The Role of The Estuary in the Life History and Biology of Atlantic Menhaden

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THERE IS AT PRESENT a keen interest in estuarine research among marine biologists on the Atlantic Coast of the United States. The reason for this recent attention is the realization that man's activities in this environment may destroy a vital link in the life cycle of many marine organisms which support many of our coastal fisheries. The lives of many of these organisms, therefore, are dependent on the continued existence of this unique environment.

Between Cape Canaveral and Cape Cod there are approximately thirty-eight estuarine systems which are now known to provide an environmental link in the life history and biology of the Atlantic menhaden (*Brevoortia tyrannus*). There is no reason to doubt that most of the numerous unstudied estuaries along the Atlantic Coast also serve the same role. It is for this reason that detailed knowledge of the estuarine environment is essential for understanding the biology of this prolific species.

The findings which are summarized in this paper are based primarily on six year's study of Indian River, Delaware, an estuary located in the central part of the range of Atlantic menhaden. Additional observations over the past three years in thirty-four other estuaries from the Halifax River, Florida to the Sheepscott River, Maine, have furnished comparative and corroborative information.

In discussing the results, we should like to (1) summarize briefly what we know of the relation between the estuary and the events in the life history of Atlantic menhaden, (2) point out how certain physical and biotic features affect the behavior, distribution, and abundance of this species in the estuary, and (3) mention some of the problems concerned with the estuarine phase of our investigations.

The first event in the life history of this species associated with the estuary commences a matter of weeks, or perhaps months, after hatching of the eggs at sea. The larvae occur in large numbers outside the river mouths, and under suitable conditions they enter and become established within. Throughout most of the spawning season they can easily be obtained in large numbers at the river inlets by means of plankton nets suspended in the tidal currents. Hundreds of such collections made during the course of our work have shown conclusively that those made on the flood current consistently yield much greater numbers than those on the ebb. Furthermore, surface tows are much more productive than those made at intermediate depths and on the bottom. Yet the mechanisms controlling the orientations of the larvae which lead to their recruitment into the estuary are not understood. Entering larvae range from about eight to forty-two millimeters in length, but most are around twenty-six millimeters. At this stage they are rather elongated and quite transparent, with black pigment spots prominent on the lower surface of the body and about the head; they are devoid of scales, and the fins are only partially formed.

Entry of the larvae into the estuaries varies in time and duration in different localities, but it occurs mostly in the late winter and spring months and may continue anywhere from two to seven months in a given locality.

Following their entry into the estuary, the larvae are found congregated near the upstream limits of the tidal zone in groups of many thousands of individuals. Here, and even during their migration from the ocean, they undergo metamorphosis into juveniles. During this transformation the body deepens, scales are laid down, all of the fins become fully differentiated, and the fish take on the color of the adults. The gut becomes highly elongated and convoluted, and the gill rakers, used in filter feeding, become much more numerous. This transformation commences at a body length of about twenty-six millimeters, but is retarded during the winter and early spring months. Larvae entering the estuary during the winter and early spring complete differentiation at a body length of about fifty-five millimeters, while those entering in late spring complete metamorphosis at about forty-two millimeters. As the fish increase in size, schools of the larger individuals spread out from the initial nursery areas and move farther downstream until a size gradient is established over their range of distribution in the estuary. It is of interest to note that this species has been observed schooling at the smallest sizes encountered in these waters.

After spending the summer months in the estuary, the schools of juveniles congregate in larger bodies inside the river mouths and eventually move out into the ocean. Generally, this emigration commences in late August in northern estuaries, while in southern estuaries, it may be delayed into January. At the time of their departure, the juveniles range in size from roughly fifty-two to one hundred and sixty millimeters in fork length.

During the following summer, as one-year olds, they support the bulk of the purse seine fishery along the south Atlantic Coast and in Chesapeake Bay, but large numbers occur in the sounds and rivers from Florida to the North Carolina-Virginia border. Indeed, two-year-old fish often are found in these inland waters. The relative proportion of these age groups which use such areas as post-nursery grounds has not been determined.

At least part of the adult population also utilizes the estuaries within Chesapeake Bay and along the middle Atlantic Coast, apparently for feeding purposes, during the late winter and early spring. They enter and leave these waters throughout the winter, but usually congregate in greatest numbers for a short period in late February and early March, after which time they are largely absent, although abundant along the adjacent coast.

In consideration of some of the specific features of the estuarine environment which relate to the biology of Atlantic menhaden, it would appear that food—its availability and kinds—is perhaps the single most important factor governing the distribution of larvae and juveniles. Examinations of stomach contents of the fish at these stages show that diatoms and holophytic flagellates form the bulk of the ingested material. The shallow waters of the upper tidal areas are particularly rich in these organisms, and here the menhaden are in the greatest abundance throughout the summer and remain latest in the fall. Nutrients essential to plankton growth are in strong supply in such areas, being delivered, in large part, by runoff from the surrounding countryside. The character and quality of the soil within the drainage basin and the extent of agriculture probably have a considerable influence.

Salinity appears to be a rather critical factor in the development and growth of the young fish. Larvae reared through metamorphosis in highly saline waters at the U. S. Fishery Laboratory, Beaufort, North Carolina, for example, developed abnormalities in body form and structure, while those reared in reduced salinities developed normally. Repeated attempts to transplant larvae and metamorphosing individuals from the low salinity of the upper estuary to the more saline waters of the rearing ponds invariably met with failure. Yet, when such transplants were made several weeks after metamorphosis, they were successful. During March 1958, when prolonged rainfall had reduced the salinity near the Beaufort laboratory to about 10 ‰, larvae and small juveniles occurred in tremendous numbers in the area for the first time in the last four years. Several thousand were successfully established and growing rapidly in the rearing ponds until June, when reduced rainfall and high tides raised the salinity to near-oceanic values, and all juveniles soon died. Similar observations were made under natural conditions in Indian River, Delaware in March 1953 when heavy mortalities and structural abnormalities followed intrusions of highly saline water, occasioned by high tides and persistent, high onshore winds. These findings might be related to the delayed development of the water-balance mechanism of the euryhaline adult; however, they could also simply relate to starvation resulting from poor plankton production in the highly saline water at the times when mortalities were recorded. Histological investigation of the water-balance mechanism during its early development, in the light of the presumed fresh water or anadromous ancestry of menhaden, could be enlightening. Indeed, laboratory experiments for determining the salinity tolerences from the larval through the juvenile stages of development are urgently needed.

Water temperature also is related to certain life history features and behavior patterns of the fish. There appears to be a minimum temperature associated with the occurrence of larvae at the river mouths during winter. Over the past three years, for example, water temperatures below about 3° C at the mouth of Indian River have coincided with an absence of menhaden larvae in our plankton tows. When low temperatures have prevailed over a period of several weeks, we have found a high percentage of structural abnormalities, especially among the larger larvae, once recruitment into the estuary recommenced. Thus, water temperature during the period of entry may be a source of mortality in some years. A heavy winter kill of one-year-old menhaden in the Neuse River, North Carolina in February 1958 was attributed to freezing water temperatures which persisted over a period of two weeks. Also, all young menhaden being reared in the outdoor ponds at Beaufort (ca. 500) were killed during this period.

The fall emigration of juveniles from the estuaries also appears to be directly related to water temperature. Our records from Indian River indicate that it commences when temperatures in the estuary first fall below those of the adjacent ocean. Such a drop may occur in the shallow waters on each cold night after the end of August, each occasion being accompanied by a departure of juveniles. On the other hand, during warm periods in the fall, numerous juveniles reappear in this estuary. Comparisons of size distributions and meristic characters of these late inhabitants have shown that they were not members of the endemic summer population, but probably originated in estuaries north of Long Island and presumably entered the river while migrating southward.

Among the many problems concerned with our estuarine studies, perhaps the most difficult and important of these deal with estimating the relative strength of a year class while it is still in the estuary and the mortality sustained during its stay in these waters. In attacking these problems, we have worked out techniques at Indian River which have been extended to other locations along the coast. One of these methods, for example, was applied in a number of tributaries from Massachusetts to North Carolina during the past summer. It essentially consists of marking large numbers of individuals by clipping the ventral lobe of the caudal fin and estimating the size of the population in the estuary from the proportion of recaptures in random samples. With this method, if the population chosen is too large, it is impractical to mark enough fish to obtain a reliable estimate. And estuarine populations of menhaden tend to be quite large. In consequence, the marking experiments were restricted to a tributary portion of an estuarine population. The question then arises whether such tributary populations can be found which are sufficiently stable to estimate reliably. That they are appears to be the case in those estuaries consisting of a central bay fed by a number of tributary streams. Earlier it was mentioned that the larvae and metamorphosed juveniles congregate near the upstream limit of tide. Accordingly, the population in an estuary during the early summer has been found to consist of a number of tributary subpopulations which, as the season progresses, partially merge in the lower reaches of the river. Initial attempts to estimate such a tributary population in late spring, when its integrity presumably is greatest, resulted in a high mortality among both marked and unmarked fish. However, by closing off a tributary creek with either a wall of netting, or a semi-permanent fence of galvanized hardware cloth, the contained subpopulation could be marked at such time when its constituent individuals were large enough to minimize mortality from capture and marking. Results have shown that the latter procedure not only results in virtually no mortality, but it can be applied in a large number of tributaries along the coast for the purpose of establishing an index of the relative abundance of a year class. The reliability of this method is being assessed from the results of other comparative methods of estimation which were conducted in certain areas; these include: (1) catch depletion from intensive seining, (2) school censusing, both from the surface and from the air, and (3) an absolute count of the fish in the fenced off tributary by trapping all individuals as they leave. Since some phases of this work are still going on, an evaluation of the results is precluded. If reliable, the marking method eventually may furnish a means for comparing the relative abundance from one year to another. Ultimately, of course, its reliability will be determined by its relation to the abundance of a given year class when the fish enter the commercial fishery as one-year-olds.

Further efforts along these lines have been concerned with the use of fluorescein dyes and radioactive tags. If practical means of marking and recovering larval and juvenile menhaden can be accomplished, by one or both of these techniques, they not only will be useful for population estimates, but also will yield information on the migration of the fish. Results of some of the laboratory work now await further trials. Suffice it to say that both methods offer promise of success.

A measure of natural mortality sustained during the estuarine phase of the life of Atlantic menhaden is, of course, entirely contingent upon reliable population estimation methods. The fin-clipping method, mentioned in the foregoing, indicates the mortality sustained only during the last few months that the fish occupy the estuary. However, if we can achieve an estimate of mortality which would cover the entire period that the fish occur in these waters, it would provide the information necessary for determining whether conditions in the estuary are responsible for the success of a year class. Once we know the stages in the life history which sustain the greatest mortality, we can direct attention to the causative factors. The marking of entering larvae by means of a flourescein dye renders solution of this problem less remote.

A final problem deals with the need for a realistic evaluation of the importance of the estuary in the face of man's growing use of this environment. In its virgin state, an estuary is entirely kinetic, the result of natural influences, such as the shape of the basin (and its drainage system), wind, tides, rainfall, sunlight, temperature, etc. It fluctuates around its mean conditions, shifting little geographically, and remains, in most cases, a productive aquatic environment, only to the extent that these influences tend to balance one another quite rapidly. Even violent phenomena, such as hurricanes, floods, and droughts, which are often catastrophic to organisms in the estuary, are of relatively brief duration and have only an immediate, direct effect. Furthermore, natural catastrophies seldom influence more than a small part of the extensive range of an animal species such as Atlantic menhaden.

Man's activities are a striking exception. When he, at any time, alters the inherent balance of the estuary, he can never be quite certain of the result. Dredging, filling, marsh drainage, impoundments, recreational developments, and pollution are enduring influences seemingly destined to occupy all the estuaries on the Atlantic Coast. It, indeed, would be difficult to imagine an activity more purposefully devised to quickly affect all estuaries than the mosquito spraying program on the coastal marshes. The changes wrought in the estuary by such activities often are subtle, and it becomes especially difficult to measure both their immediate and long-term effects. Obvious, widespread, deleterious effects are not yet common, but one example of their far-reaching implications perhaps will suffice. Last summer we were called upon to investigate a mass mortality of young menhaden in a southern river which has been developed for summer recreational purposes. The number of dead fish which littered the beaches (to a depth of several feet in some areas) was estimated to have exceeded the total number of fish caught during the fall menhaden fishing season off North Carolina in 1957. The cause of this particular mortality was traced to industrial pollution. Such incidences of man's influence on the estuary are becoming more evident as his number increases.

The solution of these and related problems is not simple, but laboratories devoted to estuarine research along the Atlantic Coast are making headway. For only by continued, intensive study of the inherent and induced features of the estuary and their interaction can we, in time, hope to understand how they relate, not only to the biology of Atlantic menhaden, but also to all organisms associated with this unique environment.
