Managing Forage Fishes in the Mid-Atlantic Region
A White Paper to Inform the
Mid-Atlantic Fishery Management Council
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Introduction

The Mid-Atlantic Fishery Management Council (Council) has identified forage fishes and their management as key elements in a Guidance Document to support Ecosystem Approaches to Fisheries Management (EAFM). Maintaining an adequate forage base to support feeding and production of economically valuable predator fishes has become a high priority for fisheries management in the past two decades. This white paper provides information on forage fishes and recommendations on management approaches that the Council can consider to insure sustainable fisheries on both the forage species and their predators while maintaining a healthy and productive ecosystem. The paper supports the four tasks being addressed in the Council's EAFM Guidance Document now under development:

- Finalize forage definition
- Fully develop list of forage species in MA – describe past and present abundance
- Assess current forage base in MAB; define/describe functional groups (in assessing forage base adequacy; develop policy analysis in support of potential prohibition of new forage/LTL fisheries)
- Develop options for ABC control rule protocol and risk policy modifications.

The Council's EAFM Guidance Document, when completed, is intended to provide overall guidance to the Council with respect to incorporation of ecosystem considerations into its current management programs. Based on this guidance, initial implementation of Council management actions with ecosystem considerations can be implemented consistently within the existing FMP structure. The Guidance Document is being developed to accommodate a transition to EAFM, but is written such that it could ultimately be converted into a regulatory document.

To support its effort to develop EAFM policies and the Guidance Document, the Council is preparing a series of policy *white papers*, which are intended to highlight key ecosystem considerations for focused Council discussion on aspects of EAFM. These white papers will facilitate Council discussion and decision-making while the EAFM Guidance Document is developed. This Forage Fish white paper is intended to serve that purpose.

1. Role of forage fishes in fisheries and marine ecosystems

Forage fishes are predominantly small pelagic species (e.g., <12 inches in length) and thus serve as prey for diverse predators throughout their lives. In healthy ecosystems forage fishes are abundant and often present in large schools or shoals. Fishes commonly included in the forage category are sardines, herrings and anchovies, but many other taxa, including invertebrates such as squids and krill, also are considered forage species. During recent MSA reauthorization discussion 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).

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

Is the stock a "forage" fish? Forage is defined as a species that:

- Is small to moderate in size (average length of ~5-25 cm) throughout its lifespan, especially including adult stages:
- Is subject to extensive predation by other fishes, marine mammals, and birds throughout its lifespan;
- Comprises a considerable portion of the diet of other predators in the ecosystem in which it resides throughout its lifespan (usually >5% diet composition for > 5 yrs.);
- Has or is strongly suspected to have mortality with a major element due to consumptive removals;
- Is typically a lower to mid trophic level (TL) species; itself consumes food usually no higher than TL 2-2.5;
- Has a high number of trophic linkages as predator and prey; serves as an important, major (as measurable by several methods) conduit of energy/biomass flow from lower TL to upper TL;
- Often exhibits notable (pelagic) schooling behavior;
- Often exhibits high variation in inter-annual recruitments; and
- 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 10^{-3} to 10^{-4}

Forage fishes often are low trophic level species that feed primarily on plankton. In this capacity, they serve as conduits for transfer of energy from the lowest trophic levels to high- level predators. Forage fishes and invertebrates (e.g., squids and krill) are key constituents of bird and mammal diets in addition to diets of piscivorous fishes. Fishery scientists and managers 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. 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 fish biomasses to <33% of the forage species' unfished biomass (B_0). In a recent investigation of the trophodynamic signature and effects of forage fishes on the South Atlantic coastal ecosystem, forage fishes were shown to exercise strong control over piscivore productivity based on an ecosystem (Ecopath-Ecosim) modeling approach (Okey et al. 2014). Many of the fish species in the South Atlantic model and analysis also are common in the Mid-Atlantic region.

In most marine ecosystems, a few forage fish species are dominant. Such systems have been described as "wasp-waisted" because a relatively few species of forage fishes, which feed on a diverse plankton community, are themselves fed upon by a moderately diverse assemblage of predators (Cury et al. 2000) that include not only piscivorous fishes but also birds and mammals. This characteristic of ecosystem structure emphasizes the key role of forage fishes in food webs and the need to maintain them at relatively high levels of abundance (Smith et al 2011; Pikitch et al. 2012). For forage species that support targeted fisheries, management actions can control their abundances. Many important forage species are managed as the targets of major fisheries. For example, in the Mid-Atlantic region the Atlantic herring and Atlantic menhaden are by definition typical forage species, and their fisheries are managed with designated ABCs and effort controls commonly applied in single-species management. But, other forage fishes in the region, for example the abundant bay anchovy, while not managed do play a role in supporting production of managed fish and other predators in the ecosystem.

Globally, forage fishes are major contributors to marine fisheries, constituting >35% of annual landings in recent decades. Most of these landings are converted to meal and oil, and used as feeds in livestock and aquaculture industries, or used as bait. 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 landings of targeted forage species, combined for the Mid-Atlantic and New England regions, exceeded 210,000 metric tons in the 2008-2012 period (Table 2).

The dockside value of global forage fish landings was $5.6 Billion in 2009 (Pikitch et al. 2012, 2014). While the landed value of forage fish is high, the global value of the forage fish contribution to the production of predator fishes in marine commercial landings was estimated to be $11.3 Billion (Pikitch et al. 2012, 2014), highlighting the importance of managing these species with a view toward conserving their valuable contribution to consumption and production of managed piscivorous fish. This management strategy may be particularly important in heavily fished ecosystems.

2. Management Consideration for Forage Species

The Councils must include measures in FMPs to conserve both target and non-target species and habitats, considering ecological factors that affect fishery populations (MSA 2006, 109-479, p. 78). Considering unfished and unmanaged forage fishes, the Pacific Fishery Management Council and its Ecosystem Workgroup have initiated actions to develop protocols and plans for including them in the overall Council management portfolio. The initiative recognizes the valuable ecosystem services of forage and the concern that presently unfished species could be targeted for directed fisheries in the future (http://www.pcouncil.org/wp-content/uploads/I1a_ATT1_Eco_Initiative1_forage_APR2014BB.pdf). 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 Mid-Atlantic, fewer taxa of unfished forage species are of concern to the MAFMC, but the initiative and approach adopted by the PFMC bears consideration.

Historically, the abundant shoaling pelagic fishes that include most forage fishes were considered to be relatively insensitive to fishing. Major fluctuations in abundance of these short-lived species were attributed to climate and environmental factors. The Peru anchoveta is a classic example in which the population waxes and wanes in response to El Nino conditions in the Humboldt Current (Barange et al. 2009). Decadal-scale variability in abundance of major forage fisheries 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). In fact, the shoaling behavior of forage fishes increases their vulnerability to fishing in years of low abundance because schools remain easy to locate. As a consequence, catch-per-unit effort may not decline at low stock abundance, leading to a false security about status of such stocks and a high risk of stock collapse (Csirke 1988).

Most forage species are short-lived, with only a few age classes represented in a population. Thus, their abundances fluctuate, sometimes dramatically, in response to environmental variability that controls recruitment success. Fishing such stocks at high levels of exploitation increases the possibility of stock collapse when environmental conditions are unfavorable for reproduction and production of new year classes (Murphy 1967, 1977; Pinsky et al. 2011).

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). In a few well-assessed forage stocks, minimum biomass thresholds have been used as reference points to terminate fishing (e.g., Barents Sea capelin, California sardine). 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. A decision to ban fishing on krill was made by the Pacific Fishery Management Council. Guidelines for National Standard 1 of the MSA (overfishing) 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" (NMFS's National Standards Guidelines 50 C.F.R. 600.310 et seq).

Globally, there is a clear increase in the sensitivity of managers to the need for ecosystem-based approaches to fisheries management, with forage fishes and fisheries playing a prominent role (e.g., Smith et al. 2011). Moratoria on development of new forage species fisheries have been proposed or enacted. In a recent example, the Pacific Fishery Management Council has 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).

The collapse of the Atlantic herring fishery in the Northeast Atlantic in the 1960s and 1970s led to reviews of then current thinking regarding causes of collapse of shoaling pelagic, forage fisheries. The reviews (e.g., Csirke 1988; Beverton 1990; Patterson 1992) concluded that fishing indeed was a factor and that high fishing mortality rates (F) were associated with the collapses. Beverton (1990) and Patterson (1992) proposed that, in managing such fisheries, higher biomass (B) and lower F reference points were appropriate. To avoid collapses, Patterson's (1992) analysis indicated that fishing mortality (F) should not exceed 0.67 natural mortality (M). It is notable that the MAFMC's SSC has adopted this reference level in reaching its ABC recommendations for the butterfish fishery since 2013. Some proposed precautionary reference points for forage fish fisheries are provided in Table 2.

Table 2. Proposed precautionary 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

The several existing analyses and resulting recommendations all indicate that conservative F and B reference points are appropriate to lower the risk of collapse of forage fisheries (Table 2). 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 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}. These precautionary reference points are particularly recommended for data-poor stocks.

The recommendations for appropriate F and B reference levels in targeted forage fisheries, even when precautionary, are derived primarily in the context of conventional, single species management. Such management approaches typically do not directly consider predator demand and its inter-annual variability. Control rules for forage fish management historically have had fixed target and threshold F and B levels, much like those for most managed fish stocks. 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.

3. Forage Species in the Mid-Atlantic Ecosystem(s)

A diverse assemblage of shelf and coastal fishes and squids can be categorized as forage species in the Mid-Atlantic region. Some species and their targeted fisheries are actively managed by the Regional Councils, the Atlantic States Marine Fisheries Commission and the coastal States, but many are unmanaged (Table 3) and not included in FMPs. 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.

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 (Table 3). Taxa in this list are potentially important as forage for one or more of the managed MAFMC 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 in Table 3

Table 3. Forage fishes and squids in 1) managed, targeted fisheries in the Mid-Atlantic region and 2) present but not targeted or managed in the Mid-Atlantic. 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.

Common name	Species	Fished Y/N	Mean Annual Landings (mt) (2008-2012)	Management Authority	Bycatch Important Y/N
Atlantic herring	*Clupea harengus*	Y	82,422.4	NEFMC/ASMFC	Y
Atlantic menhaden	*Brevoortia tyrannus*	Y	210,776.0	ASMFC	N
Atlantic mackerel	*Scomber scombrus*	Y	12,003.2	MAFMC	Y
Butterfish	*Peprilus triacanthus*	Y	244.1	MAFMC	Y
Alewife	*Alosa pseudoharengus*	Y	605.2	ASMFC	Y
Blueback herring	*Alosa aesitvalis*	Y	6.2	ASMFC	Y
Longfin squid	*Doryteuthis pealii*	Y	9,892.0	MAFMC	Y
Illex squid	*Illex illecebrosus*	Y	11,227.5	MAFMC	Y
Bay anchovy	*Anchoa mitchilli*	N			N
Striped anchovy	*Anchoa hepsetus*	N			N
Silver anchovy	*Engraulis eurystole*	N			N
Round herring	*Etrumeus teres*	N			N ?
Thread herring	*Opisthonema oglinum*	Y	0		Y, small
Spanish sardine	*Sardinella aurita*	Y	0		Y, small
Sand lance	*Ammodytes americanus* and *A. dubius*	N	0		N
Atlantic silverside	*Menidia menidia*	Y	6.4		N

Unfished and Unmanaged Species: Brief Synopsis

The unmanaged forage fishes in the Mid-Atlantic 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 or 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)

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).

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 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.

Identification of Forage Fish in the Mid-Atlantic Based on Predator Diets

Forage species in the Mid-Atlantic were identified by looking at 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. Predators are listed in Table 4.

Table 4. Predator species in the Mid-Atlantic 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 Mid-Atlantic region are listed in other categories.

Fish	Marine mammals	Sea Turtles	Seabirds
MAFMC managed Spiny dogfish Summer flounder Monkfish Butterfish Scup Atl. mackerel Bluefish Black sea bass Tilefish	**Baleen Whales** Fin whale Humpback whale Sei whale Minke whale N Atlantic right whale	Loggerhead Leatherback Kemp's ridley	**Pelagic (on shelf unless otherwise indicated)** (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
Other managed Little skate Spotted hake Silver hake Fourspot flounder Windowpane Atlantic herring Winter skate Smooth dogfish Red hake Winter Flounder Weakfish Clearnose skate Ocean pout Blueback herring Yellowtail flounder N. Searobin Witch flounder Rosette skate Spot Atlantic croaker Gulf Stream flounder	**Toothed Whales and Dolphins** Pilot whale White-sided dolphin Common dolphin Bottlenose dolphin Harbor porpoise		

Fish	Marine mammals	Sea Turtles	Seabirds
Sea raven Cusk eel Longhorn sculpin Striped bass American shad			Common tern (spring) Royal tern (summer, fall, nearshore) Razorbill (winter, spring)
Highly Migratory Large coastal sharks Pelagic sharks Billfish Tunas	**Seals** Harbor seal Gray seal		**Coastal** Great cormorant Double-crested cormorant Loons Brown pelican American bittern Great blue-heron Great egret Snowy egret Tricolored heron Little blue heron Green heron Black-crowned Night-heron Common merganser Red-breasted merganser Osprey Black skimmer
ESA listed Atlantic sturgeon Shortnose sturgeon			

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 Mid-Atlantic 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), 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, sandlance, and herrings were most commonly encountered. Mollusks were found in 10% of stomachs, with squids (including Loligo 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 sandlance (Logan et al. 2010).

Protected species foraging in the mid-Atlantic region include marine mammals, sea turtles, and seabirds, as well as fish species listed under the Endangered Species Act (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). Sandlance, 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%), sandlance (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.

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 sandlance 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. While these birds also forage in the Mid-Atlantic, they are less dominant there. Averaged over the course of a year, the dominant seabirds (by abundance) in the Mid-Atlantic are gulls (48%), followed by shearwaters (15%), storm petrels (11%), gannets (10%), and phalaropes (8%) (derived from Powers 1983; Table 3). Based on this ranking, we would expect fish to be even more important seabird forage in the Mid-Atlantic, although the species are not well documented. (Squid and zooplankton (including fish eggs) are also critical prey (Table 2). 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.

Table 5. Ranking of important forage species groups by predator type (highest frequency and/or consumption are first on the list)

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

Food habits information provides a picture of key forage for important mid-Atlantic commercial fish as well. For example, summer flounder diet composition in the mid-Atlantic (Fig 1) 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.

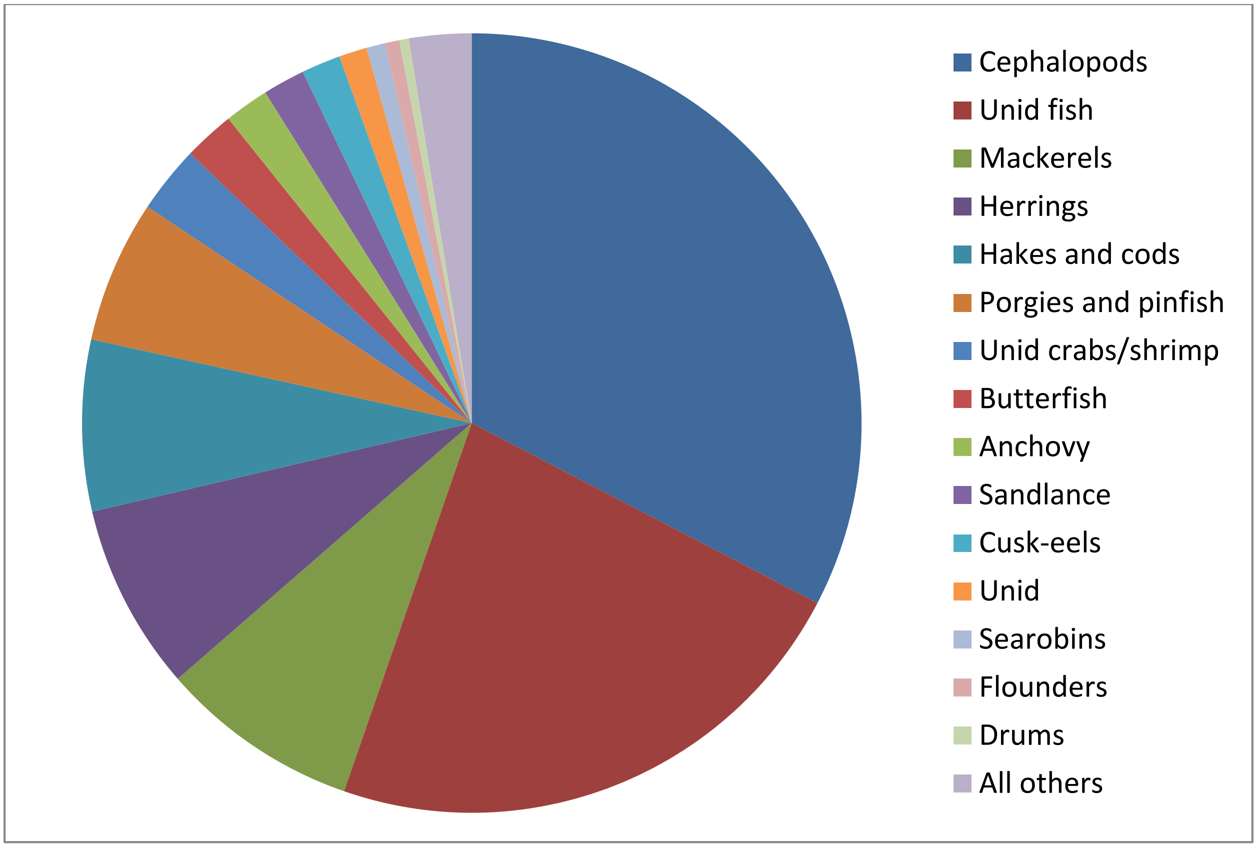

Figure 1. Summer flounder diet in the Mid-Atlantic, NEFSC diet database 1973-2012

Bluefish, another important mid-Atlantic managed predator, has a diet composition more based on fish (Fig 2). For bluefish, cannibalism represents an important part of their diet, estimated at 6%.

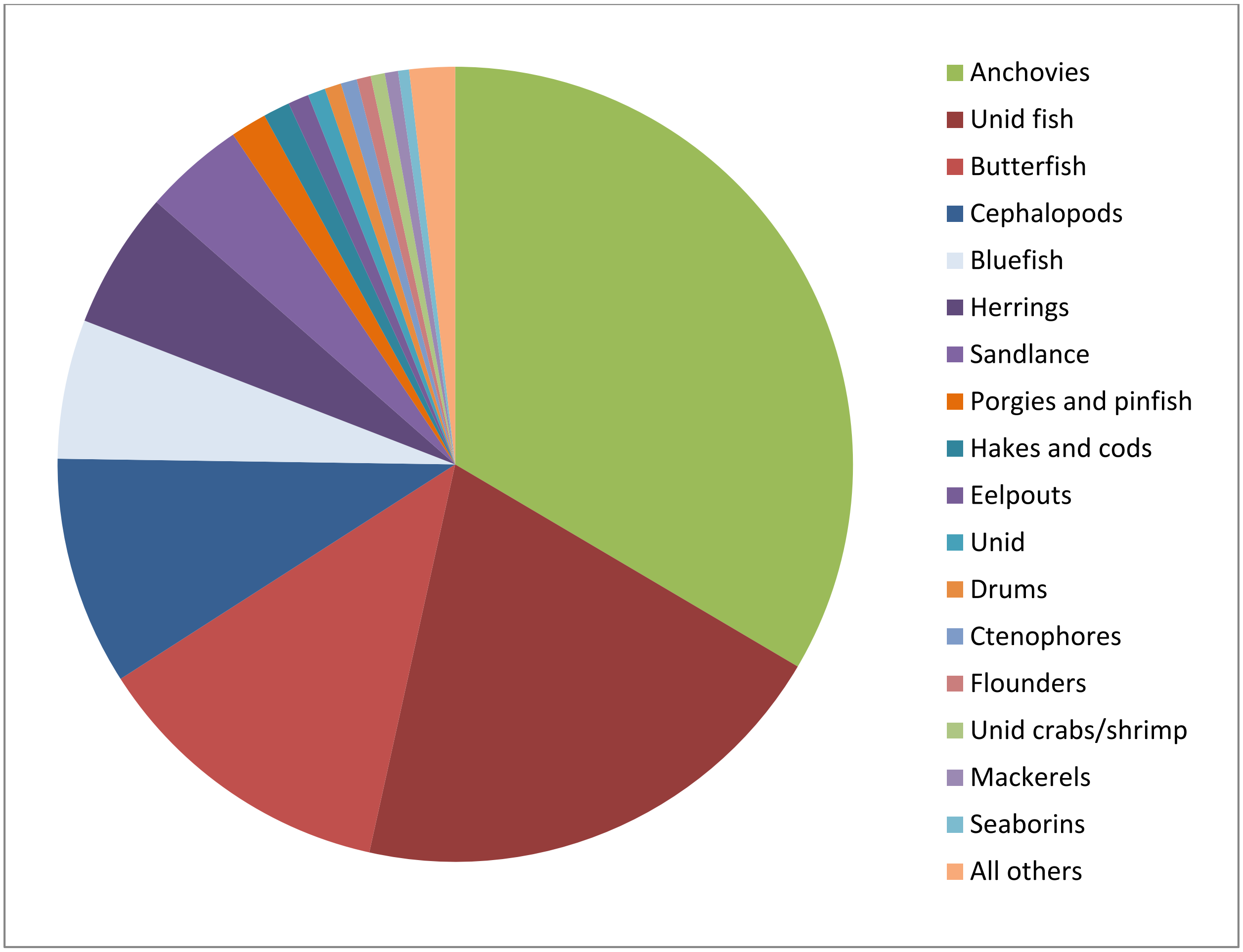

Figure 2. Bluefish diet in the Mid-Atlantic, NEFSC diet database, 1973-2012

Other mid-Atlantic fish predator diets could be provided in more detail to determine which species represent important forage.

A preliminary list of forage species for initial consideration by the MAFMC was developed at the April 2013 Forage Fish Workshop (Table 3). This list is supported by the analyses above. However, in considering the total forage available for various predators in the Mid-Atlantic region, unexploited benthic invertebrates should also be included based on the information summarized in Table 2.

The Mid-Atlantic food web (Fig X) 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 menhaden), as well as demersal piscivores (groundfish and elasmobranchs), and filtering megabenthos (scallops, surf clams, and ocean quahogs). piscivores (groundfish and elasmobranchs), and filtering megabenthos (scallops, surf clams, and ocean quahogs).

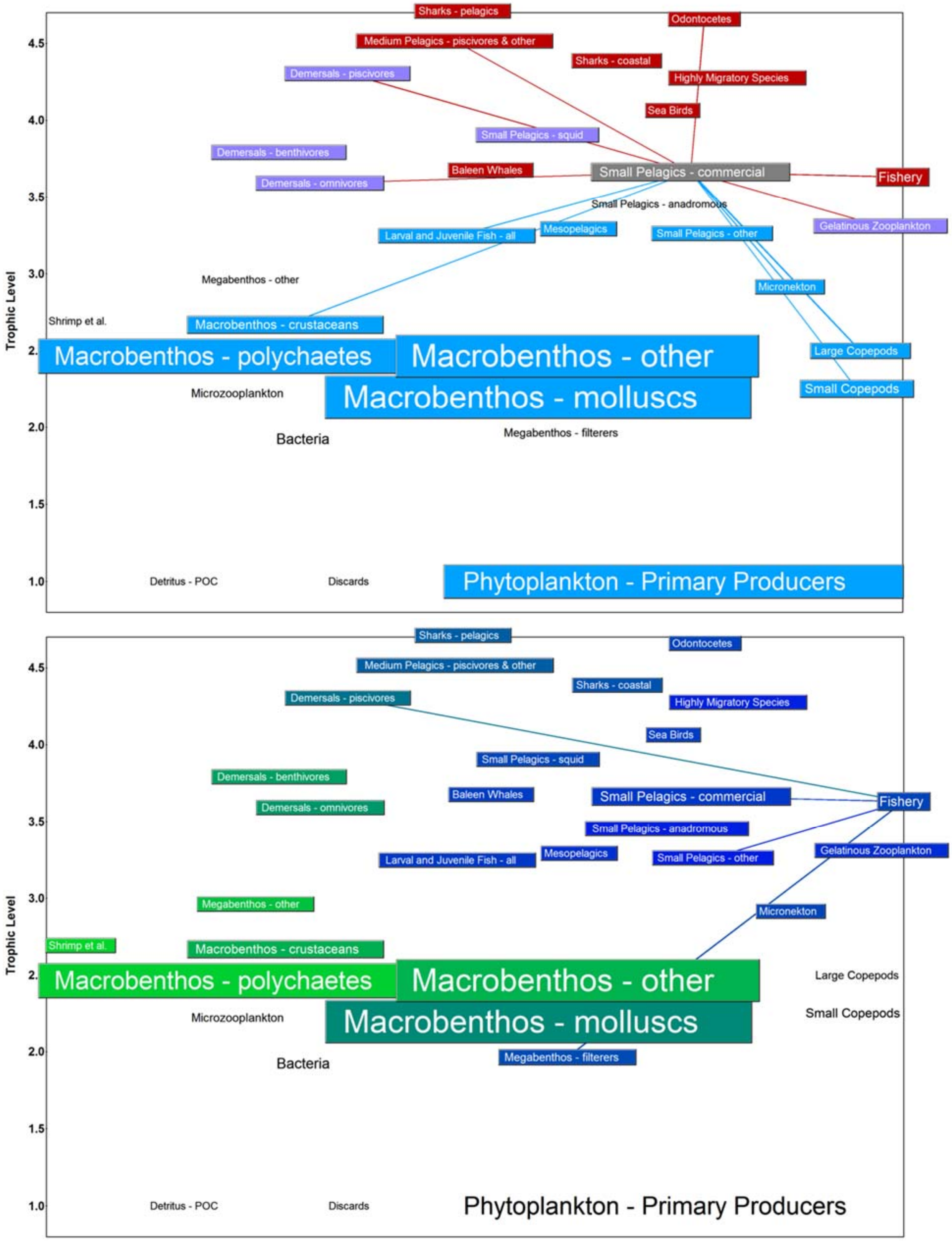

Figure X: Food web model for the Mid-Atlantic region. Top panel: key links to commercial forage fish; bottom panel, key links to fisheries. See text for full description.

4. Management Alternatives for Forage Species in the Mid-Atlantic

The MAFMC and stakeholder groups have expressed strong interest in ecosystem-based approaches to fishery management and, in particular, the development of a policy approach for managing forage fishes (MAFMC 2012). In this regard, the MAFMC and many of its stakeholders hold views similar to those expressed nationally and internationally. There is a desire to conserve and manage forage species for sustainable landings while at the same time conserving their value as prey for a diverse suite of predators in the mid-Atlantic EEZ.

Two broad categories of forage species are recognized in the EEZ of the MAFMC management region (see Table 3). The two categories include 1) the targeted, managed species and 2) unfished and unmanaged forage species. Four species (*Illex* and *Doryteuthis* squids, butterfish, and Atlantic mackerel) are targeted fisheries and have been managed under the Squid-Mackerel-Butterfish FMP since 1983. Atlantic herring occurs in the MAFMC region but is managed by the NEFMC and ASMFC. The second broad category of forage species in the MAFMC's region includes numerous small and abundant fish (and some large invertebrates) that are not targeted by fisheries. Some occur as bycatches in managed MAFMC fisheries but many do not presently occur in fisheries (Tables 3 and 5). These species could be considered for assignment as Ecosystem Component (EC) species in MAFMC FMPs.

There is a growing consensus that optimum yields of forage fisheries should be precautionary and that additional buffers should be considered when deriving Annual Catch Limits (ACLs) and Annual Catch Targets (ACTs) in managed forage fisheries. Recommendations now lean toward reducing F levels substantially below F_{msy} and insuring that biomass levels are maintained near B_{msy} or even higher in data-poor stocks (Table 2). Conceptually, a control rule for forage fisheries could resemble the current risk policy, modified to require lower F or a higher biomass (Figure 4). Alternatives for both currently targeted and unfished/unmanaged species are described below.

Targeted, Fished Forage Species

The MAFMC could adopt a policy to reduce risk in targeted forage fisheries. The MSA National Standard 1 Guidelines urge consideration be given to managing forage stocks for higher biomass than Bmsy to enhance and protect the marine ecosystem. In the MAFMC region, fishing mortality presently is believed to be below F_{msy} for the butterfish and squid stocks and unknown for the mackerel stock. A precautionary policy for these stocks would be to require F levels substantially lower than M and less than F_{msy} to conserve biomass while still supporting viable and sustainable fishing. Another precautionary recommendation for consideration is to set a minimum biomass threshold, below which fishing is not allowed on the forage fishery stocks. Additionally, in deriving ABC, scaling the degree of precaution (buffering) in setting F and B reference levels to the quality of available assessment data (p* approach) is desirable.

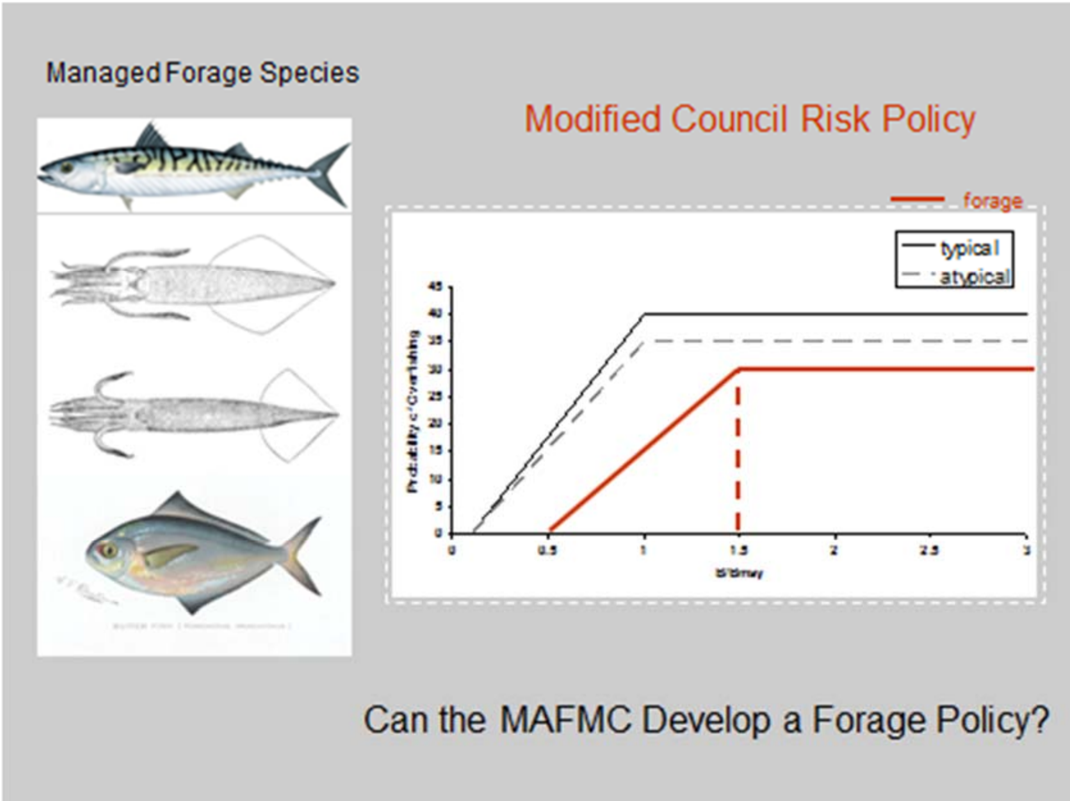

Figure 4. Conceptual illustration of a control rule with recommended buffers for targeted forage species in a managed fishery. In this version (one of a nearly infinite set of possibilities), substantial buffers to F and B are indicated as a precaution to conserve biomass and the benefits the forage 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 Bmsy, the required probability begins decreasing at 150% of Bmsy, which is more precautionary than the current risk policy.

Maintaining forage stocks at levels above B_{msy} is recommended by the NS1 guidelines but is not mandatory. For any managed species, the Council's first obligation is to prevent overfishing as per the NS1 guidelines. Overfishing under MSA has been interpreted to mean fishing at a rate that will jeopardize the ability of the stock to produce maximum yield on a continuing basis (i.e., MSY). Thus, the basis for the overfishing level is F_{msy} or a suitable proxy. In theory, maintaining the exploitation rate at F_{msy} should lead to stock sizes that fluctuate around B_{msy}.

Several approaches are available to the Council to maintain forage species at levels above B_{msy} (as per NS1 advice described above). 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. Maintaining fishing mortality rates well below F_{msy} should result in population biomass levels (on average) that are above B_{msy}. In practice, the Council has adopted overfishing threshold mortality rates for its managed species based on reference fishing mortality rates that correspond to various ratios of spawning stock biomass per recruit (SPR) expressed as the ratio of SSB/R with and without fishing. The actual reference points chosen were based on accepted SPR reference levels published in the literature for species with life histories analogous to the species in question. SPR based reference points were chosen because they directly address the impact of fishing mortality on the reproductive potential of the stock. There may already be some conservatism built into the ABC specification protocol adopted by the Council, depending on how the SPR reference points map relative to MSY based reference points. This type of analysis should be considered when evaluating alternative exploitation strategies for forage stocks based on the existing risk policy during development of the EAFM Guidance Document.

Another approach to maintaining forage stocks above B_{msy} would be to adopt fishing mortality rate limits defining the OFL which are lower than the F_{msy} standard defined in MSA. Candidate reference points that the Council could consider adopting as the basis for OFL for forage stocks are given in Table 2. In this case, the Council could apply the typical risk policy to specify ABC but the OFL estimates would be based on fishing mortality rates significantly lower than F_{msy} and lower than m.

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 m2 is well estimated and it's time series reflects consumptive removals by predators, then the Council might maintain the current tolerance for risk when specifying ABC. However, if m2 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}).

Regardless of the approach chosen the Council must be mindful of the difference between accounting for scientific uncertainty when setting ABCs for 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's EAFM document should include a thorough evaluation and treatment of this issue. In addition, the utility of management strategy evaluation to determine the appropriate target biomass levels for forage stocks should be explored.

Unfished, Unmanaged Forage Species in the Mid-Atlantic Region

A complex of small, mostly planktivorous fishes includes some of the most abundant fishes in the Mid-Atlantic 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).

<u>Alternatives Available to MAFMC</u>

1. No Action.

Under this alternative, the Council could monitor abundance of these species in surveys but would not recommend or implement any management actions unless major changes in abundances occurred. Landings and discards could be tracked but would not be used in prioritizing resources.

2. Ecosystem Component Species.

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 MAFMC 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 Pacific Fishery Management Council (PFMC 2014).

3. Develop a Forage Species Plan

Some of these unmanaged, unfished species might be fished in future so there is a need to consider their role for species other than those in MAFMC FMPs, including birds, turtles, and mammals. 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 very big catches in the Eastern Atlantic and it might be targeted. Water quality concerns for some of the nearshore coastal species, e.g., bay anchovy, silverside, are real 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).

4. Declare Moratoria on New Forage Fisheries

The alternative would anticipate possible new fisheries proposed on forage species and declare moratoria. This does not mean a fishery could not be developed, but it would formalize and scrutinize processes leading to development and implementation, 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 North Pacific Fishery Management Council has taken this approach for several forage species. The Pacific Fishery Management Council 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
Socio-economic considerations for forage fish management

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, herring 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, herring serves as the primary bait for the highly valuable 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. Herring, for instance, 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. 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, 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 and ecological dependence on the forage fish of interest and social and cultural preferences that can affect and occasionally trump direct consumptive values for the resource. 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. The second is the forage fish's role in the economy, in terms of both value and substitutability. 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, when more precautionary biological thresholds are adopted.

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