"A Review of the Atlantic menhaden (*Brevoortia tyrannus*) fishery in coastal Maine waters: ecology, assessment, management, and future research recommendations"

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Table of Contents

(updated July 2024)

Introduction

Atlantic menhaden *(Brevoortia tyrannus*) is a schooling Clupeid fish found from northern Florida through Nova Scotia, Canada (SEDAR 2020). They are found often in estuarine and coastal systems in their range, often forming large dense schools. Menhaden, also called Pogie, Moss Bunker, or Bunker, are important both economically and ecologically. Ecologically, menhaden serves as a vital link between primary production and secondary consumers. Menhaden feed largely on phytoplankton and particulate organic matter (POM) and in turn are prey for many commercial and recreationally important species, such as tuna, striped bass, bluefish, and others (SEDAR 2020, ASMFC 2020). Economically menhaden are an important bait source for the lobster fishery, particularly as Atlantic herring population abundance has declined in recent years.

To date, Menhaden have been episodic visitors to the coastal waters of Maine (Bigelow & Schroeder 1953). **Because their appearance is marked by multiple years of high abundance followed often by decades of near absence, DMR created this summary of their life history, assessment, harvest, and ecological importance in the Gulf of Maine to reflect upon the impact of this key species.**

Menhaden are traditionally harvested using several different gear types including purse seines, gillnets, and pound nets. The bulk of the harvest outside of Maine has traditionally been for reduction purposes, to be used for fertilizer, animal feed, and oil. Menhaden oil has had several different uses historically including fish oil supplements, cosmetics, food additives, as well as others. More recently menhaden in some parts of its range are increasingly being harvested as bait for the American lobster fishery, particularly in Maine.

Life History

For management and assessment purposes, menhaden are viewed as a single coast-wide stock. This single-stock approach is supported by tagging, length-frequency, and genetic analysis (Nicholson 1972 and 1978; Dryfoos et al. 1973, Anderson 2007; Lynch et al. 2010).

The bulk of menhaden's spawning activity generally peeks over the continental shelf (Figure 1) off the Carolinas in late autumn and early winter. After spawning adults, typically age 2 and older, move north and inshore arriving in Maine waters by May. Some adults, however, move south arriving in Northern Florida inshore waters at approximately the same time. Adult menhaden tend to stratify longitudinally by size and age; with older and larger individuals migrating further north than smaller and younger adults (SEDAR 2020).

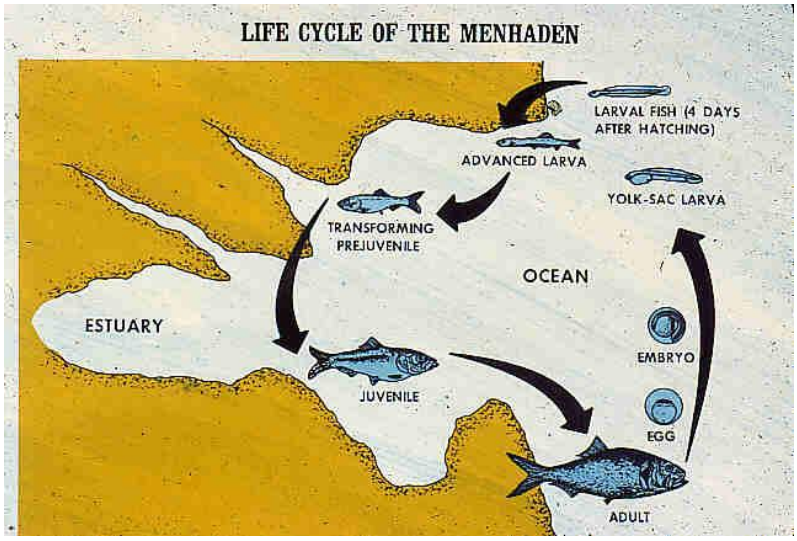

Figure 1. Schematic of the life history of Atlantic Menhaden (Photo courtesy of D. Vaughan).

After hatching, larvae are advected into the coastal and estuarine waters of the Mid-Atlantic region of the US, where they are found in upper estuarine environments until Autumn.

Meanwhile, adults inhabit lower portions of estuaries as well as coastal systems before also migrating to more southern waters to repeat the cycle. Recent evidence (SEDAR 2020), however, suggests that in the northern portion of the range, adults do not migrate as far south in these autumn migrations as those adults found in the coastal waters of the Mid-Atlantic.

Recent studies (Latour et al. 2023, SEDAR 2020) have also revealed that menhaden are intermittent batch spawners, meaning that they continuously spawn during their northern and inshore migration. This results in larvae being found in more northern and inshore areas than was previously thought and explains why it is common to see small young of the year as far north as coastal Maine, despite such a migration being unlikely for such a small fish.

Current assessment

The stock assessment for menhaden currently uses a combination of a single species assessment and an ecosystem modeling approach based on Ecopath with Ecosim (EwE). In this process, the fecundity (a measure of spawning output) and fishing mortality reference points are determined through the EwE to account for menhaden ecological role within the ecosystem, while the single species assessment determines status relative to those reference points (ASMFC 2020b).

The single-species model is a typical statistical catch-at-age approach that uses fishery-independent and dependent data along with catch information to produce estimates of stock fecundity and fishing mortality (SEDAR 2020). The single species model itself, called the Beaufort Assessment Model (BAM) is widely used by the Southeast Fishery Science Center of NOAA fisheries to assess fish populations in the Southeast region of the US.

The modeling approach to determine the Ecological Reference Points (ERPs) for menhaden is a simplified version of a shelf-wide EwE developed by (Buchheister et al. 2017). This simplified model, termed NWACS-MICE (Northwest Atlantic Continental Shelf: Model of Intermediate Complexity for Ecosystems), is an EwE approach that only incorporates stocks that either have a dramatic effect on the menhaden population or is heavily reliant on menhaden as prey (ASMFC 2020a, Chagaris et al. 2020). The advantage of using this sort of approach is that it allows estimation of bottom-up effects on the predator stocks, where the lack of menhaden can play a role in reduced growth and survival of predator populations.

Used together, both models allow for the examination of trade-offs in managing the menhaden population and determination of harvest levels. As ERPs will change based on stock status or important predators, which in turn affects the abundance of menhaden as prey, managers can use these two models as tools to balance the trade-offs between menhaden harvest, predator population sizes, and forage demands.

While the incorporation of both models to determine ERPs and measure stock status against them is relatively novel, the main drawback of this approach is that it is a coast-wide model. As such, it cannot address stakeholder and manager concerns about localized depletion in any

region within the overall range of menhaden. Work is currently underway (ASMFC 2023a) to examine this issue by incorporating more spatial explicit information into both EwE and BAM, to allow for the possible setting of regional reference points and quotas. This is a daunting task, however, as information, particularly on the predator-prey relationship between menhaden and important predators, is lacking on small spatial scales. While some of this information is being incorporated for the 2025 benchmark assessment and peer review of the ERP model, a more robust analysis and treatment likely will not happen until the 2031 benchmark assessment.

Management

Menhaden are managed coast wide as a single stock by the Atlantic States Marine Fisheries Commission (ASMFC). Atlantic menhaden management currently falls under Addendum I to Amendment 3 of the Interstate Fishery Management Plan (FMP). This Addendum deals with commercial quotas and introduces a tiered system for state allocations. ASMFC in effect sets the overall coast-wide quota which is allocated among the different states. Minimum quotas are set at 0.01% for Pennsylvania, 0.25% for South Carolina, Georgia, Connecticut, Delaware, North Carolina, and Florida, and at least 0.5% for the remaining states (Table 1). The remainder of the Total Allowable Catch (TAC) is allocated based on historical landings data from 2018, 2019, and 2021, excluding a 1% set aside for episodic events in states from New York to Maine under the Episodic Event Set Aside (EESA) Program. Individual state quotas are then managed by those states, often among gear types, seasons, or other measures. Provisions within Addendum I to Amendment 3 allow for quota transfers among states. Provisions within this Addendum also mandate payback of quota overages should a state exceed its allocation. While recognized as a single stock, managers have put in place a Chesapeake Bay cap on harvest (51,000 mt: ASMFC 2022a), as a precautionary measure to mitigate possible localized depletion within the Bay.

Table 1. Current State allocations of Atlantic Menhaden Coast Wide Quota. (ASMFC 2022a).

Addendum I Quota Allocations	
State	Addendum 1 Allocations (%)
Maine	4.80%
New Hampshire	1.19%
Massachusetts	2.12%
Rhode Island	0.81%
Connecticut	0.33%
New York	0.84%
New Jersey	11.00%
Pennsylvania	0.01%
Delaware	0.27%
Maryland	1.17%
Potomac River Fisheries Commission	1.09%
Virginia	75.21%
North Carolina	0.37%
South Carolina	0.25%
Georgia	0.25%
Florida	0.29%
Total	100.00%

For the 2023-2025 fishing seasons, the TAC has been increased by 20% to 233,550 metric tons based on a positive stock assessment update conducted in 2022 (ASMFC 2022b). This increase is projected to have a less than 40% probability of exceeding exploitation management targets, and an even lower chance of exceeding the exploitation threshold based on the ERP model (ASMFC 2022b). This reflects a conservative approach to management

Within Maine waters, menhaden are managed by the Maine Department of Marine Resources (See Chapter 41). Provisions of the State's regulations include.

- Maximum vessel size.
- Requirement to hold a license.
- Reporting requirements by trip
- Provisions against harvest by midwater trawling and other prohibited gears.
- Dedicated harvest days and seasons.
- Landing limits.
- And other provisions during small-scale, incidental, and personal use fisheries.

The goals of these regulations are to allow for an orderly fishery to take place, supplying bait to the lobster fishery, while also adhering to ASMFC mandates by only allowing harvest up to the allocated quota. As such, landing limits, seasons, and the days available to fish are variable

each year and reflect the amount of quota allocated by ASMFC as well as recent rates of harvest.

Fishing history

Menhaden has a rich history in the Gulf of Maine as outlined by NHS 2022 and SEDAR 2015.

Menhaden were likely harvested for use as fertilizer and bait by both indigenous Americans, as well as early European colonists. In the early 1800s, the American Atlantic coast witnessed the early stages of the menhaden fishery, primarily utilized for bait in the growing commercial lobster and crab industries. These modest beginnings marked the origin of what would soon become a significant commercial endeavor, driven by the increasing demand for menhaden in various industrial applications.

By the mid-19th century, as the need for fish oil and fertilizer surged—partially propelled by the decline in whale oil due to overharvesting—the menhaden fishery expanded dramatically. This period saw the establishment of numerous small, family-operated reduction plants along the Atlantic seaboard. These facilities employed simple kettles and presses to extract oil, which found a ready market. The advent of steam-powered vessels and purse seines around this time revolutionized the fishery, enabling more efficient capture of menhaden, whose oil-rich content and high-protein fishmeal were increasingly sought after by industries such as soap and fertilizer production.

By 1867, competition, diminishing local stocks, and regulatory pressures prompted Elijah Reed, a fishing Captain from Maine, to relocate from Maine and establish the town of Reedville in Virginia, which became a new hub for menhaden processing. The industry reached its zenith around 1870, with some 90 reduction plants operating coast wide. Notably, menhaden from Maine were particularly valued for their high oil content, having fattened during their northward migration. However, the rapid expansion and intensive harvesting practices soon led to ecological concerns and regulatory interventions. Initially, in 1865, regulations limited out-of-state harvests by large vessels within three miles of the coast, although these restrictions were briefly loosened in 1866. By 1879, significant declines in menhaden stocks led to the migration of the reduction industry southward to places like Rhode Island, New York, and particularly the burgeoning facilities in Reedville.

Post-1879, the industry predominantly centered around New Jersey and Virginia, until a resurgence in the 1950s expanded activities back into the Gulf of Maine (Figure 2), with plants re-emerging in Portland and Gloucester. However, this revival was short-lived as another collapse happened in the 1960s. This was followed by yet another resurgence in the 1970s through the early 1990s, with new plants in Rockland, Portland, Gloucester, and New Brunswick. By 1989, all shore-side reduction plants in New England had closed, primarily due to conflicts with local municipalities over odor abatement issues. A brief period in the early 1990s

saw a Canadian plant in Nova Scotia process Atlantic menhaden from southern Maine, but this too ceased by the summer of 1993. Prior to the decline in abundance in Maine state waters, a Russian Internal Waters Processing (IWP) operated in the Gulf of Maine, processing menhaden caught by local fishermen, into food and other reduction products for import into the then Soviet Union.

Since the closure of many reduction plants due to odor concerns and fluctuating market forces affecting the fish meal and oil market, only one plant remains active today in Reedville, Virginia. In the late 2000s, a small-scale bait harvest resumed in Maine, which has seen a further resurgence since 2016, mainly serving as lobster bait. Today, menhaden has become the primary bait used in the Maine lobster fishery, particularly with the decline in Atlantic herring in New England waters. This history illustrates the cyclical nature of this menhaden's availability in Maine waters, as well as the often-episodic nature of the fishery that harvests it.

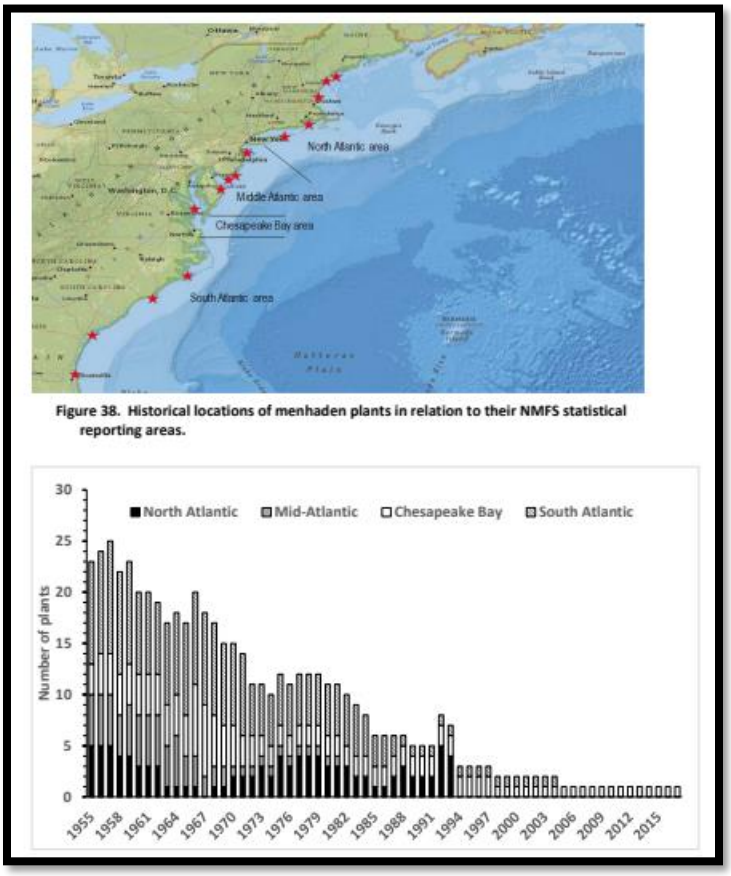

Figure 2. NMFS Statistical reporting area, historical location of menhaden plants, and the number of plants by area for the menhaden fishery 1955-2013 (Top). Staked chart of the number of menhaden plants by area and year (Bottom; SEDAR 2020).

Landings and Commercial Sampling

Cost-wide landings of Atlantic menhaden have been variable but have overall declined since 1955 (ASMFC 2022a and Figure 3). Early in the time period, landings averaged around 400,000 mt, dropped to 300,000 mt from the 1970s to late 1990s, then further declined to around 200,000 mt on average. Since the early 2000s landings have slowly declined, though with high yearly variability. This decline is well explained by the decrease in reduction processing facilities coast-wide, as the demand for reduction products has also declined. Despite this decline in reduction landings, bait landings have increased and now are approximately 30% of the overall coast-wide landings. It is thought that the bulk of landings for the bait sector goes to the Maine lobster fishery even if it is landed in other states.

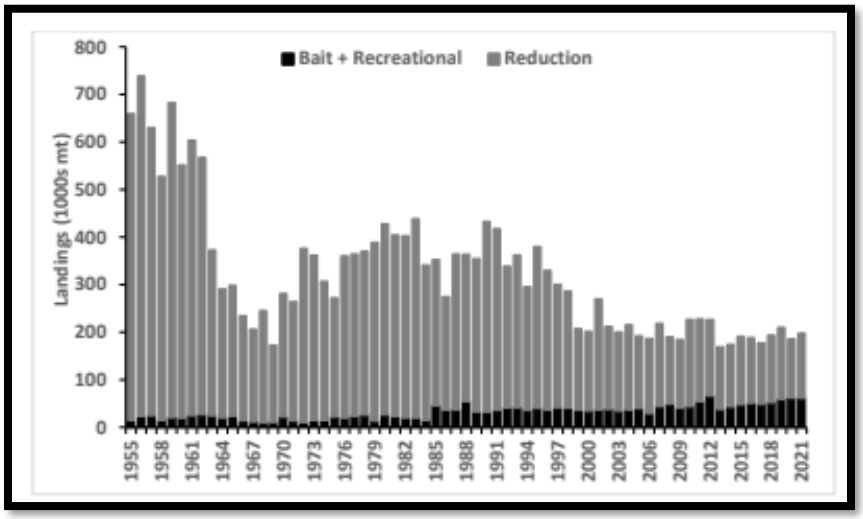

Figure 3. Total Menhaden landings, 1955 to 2021 (ASMFC 2022b).

Maine landings have also been variable, but cyclical (Figure 4). With the increased abundance in the Gulf of Maine from 1973 to 1993, landings for both reduction and bait use increased to the highest recorded levels in the State of Maine. As mentioned previously, a Russian IWP operated in the region taking advantage of the abundance of menhaden, which otherwise had little market at the time for bait. Landings again subsided from 1994 through 2016, except for a small peak in 2008. The drop off in landings in 1994 is notable, suggesting a rather abrupt change in the availability of menhaden to Maine fishermen rather than a slow decline. Since 2016 landings have rapidly increased, at times exceeding 1973 to 1993 levels. This is in part due to the coincidental decline of Atlantic herring in the Gulf of Maine (NEFSC 2022), the most popular bait for the lobster fishery prior to the most recent increase in menhaden availability.

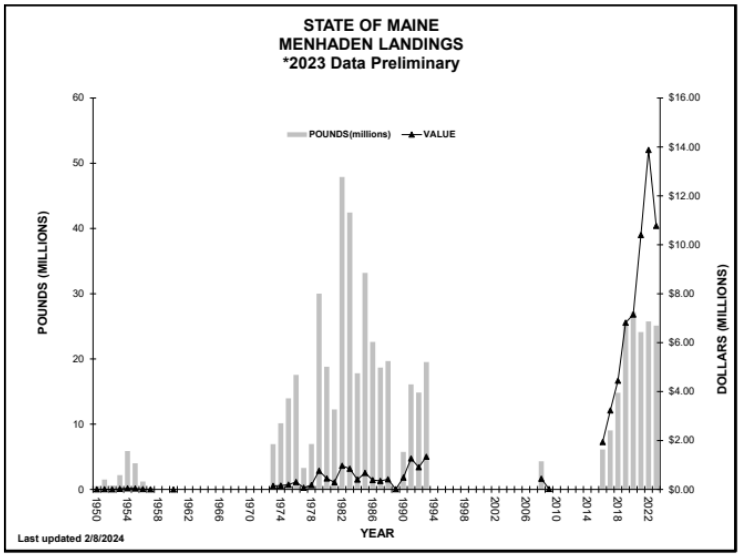

Figure 5. Menhaden landings in the State of Maine 1950-2023. From Maine DMR.

As mentioned under management, catch in Maine is constrained by the State's quota. Prior to 2023, Maine's quota was 0.52% of the coastwide Total Allowable Catch which represented a little over 2 million pounds. As abundance of menhaden increased, this quota was quickly caught and Maine sought additional harvest opportunities via quota transfers from other states, use of the Episodic Events Set Aside, and landings under a small-scale fishery provision. In 2023 (ASMFC 2023b), there was a reallocation of menhaden quota between the Atlantic coast jurisdictions and Maine's quota dramatically increased to 4.80% of the coastwide Total Allowable Catch, representing roughly 24 million pounds in 2023 (~11,000 mt). Maine landings have been dominated by purse seine landings, while small gillnets are often used by lobstermen harvesting bait for their commercial operations (Table 2).

Table 2. Percentage of menhaden catch in Maine by gear type 2007 to 2023. Note Confidential data 2010 to 2015

Year	Gill net	Other	Purse	Unknown
2007	27.3	0.5	71.1	1.0
2008	11.3	1.4	87.3	0.0
2009	31.8	0.0	68.2	0.0
2010	Con	Con	Con	0.0
2011	Con	Con	Con	0.0
2012	Con	Con	Con	0.0
2013	Con	Con	Con	0.0
2014	Con	Con	Con	0.0
2015	Con	Con	Con	0.0
2016	5.5	2.1	92.5	0.0
2017	15.9	0.3	83.8	0.0
2018	9.0	0.5	90.5	0.0
2019	6.9	0.7	92.3	0.1
2020	6.8	0.7	92.5	0.0
2021	7.5	0.3	91.9	0.3
2022	8.0	0.4	91.3	0.2
2023	2.2	0.1	97.4	0.3

ASMFC has mandated sampling at a rate of one 10 fish samples for every 300 mt of landings in all states since 2005. Due to low landings in Maine, sampled data is only available from those years that had appreciable landings. Because Maine's fishery sampling was not focused on menhaden during the 1973 to 1993 fishery, little data from that time period is currently available. Sampling has increased as Maine landings have increased, with between 32 and 45 samples taken each year, spread out among different gear types, from 2017 to 2023.

Samples are normally collected from individual fishing operations, either commercial or less regular from personal use bait fishing. Each 10-fish sample has each individual fish weighed and measured. Scales from the fish are scraped into an envelope to be sent to NOAA Beaufort (NC) for aging. Scales are then prepared and read at the Beaufort lab before incorporation into the stock assessment. More recently aging has started to be done by individual states for their bait fisheries, while the overall collection and processing of both length and age samples from the reduction fleet is retained by NOAA Beaufort. This transition, however, is not complete. The sheer volume of samples to be aged has resulted in a backlog of aging such that only age data to 2021 were available at the time this report was created.

Comparing the age structure of the 2008 samples to the 2016-2021 samples shows an interesting trend (Figure 6). Compared to 2008 and 2016-2018, more recent samples in 2020 and 2021 show a marked increase in the frequency of younger fish (Age 2), with a slight secondary increase in the frequency of older fish (Age 4). This suggests that while the bulk of the fish caught in Maine waters are 3 years old, the age structure appears to be broadening, and an influx of younger fish is apparent. What this means for the future of the Maine fishery is unclear.

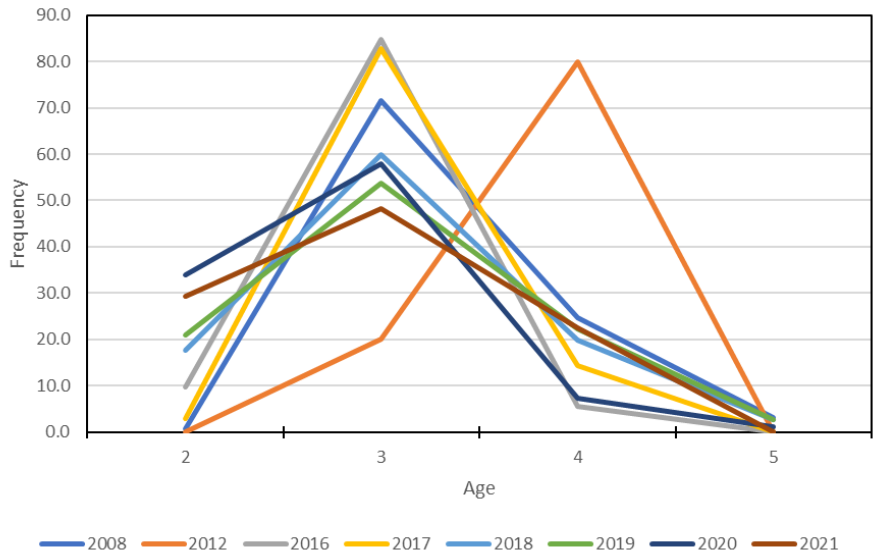

Figure 6. Age-frequency for Menhaden sampled from the commercial fishery in Maine 2008- 2021.

Ecosystem Relevance in the Gulf of Maine

In addition to providing an important source of bait to the lobster fishery, as well as income for harvesters, menhaden are an important forage species. Outside of the Gulf of Maine, menhaden are important prey for a number of commercially and recreationally important species coast-wide (ASMFC 2020a). Nelson et al. (2003), found that striped bass consumed some menhaden, though the amounts appear relatively small compared to other prey items. This was likely due to a lack of menhaden abundance in sampled waters during that particular study.

More recently (Nadeau 2021) and unpublished data from B. Jenner (DMR/UMaine) have documented the change in bluefin tuna (BFT) diets in response to increased menhaden abundance from 2019 to 2023. As Figure 7 shows, BFT diets transitioned from being composed of Atlantic herring, squid, mackerel, and whiting, to being dominated by menhaden from 2019 to 2023. Prior to this (Logan et al 2015), showed that herring and whiting made up the bulk of BFT diets on Stellwagen Bank and presumably other portions of the Gulf of Maine.

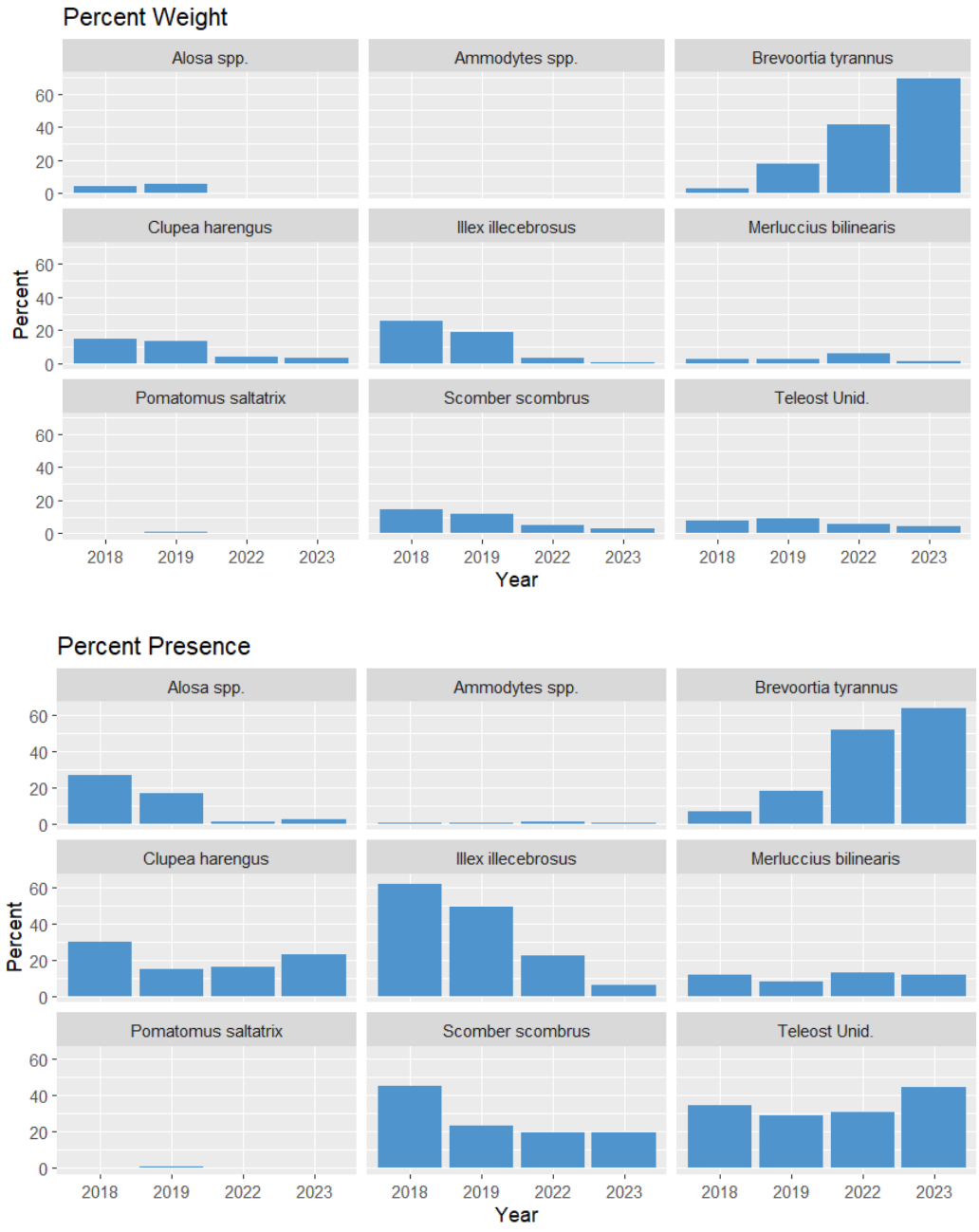

Figure 7. Percent Weight (top) and Percent Occurrence (Bottom) of different prey items in the stomachs of Bluefin Tuna 2018 to 2023. From Nadeau 2021 and Jenner Unpublished.

Other than the work done on BFT and striped bass diets by Nelson et al. (2003) mentioned, there has been little in the way of data on diets for important predators in the coastal regions of the Gulf of Maine. While both the ME-NH and NOAA bottom trawl fishery-independent surveys capture potentially important predators of menhaden, these surveys often occur in deeper waters where menhaden are usually less abundant. As such it is difficult to know if the recent increase in menhaden abundance in the Gulf of Maine contributes to the overall forage field for other important predators such as striped bass pollock, Atlantic cod, and others.

Conclusions

Both historical records and recent landing data suggest that menhaden are episodic in the Gulf of Maine, with many years of high abundance punctuated by many years of almost complete absence. The cause of this is unknown but is likely tied to climatic effects such as water temperature/salinity, coast-wide recruitment, potential predator behavior, or limited food availability for menhaden south of Cape Cod. It seems unlikely that menhaden abundance in the Gulf of Maine is negatively correlated with Atlantic herring abundance, as the abundance of menhaden overlapped the large landings of Atlantic herring from 1975 to 1985. Additionally Atlantic herring and menhaden feed on different trophic levels, with Atlantic herring consuming mostly large zooplankton such as copepods, while menhaden filter feed for phytoplankton and POM.

It is clear that these cycles are rather abrupt, with menhaden being in the Gulf of Maine one year, but not the following year, and vice versa. Such rapid changes in distribution present challenges for both management and fishery science, as monitoring programs and allocation of quota, become much more difficult when with a rapidly appearing and disappearing resource.

What is less clear is the impact these rapid changes have on potential predators, particularly commercially and recreationally important species such as striped bass, BFT, pollock, and others. It is certainly possible predators simply switch between Atlantic herring and menhaden based on the local level of abundance, given they have a similar size and shape. To date, there is only limited information on the feeding habits of these predators in the near-shore waters of the Gulf of Maine, and except for the recent BFT research, none have captured this transition between Atlantic herring and menhaden.

Overall, more research is needed to 1) examine how the abundance of menhaden, and its resulting biomass, affects predators within the Gulf of Maine, 2) document the abundance of menhaden in the Gulf of Maine independent of fishing activity, and 3) explore the potential causes for increasing or decreasing menhaden abundance as well as potential climate-related covariates.

Research Recommendations

There is a need to both continue the current monitoring of BFT stomach contents and start monitoring the food habits of coastal fin fish predators in the coast waters of the Gulf of Maine, such as striped bass. Research into the food habits of a coastal predator could shed light on the role of menhaden in the diets of these predators, while the continuation of the diet studies for BFT could elucidate the importance of menhaden to more apex predators. **As such the continuation of the BFT diet study, already conducted by DMR as well as starting a food habits study for striped bass and potentially pollock is recommended.**

Fishery-independent indices of abundance are difficult for menhaden. Fishery-dependent indices, such as catch per unit effort, are notoriously difficult for schooling pelagic species

harvested via purse seine due to concerns about hyperstability. Moreover, market conditions also routinely affect high-value, low-value stocks making standardization very difficult. As such, fishery-independent indices offer the best chance of documenting menhaden abundance. Unfortunately, menhaden are not well sampled via trawl surveys, as they tend to be high in the water column most of the time. Likewise, their schooling behavior also makes data interpretation very difficult. Despite this, the overall stock assessment uses a number of fishery-independent methods to provide management advice, though none of these are currently in use in the Gulf of Maine. **As such, it is recommended that a fishery-independent survey of menhaden be conducted within the Gulf of Maine.** Methods could include aerial surveys, pound net indices, and even gillnet surveys to accomplish this goal. A workshop or other meetings with industry would likely be instrumental in choosing the right methods for scientifically documenting the abundance of menhaden in the Gulf of Maine. Such an effort may allow for better decision-making by managers on quota allocation among states.

Another area of interest is the sometimes abrupt, cyclical nature of menhaden's abundance within the Gulf of Maine. Currently, the factors that dictate this increased abundance are not well understood. It is likely that climatic effects, population recruitment, and other factors may play a role. But as of now, there has been little work on this subject. **Therefore, it is recommended that a study be commissioned to examine the potential factors that affect menhaden abundance within the Gulf of Maine.** It is likely that such a study would be statistical in nature and would likely take a concerted effort of both Maine DMR science staff as well as the ASMFC technical committee. It is not a light undertaking, but success could help unravel an important question surrounding menhaden abundance as well as provide clues for other species whose abundance may be dictated by similar factors.

An important aspect of menhaden, as well as Atlantic herrings, harvest is the end use; as bait for the lobster fishery. Both Atlantic herring and menhaden are important sources of bait for this important fishery. **Given this, it is recommended that a socio-economic study be undertaken to examine bait use by the lobster fishery.** Such a study would help answer questions on how the importance of Atlantic herring and menhaden to the overall operating costs of lobster harvesters, the feasibility of alternative baits, the importance of non-native baits, as well as the best way to allocate Atlantic herring and menhaden for maximum efficiency and socio-economic considerations.

Menhaden has a long and fascinating history within the Gulf of Maine. From the development of the Reduction Fishery to its current use as a bait species in one of the most lucrative fisheries in the US, the importance of menhaden economically and socially cannot be denied. As important however is the ecosystem services provided by menhaden, as forage for other commercial and recreationally important species. It is hoped that by increasing scientific efforts on menhaden in the Gulf of Maine, managers may allocate more equitably, while the role of menhaden in the ecosystem can be protected even in the face of rapid climate change.

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