Atlantic States Marine Fisheries Commission

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MEMORANDUM

TO: Atlantic Menhaden Board

FROM: Atlantic Menhaden Technical Committee

DATE: April 21, 2026

SUBJECT: Menhaden Environmental Literature Review

Board Tasking

At the Commission's 2025 Annual Meeting, the Atlantic Menhaden Board tasked the Technical Committee (TC) with reviewing information from NOAA's Ecosystem Dynamics and Assessment Branch and Chesapeake Bay Office, and the Woods Hole Oceanographic Institution to evaluate the possible effect of cold water on the Continental Shelf on menhaden migration and migratory patterns, particularly in relation to the timing of osprey arrival, nesting, and breeding. The Board also tasked the TC with considering what role water temperature, dissolved oxygen levels, shoreline hardening, and other environmental factors play in the local abundance of menhaden and other forage species in the Chesapeake Bay.

To address this task in a comprehensive, quantitative manner requires a significant amount of time and data. As a first step, the TC conducted a literature review on the key topics identified by the Board. If the Board would like the TC to pursue a more quantitative approach, this literature review can also serve as the basis for that task.

2025 State of the Ecosystem Report

The original impetus for this tasking was NOAA's 2025 State of the Ecosystem Report for the Mid-Atlantic region (Gaichas et al. 2025), which highlighted the fact that water temperatures on the NE shelf were colder than average in 2024 and members of the fishing community reported that some species were outside of the typical fishing grounds and in higher abundance than recent years (ex. Atlantic mackerel), as well as delayed fishing due to multiple species migrating into fishing areas later in the season.

The Northeast US shelf has experienced a long-term warming trend in annual sea surface temperature as well as seasonal surface and bottom temperatures. However, in 2024, surface and bottom temperatures were near normal/cooler than normal in all seasons in the Mid-Atlantic Bight (MAB). Variability in the Gulf Stream contributes significantly to the temperature variation on the Northeast shelf. The Gulf Stream has been less stable and shifting northward in the last decade, moving closer to the Grand Banks, which reduces the amount of cold water from the Labrador current coming onto the shelf. In 2024, the northern extent of the Gulf Stream was further south than in recent years, allowing colder, fresher and less buffered water into the Northwest Atlantic compared to 2020-2023. The cooler water seen in 2024 was linked anecdotally to the delay in migration of some species (longfin squid, black sea bass, haddock) and the redistribution of other species (pollock, bluefin tuna, Atlantic mackerel, longfin squid, bluefish, and bonito observed in unusual locations). Some species were also reported as having higher abundance, such as Atlantic mackerel on the shelf and red drum in the Chesapeake Bay, which saw record high numbers in the Poplar Island survey. However, this cooler water on the shelf did not extend to all parts of the region, with Chesapeake Bay seeing sea surface temperatures above the 2000-2020 average as well as low dissolved oxygen, leading to a less suitable environment for high profile species like striped bass and blue crabs in the Bay. The extent of marine heatwaves was also reduced compared to recent years. Bottom marine heatwaves are defined as warming events with temperature above the 90th percentile of daily climatology that last for 30 or more days. Only the southern MAB had any bottom habitat that exceeded 24°C and that was for less than 30 days.

In addition to the overall warming trend in the MAB, there have also been long term changes to the timing of seasonal changes like the transition from spring to fall and the formation and extent of the Atlantic cold pool. Summer conditions have been lasting longer in the MAB, with the time between the spring and fall transitions increasing over time. Although the transition in 2024 was shorter than 2020-2023, it was still in line with the overall increasing trend in this metric. Changes in transition timing can affect biological processes like migration and spawning for fish species and may also affect the timing of the fall phytoplankton bloom. There is no clear trend in overall primary production, but there has been a decrease in chlorophyll in September and an increase in January compared to the start of the time series, suggesting the fall bloom could be shifting later as warmer water temperatures persist longer. The cold pool in the MAB – the remains of cold winter waters that persist into spring and summer near the bottom – has been getting warmer and smaller as well as lasting for a shorter period. The cold pool represents important spawning and nursery habitat for some species like yellowtail flounder, therefore changes to the extent and persistence of the cold pool can affect their dynamics. However, the cold pool in 2024 was near the long-term average in terms of temperature, extent, and persistence, more similar to 2017-2019 values than other recent years.

In addition to highlighting the physical environment, the Ecosystem Report also noted changes in the zooplankton and forage community over time. Zooplankton in this region have shown a significant increasing trend in diversity over the time-series. Large-bodied copepod biomass has been variable without a significant trend, while small-bodied copepod biomass has shown a declining trend and Euphausiids (e.g., krill) biomass has been increasing. This changing mix of species can affect the forage fish that feed on them, since smaller bodied copepods and krill have lower energy content than larger bodied copepods.

The center of biomass for forage species in the Northwest Atlantic has shifted northward and eastward (i.e., more offshore) for the species encountered by the NEFSC trawl surveys. This change in distribution may be driven by the changes in the physical environment over time. Similar changes in distribution have been detected for some predator species, including marine mammals like whales and dolphins, which may be responding to the environment or following distributions of forage species, or both.

Overall, the report notes that the episodic or short-term events like the cooler conditions in 2024 result in more variable conditions, but species distributions are unlikely to revert to historical ranges in the short-term. While 2024 conditions were notable compared to 2020-2022 conditions, SST, the Gulf Stream index, spring to fall transition timing, and cold pool conditions all remain elevated/warmer compared to even the early 2000s. Long-term projections forecast a temporary pause in warming over the next decade because of the variability in the Gulf Stream, but short-term projections are highly uncertain.

Menhaden Environmental Preferences

Atlantic menhaden spawn off the coast of the Carolinas in the winter months (Nicholson 1978; Lewis et al. 1987), as well as spawning during their coastal migration (Ahrenholz 1991). Atlantic menhaden are multiple spawners with indeterminate, batch spawning (Latour et al. 2023); ichthyoplankton surveys have found significant levels of Atlantic menhaden larvae in shallow waters along the Atlantic coast during most of the year (September – June; Simpson et al. 2016). Atlantic menhaden rely on ocean currents to deliver larvae from the offshore spawning grounds to inshore nursery grounds along the coast, where juveniles develop before recruiting to the adult population. Depending on physical processes and ocean circulation, larvae can be transported hundreds of kilometers from the spawning ground to estuaries (Epifanio and Garvine 2001). Nursery ground productivity may vary annually due to environmental and biological factors such as the amount of larvae near estuarine mouths, time and location of spawning, number of eggs produced and the size of the spawning stock biomass, changes in the Gulf Stream, temperature, accessibility of estuarine mouths, and winter storms (Nelson et al. 1977; Checkley et al. 1988; Quinlan et al. 1999; Werner et al. 1999). In Chesapeake Bay, Houde et al. (2016) found that the abundance of age-0 Atlantic menhaden was positively correlated with chlorophyll *a* and Secchi depth (i.e., turbidity) and negatively correlated with Susquehanna River discharge. Also in Chesapeake Bay, Atkinson and Secor (2017) found evidence that cold winter water temperatures could cause a recruitment bottleneck due to increased larval mortality and reduced growth of early winter hatched Atlantic menhaden. Coastwide, Simpson et al. (2016) found that cooler temperatures, intermediate wind speeds, and negative-phase Atlantic Multidecadal Oscillation (AMO) were the most favorable for the survival of larval Atlantic menhaden. Deyle et al. (2018) determined there was clear evidence that recruitment of young-of-year menhaden is driven nonlinearly by ecosystem interactions, but incorporating sea surface temperature, the best indicator of environmental effects on recruitment in their study, did not improve model predictions of recruitment in the Atlantic. While Deyle et al. (2018) conducted their analysis at the coastwide level, Buchheister et al. (2016) found that the AMO was the best predictor of regional recruitment abundance, but the relationship between the AMO and recruitment differed across the region, showing a positive relationship in the southern New England region and a negative relationship in the Chesapeake Bay region. Midway et al. (2020) found relationships between environmental variables in the size-at-age of age-1 Atlantic menhaden in the north Atlantic, with the AMO and northern wind patterns having a negative effect on growth and eastern wind patterns having a positive effect on growth; no relationships were detected between temperature and wind for age-1 menhaden in the south or mid-Atlantic.

Atlantic menhaden migration patterns have been documented through historical tagging data, fishery data, and ichthyoplankton survey data (Roithmayr 1963; Dryfoos et al. 1973; Nicholson 1978; Simpson et al. 2016; Liljestrand et al. 2019). Adults begin migrating inshore and north in early spring following the end of the spawning season off the Carolinas during December-February. The oldest and largest fish migrate farthest, reaching southern New England by May and the Gulf of Maine by June. Adults that remain in the south Atlantic region for spring and summer migrate south later in the year, reaching northern Florida by fall. In the fall, a large proportion of the adult population that summered north of Chesapeake Bay moves south. However, even during the winter, not all fish migrate. Liljestrand et al. (2019) estimated that approximately a third of the fish in mid-Atlantic and southern New England waters and three-quarters of the fish in the Chesapeake Bay region remained in those respective regions over the winter, which is consistent with the presence of larvae in those regions during that time period (Simpson et al. 2016).

While there is a large body of literature on the environmental factors influencing Atlantic menhaden recruitment and growth, there is less information on the environmental preferences of adults and how environmental conditions affect their abundance and migration patterns. Woodland et al. (2021) found a positive relationship between menhaden abundance in Chesapeake Bay and river discharge, the AMO, and years with a long warming trajectory in spring months. The 2020 Atlantic menhaden benchmark assessment inferred habitat preferences from state surveys ranging from CT to northern Florida and found broad habitat envelopes with peak mean abundance occurring around 10°C bottom temperature, 30 ppt salinity, and 8 ft of depth (SEDAR 2020). An analysis of the NEFSC bottom trawl data found that more of the population was present in the northern end of the stock area in the spring than in earlier years, consistent with overall warming trends in the region (SEDAR 2020). Although the results should be interpreted with caution as the NEFSC bottom trawl does not reliably capture Atlantic menhaden, this is consistent with fishery data in recent years as well.

Osprey Timing

There have been several studies on osprey behavior within the Chesapeake Bay from the 1970s (Kennedy 1971, 1973; Reese 1972, 1975; Henny et al. 1974, 1977; Seek 1977) as well as some more recent work (Watts and Paxton 2007; Glass 2008). Overall, the literature indicates that osprey arrive in Chesapeake Bay in March and lay eggs in April. The eggs hatch between mid-May and mid-June, depending on when individual clutches were laid (incubation is 38-42 days), and fledging occurs from mid-July to early August. Osprey begin leaving the Bay during the last week of August and have generally fully departed by mid-October. Osprey in the mid-Atlantic Bight area and the New England area had similar timelines, arriving slightly later than in Chesapeake Bay and departing slightly earlier (Henny and van Velzen 1972; Poole and Agler 1987; Martell et al. 2001). None of the literature identified relationships between environmental factors and the timing of osprey migration, nesting, or fledging, nor were changes in the timing of these events over time noted.

Environmental Preferences of Other Forage Species in Chesapeake Bay

The TC reviewed literature on the environmental preferences of several species that have been identified as important forage species based on stomach content analysis and life history: alewife, blueback herring, bay anchovy, and juvenile spot and croaker.

Alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) are anadromous species that undergo spawning migrations cued by temperature, with a minimum spawning temperature of 10.5°C for alewife and 14°C for blueback herring (Mullen et al. 1986). Both species cease spawning at 27°C. Alewife typically begin the spawning migration when water temperatures are 5-10°C, while blueback herring typically migrate to spawn when water temperatures are 14-22°C, meaning alewife arrive earlier than blueback herring to the rivers and estuaries (Brown et al. 2024). Larvae and YOY nursery grounds include low-salinity tributaries near the salt/freshwater interface and high salinity waters in early fall before departure to ocean in late fall; as temperatures drop in fall, juveniles are less abundant in surveys (NMFS 2019; Able et al. 2020). Smith et al. (2025) identified a temporal pattern in the distribution of juveniles within the Virginia portion of the Chesapeake Bay, with juveniles concentrated in the upper portions of the sub-estuaries during autumn, the middle of the sub-estuaries during winter, and the mouth of the sub-estuaries during spring.

Bay anchovy (*Anchoa mitchilli*) tolerate a wide range of temperatures (as evidenced by extensive geographic range), and salinity appears to have little influence over their distribution (Morton 1989). Spawning occurs when water temperatures are at least 12°C, with peak spawning occurring at temperatures of 20.8-23.5°C and salinities of 13-15 ppt (Morton 1989, Castro and Cowen 1991). In Chesapeake Bay, spawning occurs May – September with peak in July; the spawning season is shorter further north and earlier spawning induced by earlier warming and sustained higher temperatures

(Zastrow et al. 1991). Bay anchovy undertake some seasonal offshore/onshore migrations. Biomass of bay anchovy in Chesapeake Bay peaks in summer and fall, with abundance in the winter being positively correlated with water temperature, suggesting that emigration out of the Bay may be more pronounced during cold winters (Wang and Houde 1995).

Juvenile spot (*Leiostomus xanthurus*) and croaker (*Micropogonias undulatus*) are tolerant of a wide range of conditions (Diaz and Onuf 1985, Parker 1971). Juvenile spot are generally found between 6–20°C, with a tolerable temperature range extending from 1.2–35.5°C, and in salinities ranging from 0–30 ppt (polyhaline to freshwater) (Parker 1971, Akin et al. 2012). Juvenile croaker are found in waters from 0.4–35.5°C and tolerate colder temperatures than adults; they are primarily associated with salinities of 0.5 to 18 ppt (Diaz and Onuf 1985).

Shoreline Hardening Impacts

Studies that have looked at the effect of shoreline type on Atlantic menhaden abundance have either found a positive relationship with hardened shorelines compared to natural shorelines (Bilkovic and Roggero 2008) or no relationship (Balouskus and Targett 2017; Kornis et al. 2017, 2018). A number of studies have found lower species diversity at hardened shorelines compared to natural shorelines in some estuaries (Bilkovic and Roggero 2008; Seitz and Lawless 2008; Gittman et al., 2016a,b; Balouskus and Targett 2017), while others have found no relationship with diversity (Seitz et al. 2006; Seitz and Lawless 2008; Long et al. 2011; Lawless and Seitz 2014; Lovall et al., 2017). Effects of shoreline hardening varied by species and, in some studies, by estuary. These studies also found no significant differences in temperature, dissolved oxygen or salinity by shoreline type (Seitz et al. 2006; Seitz and Lawless 2008, 2014; Long et al. 2011; Davenport et al. 2017; Lovall et al. 2017; Kornis et al. 2018). Atlantic menhaden had a positive relationship with total nitrogen, but that was more related to land cover/land use than shoreline hardening (Kornis et al. 2017).

TC Discussion

Many factors within a species' physical environment will influence abundance, distribution, and timing of population events such as spawning and migration. The TC has conducted this literature search to establish a baseline of knowledge regarding menhaden preferences and environmental conditions. If the Board would like a more detailed, quantitative analysis of the influence of recent environmental conditions on availability of menhaden on the continental shelf and within Chesapeake Bay, the TC would request additional guidance on the parameters and relationships of greatest interest to the Board in order to prioritize the work and complete it in a timely fashion. However, the TC also stresses that the existing datasets may not be sufficient to fully address the Board's questions, given the limited spatial and temporal coverage of both fishery dependent and fishery independent data.

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