Atlantic States Marine Fisheries Commission

ADDENDUM I TO AMENDMENT I TO THE INTERSTATE FISHERY MANAGEMENT PLAN FOR ATLANTIC MENHADEN

***ASMFC Vision Statement*:**
Healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

August 2004

Acknowledgements

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Addendum I to Amendment I to the
Atlantic States Marine Fisheries Management Plan
Fishery Management Plan for Atlantic Menhaden

INTRODUCTION

At its March 2004 meeting, the Atlantic Menhaden Management Board approved the initiation of the development of this addendum to Amendment 1 to the Interstate Fishery Management Plan (FMP) for Atlantic menhaden. This Addendum addresses Biological Reference Points for menhaden, the frequency of stock assessments, and updating the habitat section currently in Amendment 1.

Background

The Atlantic Menhaden Management Board approved the original Atlantic Menhaden FMP in October 1981. The plan did not recommend any specific management measures, but provided a discussion of options, for future considerations. In 1982, the Board recommended seasonal limits as a means to provide long-term benefits to the fishery. This recommendation was approved by the Commission and referred to the states for implementation, however full implementation was not achieved.

The FMP was revised in 1992. The plan revision objectives included public education; continuation of the existing fishery monitoring program, improvement in collection of data on menhaden taken in directed bait fisheries and as bycatch in other fisheries; improvement of the Captain's Daily Fishing Report (CDFR) program; promotion of needed research on biological, economic, sociological, and habitat issues; encouragement of product research; maintenance, and enhancement; and utilization of the best available scientific data as the basis for coordinated management actions (ASMFC, 2001)

After the 1992 revision there were concerns over declines in the Atlantic menhaden population. This decline led the Management Board to recommend that the Commission conduct an external peer review of the menhaden stock assessment. This peer review was completed in November 1998 and provided some major recommendations for improving the assessment and management of menhaden. Upon receiving the report of the Peer Review Panel in January 1999, the Board recommended that a full amendment to the FMP be developed and the recommendations of the Peer Review Panel be addressed through the development of the amendment.

Amendment 1 addressed a number of management measures and set up a process for future management of the Atlantic menhaden pursuant to the requirements of the Atlantic Coastal Fisheries Cooperative Management Act. This amendment also adopted a new overfishing definition by which the Management Board can measure the status of the resources. In addition, Amendment 1 requires mandatory reporting from all menhaden purse seine fisheries (ASMFC, 2001)

MANAGEMENT ISSUES

I. Biological Reference Points

In 2003, a new benchmark stock assessment for Atlantic menhaden was completed by the Technical Committee (TC) and peer reviewed through the Southeast Data and Assessment Review (SEDAR) process. In this assessment the TC recommended changing from using a Spawning Stock Biomass (SSB) target and threshold to a Fecundity based target and threshold. They also recommended changing the Fishing Mortality (F) target and threshold.

With the approval of Amendment 1, biological reference points for Atlantic menhaden were adopted. These biological reference points were as follows: F (target = 1.04 and threshold =1.33) and SSB (target = 37,400 mt, and threshold = 20,570 mt) (ASMFC, 2001).

In the 2003 benchmark stock assessment, the TC recommended using population fecundity (number of maturing or ripe eggs) as a better measure of reproductive output of the population compared to Spawning Stock Biomass (the weight of mature females). Older menhaden release more eggs than younger menhaden. By using the number of eggs released there is more importance given to older fish in the population and therefore population fecundity is a more direct measure of reproductive potential. The SEDAR peer review panel agreed with the TC that population fecundity was a better measure of reproductive output compared to SSB (ASMFC, 2004A).

F-based and SSB-based reference points should be based on an underlying population dynamics (e.g. F_{MSY} and B_{MSY} from Ricker or Beverton-Holt spawner recruit models). However, traditional methods of specifying these reference points perform poorly when applied to historical Atlantic menhaden. Hence, the reference points in Amendment 1 were developed from historical spawner and recruit relationship. As such, F_{MED}[1] (an estimate of F_{REP}[2]) was used as the *F*-threshold and its corresponding spawning stock biomass became the SSB-target. The threshold for SSB was calculated to account for natural mortality. *F*-target was estimated at F_{MAX}[3]. The values calculated for these reference points were 1.04 and 1.33 for the *F*-target and *F*-threshold, respectively, while 37,400 mt and 20,570 mt were the SSB-target and SSB-threshold, respectively (ASMFC, 2004B).

In estimating the reference points using the new model, the TC has maintained the basic approach from Amendment 1, but with some modifications. They recommended that SSB be replaced with population fecundity (number of maturing or ripe eggs) as an improved measure of reproductive capacity. They continue to use F_{MED} to represent F_{REP} as the *F*-threshold, but

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[1] F_{MED} is used as a proxy value for F_{REP} and is derived from the SSB/R plot
[2] F_{REP} is the mortality at which the stock will replace it self
[3] F_{MAX} is the maximum fishing mortality before the process of recruitment overfishing begins

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estimated it using fecundity rather the SSB. Because the analysis calculated an F_{MAX} that was greater than F_{MED} (and may be infinite), they recommended instead that *F*-target be based on the 75th percentile. This approach would then be consistent with the approach used for the *F*-threshold. For biomass (or egg) benchmarks, the TC recommended following the approach of Amendment 1.

This addendum establishes the following biological reference points: F target = 0.75, F threshold = 1.18, fecundity target (trillions) = 26.6 and fecundity threshold (trillions) = 13.3.

The changes in the biological reference points, while seemingly large, are a re-estimation of population parameters. These changes are a refinement over previously derived reference points and are a substantial improvement. Because the newer model estimates these reference points differently, they are neither more nor less conservative than previous estimates using other approaches. Figure 1 shows the historical fishing mortality using the new reference points and Figure 2 shows the historical population fecundity of menhaden.

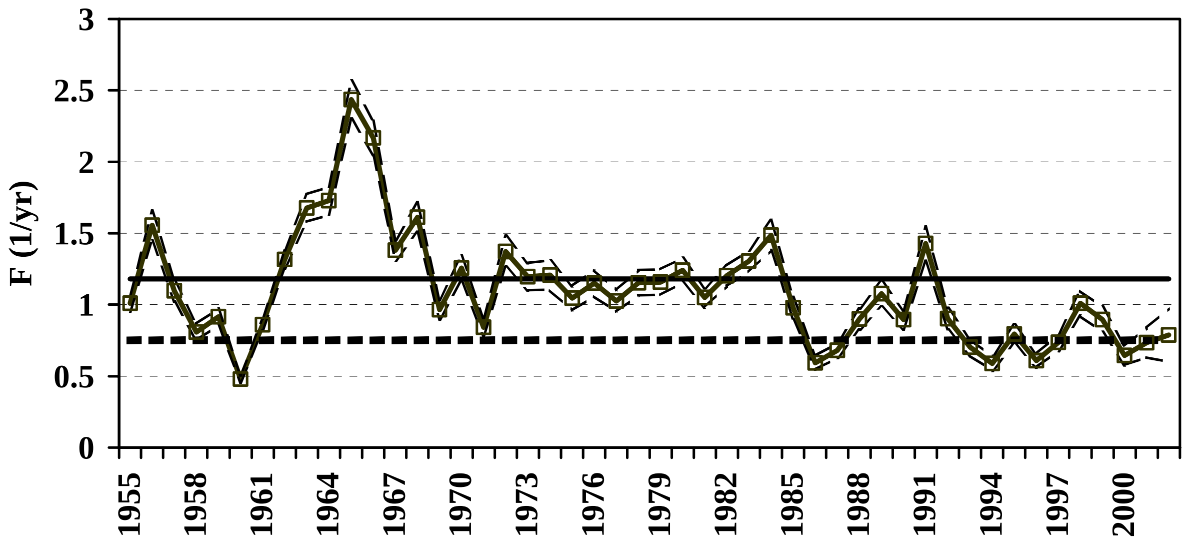

Figure 1. Atlantic menhaden fishing mortality rate, F (ages 2+) plus/minus 2 standard errors. Horizontal lines represent target (dashed) and threshold (solid).

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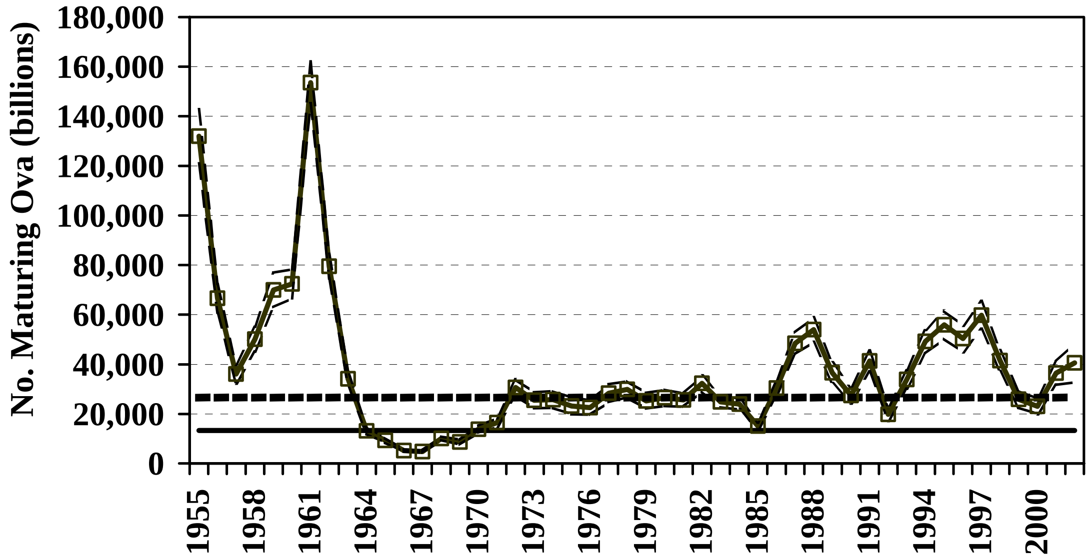

Figure 2. Atlantic menhaden population fecundity (no. maturing ova) plus/minus 2 standard errors from Ricker model. Horizontal lines represent target (dashed) and threshold (solid).

II. Frequency of Atlantic menhaden Stock Assessments

Amendment 1 to the Atlantic menhaden FMP states "An Atlantic menhaden stock assessment will be performed on an annual basis by the stock assessment subcommittee". It also states that SSB will be estimated from the Virtual Population Analysis (VPA) on an annual basis. The VPA was used in the Atlantic menhaden stock assessments before the benchmark assessment in 2003. In the 2003 benchmark assessment, the TC used a forward-projecting statistical catch-at-age model as the primary assessment tool. The essence of forward-projecting age structured models is to simulate a population that is projected forward in time like that population being assessed

The new forward projection model is much more complex than the previous VPA used. Due to the complexity of the model, the TC will update the assessment every three years. The next Stock Assessment will be conducted in 2006. On each non-assessment year the TC will meet to review landings, catch-at-age matrix, effort, and fishery independent abundance data. The TC has specified "triggers" that will initiate an assessment in any non-assessment year. These triggers are:

1) The CPUE index falls below the 5^{th} percentile for the past 20 years (0.374; Figure 3)
2) The ratio of ages 2-4 to the total catch of all ages falls below the second standard deviation unit over the last 20 years (0.322; Figure 4)

The first trigger examines fishery performance and relative abundance to determine if there has been a significant change. The second trigger was designed to look at the age 0-1 harvest,

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determine if radical changes in the age composition of the catch, and proceed with a stock assessment if such a change is significant. Because both triggers are statistically related, both should be reached to initiate an assessment. It should be noted that these are not management triggers, but are designed around the sensitivity of the model to the input data.

These triggers are a minimum requirement to update the assessment, however, if the TC reviews the landings, catch-at-age matrix, effort, fishery independent data, and notes a marked change, they can request that an update of the assessment be done in the absence of hitting those triggers.

Figure 3

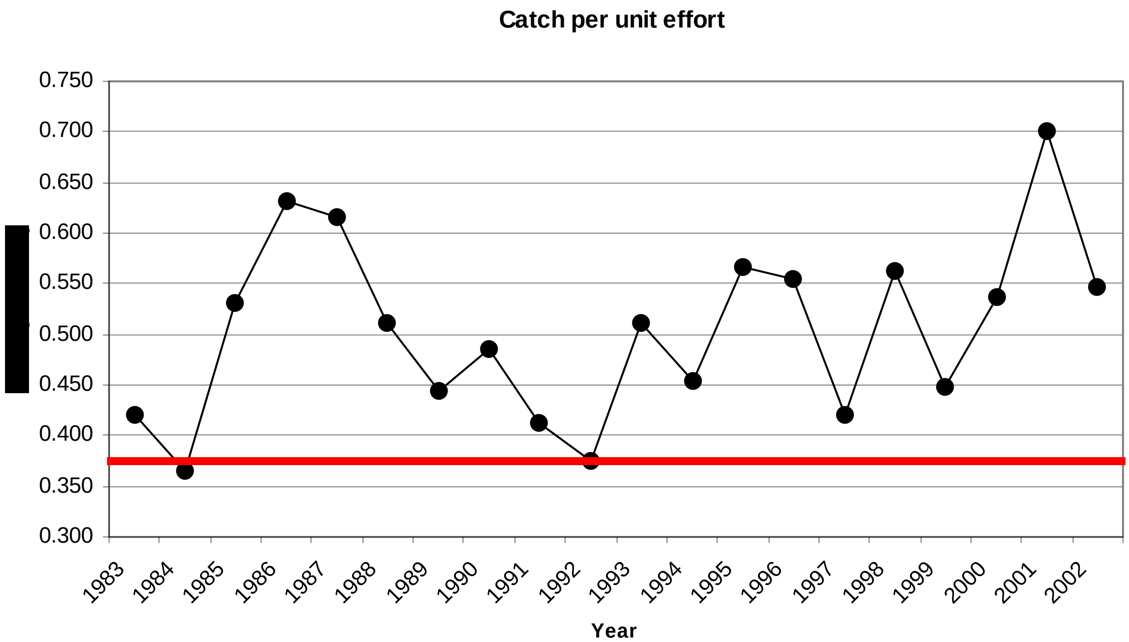

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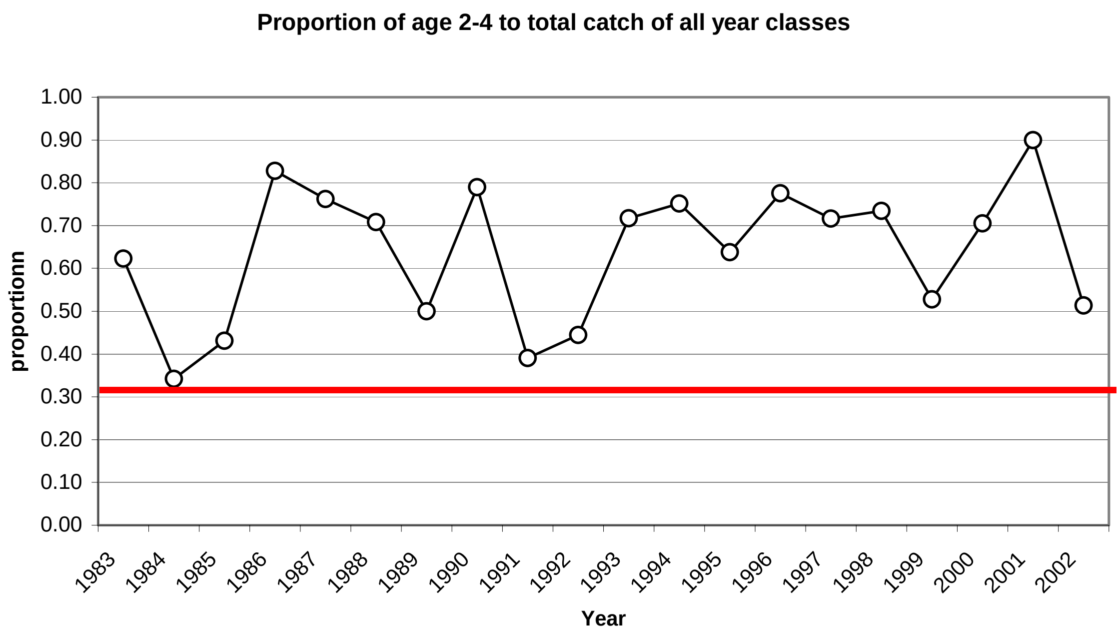
Figure 4



III. Revised Habitat Section

I. Description of Habitat

A. Spawning Habitat

Geographical and temporal pattern: There is some degree of spawning by Atlantic menhaden during all months of the year, but not in all portions of its range at the same time (Higham and Nicholson 1964; Judy and Lewis 1983). Spawning is associated with the presence of the sexually mature portion of the Atlantic menhaden population during its seasonal migrations. Following some spawning during June, a low level of sexual activity (as indicated by ovarian indices) exists during July and August in the more northern portion of the fishes range, i.e. in waters off Long Island, Massachusetts, and during some years, the Gulf of Maine. Sexual activity increases markedly during September and peaks for the Northern Atlantic area during October (Higham and Nicholson 1964). Spawning occurs in the U.S. middle Atlantic region in September and October during the southerly, fall migration, and again from March to May during the northerly, spring migration. Spawning may occur offshore of Chesapeake Bay during late-September, October, and November during the fall migration, and then again sometime from March to May in the Spring. Spawning in the U.S. south Atlantic can occur from October to March. Based on frequency of sexually active females in the population, the majority (or at least

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a major portion) of Atlantic menhaden spawning occurs in the U.S. south Atlantic (Higham and Nicholson 1964; Nelson et al. 1977).

Spawning site physical characteristics: Atlantic menhaden are pelagic spawners, although direct observations of spawning have not been documented. Spawning sites are identified by the presence of their buoyant, pelagic eggs. Spawning appears to occur over much of the continental shelf (Nelson et al. 1977). Spawning off the Carolinas may be as far east as the western edge of the Gulf Stream (Checkley et al. 1988). In the US middle Atlantic, spawning may occur 70 - 100 km off shore. Proceeding further north, spawning continues to occur off shore, but can also be inshore, with some spawning occurring in bays and sounds in the U.S. north Atlantic (Nelson et al. 1977).

Spawnings documented by the presence of eggs were noted by Matthiessen (1974) (cited by Nelson et al. 1977) in Narragansett Bay, R.I. during June of 1972. Ferraro (1980a) found Atlantic menhaden eggs in the Peconic Bays (within Long Island Sound), N.Y. Data has recently been made available from MARMAP (Marine Resource Monitoring Assessment and Prediction) collections ranging from the Gulf of Maine to Cape Hatteras (Berrien and Sibunka 1999). More recent spawning site information (south of Cape Lookout, NC) has been obtained from the SABRE (South Atlantic Bight Recruitment Experiment) cruises (Checkley et al. 1999). Earlier egg data from RV *Dolphin* cruises covers the U.S. Atlantic coast from Martha's Vineyard, MA to Cape Lookout, NC (Kendall and Reintjes 1975). Atlantic menhaden eggs were also noted from cruise data of the MV *Theodore N. Gill* which sampled the U.S. south Atlantic from Cape Lookout, NC to southern Florida (Reintjes 1961). (Menhaden eggs were collected near Jupiter Inlet and Cape Canaveral, FL, and Cape Fear and Cape Lookout, NC. The Florida samples could actually be eggs from yellowfin menhaden, *Brevoortia smithi*, Atlantic menhaden, or hybrids of the two; however, it is very likely that the egg samples from North Carolina waters are from Atlantic menhaden.) The most southerly report of spawning inside bays or sounds, as determined by the presence of eggs, was in Chesapeake Bay (Dovel 1971).

Bottom composition in the spawning areas is of the class "unconsolidated bottom" (after Cowardin et al. 1979). In the U.S. south and mid Atlantic area, the bottom is mostly sand, with some mud. Rockier bottoms become more common in the U.S. north Atlantic area. Because this species is pelagic and its eggs float, bottom type is not pertinent most months of the year.

Depths of water in presumed spawning areas were obtained directly from two sources. Kendall and Reintjes (1975) reported a range from 23 to 54 m. Checkley et al. (1999) data range from 10 to 120 m, with a very dominant mode at 20 m. Unfortunately, depth data was not available in Berrien and Sibunka (1999). The shallowest water where spawning was documented, was less than 7.6 m in Narragansett Bay, RI (Bourne and Govoni 1988).

Temperatures of spawning waters were similarly obtained. Temperatures recorded at egg collection sites reported by Kendall and Reintjes (1975) ranged from 13.5 to 17.3 °C (upper water column temperatures). Checkley et al. (1999) reported eggs in waters ranging from 15 to 24 °C (recorded at 3 m depth). Temperature data from individual collection sites from the MARMAP cruises (reported by Berrien and Sibunka (1999), is presented in Stegmann et al. (1999). Atlantic menhaden eggs were found in water temperatures ranging from 13 to 24°C (upper 15 m of water column). The greatest density was noted at 17°C. The coolest temperature where eggs were found was about 9.0°C of Nantucket (Marak et al. 1962) and the warmest, 26.7°C in the Long Island area (Perlmutter 1939).

Salinities at sites where eggs were reported by Kendall and Reintjes (1975) ranged from 30.5 to 32.8 ppt in the U.S. middle Atlantic area; while Checkley et al. (1999) reported a range of 35.8 to 36.6 ppt in the U.S. south Atlantic area. The lowest salinities were reported with inside spawnings, i.e. 18 to 28 ppt in Long Island Sound (Wheatland 1956) and 10 to 22 ppt in Chesapeake Bay (Dovel 1971). The minimum salinity necessary to retain egg buoyancy has not been determined. Cambalik et al. (1998) found a positive ascent rate for eggs at 28 ppt. Some marine fish species can adjust the aqueous content to maintain positive buoyancy in different salinities (Craik and Harvey 1987).

B. (Egg and) Larval Habitat

Geographical and temporal patterns: Since Atlantic menhaden are assumed to spawn in aggregations or large schools, the distribution of eggs will be patchy (contagious) (Reintjes 1969; Checkley et al. 1999). Within the temperature ranges associated with spawning, eggs will hatch within two or three days (see Ferraro 1980b). Hence, eggs have not been sampled over a wide range during any particular cruise. Geographic locations of what egg collections have been made are summarized without regard to temporal patterns on Map 1. On the other hand, larvae can exist in oceanic waters over a much greater period of time. Larvae can then become increasingly dispersed as time passes from spawning. Thus, larvae can be found over much broader geographic ranges and are temporally lagged long after spawnings and subsequent adult migrations. Judy and Lewis (1983) reported on catches of Atlantic menhaden larvae 400 km off the mainland U.S. (Map 2). A number of reports from sampling cruises indicate that the larvae tend to be larger (and older) as sampling proceeds closer to shore (Warlen 1992; Checkley et al. 1988; Massman et al. 1962; Kendall and Reintjes 1975; Hettler and Hare 1998). Wider ranges in other variables associated with spawning and egg distributions are also prevalent, as noted below. Warlen (1974) reported larvae as old as 120 days entering inlets, although a range of 30 to 90 days is more common.

(Egg and) Larval habitat physical characteristics: The physical habitat description for eggs is the same as for spawning habitat because of the short duration of the egg stage (about 48 hours). During the oceanic phase, many larvae will range from relatively deep, warmer areas off shore to cooler, shallower areas near shore, over a matter of a few weeks to a few months.

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Bottom composition of the habitat for this like stage is the same as spawning area above, i.e. unconsolidated bottom of mostly sand and mud. Again, in the more northerly portions of the range, some rocky bottoms become more common. Since the eggs float and the larvae are pelagic, bottom composition is not pertinent.

Depths recorded in areas where (oceanic) larvae were taken range from 5 m (Hettler and Hare 1998) to >200 m (Govoni 1993). Since larvae are apparently dependent on alongshore and inshore transport to reach inshore, estuarine areas over much of their range, the depth occupied by these larvae will be critical for survival, as certain depths may tend to have unfavorable directional currents. Larvae tend to stay above the pycnocline, and undergo complex, behavioral responses to salinity, temperature, and diurnal periods during their oceanic phase that change ontogenetically (Forward et al. 1999).

Temperatures where larval Atlantic menhaden have been captured ranged from 0 to 25° C on the cruises reported by Kendall and Reintjes (1975). The warmest water where larvae were sampled was 26.3° C in the Long Island area (Perlmutter 1939). {-check winter spawnings-shoreward movement into cooler waters- (Warlen and also Checkley, et al.)}

Salinities in areas where small larvae were generally found ranged from 20 to 37.8 ppt. Very small larvae were also reported in Chesapeake Bay by Dovel (1971), with observed salinity ranging from 0 to 11 ppt. (Low salinities are more common with advanced size and age of larvae as will be noted subsequently.)

C. (Late larval and) Juvenile Habitat

Geographical and temporal patterns: Relatively recent studies (Warlen 1994; Hettler and Barker 1993) have documented the estuarine immigration of larvae from November to May in the U.S. South Atlantic area. Reintjes and Pacheco (1966) give the period for estuarine entry as ranging from October to June for the U.S. Middle Atlantic area, and May to October for the New England area. It is interesting to note, that the larvae in the New England area are comprised of individuals that represent the end of one spawning season and the initiation of the next. U.S. Middle Atlantic immigrating larvae are comprised of individuals from spawning activities on both the fall, southerly migration and the spring, northerly migration of the spawning stock. Immigrating larvae in the U.S. South Atlantic appear to represent products from late fall, winter, and very early spring spawnings (see Ahrenholz 1991 for a more detailed discussion).

Metamorphosis (transformation) to the juvenile stage normally occurs in lower salinity estuarine water. The rate of occurrence of this event is temperature dependent. Many of the fall immigrants begin metamorphosis soon after estuarine entry, but because of rapidly cooling water in the late fall, early winter; the process is frequently not completed until the following spring in the U.S. South Atlantic area and in the Chesapeake Bay area. Under these circumstances the young menhaden over winter as late larvae / prejuveniles (Ahrenholz, et al. 2000). Estuarine residency continues during the summer months. From fall through early winter, schools of juvenile menhaden emigrate from their estuarine nursery areas and migrate southward along the

U.S. Atlantic coast. While many of the juveniles leave the estuarine systems, some over winter within estuaries in Chesapeake Bay and the U.S. South Atlantic area.

Juveniles that were spawned from late-summer through December, are considered members of the next year's year-class. Each year class is advanced a year of age on March 1 (an arbitrary birthdate.) Hence, juveniles become sub-adults (age-1) on March 1 of the year after their year-class designation. In actual age on their first "birthday", these fish are commonly 9 to 18 months of age, but can be as young as eight or as old as 20 months. From late fall until the following March, their can be two different year classes in the estuaries, both designated as age 0. But, as noted above, the new year class of larvae do not frequently complete the transformation to juveniles until sometime after March 1.

(Late larval and) juvenile habitat physical characteristics: Juvenile Atlantic menhaden are generally considered as being ubiquitous in lower salinity (<10 ppt) estuarine areas. They have been commonly found in estuarine streams from Lanceford Ck., Florida, to harbors and ponds in Massachusetts (Ahrenholz, et al. 1989), and occasionally even further north to Annapolis River, Nova Scotia (Stokesbury and Stokesbury 1993).

Bottom Composition in the estuarine nursery areas is of the class "unconsolidated bottom", and is mostly sand, mud, with various mixtures of organic material. The bottom type is of greater interest in some of the areas, as some documentation of detrital consumption exists (Lewis and Peters 1984, 1994; Peters and Schaaf 1991). In more northerly areas, postlarvae and juveniles can be found in rocky coves, with mixtures of cobble, rock, and sand bottoms.

Depth selection in estuaries by newly immigrated larvae will relate to up estuary transport to lower salinity areas (Forward et al. 1999). Juveniles can be in water less than a meter in total depth. They are pelagic, and during most months are within a meter or less of the surface.

Temperatures have been recorded at inlets when larvae were observed that ranged from about 0° C to 21° C. Reintjes and Pacheco (1966) speculated that 3° C appears to be a critical or threshold value relative to estuarine entry and subsequent survival. Juveniles have been observed in waters up to at least 33° C (Friedland et al. 1989).

Salinities at sites of larval immigration have been observed from about 9 ppt to 36 ppt (Hettler and Barker 1993). Juveniles have normally been found in salinities that ranged from 0 ppt to about 15 ppt, but ultimately the latter will range to that of seawater. Metamorphosis appears to occur at the lower of the salinities, and then during the season larger juveniles will be found at progressively higher salinities. Metamorphosis can occur in areas with salinities >20 ppt (harbors and coves), but the highest densities of postlarvae and pre-juveniles are found in <10 ppt.

D. Sub-Adult Habitat

Geographical and temporal patterns: For purposes of this discussion, all of age-1 fish (second year of life), and all age-2 fish until the fall of their third year of life, will be considered sub-adults. After the fall age-2 fish will be considered (sexually mature) adults. Similar assumptions were made for earlier analyses of this fishery (Ahrenholz, et al. 1987; Nelson et al. 1977). With some exceptions, the bulk of the information on the distribution of sub-adult (and adult) Atlantic menhaden is dependent on location of purse-seine sets and landings of the reduction fishery.

The population is distributed by size and age along the U.S. Atlantic coast by June. Age-1 and smaller age-2 fish are common in the U.S. South Atlantic area near shore, and within some bays and sounds. Chesapeake Bay proper will generally contain age-1 and age-2 fish, but they will probably be larger than individuals to the south. Similarly, the U.S. Middle Atlantic area, including Delaware Bay, will contain proportionately greater numbers of older and larger fish and lesser numbers of younger and smaller. The greatest numbers of older fish and fewest numbers of younger fish will be in the U.S. North Atlantic area, including Long Island Sound (note: Nicholson 1971; Nicholson 1972; and Nicholson 1975). The major source of summer distribution (both north-south, and distance from shore) of these fish can be deduced by the frequency and location of purse-seine sets (see Appendix Table V). (The absolute offshore distribution is unknown, perhaps because of the limitation on depth that can be effectively fished by purse seine.) During late summer, the most northerly fish (north of Cape Cod, Gulf of Maine) will begin to move southward. These schools will join other migratory schools from Long Island, south to Chesapeake Bay during October and November. By early December, schools of migratory juveniles, sub-adults, and adults will be off the North Carolina capes. These fall, early winter, migratory schools are frequently very close to shore. It is presumed that a major portion of the migrating sub-adult stock moves south of Cape Hatteras. While the larger fish can be expected to over winter off the North Carolina coast, tagging data has shown that some juveniles apparently move as far south as northern Florida for their first winter, as they were available as sub-adults to a purse-seine fishery at Fernandina Beach, FL the following summer. A fishery independent trawl survey caught relatively large numbers of small Atlantic menhaden in January, from Charleston to northern Florida (Wenner and Sedberry 1989). Most of these fish would turn age-1, (sub-adults) about one month after the sampling. Spring, summer, and fall abundances of this species in this survey very far less abundant. The survey trawled shelf waters ranging from 4.6 to 9.1 m deep from Cape Fear to Cape Canaveral.

Sub-adult habitat physical characteristics: Sub-adult Atlantic menhaden will tend to be in the more southerly portion of the species range, more commonly Chesapeake Bay and south. Hence, the physical characteristics of their habitat will reflect temperate, near-shore marine and estuarine areas.

Bottom composition in areas inhabited by this life history stage of Atlantic menhaden will consist of unconsolidated bottom, mostly of sand and mud with increased amounts of organic material in the estuarine areas as opposed to the marine.

Depths where sub-adults have been captured range from less than a meter to at least 9 m, but they are probably located in waters of greater depth.

Temperatures recorded (bottom) during the trawl survey in the U.S. south Atlantic, ranged from about 7 to 15° C in January, with most of the fish in the waters >9° C (Wenner and Sedberry 1989). Fish overwintering in the estuaries will most likely endure lower temperatures. Summer temperatures during the trawl survey ranged up to 28.8° C. Similarly, estuarine resident fish will endure higher temperatures during the summer months.

Salinities recorded for the oceanic, overwintering juveniles (near sub-adults) ranged from 33.2 to 35.6 ppt (Wenner and Sedberry 1989). Similarly, estuarine overwintering fish will be subjected to much lower salinities. Regardless of season, the survey found Atlantic menhaden in salinities of 33.2 to 36.9 ppt.

E. Adult Habitat

Geographical and temporal patterns: During June, most mature adults are in the more northerly portion of the range, from Long Island northward into the Gulf of Maine. The northern extreme of the range is variable and dependent on environmental conditions, probably predominately temperature, and age structure of the stock. That is, the older the individuals are, the farther north they can be expected to venture. During late summer, these fish will begin to move southerly, and during October and November they will join sub-adults and estuarine-emigrant juveniles. Some of the sub-adults will be maturing at this time, and may well contribute to the fall-winter spawning in the U.S. mid- and south Atlantic area. There is generally a newly maturing group of fish that summered in Chesapeake Bay and North Carolina coast that migrate south just ahead of the migratory schools from more northerly waters. These fish, termed "fore-runners", may initiate spawning in the fall off the North Carolina coast (Smith and Ahrenholz 2000). After the surface schools disappear, these fish are felt to overwinter somewhere off the North Carolina coast. During the winter, adult Atlantic menhaden have been taken by the small-mesh, sink-net fishery. Successful purse-seine sets have also been made during this time by setting on "bubbles" and/or mud roils. Relatively large numbers of adults have also been taken in gill nets during February and March within North Carolina's sounds.

Adult habitat physical characteristics: Any differences between adult and sub-adult Atlantic menhaden will result from the more northerly range of the larger and older mature fish; and the more southerly range of the younger, smaller sub-adults. The bottom composition will tend to be more rocky and the upper end of the temperature range cooler, proceeding northward for the summer months.

Bottom composition in the habitat occupied by adults ranges from unconsolidated, estuarine bottoms of sand, mud, and organic material to marine sand and mud, with increasing amounts of rock in the more northerly areas.

Depths where adult menhaden have been captured range from less than a meter in inshore areas to least 20 m in the ocean. Depths of areas where eggs were found exceeded 200 m.

Temperatures near 18° C are (felt by some to be) preferred by the sexually mature individuals. Seasonal migrations and on-shore, off-shore movement may be attributed to adults seeking waters within a certain temperature range. If this is the case, then younger fish, i.e. larvae, juveniles, and sub-adults are actually subjected to greater temperature extremes that adults.

Salinities recorded in areas where mature adults have recently been, i.e. where eggs were located, normally range from 28 to 32 ppt, but have been noted from 18 to 37 ppt.

Table 1. Significant environmental, temporal, and spatial factors affecting Atlantic menhaden's life history stages.

Life Stage	Time of Year	Location	Temperature	Depth (m)	Salinity	Substrate	Estuarine Use	Notes
Spawning Adults	June - August	Mostly from Long Island, NY and north	About 12 - 27 °C	< 7 to ~ 100 m or greater	18 - 32 ppt (see text re: pelagic eggs)	Unconsolidated bottom: sand, mud, some rock	Some spawning occurs in bays and sounds	
	September - November	Mostly North Atlantic to Cape Hatteras, NC	About 12 - 24 °C	As above	As above	As above	as above for areas north of NJ	
	December - February	Mostly mouth of Chesapeake Bay to off NC coast	About 15 - 24 °C	~ 10 to 120 m	~ 30 - 37 ppt	As above	Limited evidence for *spawning* in Chesapeake Bay; none inside south	Some adults with developed ova occupy bays and sounds
	March - May	Limited amount on northerly migration NC to New England	10 (?) - ~20 °C	~ 10 to 120 m	~ 28 - 32 ppt	As above	As above	
Eggs/Larvae	June - August	Mostly north of DE	~ 10 - 27 °C	< 7 to ~ 100 m or greater	~ 0 - 32 ppt	Unconsolidated bottom: sand, mud, some rock	larvae (appear) to seek lower salinity water	
	September - November	North Atlantic area to Cape Hatteras, NC		< 7 to > 200 m	~ 0 - 36 ppt	As above	[Older larvae are entering estuaries (see text)]	
	December - February	Mostly NC coast to northern FL; some north to at l Delaware Bay	~ 0 - 24 °C	As above	~ 0 - 37 ppt	As above	As above	
	March - May	Northern FL to NJ; younger proceeding north	>0 - ~ 24 °C	As above	~ 0 - 37 ppt	As above	As above	

Table 1. (Continued)

Life Stage	Time of Year	Location	Temperature	Depth (m)	Salinity	Substrate	Estuarine Use	Notes
Juvenile (includes post-larvae /pre-juvenile)	Year around; greatest abundance May to July	NC through Chesapeake Bay -	~ 0 - 33 °C (3 °C threshold for survival [?])	All available depths from about 0.5 m and greater	~ 0 to 36 ppt	Unconsolidated bottom: sand, mud, and organic material.	Predominately	See text for year class separation and definition
	At least most of year - Spring through Fall - (Surveys incomplete during winter months)	FL to SC; DE to NJ	As above	As above	As above	As above	As above	Note above
	June through October	Long Island and north		as above	probably about 10 to 32 ppt	Unconsolidated bottom; sand, mud, some rock	Where available	
Sub-Adult	June - November	Mostly US mid-Atlantic and south to northern FL	recorded values up to 28.8 °C	0.5 meters and greater	~ 10 to 36 ppt	Unconsolidated bottom; sand, mud, organic material	Mixed near shore and estuarine occupancy	
	December - February	Most appear to over winter off the Carolinas to FL	Appear to seek waters > 9 °C	Recorded to 9 m	recorded to 36 ppt	As above	Presumed mostly off shore; but some in NC and Chesapeake Bay	
	March - May	Redistributing from northern FL to US mid-Atlantic		0.5 meters and greater	~ 10 to 36 ppt	As above	Mixed nearshore, and estuarine occupancy	
Adults	Year Round	Similar to spawning adults given above, except newly maturing, fish are more southerly					Mixed nearshore and estuarine occupancy	

II. Identification and Distribution of Habitat Areas of Particular concern

Most Atlantic menhaden spawning occurs offshore, so this habitat type is probably the least sensitive, and one of the least limited. (The only exceptions would be inshore spawning areas such as Long Island Sound or Narragansett Bay, RI, but these areas probably do not make significant contributions to the stock as a whole.)

Inlets required for estuarine entry are critical to the larval stage of this species as well as to a large number of other estuarine dependent fishes.

In the mid- and U. S. South Atlantic, estuarine habitat utilized for transformation and early development is one of the most critical as well as vulnerable habitats. The early nursery area is generally at the head of estuarine systems, near, if not at 0 ppt salinity. Much of the early development takes place in estuarine water where the salinity is normally less than 10 ppt. These areas are subject to nutrient and chemical (non-nutrient) overloading. Toxic and/or anoxic (hypoxic) conditions can result. A minimum estuarine residence for developing young is about 7 months, but residence can extend for as long as 22 months. After the initial estuarine emigration, the habit frequented by sub-adults and adult Atlantic menhaden is most commonly nearshore. It is also apparent, that older individuals will frequently re-enter estuarine systems for extended periods of time.

A historical perspective of production by area of estuarine nursery can be extrapolated on a geographical perspective from data collected during earlier NMFS juvenile abundance surveys (JAS) (Ahrenholz et al. 1989). Since an individual trawl tow covered almost a surface acre, catch per tow (CPT) values reflect minimum estuarine density of juvenile Atlantic menhaden. (The methodology was most effective for juveniles ranging from about 35 to 60 mm, but with night/turbid water surveys, juveniles ranging in sizes >80 mm appeared to be effectively captured.) Individual CPT values in the JAS ranged from 0 to >200,000. Arithmetic mean CPTs for the Atlantic coast from 1972 to 1978, ranged from 653 to 5,248.

III. Present Conditions of Habitats and Habitat Areas of Particular Concern

A. Marine-subtidal; unconsolidated bottom:

1. **Habitat quantity -** This habitat type is utilized by spawning adults (eggs), pre-estuarine immigrant larvae, post-estuarine emigrant juveniles and sub-adults. It is also the most abundant or vast habitat type, consisting of most of the U.S. continental shelf of the north-western Atlantic (near-shore to the shelf break).

2. **Habitat quality -** Of the habitats utilized by Atlantic menhaden, this is the least degraded and/or anthropogenically disturbed.

3. **Current threats -** Petroleum products from maritime shipping accidents, off shore drilling mishaps, and excessive quantities of domestic waste, both nutrifying and toxic industrial wastes from over-abundant sewage outfalls.

4. **Effects of degradation on harvesting/marketing -** None apparent relative to Atlantic menhaden.

B. Estuarine-subtidal; unconsolidated bottom:

1. **Habitat quantity -** Using USFWS (1970) estimates of estuarine habitat that most closely matched that of juvenile Atlantic menhaden, geographic (although somewhat arbitrary) regional break outs were: North Atlantic (NY, CN, RI, MA) 173,700 acres; Middle Atlantic (including Chesapeake Bay) (VA, MD, DE, NJ) 1,302,300 acres; and South Atlantic (10% of FL acreage, GA, SC, NC) 1,248,650 acres (see Ahrenholz et al. 1989). (Acreage in Maine and further north are minor.) These values have been reduced to reflect habitat loss due to dredge and fill operations for a twenty year period ending about 1967. During this period, losses in the North Atlantic area averaged 10.4%; Middle Atlantic area 4.9%; and South Atlantic area 2.7%. (Changes in methodologies have prevented a comparable computation of additional [more recent] habitat loss.) A sub-set of the remaining acreage that is considered most critical (and vulnerable) is the areas that range along salinity gradients with 0 to 5 ppt salinity. The next most critical are areas from 5 to ~10 ppt salinity. The most common bottom type is mud, sand, and organic for most of the U.S. mid and south Atlantic, with increasing amounts of cobble-gravel in the U.S. north Atlantic. Some rocky bottom is also present in the more northerly areas.

2. **Habitat quality -** US Atlantic coast estuaries have historically received increasing amounts of nutrient and other chemical pollutants from adjacent development and upstream sources. Hence, many estuarine areas can be deemed nutrient overloaded and contaminated. Significant amounts of estuarine nursery areas have been reduced in quality and quantity due to dredge and fill activities, and hardening of the shoreline.

3. **Current threats -** Increasing numbers of people are moving to U.S. coastal areas. There are resulting increases in point and non-point runoff of contaminants associated with this population shift. Coastal developments are continuing to support dredge and fill activities along with increasing amounts of developed, hardened shoreline. Agricultural practices, including high-density poultry and swine farming, have also resulted in high levels of water shed contamination. Large quantities of pesticides, herbicides, and chemical fertilizers, along with livestock fecal waste, continue to enter estuarine systems. [During the fall of 1984 an apparent outbreak of ulcerative mycosis (UM) occurred on juvenile Atlantic menhaden in estuarine nursery areas from New York to Florida (Ahrenholz et al. 1987b; Hargis 1985; Noga et al. 1988). The primary agent for UM has been attributed to the fungus, *Aphanomyces invadens* (Blazer et al. 1999; Blazer et al. 2002). The presence of UM was perceived by managers and some scientists as a habitat quality problem, that reflected reduced viability of estuarine nursery areas. A number of fish kills with high numbers of

Atlantic menhaden included, have been reported in North Carolina, Virginia, and Maryland. Some of the kills were attributed to a dinoflagellate, *Pfisteria piscicida*, or other *Pfisteria* like dinoflagellates (Burkholder and Glasgow 1997) (for taxonomy see Litaker et al. 1999). Not infrequently, the fish that succumb have a background UM infection. Although associated, the actual linkage between UM and the dinoflagellates has yet to be determined. These problems appear to be natural events made more frequent and prominent by anthropogenic activities deteriorating the habitat**.** A reversal of the impacts is unlikely in some areas and long term in others.**]**

4. **Affects of degradation on harvesting/marketing -** Habitat degradation problems made apparent by publicized impacts on Atlantic menhaden by UM, have affected the harvest and marketability of fish species landed for human consumption; both by direct closures (Neuse-Pamlico area in NC; and Pocomoke River in MD) and general public perception. Atlantic menhaden fish meal is commonly used as a feed supplement for poultry and swine, and has become increasingly important in manufacturing feed for the growing aquaculture and mariculture industry. Demand for menhaden fish meal could dramatically decrease if any toxic compounds currently being found in some aquacultural products can be traced back to Atlantic menhaden (meal) or if high incidences of UM cause fish meal buyers to assume "something is wrong" and seek meal from other species of fish from other countries.

C. Riverine-tidal (and -lower perennial); unconsolidated bottom:

1. **Habitat quantity -** The interface of this habitat type and estuarine areas represent the upstream extent of larval movement for transformation and early juvenile development. This type of habitat is frequently geographically encountered, but does not consist of a large amount of area in comparison to other Atlantic menhaden life-stage habitat types.

2. **Habitat quality -** This habitat type has been subjected to similar activities as the estuarine areas. The degree of nutrient flushing in these habitats is probably intermediate between the areas upstream, that have higher flow rates, and estuarine area, which has a low rate of water exchange with the ocean.

3. **Current threats -** Hypoxic conditions can occur in these habitat types as in the estuarine area. UM infected fish have been found in this habitat type (- check NC Rapid Response Team records -) Some of the negative impacts are reversible, but since anthropogenic factors are exacerbating natural phenomena, they won't be eliminated entirely.

4. **Affects of degradation on harvesting/marketing -** Similar problems (note above - estuarine areas) in terms of public reaction and attitude may have occurred relative to these habitat types, but not as pronounced.

IV. Recommendations and/or Requirements for Fish Habitat Conservation/Restoration

1. State resource management agencies should identify, inventory, and protect menhaden habitat under their stewardship. Habitat integrity should be monitored to retain functional characteristics essential for survival of Atlantic menhaden. While menhaden are wide spread in estuarine systems, areas of higher density (and use) should be identified.

2. Atlantic menhaden habitat areas of particular concern (HAPC) should be identified, quantified, and closely monitored to enhance protection efforts. Habitats associated with sensitive life history stage(s) or critical life history events should be identified and time periods of particular sensitivity noted.

3. Information obtained in items 1 and 2 above should be made available to local, state, and federal permitting agencies to minimize habitat loss and to aid in mitigation where losses have occurred. Information from item 2 should be used to allow scheduling of potentially damaging habitat alterations (such as dredging, fresh water releases and diversions, etc.) during less sensitive time periods. The larval stage of Atlantic menhaden is probably the most vulnerable. On a seasonal basis, larvae will pass through and occupy all habitat zones, i.e. open ocean, inlets, lower estuarine areas, and upper estuarine reaches where salinities may be at or near 0 ppt (note Appendices II, III, and IV).

4. State resource managers should be vigilant with respect to water quality. Juvenile and adult Atlantic menhaden form dense schools, where hypoxia can occur under certain (natural) circumstances. Poor water quality exacerbates this situation. Atlantic menhaden apparently have a thinner epidermal layer than many species of estuarine fish, making it especially vulnerable to disease and parasites. Water borne contaminants can increase their susceptibility and increase negative impacts at individual and population levels.

5. In order to restore or maintain historic salinity gradients, state fisheries managers should work closely with other agencies that influence freshwater runoff patterns (rates), river drainage basins, and general integrity of estuarine systems.

6. Although significant filter feeding activity occurs in pelagic areas, Atlantic menhaden feeding schools commonly swirl over bottom areas, suspending and subsequently feeding on diatoms and other settled biotic material. Hence, state fisheries managers should work closely with appropriate agencies that influence and monitor sediment loads and sediment borne contaminants that may ultimately affect the well being of the menhaden population.

7. Because inlets required for estuarine entry are critical to the larval stage of this species, state and federal agencies should ensure that actions such as construction jetties does not threaten inlet integrity and larval passage for menhaden.

V. Information Needs/Recommendations for Future Habitat Research

1. Considerable funds and energy are being expended (and should continue to be) on issues relating to factors causing/exacerbating *Pfiesteria* sp. and *Pfiesteria*-like fish kills. Linkages/associations with ulcerative mycosis (UM) need to be further elucidated. The impacts of UM (*Aphanomyces invadens*) needs to be further investigated. Infection rates among fishery pre-recruits need to be determined and monitored, and potential impact on recruitment quantified.

2. Factors causing hypoxic conditions in some of the key nursery areas need to be further clarified and population impact determined. Interactions with agents in 1) above should be examined.

3. Knowledge of geographic and seasonal distributions of sub-adult and adult menhaden need to be expanded by using incidences of catches by gear other than commercial purse-seines. For example, valuable information on the winter distribution of sub-adults was obtained from the fishery independent surveys (MARMAP) reported by Wenner and Sedberry (1989). There are some recent reports of juvenile/sub-adult Atlantic menhaden off the coast of New England from November - January.

4. Tolerances of individual life-stages to environmental variables such as temperature and salinity should be obtained by observation and record keeping of naturally occurring events to enhance and supplement laboratory studies such as Lewis (1965;1966) and Lewis and Hettler (1968).

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Map Legends for Habitat Section

Map 1: Sites (Appendix I) where one or more menhaden eggs were collected during research cruises. Data are pooled for all seasons because of the limited number of collections. Seasonal aspects of spawning are apparent on the following larval distribution map. The egg collections off the Florida coast may be yellowfin menhaden, Atlantic menhaden, or yellowfin x Atlantic menhaden. All the North Carolina and collections further north are assumed to be Atlantic menhaden. The lack of eggs taken from waters off the Georgia and South Carolina coast is revealing, as a number of surveys were conducted in that area during fall, winter, and spring months. Note also the lack of eggs in the Gulf of Maine.

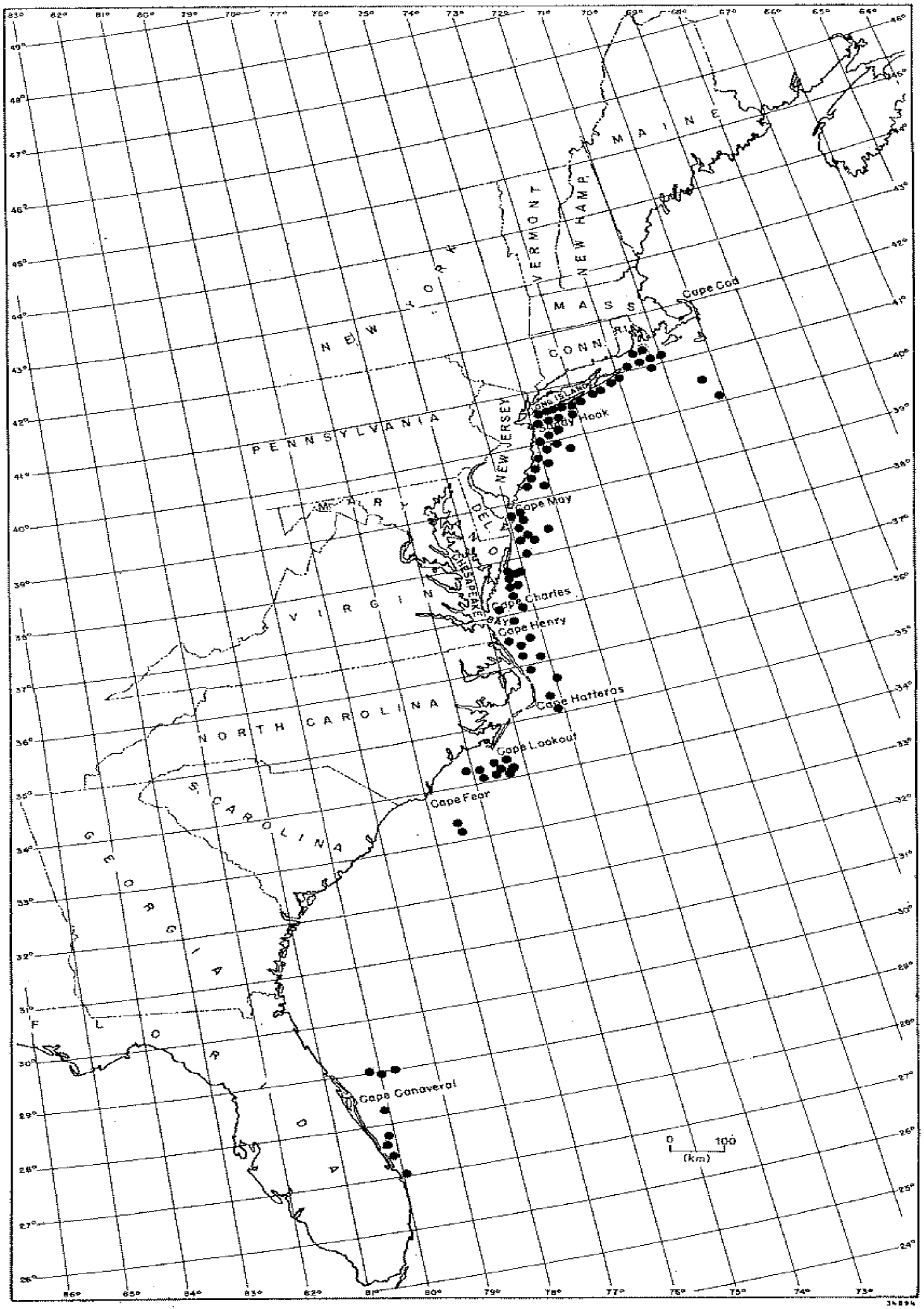
Map 2: Sites (Appendix II) where one or more larval Atlantic menhaden were collected during research cruises. The maps are from Judy and Lewis (1983), but simplified. Sites where no menhaden were taken were deleted, as there appeared to be adequate cruise coverage both geographically and seasonally, except for the months of September and January north of Cape Hatteras (Judy and Lewis [1983] Table 3). Maps are presented in the temporal order of the formation of a single year-class, i.e. **Map 2a** = July - September; **Map 2b** = October - December; **Map 2c** = January - March; and **Map 2d** = April - June.

Map 3: Sites (Inlets [Appendix III] and estuarine streams [Appendix IV]) of historical interest for early life history studies of Atlantic menhaden. Inlets where larval immigrants were sampled are located at White Creek , DE; Newport River, NC; White Oak River, NC. (Oregon and Ocracoke Inlets, NC are not shown on this map). Estuarine streams where abundance surveys were conducted by the NMFS from 1972-1978 are shown. Juvenile distributions were examined by the old Bureau of Commercial Fisheries in as many as 65 estuarine streams in 1968. During some years, some juvenile yellowfin menhaden were taken in Lanceford Creek, FL, but during most years, Atlantic menhaden were taken. Arrow denotes Annapolis River, Nova Scotia (Stokesbury and Stokesbury 1993).

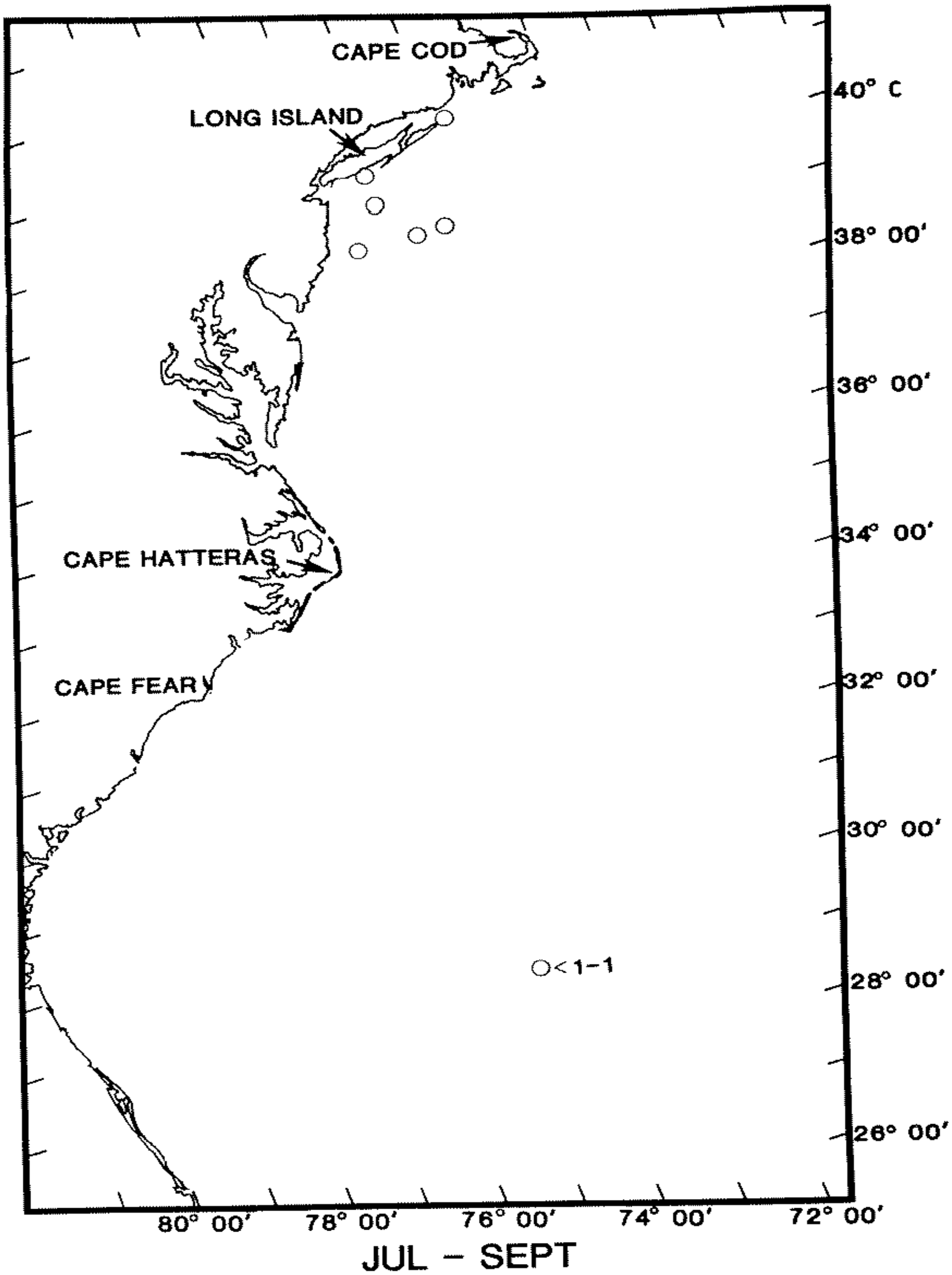
Map 4: Sites (purse-seine sets [Appendix V]) where sub-adult/adult (see narrative) Atlantic menhaden were captured by month of year, pooled for 1955-59. **Map 4a =** April - August; **Map 4b =** September - January. Map figures are from Roithmayr (1963). Because of the greater number and geographic range of reduction plants during these years than more recently, and fewer geographic fishing closures, this series best depicts monthly distributions of fish. Sub-adult/adult fish are also found in shallower, estuarine areas not suitable for purse-seineing by large vessels in the reduction fleet. These figures, however, best depict seasonal migrations/geographic availability.

Map 5: Seasonal migratory patterns of Atlantic menhaden. Figure is modified from Dryfoos et al. (1973), with the addition of arrows around Cape Cod, into and returning from the Gulf of Maine.

Map 1

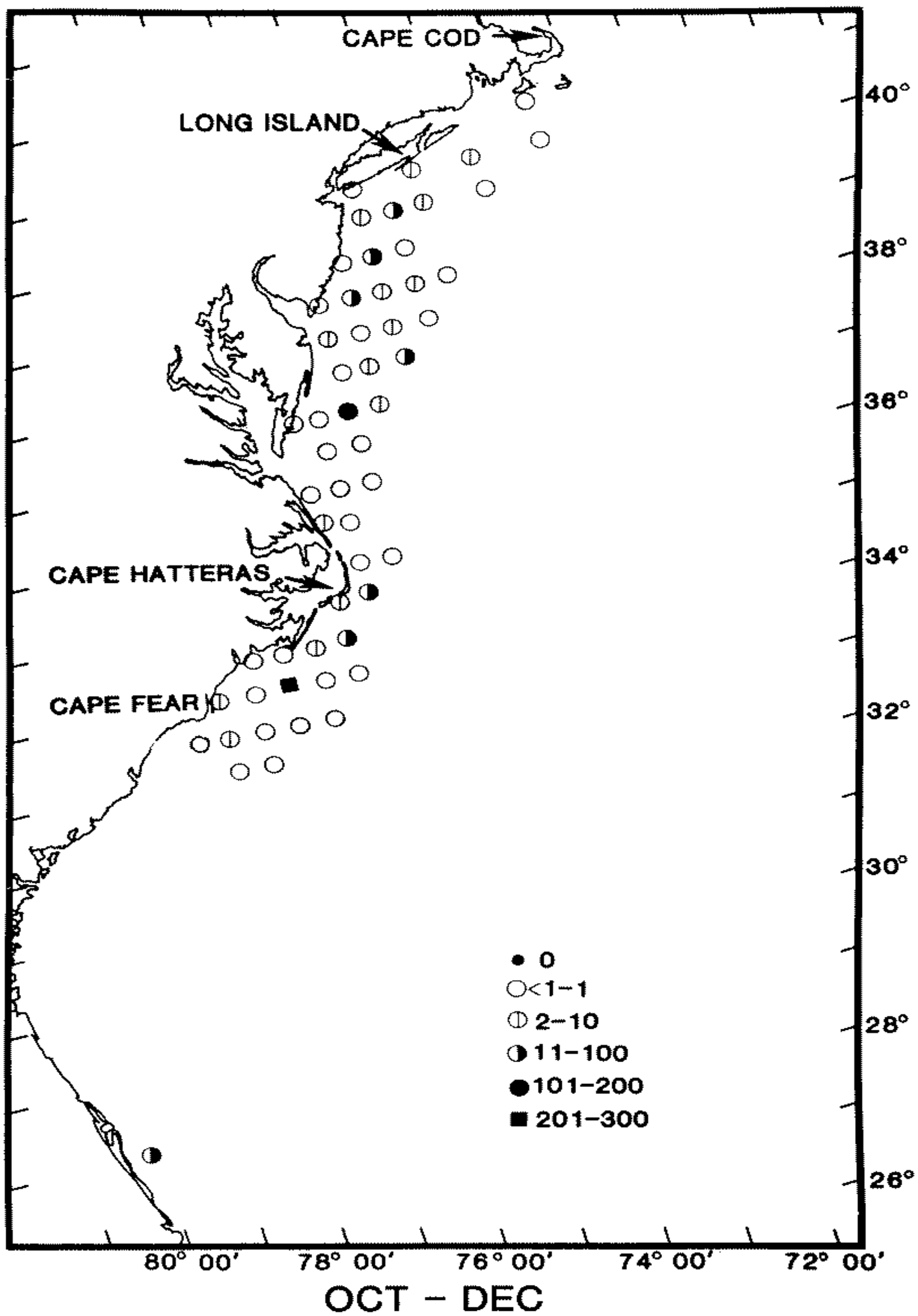

MAINE
VERMONT
NEW HAMP.
NEW YORK
MASS
CONN
R.I.
Cape Cod
LONG ISLAND
Sandy Hook
NEW JERSEY
PENNSYLVANIA
MARYLAND
DEL
Cape May
CHESAPEAKE BAY
VIRGINIA
Cape Charles
Cape Henry
Cape Hatteras
NORTH CAROLINA
Cape Lookout
Cape Fear
S. CAROLINA
GEORGIA
FLORIDA
Cape Canaveral
0 100
(km)

Map 2a

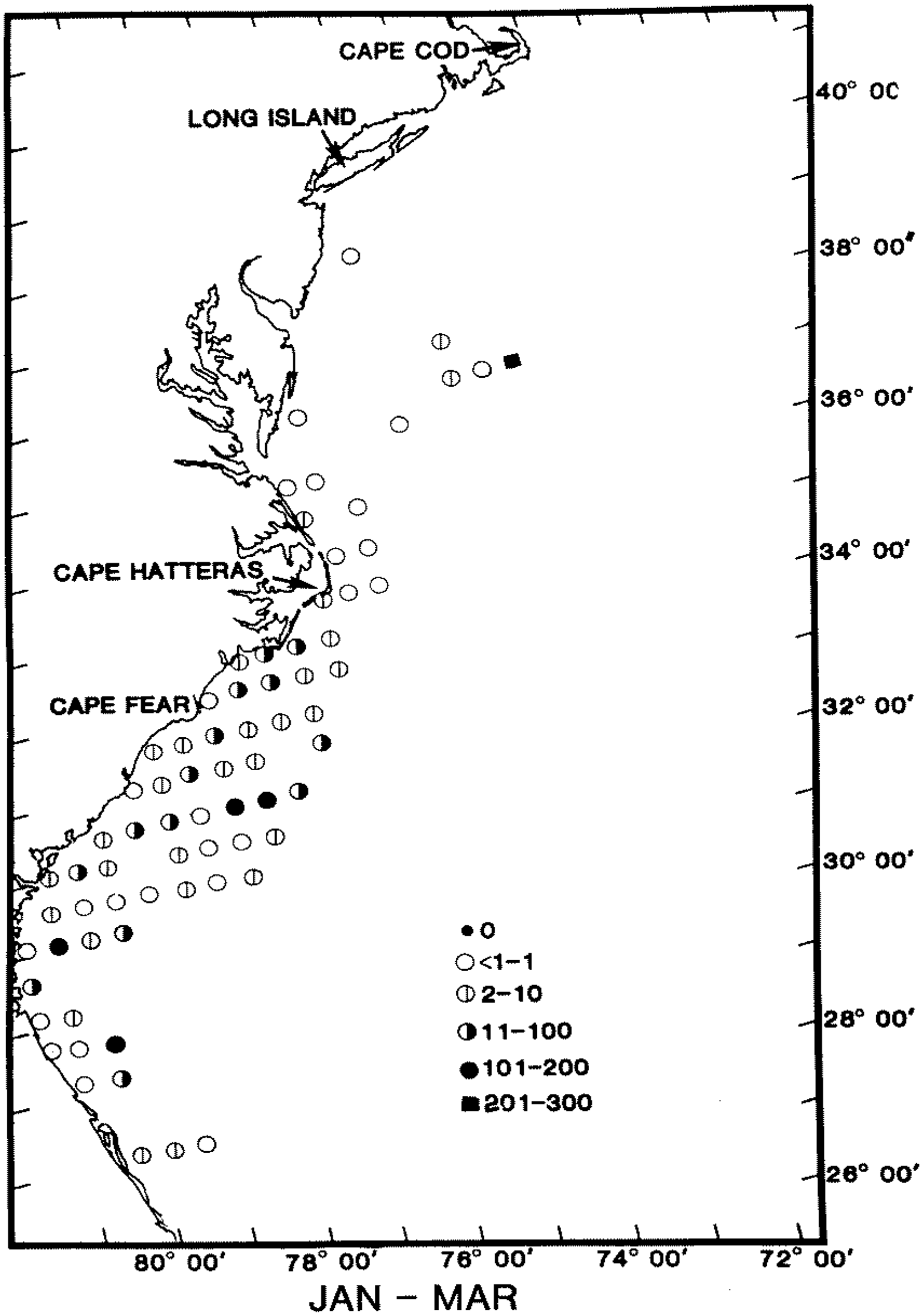


CAPE COD
LONG ISLAND
CAPE HATTERAS
CAPE FEAR
40° C
38° 00'
36° 00'
34° 00'
32° 00'
30° 00'
28° 00'
26° 00'
80° 00'
78° 00'
76° 00'
74° 00'
72° 00'
○< 1-1
JUL - SEPT

Map 2b

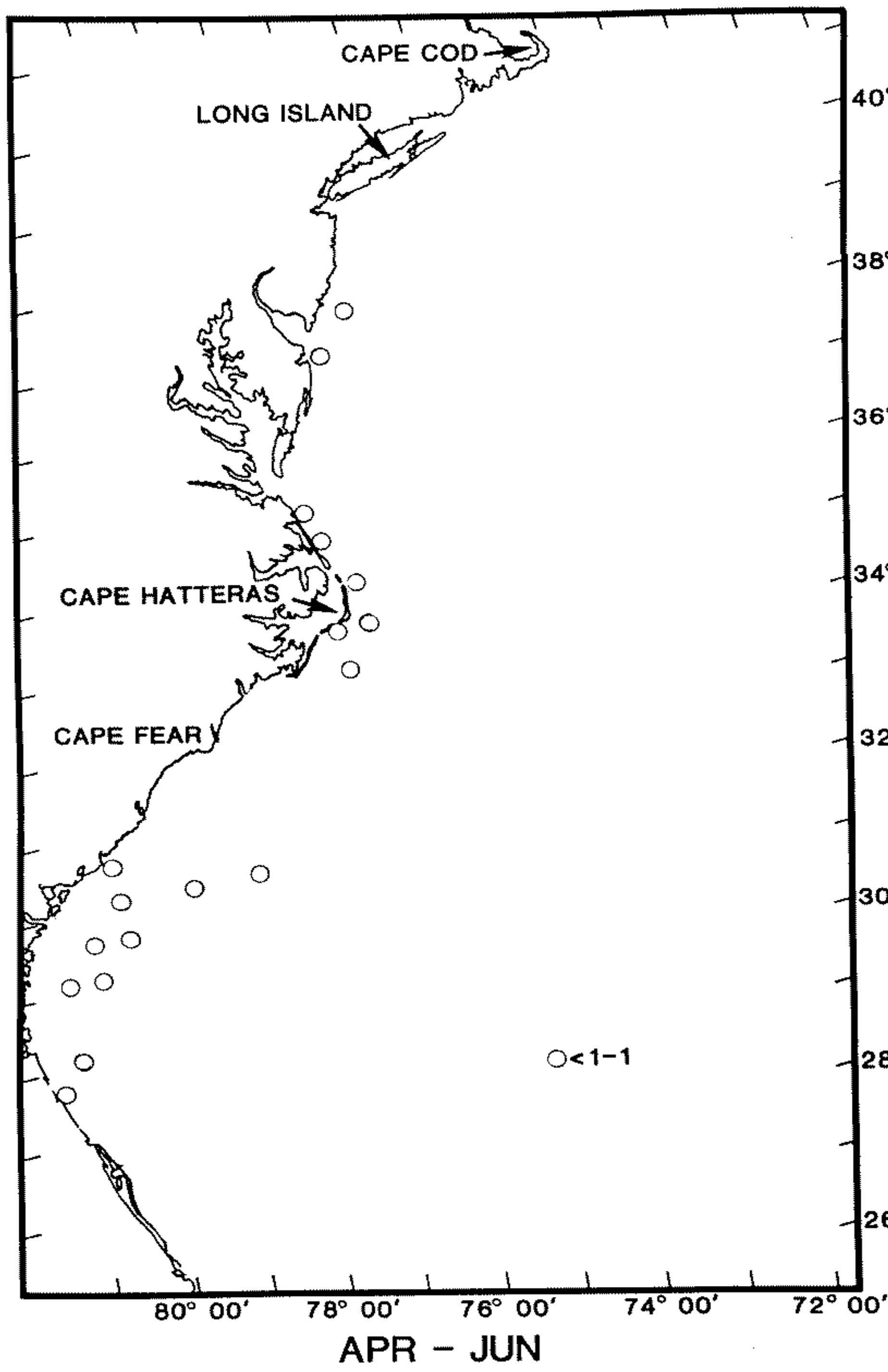

CAPE COD
LONG ISLAND
CAPE HATTERAS
CAPE FEAR
40°
38°
36°
34°
32°
30°
28°
26°
0
<1-1
2-10
11-100
101-200
201-300
80° 00'
78° 00'
76° 00'
74° 00'
72° 00'
OCT - DEC

Map 2c

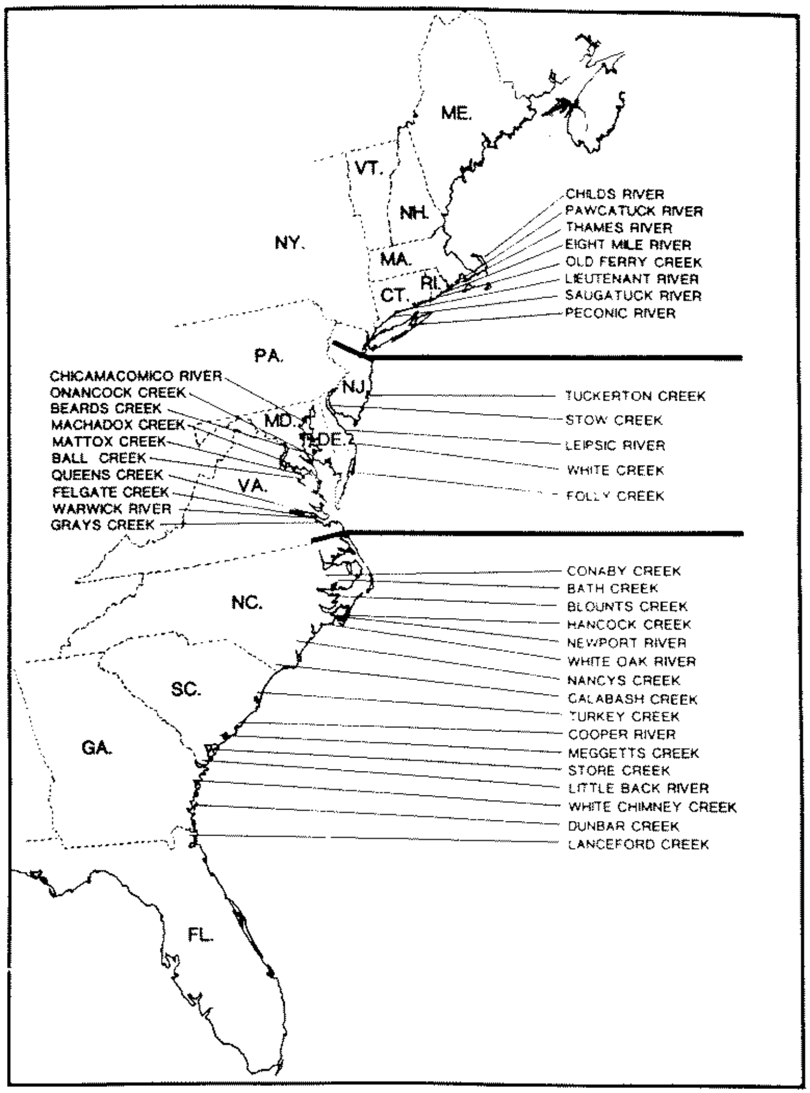


CAPE COD
LONG ISLAND
CAPE HATTERAS
CAPE FEAR
40° 00
38° 00'
36° 00'
34° 00'
32° 00'
30° 00'
28° 00'
26° 00'
80° 00'
78° 00'
76° 00'
74° 00'
72° 00'
0
<1-1
2-10
11-100
101-200
201-300
JAN - MAR

Map 2d

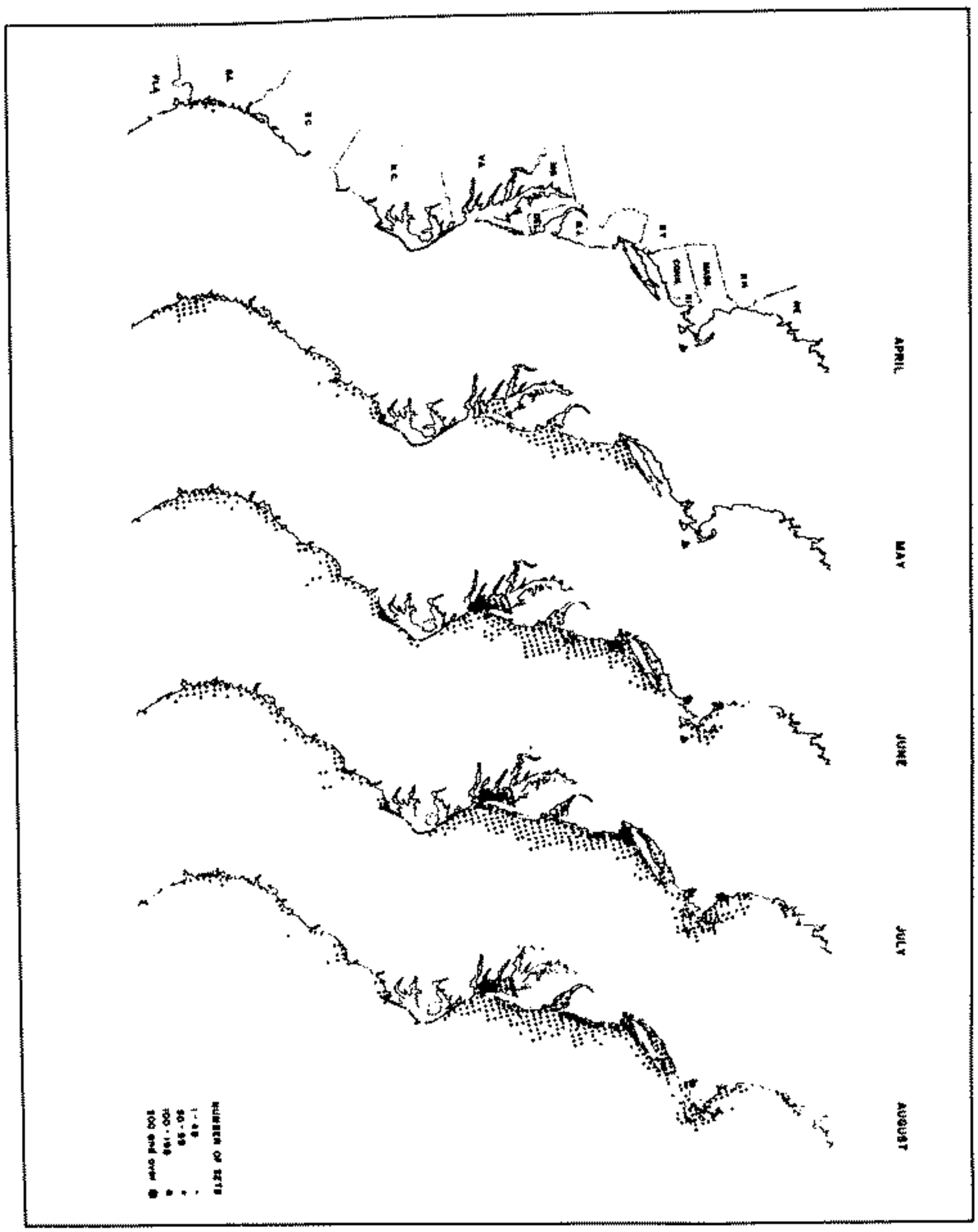

CAPE COD
LONG ISLAND
CAPE HATTERAS
CAPE FEAR
<1-1
40°
38°
36°
34°
32°
30°
28°
26°
80° 00'
78° 00'
76° 00'
74° 00'
72° 00'
APR - JUN

Map 3

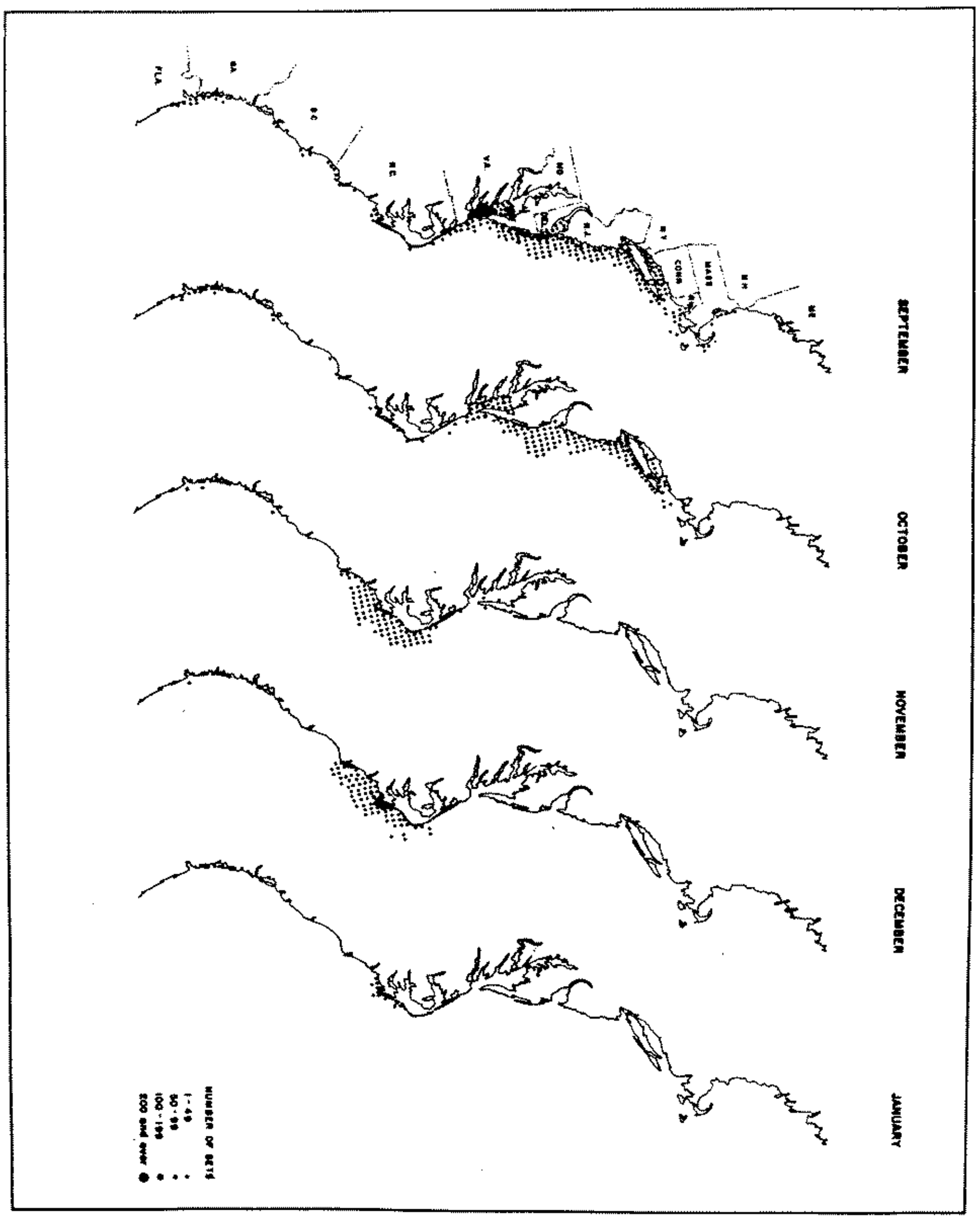


ME.
VT.
NH.
NY.
MA.
CT.
RI.
PA.
NJ.
MD.
DE.
VA.
NC.
SC.
GA.
FL.
CHILDS RIVER
PAWCATUCK RIVER
THAMES RIVER
EIGHT MILE RIVER
OLD FERRY CREEK
LIEUTENANT RIVER
SAUGATUCK RIVER
PECONIC RIVER
CHICAMACOMICO RIVER
ONANCOCK CREEK
BEARDS CREEK
MACHADOX CREEK
MATTOX CREEK
BALL CREEK
QUEENS CREEK
FELGATE CREEK
WARWICK RIVER
GRAYS CREEK
TUCKERTON CREEK
STOW CREEK
LEIPSIC RIVER
WHITE CREEK
FOLLY CREEK
CONABY CREEK
BATH CREEK
BLOUNTS CREEK
HANCOCK CREEK
NEWPORT RIVER
WHITE OAK RIVER
NANCYS CREEK
CALABASH CREEK
TURKEY CREEK
COOPER RIVER
MEGGETTS CREEK
STORE CREEK
LITTLE BACK RIVER
WHITE CHIMNEY CREEK
DUNBAR CREEK
LANCEFORD CREEK

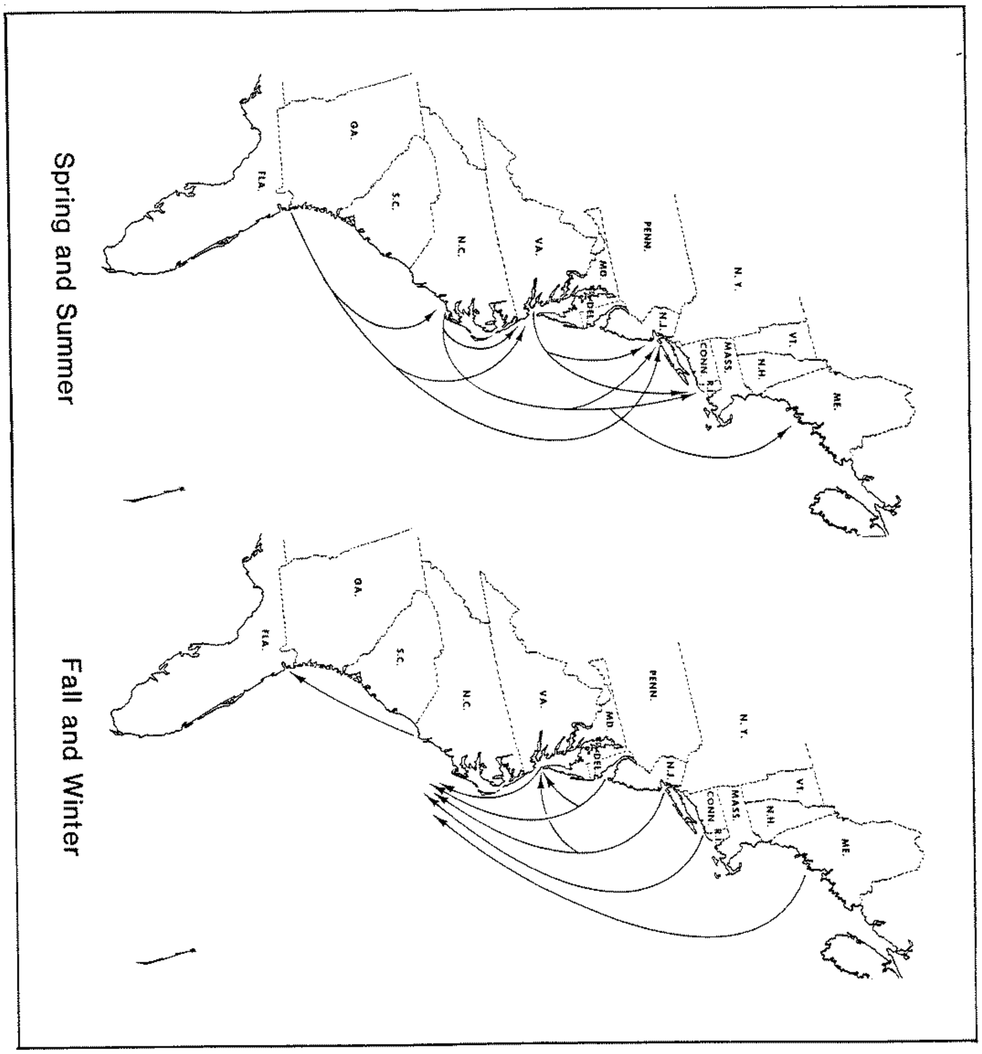
Map 4a



Map 4b


SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FLA
GA
SC
NC
VA
MD
NJ
NY
CONN
MASS
NH
ME
NUMBER OF SETS
1-49
50-99
100-199
200 and over

Map 5


Spring and Summer
Fall and Winter
FLA.
GA.
S.C.
N.C.
VA.
MD
DEL.
PENN.
N.Y.
N.J.
CONN.
R.I.
MASS.
VT.
N.H.
ME.

Appendix Table I. Sources for data on Atlantic menhaden egg distributions and supporting information.

Authors	**General Location of Eggs**	**Time Period**	**Number/Density**	**Depth**	**Temperature**	**Salinity**	**Notes**
Checkley et al. 1999 SABRE - *Oregon II*	SE and SW of Cape Lookout, NC	Dec to Feb, 1994-95	2.6 - 346 m^{-3}	10 - 120 m - range mode at 20 m	15 - 24 °C most 17 - 23 °C	35.9 - 36.6 ppt	
Stegmann et al. 1999 SABRE - (MARMAP)	Coastal RI to Cape Hatteras	May to Nov, Jan 1978-87			13 - 24 °C most 13 -21 °C		
Berrien and Sibunka 1999 MARMAP	Data Summarized above in Stegmann et al. 1999	locations and dates given on individual maps in paper					
Checkley, et al. 1988	SSW off Cape Lookout, NC, near western wall of Gulf Stream	Jan 21-22, 1986					
Kendall and Reintjes 1975 R/V *Dolphin*	Northern Long Island to just north of Chesapeake Bay	October to December 1966 cruise	<100 Oct, except 2000 off Delaware <100 November	23 - 54 m	13.5 - 17.3°C	30.5 - 32.8 ppt	
Reintjes 1969 (Also in Judy and Lewis 1983)	65 km off New River Inlet, NC	Dec 1966	"...hundreds of thousands..."				
Reintjes 1961	off Cape Fear, NC and off Cape Lookout, NC	Feb 1954, Dec 1954	80 total				Eggs taken off FL, but were probably yellowfin hybrids
Ferraro 1980	Long Island Sound	June 1972-73 -?- ?-	568 total				
Marak and Colton 1961	Off Martha's Vineyard	June 1953	1		apx 12.8°C	apx 31.6 ppt	
Marak, Colton, and Foster 1962	130 km off Nantucket	May 1955	12		9.0 - 9.3 °C	32.1 ppt	

Appendix Table I. - Continued -

Authors	General Location	Time Period	Number/Density	Depth	Temperature	Salinity	Notes
Perlmutter 1939	Long Island, NY vicinity	May-Oct, mostly May-June	0 to 589 per sample		12.8 - 26.7°C		
Judy and Lewis 1983 RV *Eastward*	East-northeast Cape Lookout, NC	November	1,627 total				
Judy and Lewis 1983 RV *Advance II*	Southeast Cape Fear, NC	Dec - Jan	91 total				
Croker 1965	Sandy Hook, NJ area	May - June 1961	258 total	≤9 m		≤ 28.6 ppt	
Wheatland 1956	Long Island Sound	June-Oct, 1952-53	0.01 - 2.28 m^{-3} 633 total		13.30 - 23.25 °C	18.15 - 28.41 ppt	
Richards 1959	Long Island Sound	May - July, Sept - Oct 1954-55	81 total		As low as 10 °C		
Herman 1963	Narragansett Bay, RI	May-Aug, Oct	0.897 m^{-3}		12.0 - 24.4 °C	apx 29 - 32 ppt	
Bourne and Govoni 1988	Narragansett Bay, RI	"Summer" 1972-73	<10 - >1000 / m^3	<7.6 - 57.3 m		~31 ppt	
Kuntz and Radcliffe 1917	Woods Hole, MA Region	June-Aug, Oct. mostly 1915					
Bigelow and Schroeder 1953 *Grampus*	Nantucket Sound; westward of Martha's Vineyard	Oct, 1915 (reported spawning occurred from June - August)					
Dovel 1971	Chesapeake Bay; Near mouth of Patuxent River; upper bay	1963-65 - Patuxent; May-June, Oct-Nov; 1966-67 - upper bay	9,942 total		13 - 20 °C	10 - 22 ppt	

Appendix Table II. Sources for data on Atlantic menhaden larval distribution and supporting data.

Authors	General Location	Time Period	Number/Density	Size Range	Depth	Temperature	Salinity
Judy and Lewis 1983	Reports on a number of cruises between Martha's Vineyard, MA to Cape Canaveral, FL	1953 - 1975 Some larvae captured every month of year, but not over entire area at same time.	0 to >1000				
Kendall and Reintjes 1975	Martha's Vineyard, MA to Cape Lookout, NC	Larvae caught on all of eight cruises Dec 65 - Dec 66.	0 to 2,553	5 to 30 mm Size Increase Shoreward noted for Nov - Dec, South of Delaware Bay	9 to 145 m	0 to 25 °C	24.3 to 37.8 ppt
Checkley et al. 1988 (see Maillet and Checkley 1991)	SSW: 6 - ~90 km off Cape Lookout, NC	Jan - Mar, 1986		4.7 to ~ 24 mm Size Increase Shoreward	~18 to >183 m	~14 to ~21 °C	
Massmann, Norcross, and Joseph 1962	transects from mouth of Chesapeake bay, out 64 km	Nov 1959 to Dec 1960; except Oct No larvae captured May to Sept.	94 total	7 to 29 mm Size Increase Shoreward		1.3 to 14.8 °C	
Croker 1965	Sandy Hook Bay, NJ; Navesink River	Nov - Dec	5 total		4.5 m		
Wheatland 1956	Long Island Sound	June, Sept-Dec	150 total	2.35 - 20.6 mm		<10.3 °C	25.11 - 28.44 ppt
Kuntz and Radcliff 1917	Woods Hole, MA Region	June - July		Gave size at hatch as 4.5 mm			
Marak, Colton, Foster, and Miller 1962	Off Woods Hole	June 1956	3 total	4.480 - 8.25 mm		15 °C	32.1 ppt
Warlen 1992	SE transect off Cape Lookout, NC	Dec 1979 - April 1980	353 total	4.7 - 25.9 mm SL Size Increase Shoreward	~10 m to >183 m	~7 to 24°C	

Appendix Table II. - Continued -

Authors	**General Location**	**Time Period**	**Number/density**	**Size Range**	**Depth**	**Temperature**	**Salinity**
Reintjes 1961	Cape Canaveral, FL to Cape Lookout, NC	1953-54; Nov, Dec, Feb, Mar	0 to 22,000 per tow	4 to 21 mm			
Govoni 1993	Three US south Atlantic bight transects	Jan-Feb 1990; Feb 1991	0 to >7 million m^{-3}		~20 - > 200 m	~11 - ~24 °C	~34.6 - ~36.4 ppt
Wheatland 1956	Long Island Sound	1952-53 June; Sept - Dec	150 Total	2.35 - 20.6 mm		>10.3 °C	25.11 - 28.44 ppt
Bigelow and Schroeder 1953	Casco Bay	Oct , 1900		"Young fry"			
Perlmutter 1939	Long Island NY vicinity	May - Sept; 1938	138 total	4.0 - 15.4 mm		~18.7 - ~26.3 °C	
Herman 1963	Narragansett Bay, RI	June-July; Oct-Feb	374 total	3.2 - 26.6 mm		1.2 - 22.2 °C	~20 - ~29 ppt
Bourne and Govoni 1988	Narragansett Bay, RI	"Summer" 1972-73	<10 - >1000 / m^3		<7.6 - 57.3 m		~31 ppt
Richards 1959	Long Island Sound	June-July; Sept-Dec 1954-55	68 total	3.5 - 10.9 mm			
Hettler and Hare 1998	Synoptic, parallel SSW transects off Beaufort Inlet, NC	Feb-April, Dec 93; Jan-March 94	>200	~ 7 - ~ 31 mm SL; 13 - 132 days old; Older and larger shoreward	5 - 17 m	Correlation analyses conducted but no actual data given	
Tagatz and Dudley 1961	Just of Atlantic Beach, NC	Mar - May; 1957-60	28,270 total	21 - 46 mm FL			
Dovel 1971	Chesapeake Bay; MD waters	Mar - June, Nov; 1964-66	2,322 total	10 - 40 mm TL (Most 25 - 40 mm; 25 < 20 mm TL)		12 - 22 °C	0 - 11 ppt

Appendix Table III. Sources of data on Atlantic menhaden larval immigration at inlets and supporting data.

Authors	General Location	Time Period	Number/Density	Size Range	Notes	Temperature	Salinity
Reintjes and Pacheco 1966	White Creek, DE (Indian River)	1955-61 Cap. ~ Oct - June (Peaks Dec to Mar)	<1 - ~120 /1000 m^3	14 - 34 mm FL		~0 - ~20 °C ~3 °C threshold	
Tagatz and Dudley 1961	Newport River, Beaufort Channel	Jan, April-May 1957-60	6,009 total	18 - 49 mm FL			
Lewis and Mann 1971	White Oak River; Newport River, NC (Beaufort and Bogue Inlets)	1966-68 Cap. ~ Nov - April (peak late March)	<1 - ~3.9 / 100 m^3		(Condition factors estimated by month) (Ingress: depth, tidal stage, time of day)		
Lewis and Wilkins 1971	Newport River, NC Beaufort Channel	19-20 March, 1968	Tested day-night, surface-bottom, ebb-flood tide abundance		24 Hour Sampling		
Wilkens and Lewis 1971	White Oak River, NC (Bogue Inlet)	1967-69 Cap. ~ Nov - early May	Bi-modal abundance distribution; Nov - Dec, Feb-March. <1 - ~ >200 / 100 m^3		Includes upstream pre-juvenile and juvenile sampling		
Lewis et al. 1972	White Oak River, NC (Bogue Inlet)	March to Sept, 1969		8 - 83 mm TL	Weight /Length Relationship: Larvae, pre-juvenile, juvenile		
Warlen and Burke 1990	Newport River, Beaufort Channel	Cap. ~ Nov - April, 1985-86	<1 - >220 / 100 m^3	16.2 - 25.8 mm SL		~ 7 - ~20 °C	
Warlen 1994	Newport River, Beaufort Channel	Cap. ~ Nov - May, 1985 - 92	<1 - 573 / 100 m^3	~ 13 - ~ 30 mm SL	~23 to ~120 days old; most 30 - 90 d		
Hettler and Barker 1993	Ocracoke and Oregon Inlets, NC	Cap. Ocracoke: Dec - April; Oregon: Nov - May	<1 - 221 / 100 m^3	Mean SL Ocracoke: 23.6 mm Oregon: 23.2 mm	Other Species Summarized; day/night; surface/bottom	Ocracoke: ~ 11 - ~ 20 °C Oregon: ~ 7 - ~ 21°C	Ocracoke: ~ 25 - ~ 36 ppt Oregon: ~ 9 - ~ 33 ppt

Appendix Table III - Continued -

Authors	**General Location**	**Time Period**	**Number/Density**	**Size Range**	**Notes**	**Temperature**	**Salinity**
Warlen et al. 1998	Newport River, Beaufort Channel	1985 - 1993	Seasonal Mean: ~ 1.8 - ~ 14.5 / 100 m^3		Mean seasonal densities compared to densities during a red tide (*Gymnodinium breve)* event		
Hettler et al. 1997	Newport River, Beaufort Channel	1991-92 Mid-Nov to Mid-April	Daily: <1 - ~ 160 /100 m^3 Mean: 10 / 100 m^3	~ 10 - ~ 32 mm SL	Multi-species: Sampling conducted every day. Daily age: ~ 17 to ~ 106 days.	~ 7 - ~ 18 °C	~ 25 - ~ 36 ppt
Rice et al. 1999	Newport River, Beaufort Channel; Ocracoke and Oregon Inlets	1994-95 all three Inlets; 1995-96 without Oregon Inlet	Seasonal Means - "Beaufort Inlet": 24.8 and 23.7; Ocracoke: 44.3 and 27.6; Oregon: 42.4; all in #'‘s / 100 m^3	~ 11 to ~ 25 mm SL	~ 25 - ~ 100 days old		

Appendix Table IV. Sources of Data on Estuarine-Resident Atlantic Menhaden Larvae and Juveniles and supporting data.

Authors	General Location	Time Period	Number/Density	Size Range	Depth	Temperature	Salinity
Massman et al. 1954	Chesapeake Bay tributaries	1950-52	>8,000 young menhaden taken	Mar - May, 24-30 mm (post-larvae); June - July, mean 40.6 mm (juvenile); Sept - Oct, mean 94 mm (juvenile)			Brackish to fresh. Sampling results given by river mile.
Pearson, J. C. 1941	Chesapeake Bay (Inside, near mouth)	1929-30	a few	20 - 24 mm (larvae)			
Pacheco and Grant 1965	White Creek (Indian River) DE	1957-58; Cap. ~April - Jan, not Feb or March	0 - >5,000 / month 0 - 201 / seine haul	22 - 170 mm		3.2 - 32.0 °C	0.2 - 32.0 ppt
Tagatz and Dudley 1961	Two Neuse River, NC estuarine stations	1957-60; Cap All months of year between the two stations		19 - 159 mm		4.2 - 32.0 °C (some values include larvae at inlet and ocean)	0.0 - 36.0 ppt (some values include larvae at inlet and ocean)
Warfel and Merriman 1944	Morris Cove, Conn.	1942; Cap. July - Nov	1 - 1,565	9 - 79 mm	<12 feet; bottom sandy, sandy beach with boulders at each end		
Pearcy and Richards 1962	Mystic River, Conn	1959-60; Cap. June and July	2	4.7 and 11.8 mm			
Scattergood, et al. 1951	Sheepscot River, Maine	1949; Cap. Dec		52 - 95 mm		4.4 - 7.8 °C	
Turner 1973	-Abundance Survey- 4 estuarine tributaries; NC - MA	1961-66	0 - >1000 / haul	juveniles			
Ahrenholz et al. 1989	-Abundance Survey- 39 estuarine streams; FL - MA	1972-78	Mean: >600 - >5,000 / tow	juvenilea ~29 - ~ 100 mm FL			~ 0 - >15 ppt

Appendix Table IV. - Continued -

Authors	General Location	Time Period	Number/density	Size Range	Depth	Temperature	Salinity
Sutherland 1963	45 estuarine streams; FL - MA morphometric study	1956-59	17,024	juveniles			
Stokesbury and Stokesbury 1993	Annapolis River, Nova Scotia	1985-86; 1989 Cap. Aug - Nov	209 total	41 - 109 mm			
Friedland et al. 1996	Neuse and Pamlico Rivers, NC	1984; Spring	<25 - >1000 / tow	~25 - 60 mm (post-larvae - Juveniles)			<1 - ~ 7 ppt
Friedland et al 1989	Two NC estuaries Two VA estuaries	1983; Spring - summer	0 - 27,000 / tow	Pre-juveniles and Juveniles		11 - 33 °C	0 - 10 ppt
June 1958	22 estuaries; GA to MA	1955; Summer - fall	1,961 total	28 mm (Post larvae) to 150 mm FL	Sampled individuals used for stock ID, meristic study		

Appendix Table V. Sources for data on Atlantic menhaden adults/subadults and supporting data.

Authors	**General Location**	**Time Period**	**Number/density**	**Size Range**	**Depth**	**Temperature**	**Salinity**
Scattergood et al. 1951	Gulf of Maine	July-Sept 1949	500 sampled	272 - 357 mm			
McHugh et al. 1959	Chesapeake Bay	1954 - 57 (Cap. ~ all year)	several fisheries sampled	<80 - >375 mm			
June and Reintjes 1959	1952 - DE and NJ 1953 - DE to MA 1954 - DE to ME 1955 - FL to ME	1952-55	US Purse-seine and pound net landings sampled	Size and age composition tabulated	Sites mapped for purse-seine sets		
June and Reintjes 1960	FL to ME	1956	US Purse-seine and pound net landings sampled	Size and age composition tabulated	Sites mapped for purse-seine sets		
June 1961	FL to ME	1957	US Purse-seine landings sampled (Pound nets de-emphasized)	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		
June and Nicholson 1964	FL to ME	1958	US Purse-seine landings sampled	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		
Nicholson and Higham 1964a	FL to ME	1959	US Purse-seine landings sampled	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		
Nicholson and Higham 1964b	FL to ME	1960	US Purse-seine landings sampled	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		
Nicholson and Higham 1965	FL to ME	1961	US Purse-seine landings sampled	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		

Appendix Table V. - Continued -

Authors	General Location	Time Period	Number/density	Size Range	Depth	Temperature	Salinity
Nicholson and Higham 1966	FL to ME	1962	US Purse-seine landings sampled	Size and age composition tabulated / graphed by fishing area	Sites mapped for purse-seine sets		
Nicholson 1975	FL to RI (Northern catches diminished in range and % of Landing)	1963-71	US Purse-seine landings sampled	Size and age composition tabulated by fishing area and port	Set sites not mapped		
Smith et al. 1987	Fl to ME (Increase in Northern catches and range of fishery)	1972-84	US Purse-seine landings sampled	Age composition tabulated by fishing area	Length frequency distributions graphed for 1967 and 1983		
Roithmayr 1963	FL to ME	1955-59	Distribution of purse-seine fishing activity		set sites mapped for each month and year		
Smith 1999	NC to RI	1985-96	Distribution of purse-seine fishing activity		Summary of activity and landings by geographic sites - Sets not mapped		
Nicholson 1971	FL to ME	1955-59	Purse-seine fishery samples	Length frequency compared by season and US Atlantic port	Developed hypothesis of seasonal adult/subadult migrations		
Nicholson 1972	FL to MA	1955-64	Purse- seine fishery samples; 500 - 3,500 annually	Distribution by US Atlantic port, time of year verses back calculated size at age	Hypothesis of single stock composition		
Wenner and Sedberry 1989	Cape Fear, NC to Cape Canaveral FL	1980-1982	Fishery Independent Trawl Survey	60-210 mm FL	Sampled 4.6-9.1 m	Fish Captured 7.7 - 28.8 ° C	Fish Captured 33.2-36.9 ppt

Table V. -Continued-

Authors	General Location	Time Period	Number/Density	Size Range	Depth	Temperature	Salinity
Kroger and Guthrie 1973	FL to MA	1967-71	Juveniles tagged in fall; recovered at reduction plants (>80,000 tagged)	Mean 65-153 mm FL	Preliminary returns; documentation of movement		
Dryfoos et al. 1973	FL to NY	1966-69	Most adults captured by purse-seine fleet (>1,000,000 tagged)		Preliminary mortality rate estimates; documentation of movement patterns		
Nicholson 1978	FL to ME	Releases through 1973; recoveries through 1975.	Summaries from the above two tagging programs	Juvenile through adult	Further documentation of movement; population structure		