

# Managing Forage Fishes in the New England Region

A Draft White Paper to Inform the  
New England Fishery Management Council

[based on the Mid-Atlantic Fishery Management  
Council's Forage Fish White Paper]

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## **Introduction**

This draft white paper (summarized from the Mid-Atlantic Fishery Management Council's Forage Fish White Paper) provides information on forage species and recommendations on management approaches that the New England Fishery Management Council could consider to ensure sustainable fisheries on both the forage species and their predators, while maintaining a healthy and productive ecosystem. In reaching decisions on forage management, tradeoffs are inevitable and careful analysis of how tradeoffs affect yields, employment, profits, social well-being and stock sizes of forage species, as well as other Council-managed species and unmanaged predators need to be considered.

### **1. Context: Current status of NEFMC managed fisheries and management objectives**

The NEFMC has expressed interest in the development of a policy approach for managing forage fishes, in particular Atlantic herring under proposed Amendment 8 to the Herring FMP.. Ultimately, ecosystem-based management necessitates the explicit recognition of the trade-

offs associated with management decisions. In the context of forage species, this means weighing the trade-off between direct and indirect uses of these species. For example, National Standard 1 (NS1) of the Magnuson-Stevens Fisheries Conservation and Management Act (MSA) identifies optimum yield as a goal of fisheries management, with the term optimum defined elsewhere in the Act as "...maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor..." (16 U.S.C. § 1802 (33)(B))<sup>1</sup>. Currently, building on 16 U.S.C. § 1802 (33)(A), the National Standard Guidelines Final Rule for NS1 (50 CFR § 600.310<sup>2</sup>) specifically identifies human food production, recreational opportunities, and maintaining adequate forage for all components of the ecosystem as relevant economic, social, and ecological factors that should inform the setting of optimum yield levels. The MSA further states, in National Standard 8 (NS8), that "Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities" (16 U.S.C. § 1851(a)(8)). And as the guidelines for its implementation state, "...dependence, engagement, and sustained participation are not measured solely in terms of the percent of fishing activity in relation to the entire economic base of the community; there are other social, cultural, and economic assessments specifically focused on the harvesting, processing, and fishery-support industries" (50 CFR § 600.345). Analyzing the trade-offs associated with competing values for forage fish is therefore enshrined in the MSA, and plays a central role in identifying the most appropriate management measure for these species.

The NEFMC directly manages fisheries for 35 stocks (of which 3 are jointly managed with the New England Fishery Management Council). As of July 2014, 6 of the 24 stocks with known status were subject to overfishing (fished above established maximum fishing mortality rates) and 9 were overfished (biomass below 50% of the level expected to provide maximum sustained yield). Ten stocks -- red crab, offshore hake, GOM winter flounder, and all 7 skate species -- have unknown status with respect to one or both of these performance measures.

The 35 stocks are managed by the NEFMC under 9 Fishery Management Plans (FMPs). Atlantic herring is managed under its own FMP. Based on the 2012 benchmark assessment, Atlantic herring are neither overfished nor subject to overfishing; biomass was estimated to be more than three times B<sub>msy</sub> and fishing mortality was estimated to be just above half F<sub>msy</sub>.

NEFMC's stated management objectives are ???. In examining changes to forage fish policy, there are a number of additional objectives that have proven important in other settings, but

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<sup>1</sup> The full text of the MSA is available online at:  
[http://www.nmfs.noaa.gov/sfa/magact/MSA\\_Amended\\_2007%20.pdf](http://www.nmfs.noaa.gov/sfa/magact/MSA_Amended_2007%20.pdf).

<sup>2</sup> NMFS's National Standards Guidelines, 50 C.F.R. 600.310 et seq., are available online at:  
[http://www.nmfs.noaa.gov/sfa/laws\\_policies/national\\_standards/index.html](http://www.nmfs.noaa.gov/sfa/laws_policies/national_standards/index.html)

whose appropriateness for forage fish under NEFMC management would need to be evaluated on a case by case basis. These include, but are not limited to, increasing the beneficial contribution of forage fish to the dynamics of both managed and unmanaged species, bolstering the resilience of the system, and enhancing the role forage fish play in the economy, and society more generally.

## **2. Evaluating management changes and tradeoffs between objectives—a proposed process**

Optimal management of forage fish ultimately depends on the trade-off between their indirect *in situ* value versus their direct market value. This trade-off is often complicated, and differs wildly from species to species. For example, Atlantic herring (*Clupea harengus*) serve as an important prey species for many animals, including commercially valuable fish such as Atlantic cod and certain species of tuna, recreationally valuable species such as striped bass, and protected species including harbor porpoise and grey seals, to name but a few. Conversely, Atlantic herring serves as the primary bait for the highly valuable American lobster fishery. Managing these trade-offs necessitates deep knowledge of not only the species ecology, but also the uses of and substitutes for these species within the economy. Further these tradeoff choices are based not just on ecological preferences and commercial uses, but cultural and social preferences as well. Some societal preferences may favor forage fish *in situ* not only for their forage value within the ecosystem but also, for instance, because large schools of forage fish close to the coast can attract marine mammals that people like to view from the beach or whale watch vessels. In a different example favoring extraction, herring, was once a major food fish in the US and still is elsewhere. While US preferences for herring as food have declined (there were once 17 herring canneries in Maine, but only one is left), that trend may be changing. Some upscale restaurants along the east coast have begun serving fresh herring, for instance. Additionally, many ‘eat local’ and ‘slow food’ movements promote eating whatever is off your coast and starting as low on the food chain as you can. Such movements have been gaining adherents (Olson et al. 2014). Different communities within New England will be more and less dependent on forage species for harvest and sale and/or as supports for other species they target that predate on forage species or for the tourism value of the marine mammals they attract. Further, global markets can also change based on changing social preferences in nations that might import our forage fish. Given adequate information on all of these fronts, 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. However, the state of the science is such that these models have yet to be practical.

Barring full bio-socio-economic models, population dynamics, ecology, economics, anthropology, sociology and other 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 identify which strategies are likely to generate the benefits of interest.

For example, section 3 identifies the importance of cephalopods for the diet of inshore summer flounder (*Paralichthys dentatus*). For argument's sake, assume that enhancement of summer flounder productivity is a management objective. *Illex* and longfin squid are both highly migratory and have life spans of less than a year (Jacobson 2005; Hendrickson and Holmes 2004). An optimal management strategy for cephalopods in support of the summer flounder fishery would thus necessitate the understanding of seasonal migration patterns, among other things, to identify times at which these cephalopod species are available to inshore summer flounder. This might, in turn, suggest seasonal harvest restrictions, as opposed to augmented ACLs, as the most appropriate management strategy in this hypothetical case, and underlines the importance of a nuanced approach to the issue of forage fish management. Forage fish's role 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. For example, forage fisheries are less likely to benefit from stock effects, or large changes in CPUE driven by changes in total biomass, given their schooling behavior (Smith 2014). This makes it less likely that targeted fisheries would benefit substantially from biomass levels above  $B_{msy}$ , and a more conservative biomass target could thus be expected to generate costs to the industry, which must be weighed against any perceived benefits of the management change. 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, when more precautionary biological thresholds are adopted.

### **3. Ecosystem services and forage species**

Collectively, forage species provide an important supporting ecosystem service. The primary ecological role of forage species is energy transfer; these relatively small fish and invertebrates (e.g., squids and krill) tend to be central in food webs. They eat very small prey (zooplankton or small benthic invertebrates), and are themselves eaten by larger animals in the ecosystem, including the predatory fish often targeted in commercial fisheries, as well as marine mammals, seabirds, and other protected species. Forage species tend to be highly productive relative to larger predatory fish, marine mammals, and birds. These characteristics can be used to formally define forage species. During recent MSA reauthorization discussions, the following forage fish definition was proposed: "The term 'forage fish' means any low trophic level fish that contributes significantly to the diets of other fish and that retains a significant role in energy transfer from lower to higher trophic levels throughout its life

cycle.’’ In 2012, the Ecosystem Subcommittee of the MAFMC’s Scientific and Statistical Committee provided its definition and detailed description of forage fish (Table 1). Other US Regional Fishery Management Councils have also developed forage-specific policy (see section 6). Fishery scientists and managers therefore recognize this key role of forage species in fueling production of valuable predator fishes (Smith et al. 2011). But, the broader role of forage species in sustaining productivity and structure of marine ecosystems is less understood or appreciated (Engelhard et al. 2014).

**Table 1.** Definition of forage fish provided to MAFMC by its Ecosystems Subcommittee of the Scientific and Statistical Committee, March 2012.

<p>Is the stock a “forage” fish? Forage is defined as a species that:</p> <ul style="list-style-type: none"> <li>• Is small to moderate in size (average length of ~5-25 cm) throughout its lifespan, especially including adult stages;</li> <li>• Is subject to extensive predation by other fishes, marine mammals, and birds throughout its lifespan;</li> <li>• Comprises a considerable portion of the diet of other predators in the ecosystem in which it resides throughout its lifespan (usually &gt;5% diet composition for &gt; 5 yrs.);</li> <li>• Has or is strongly suspected to have mortality with a major element due to consumptive removals;</li> <li>• Is typically a lower to mid trophic level (TL) species; itself consumes food usually no higher than TL 2-2.5 (typically zooplankton and or small benthic invertebrates);</li> <li>• Has a high number of trophic linkages as predator and prey; serves as an important (as measurable by several methods) conduit of energy/biomass flow from lower to upper TL;</li> <li>• Often exhibits notable (pelagic) schooling behavior;</li> <li>• Often exhibits high variation in inter-annual recruitments; and</li> <li>• Relative to primary production and primary producers, has a ratio of production and biomass, respectively, to those producers not smaller than on the order of <math>10^{-3}</math> to <math>10^{-4}</math></li> </ul>
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Fisheries for forage species represent an important ecosystem provisioning service. Globally, forage species are major contributors to marine fisheries, constituting >35% of annual landings in recent decades. The dockside value of global forage species landings was \$5.6 billion in 2009 (Pikitch et al. 2012, 2014). Most of these landings are converted to meal and oil, and used as feeds in livestock and aquaculture industries, or used as bait. These linkages between industries demonstrate forage species economic as well as ecological support roles. In the Mid-Atlantic region, forage species, especially the Atlantic menhaden, are key contributors to the quantity and value of regional fisheries landings, in addition to their value as prey for diverse predators. Annual combined Mid-Atlantic and New England landings of targeted forage species exceeded 210,000 metric tons in 2008-2012 (Table 2).

While the landed value of forage fish is high, the global value of the forage fish supporting the production of marine commercial predator fishes was estimated to be even higher at \$11.3 billion (Pikitch et al. 2012, 2014). This highlights the importance of managing forage species for both sustained production of managed piscivorous fish and for direct fishery removals. Additional management considerations extend to unfished protected species such as seabirds. In a recent review and analysis, Cury et al. (2011) found that seabird populations were especially sensitive to declines in forage fish biomass, with seabird reproductive failure often associated with declines in forage biomasses to <33% of the forage species' unfished biomass ( $B_0$ ). However, since successful seabird fledging requires forage to be available near breeding colonies during breeding season (Elliot et al 2009, Bertrand et al 2012); where and when fishing occurs is as important as how much if management objectives include sustaining seabird reproductive success.

Forage species life history is also important to consider for effective management. These species tend to be highly productive and short-lived, with only a few age classes represented in a population. Some can also exhibit population “boom and bust” cycles. Historically, shoaling pelagic forage fishes were considered to be relatively insensitive to fishing, although extreme abundance fluctuations were observed. Climate drivers have a strong role in controlling what sometimes has been called “the forage fish rollercoaster” (Dickey-Collas et al. 2014). For example, the Peru anchoveta population waxes and wanes in response to El Niño conditions in the Humboldt Current (Barange et al. 2009). Decadal-scale variability in abundance of major forage fish is often associated with ocean regime shifts that signal shifts in ecosystem productivity (Alheit et al. 2009). In recent decades, it has become increasingly apparent that intense fishing can deplete forage species as commonly as other types of fishes (Beverton 1990; Patterson 1992; Pinsky et al. 2011). When environmental conditions are unfavorable for reproduction and recruitment, fishing such stocks at high levels of exploitation increases the possibility of stock collapse (Murphy 1967, 1977; Pinsky et al. 2011). Forage species exhibiting strong shoaling behavior can have increased vulnerability to fishing in years of low abundance because schools remain easy to locate. Fishery catch-per-unit effort may not decline at low stock abundance, leading to excessive optimism about stock status and a high risk of stock collapse if CPUE is the only information used to assess stocks (Csirke 1988).

**Table 2.** Forage fishes and squids in 1) managed, targeted fisheries in the New England region and 2) present but not targeted or managed in New England. For the targeted species the combined, Mean Annual Landings (metric tons) for the New England and Mid-Atlantic regions (from NOAA Commercial Fishery Statistics) are given for the five-year period, 2008 – 2012. Atlantic menhaden mean annual landings are from reports of the Atlantic States Marine Fisheries Commission and include landings from New England, the Middle Atlantic and South Atlantic. The “Fished Y/N” column refers to fisheries in the western North Atlantic. The “Bycatch Important” column refers to importance of the species as a bycatch in managed MAFMC fisheries. This table considers only species that are forage-sized throughout the lifespan.

Common name	Species	Fished Y/N	Mean Annual Landings (mt) (2008-2012)	Current status B/B <sub>msy</sub> F/F <sub>msy</sub>	Management Authority	Bycatch Important Y/N
Atlantic herring	<i>Clupea harengus</i>	Y	82,422.4	3.3 0.52	NEFMC/ASMFC	Y
Atlantic menhaden	<i>Brevoortia tyrannus</i>	Y	210,776.0	0.22-1.4* 3.36	ASMFC	N
Atlantic mackerel	<i>Scomber scombrus</i>	Y	12,003.2	Unknown Unknown	MAFMC	Y
Butterfish	<i>Peprilus triacanthus</i>	Y	244.1	1.7 0.025	MAFMC	Y
Alewife	<i>Alosa pseudoharengus</i>	Y	605.2	“Depleted” Unknown	ASMFC	Y
Blueback herring	<i>Alosa aestivalis</i>	Y	6.2	“Depleted” Unknown	ASMFC	Y
Longfin squid	<i>Doryteuthis pealii</i>	Y	9,892.0	1.284 Unknown	MAFMC	Y
Illex squid	<i>Illex illecebrosus</i>	Y	11,227.5	Unknown Unknown	MAFMC	Y
Bay anchovy	<i>Anchoa mitchilli</i>	N		Unassessed		N
Striped anchovy	<i>Anchoa hepsetus</i>	N		Unassessed		N
Silver anchovy	<i>Engraulis eurystole</i>	N		Unassessed		N
Round herring	<i>Etrumeus teres</i>	N		Unassessed		N ?
Thread herring	<i>Opisthonema oglinum</i>	Y	0	Unassessed		Y, small
Spanish sardine	<i>Sardinella aurita</i>	Y	0	Unassessed		Y, small
Sand lance	<i>Ammodytes americanus</i> and <i>A. dubius</i>	N	0	Unassessed		N
Atlantic silverside	<i>Menidia menidia</i>	Y	6.4	Unassessed		N

\*The Atlantic menhaden technical committee (2012) pointed out a mismatch between F and B reference points used; if compatible F and B reference points are used, menhaden B is below the target reference threshold assumed to be equivalent to B<sub>MSY</sub> (B/B<sub>30%</sub> = 0.22), and also below the limit reference point assumed to be ½ B<sub>MSY</sub> (B/B<sub>15%</sub> = 0.44) while it is above the currently used B threshold (B/B<sub>MED.T</sub> = 1.4).

#### 4. Forage Species in the New England Ecosystem(s)

A diverse assemblage of shelf and coastal fishes and squids can be categorized as forage species in the New England region (Table 2) according to the MAFMC 2012 Forage Species definition (Table 1). 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 New England region (see Appendix A for a brief synopsis of each species). While not targeted currently in New England 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 GB EPU 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 Appendix B. Predators are listed in Table 3, and the suite of forage species identified for each predator category are in Table 4.

Food habits information provides a picture of key forage for important New England commercial fish as well. We present estimated diet compositions for the top three predators of Atlantic herring over the past 40 years according to food habits data: spiny dogfish, Atlantic cod, and silver hake (Fig 1). Atlantic herring consumption estimates as presented in the 2012 assessment also give context for potential management as forage fish (Fig 2).



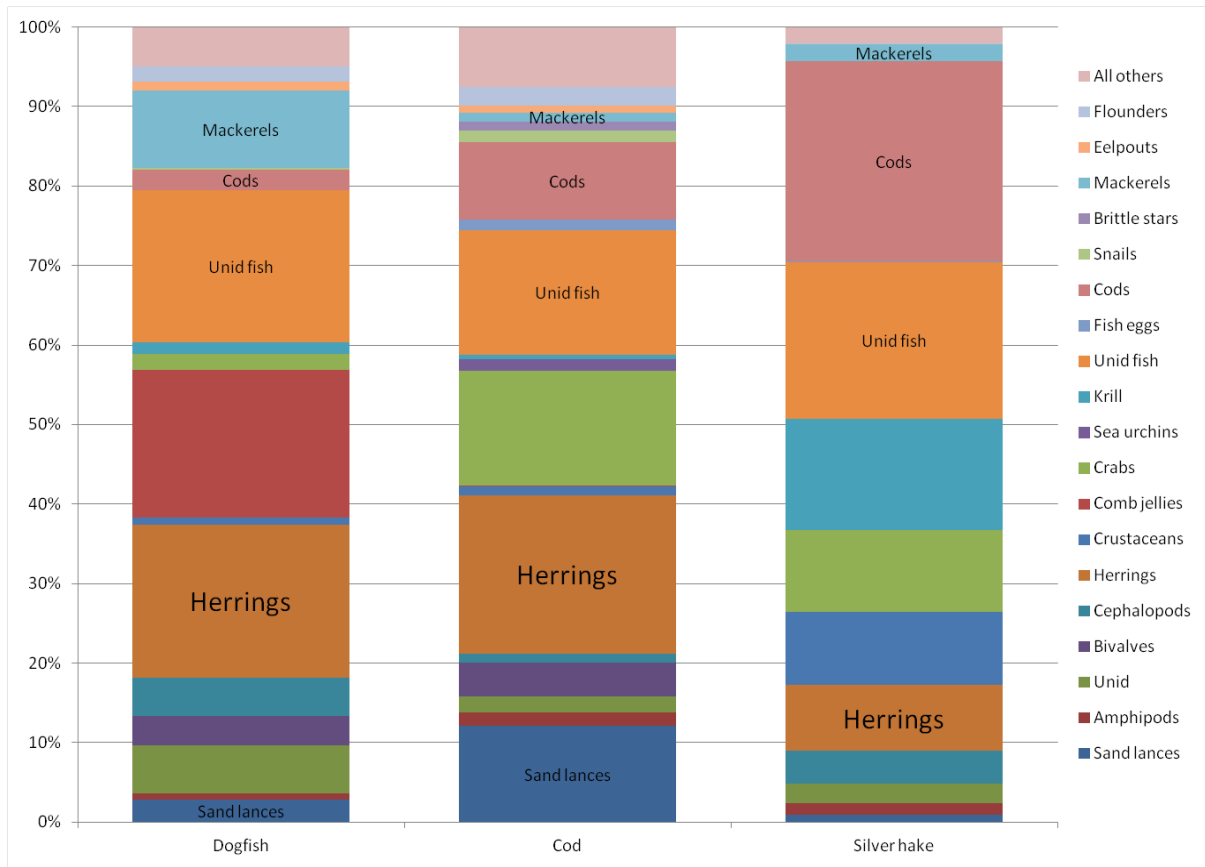
**Table 3.** Predator species in New England used to derive lists of forage species. Fish are listed in descending order of representation in the NEFSC database by number of collection locations, 1973-2012. Only relatively common predators in the New England region are listed in other categories.

Fish	Marine mammals	Sea Turtles	Seabirds
<b>NEFMC managed</b> Spiny dogfish Monkfish Little skate Spotted hake Silver hake Windowpane Atlantic herring Winter skate Red hake Winter Flounder Yellowtail flounder Witch flounder Clearnose skate Rosette skate	<b>Baleen Whales</b> Fin whale Humpback whale Sei whale Minke whale N Atlantic right whale	Loggerhead Leatherback Kemp's ridley	<b>Pelagic (shelf unless noted)</b> (spring, fall, winter) Herring gull Great black-backed gull Laughing gull (spring, summer, fall) Bonaparte's gull (spring) Black-legged kittiwake (spring, winter) (spring, shelf break) Red phalarope Red-necked phalarope (spring, winter) Northern gannet Northern fulmar (summer, shelf break) Wilson's storm-petrel Leach's storm-petrel (summer, fall) Great shearwater Cory's shearwater Manx shearwater Audubon's shearwater Sooty shearwater Common tern (spring) Royal tern (summer, fall, nearshore) Razorbill (winter, spring)
<b>Other managed</b> Summer flounder Butterfish Scup Atl. mackerel Bluefish Black sea bass Tilefish Fourspot flounder Smooth dogfish Weakfish Ocean pout Blueback herring N. Searobin Spot Atlantic croaker Gulf Stream flounder Sea raven Cusk eel Longhorn sculpin Striped bass American shad	<b>Toothed Whales and Dolphins</b> Pilot whale White-sided dolphin Common dolphin Bottlenose dolphin Harbor porpoise		<b>Coastal</b> Great cormorant Double-crested cormorant Loons Brown pelican American bittern Great blue-heron Snowy egret Great egret Tricolored heron Little blue heron Green heron Black-crowned Night-heron Common merganser Red-breasted merganser
<b>Highly Migratory</b> Large coastal sharks Pelagic sharks Billfish Tunas	<b>Seals</b> Harbor seal Gray seal		
<b>ESA listed</b> Atlantic sturgeon Shortnose sturgeon			

<b>Fish</b>	<b>Marine mammals</b>	<b>Sea Turtles</b>	<b>Seabirds</b>
			Osprey Black skimmer Bald eagle

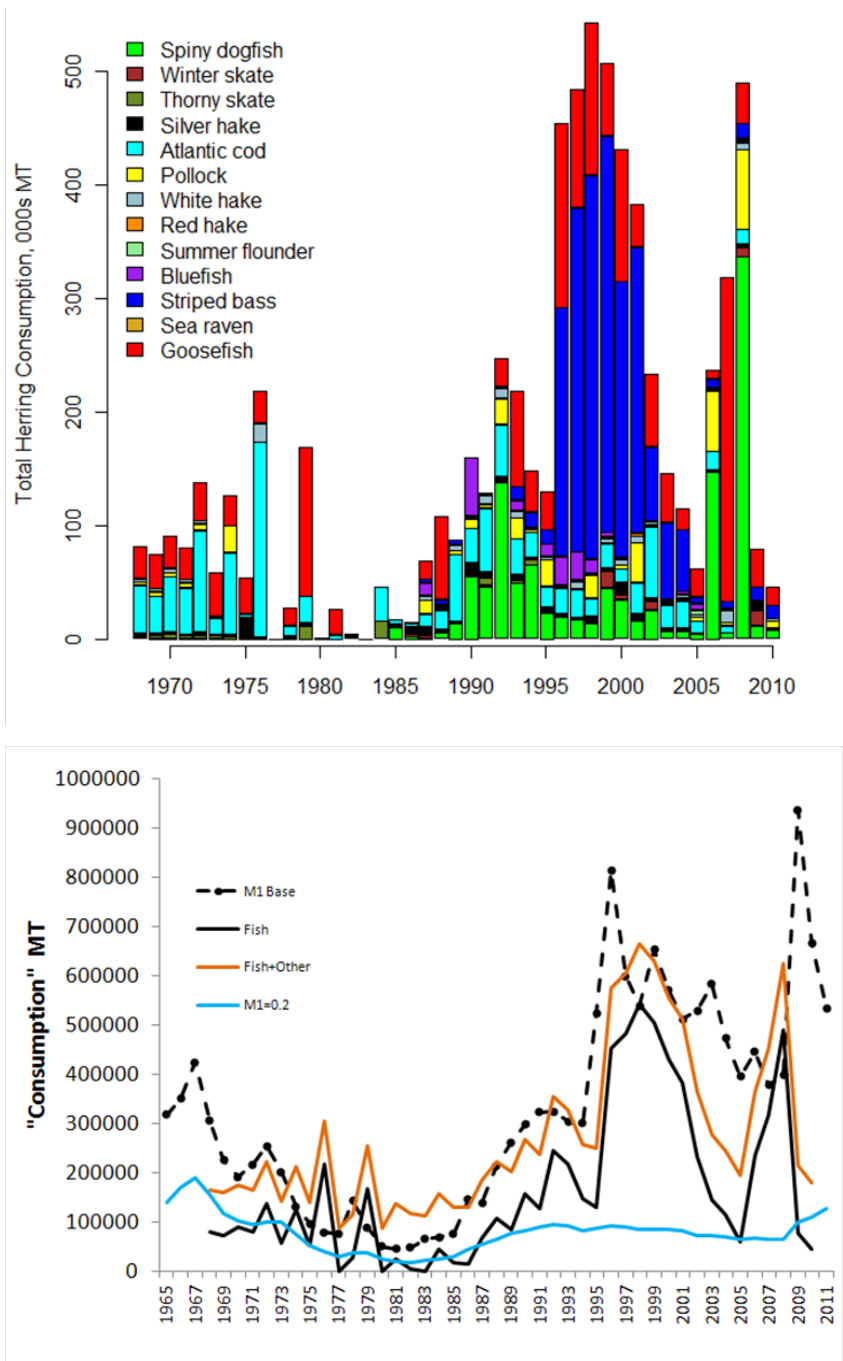
**Table 4.** Ranking of important forage species groups by predator type (highest frequency and/or consumption are first on the list).

<b>Fish</b>	<b>Marine mammals</b>	<b>Sea Turtles</b>	<b>Seabirds</b>
<b>All in NEFSC database, including MAFMC managed</b> Crabs and shrimp Amphipods Other zooplankton Fish (incl. unid.) Anchovies Hakes Sand lance Herrings Molluscs Unid. cephalopods Longfin squid Bivalves Annelids Ctenophores	<b>Baleen Whales</b> Krill Herrings Other zooplankton Sand lance Large gadids Mackerels Other fish	Crabs Fish (scavenged?) Ctenophores and jellyfish	<b>Pelagic/coastal Gulls:</b> fish, offal and fish scavenged from commercial fishing operations, euphausiids <i>Shearwaters:</i> fish (sand lance, saury), squids <i>Storm petrels and Phalaropes:</i> zooplankton, fish eggs and larvae <i>Gannets:</i> fish (menhaden, mackerel, saury) <i>Fulmars:</i> euphausiids, squids
<b>All in NEAMAP database</b> Crabs and shrimp Fish (incl. unid) Anchovies Butterfish Sand lances Scup Menhaden Drums Amphipods Polychaetes Molluscs Bivalves Longfin squid Mysids	<b>Toothed Whales and Dolphins</b> Squids Mackerels Other fish Small gadids Herrings Mesopelagics		
<b>Highly Migratory</b> <i>Large coastal sharks:</i> Fish (unid, bluefish, summer flounder) Skates/rays/sharks Crabs <i>Large pelagics:</i> Squids (incl. Illex sp.) Fish (unid, mackerel, butterfish, bluefish, hakes, sand lance)	<b>Seals</b> Other fish Sand lance Small gadids Flatfish Herrings Large gadids Squids	<b>ESA listed fish (sturgeons)</b> Annelids Shrimp Other benthic invertebrates	<b>Coastal</b> Fish and crustaceans; extremely varied diet along salinity gradients  Osprey, Cormorants and Pelicans— Menhaden, herring, estuarine fish (mullet, drums, anchovy...)



a) b) c)

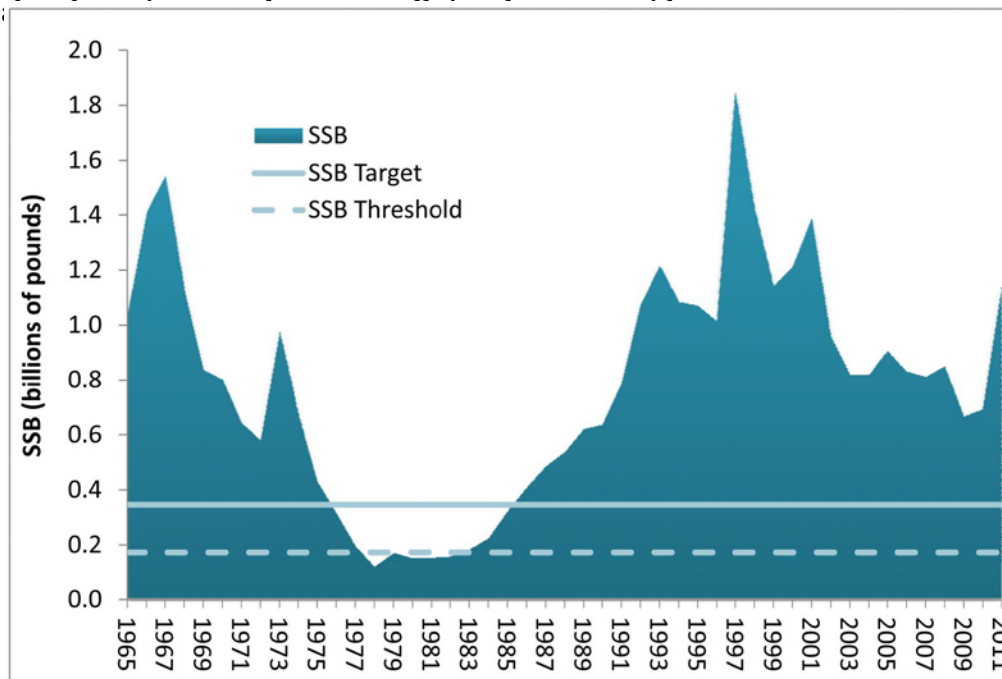
**Figure 1.** Estimated diet from Gulf of Maine, Georges Bank, and Southern New England combined for **a )** Spiny dogfish, **b)** Atlantic cod, **c)** silver hake; NEFSC diet database 1973-2012.



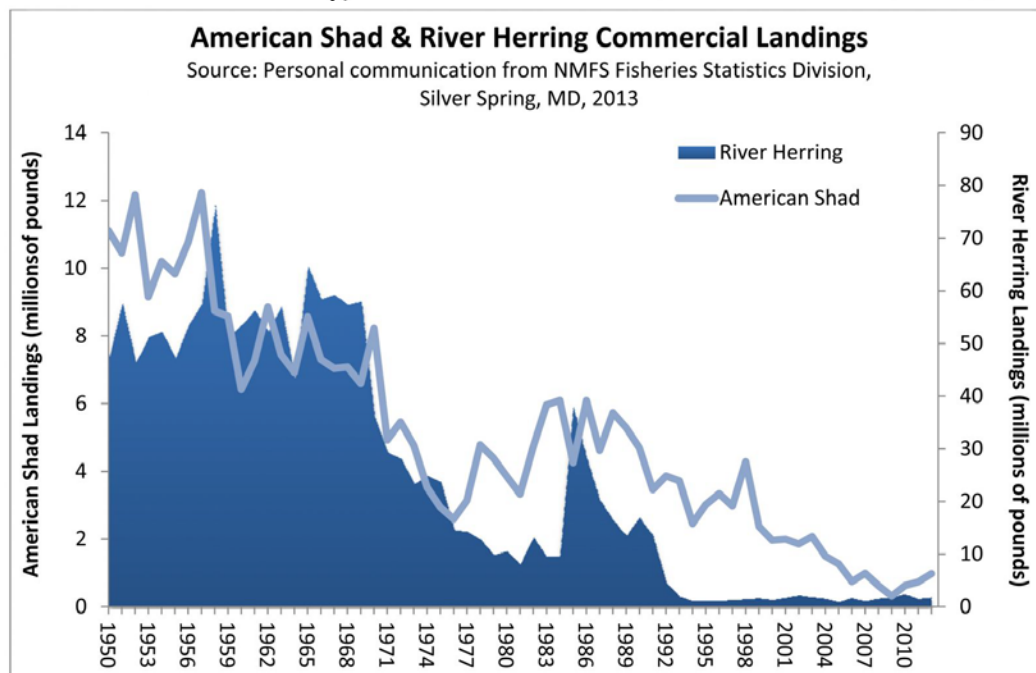
**Figure 2.** Consumption estimates of Atlantic herring, 2012 benchmark stock assessment.

The past and present abundance of NEFMC managed forage species and other important forage species in the region can be partially reconstructed from stock assessments (Fig 3). However, methods applied differ across stock assessments, and not all assessments have been accepted for use in management (e.g., Atlantic mackerel, squids) so those assessments are not included here.

Managed forage abundance trends are mixed. Atlantic herring are abundant at present after recovering from low levels in the late 1970s, while American shad and river herring



**Atlantic Herring Spawning Stock Biomass (SSB).** Source: 54th Northeast Regional Stock Assessment Workshop, 2012



**Figure 3.** Assessment results or landings trends for major forage fish in New England

The Gulf of Maine and Georges Bank food webs have been characterized quantitatively using the information sources listed above and many others (Link et al. 2006, Link et al. 2008). An updated set of food web models for the region is currently in development at NEFSC. Many studies exist in the literature where food web models were used to evaluate the impacts of severe overfishing of forage fish. However, it is rarer to find analyses of more subtle changes in forage management for populations that are not currently overfished, and analyses examining the implications for the ecosystem and predators when some forage species are depleted but others are abundant. Therefore, model analyses more tailored to the New England region and the suites of forage and predator species of varying status would be necessary to evaluate the potential effects of alternative management actions here.

### **Assessing the forage base in the New England region**

A multi-faceted approach is necessary to assess the status of the forage base in aggregate. Simply put, total forage species production is constrained by the amount of primary production in the ecosystem, and total predator demand for forage species is based on consumption rates combined with the total biomass of predators. Predator demand plus fishing removals cannot exceed forage species production in aggregate or forage species biomass will decline. Estimates of primary production can be used to determine the potential forage species production in an ecosystem. Food web models can be used to estimate aggregate predator consumption demand. Food web models can also simulate ecosystem responses to changes in forage fish production, consumption, and/or fishery removals. These models can also be linked to economic models to determine how ecosystem responses alter economic relationships. For example, Fay et al. (2014) recently coupled an economic input/output model, capable of estimating short-term impacts of policy changes, to the Northeast United States Atlantis ecosystem model. Although not estimating economic value, this type of model coupling can provide an understanding of employment, income, and sales impacts the regional economy is likely to face due to changes in fishery management strategies.

A suite of ecosystem indicators can also be developed to monitor and assess the status of the aggregate forage base. Food web and multispecies models can help aggregate time series of abundance for multiple forage fish to estimate aggregate forage biomass. In addition, indices of primary production can be monitored to evaluate the production available for forage species, and condition factor of predatory fish, and reproductive success of seabirds, marine mammals, and other unexploited predators can be monitored to evaluate whether consumption needs are being met. Multiple metrics must be monitored together because any one of these could be driven by something other than forage fish status. Many of these indicators already exist for the New England region and are presented in the Ecosystem Status Report (NEFSC 2011); further development of an aggregate forage base status indicator is ongoing. This development will continue with the input of NEFMC.

## 5. Communities and fleets landing Herring

National Standard 8 (NS8) provides for the sustained participation in fishing of communities and the minimization of adverse economic impacts (16 U.S.C. § 1851(a)(8)). As noted on the MAFMC website: “There is recreational fishing for Atlantic mackerel (for food and bait), but the majority of harvest is commercial for all four species, with bottom and mid-water trawling accounting for most landings. Commercial landings are used in a variety of food and bait markets, both domestically and for export.”<sup>3</sup>

Species from this FMP are landed from Portland, ME to Virginia Beach, VA. The top three ports by landed pounds are North Kingstown/Saunderstown, RI; Cape May, NJ; and Narragansett/Point Judith, RI. These three communities all land over 10 million pounds. The community with next highest level of landings has just under 4 million pounds. In fact, 10 of the top 17 communities by landed pounds (all those with 100,000lbs or more of SMB landings) are in southern New England rather than the Mid-Atlantic. The same three communities are top for value (all over \$8 million, with the next highest value being about \$5 million), though the order changes: Narragansett/Point Judith, RI; North Kingstown/Saunderstown, RI; and Cape May, NJ. Of the 18 communities with landed value of SMB over \$100,000, 11 are in southern New England. Obviously, the more dependent communities are economically on sales of forage fish the more affected they will be by changes in the regulation of those species. However, this must be considered in the broader context of all landings in a port.

**Table 5.** Communities landing over 100,000 lbs and/or \$100,000 of Squid-Mackerel-Butterfish in 2012

Community	Pounds	Community	Value
North Kingstown/Saunderstown, RI	18,972,719	Narragansett/Point Judith, RI	\$10,953,170
Cape May, NJ	18,776,939	North Kingstown/Saunderstown, RI	\$10,495,820
Narragansett/Point Judith, RI	10,288,046	Cape May, NJ	\$8,564,656
Montauk, NY	3,903,965	Montauk, NY	\$4,941,669
Hampton Bays, NY	3,625,168	Hampton Bays, NY	\$3,294,589
New Bedford, MA	3,460,644	New London, CT	\$2,089,494
New London, CT	1,656,386	New Bedford, MA	\$1,506,719
Gloucester, MA	1,477,881	Stonington, CT	\$1,417,898
Stonington, CT	1,357,003	Point Lookout, NY	\$535,135

<sup>3</sup> <http://www.mafmc.org/msb/>



Hampton, VA	682,747	Belford, NJ	\$514,341
Point Lookout, NY	567,555	Woods Hole, MA	\$455,104
Woods Hole, MA	492,742	Point Pleasant, NJ	\$268,772
Belford, NJ	463,610	Gloucester, MA	\$220,924
Point Pleasant, NJ	361,013	Hampton, VA	\$193,469
Fall River, MA	346,158	Newport, RI	\$190,148
Newport, RI	219,726	Sandwich, MA	\$144,237
Sandwich, MA	133,950	East Lyme, CT	\$136,992
		Falmouth, MA	\$111,086

In Narragansett/Point Judith, for instance, SMB landings were the largest of any FMP group. In North Kingston/Sauderstown, RI, SMB landings comprised almost the whole of landings for the community. In Cape May, NJ, on the other hand, while SMB was the second most landed FMP group, it was overwhelmed in both pounds and value by scallop landings. An even more extreme case is New Bedford, MA, where the large scallop landings make the \$1.5 million in SMB landings insignificant at the community level. Details on relative importance of SMB landings for each community can be found in the NEFSC Social Sciences Branch Community Snapshots.<sup>4</sup> However, even where these species are not important at the community level, they are important at the target fleet and individual vessel level and managers are responsible for analyzing impacts to both “participants in the fisheries and fishing communities affected by the plan or amendment” under 16 U.S.C. § 1853 (a)(9)(A) of the MSA. Communities with processors that handle SMB species have another level of involvement, and the NS8 Guidelines make it clear they must be taken into account when they stress the importance of considering “harvesting, processing, and fishery-support industries” (50 CFR § 600.345). Making tradeoffs requires knowledge and a clear understanding of all these levels of impacts.

## 6. Background on forage species management

Globally, there is a clear increase in the sensitivity of managers to the need for ecosystem-based approaches to fisheries management, with forage species and fisheries playing a prominent role (e.g., Smith et al. 2011). Current US fishery management legislation defines optimum yield from a fishery as that which will “provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems.” Given the multiple ecosystem services

<sup>4</sup> <http://www.nefsc.noaa.gov/read/socialsci/communitySnapshots.php>

provided by forage species, a fuller consideration of economic and ecosystem tradeoffs, as well as forage species life history and societal preferences, is likely required to meet objectives for all managed and protected species within an ecosystem, as well as humans.

US Fishery Management Councils must include measures in FMPs to conserve both target and non-target species and habitats, considering ecological factors that affect fishery populations (16 U.S.C. 1853 § (c)(12)). The National Standard Guidelines Final Rule for NS1 recognize the special status of forage fishes and the need for precaution, stating, “In addition, consideration should be given to managing forage stocks for higher biomass than  $B_{msy}$  to enhance and protect the marine ecosystem.” ((50 C.F.R. § 600.310)). There are several forage species management approaches that have been proposed generally, and others which have been applied in other US regions which may be relevant to Mid-Atlantic forage species management. These approaches differentiate forage species which are already exploited by fisheries from those that are not subject to directed fishing (“non-target” species).

Exploited forage fishes generally are managed in an approach similar to other fish stocks, with a degree of precaution added in recent decades to acknowledge their key role in ecosystems. Quota-based, single-species management, based on age-structured assessment models and  $F_{msy}$ ,  $B_{msy}$  reference points (or proxies) are the typical management approach (Barange et al. 2009). The Lenfest Task Force (Pikitch et al. 2012) proposed reference points that are scaled to level of confidence in scientific knowledge and assessment reliability, with lowest  $F$  and highest  $B$  reference points associated with stocks that are the most data-poor. Summary recommendations for forage fish management indicate that  $F < M$ , probably considerably less, and  $F < F_{msy}$  should be adopted as reference points for forage fisheries while maintaining  $B$  well above the 40-50%  $B_0$  that is conventionally specified as  $B_{msy}$ . In a few well-assessed forage stocks, minimum biomass thresholds have been used as reference points to terminate fishing to protect these stocks when recruitment conditions are likely poor, the population is low, and maintenance of predator productivity is threatened (e.g., Barents Sea capelin, California sardine).

The recommendations for appropriate  $F$  and  $B$  reference levels in targeted forage fisheries, even when precautionary, typically do not directly consider predator demand and its inter-annual variability. It has been proposed that  $F$  in forage fisheries should scale to predator demand (e.g., Collie and Gislason 2001) since  $M_2$  (predation mortality) varies substantially from year to year, scaling to predator abundances. In this approach, if total mortality is held constant, then  $F$  will vary inversely with  $M$ , rising when predator demand is low and falling when predator demand is high. Annual landings also are likely to vary substantially under this management approach, which may be undesirable from an economic, and more broadly social, standpoint.

All of these augmented targets induce costs as well as benefits, and assessing both sides of the equation is paramount in making sound policy decisions. Ultimately, the appropriateness of any target will depend on the management objectives, and will vary with the species under consideration. Setting aside scientific uncertainty regarding estimating the appropriate stock levels, the ability of precautionary management to translate additional biomass into realized management goals ultimately depends on the exact role each forage fish species plays in the environment. For example, enhancing productivity of specialist predators through enhanced availability of preferred prey is likely a more attainable goal than enhancing the productivity of an opportunistic predator by enhancing the availability of a sub-set of forage species they predate on. This is particularly true given that, as defined, the four forage fish under MAFMC management make up a small fraction of the total forage assemblage of importance to the NEUS LME, both in terms of diet frequency and total species number (see table 5).

Moratoria on development of new forage species fisheries have been proposed or enacted throughout the US. In U.S. waters of the North Pacific and Bering Sea, fisheries on many forage species are not allowed by the North Pacific Fishery Management Council (NPFMC). Considering unfished and unmanaged forage fishes, the Pacific Fishery Management Council (PFMC) and its Ecosystem Workgroup have developed policy on a diverse assemblage of unfished forage species, with an eye to their conservation and insurance that they are not targets for new fisheries without rigorous assessment, evaluation, and deliberation by the Council (PFMC 2014). Targeted forage species already are included in the PFMC Coastal Pelagic Species FMP (sardine, anchovy, jack mackerel), which also includes krill as a prohibited species. The PFMC's Ecosystem Workgroup has proposed to include a complex of unfished forage species in each of its four FMPs as Ecosystem Component species, recognizing their value as forage for managed, targeted species and as a caution against uncontrolled development of fisheries on a diverse group of poorly known pelagic and mesopelagic species.

In the New England region the Atlantic herring and Atlantic menhaden are by definition typical forage species, and their fisheries are managed with designated ABCs and effort controls based on biomass and fishing mortality reference points commonly applied in single-species management. At present, Atlantic herring has good status relative to these reference points. Other forage species like the sand lance are not currently fished or managed, but do play a role in supporting production of managed fish and other predators in the ecosystem. In the next section, we describe potential alternative management measures for currently fished and unfished New England forage species.

## **7. Potential alternative management measures for New England forage species**

As in other regions, the two broad categories of forage species categories recognized in the EEZ of the NEFMC management region include 1) the targeted, managed species (Atlantic herring) and 2) unfished and unmanaged forage species (Table 2). The second broad category of forage species in the NEFMC's region includes numerous small and abundant fish (and some large invertebrates such as krill and benthic invertebrates) that are not targeted by fisheries. Some occur as bycatches in managed NEFMC fisheries but many are unfished. Alternatives for both currently targeted and unfished/unmanaged species are described below.

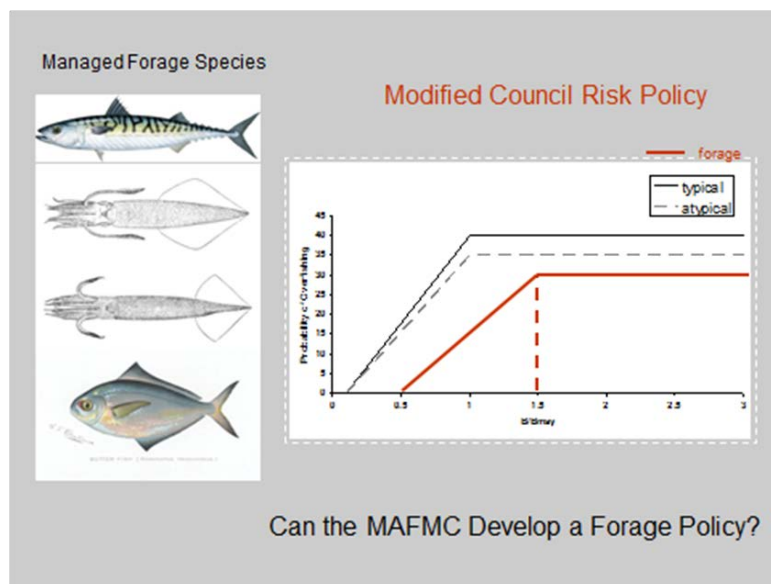
### **Targeted, Currently Managed Forage Species**

Atlantic herring, the managed NEFMC forage species is not currently overfished or subject to overfishing according to the most recent benchmark assessment. The first step in developing appropriate forage fish policies is setting management goals and objectives. Three broad goals have been discussed in this white paper: 1) system stability, 2) enhancing predator productivity, and 3) sustaining fishing communities. A number of objectives have been suggested to help reach these goals including a more precautionary approach in accounting for scientific uncertainty and maintaining managed stock biomass above  $B_{msy}$ . The most appropriate objective for attaining each of these goals will depend on the exact nature of the goals, and the species of interest. However, in what follows a number of tools by which these objectives could be met are detailed, to provide a sense of the range of options available.

Maintaining forage stocks at levels above  $B_{msy}$  can be considered under the NS1 Guidelines but is not mandatory. Several approaches are available to the Council if the primary objective is to maintain fished forage species at levels above  $B_{msy}$ . The first approach would be to maintain the current basis for biological reference points (i.e.,  $F_{msy}$ ) and modify the Council risk policy by lowering the probability of overfishing ( $P^*$ ) when selecting the appropriate ABC level for species categorized as forage species (For example, a possible modification to MAFMC risk policy is shown in Fig 4). Another approach to maintaining forage stocks above  $B_{msy}$  would be to adopt fishing mortality rate limits defining the overfishing limit (OFL) which are lower than the  $F_{msy}$  standard defined in MSA. Yet another option would be to scale the level of risk of overfishing based on whether  $M$  assumed in the stock assessment is scaled to predator abundance (demand). For example, if  $M_2$  is well estimated and its time series reflects consumptive removals by predators, then the Council might maintain the current tolerance for risk when specifying ABC. However, if  $M_2$  is not estimated explicitly in the assessment model through time, then the Council might reduce its tolerance for risk by invoking the atypical penalty (i.e., maximum  $P^*$  would be 35% and ramp down linearly as stock size falls below  $B_{msy}$ ; Fig 5).

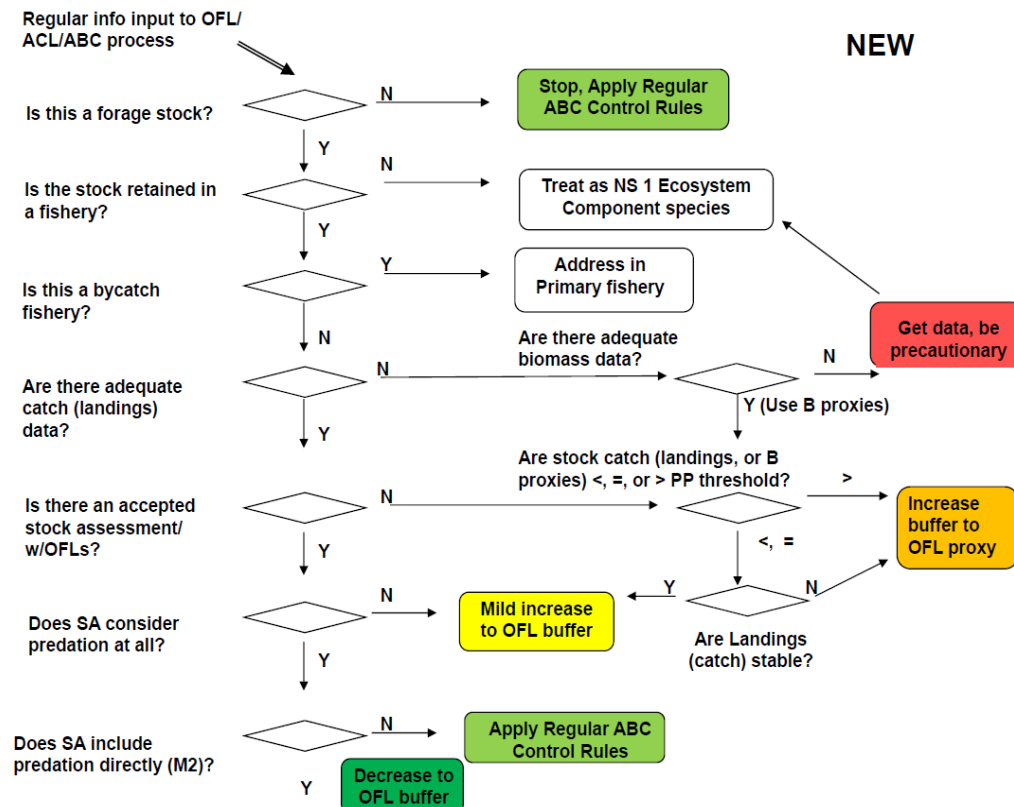
Improving habitat for key life stages of some forage species to increase their productivity also has a role in management. For example, the NEFMC should be supportive of efforts to remove dams on coastal rivers to improve spawning success and abundance levels of Alosines (river herrings and shads). Spatial management and temporal closures also have roles in forage fish management, for example to reduce their bycatches at times and in areas where they (or their predators) are particularly vulnerable. Alternatively, seasonal closures could be used to help ensure the availability of preferred prey to specific predators at the most appropriate time. An example already postulated would be seasonal cephalopod fishery closures to enhance prey availability to inshore summer flounder.

Regardless of the approach chosen the Council must be mindful of the difference between accounting for scientific uncertainty, natural stock size variability, and provision of ecosystem services to NEFMC (Georges Bank EPU regardless of management authority?) managed species when setting ABCs for fished forage species versus adopting more conservative reference points (i.e., to maintain forage stocks at levels higher than the MSA standard of  $B_{msy}$ ). The Council should include a thorough evaluation of this issue and the social and economic tradeoffs between alternative levels of forage fish harvest and risks to predator production. In addition, the utility of management strategy evaluation to determine the appropriate target biomass levels for forage stocks should be explored, and each species should be assessed individually to help ensure net benefits to society are maximized.



**Figure 4.** Conceptual illustration of a control rule with recommended buffers for targeted forage species in a managed fishery. In this version (one of a nearly infinite set of possibilities), substantial buffers to  $F$  and  $B$  are indicated as a precaution to conserve biomass and the benefits the forage species provides as prey for marine predators. In this illustration, there is a reduction in the acceptable probability of overfishing at any stock size, and instead of

requiring sequentially lower probabilities of overfishing below  $B_{msy}$ , the required probability begins decreasing at 150% of  $B_{msy}$ , which is more precautionary than the current risk policy.



**Figure 5.** Forage management process proposed by MAFMC SSC (2012).

## Unfished and Unmanaged Forage Species in the New England Region

Small, mostly planktivorous fishes includes some of the most abundant fishes in the New England region (Table 3). Some of these fishes occur predominantly in the estuaries, coastal embayments, and three-mile zone, for example bay anchovy and Atlantic silverside. 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. Sand

lance, while not fished much historically in the western Atlantic, has had large catches in the Eastern Atlantic and might be targeted.

Several options are available to the Council regarding currently unfished and unmanaged species:

1. The Council could monitor abundance of these species in surveys to assess the adequacy of the aggregate forage base, but would not recommend or implement any management actions unless major changes in abundance occurred. Landings and discards would be tracked but would not be used in prioritizing resources.
2. These species could be considered for assignment as Ecosystem Component (EC) species in NEFMC FMPs. Following NS1 guidance (50 CFR 600.310(d)(5)), some of the unmanaged, unfished forage species, or the complex of species, could be declared Ecosystem Component species in NEFMC FMPs where these species are important as prey for managed species or possibly occur as bycatch in the managed fishery. EC species in this case would not be included as managed species in the FMPs, but their abundances and their habitats would be monitored as part of the Council's management considerations for the FMP. The Council could be prepared to act to reduce ACTs in FMPs (increase the buffer) in response to declines in the forage species complex or key species in that complex. A version of this alternative is now being proposed by the PFMC (PFMC 2014).
3. Regulations could prohibit directed fishing on non-target forage species until adequate scientific information is available to ensure sustainability of the species itself, its predators, and existing fisheries. This means a fishery could be developed, but it would formalize and scrutinize processes leading to development and implementation of the fishery, including need for assessments, determination of effects on existing fisheries and FMPs, agreements, FMP development, etc. Moratoria could highlight the important role of these species in supporting the ecosystem and protect them from fishing. The NPFMC has taken this approach for several forage species and the PFMC has taken the moratorium approach for krill (which is included as an off-limits species in the PFMC's Coastal Pelagic Species FMP).

Whether introduced via the EFP process, or via the notification process at 50 CFR 600.747, the Council would view new fisheries as having the potential to affect its conservation and management measures if these fisheries had an effect on: Any Council-managed species; species that are the prey of any: Council-managed species, marine mammal species, seabird species, sea turtle species, or other ESA-listed species; habitat that is identified as EFH or otherwise protected within one of the Council's FMPs; critical habitat identified or protected under the ESA; habitat managed or protected by state or tribal fishery or habitat management

programs; species that are subject to state or tribal management within 0-3 miles; and species that migrate beyond the U.S. EEZ.



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## Appendix A

### Unfished and Unmanaged Species: Brief Synopsis

The unmanaged forage fishes in the New England region are not targeted by fisheries nor are they presently of special concern as bycatch species. While not likely in the near future, it is conceivable that some of these species could be targeted by fisheries. It also is possible that some of these species could increase in bycatches. Ongoing climate change may result in increased abundance and availability in the Mid-Atlantic of some southern species, for example thread herring and Spanish sardine. Such shifts in distribution are also likely to involve shifting distributions of predators and changes in food web structure. All of the unmanaged forage species in Table 3, while common, are data-poor with respect to knowledge of abundances, spatial- temporal distributions, and population biology.

A brief synopsis of each of the unfished and unmanaged species is provided here.

**Bay Anchovy:** Bay anchovy may be the most abundant coastal fish in the western North Atlantic Ocean (Houde and Zastrow 1991). It is common in estuaries, coastal embayments and on the nearshore continental shelf (Able and Fahay 2010) where it is important prey of piscivorous fishes, e.g., bluefish, striped bass, weakfish, and also seabirds. Bay anchovy is a short-lived, highly productive species, seldom reaching 100 mm in length and uncommonly living to two years of age (Newberger and Houde 1995; Jung and Houde 2004).

**Striped anchovy:** Striped anchovy is frequently sampled in surveys on the inner continental shelf and in estuaries in the western North Atlantic from Chesapeake Bay through the Gulf of Mexico. It can be found in the same habitats as bay anchovy, but occurs more frequently on the shelf than in estuaries. Striped anchovy grows to > 150 mm in length (Bigelow and Schroeder 1953; Able and Fahay 2010). It is larger but less abundant than bay anchovy and presumably serves as prey for the same predators in the Mid-Atlantic region. Although common, relatively little has been published on the biology of silver anchovy.

**Silver anchovy:** The silver anchovy is less common than the bay or striped anchovy, and except for taxonomic studies is poorly known. It is primarily an ocean species found on the continental shelf from New England to the Gulf of Mexico in the western North Atlantic (Able and Fahay 2010). It closely resembles, and may be conspecific with, the European anchovy *Engraulis encrasicolus* (Silva, G. et al. 2014). Maximum length is reported to be 155 mm.

**Round herring:** Round herring occurs in coastal seas and upwelling areas in all of the world's oceans. It is common to abundant in the western North Atlantic from New England to the Gulf of Mexico in shelf waters 50-150 m in depth (Encyclopedia of Life,



<http://eol.org/pages/205036/overview>). It occurs as both targeted and incidental catches in fisheries in many seas, but is not fished in North America. Round herring is abundant in the eastern

Gulf of Mexico where its estimated biomass may exceed 500,000 tons (Houde 1977). Its maximum length is ~350 mm.

**Atlantic thread herring:** The Atlantic thread herring is a tropical species that occurs in embayments and on the continental shelf from the Gulf of Maine and throughout the Gulf of Mexico. Based on egg and larvae catches, it may be increasing in abundance in the Mid-Atlantic region (Able and Fahay 2010), possibly an indication of response to climate change. The thread herring supports small, directed bait fisheries in the South Atlantic and in the Gulf of Mexico, with mean reported annual landings of 524 metric tons in the 2008-2012 timeframe. Maximum reported length is 380 mm but most specimens are much smaller. In Florida waters, thread herring is an important prey of piscivorous fishes, including king mackerel and bluefish, and also marine mammals and birds

([http://myfwc.com/media/194720/atlantic\\_thread\\_herring.pdf](http://myfwc.com/media/194720/atlantic_thread_herring.pdf))

**Spanish sardine:** Spanish sardine is an abundant tropical and subtropical sardine found in both the eastern and western Atlantic Ocean. It supports major fisheries in the eastern Atlantic. Spanish sardine occurs from Cape Cod to Argentina in the western Atlantic. It is found in shallow coastal waters and seaward to depths of 350 m

(<http://www.fishbase.org/summary/Sardinella-aurita.html>). Maximum length is 310 mm. In the United States, Spanish sardine supports small directed fisheries in the South Atlantic and Gulf of Mexico, with mean annual landings of 596 metric tons from 2008-2012, but there are no reported landings in the Mid-Atlantic region. In Florida waters, Spanish sardine is prey of tunas, bluefish, dolphin fish, and the king and Spanish mackerels region

([http://myfwc.com/media/195536/spanish\\_sardine.pdf](http://myfwc.com/media/195536/spanish_sardine.pdf)).

**Sand lance:** Two species of sand lance (or sand eel) are common from New England through the Mid-Atlantic region. The *Ammodytes americanus* is generally found closer to the coast while the

*A. dubius* is common on the shelf and in Canadian waters. These fishes, which burrow into sandy habitat, can form large feeding aggregations in the water column where it is prey for many piscivorous fishes and birds (Bigelow and Schroeder 1953). Maximum length of the sand lances is about 300 mm. Historically, there were small bait fisheries for sand eels (= sand lance) in New England. Major reduction fisheries on *Ammodytes* spp. in Europe developed after WWII. From 1994-2003, average annual landings of *A. marinus* were 880,000 tons from the North Sea, resulting in depletion of the sand lance and related declines in predatory seabird populations that fed on sand lance (<http://jncc.defra.gov.uk/page-5407>). Remarkable increases in abundance of sand lance in the northwest Atlantic during the 1970s is attributed by many

to the depletion and collapse of Atlantic herring under heavy fishing pressure (Sherman et al. 1981; Nelson and Ross 1991), which reduced competition and increased availability of plankton prey for sand eels. The possibility of directed fisheries on sand eels should not be ruled out in the western Atlantic.

***Atlantic silverside:*** This small fish is found along the coast of N. American from Canada to Florida and is one of the most abundant fishes in the Middle Atlantic Bight. Maximum size is at least 175 mm. It is most common in estuaries and embayments and also occurs along ocean beaches. In

the winter, it may migrate offshore to overwinter on the continental shelf (Able and Fahay 2010). It is a common prey of striped bass and bluefish (Bigelow and Schroeder 1953), and also other predator fishes and birds.

## **Appendix B**

### **Data sources for characterizing New England forage base**

Sources of information for identifying key forage species varied by predator group. For fish, an extensive food habits collection from coastwide trawl surveys (Link and Almeida 2000, Smith and Link 2010) was used to determine which prey items were most commonly eaten across all fish species captured in the New England region between 1973-2012. Quantitative data are less available for the other groups; key forage species were determined using literature sources for coastal sharks and other highly migratory fish (Stillwell and Kohler 1982, 1985, Gelsleichter et al. 1999, Chase 2002, MacNiel et al. 2005, Ellis and Musick 2006, Wood et al. 2007), Endangered Species Act (ESA) listed fish, marine mammals (Overholtz and Waring 1991, Gannon and Waples 2004, Gavrilchuk et al. 2014, Smith et al. in press), sea turtles (Shoop and Kenney 1992, Burke et al. 1993, Burke et al. 1994, McClellan and Read 2007, Seney and Musick 2007), and seabirds (Powers 1983, Powers and Backus 1987, Powers and Brown 1987, Schneider and Heinemann 1996, Barrett et al. 2007, Overholtz and Link 2007, Bowser et al. 2013). Key forage species for each predator group and/or habitat type are summarized in Table 2.

Over 158,000 fish stomachs have been collected at 59,000 locations in the Mid-Atlantic continental shelf region between 1973 and 2012. Overall, arthropods (crabs, shrimps, amphipods, and smaller zooplankton) are the most common prey for fish represented in the NEFSC food habits database in this region, found in 54% of all stomachs. (This contrasts with analyses done for the entire northeast shelf, where fish were more common prey than invertebrates (Smith and Link 2010)). Fish of all types were found in 21% of stomachs in the mid-Atlantic region. Of fish which could be identified in stomachs, anchovies, hakes, sand lance, and herrings were most commonly encountered. Mollusks were found in 10% of stomachs, with squids (including Longfin sp.) and octopus most commonly found, followed by bivalves. Annelid worms (bristleworms) were found in 9% of stomachs, and ctenophores (sea grapes) were found in 1% of stomachs. All other prey were present in less than 1% of collected stomachs.

Less quantitative data are available for coastal and pelagic sharks and other highly migratory species. However, a literature review shows that several MAFMC managed species are important prey for these predators. Large coastal sharks in the mid-Atlantic region have been found to prey mainly on fish, including bluefish and summer flounder, as well as other elasmobranchs, with crabs also important prey for juveniles (Gelsleichter et al. 1999, Ellis and Musick 2006). Large pelagic predators, including sharks, billfish, and tunas, rely on squids (including *Illex* sp) for a large proportion of their diet (Logan et al. 2013, Staudinger et al. 2013), and on pelagic fish such as mackerel, butterfish, bluefish, and hakes (Stillwell and Kohler 1982, 1985, Chase 2002, MacNiel et al. 2005, Wood et al.

2007). Juvenile bluefin tuna feeding in the mid-Atlantic consumed a high proportion of sand lance (Logan et al. 2010).

Protected species foraging in the New England region include marine mammals, sea turtles, and seabirds, as well as fish species listed under the ESA. ESA listed fish species relevant to the mid- Atlantic continental shelf include the Atlantic sturgeon, and possibly the shortnose sturgeon. These species eat invertebrates buried in sediments; while mollusks are commonly reported prey of sturgeons, in the mid-Atlantic they were found to prey on primarily polychaete worms, isopods and crangon shrimp (Johnson et al. 1997, Savoy 2007).

Marine mammals include at least three basic categories of foragers: baleen whales, toothed whales/dolphins, and pinnipeds. While data specific to the mid-Atlantic for this group of predators is sparse, a recent study estimated consumption of prey by marine mammals for the entire northeast US continental shelf (Smith et al. in press); we summarize that information here. Baleen whales mainly consume krill (over 40% of shelfwide diet), followed by fish in the herring family and other zooplankton (13-14% of diet each). Sand lance, mackerel, and other large fish each comprised <10% of diet. In contrast, toothed whales and dolphins consumed primarily squids (36% of diet) followed by mackerels (18%), miscellaneous fish (16%), and hakes (11%). Herrings and mesopelagics comprised <10% of toothed whale diet each. Pinniped diets favored miscellaneous fish (26%), sand lance (23%), hakes (16%), flatfish (14%) and herrings (11%); squids and large gadids were <10% each of consumed prey. Smith et al. (in press) found that total consumption by marine mammals is on the same scale as fisheries landings on the northeast US shelf for all fished forage groups except squids—marine mammals are estimated to consume more than twice the amount of squid that is landed. We note that much of the recent diet information for marine mammals is collected from stranded animals and animals incidentally captured in fisheries. Stranded animals may be sick or injured and not feeding normally. Incidentally captured animals often contain the same species targeted by the fishery (e.g., squids, mackerel) so they may have been captured during typical feeding or may have been attracted to the fishing operation to scavenge from fishing gear. While it is difficult to quantify how often marine mammals purposely feed from fishing operations, there are some observations of this behavior (e.g., Waring et al. 1990).

Sea turtles feed primarily on invertebrates. Loggerhead and Kemp's Ridley turtles consume mainly crabs (Shoop and Kenney 1992, Burke et al. 1994), although there was also evidence of fish consumption in one study, perhaps from fish already captured in fishing gear (Seney and Musick 2007). In contrast, leather back turtles feed almost entirely on gelatinous prey, including ctenophores and jellyfish (Dodge et al. 2011). Loggerhead turtles are most commonly sighted in the mid-Atlantic region (Shoop and Kenney 1992), so we emphasize their prey for ranking in Table 2.

Most studies of seabird diet on the Northeast shelf have focused on pelagic seabirds in the Georges Bank region, which has historically had the highest density of foraging seabirds in summer (Powers and Backus 1987, Powers and Brown 1987), but some information is available to suggest which species may be most important in the Mid-Atlantic (Powers 1983). The important forage species for seabirds in a given area depend both on the availability of food within the region, which is in turn driven by oceanographic conditions, and by the mix of seabird species foraging in each habitat, which changes seasonally (Table 1; (Powers 1983, Powers and Brown 1987, Schneider and Heinemann 1996)). For example, Northern gannets are reported to prey on different fish depending on oceanic regime and area: capelin off Canadian breeding colonies in cooler years, mackerel and saury in warmer water conditions off Canada, and menhaden in the Gulf of Mexico during winter (Montevecchi et al. 2012). On Georges Bank, fish, especially sand lance and saury, were the most important forage species for seabirds, with observations of butterfish and silver hake being taken as well. Squids (*Illex*) were next in importance, followed by large zooplankton (euphausiids and copepods; Powers and Backus (1987)). This ranking for Georges Bank is based on the relative dominance of greater shearwaters and northern fulmars in that region. Coastal birds have extremely varied diets which include both fish and crustaceans, and Mid-Atlantic estuaries and coastal bays provide critical foraging habitat for migratory shorebirds and waterfowl (Erwin 1996). In high salinity habitats, menhaden are locally important forage for osprey (Erwin 1996, Glass and Watts 2009), pelicans, and cormorants.