including summer flounder. Ocean acidification may also impact deepwater coral, but information is very limited (Movilla et al. 2014). Sea-level rise will put pressure on nearshore habitats, especially where coastal hardening has occurred and natural marsh migration is restricted (Kirwan and Megonogal 2013), and may result in lost connectivity between adult, spawning, and nursery habitats used by fish species. For example, Rhode Island has lost more than half of its saltmarshes in the last 200 years; a three-foot rise in sea level would result in the loss of a significant percentage of remaining marsh area[6]. From 1998-2004, the Atlantic coast lost 7,360 acres of estuarine saltmarsh, primarily along shorelines near Delaware Bay due to erosion and/or inundation related to increases in sea level. Possible increase in storm intensity and frequency will also impact coastal habitats.

7.2.4 Strengthen EFH designations and consider "essential" from an ecosystem perspective emphasizing connectivity between species, life history stages, etc.

Overall, to consider essential fish habitat designations from an ecosystem perspective will require evaluation of habitat use for multi-stock assemblages. This will require the definition and description of habitat using uniform and relevant criteria. In addition, it is critical that habitat be addressed at uniform spatial and temporal scales. It must be acknowledged that the marine ecosystem is comprised of a complex system defined by prey abundance/distributions and multi-species interactions with habitat (including both the water column and the benthos). Possible considerations include multi-species EFH/habitat designation for both managed and other ecosystem species (including individual species and combination of species in similar trophic levels, guilds, and/or stock complexes). In addition, indicators of habitat status for stock complexes need to be identified and evaluated. In this regard, groups conducting multi-species stock assessments should work with habitat experts to help identify key indicators (i.e., those necessary to understand the ecology of the habitat). Indicators may not necessarily be managed species - for example they may be invertebrates prey items.

Overall, the Council needs to find practical approaches to begin describing/addressing habitat based on metrics that are easy to measure and document. This should include temperature as an environmental factor in both stock assessments and EFH designations. Here the Council needs to

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[6] http://seagrant.gso.uri.edu/state-adopts-slamm-maps-wetland-restoration-adaptation/

make better use of existing technology and find better ways to collect information. Modeling techniques need to be applied to existing data to improve EFH designations based on recent or updated time series data and also consider seasonal effects.

The Council also should consider taking a layered approach to applying habitat support tools. The EFH text descriptions need to be simple to support consultation with a broad trigger for a consult and then evaluate the details of an action when making conservation recommendations. Here, designating EFH based on stock complexes may be best in an ecosystem sense, but may not be in a consultative sense. In addition, habitat designations can be included in integrated ecosystem assessments to evaluate habitat on a broad scale, but these evaluations are limited since they are largely based on trawl survey data which may not sample many important areas of production and are not capable of addressing habitat at finer scales. Also a high level of production, supporting critical life stages of managed and forage species, is probably occurring within estuaries and the continental margin, areas which have not been sampled systematically by the NEFSC trawl survey.

7.2.5 Quantitatively link habitat science and conservation to fishery outcomes, focusing on ecosystem resilience and productivity

While it may be safe to assume that marginal changes to habitat productivity are linear, values may not be additive. It would be desirable to develop a link between habitat quality and quantity to individual species productivity and a link to overall ecosystem productivity. Studies of reproduction, survival, and productivity of species within their habitats need to be linked to overall ecological productivity. Temperature is probably the easiest to measure and probably the most basic biological metric to treat as a starting point in habitat science. Other important attributes include predator and prey migration (onshore-offshore, vertical), light regimes, DO, primary production, reproduction, survival, growth, and ocean acidification. Changes in the magnitude and directionality of these factors can lead to shifts in trophic interactions.

It is also important to be mindful of benthic pelagic coupling. In the mid-Atlantic region structured habitat may be even more important given the prevalence of featureless habitat throughout the region (sand, mud and silt). The lack of fishery independent survey sampling near structured habitat limits our ability to define and evaluate these types of habitat. Also, the uniformity of habitat types throughout the mid-Atlantic region limits our ability to describe the dynamics of habitat types through mapping. Habitat assessment prioritizations are being conducted by the NEFSC to prioritize species habitat and stock assessment research.

7.2.6 Determine if existing habitat authorities are being fully utilized and provide guidance to improve efficacy of implementation

The Council attempts to minimize impacts to EFH for non-fishing activities through the consultation process and by evaluation and implementation of measures to reduce fishing impacts. To improve the efficacy of this process the Council needs to enter into agreements to identify projects of concern and to develop Council policy to expedite the commenting process. The Council also needs to consider options on how to engage advisors in this process (evaluate the types of advisors that are needed to inform habitat consultation process). The Council also needs to prioritize areas for habitat identification and/or protection from fishing and non-fishing activities. There is also a need to identify goals and criteria for designating HAPC.

7.2.7 Identify research needs and actions to support Council habitat mandates and decision-making needs (establish goals and metrics)

Habitat based sampling needs to be greatly expanded to provide data beyond the current trawl sampling (i.e., to allow for characterization of structured habitats where sampling is currently limited or nonexistent). The current time series data should be updated and improved analyses and modeling should be applied to existing data sources, including spatial analyses at finer scales. We also need to explore new technologies to find better ways of collecting habitat information. The location of different habitat types need to be identified and their impacts on growth rates and other vital population parameters should be incorporated into stock assessments. Targeted habitat mapping in areas of more critical habitat (Digital coast, NALCC, MDDNR) should be a priority based on standardized approaches of collecting and processing the data. (e.g., multibeam in shallow water, sidescan, lidar in shallow water).

Criteria and metrics for the successful management of habitat need to be identified (in addition to stock-based metrics like overfished and overfishing). The impacts of habitat loss and degradation need to be more fully integrated into the fishery management process. The Council should continue to consider measures which minimize the impacts of fishing and other activities on habitat, including ways to incentivize habitat protection.

Possible goals and metrics include 1) quantify fishing impacts and reduce the footprint of impact 2) develop productivity set aside areas, 3) identify priority stressors on habitat for key species and find ways to reduce those stressors, and 4) identify multi-species areas to set goals (possibly HAPCs) or based on selected single species.

7.2.8 Ecosystem related habitat policy statements

In addition to the habitat considerations discussed above, the Council adopted the following ecosystem related habitat policy statements:

1. **Strengthen EFH designations and consider essential from a multispecies/ecosystem perspective emphasizing the connectivity between species, life history stages, etc. and inshore and offshore habitats.**

2. **Demonstrate and communicate the value of habitat to managed fisheries and quantitatively link habitat science and conservation to fishery outcomes.**

3. **Encourage NMFS to conduct additional focused sampling in habitats at finer scales than has been historical practice (especially in non-trawl-able habitats). Also, habitat sampling should be expanded temporally and other sampling methods should be examined.**

7.3 Incorporation of Effects of Climate Change and Variability in Fisheries Management

7.3.1 Background

A recurring theme during the Council's Visioning Project was the overwhelming desire on the part of constituents across all fishery sectors to integrate ecological considerations, including environmental influences on fish stocks due to climate change and variability, into fishery stock assessments and Council management policy. In response the Council hosted a series of workshops in 2014 to evaluate the current state of climate science and the expected range of climate impacts on fish stock distribution and productivity and to evaluate the impacts of these changes on fisheries management given the existing governance structure along the Atlantic coast.

Results of the first workshop Climate Science and Fisheries, examined the current state of climate science and our understanding of the impacts related to climate change and variability on marine fish populations and the fisheries they support. The overall goal was to examine where and when climate considerations need to be addressed in the assessment management continuum and how these considerations should be integrated into the existing fishery management process. Following the climate science workshop, the Council also hosted a three-day workshop that convened more than 70 fishery managers, scientists, Atlantic Coast policymakers, and stakeholders to examine the management and governance implications of climate change and variability for Atlantic Coast marine fisheries.

The results of the two workshops are synthesized in the Council’s white paper on Climate Change and Variability (http://www.mafmc.org/eafm/). The paper was designed to frame our understanding of the impacts of climate change and variability on marine resources under the management purview of the Council, including implications for marine ecosystems, fish stocks, fishery management and the communities and economies that depend on them. Having a reasonable understanding of the future state of ecosystems in the mid-Atlantic in response to climate change and variability is a fundamental prerequisite to the development of management policies that will allow for the achievement of the Council's vision for the future of the fisheries which exist within those ecosystems

Information provided at the climate science workshop indicated that the Northeast region is experiencing profound changes in physical and oceanographic properties as a result of both natural climate variability and human induced climate change. The region is experiencing one of the fastest increases in average temperature observed globally with ocean temperatures increasing by 1.3°C since 1854 coupled with ocean acidification and increased rates of sea level rise. Climate projection models predict continued increases in temperature, decreases in salinity increases in precipitation, decreases in pH and continued sea level rise.

There are multiple potential biological responses to the pressures of climate variability and climate change. In general, the anticipated pressures that could affect fisheries in the Northwest Atlantic basin include: warmer water, changing volume of thermal habitat, shifting local hydrography (e.g., fronts, local winds and currents), changing large scale hydrography (e.g., altered boundary currents), changing water chemistry (fresher, more acidic, lower oxygen), changing primary production and other bottom up forcing, changes in species composition including invasive species, or native species from other regions, and changes to habitat including loss of deep water coral and of coastal wetlands At the community or population scale, the basic biological attributes regulating population fluctuations (and therefore of interest to fishery management) include productivity, physiology, process timing or phenology, ecological context (primarily predator-prey and competitive interactions with other species), and spatial distribution (both range and center).

Numerous studies have demonstrated long-term changes in the distribution and productivity of fish and shellfish resources on the Northeast U.S. Shelf. Changes in distribution have been documented in a large number of populations. Fewer studies have examined changes in stock productivity. The observed changes in species distributions to date and the potential for changes in productivity are discussed in detail in the Climate White Paper, as well as potential changes in species interactions. The role of climate-forced changes in predator-prey dynamics needs to be investigated, but large-scale changes in species compositions suggests large-scale changes in predator-prey dynamics. Climate change and variability will also impact protected species and thereby change the interactions between protected species and fisheries. Finally, the Climate White Paper provides a detailed discussion potential impacts of climate change on habitat.

The primary effects of climate on fisheries population dynamics parameters and stock assessments are changes to population vital rates and consequent changes in biological reference points. All of the vital rates in a stock assessment model are likely to be vulnerable to climate change, including recruitment, natural mortality, somatic growth dynamics, and maturity. Stock assessment models that treat vital rates and biological reference points as stationary (i.e., variable, but with a constant mean through time) will be slow to adjust to the impacts of climate change. Stock assessment models that explicitly incorporate environmental drivers have the potential to adapt much more quickly.

Assessing the impacts of climate change on recreational and commercial fishermen and their communities consists of assessing the current composition of fisheries, and understanding the likely social, cultural, and economic dynamics accompanying the biological and ecological changes expected to occur.

Economically, short-term impacts of marginal shifts in species distributions and expected landings can be assessed through the Northeast Region Input-Output Model (Steinback and Thunberg 2006), in terms of regional changes to income, employment, and value-added sales within the states bordering the Northeastern Shelf system. A portfolio analysis has also been developed to assess the trade-off between the revenue streams that can be generated from species under management and the variance around those streams (Jin et al. 2014). The analysis explicitly captures the interactions among species examined within the portfolio, and there are plans to extend this framework to specifically assess the Northeastern Shelf's risk exposure to climate change, using the impact assessment developed by Hare et al. (2014). Spatially modeling of fishing location choice will also play an important role in assessing impacts and predict responses for both commercial (Haynie and Layton 2010) and recreational fishermen (Jarvis 2011).

The longer-term impacts of climate change are more problematic to assess, because they necessitate the use of data not currently gathered by NMFS on a regular basis or require model predictions out of sample. Further, management based on species/area combinations – whether the division of FMPs across regional fishery management councils, the placement of closed areas for spawning grounds, or the assignment of ITQs to specific areas – will need updating as species change location. These types of pressures are already being seen in allocations that are made on a state-by-state basis based on historical landing patterns. In some cases, species will increase or decrease stock levels, again requiring management adjustments. The resolutions of these governance issues are strongly tied to social and economic impacts and the demographic and preference data referenced above will be critical in predicting and assessing those impacts. A general overview of the types of impacts that might occur and likely governance challenges are described in Himes-Cornell and Orbach et al. (2013), especially pp. 80-100 and 127-137.

Ultimately**,** a more robust understanding of the long-term dynamics expected to occur due to climate change would necessitate additional investment in socio-economic data and research. One example is to develop a better understanding of port dynamics, and what factors lead to port expansion or contraction, including the interaction of the demand for port facilities by fishermen competing with other demands for port space.

Climate-ready fisheries management requires having the science, governance structure, management tools, and political will to make challenging decisions in a changing environment (Pinsky and Mantua 2014). There are multiple points for climate science information to enter living marine resource management processes that encompasses science and research as well as assessment, advice, and management decision making. Here in the Mid-Atlantic region, we start with data collection and population modeling on the science and research side, then go into a review and status determination process during the assessment and advice stage. An increasingly important part of this process which can help in particular with incorporating climate science information into stock and habitat assessments and management advice is performance evaluation or management strategy evaluation (Punt et al. 2013).

7.3.2 Risk Assessment - NEVA Analysis

Risk assessment is a valuable tool to apply even before attempting to incorporate climate science information into specific stock assessments and management advice (Gaichas et al. 2014, Hare et al. 2016). In the sections below, we outline a potential framework for incorporating climate science within stock assessment and fisheries management that makes the best use of available tools, information, and time. Using risk assessment as a first step, limited scientific resources may be focused on a subset of high priority stocks and climate impacts can be examined with more detailed individual assessments. It is important to begin with a big-picture assessment of the economic and social importance of the stock as well as its particular vulnerabilities to the observed and projected climate variability or change.

Because multiple stocks are under management, a risk assessment framework provides a useful tool for identifying both priority risks and priority stocks requiring detailed analysis. For the Mid-Atlantic region, a recent simple risk analysis applied to benthic, pelagic, and demersal fish and invertebrate communities found that commercial and non-target benthic invertebrates might be among the most sensitive species to short term predicted and observed climate impacts in the region (Gaichas et al. 2014).

A more extensive climate vulnerability assessment has been completed for 82 individual species on the Northeast US shelf (Hare et al. 2016), including all species managed by the Mid-Atlantic Council. For the MAFMC managed species, ocean quahog was identified as being very highly vulnerable to climate change and three species (tilefish, Atlantic surfclam, and black sea bass) were highly vulnerable to climate change (Figure 3) . The remainder had moderate or low vulnerability to a change in abundance and productivity. A vast majority of MAFMC managed species had a high or very high potential for a change in distribution (12 of 13 species); only Tilefish had a low potential for a change in distribution (Figure 4). Overall, the impacts of climate change are expected to be negative for three MAFMC managed species (Atlantic mackerel, Atlantic surfclam, and ocean quahog), whereas the impacts are expected to be positive for six species (Black Sea Bass, Scup, Butterfish, Longfin Inshore Squid, Northern Shortfin Squid, and Bluefish). The effects of climate change are expected to be neutral for the remainder of MAFMC managed species.

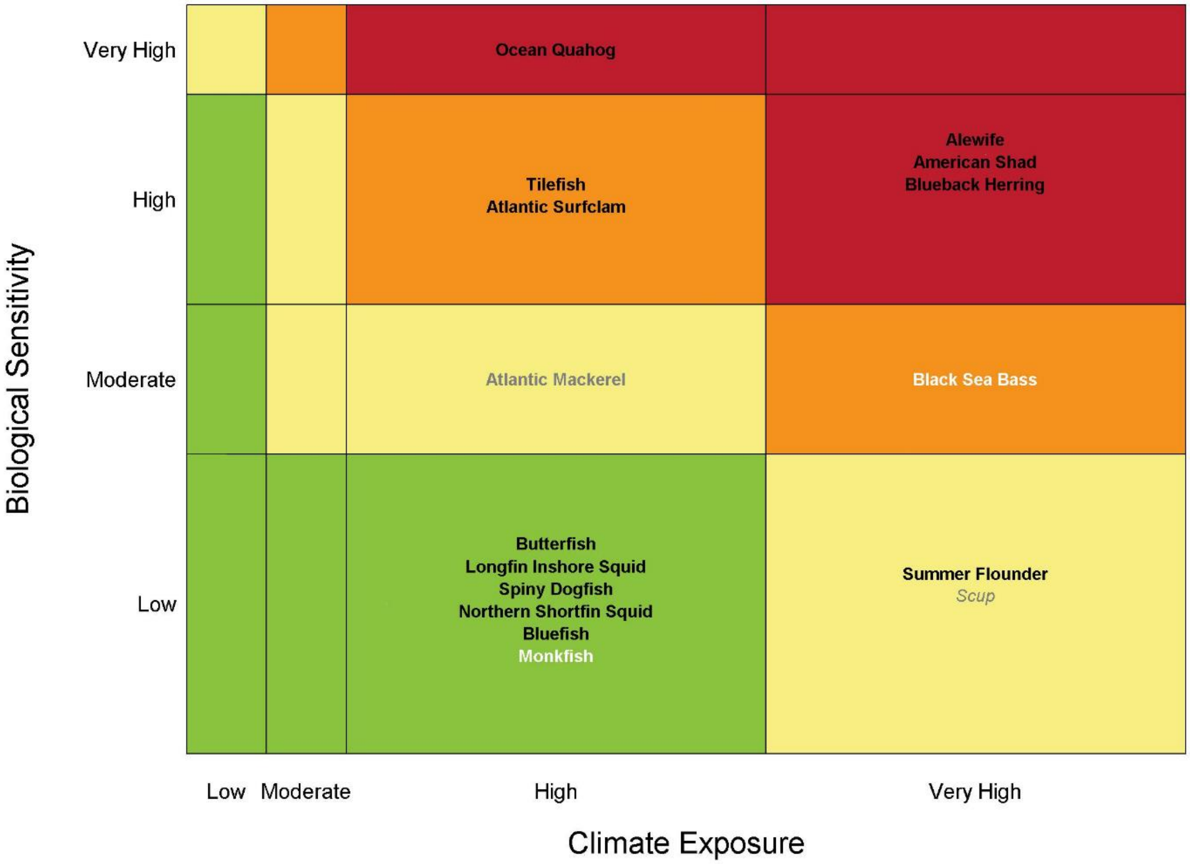


Figure 3. Summary of results from the Northeast Fisheries Climate Vulnerability Assessment (NEVA): First Implementation of a National Methodology for MAFMC managed species. Overall climate vulnerability is denoted by color: low (green), moderate (yellow), high (orange), and very high (red). Certainty in score is denoted by text font and text color: very high certainty (>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font).

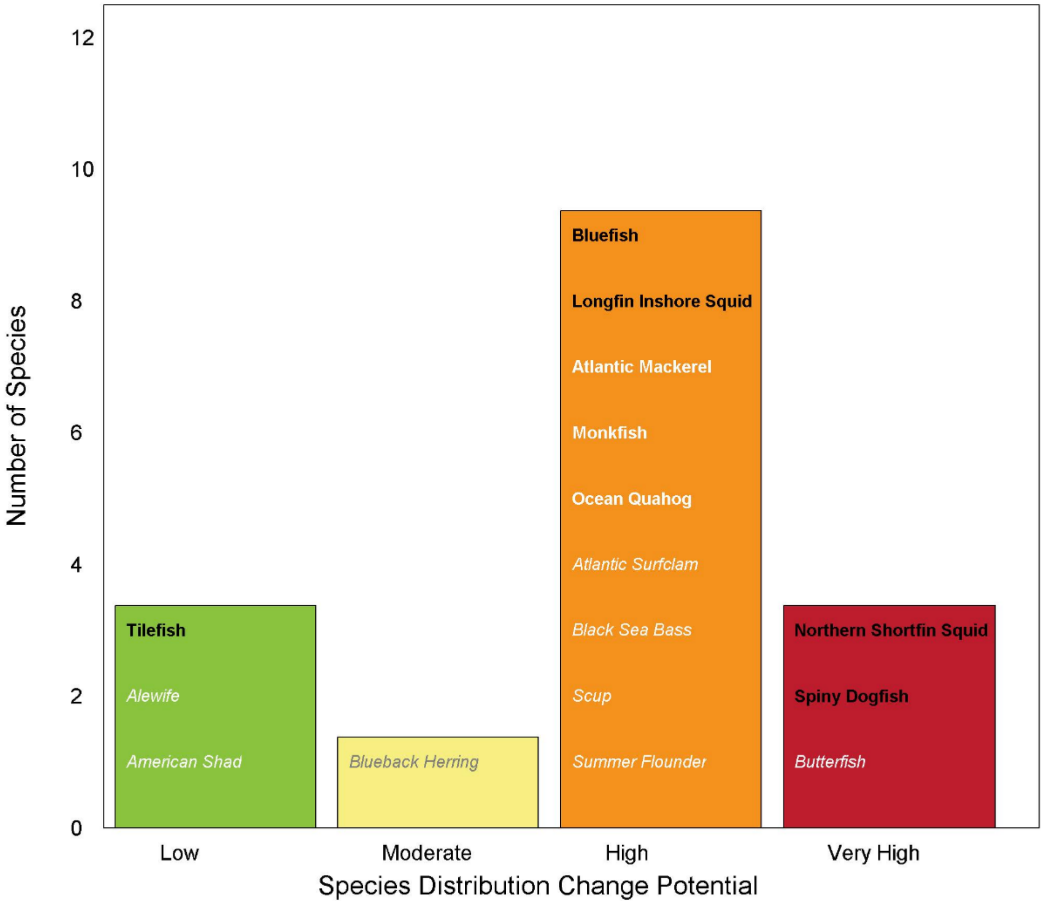


Figure 4. Potential for a change in species distribution. Potential was calculated using a subset of sensitivity attributes. Colors represent low (green), moderate (yellow), high (orange) and very high (red) potential for a change in distribution. Certainty in score is denoted by text font and text color: very high certainty (>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font).

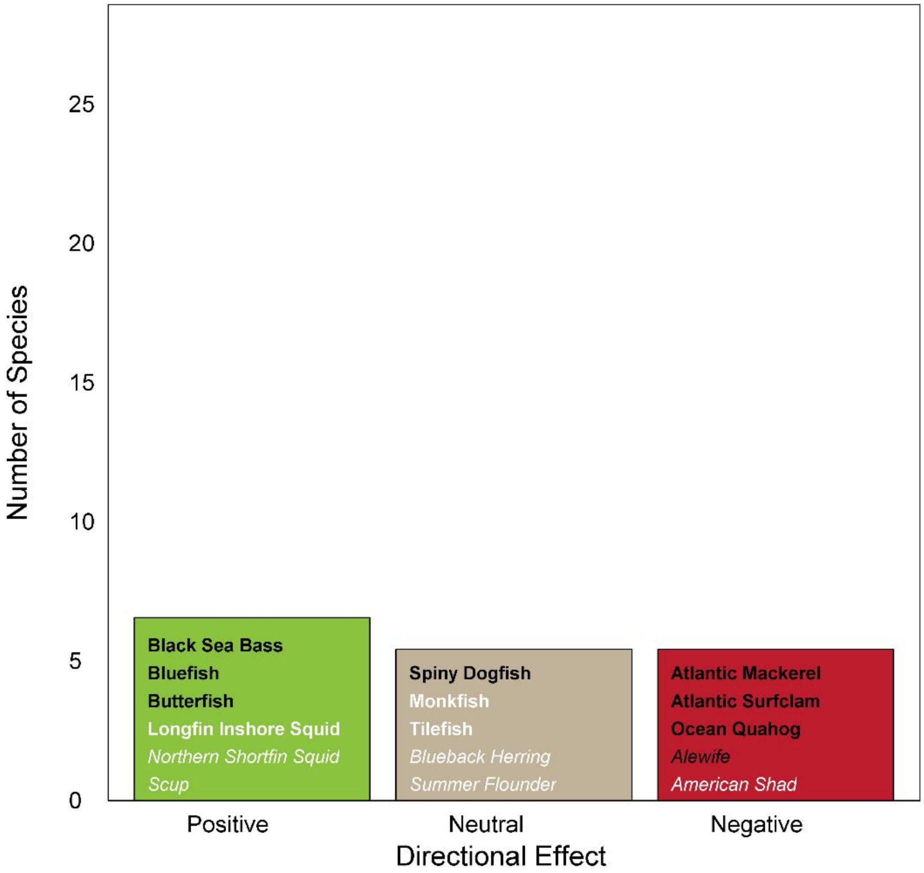


Figure 5. Directional effect of climate change. Colors represent expected negative (red), neutral (tan), and positive (green) effects. Certainty in score is denoted by text font and text color: very high certainty (>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font).

In terms of management considerations emerging from this assessment, changes in distribution will present the largest challenge to the MAFMC. Changes in productivity are likely to be less pronounced. Additional ocean acidification research on ocean quahog and Atlantic surfclam is needed and industry-scientist cooperation on understanding Atlantic mackerel should continue. The management responses to species positively affected by climate change should also be considered by the Council. The vulnerability assessment also developed specific information for each species (see Hare et al. 2016) that should be considered when developing management strategies and that can be used to guide future research.

7.3.3 Future Climate Shifts and Fishery Impacts

Additional information to guide the Council's future policy with respect to climate interactions will be forthcoming from a collaborative project by M. Pinsky and R. Seagraves, "Climate velocity over the 21st century and its implications for fisheries management in the Northeast U.S." The purpose of the proposed research is to inform the Council about the rate, magnitude, and uncertainty surrounding future distributional changes for managed and other important species likely to occur as a result of climate change over the next several decades and for the remainder of this century. This work will build upon the NEVA's initial work on likely range shifts to rank species by the rate and magnitude of range shift as well as the uncertainty in those values, while also diagnosing the dominant sources of uncertainty. In collaboration with the Council, this work will identify potential priority species for adaptation of fisheries management to climate. This would further clarify risks to the Council's management objectives and identify future issues likely to arise from climate-driven distributional shifts.

7.3.4 Recommendations for incorporation of climate change and variability into the current fishery assessment and management process (a *climate-ready check list*)

Based on the considerations described above, the following list of actionable items has been identified for incorporation of climate considerations into the current fishery assessment and management process:

1. **Continue to work with NOAA on the implementation of the NMFS Climate Science Strategy in the Northeast region (https://www.st.nmfs.noaa.gov/ecosystems/climate/national-climate-strategy).**

2. **Re-evaluate stock identification of Council managed species - a Working Group could be established modeled after the ICES Stock ID WG.**

3. **Identify new species likely to become established in the Mid-Atlantic (from the South Atlantic) and species likely to expand or shift distribution into waters under the jurisdiction of New England and Canada; evaluate current monitoring program relative to these species and consider potential management responses to developing fisheries.**

4. **Develop and evaluate approaches for MAFMC fisheries and their management to become more adaptive to change.**

5. **Incorporate temperature into all MAFMC species stock assessment models; consider incorporation of other environmental factors where appropriate; use models to develop short-term forecasts (ACL) and medium-term projections**

6. **Evaluate changing interactions of MAMC managed fisheries with protected species including marine mammals, sea turtles, and fish species.**

7. **Conduct industry, management, and scientist workshops before benchmark assessments; in anticipation of the assessment being scheduled. The workshop should build off the butterfish and Atlantic mackerel workshops.**

8. **Continue efforts to engage industry and other platforms of opportunity (academia, state sampling programs, etc.) in the oceanographic and fisheries monitoring and research in the Mid-Atlantic region.**

9. **Continue to advocate for, collaborate on, and support historical field and laboratory research to understand the effects of climate change on species managed by MAFMC**

10. **Repeat the Northeast Fisheries Climate Vulnerability Assessment in conjunction with the International Panel on Climate Change Assessment Report 6 (recently updated CO2 emission and climate change scenarios).**

11. **Provide input to the NEFSC on elements of the Annual State of the Ecosystem report to meet MAFMC needs.**

12. **Develop MSE capacity to support EAFM and ultimately EBFM and EBM activities of the MAFMC. The MSE framework should explicitly evaluate management strategies to meet MAFMC goals in response to climate change (as well as habitat, species, social, and economic interactions).**

7.3.5 Climate-related Policy Statements

The Council adopted the following policy statements related to incorporation of climate considerations into the current management system:

1. **Continue to work with NOAA on the implementation of the NMFS Climate Science Strategy in the Northeast region.**

2. **Develop and evaluate approaches for MAFMC fisheries and their management to become more adaptive to change.**

3. **Continue to advocate for, collaborate on, and support historical field and laboratory research to understand the effects of climate change on species managed by MAFMC and incorporate those results into assessment and management.**

7.4 Addressing Ecosystem Level Interactions - a Synthesis

The previous sections of this guidance document provide ecosystem level guidance focusing on forage fish management, habitat, and climate change and variability. This section provides a synthesis of approaches to deal with the complex ecosystem interactions considered by the Council throughout the development of the EAFM Guidance Document. This analysis was developed in the Interactions White Paper (http://www.mafmc.org/eafm/) based on information presented and discussed at a workshop convened by the Council to discuss potential strategies to more fully consider interactions in the stock assessment and management process (including determination of catch limits), and to build capacity within the region to conduct comprehensive management strategy evaluations (MSEs).

The workshop and white paper reviewed existing single species approaches as well as information and analytical tools available to address key interactions between species and their environment, between species within the food web, and between the ecosystem and fisheries, and between fleets due to technical or management issues. This led to development of a proposed framework and process for defining key questions, evaluating the adequacy of information and analytical tools to address the questions, and developing analyses to evaluate management strategies to achieve the Council's ecosystem level management objectives.

7.4.1 Review of Available Resources

The Mid-Atlantic region has considerable available resources for addressing interactions, both in terms of available data and in terms of analytical tools. There is a wealth of environmental, ecological, and social and economic data that could potentially be integrated into analyses to support management decisions. An overview of available information (but not an exhaustive list) is synthesized in the NEFSC Ecosystem Status Report (ESR; available at http://www.nefsc.noaa.gov/ecosys/ecosystem-status-report/sitemap.html). Despite this wealth of data, information to address particular interactions may be sparse, such that information needs should be evaluated for each management issue, and uncertainties arising from missing information should be considered, as is current practice.

A spectrum of assessment and modeling methods are available to assist the Council with incorporating species, fleet, and climate interactions into management. Models range from conceptual to statistical and mechanistic mathematical models, from single species population dynamics to integrated ecosystem assessment, and from tactical to strategic. Ultimately, the Council will need to prioritize which interactions to deal with first, and risk assessment methods can contribute to this decision process. Similarly, the Council will need to evaluate management strategies to determine how they perform in achieving Council objectives, as well as evaluate tradeoffs between those objectives, which may be inevitable when considering a range of interactions and possible outcomes. A combination of these tools designed to address particular interactions can be developed for each management issue as with data above, as is also current practice.

7.4.1.1 Single species stock assessments

In many ways, environmental, species, and fleet interactions are already accounted for in current stock assessments, depending on data inputs and model configuration. For example, single species stock assessments that use changing weight-at-age data over time as input are incorporating the effects of a changing environment and ecology on fish growth, although the sources of this variation cannot be identified. Further, some assessments incorporate changes in natural mortality (M) over time which can represent changing species interactions (most often, predation), but could also represent habitat or other environmentally mediated changes. Some effects of technical interactions between fisheries are included for individual species using the standardized bycatch reporting methodology (SBRM) to ensure that mortality from both directed fisheries and incidental catch are accounted for in assessments.

Successful fishery management can actually make the effects of interactions more important. As mortality due to fishing declines, natural mortality becomes a more important fraction of total mortality and therefore more influential on population dynamics. Reductions in fishing mortality also tend to increase lifespan and reveal traits obscured by high exploitation. To understand dynamics for rebuilding depleted stocks requires multiple disciplines, including population biology and ecology as well as bioeconomics, ecological and environmental change. Forecasting these changes can be challenging, but some key research at the interface of these disciplines can help.

Determination of absolute abundance is greatest challenge for single species, multispecies, and ecosystem models. To address this challenge, managers and scientists should foster an environment where there is increased interaction between gear technologists and stock assessment scientists (see e.g. Somerton *et al.*, 1999). Within a single species model, the ability to estimate changes in natural mortality (M) is dependent on ability to fix the quantity scaling the fishery independent index of population size to absolute population size (Q or survey catchability.

7.4.1.2 Trophic and multispecies interactions

In addition to the stock assessments currently used to provide management advice, information on predator-prey interactions can be derived from the extensive food habits databases maintained at NEFSC and VIMS. Food web models exist for 4 regions of the Northeast US shelf, including the Mid Atlantic, Southern New England, Georges bank, and Gulf of Maine (Link *et al.*, 2008, 2009). Updated models with more detail for individual species in each region and multi-fleet fisheries are currently under construction. Food web models are useful for estimating the relative proportion of fishing and predation mortality to evaluate whether assessments should consider including variable predation mortality. Food web models also quantify major prey for key species and can be used to evaluate whether assessments should consider including food-limited growth when prey fluctuate.

Multispecies models are in development for the Northeast US shelf to extend the suite of modeling tools available for assessment of species and fleet interactions. A suite of multispecies and ecosystem models already exist in this region, with several more currently in development. These include Atlantis (a spatially explicit bio-geochemical end-to-end ecosystem model), MS-PROD (a multispecies production model), MSVPA-X (an age structured multispecies model extended to include predators), several static mass-balance food web models, and several single species population dynamics models extended to include predators. Currently in development is a multispecies size structured assessment model and a set of linked static and dynamic food web models for each subregion. Another approach that has been used is to develop an index of predator abundance and use this index to scale natural mortality. While many of these models have an established role in providing strategic advice, the current challenge is to provide tactical management advice for fisheries in a multispecies context that can be readily used within the existing management framework. NEFSC is developing a system of simulation and assessment models to meet this challenge.

Models intermediate in scale between single stock and full ecosystem may be most promising in terms of providing tactical advice that incorporates species and fleet interactions as well as some environmental factors (Collie *et al.*, 2014; Plagányi *et al.*, 2014). Work is in progress by many research groups testing the capabilities of multispecies assessment models (e.g. Curti *et al.*, 2013; Van Kirk *et al.*, 2015). A prototype multispecies assessment project has been initiated for Georges Bank, which incorporates multispecies production models, multispecies delay difference models, and empirical nonlinear time series forecast models as assessment models within a multi-model inference framework. The multispecies assessment models were fit to simulated data, and assessment model estimates of biomass and catch trends were compared with "true" operating model values for each time series. This process both improves the multispecies models and informs managers of their strengths and weaknesses**.** Based on this work, multispecies models can be designed and evaluated for Mid-Atlantic stocks where appropriate.

7.4.1.3 Fleet interactions

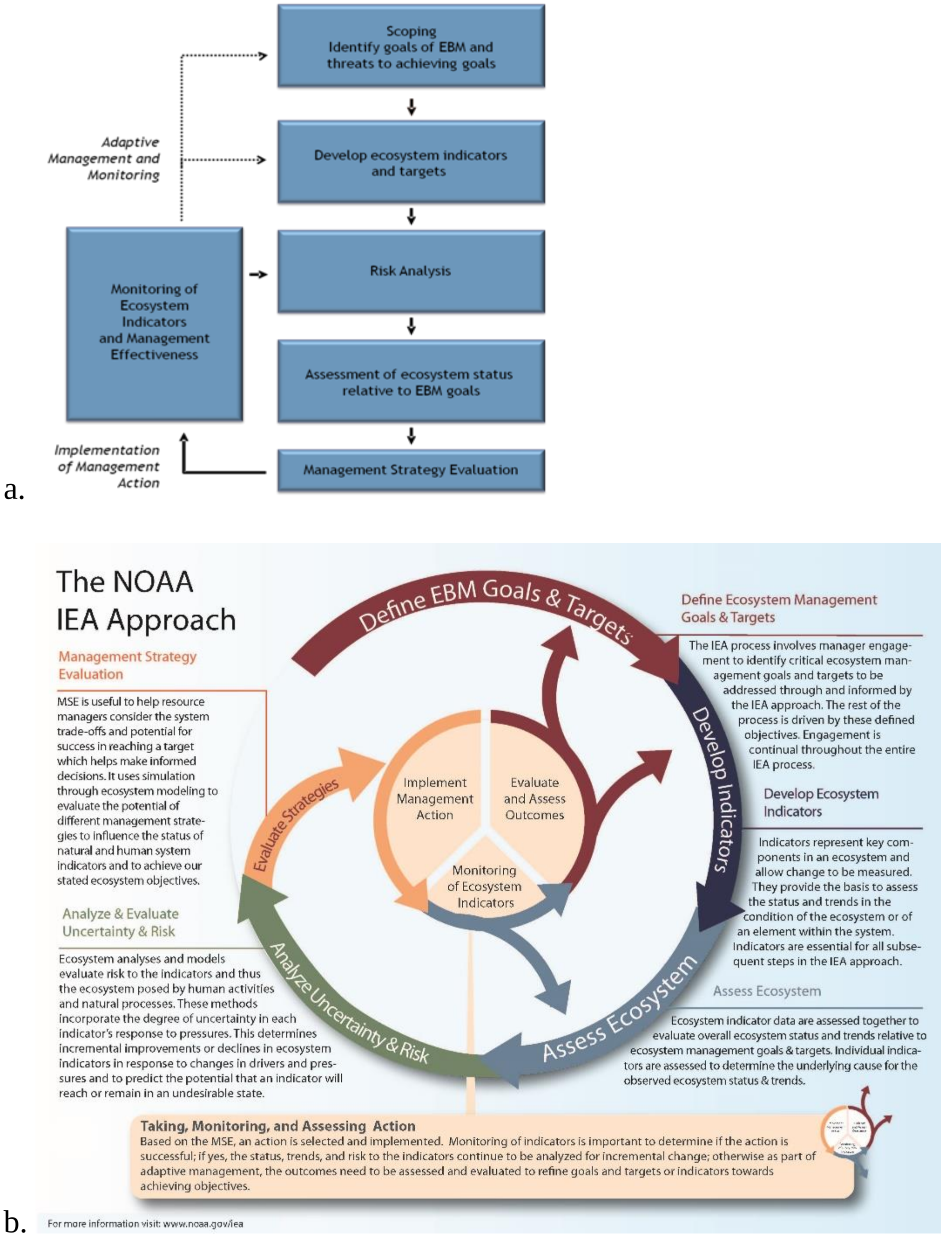
Social and economic linkages across species are important due to the fact that they can bind species that otherwise have no strong biological interactions (for example, yellowtail flounder as a bycatch in the scallop fishery), or generate effects that either reinforce or dampen the signals from biological interactions. These fishery interactions have the potential to greatly impact fishing behavior, with implications for both human and marine communities. The linkages manifest themselves in seafood and other commercial markets for marine resources, technological interactions of the fishing gear themselves, management policies, and social networks, among others. In the context of EAFM, the currently available tools for assessing these interactions are high level, due to the complexity of the interactions, and generate indicators that can be tracked over time (see the Interactions White Paper for a more detailed description).

Regulations designed for one fishery, fleet, or issue may also interact with other fisheries or fleets, creating unintentional side effects or constraining fishing opportunities. For example, limits on the catch of one depleted species may cause it to act as a “choke” species, limiting the catch of other species caught in the same habitats to well below their allowable biological catch if the limiting species cannot be avoided. Similarly, time and or area management designed to meet an objective for a single species may also limit the catch of other associated species, causing fleets targeting the other species not to meet economic objectives. These management-related interactions should be considered and analyzed prior to implementation of new management measures.

7.4.2 Additional comprehensive tools for addressing interactions

7.4.2.1 Integrated Ecosystem Assessments for Northwest Atlantic ecosystems

The NW Atlantic region has well-developed ocean observation systems, marine ecosystem surveys and habitat studies, though social and economic data collection systems are less well developed, and steps are being taken throughout the region to organize existing information and effectively communicate it to stakeholders and decision-makers. The Levin *et al.* (2009) IEA framework (Figure 6a) outlines the general process of integrated ecosystem assessment. Visualization of the IEA framework has evolved since then (Figure 6b), but its components remain the same.



Management Strategy Evaluation

MSE is useful to help resource managers consider the system trade-offs and potential for success in reaching a target which helps make informed decisions. It uses simulation through ecosystem modeling to evaluate the potential of different management strategies to influence the status of natural and human system indicators and to achieve our stated ecosystem objectives.

Analyze & Evaluate Uncertainty & Risk

Ecosystem analyses and models evaluate risk to the indicators and thus the ecosystem posed by human activities and natural processes. These methods incorporate the degree of uncertainty in each indicator's response to pressures. This determines incremental improvements or declines in ecosystem indicators in response to changes in drivers and pressures and to predict the potential that an indicator will reach or remain in an undesirable state.

Define Ecosystem Management Goals & Targets

The IEA process involves manager engagement to identify critical ecosystem management goals and targets to be addressed through and informed by the IEA approach. The rest of the process is driven by these defined objectives. Engagement is continual throughout the entire IEA process.

Develop Ecosystem Indicators

Indicators represent key components in an ecosystem and allow change to be measured. They provide the basis to assess the status and trends in the condition of the ecosystem or of an element within the system. Indicators are essential for all subsequent steps in the IEA approach.

Assess Ecosystem

Ecosystem indicator data are assessed together to evaluate overall ecosystem status and trends relative to ecosystem management goals & targets. Individual indicators are assessed to determine the underlying cause for the observed ecosystem status & trends.

Taking, Monitoring, and Assessing Action

Based on the MSE, an action is selected and implemented. Monitoring of indicators is important to determine if the action is successful; if yes, the status, trends, and risk to the indicators continue to be analyzed for incremental change; otherwise as part of adaptive management, the outcomes need to be assessed and evaluated to refine goals and targets or indicators towards achieving objectives.

For more information visit: www.noaa.gov/iea

Figure 6. Visualizing IEAs. a. Levin et al (2009) b. Refined IEA representation.

Work is under way in a variety of contexts around the North Atlantic to develop Integrated Ecosystem Assessment (IEA) methods and approaches to support an EAFM. For example, the International Council for the Exploration of the Seas Working Group on the Northwest Atlantic Regional Sea (ICES WGNARS) is comprised of scientists and managers from Canada and the US. The overarching objective of WGNARS is to develop Integrated Ecosystem Assessment (IEA) capacity in the Northwest Atlantic region to support ecosystem approaches to science and management. Considerable work has already been done compiling and reviewing ecosystem indicators across the themes of climate, biodiversity and habitat. Social sciences were integrated within the group early on, and the group continues to work on more fully integrated ecological and human dimensions in IEAs. Issues of spatial scale are important because the Northwest Atlantic

Regional Sea encompasses a variety of diverse ecoregions across a wide range of latitudes, physical oceanographic regimes, and habitats, as well as multiple administrative and management jurisdictions and boundaries, sociocultural groups and regional economies.

NOAA's Integrated Ecosystem Assessment (IEA) program (www.noaa.gov/iea) continues to make progress in all 5 regions where it is currently being implemented (i.e. California Current, Gulf of Mexico, Northeast Shelf, Alaska Complex, Pacific Islands). On the Northeast Shelf, there is an updated Northeast US Ecosystem Status Report, an entirely web-based product (http://www.nefsc.noaa.gov/ecosys/). Relative to previous releases, this version features an expansion of human dimensions, stressors and impacts, status determination, and summary sections. The summary section can also be provided as a stand-alone printed annual "state of the ecosystem" report. Plans are in place to develop cumulative impact analysis and a marine ecosystem services assessment index, which would assign numerical scores for the status of delivery of a suite of ecosystem services that we've identified. Research continues into identifying regime shifts, and in multispecies and ecosystem modeling.

7.4.2.2 Conceptual Models

"Conceptual models" developed for the California Current IEA are being adapted for the Northeast US shelf, and could be a useful tool for Fishery Management Councils to address species and fleet interactions. Conceptual models are intended to provide a unifying framework that crosses disciplines, and clarifies system boundaries and any gaps in knowledge (Heemskerk *et al.*, 2003; Orians *et al.*, 2012). They are invaluable as a communication tool within an IEA working group, with other scientists, and with the public. This frame-work allows linking of indicators with elements of the conceptual models, as well as linking concepts across ecological and social components of a given system. The California Current IEA project worked for over a year to produce a set of linked conceptual models in December, 2014, as illustrated in Fig 7.

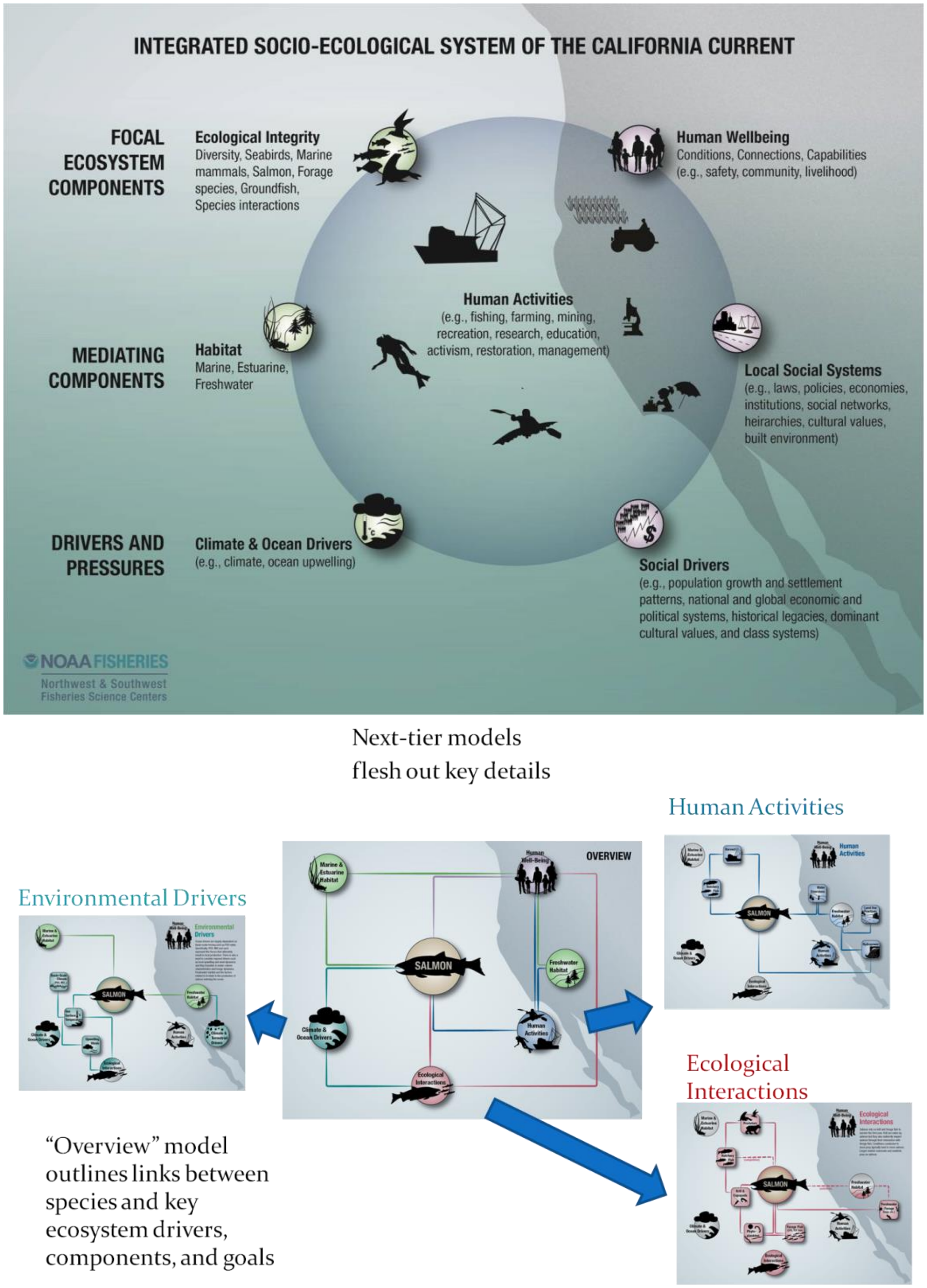


Figure 7. California Current conceptual models: overall system and detailed models linking environmental drivers, human activities, and ecological interactions for key ecosystem components. A set of models was developed for each focal component (salmon are shown here but others include coastal pelagics, marine mammals, etc).

In developing these conceptual models, the IEA team looked at each focal ecosystem component to develop links between ecological interactions (e.g. what are the strongest food web interactions), environmental drivers (what are the acknowledged drivers of abundance and community composition?), human activities (what are the strongest known human interactions or human risks posed to this focal ecosystem component?) and human wellbeing (what is the human dimension context?). Detailed linkage models were developed for six ecosystem components: salmon species, coastal pelagic species, groundfish species, marine mammals, seabirds, biodiversity, and habitat. The California Current IEA project has used these conceptual models to improve communications with regional fishery management councils regarding key linkages between managed species and the environment, in groundfish stock assessment ecosystem considerations sections, and on their webpages for navigation by users to see linked information on status, trend, indicators, etc.

7.4.2.3 Risk Assessment

Risk assessment is a process to evaluate the potential, magnitude, and consequence of negative events occurring. This is a best practice adopted originally from business management fields and encoded by the International Standards Organization (ISO) standard 31000 (ISO, 2009a, 2009b, 2009c). The ISO standard bases risk management on a three-step risk assessment process: identification, analysis, and evaluation, which ultimately determines whether risk treatment is required to meet management objectives. Built into the standard are requirements for risk communication, consultation, review, and continued monitoring. The advantage of this approach is that it is consistent, transparent, and standardized. Furthermore, the approach has been adapted to evaluate a wide range of environmental issues (e.g. Cormier *et al.*, 2013; Standards Australia, 2012; US EPA, 1998) including some instances of risk assessment for fisheries stocks (e.g. Fletcher, 2005; Hobday *et al.*, 2011; Hollowed *et al.*, 2013; Martin-Smith, 2009; Patrick *et al.*, 2010; Smith *et al.*, 2007).

A simple ecosystem based risk assessment for the Aleutian Islands Fishery Ecosystem Plan in Alaska demonstrates how this tool can be used to prioritize key interactions within an region for further research, analysis, and or management strategy evaluation (AIFEP Team, 2007). In this application, expert opinion was used to first develop a set of key ecosystem interactions not currently assessed or monitored within the fisheries management system, and then to rate the probability of key ecosystem interactions occurring and the impact of the interaction to identify the highest risk interactions as those with high probability and high impact. This risk assessment both identified high priority interactions and potential indicators suited to monitoring changes in the interactions. A quick assessment like this can form the basis for further development of management objectives. This contrasts with a more quantitative risk analysis that would be done once objectives are established, which would evaluate the risk of not meeting the management objectives, possibly under alternative management scenarios as in a management strategy evaluation.

7.4.2.4 Minimizing risks to economic returns in multispecies fisheries

The portfolio analysis developed in Jin *et al.* (2016), and following Sanchirico *et al.* (2008), provides an overview of the risk exposure associated with the mix of species managed by the Mid-Atlantic. Consideration of risk is weaved throughout the National Standards of the Magnuson-Stevens Fishery Conservation and Management Act. Portfolio theory allows the economic risk-reward trade-offs of multispecies fishery management to be assessed. Risk aversion entails choosing a mix of landings from species that minimizes the variance (risk) around an expected return (reward) from the system, subject to the biological constraints within the fishery. Put plainly, the portfolio approach identifies the mix of species that maximizes the probability of achieving the targeted returns to a system in any given year. Portfolio analysis can be used to assess historical performance of the fisheries under MAFMC management by comparing the realized level of risk to the minimum risk that could have produced the same level of returns.

The portfolio model can also be coupled to the multispecies models currently under development at the NEFSC, and provide an explicit understanding of risk-reward trade-offs of future scenarios. Given that returns are not the only objective of management, the portfolio analysis would allow an understanding of the cost, in terms of additional economic risk, of achieving the suite of management objectives.

7.4.2.5 Management Strategy Evaluation

Management decisions are always made with substantial uncertainty. For example, there is uncertainty in the estimate of the status of the resource, the population dynamics of the resource, and the effects of the management decision on the resource and on the system as a whole. There is also uncertainty and risk associated with management choices. Management Strategy Evaluation (MSE) is an approach to determine if a method for making decisions is likely to achieve specified objectives (e.g., Butterworth, 2007; Punt *et al.*, 2014; Smith, 1994; Smith *et al.*, 2007). The MSE approach requires objectives be specified, performance metrics be identified, and management strategies, scenarios, and uncertainties to be specified clearly, and then uses a simulation model to test each management strategy's ability to meet the specified objectives.

An important aspect of MSE is that defining the objectives, performance metrics, and key uncertainties should be done within an inclusive stakeholder process. MSE is a simulation analysis, but to be helpful with management decisions, framing the analysis and the control rules or other management procedures to test must include managers, policy makers, fishermen, scientists, and other stakeholders. Overall, MSE allows the Council an opportunity to test management measures before implementation. MSEs can be particularly good for identifying strategies that will not work. MSE should be considered an investment rather than a quick fix, because the time requirement can be long and MSE is inherently an iterative process. Further, not all important uncertainties and objectives can be explicitly included, and MSE results can be highly dependent on the assumed dynamics. Therefore, investment in multiple simulation models with adequate alternative structures to evaluate the interactions of interest (species, habitat, climate and fleet) is a pre-requisite for effective MSE.

7.4.3 Recommendations and Guidelines

7.4.3.1 Overview

To incorporate species, fleet, habitat, and climate interactions into management, the Council has agreed to adopt a structured framework to first prioritize interactions, second specify key questions regarding high priority interactions, and third tailor appropriate analyses to address them. The primary tools for the initial steps in the framework are risk assessment and MSE. Finally, implemented management measures would be evaluated to ensure that objectives are being met, or to adjust measures as conditions change (Fig. 8).

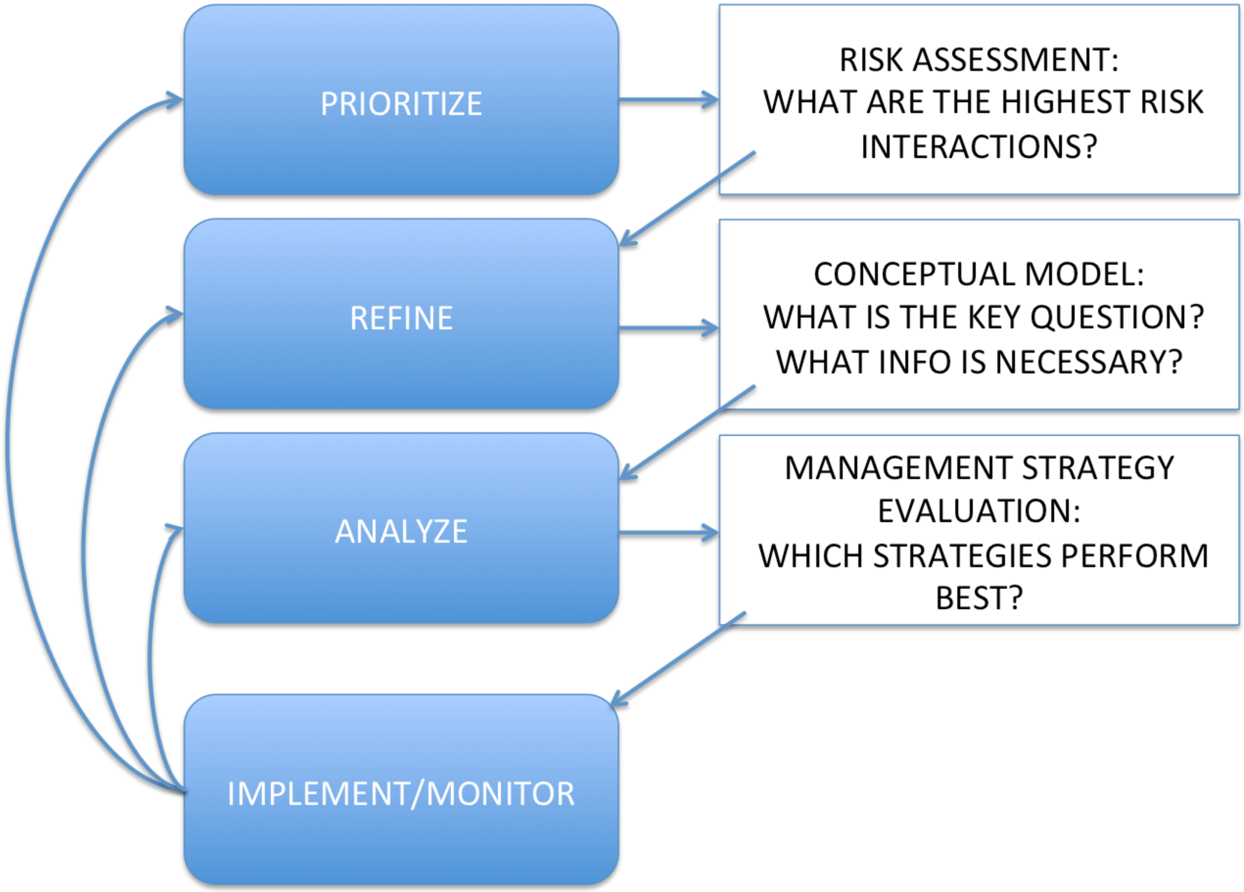


Figure 8. A potential framework for integrating interactions into management

Step 1: Prioritize with risk assessment tools

There are so many possible interactions in a fishery ecosystem that one analysis or tool cannot effectively address them all, so **risk assessment** is proposed as the initial step to identify a subset of high priority interactions for the Council to address first. The Council's goals and objectives would shape the assessment by first identifying risks and impacts of concern. Risk assessment is a critical nexus of science and management because this is where scientific information feeds directly into management decision making, in particular in developing risk criteria and consequences. Risk assessment helps managers to decide where to focus limited resources by clarifying priorities. These methods could be used much more often for screening out interactions of lesser importance that may currently have equal or more resources devoted to them than higher risk interactions.

For example, the NEVA described in section 7.3.2 has already identified which species are most likely to be vulnerable to climate/habitat change, so the Council could elect to evaluate whether species interactions pose further risks to meeting management objectives for the most climate-vulnerable species (these include ocean quahog, tilefish, Atlantic surfclam, and black sea bass). Alternatively, climate-vulnerable coastal communities (e.g. Colburn et al., *in review*) and or fishing fleets could serve as a starting point, evaluating additional risks due to management, ecological, and other interactions.

Step 2: Refine key management questions for highest risk interactions

What are the Council's primary questions regarding a given high priority interaction? What are the Council's objectives for integrating the interaction into management? As the Council refines the question with stakeholders, scientists can evaluate data availability and gaps, and identify analytical tools to address the question. While much data and many tools exist for the Mid-Atlantic region, adequate time for data acquisition and quality control and tool refinement should be allocated to ensure a tailor-made, appropriate analysis.

Basic conceptual models can be developed for the particular question during this process to ensure that key ecological, climate, habitat, fleet, social, and economic interactions are addressed. Conceptual models help organize analyses and information, and clarify interactions for all stakeholders to work from a common understanding. For example, a question centered on climate impacts to a particular species might start with a conceptual model of known climate and habitat interactions for that species, but build in any critical interactions with other species, fishing fleets, fishing communities, regional and global economic markets, etc., as necessary to address the questions and management objectives.

This step is critically important in the framework, because it adds a point in the process where interactions are systematically considered. In particular, management interactions and inter-jurisdictional issues can be formally considered here (e.g. Council managed species discard in other regions; species moving into or out of the region due to climate and habitat change; land use practices altering nursery habitat for managed species). It may be necessary to consult with other management entities and involve them in further steps.

Step 3: Analyze management procedures with comprehensive MSE

The Council's questions and objectives identified in Step 2, along with available data, tools, and management strategies feed into comprehensive Management Strategy Evaluation employing performance measures across biological, ecological, management, social, and economic outcomes. This iterative and stakeholder-driven process can evaluate the impacts of uncertainties in data collection systems, assessment methods, management decision processes, implementation of management measures, and other human activities as well as in the underlying climate, habitat, and ecology.

Some simulation models with capabilities to address species, habitat, climate, fleet, social, and economic interactions are available in the Mid-Atlantic region, although further development would be necessary for any particular MSE. Addressing questions with multiple simulation models and linking existing economic, single species, and ecosystem models expands analytical possibilities.

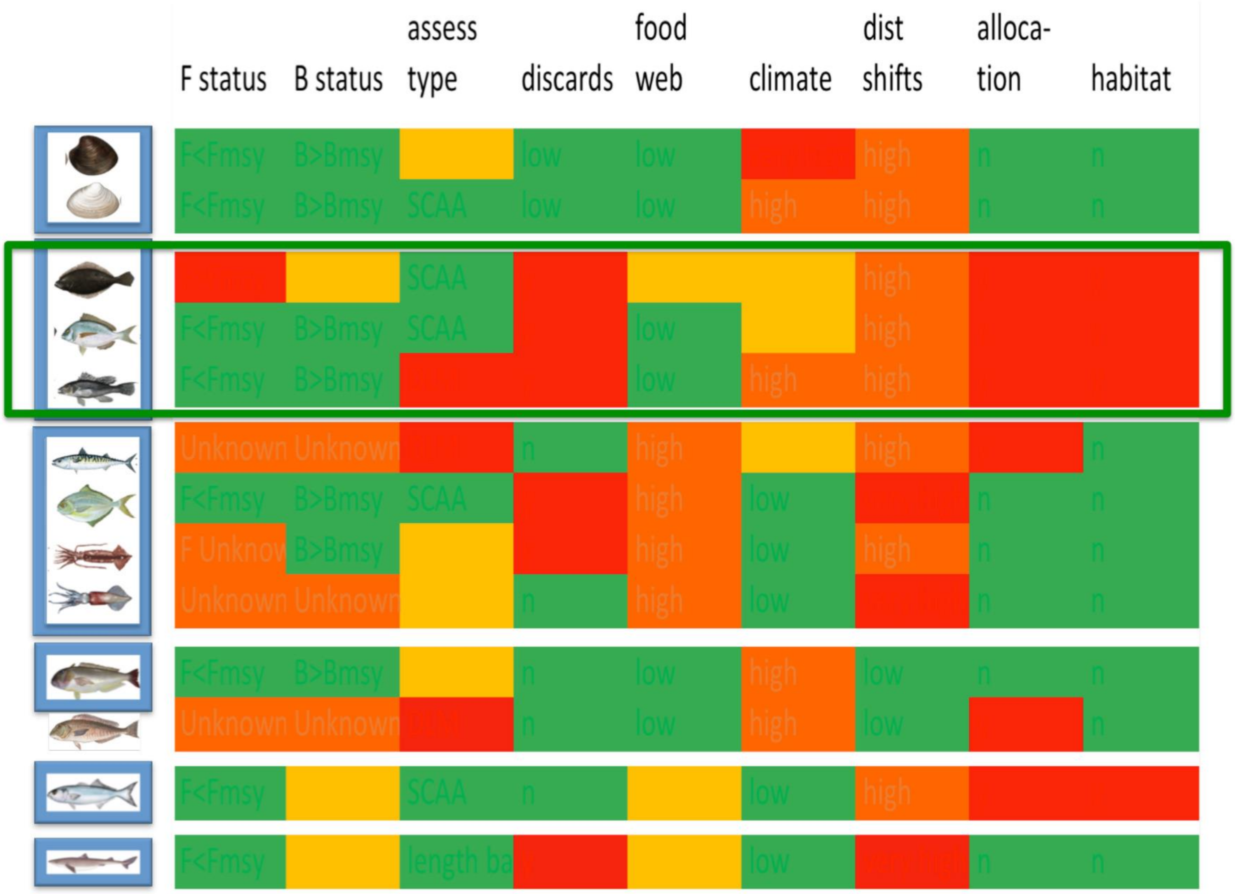
Step 4: Implement, monitor, adapt, and iterate as needed

Management measures designed to address interaction between species, habitats, fleets, and climate forcing may require additional or different monitoring to determine if objectives are being met. Careful consideration of performance measures and monitoring systems to be used in real time (as well as in MSE) needs to be part of this process. There is considerable potential to make better use of existing real time observing systems, in particular for climate and habitat interactions, as well as fishermen-based observation systems to evaluate management success.

7.4.3.2 How might the Framework be used? An Example

Step 1: Prioritize with risk assessment tools

The Council could conduct a comprehensive risk assessment relatively quickly that addresses all managed species and multiple risk categories. For example, the current status of each stock with respect to single species objectives could be included first, because preventing overfishing and keeping stocks above the overfished level are legally mandated objectives. Second, the Council could consider the level of stock assessment uncertainty and or data availability for each stock (addressing abundance estimates, etc., considered under section interactions and single species stock assessments above). Next, the level of fishery discards and how well/poorly they are accounted for in assessments could be considered. Food web considerations (whether species are key pray for other managed species, or predators that rely on other managed species), climate considerations (whether species productivity or distributions are expected to change), threats to habitat, and difficulties with allocation between fleets, fishery sectors, or regional jurisdictions could also be considered. While the Council would define these risk categories and others may be included, it is possible to visualize risks across species and categories (Figure 9). From here, the Council might consider species groups with the most high risks as priority candidates for further analysis of ecosystem interactions.



	F status	B status	assess type	discards	food web	climate	dist shifts	allocation	habitat
	F<Fmsy	B>Bmsy	🟨	low	low	🟥	high	n	n
	F<Fmsy	B>Bmsy	SCAA	low	low	high	high	n	n
	🟥	🟨	SCAA	🟥	🟨	🟨	high	🟥	🟥
	F<Fmsy	B>Bmsy	SCAA	🟥	low	🟨	high	🟥	🟥
	F<Fmsy	B>Bmsy	🟥	🟥	low	high	high	🟥	🟥
	Unknown	Unknown	🟥	n	high	🟨	high	🟥	n
	F<Fmsy	B>Bmsy	SCAA	🟥	high	low	🟥	n	n
	F Unknow	B>Bmsy	🟨	🟥	high	low	high	n	n
	Unknown	Unknown	🟨	n	high	low	🟥	n	n
	F<Fmsy	B>Bmsy	🟨	n	low	high	low	n	n
	Unknown	Unknown	🟥	n	low	high	low	🟥	n
	F<Fmsy	🟨	SCAA	n	🟨	low	high	🟥	🟥
	F<Fmsy	🟨	length ba	🟥	🟨	low	🟥	n	n

Figure 9. Example qualitative risk assessment across Council managed species (left column) and mulitple risk categories (top row: see text for descriptions). Colors represent low (green), moderate (yellow), high (orange) and very high (red) risks within each category.

The risk categories included in the first iteration of risk assessement focused on biological attributes of the system and failed to consider the human dimensions. In future iterations, the following risk categories (columns) will to be added: economic value, fleet diversity, management control (catch measurement and monitoring), economic vulnerability, social diversity (recreational component?) and vulnerability to other human uses (offshore energy development, etc.).

Step 2: Refine Key Management questions for highest risk interactions

A conceptual model linking climate, habitat, species, fleet, and regulatory interactions can be constructed for the set of species using a multidisciplinary team with expertise appropriate to identify key interactions. For example, the existing mid-Atlantic food web model is used to define key species interactions for each managed species, habitat expertise is needed to link habitat for species, physical oceanographic and climate expertise is needed to link key climate drivers to habitats, and the expertise of fishermen, economists and other social scientists and fisheries managers is needed to link fish with fisheries and objectives for human well-being (Fig. 10). The key link between fisheries and human well-being objectives is identified as a system of regulatory allocations of the total allowable catch between states along the mid-Atlantic coast. The interaction between this allocation system (based on historical catch) climate driven distributional shifts of the managed species is creating considerable difficulty in this region. This conceptual model clearly connects climate considerations to management as well as habitat considerations of concern of the Council but outside Council jurisdiction (water quality in coastal estuaries).

Step 3: Analyze Management Procedures with Comprehensive MSE

Once key interactions are identified, objectives for a more detailed MSE would be defined by the Council, along with stakeholders (Figure 11). Using the example above, further development would then occur depending on the direction the Council wanted to take. We offer two examples below. There are many other examples of questions the Council could ask. These would each lead to a different analysis using different tools. These are only examples and not recommendations.

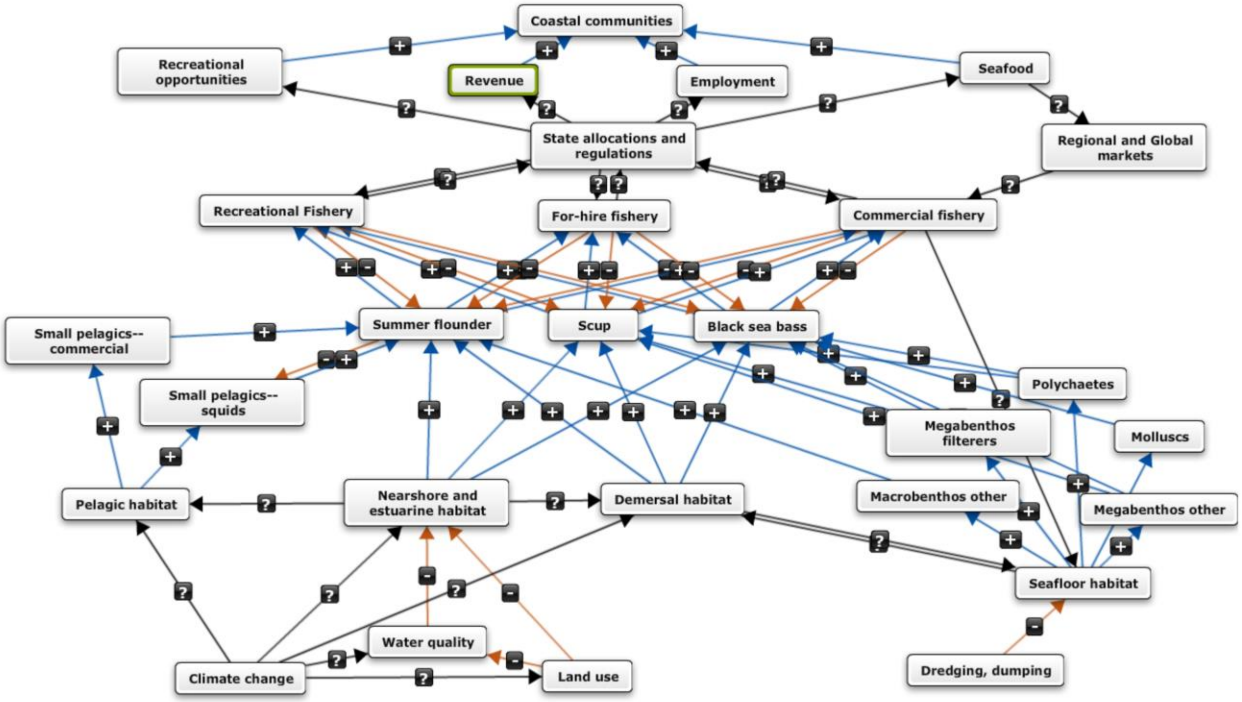


Figure 10. Conceptual model linking climate, habitat, species, fleet, and regulatory interactions for Council managed species summer flounder, scup, and black sea bass. The focal managed species are at the center of the model. Climate and human activity impacts on habitat are oriented toward the bottom of the model, and species interactions between the habitats and focal species (because prey species are associated with habitats as well). Fishing fleet and regulatory interactions with human well-being objectives are placed at the top of the conceptual model. We note that this is only an example for illustration and not a Council analysis. Image created in online Mental Modeler Software (http://www.mentalmodeler.org/#download).

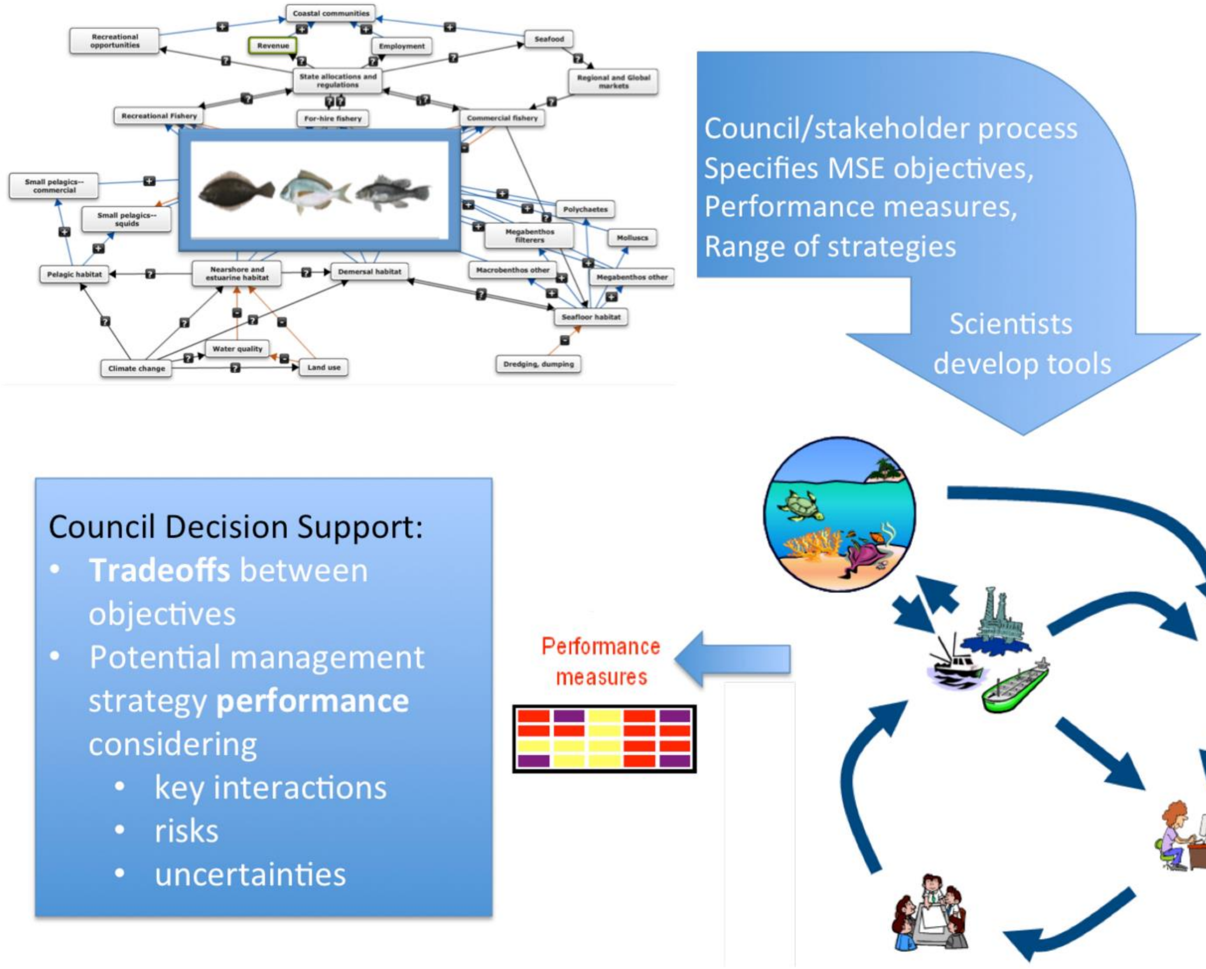


Figure 11. Linkages Between the conceptual model and the MSE process. MSE representation adapted from figure by Beth Fulton at CSIRO; (http://www.cmar.csiro.au/research/mse/).

Example questions to be addressed using the framework

Question 1: "What management structure (i.e. licensing, allocations, etc.) provides the flexibility necessary to absorb the impacts of climate change, including shifting species distributions, and more broadly any large perturbation to the system?"

Tools that could be used to answer question 1:

- Experimental economics can be used to understand the magnitude of both the intended and unintended consequences of management decisions. A good example of this would be the experiments investigating the point system that was proposed as part of scoping for Amendment 16 of the New England Fishery Management Council's Northeast Multispecies FMP (Anderson, 2010).

- Participatory modeling and management strategy evaluation with the Council and stakeholders could be used to inform potential outcomes of alternatives during the design of alternatives, for which historical data might not provide much insight (i.e., reallocation of stocks).

Question 2: "Under the current management system, what are the likely effects of inaction in the face of shifting species distributions and how quickly do they accrue?"

To address Question 2, exposure of species, fishermen, and communities to climate can be drawn together relatively quickly, given the current knowledge and models available. However, specific models would need to be developed to assess the changes in welfare associated with future shifts.

- Economic models could be developed to assess which fishermen are likely to continue fishing, and what species would be caught.
- There are not currently off-the-shelf models to answer either question, and it would take time to generate the models/build up capacity. Therefore, having the Council identify priority questions is vital.

Similarly, for ecological interactions, priority questions could include:

- Are there strong interactions between managed species (high energy flow and/or mortality) that should be considered in setting ACLs or other fishery management measures?
- Are there strong interactions between managed and protected species which should be considered in setting ACLs or other fishery management measures?
- What is the status of key forage species supporting many managed and protected species, and should that be considered in setting managed species ACLs or other fishery management measures?? (raised in the Forage White Paper)
- Are there key habitats for multiple species that require protection by the Council? How will the condition or extent of these key habitats be altered by projected climate change, and how should the Council consider this in setting ACLs or other fishery management measures?

Each of these requires a different supporting analysis and set of modeling tools, as noted above.

Step 4: Implement, Monitor, Adapt, and Iterate

The MSE would suggest alternate management strategies and give information on how well each would meet the range of objectives established by the Council. MSE requires the specification of performance measures to determine how well objectives are met; assuming that the performance measures represent actual data streams available to the Council these could also be used to monitor the actual performance of selected and implemented management measures. However, given that both climate and human uses of the ecosystem change over time, revisiting risk assessment, interactions conceptual models, and management strategies over time will be necessary.

7.4.4 Conclusions

An ecosystem approach to fisheries management emphasizes a more integrated approach to habitat, sustainability, multi-species interactions, connectivity, and dynamic change. To address these ecosystem factors in terrestrial systems, there is high quality, easily collected data with a well mapped landscape, standard classification systems for habitat types and guilds of species (i.e., Southern Oak Pine Forest; Northern Peatland & Fens), and timely data collection systems. In the marine and aquatic environment there are none of these terrestrial advantages. The data is patchy in both space and time, and oceanographic data and biological data are incomplete. It is also very difficult to collect information in the very deep waters of the continental shelf.

So what do we do? Acknowledge we are in a transitional state and the incomplete nature of the data and science with which we have to work, and move forward both strategically and systematically. We first need to recognize that most of the Council's managed resources have strong nearshore and coastal linkages to habitat, and in many cases the nearshore and offshore environment for these managed resources is one continuum.

We need to start expanding how we describe Mid-Atlantic species habitat by focusing on biological, physical-hydrographic, and ecological criteria. This should include taking tips from the landscape ecology approaches on land, which use the synecological/biotope approaches to describing habitat and associated species assemblages. As a first step this should include improving how EFH is designated.

Temperature can serve as a basic biological point to start mapping and modeling habitat. While salinity may set the biological boundaries between the freshwater, estuarine, and marine environment, temperature is a driving factor in a variety of biological processes. It plays a role in predator and prey migration (onshore-offshore and vertical movements), light regimes, dissolved oxygen concentrations and fluctuations, and drives primary production, reproduction, survival, growth, and is a factor in ocean acidification.

To improve how we describe habitat, we need to prioritize the collection of data. This should include sampling both habitat types and use by species. The current fishery-independent trawl surveys and seine surveys actually sample trawl-able habitat and beaches often during migratory/transitional behaviors – we should be sampling across all habitat types seasonally to describe habitat characteristics and use by species. Under the current sampling, food habitat data and information may be biased for some species. We need to prioritize resources for habitat science to address these information gaps. Using technology and more efficient ways to collect and validate the information will be necessary given that current sampling resources are limited.

To address habitat in the larger context, we must first:

1. Consider multi-stock assemblages and habitat use,
2. Define habitat by uniform and relevant biological, physical-hydrographic, and ecological criteria, and,
3. Address spatial and temporal scales in a uniform way

To address climate driven changes in productivity for some species

- Consider evaluating for changes in reference points
- Consider adjusting risk polices

    - Declining productivity ~ less risk
    - Increasing productivity ~ more risk

To address climate driven changes in distribution for many species

- Re-evaluate stock boundaries and data collection systems
- Re-evaluate spatial allocations (4 species)
- Re-evaluate time and space closures
- Food-web will change; evaluate impacts on consumption/natural mortality
- New species will come into area (e.g., Blueline Tilefish, Chub Mackerel, others?)

To address climate driven changes in productivity and distribution of forage species and protected species

- Consider effect of increased interaction with protected species
- Consider mechanisms to decrease interactions of MAFMC managed species with protected species
- Consider effect of changes in forage fish

To address climate driven change in fish and invertebrate populations will force changes in the socio-economics of fishing

- Community vulnerability to climate factors
- Changes in interactions with protected species or choke species
- Changes in markets
- Long-term economic decisions (individual and community)
- Consider other co-stressors (e.g., contaminants, habitat, invasive species)

To integrate trophic interactions into management, consider prioritizing:

- Strong interactions between MAFMC managed species (high energy flow and/or mortality)
- Strong interactions between MAFMC managed and protected species
- Key forage species supporting many managed and protected species (see Forage White Paper)

To manage strongly interacting species, (in addition to forage recommendations)

- Consider conditional reference points for strongly interacting species (e.g. Species X Bmsy is dependent on Species Y F or B and or prevailing habitat volume/climate conditions)
    - How would these be put through the management and regulatory process? How often would they need updating?

To manage fleets and any interactions consider:

- How would fishermen react to different management alternatives?
- What other options do they have from both a regulatory and ecological perspective?

Profit and production functions can provide much more detailed evaluation of fishery interactions at the level of the fishing business, and help answer questions surrounding fleet dynamics across numerous margins. For example, expected shifts in species distribution have the potential to affect fleet composition, species targeting and bycatch, fishing locations, and landing ports, among others. Each of these margins, in turn, provide understanding that help answer a different question, and although they all rely on a single underlying theoretical model, require a different specification of the empirical model to be estimated for tractability. Thus, the models are developed to answer specific questions which need to be defined as a first step, with specific guidance from the Council.

7.5 EAFM within the context of Regional Ocean Planning

In 2009, a federal Interagency Ocean Policy Task Force (Task Force) was established to develop recommendations for the nation's first national ocean policy. The recommendations of the Task Force were formally adopted in 2010 through Executive Order 13547, to establish a National Ocean Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes. The Executive Order created the National Ocean Council (NOC) to implement the Task Force recommendations and to ensure Federal agency participation in any regional ocean planning processes that the regions elected to pursue. One of the first accomplishments of the NOC was to publish the National Ocean Policy Implementation Plan in 2013. This Implementation Plan provides guidance not only for the regional planning process, but also for the National Ocean Policy as a whole. It outlines actions that can be taken by Federal agencies to improve the ocean economy, safety, security, and resilience, and to empower local communities.

The impetus behind regional ocean planning in the Mid-Atlantic was to improve communication and collaboration among Federal, State, and Tribal management entities at the Mid-Atlantic regional scale and facilitate the transition to a more systems-based approach to ocean management. Principles for moving the process forward include: (1) ecosystem-based management, which integrates ecological, social, economic, commercial, health, and security goals, recognizing that humans are key components of ecosystems and that healthy ecosystems are essential to human welfare, and (2) adaptive management, which calls for routine reassessment of management actions to allow for better informed and improved future decisions.

After the establishment of the NOC in 2010, Federal agencies prepared for Mid-Atlantic regional ocean planning by assigning and convening representatives for the Mid-Atlantic region. Then the NOC conducted outreach to the Mid-Atlantic States and federally recognized Tribes to encourage them to participate in the regional planning process. The RPB is a collaboration of Federal, State, Tribal, and MAFMC representatives. The RPB is governed by the Charter for the Mid-Atlantic Regional Planning Body that outlines the RPB's purpose, participants, and a preliminary delineation of roles and responsibilities. The goal of the regional planning process is to guide and align Federal and State activities, consistent with their existing authorities as described in Executive Order 13547 and the RPB Charter. Most recently, the Mid-Atlantic RPB has developed a draft Ocean Action Plan which, at the time this EAFM document was approved by the Council, was available for public comment at: http://www.boem.gov/Ocean-Action-Plan/.

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Appendix 1
Description of the Ecosystem

Delineating the Ecosystem

Most of the fishery resources managed by the Council are found principally within the boundaries of the Northeast U.S. Continental Shelf Large Marine Ecosystem (NES LME) which encompasses an area of approximately 260,000 km2 from Cape Hatteras in the south to the Gulf of Maine in the north. The shelf is wide off northern New England, extending over 200 km from shore, and relatively narrow off Cape Hatteras where the shelf break is approximately 30 km from shore. The Mid-Atlantic Bight spans the region from Cape Hatteras to southern Massachusetts. Other major subdivisions of the NES LME include Georges Bank and the Gulf of Maine (Figure 1). The Mid-Atlantic Bight is a well-recognized Zoogeographic Province. This Virginian Province supports a distinct faunal assemblage, including fish populations, relative to the adjacent Acadian Province to the north. The Acadian Province encompasses the Gulf of Maine and Georges Bank. The Nantucket Shoals region (Figure 1) is considered to be part of a transition zone.

These sub-divisions not surprisingly reflect major differences in physiography in the NES LME. In the Middle-Atlantic Bight, the topography is uniform and the shelf gently slopes to the edge of the continental shelf. This system is strongly influenced by the effect of outflow from major estuaries in the region, most notably Pamlico Sound, Chesapeake Bay (the largest estuary in North America), Delaware Bay, and Narragansett Bay. Outflow from the Hudson River is also a major influence in the Mid-Atlantic Bight.

The Gulf of Maine, a semi-enclosed continental shelf sea, is characterized by an extremely complex physiographic structure. Three major deep basins occur in the Gulf. There are over 20 smaller basins located with the Gulf of Maine. Two relatively large ledge-bank systems (Stellwagen and Jeffries Ledges) occur within the Gulf of Maine proper. Four major river systems feed into the Gulf of Maine (the Androscoggin, Penobscot, Merrimack, and Kennebec Rivers), playing an important role in the oceanography of the coastal Gulf of Maine.

Georges Bank, a broad shallow submarine plateau forming the seaward boundary of the Gulf of Maine, is delineated to the north and east by the Northeast Channel and to the south and west by the Great South Channel. The bank encompasses approximately 42,000 km2 within the 100 m isobath. The seaward margin of Georges Bank on the continental slope is incised with 11 major submarine canyons.

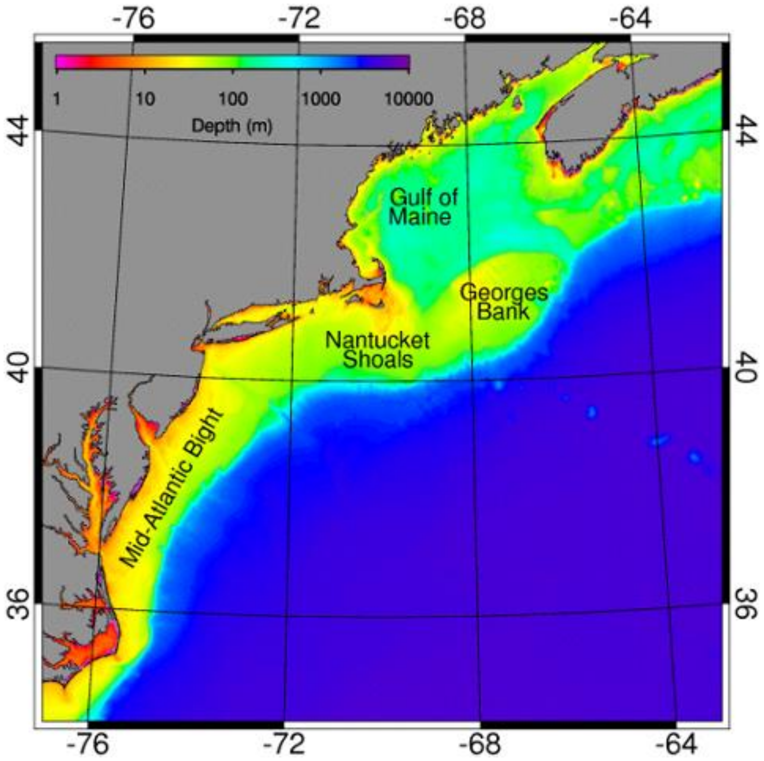

Figure 1. Bathymetric map of the Northeast Continental Shelf Large Marine Ecosystem.

Biological Components and relationships

The Mid-Atlantic food web (Fig. 2) has been characterized quantitatively using the information sources listed above and many others (Link et al. 2006, Link et al. 2008). Here, marine plants and animals are pictured as functional groups of similar organisms in boxes which are proportional to the total biomass of the group in the ecosystem. Lines between boxes represent important energy flows (predator-prey interactions). In the figure, we have highlighted relationships between the commercial small pelagics functional group in grey (containing Atlantic mackerel, butterfish, and Atlantic herring) and their predators (red) and prey (blue). Boxes colored purple are both predators and prey of commercial small pelagics. Any box with color is connected with commercial small pelagics, but the most important predator prey links are indicated with lines connecting the boxes. Therefore, in terms of energy flow, we see that the most important prey of commercial small pelagic are small and large copepods, micronecton (including euphausiids), macrobenthos, and larval/juvenile fish. The most important predators of commercial small pelagic include toothed whales and dolphins, medium pelagics and the fishery. More complex interactions in both directions happen between commercial small pelagics, demersal piscivoves (hakes, sharks, large flatfish, monkfish) and omnivores (skates and black sea bass), and gelatinous zooplankton functional groups. The most important direct energy flows for Mid-Atlantic fisheries include two small pelagic groups: commercial and other (which includes Atlantic menhaden), as well as demersal piscivores (groundfish and elasmobranchs), and filtering megabenthos (sea scallops, surf clams, and ocean quahogs).

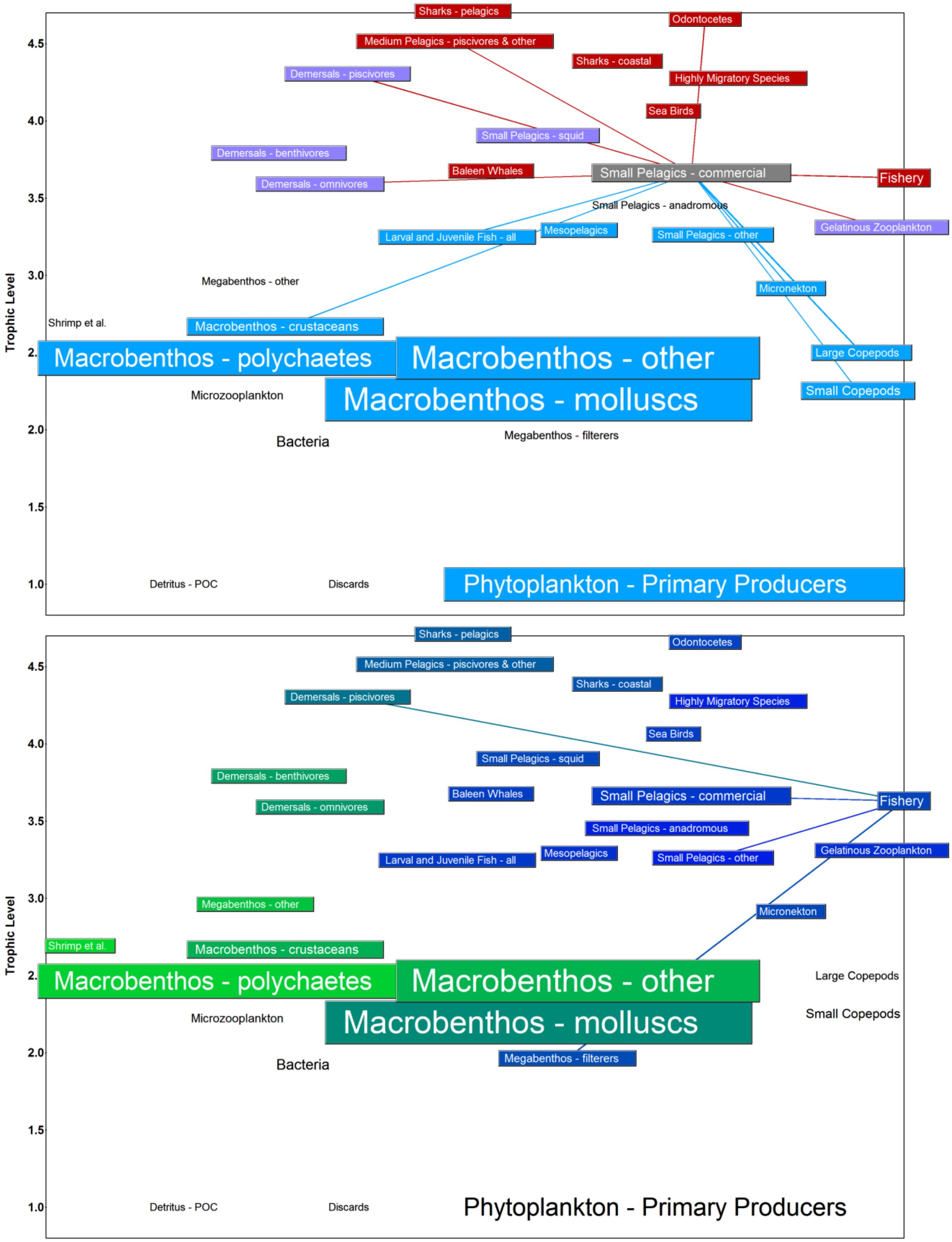

Figure 2. Food web model for the Mid-Atlantic region. Top panel: key links to commercial forage fish; bottom panel, key links to fisheries. See text for full description

A diverse assemblage of shelf and coastal fishes and squids can be categorized as forage species in the Mid-Atlantic region according to the MAFMC 2012 Forage Species definition (see the MAFMC Forage White Paper, Tables 1 and 2). The Atlantic menhaden supports the single largest fishery on the U.S. east coast by weight and is managed by ASMFC. The Atlantic herring is managed jointly by the New England Fishery Management Council and ASMFC. Blueback herring and alewife fisheries, which have declined dramatically in the past 50 years and are under moratoria or greatly restricted landings in most coastal States, are managed jointly by the States and ASMFC. Atlantic mackerel, butterfish, and the longfin and Illex squids are managed by the MAFMC under a single FMP. Several taxa of small fishes that are not targeted in directed fisheries and are unmanaged, but are important as forage, occur in the coastal and shelf waters of the Mid-Atlantic region (see Appendix A for a brief synopsis of each species). While not targeted currently in Mid-Atlantic fisheries, some (e.g., the Alosines) once supported substantial fisheries in the coastal zone. Some of the unmanaged forage species may be included in bycatches of targeted fisheries, for example Alosines (river herrings) in the Atlantic herring and Atlantic mackerel fisheries. At present, there are no declared proposals or plans to exploit the unfished forage species listed here.

A broader characterization of the forage base in the Mid-Atlantic used predator diets to determine which species or groups are consumed by many predators, as well as which species are important to different types of predators and in different habitats. Diet and consumption data of varying quality are described in detail in the MAFMC Forage White Paper, Appendix B. Predators are listed in the MAFMC Forage White Paper, Table 4, and the suite of forage species identified for each predator category are in the MAFMC Forage White Paper, Table 5.

Food habits information provides a picture of key forage for important Mid-Atlantic commercial fish as well. For example, estimated summer flounder diet composition on the Mid-Atlantic shelf (Fig 3a) reinforces the importance of cephalopods, mackerels, hakes, and herrings, as well as porgies/pinfish, if diet composition of 5% or more is considered important prey. Inshore, summer flounder eat more invertebrates according to the NEAMAP database. Bluefish, another important Mid-Atlantic managed predator, has a diet composition more based on fish on the shelf and in nearshore areas (Fig 3b). For bluefish, cannibalism represents an important part of their diet, estimated at 6%. Other Mid-Atlantic fish predator diets could be provided in more detail to determine which species represent important forage.

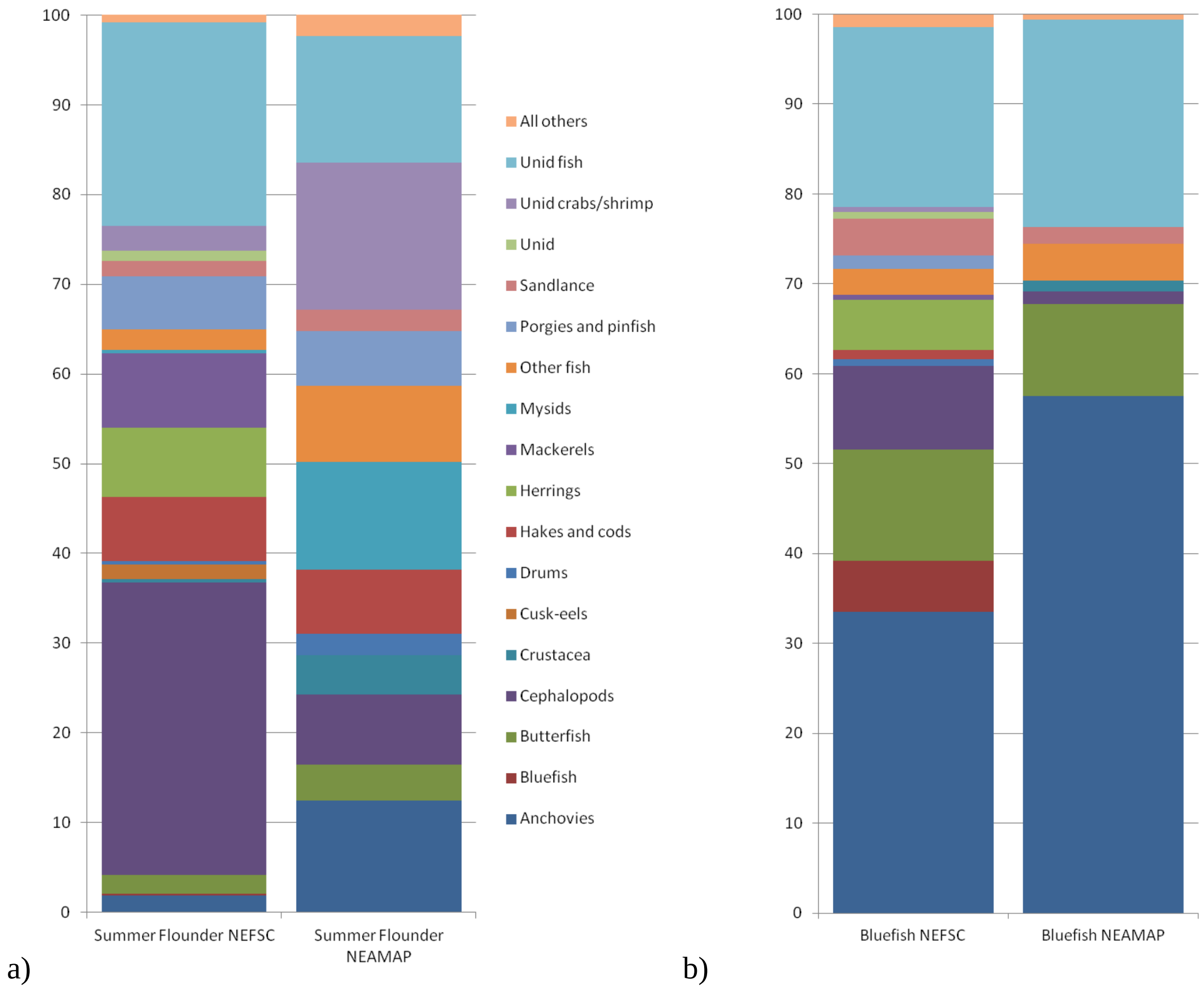

Figure 3. a) Summer flounder diet in the Mid-Atlantic, **b)** Bluefish diet in the Mid-Atlantic; NEFSC diet database 1963-2012 and NEAMAP database 2006-2012.

Oceanographic features (physical, chemical)

The oceanography of the NES LME is shaped by a number of factors including the flow of water from the north into our region, the influence of major river systems, winds, and tidal forces. The physical oceanography of the region is further strongly influenced by two major current systems, the equatorward flowing Labrador Current from the north and the poleward flowing Gulf Stream (Figure 4). Hydrographic characteristics such as temperature and salinity and oceanographic features such as circulation patterns and the position of frontal zones affect every aspect of the ecology of the system, including the distribution patterns of species at all levels of the food web, the basic biology of individual species, and dispersal and migration pathways.

Water entering the northern Mid-Atlantic Bight from the Gulf of Maine and Georges Bank flows equatorward (Figure 4). This generally southwesterly flow regime parallels the isobaths on the shelf. However, the flow highly variable and may reverse direction at times, notably during the summer months.

The surface circulation in the Gulf of Maine is cyclonic (counterclockwise), driven by buoyancy-driven flow resulting from the contrast between freshwater inputs from river systems and higher density water over the central gulf (Figure 4). The eastern Maine coastal current (EMCC), originating on the Scotian Shelf and flowing along the coast, is an important pathway for the transport of nutrients and planktonic organisms in the gulf.

Tidal forces also play an important role in the dynamics of the Gulf. Tides within the Gulf of Maine are among the strongest in the world ocean with the Bay of Fundy having the highest overall tidal amplitude. Smaller-scale circulation patterns may form over several of the features of the Gulf of Maine including some of its deep-water basins.

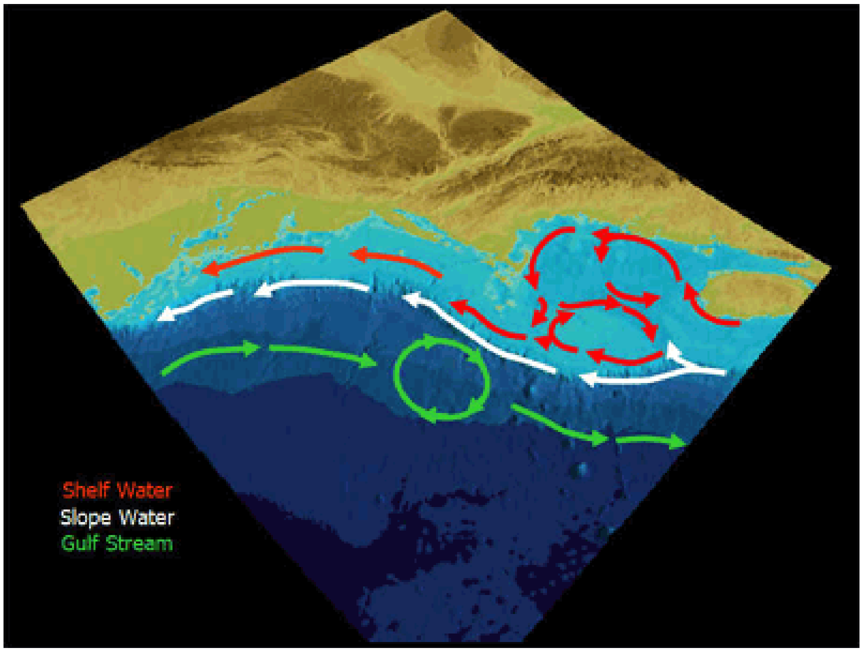

Figure 4. Principal circulation features on the NES LME and adjacent offshore regions showing equatorward flow of shelf and slope waters and poleward flow of the Gulf Stream with a warm core ring depicted.

Tides and topographic features of the Georges Bank region result in the establishment of an anticyclonic (clockwise) circulation pattern, particularly during the stratified period on the bank (see Figure 3). This semi-closed gyre holds important implications for the retention of planktonic organisms on the bank. A strong tidal circulation 'jet' forms on the steep northern edge of the bank and continues in more diffuse form around the northern edge and its southern flank. In the general flow, some water exits over the Great South Channel while the remainder recirculates on the bank. It has been estimated that the average retention time of a parcel of water (and associated organisms) is approximately 5 months during the stratified season and on the order of two months in the remainder of the year.

The Gulf Stream is a classic western boundary current system, driven by wind fields and serving as a major mechanism of heat redistribution in the North Atlantic. The Gulf Stream exerts important influences on the NES LME, particularly through the formation of meanders and eddies.

Warm core rings - meanders that separate from the Gulf Stream and form a clockwise rotation pattern - can draw large volumes of water off the shelf, along with the phytoplankton and zooplankton in that water.

Water Masses

Seasonal warming of surface water of the Mid-Atlantic Bight (MAB) results in the establishment of a strong thermocline and the isolation of a cooler subsurface water layer between the warmer surface waters and the foot of the shelf-slope front near the shelf-break. This 'Cold Pool' is a persistent and distinctive characteristic of the Mid-Atlantic region. The Mid-Atlantic Bight exhibits strong seasonal cycles in temperature and salinity. The annual temperature range in the Bight is the most extreme within the region with surface temperatures spanning 5-30°C. Freshwater inputs from the Hudson River and through Delaware and Chesapeake Bays strongly influence the salinity characteristics of the Bight. Warm, saline continental slope water extends seaward from the MAB shelf water with a sharp discontinuity of these water masses at the shelf-slope front throughout the Bight and extending northward to Georges Bank.

Water mass characteristics of the Gulf of Maine are strongly influenced by input of Scotian Shelf water at the surface and continental slope water entering the Gulf through the deep Northeast Channel. Three distinctive water mass units have been identified in the Gulf. The influx of relatively warm, salty slope water through the channel forms the distinctive Maine Bottom Water layer below approximately 100m depth. This layer is relatively stable with respect to temperature (6-8°) and salinity (34-35 parts per thousand, ppt) characteristics. Overlying this layer is the colder Maine Intermediate Water (MIW) characterized by relative fresh waters (31-32 ppt). The temperature minimum generally occurs in the MIW layer except in the winter months when convective overturn results in mixing from the surface to the bottom water layer or below. The relatively fresh (31-33ppt) Maine Surface Water in the upper 50m or so of the water column undergoes wide seasonal temperature excursions (from 1-15° C) as a result of atmospheric influences. The relative contribution of the Scotian Shelf Water to fresh water inputs to the Gulf is approximately equal to that of the major river systems.

On Georges Bank, strong tidal forces keep the water on the shallow crest of the bank (<60m) well mixed and isothermal throughout the year. Recent evidence suggests the importance of cross-over events from the Scotian Shelf onto Georges Bank, particularly in winter and short-circuiting the 'typical' pathway of water exchange from the shelf to the bank. The salinity on the bank is relatively stable and slightly higher than the Maine Surface Water, suggesting an influence from slope waters or deeper waters in the Gulf of Maine.

Climate and Physical interactions

Climate and weather patterns over the North Atlantic are strongly influenced by the relative strengths of two large-scale atmospheric pressure cells - the Icelandic Low and the Bermuda-Azores high pressure system. A deepening of the Icelandic Low is typically accompanied by a strengthening of the Azores High and vice versa. This characteristic pattern is called the North Atlantic Oscillation (NAO) and a simple index of its state is given by the difference in sea level pressure in the vicinity of the Azores and Iceland in winter (December- February). When the NAO index is positive, we see a northward shift and increase in westerly winds, and an increase in precipitation over southeastern Canada, the eastern seaboard of the United States, and northwestern Europe. We also see increased storm activity tracking toward Europe. Water temperatures are markedly lower off Labrador and northern Newfoundland, influencing the formation of Deep Labrador Slope water, and warmer off the United State. Conversely, when the NAO index is negative, we have a southward shift and decrease in westerly winds, decreased storminess, and drier conditions over southeastern, the eastern United States, and northwestern Europe. Water temperatures are warmer off Labrador and Newfoundland, but cooler off the eastern United States. These changes in the state of the North Atlantic Oscillation tend to persist over decadal time scales. Changes in winds, precipitation and temperature associated with the North Atlantic Oscillation can have far reaching effects on the oceanography of our region.

Over the last several decades, the NAO has primarily been in a positive state, however, we have experienced increased variability in the NAO over the last decade. We have generally experienced warm water temperatures during this period, particularly in nearshore areas. This temperature increase closely tracks the change in the NAO index.

Multidecadal patterns in sea surface temperature (SST) in the North Atlantic are represented by the Atlantic Multidecadal Oscillation (AMO) index. The AMO signal is based on spatial patterns in SST variability after removing the effects of anthropogenic forcing on temperature, revealing natural long term patterns in SST. The AMO is characterized by warm and cool phases with periods of approximately 20-40 years. The AMO index is related to air temperatures and rainfall over North America and Europe and is associated with changes in the frequency of droughts in North America and the frequency of severe hurricane events. The AMO is thought to be related to the North Atlantic branch of the deep thermohaline circulation.

Temperature is one of the most important governing environmental factors for marine organisms. Marine organisms have minimum and maximum temperatures beyond which they cannot survive. Additionally, they have preferred temperature ranges and within these bounds, temperature influences many processes including metabolism, growth, consumption, and maturity. Thus, changes in temperature will have far-reaching impacts on species in the ecosystem and on the ecosystem itself. The NES LME experiences some of the highest amplitude changes in seasonal water temperatures on the planet. In addition, there are very large differences among the different regions of the shelf system (Figure 3).

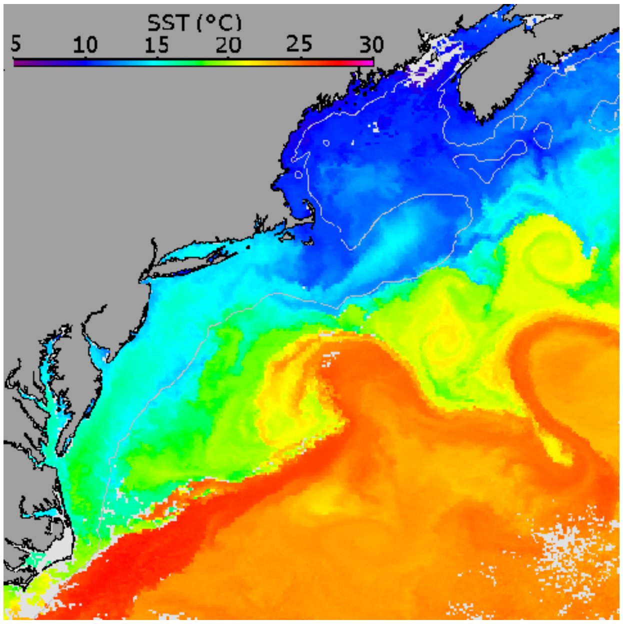

Figure 5. This satellite image depicts a daily snapshot of fall surface water temperature patterns on the Northeast U.S. continental shelf. Cooler temperatures are represented by darker colors shading to blue. Warmer temperatures, such as those associated with the Gulf Stream are represented by the warmer colors shading to red.

Temperature in the NES LME has varied substantially over the past 150 years (Figure 6). The late 1800s and early 1900s were the coolest in the 150 year record. This relatively cool period was followed by a period of warm temperatures from 1945-1955. There was a rapid drop in temperatures through the 1960s followed by a steady increase to the present. Summer temperatures over the past 5 years are comparable to the warm period in the late-1940s/early 1950s and the summer 2012 surface temperature was the highest in the 158-year record. Winter temperatures in recent years, however, remain near the long-term mean indicating that the seasonal range in temperature has increased.

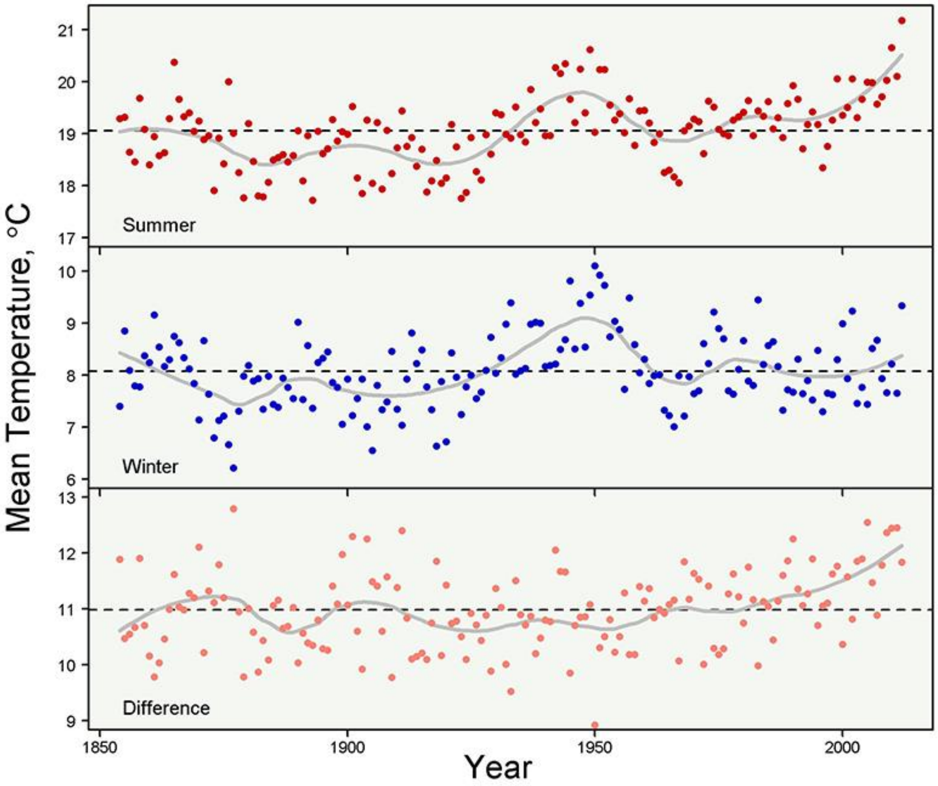

Figure 6. Long-term summer and winter sea surface temperatures averaged over the northeast U.S. continental shelf and adjacent waters from the ERSSTv3b dataset.

Regional water column temperatures measured by the Northeast Fisheries Science Center (NEFSC) give spatial context to the shelf-wide trends in sea-surface temperature (Figure 6). Surveys began in the late 1960s, so the time series are shorter than sea-surface temperature records shown in Figure 5. Time series constructed within each region reveal interannual temperature fluctuations larger than 2°C near the surface and bottom. Long-term warming trends are observed at the surface and bottom in the Mid-Atlantic Bight, Gulf of Maine, and Georges Bank regions and at the surface in the Scotian Shelf region, with waters warming by 1°-1.5°C over the length of the records. Even larger warming trends have been observed in recent years, with the surface and bottom waters warming by more than 2 degrees since 2004 within all regions except the Mid-Atlantic Bight. Perhaps most notable, 2012 temperatures were the warmest observed in the 35-year record at the surface and bottom over all regions of the NES, exceeding long-term annual mean values by up to 2 degrees at the surface and 1 degree at the bottom.

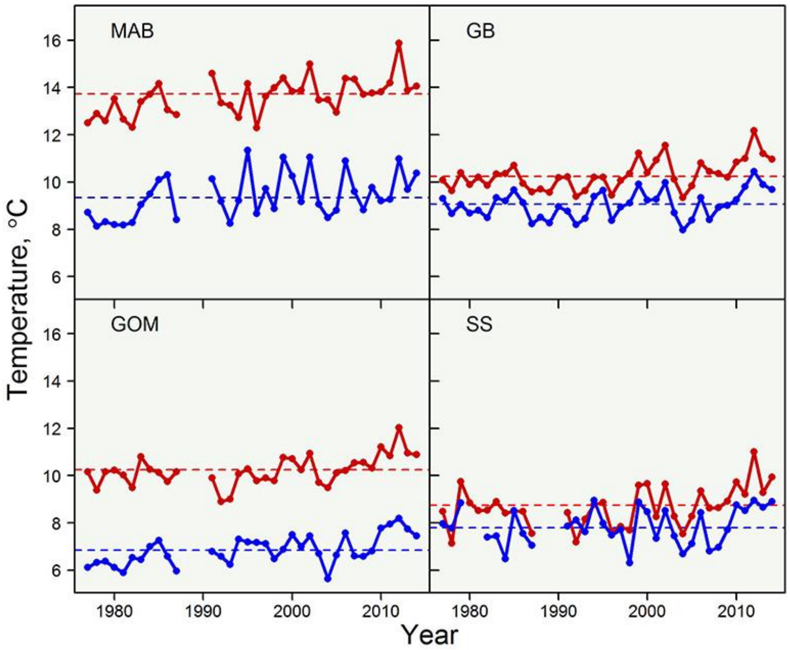

Figure 6: Annual mean surface (red) and bottom (blue) water temperatures from the NEFSC survey programs from the four Ecological Production Units.

Shifts in distribution of marine populations in our region have been documented as water temperatures have increased. Most marine species exhibit distinct thermal preferences with well-defined optimal temperatures. Populations of marine animals at the high end of their thermal range will be adversely affected under current climate change scenarios if redistribution to more favorable conditions is not possible. Temperature preferences of species and overall habitat requirements (for example, substrate type, prey and predator abundances, etc.) will determine the extent of potential distributional changes and adaptation by marine organisms. Overall, poleward shifts in distribution have been observed for species occupying the Mid-Atlantic Bight and Georges Bank, although compensatory changes in depth distribution also occur. However, other habitat requirements may prevent or limit movement for some species, requiring them to accommodate to higher temperatures. Because growth, survival, and reproduction function most efficiently within fairly narrow temperature ranges, energetic costs associated with living at unfavorable temperatures may result in loss or decline of regional populations. In the Gulf of Maine, the movement of many species is toward the southwest. Perhaps paradoxically, the bottom water temperature in the southwestern Gulf of Maine is colder than that of the northeastern Gulf.

Collectively these changes in distribution with respect to latitude or depth will affect the availability of fish and invertebrate species to regional fisheries, in some instances changing the character of these fisheries and the communities they support.

Temperature change may also affect the relative timing of the production cycles of the base of the food chain and consumers thus affecting their growth and survival. During the early life history stages of many fish and invertebrate species there are critical timing relationships between the seasonal primary production cycle and their spawning cycle. As the timing of the primary production cycle is changed by shifting thermal conditions, fish species may not be able to respond to these changes and suffer reduced growth and survival because food resources were not available at the right time of year.

Temperature plays a direct role in the physiology of fishes and marine invertebrates, controlling rates of growth and other processes with important implications for survival. Optimal temperatures for growth are critical for organisms to transition through vulnerable periods of their life history, thus temperature change will upset the growth strategies species use in a particular habitat.

Regional changes in salinity are also expected under climate change. Decreased salinity is expected in coastal areas affected by high precipitation and runoff. Increased runoff will intensify buoyancy-driven coastal currents and the effect these currents have on a range of ecosystem properties including organism transport and primary productivity. Increased salinity is anticipated in offshore areas where higher temperatures will lead to higher evaporation rates. Many marine organisms exhibit distinct salinity tolerance levels and it is anticipated that these changes will contribute to overall changes in distribution patterns of marine species. Changes in salinity will also affect the density of sea water and hence stratification.

Increases in water temperatures and in precipitation under global climate change will result in enhanced stratification of the water column with important implications for productivity. The overall effect will be to increase the energy required for mixing in the water column, resulting in less turnover and a reduction in the mixed layer depth. Replenishment of nutrients in marine ecosystems is dependent on enrichment of the water column from bottom waters, which will be directly affected by changes in stratification. The consequences of these changes can be expected to vary regionally

A reduction in wind-driven forcing in the major current systems such as the Gulf Stream will affect transport and can also be expected to reduce the formation of meanders and rings which can affect advective loss of continental shelf biota. For example, the frequency of warm core ring formation from the Gulf Stream has been related to recruitment success of a number of fish populations. In years in which larger numbers of ring events occur, recruitment is reduced, presumably due to advection as the rings entrain water from the continental shelf and slope regions.

Habitat(s) (including human effects)

Sediments are the bottom materials deposited by water, wind or glaciers, as opposed to the more permanent bedrock. Sediments are by far the dominant type of surficial substrate in the NES LME and slope. They are important in an ecosystem context due to their abundance and for other reasons including: 1) some or all life stages of many plant and animal species are closely tied to certain sediment types, so their distribution and abundance are partly determined by sediments; 2) sediment-dwelling organisms from microbes through benthic macrofauna are important in food webs and other ecosystem functions; 3) sediments are a significant site for deposition and uptake of organic carbon and contaminants, and nutrient regeneration, and they sometimes contribute to bottom water hypoxia and release of toxic compounds such as hydrogen sulfide and ammonia; and 4) sediments are relatively amenable to monitoring to determine trends over space and time in contamination and other ecosystem indicators.

Geologists typically divide sediments into several size classes. The largest is gravels, which are 2 mm or more in diameter; with increasing size, these sediments are termed pebbles, cobbles, and then boulders. Sands are between 2 mm and 62.5 microns. Silts are from 62.5 down to 4 microns, and clays are 4 microns or less. Both silts and clays are also called "muds". The finer sediments are more easily moved by bottom currents, which gives rise to the familiar pattern of sands and gravels being found in inshore and other high-energy ("erosional") areas, and silts and clays in deeper and less energetic ("depositional") areas.

In the Middle Atlantic Bight, the pattern of sediment distribution is relatively simple (6). Most of the surficial sediments on the continental shelf are sands and gravels. Silts and clays predominate at and beyond the shelf edge, with most of the slope being 60-100% mud. Fine sediments are also common in the shelf valleys leading to the submarine canyons, as well as in areas such as the "Mud Patch" south of Rhode Island. There are some larger materials, left by retreating glaciers, along the coast of Long Island and to the north and east. North and east of Cape Cod, sediment distributions are more complex (Figure 4). This is partly due to the area's rugged bottom topography, which features many basins, swells, knolls, banks, and submarine canyons. Glacier-transported materials are much more common in this region. Bottom currents are also complex, and have a large influence on the area's sediment types. The shallower parts of Georges Bank are predominantly sandy, and areas with relatively stable sands (which are moved only by storms) can be distinguished from areas where the sands are often in motion - this has important implications for faunal distributions. On the southern flank of the bank, sand waves over 15 m in height occur. The bank also has large areas of gravel pavement, especially at its northern edge, which are considered valuable habitat for species such as cod and scallop.

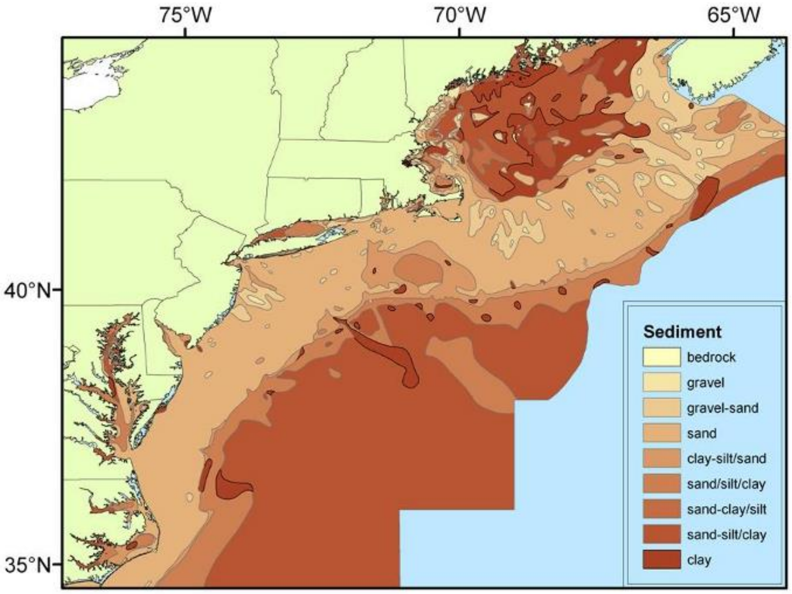

Figure 8. Sediment distribution in the NES LME.

North of Georges Bank, in the Gulf of Maine proper, the topographic highs have sands and larger materials including glacial erratics (boulders), while the basins are floored with muds interspersed with boulders and rocky outcrops. The sedimentary characteristics of the Gulf of Maine are the most complex in the region, with an intricate mosaic of bottom types in the nearshore Gulf of Maine, expanses of clay and silty sands in the deeper portions of the central and western gulf and a mix of sand/silt/clay in the deepest reaches. Areas of exposed bedrock are also found throughout the gulf (Figure 8).

Complex Physical Habitats

Hard, immobile substrates (including the larger of the sediment types discussed above) provide a distinct, important habitat for biota to attach to or live within or near. Besides providing stable attachment sites and shelter, the added surface area of complexly-structured hard substrates often increases food supply. Some or all life stages of many species are dependent on complex hard substrate, while other species use this structure although they are not as strictly tied to it. Man-made structures such as bulkheads, piers, bridges, shipwrecks and artificial reefs provide many of the same functions as do the natural hard substrates.

Rocky coastal areas are rare in the southern Middle Atlantic Bight, but become more common north and east of New Jersey and Long Island. Offshore (as noted in the Sediments section), bottom substrates in the Middle Atlantic include relatively little natural rock. However, the amount of complex hard substrate has been substantially augmented by man, especially via shipwrecks and construction of artificial reefs. It has been estimated that there is now more man-made than natural habitat of this type in the Middle Atlantic. The increase in amount of this habitat has probably affected distribution and abundance of harvested stocks including lobster, cod, red hake, ocean pout, scup, black sea bass and tautog, as well as the many other species associated with the habitat. There is a long-standing scientific debate over the extent to which artificial reefs increase overall production of fishery species, versus simply concentrating these resources, which in turn could increase the risk of overfishing them.

In northern New England, rocky substrates are the rule along exposed coastlines and in shallow waters. Bedrock and boulders left by glaciers are also very common at greater depths. There are several large submarine ledges (e. g., Jeffreys, Cashes) rising above the surrounding bottom.

Complex Biogenic Habitats

Seabed habitats comprise a complex blend of bottom features and associated animal communities. Often, habitats are “biogenic”; that is, formed by the animals themselves. These may also provide shelter for other species, including fish. Areas that are structurally complex as a result of geological features or biogenic structures often support highly diverse biological communities. Some of these habitats are also particularly vulnerable to disturbance by natural forces and human activities. It is for this latter reason that habitat protection has assumed an important role in current fishery management.

The types of habitat described above are centered on physiographic features associated with the sea bed. However, many marine animals spend their lives in the water column itself with some taking excursions to the sea floor for feeding and other purposes.

The physical geography of the sea is defined not only by bottom characteristics but by a complex array of oceanographic features including currents and frontal zones. Animals principally associated with the water column are considered to inhabit the pelagic ecosystem. Many types of schooling fish, marine mammals, sea turtles and top predators such as sharks, tunas, and billfish are important components of the pelagic ecosystem. Other important members of these pelagic communities include small (in some cases microscopic) animals that are important links in the food web. These zooplankton species drift in the ocean currents and are often concentrated in frontal zones and other oceanographic features. Frontal zones can be generated by tidal forces or by the confluence of water masses characterized by different temperature and other features. Fronts can often be recognized at the surface by concentrations of sea foam, debris, or other materials. In areas such as Georges Bank, fronts or convergence zones separate areas that are well mixed by tidal forces and winds from areas that are seasonally stratified (or layered, with warmer and/or fresher water on top) and these are important pelagic habitat areas for many species.

Many species forage in oceanographic structures such as fronts where their prey are concentrated. For example, large shoals of small pelagic fish such as herring and mackerel are often found at tidal mixing fronts where high densities of their planktonic prey are found. In turn, fishing activities directed at pelagic species are often concentrated in these areas to capitalize on these natural associations between predators and their prey.

Essential Fish Habitat

Essential Fish Habitat is defined as:

> *"...those waters and substrates necessary to fish for spawning, breeding, feeding or growth to maturity. For the purposes of interpreting the definition of essential fish habitat, 'waters' include aquatic areas and the associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; 'substrate' includes sediment, hard bottom, structures underlying the waters, and associated biological communities; 'necessary' means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and 'spawning, breeding, feeding or growth to maturity' covers a species' full life cycle"*

Habitat protection is a cornerstone in the development of ecosystem based fisheries management. Ecosystem based fisheries management is inherently geographically specific, and therefore naturally linked to considerations of habitat and local seascapes. The specification of "habitat areas of particular concern" under current management measures shows how fine-scale information on habitat and associated biological communities can be used to protect critical areas.

The interest in protecting vital habitat centers on the role it plays in the productivity of living marine resources. Habitats provide food and shelter for many species and therefore directly affect their productivity. If we lose critical habitat, the ability to support these organisms is diminished. The amount of sea life that an ecosystem can sustain – its carrying capacity – depends on the availability of appropriate habitat, among other factors. For species that live on or near the seabed, the types of physical habitat we have described is critical. For other species that spend their lives in the water column, oceanographic features such as frontal zones may be critical habitats.

Description of Managed Fisheries

Central to EBM is an understanding of coupled socio-ecological systems (human and natural environment) which reflects the interface and reciprocal interactions that link human (e.g., economic, social, cultural) and natural (e.g., oceanographic, atmospheric, geological, biological) sub-systems. Coastal communities of the NES LME (and around the U.S.) depend on the ocean for meeting economic, social, and cultural needs. Fishing (commercial, recreational, and subsistence), coastal tourism and recreation, shipping, and spiritual or cultural practices centered on marine locations or species are but a few examples. In turn, human activities shape the marine environment, generating a feedback mechanism between the coupled systems. The following overview highlights some indicators of these dependencies, and new avenues by which our scientific understanding of the underlying processes are being bolstered.

It also provides an initial understanding of the potential tradeoffs that must be made under both EBM and MSP, as we analyze the nation's use of the marine environment and understand: 1) how marine resources are utilized; and 2) potential user conflicts inherent in access to these resources. As technology allows new development in and uses of ocean waters, traditional uses of marine resources (e.g., boating, fishing, shipping, spiritual practices) must be considered in the planning process for evolving new activities such as renewable energy in the form of wind farms or tidal generators. MSP is utilized by ocean resource managers, in conjunction with EBM, to better determine how resources may be sustainably used and/or protected.

Social and Economic

Harvest and processing sector

The commercial fisheries of the NES LME have historically played a critical role in the economy of coastal communities throughout the region. Fishing has been called America's First Industry and the lure of unexploited resources was a major catalyst in the exploration and colonization of eastern North America by European fishing nations. In the Gulf of Maine (GOM), the total biomass extracted peaked between the late 1960s and 1990s (Figure 6). However, the maximum annual removal of crustaceans occurred in 2012, driven primarily by landings of American lobster (Homarus americanus), and landings of pelagics are near the time series' average. Crustacean landings in the Scotian Shelf are likewise at a series high, while mollusc landings are on par with the series average. Mollusc landings are also near long-run averages in Georges Bank. Although the landings composition has shifted dramatically, the total biomass removed from the Mid-Atlantic is very close to the series average [note that these estimates differ from previous Ecosystem Status Reports in using live weight rather than processed weight (e.g. scallop meat weight) to reflect more fully the biological dynamics of the systems]. The shift towards mollusc landings highlights the importance of Atlantic surf clams (Spisula solidissima), ocean quahogs (Arctica islandica), and Atlantic sea scallops (Placopecten magellanicus) to the Mid-Atlantic, while crustacean landings in this Ecosystem Production Unit are composed primarily of blue crab (Callinectes sapidus). Notwithstanding the above, recent landings are by and large substantially below historical levels.

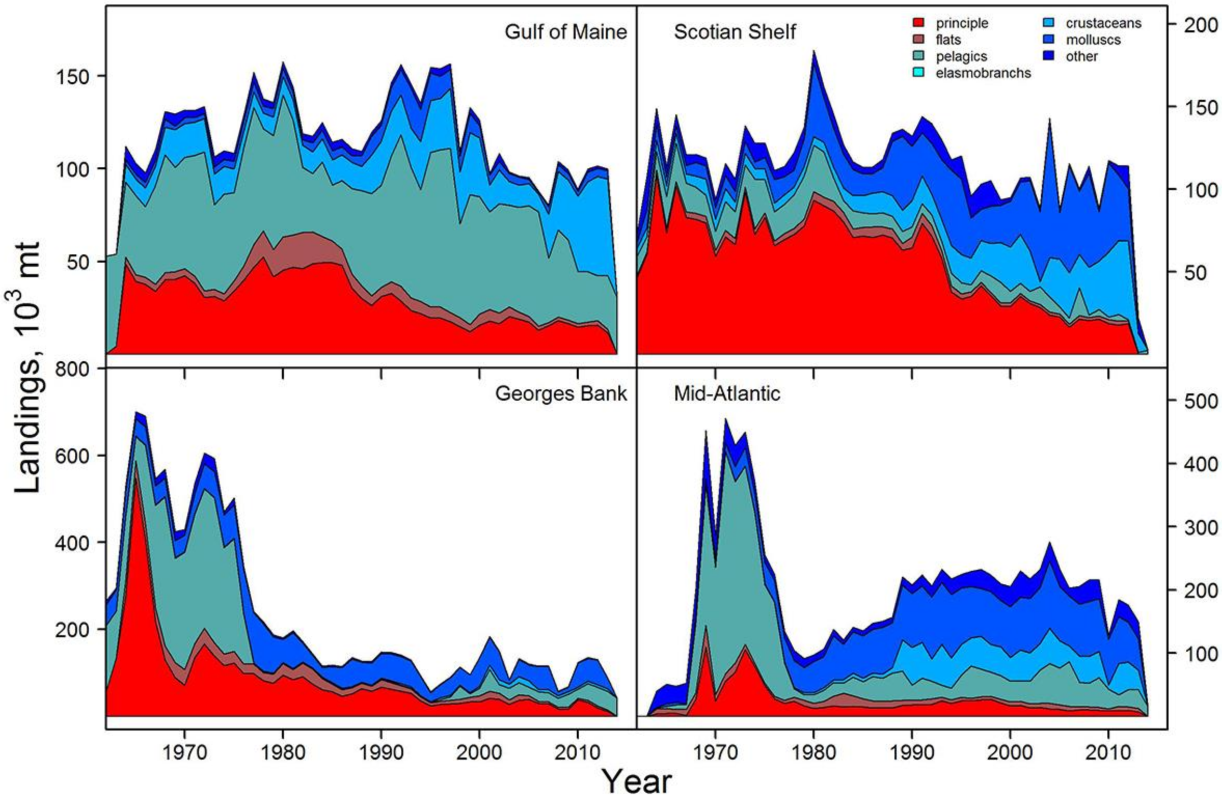

Figure 9. Landings (live weight) by subregion for the NES LME. The groups represented are: principal groundfish (Atlantic cod, haddock, pollock, silver hake, red hake, white hake, red fish, and monkfish), flatfish (i.e. summer flounder, winter flounder, yellowtail flounder), pelagics (i.e. Atlantic herring, Atlantic mackerel), elasmobranchs (i.e. spiny dogfish, winter skates), crustaceans (i.e. American lobsters, red crab), molluscs (i.e. Atlantic scallops, ocean quahogs, surfclams), and other. Note: landings of lobster are underrepresented in the time series.

Providing food is an important dimension of the recreational fishing experience, as reflected in the magnitude of the catch taken for consumption. It is however also an aesthetic pursuit and must also be considered as an important Cultural Service as well. Here we focus on recreational catch statistics. A downward trend in recreational fishing effort and landings has occurred over the last few years. Attributing the trend to a single cause is problematic, as recreational fisheries are a complex amalgam of for-profit party and charter vessels together with private boat and shore fishing more purely characterized as leisure and/or subsistence activities. The recent recession, lethargic economic recovery, and an increase in real fuel prices likely explain a portion of the recent trend, as individuals slow expenditures on recreational activities or substitute less expensive leisure activities for fishing. The recreational fishery also depends on many of the same depleted fish stocks as some of the most contracted commercial fisheries in the Northeast, and these depletions likely account for a portion of the longer trends in landings observed.

Fishery Dependent Communities

Coastal communities are currently experiencing impacts of multiple stressors: economic, social, and ecological. Factors affecting vulnerability include levels of access to resources and power (political, cultural, economic, and social) and of susceptibility to harm or loss. Existing levels of social vulnerability affect the level of impact that a community experiences from stressors. Therefore, identification and monitoring of socially vulnerable communities in the coastal zone is a critical aspect of EBM. Similarly, levels of dependence on and use of ocean-related resources and conditions create greater or lesser likelihood of specific kinds of impacts. Further, coastal gentrification trends may be an indication of community vulnerability to development that can transform the coastal zone and increase coastal community vulnerability to the impacts of disruptive events (Jepson and Colburn 2013), such as extreme weather conditions.

The NMFS Community Social Vulnerability Indicators (CSVIs; Jepson and Colburn 2013) are statistical measures of the vulnerability of communities to events such as regulatory changes to fisheries, wind farms, and other ocean-based businesses, as well as to natural hazards, disasters, and climate change. The CSVIs currently serve as indicators of social vulnerability, gentrification pressure vulnerability, and commercial and recreational fishing dependence (with dependence being a function of both reliance and engagement; Figure 8).

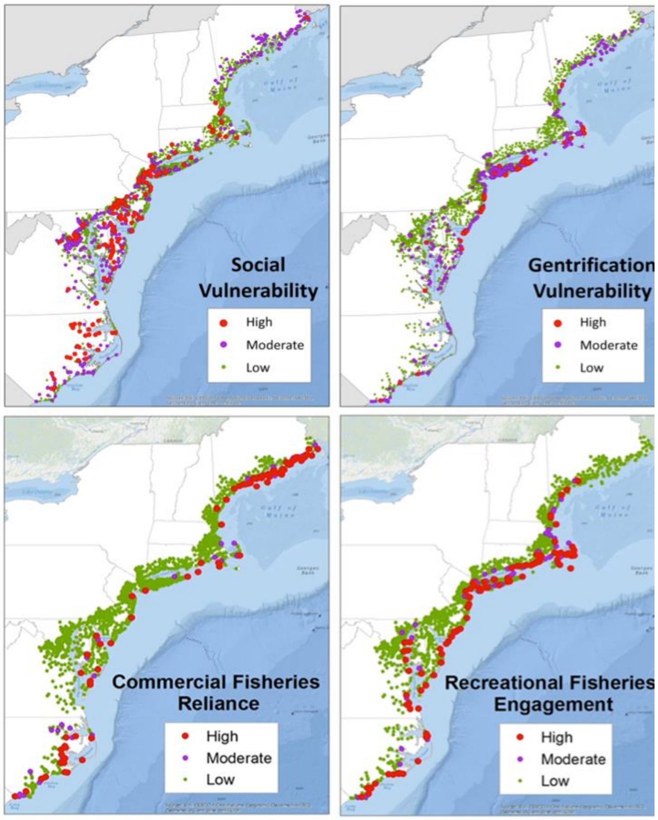

Figure 10. Rankings of social vulnerability, gentrification pressure vulnerability, and commercial fishing reliance and recreational fishing engagement.

Communities in the Northeastern U.S. are ranked as high, moderate, or low relative to the respective indicator. Figure 8 shows a high concentration of socially vulnerable communities in the Mid-Atlantic, while we see a high to moderate concentration of communities that may be vulnerable to gentrification pressure in Massachusetts, New York, and New Jersey. Community dependence on recreational and commercial fishing is mixed, with notably more communities in the Mid-Atlantic engaged in than reliant on recreational fishing (Figure 10).