DISTRIBUTION OF THE PLANKTONIC LARVAE OF SOME BENTHIC INVERTEBRATES WITHIN THE PISCATAQUA - GREAT BAY ESTUARY, NEW HAMPSHIRE

DONNA DEMORANVILLE TURGEON

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DISTRIBUTION OF THE PLANKTONIC LARVAE OF SOME BENTHIC INVERTEBRATES WITHIN THE PISCATAQUA-GREAT BAY ESTUARY, NEW HAMPSHIRE

by

DONNA DEMORANVILLE TURGEON
B.S.Ed., Bridgewater State College, 1965
M.A., The College of William and Mary, 1968

A THESIS

Submitted to the University of New Hampshire
In Partial Fulfillment of
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Department of Zoology
September, 1976
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ABSTRACT

Distribution of the planktonic larvae of some benthic invertebrates within the Piscataqua-Great Bay Estuary, New Hampshire

by

Donna DeMoranville Turgeon

A four-year investigation (1970-1973) of the larval distributions of benthic invertebrates and selected hydrographic parameters (temperature, salinity, pH, water transparency, dissolved oxygen) was conducted on the Piscataqua-Great Bay Estuary, New Hampshire. Estuarine distributions of the larval populations of such species as Modiolus modiolus, Hiatella arctica, Mytilus edulis, Anomia aculeata, Myriochele heeri, Harmothoe imbricata, Balanus balanoides and B. crenatus are presented. Spawning stimulation, larval survivorship and settlement success are dependent on characteristics of an estuarine system which is 8 km in length from Portsmouth Harbor to Great Bay with fast currents (peak currents average 5 kts), a deep, narrow channel, a particle transport time of four days to traverse 4 km, and a flow pattern changing from vertical stratification to temperatures and salinity in spring and autumn to vertically and horizontally well mixed waters in summer and winter. Morphologically diverse species of larvae exhibited consistent horizontal and vertical distributional patterns despite gross differences in the estuary from temporal variations in run-off, flow pattern, salinity, temperature, phytoplankton composition and light penetration. Observations on seasonal, annual, spatial and tidal distributions of larvae are discussed in relation to adult distributions and identification of the significant hydrographic
parameters which affected these distributions. Distinct meroplankton communities which did not mix on changing tides existed in Portsmouth Harbor and Great Bay and reflected distributions of their respective adults. Characteristic flow conditions of the Piscataqua system accounted for the differences between larval distribution of B. crenatus in this study and that of other studies as well as the irregular annual recruitment observed for sessile brackish water species in Great Bay. Conclusions were drawn from a series of four 24-hour studies in spring, summer, and autumn that although species composition of meroplankton changed, density related consistently to tidal stage and such factors as changes in magnitude of temperature or salinity, haloclines, or day-night regimes did not alter the relationship. Lower estuarine species were most abundant on high flood stages of tide; whereas, upper estuarine species were most abundant on low ebb stages of tide.
INTRODUCTION

The purposes of this study were to 1) describe the distribution of the planktonic larvae of benthic invertebrates in the Piscataqua-Great Bay Estuary, New Hampshire; and to 2) relate larval distribution to adult populations and to hydrographic conditions. The study was designed to investigate the hypothesis that observed patterns of meroplankton distribution within this estuarine system are determined by certain hydrographic variables of the estuary. Identification of hydrographic parameters affecting the distributions of benthic invertebrates are presented.

Benthic populations will be replenished only if adequate numbers of larvae are retained in the estuary through their periods of metamorphosis and settlement. Predation, interspecific competition, seasonal extremes in temperature and salinity, and tidal currents deplete planktonic larvae everywhere and some unique characteristics of the Piscataqua River-Great Bay system compound problems of larval retention.

1. The estuarine system from Portsmouth Harbor to Great Bay is only 8 km in length (Fig. 1).
2. Peak tidal currents average 5 kts.
3. The deep narrow channel between Portsmouth Harbor and Great Bay has oscillating currents which flow between these two different and distinct bodies of water.
4. Transport time for waterborne particles is approximately four days from mid-estuary to the harbor and from mid-estuary to Great Bay.
5. Vertical stratification of temperature and salinity occurs throughout the estuary during the spring and autumn, but
Figure 1. Piscataqua-Great Bay Estuary and major drainage system with location of station numbers used in this study.
well-mixed waters characterize the estuary in summer and winter.

6. The annual variation in measurements of salinity, temperature and turbidity was moderate in the Harbor and similar to coastal waters. But, annual variations in salinity and temperature are extreme in Great Bay and turbidities are always high.

A preliminary study made in 1970 suggested that meroplankton distributions were not random and that densities in bivalve and barnacle larvae varied with seasonal and hourly changes in certain hydrographic factors. Such factors as temperature, salinity, pH and dissolved oxygen were measured concurrently with plankton collections; hydrographic measurements and planktonic collections were replicated. The following initial observations were drawn from preliminary meroplankton analyses:

1. Concentrations of bivalve larvae generally decreased from the mouth to the head of the estuary;
2. The number of individual species increased from an April low to late July, decreased in August, increased again in September, and then decreased in October.
3. A greater number of early stage bivalve larvae were in near-surface waters, while there were more late stage larvae in deeper water;
4. The preliminary study indicated that bivalve larvae were most abundant in near-surface waters just after slack high tide.

Early investigations of meroplankton concentrated on seasonal
abundance, modified species lists or the transportation of larvae in estuaries. Conclusions of the various authors did not agree and several questions were unanswered.

Literature on the seasonal distribution and dispersion of coastal meroplankton is extensive. But earlier investigations were either limited to the larval ecology of selected commercial species, such as oysters and lobsters (J. Nelson, 1912; T. Nelson, 1931; Hopkins, 1936; Templeman, 1937; Medcof, 1939; Smith, 1939; Sherman and Lewis, 1967; Lund and Stewart, 1970), or to a list of species found. In the past, larvae were isolated from water samples, illustrated, reared to recognizable size and then named (Stafford, 1912; Thorson, 1946; Sullivan, 1948; Rees, 1950). The majority of early stage larvae can not be identified by this method. Loosanoff (1966) stated that in articles on oyster propagation, including Loosanoff and Engle (1940), "many figures were based on the counts of younger, so-called straight-hinge stages of larvae". Since the shells at this stage are almost identical in several species, their counts are not wholly reliable. Carriker (1967) cautioned against using intuition in larval identification and strongly suggested raising populations in the laboratory from known adults. Larval identifications to the species level should be made only on comparative illustrations that were prepared from laboratory-reared larvae of known adults, such as those of Connolly (1922), Pyefinch (1948), Jones and Crisp (1954), Loosanoff, Davis, and Chanley (1966), Blake (1969), and Chanley and Andrews (1971). Reliable data of this nature exist for the larvae of regional estuarine species of barnacles, certain polychaetes (e.g. Myriochele heeri, Harmothoe imbricata, Eulalia viridis), and several bivalves (e.g. Mytilus edulis, Anomia aculeata, Crassostrea virginica,
Zirphaea crispata).

The seasonal appearance and duration of larval populations within estuaries and coastal waters have been described by Fish (1925), Bigelow (1926), Prytherch (1928), Deevey (1948 and 1960), Carriker (1951), Barlow (1955), Bousfield (1955), and Williams and Porter (1971). A number of authors have attempted to correlate physical factors with spawning periodicity and seasonal meroplankton distributions. In Long Island Sound and adjacent waters, Loosanoff, J. Nelson and T. Nelson and numerous associates studied on a long-term basis, the effects of temperature, salinity, precipitation, river discharge, hours of sunshine and the direction and velocity of winds on adult and larval oysters.

The time of spawning and duration of the planktonic period in northern estuaries are generally controlled by temperature (J. Nelson 1910 and 1915; Thorson, 1950; T. Nelson, 1952 and 1955; Kinne, 1963; Galtsoff, 1964; Loosanoff, 1966; and Calabrese, 1969). The length of the setting period of Crassostrea virginica increases from north to south (Loosanoff, 1932; McNulty, 1953; Beaven, 1954; Hopkins, 1954) and the annual appearance of oyster larvae can be predicted on the basis of temperature monitoring (Prytherch, 1928; Loosanoff and Nomejko, 1951).

The results of meroplankton studies within estuaries suggested that larval populations have patchy distributions which coincide with tidal oscillations (Churchill and Gutsell, 1921; Pritchard, 1953 and T. Nelson, 1955). J. Nelson (1912) and T. Nelson and Perkins (1930) noted that oyster larvae in Milford Harbor tended to move upstream from parent populations and suggested that larvae swam with the flood tide
and rested on the bottom during ebb tide. Thus larval populations were retained within the estuary and gradually moved upstream. Carriker (1951), Pritchard (1953) and Kunkle (1957) noted that younger larval stages move passively with the tide. Older stages of oyster larvae remain low in the water column or on the bottom during ebb tide, and rise in the water column in response to the increased salinities or current velocities of flood tide (T. Nelson and Perkins, 1930; Carriker, 1951; Manning and Whaley, 1954; Wood and Hargis, 1971). Kunkle (1957) hypothesized that late stage larvae congregated on or near the bottom during slack water and ebb periods, swimming only during the flood tide. According to Prytherch (1928), larvae were most abundant during slack water of the ebb and flood tides in Milford Harbor. In the same estuary Loosanoff (1949) found neither a correlation between oyster larval movements and tidal stage nor evidence that late stages were more common near the bottom. Data supplied by Wood and Hargis (1971) from a single 24-hour study in the James River, Virginia indicated that bivalve larvae occurred in greatest abundance near slack current of high water, whereas the slack water of low tide was the time when minimum concentrations occurred. This behavior, they stated, correlated with the increasing salinities of flood tide.

Bousfield (1955) noted that the vertical position of *Balanus improvisus* larvae in the water column changed with tidal stage in the Miramichi Estuary, eastern Canada. Nauplii were nearest the surface at high and low water, and deepest at mid-ebb and mid-flood; cyprids were farthest above the bottom on flood tides. He suggested that three-dimensional distributions of barnacle larvae and several other species
of zooplankton in this estuary resulted primarily from bathymetrically selective swimming by the organisms coupled with horizontal transport by the estuarine circulation.

Rogers (1940) and Manning and Whaley (1954) offered a contrasting hypothesis to that of selective swimming. They suggested that those organisms which remain in bottom waters due to increased density with age or behavioral preference will be moved upstream by net transport of inflowing bottom currents alone. They concluded that selective swimming was not necessary to transport larvae upstream. However, selective swimming both accomplishes and expresses a behavioral preference.

Most tidal investigations were conducted over a short period of time; several reported on data from only one diurnal cycle. Except for the work of Bousfield, all previous field studies have been conducted on estuaries with average surface velocities of approximately one knot or less. Work in the United States has been directed toward larval behavior of *Crassostrea virginica*. Several investigators collected their specimens by towing nets. Gibbons and Fraser (1937), Wiborg (1948), Barnes (1949), and Pyefinch (1949) compared pump and net plankton hauls and concluded that nets gave an adequate record, but were inadequate for quantitative meroplankton work.

The preliminary observations of meroplankton in the Piscataqua-Great Bay Estuary and the review of the literature mentioned above suggested that there were several areas which needed further investigation. The following questions dictated the design of the four year study presented herein:

1. What are the seasonal distribution patterns of meroplankton
in the Piscataqua-Great Bay Estuary and how do they vary from year to year?

2. How is the meroplankton distributed horizontally and vertically within this estuary?

3. How do regular changes of hydrographic variables affect meroplankton distributions?

This dissertation attempts to answer the preceding four questions and evaluate the impact of hydrographic variability on natural populations. Annual variations in meroplankton distribution were monitored by means of a four year program, for 1970 through 1973. Variations in the density and species composition of the meroplankton were investigated each month on the flood and ebb tides at 0.5 and 8 m depths from four stations within the estuary. The present results conclude four years of seasonal studies of the meroplankton and the selected hydrographic measurements of the Piscataqua-Great Bay Estuary in New Hampshire. It includes four 24-hour studies of meroplankton and hydrographic measurements at one station for different seasons and years (June 1970, September 1971, November 1972, March 1973).

Measurements of physical and chemical parameters and most of the planktonic collections from April to November of the years 1970 through 1973 were taken by staff members of Normandeau Associates, Inc. as part of an environmental monitoring study for Public Service Company of New Hampshire. This portion of the sampling program was designed to meet contract specifications and to provide a monitoring assessment of seasonal plankton distributions within the estuary. Results from the preliminary plankton sampling of 1970 were used to design the structure
of this dissertation and to modify the sampling program for the monitoring study. The winter study and the remaining 24-hour studies were necessary additions to answer the questions which remained.
THE ESTUARY

The Piscataqua-Great Bay estuarine complex drains about 1069 km$^2$ of gently sloping to hilly terrain in New Hampshire and Maine (Fig. 1). The Winnacunnet, Squamscott and Lamprey Rivers enter Great Bay; Oyster River and the Bellamy River flow into Little Bay; and the Salmon Falls and Cocheco Rivers join to form the Piscataqua River which flows into coastal waters at Portsmouth Harbor. Low tide volume of the total estuary has been calculated as 1466.7 x 10$^6$ m$^3$ and high tidal volume as 2476.5 x 10$^6$ m$^3$ (Jackson and Moreland, 1970).

Great Bay is an unusual feature of the estuarine system. The large inland embayment covers about 2307 x 10$^4$ m$^2$ at mean high water and about 1093 x 10$^4$ m$^2$ at mean low water. The total volume of the bay at mean low water is about 393 x 10$^6$ m$^3$. Areas and volume were derived by Ebasco Services, Inc. (1969).

The channel from the Harbor to Great Bay is deep and narrow with shallower waters extending from river mouths, islands and points of land toward the main channel (Fig. 2). The channel of the Salmon Falls-Cocheco River branch, however, shoals to 4 m immediately above Station 4 on ebb tides, with decreasing depths upriver. The lower estuary is underlain by rock and cobble (personal observation). The upper estuary has a higher incidence of sand and mud in the channel and shoreward marshes. Depth of the shipping channel is maintained by occasional dredging between Stations 2 and 4, subsequently increasing turbidities in the lower estuary. The sill depth for Little Bay is approximately 6 m on low slack tides near the General Sullivan Bridge and waters deepen upriver of this forming the smaller of two bays. Several shoal areas were found in the upper
Figure 2. Echo-sounding pattern of channel profile taken on ebb slack tide from Portsmouth Harbor to Great Bay.
reaches of Little Bay, but Furber Strait has the most prominent sill formation. Deep waters of 12-16 m lie between Stations 6 and 7 in Great Bay, but shoal waters comprised the remainder of the larger bay.

Dye studies conducted by Ebasco Services, Inc. (1969) in September 1968 near Station 3 indicated that the water exchange rate is approximately 2743 m$^3$/sec and the total time required to replace all water in the area would be approximately 46 hours. Dye concentrations were nearly uniform both transversely across each tracking station and vertically in the water column. An average of 4-5 days was required for dye released at Station 3 to be detected in Portsmouth Harbor or Great Bay. These studies showed evidence of a slight salt wedge in Great Bay, yet the net difference in temperature and salinity was usually less than 2°C and 2 °/oo, respectively, between surface and bottom. Measurements were taken only in September, a period of lowered discharge from rivers. The estuary is vertically stratified in Great Bay and in Portsmouth Harbor at certain times of the year, but is usually well mixed between these two areas (monitoring data by Normandeau Associates, Inc. from 1970 to 1973). A deep, narrow channel and fast currents between the Harbor and Little Bay account for these differences. The Ebasco studies (1969) described these currents as strong, with maximum velocities in the tidal cycle averaging 4-5 kts and reaching 6 kts during the test period. These were strongly directional and swung 180° during a very short slack period (0 velocity) which seldom lasted as long as ten minutes; periods when velocities were less than 2 kts seldom lasted more than 25 minutes.

The daily freshwater inflow to the Piscataqua is insignificant during summer months compared to tidal volume. According to Ebasco
Services, Inc. (1969), an average freshwater inflow of 33.5 m$^3$/sec that entered the estuary above Station 3 in September of 1968, represents only 7% of the long-term average inflow. According to Jackson and Moreland (1970), monthly average tidal flows into the estuary were approximately 35,662 m$^3$/sec, above Station 3, with an average velocity of 2 kts. The latter study, however, indicated that average river flow may approach zero. The large flow rates in the estuary are due mainly to the volumes of Great Bay and Little Bay. The river serves primarily as a duct between these bays and coastal waters with periodically reversing tidal flow.

The estuary is extremely well mixed both vertically and horizontally in its main channel, as shown by temperature-salinity traverses made in 1968-1969 by Webster and Martin (for Public Service Company of New Hampshire, unpublished data), dye diffusion tests in 1968 (Ebasco Services, Inc., 1969) and temperature-salinity studies from 1970-1973 (Normandeau Associates, 1971, 1972, 1973, and this study).
METHODS AND MATERIALS

The author and other staff members of Normandeau Associates, Inc. designed a sampling program to study the plankton of this estuary in relation to selected hydrographic parameters. All plankton were analyzed by the author, but the majority of the seasonal data was collected and analyzed by the staff of Normandeau Associates, Inc. Results and conclusions presented herein are the author's interpretations of these raw data. All collection and analyses of the winter and tidal data are the author's.

Preliminary Sampling

To gain a general impression of species composition and abundance, preliminary plankton sampling was begun in June and extended through November of 1970. At each station, plankton samples were collected from depths of 0.5 and 8 meters with a Clarke-Bumpus plankton sampler (12.5 cm diameter) fitted with a #20 (0.076 mm mesh) net which was towed for two minutes (approximately 1000-2000 liters of water sampled). Collections were made every two weeks in the summer and fall at Stations 1, 3, and 7 approximately one hour prior to high and low tides (Fig. 1). A 24-hour study was conducted at Station 3 on 30-31 July 1970 to determine whether tidal studies would be desirable. Nets were towed every three hours at 0.5 meters. Deeper samples were not possible because the weighted plankton sampler was carried to near-surface waters.

Since a high proportion of meroplankton within each towed sample was damaged (10-20% of the larvae), submersible pumps were tried alternatively. Species composition and abundance of the pump samples were
similar to that of the tows (compare 1970 data with those of 1971 on Figures 12 through 15), while damage to the specimens was minimized (less than 1%). The pump hoses remained vertical as the boat drifted with the current so the depth of sampling could be determined more accurately. Plankton pumps were used for all further collections.

Temperature and salinity were measured at most of the plankton stations from early April through early December. Dissolved oxygen and water transparency were measured occasionally.

**1971 Seasonal Sampling**

Plankton samples were collected every two weeks at two depths for each of four stations (Stations 1, 3, 4, and 7) from April through November 1971; time of collection ranged from one hour prior to the slack water of both high and low tides to full slack. These samples were collected from 0.5 and 8 m by pumping for seven minutes (approximately 200 liters of water sampled) with two Little Giant® submersible pumps. Water was pumped up through a rubber hose (1.9 cm inside-diameter) into two #20 nylon plankton nets suspended in a box filled with continuously flowing water (Fig. 3). Submergence of the nets in the box reduced damage to the specimens from being forced into the netting. Threaded glass vials (25 x 90 mm) were fitted into a threaded metal flange attached to the cod end of the plankton net. The sides of the net and flange were carefully washed and the plankton were concentrated in the vial. This plankton sampling rig was slightly modified from a design by L. Wood. The sample was then preserved with a two percent solution of formalin buffered with a supersaturated solution of CaCO₃.
Figure 3. Detailed view of submersible plankton pump system.
VESSEL DRIFT

OVERFLOW - OUTLET

PLANKTON NET.

PLANKTON VIAL

Hose

WATERPROOF ELECTRICAL CABLE

GARDEN HOSE

SUBMERSIBLE PUMP

NYLON SUPPORT LINE

WATER

ELECTRICAL OUTLET TO GENERATOR

INTAKE
Water temperature, salinity, pH and transparency were measured at Stations 1 through 7. Submersible instruments were kept at depth by drifting with the current. Water temperature and salinity were measured in situ with a Beckman RS-5 salinometer at one meter intervals from just below the surface to a depth of 12 meters. All other measurements were taken at the sampling depths of 0.5 and 8 meters. A portable Orion pH meter was used to measure pH on deck. Dissolved oxygen samples, collected from Stations 1 through 7, were preserved aboard ship by the Winkler procedure through acidification and analyzed by a modified titration described in Standard Methods for the Examination of Water and Waste­water, 12th ed. (American Public. Health Association, 1965). Water transparency (depth of visibility) was recorded as the depth at which a standard Secchi disc was just visible from the surface.

Three additional hydrographic stations (Stations 2, 5 and 6) were established to help explain any differences which might have occurred between the widely separated plankton Stations 1 and 3, 4 and 7.

1972 Seasonal Sampling

During 1972, simultaneously replicated samples from 8 m were taken at Stations 1, 3, 4, and 7 on flooding tides, which contained a greater number of meroplankton than ebb tides during preceding years. Replicated samples were taken on flood and ebb tides at Station 3 from 0.5 and 8 m. Collection time on the respective stage of tide remained the same as for 1971. All plankton samples were preserved. This scheme was used from April through November (16 samples per month). Samples were collected during December from both depths at the four stations on flood
and ebb tides. Due to ice conditions, winter sampling at some upriver stations on ebb tide was impossible.

Sampling equipment and measurement of hydrographic variables were the same as in 1971.

Population changes were monitored by replicate surface samples taken at 0900 hours each week near Station 3. Samples were pumped for five minutes (approximately 150 l pumped) at 0.5 m from January through May by B. Smith of Public Service Company of New Hampshire and from July through December by the author. These samples were not preserved and were counted live to confirm identification of several species which were difficult to identify after preservation.

1973 Seasonal Sampling

Sampling extended from January through November and all methods and equipment were the same as in 1972. Sampling from January through February was the same as for December 1972, but March ebb-flood samples were not collected because a vessel was not available. January through March samples were collected by the author and the remaining monthly samples were collected by the staff of Normandeau Associates, Inc. Plankton samples from August through November were analyzed by Normandeau Associates and were used herein to complete the seasonal data for 1973 (the author was out of the country at the time).

Diel Studies

Three 24-hour studies were conducted by the author and volunteer crew in the summer, fall and early spring at Station 3 to consider tidal
and diurnal effects. On 8-9 September 1971, 17-18 November 1972 and
16-17 March 1973, hourly samples were taken at 0.5 m from the R/V Jere
Chase held at anchor. The physical characteristics of the river, boating
traffic and the limited maneuverability of the vessel precluded drift
sampling. Samples from 8 m were attempted at anchor but were abandoned
because the sampling pumps, each with a 30 lb additional weight, were
carried almost to the surface. Replicate samples were obtained from the
summer and spring studies only (96 samples each in summer and spring,
48 in the autumn). During November, one of the series of pumps entangled
with the anchor line and was lost. In addition to the hydrographic
variables measured during the normal monthly sampling, air temperature,
time of slack tides, current direction, tidal height, and weather con­
ditions were indicated for the 24-hour studies.

Analysis of Plankton Samples

During 1970 total counts of meroplankton were made from each
plankton sample. The increased volume of samples collected from 1971
to 1973 necessitated using subsampling techniques for more abundant
species. In 1971, total counts were recorded of all bivalve larvae
before subsampling estimates were tallied for the remaining abundant
organisms. All plankton analyses were conducted by the author from April
1970 to July 1973. Plankton analyses by the staff of Normandeau Asso­
ciates, Inc. from August 1973 to November 1973 were included to complete
data for that year.

From 1971 to 1973, all preserved samples of seasonal plankton
were brought to constant volume and evenly dispersed. A 1/10th sub­
sample was then withdrawn by pipet and expelled into a gridded Falcon
phage dish. This subsample was evenly dispersed in the dish and 13.1% (5 out of 38.2 total squares) of the dish area was counted on 48 x power. To account for the less abundant species, half of the total sample was poured into the phage dish, evenly dispersed, and counted on 24 x power. All larvae in this half aliquot with an abundance of 100 or less were totally counted. Any larvae which appeared in the 1/10 sampling estimate, but were now determined to exist in low abundance, were tallied by the half aliquot method. The half subsample was returned to the original sample. Two 1/50th aliquots were removed and placed on two Sedgewick-Rafter cells to count the micro-zooplankton that may have been missed by previous analyses. These subsamples were evenly dispersed as before and 8.2% (3 slide heights out of 36.5 total) of the slide area was viewed on 125 x power. Straight hinge stages of bivalve veligers were consistently counted by the latter method. Plankton samples from the 24-hour series were not subsampled; total counts were tallied for all species.

Live plankton samples were poured directly into a clean phage dish. All moving meroplankton within each of 36 squares were counted on 30 x power. Non-moving animals, or any entering a square from one which was previously counted, were not tallied. Specimens were frequently removed and identifications verified under higher power.

All values for both preserved samples and the live series were converted to numbers of meroplankton per 100 liters of water. All biological and physical-chemical data collected from April through November of each year were stored on computer tape and filed with Normandeau Associates and the author. Data collected from the 24-hour studies and during winter of 1972-1973 remain with the author. A condensed set of
these data are included in this dissertation as appendices.

An analysis of variance (ANOVA) was performed to test for significant variation among subsamples and field variation among replicates (Table 1). The ANOVA test on the subsampling methodology which follows was designed a priori as a mixed model, nested sampling experiment (Mendenhall, 1968). The term "nested" is derived from the random subsampling of measurements withdrawn from randomly selected n1 aliquots (prime units) from each plankton sample. Three primaries were randomly selected from each replicate and five aliquots were analyzed from each primary. Data were from replicated samples collected on the same day with submersible pumps from two depths (0.5 and 8 m) at Station 3.

The F-ratio is not significant for either variation among primaries or field variation among replicates. An estimate of the variance within B, C, and N (replicates, primaries and aliquots) indicates a negligible field component (Table 1). Variation among primaries is only 9 percent of the total variation for the three nested factors. The greatest variation occurs within aliquots (98%). Data were always recorded as primary counts which were averaged for each replicate. The replicated results were then averaged. Thus, sampling error was further reduced from that determined for primaries or replicates.

A three way analysis of variance with replication was performed to determine the degree of variation between treatment effects (Appendix A). Data from Station 3 at 0.5 and 8 m depths were collected during the period April 1971 through November 1973 on both flood and ebb tides. The degree of variation between the two depths and between the interaction of month and depth was not significant. Monthly and tidal variations, interactions between month and tide, and depth-tide interactions were
Table 1. A mixed-model nested ANOVA was used to determine variations in counting methodology. Densities of the umbo stage larvae of *Mytilus edulis* were used with transformation \([\text{Ln}(x+1)]\).

Factors:
- **A**: two depths (fixed)
- **B**: two replicates within each depth
- **C**: three primaries within each replicate
- **D**: five aliquots within each primary

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<th>MS</th>
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<td>Total</td>
<td>59</td>
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</table>

Estimate of Variance Components:

\[
S^2 \text{ error} = 0.506246 \quad 98.4724% \\
S^2 C \times B = 0.04488 \quad 8.7298% \\
S^2 B \times A = -0.03703 \quad -7.2% 
\]
significantly greater than those attributable to replication.

A two way analysis of variance was used to determine whether significant variation existed between stations from April through November 1971 to 1973. Meroplankton from 8 m on flood tides were summed for this analysis. Variation among years was not statistically significant (as expected for a random treatment), but variance among stations was significant ($\alpha \leq 0.001$).
RESULTS

Seasonal Variation of Physical Factors

Results were drawn on data collected by Normandeau Associates, Inc. from April through November of 1970 through 1973 and on data collected by the author from December through March of 1972.

Salinity

Analysis of the four-year collection of data shows that estuarine salinities increased from a spring low to a mid-summer high then decreased during the autumn (Fig. 4A). The maximum range of seasonal values occurred in the upper estuary and diminished downriver. Portsmouth Harbor salinity showed the least seasonal variation. Great Bay salinity increased steadily from a low of 5 °/oo in April to a high of 30.8 °/oo in August, while Portsmouth Harbor salinity increased from an April low of 23 °/oo to the nearly constant summer-through-winter high of 32.7 °/oo.

Measurements of salinity recorded during 1970 and 1971 were similar, whereas those of 1972 and 1973 differed substantially from the preceding two years. In the spring of 1972 salinity in the estuary was 3 to 13 °/oo higher than during the spring of 1970, 1971, and 1973, otherwise salinity measurements were consistently lower for 1972 and 1973 than for the other two years (Fig. 4A). The least annual variation occurred in Portsmouth Harbor.

Results from salinity measurements recorded each month at one meter intervals from the surface to a depth of 12 m indicated that the
Figure 4. A. Seasonal variation in salinity at 8 m on high water of flood tide from 1970 through 1973 for the four meroplankton sampling stations. B. Flood-ebb variations in salinity measured at Station 3 near slack water stages of flood and ebb tides at the depth of 0.5 m from 1970 through 1973.
A. SEASONAL VARIATION IN SALINITY

B. FLOOD-EBB SALINITY AT STATION 3
The estuary was vertically stratified during the spring (Appendices C-H). The estuary was stratified for a greater portion of the time during 1972 and 1973, however, than in 1971. Estuarine waters were generally well mixed vertically for the remainder of the year. Stratification occurred from the Harbor to Great Bay on high and low tides during April of all years. Estuarine waters were well mixed on both tides for the rest of the year except in Great Bay during the winter on near high tides. This was most likely due to ice melt (Fig. 5). Stratification, however, occurred throughout 1972 at the Harbor station and also in the autumn at upriver stations (Appendices E and F).

Measurements of salinity at Station 3 on flood-ebb stages of tide showed considerable differences with tide; flood tide salinity was always greater than ebb tide salinity (Fig. 4B). Tidal patterns of surface salinity were most similar during 1970 and 1971, but differed from those of 1972 and 1973. Salinity measurements were higher in the latter two years during spring and were not as high as peak summer salinity from the preceding years. Flood tide measurements, however, were always greater than those of ebb tide, irrespective of year.

Salinity data were plotted for all seven stations in the estuary from 1971 through 1973 (Appendix I), but 1971 was selected as the typical year to describe horizontal differences on flood and ebb tides (Fig 6). Total precipitation in 1971 was close to the 40 year average calculated for Durham, New Hampshire; however, it was 144 cm above the long term average in 1972 and 137 cm above average in 1973 (U.S. Department of Commerce, National Wildlife Service, 1970-1973). Station differences were greater between tides in autumn of 1972 and 1973 than for that of
Figure 5. Typical vertical patterns of salinity (dashed lines) and temperature (solid lines) for selected months at the four meroplankton stations on near slack water stages of flood and ebb tides.
Figure 6. Horizontal pattern of salinity during 1971 at seven sampling stations from Portsmouth Harbor to Great Bay at 8 m on near slack water stages of flood (solid lines) and ebb (dashed lines) tides.
Differences in salinity between flood and ebb tides were high at all stations during early spring of 1971 (maximum range of 9 °/oo), gradually decreasing until about 1 °/oo separated flood and ebb tides in September. Seasonal and tidal ranges in salinity increased upriver and were greater on ebb tides than on flood.

Temperature

Annual cycles of temperature were generally similar in the years 1970-1973 (Fig. 7). The estuary warmed rapidly from April to a summer maximum in August or September, then cooled to a winter minimum in January or February. Ice formed in the upper estuary in late November and was present through March in all four years. Maximum temperatures differed slightly at each station over the four year period. Maximum temperatures on the flood tide ranged from 14.5 to 17.7°C in the Harbor and from 19.6 to 22.8°C in Great Bay. Maximum temperatures were higher on the ebb tide, ranging annually between 15.6 to 18.2°C in the Harbor and between 21.6 to 25.7°C in Great Bay. Minimum temperatures, measured during the winter survey of 1972 to 1973, were 2.6°C in the Harbor to less than 0°C (below ice cover) in Great Bay. Winter temperatures were similar on flood and ebb tides. The greatest annual range of temperatures in all years occurred in Great Bay, with the least range in temperature occurring in the Harbor. Great Bay temperatures ranged from less than 0°C under winter ice to a maximum of 25.7°C during summer. Harbor temperatures ranged from a winter low of 2.6°C to a summer high of 18.2°C.

Results of temperature profiles taken at 1 m intervals between the surface and 12 m indicated that a thermocline existed at most
Figure 7. A. Seasonal variation in temperature at 8 m on high water of flood tide from 1970 through 1973 for the four meroplankton sampling stations. B. Flood-ebb variations in temperature measured at Station 3 near slack water stages of flood and ebb tides at the depth of 0.5 m from 1970 through 1973.
A. SEASONAL VARIATION IN TEMPERATURE

- Station 1
- Station 3
- Station 4
- Station 7

B. FLOOD-EBB TEMPERATURE AT STATION 3

- Flood
- Ebb
stations during each spring (Fig. 5; Appendices C-H). Stratification persisted through the summer of 1972 at lower estuarine stations and frequently occurred at other stations on ebbing tides in 1972 and 1973.

During all four years, temperature variations among stations were slight in spring and autumn, but increased substantially during the summer (Appendix J). The range of temperature was minimal during September between Stations 1 and 7 on any single tidal cycle. A maximum difference of only 1°C occurred between flood and ebb tides in April and November of all years, but temperatures differed 5 to 7°C between tides in July and August. Ebb tide temperatures were consistently higher than flood tide temperatures from April through October, but flood tide temperatures were higher from late autumn through winter. Horizontal differences during the typical year of 1971 were least during spring and autumn (Fig. 8). Temperatures were warmer up-estuary in the spring and summer, but the reverse occurred during autumn and winter. Horizontal temperature variations from the Harbor to Great Bay were greater during June through September than during the rest of the year.

**pH**

The pH was higher from April through November of all four years (approximately 7.5 to 8.0) than during the single winter survey of 1972 to 1973 (approximately 6.0 to 6.5; Fig. 9A). It was lower during the same months throughout the estuary in 1972 than during 1970, 1971 and 1973. Spring and autumn measurements of pH were slightly higher than summer values at most stations. Upper estuarine samples were usually more alkaline than Harbor samples.
Figure 8. Horizontal pattern of temperature during 1971 at seven sampling stations from Portsmouth Harbor to Great Bay at 8 m on near slack water stages of flood (solid lines) and ebb (dashed lines) tides.
Figure 9. A. Seasonal variation in pH at 8 m on high water of flood tide from 1970 through 1973 for the four meroplankton sampling stations. B. Flood-ebb variations in pH measured at Station 3 near slack water stages of flood and ebb tides at the depth of 0.5 m from 1970 through 1973.
A. SEASONAL VARIATION IN PH


PH

STATION 1

PH

STATION 3

PH

STATION 4

PH

STATION 7

B. FLOOD-EBB PH AT STATION 3


PH

EBB

FLOOD
Considerable vertical pH differences were evident within the water column of the upper estuary during the spring and autumn of 1971 and during August of 1972. Differences between flood and ebb tides were variable at all stations (Fig. 9B). Seasonal pH values showed no relationship of pattern with tide, station or month (Appendix K).

Dissolved Oxygen

Dissolved oxygen remained generally above 8 mg/l at all sampling stations during the entire study period (Fig. 10). The highest measurement of dissolved oxygen was 13.9 mg/l in April 1972 and the lowest was 6 mg/l in September 1971; both were in Great Bay on ebb tide. No major differences were noted between 0.5 and 8 m samples on ebb and flood tides. Oxygen levels were highest (at and above 12 mg/l) when the waters were cold and lowest in the warm months of summer.

Dissolved oxygen remained near or above saturation throughout the survey. Percent saturation values as derived from Green and Carrett (1967) ranged from 78 to 118 percent at all stations from 1971 to 1973. Because dissolved oxygen remained above saturation most of the time and never decreased to critical levels for animal survival, values were not plotted for the seven sampling stations. Dissolved oxygen will not be dealt with further in this dissertation.

Transparency

Estimates of water transparency were obtained with a standard Secchi disc. Measurements were taken intermittently in 1970 and recorded values are entered on Figure 11A. Depth of visibility consistently
Figure 10. A. Seasonal variation in dissolved oxygen at 8 m on high water of flood tide from 1970 through 1973 for the four meroplankton sampling stations. B. Flood-ebb variations in dissolved oxygen measured at Station 3 near slack water stages of flood and ebb tides at 0.5 m depths from 1970 through 1973.
A. SEASONAL VARIATION IN DISSOLVED OXYGEN

B. FLOOD-EBB DISSOLVED OXYGEN AT STATION 3
Figure 11. A. Seasonal variation in depth of visibility at 8 m on high water of flood tide from 1970 through 1973 for the four meroplankton sampling stations. B. Flood-ebb variations in depth of visibility measured at Station 3 near slack water stages of flood and ebb tides at 0.5 m depths from 1970 through 1973.
A. SEASONAL VARIATION IN DEPTH OF VISIBILITY

- Station 1
- Station 3
- Station 4
- Station 7

B. FLOOD-EBB DEPTH OF VISIBILITY AT STATION 3

- Ebb
- Flood
decreased from the Harbor to Great Bay from 1971 through 1973. Visibility in Great Bay ranged from a low of 0.8 m to a high of 2.4 meters. Depth of visibility in Portsmouth Harbor ranged from a low of 2.3 m in spring to a high of 10.4 m in August. Visibility on the ebb tide was always less, by as much at 50 percent, than on the flood tide (Fig. 11B). Seasonal differences between ebb and flood tides from the Harbor to Great Bay were more moderate in 1972 and 1973 than during 1971 (Appendix L).

**Seasonal Meroplankton Distributions**

**Seasonal Variation**

Planktonic larvae were collected in the Piscataqua-Great Bay Estuary from February through December; larvae were lacking in January samples. Seasonal (monthly) variance in total meroplankton abundance was statistically significant from 1971 through 1973 (Appendix A). The majority of meroplankton were in the water column from June through October, with notably low densities of all phyletic groups in August. Several consistent patterns were observed in seasonal meroplankton data collected at the four stations (Figs. 12-16). Cirripede nauplii (Balanus balanoides Stage I and II) were the first meroplankton to appear. These nauplii were in February samples from the lower estuary and were most abundant from mid-March to early April. The spring phytoplankton bloom occurs coincident with peak barnacle naupliar densities. Trochophores and early stage larvae of spionids were abundant from April through May, with highest densities in the upper estuary. Ophiopluteus larvae of echinoderms were abundant from April through June.
Figure 12. Seasonal patterns in the measurements of selected hydrographic parameters and meroplankton distributions from Station 1 (Portsmouth Harbor) at 8 m on high water of flood tides.
Figure 13. Seasonal patterns in the measurements of selected hydrographic parameters and meroplankton distributions from Station 3 at 8 m on high water of flood tides.
Figure 14. Seasonal patterns in the measurements of selected hydrographic parameters and meroplankton distributions from Station 4 at 8 m on high water of flood tides.
SALINITY (%o)

TEMPERATURE (°C)

pH

DISSOLVED OXYGEN (mg/l)

DEPTH OF VISIBILITY (m)

AVERAGE NUMBER OF LARVAE / 100L

KEY FOR MEROPLANKTON
- BIVALVIA
- POLYCHAETA
- GASTROPODA
- CIRRIPEDEA
Figure 15. Seasonal patterns in the measurements of selected hydrographic parameters and meroplankton distributions from Station 7 at 8 m on high slack water of flood tides.
Figure 16. Depth (0.5 and 8 m) and tidal (near slack water stages of flood and ebb tides) patterns of meroplankton distributions at Station 3 over the four year study period. Note that during March data were collected for A and B but not for C and D. This fact accounts for the apparent anomaly of a lack of barnacle nauplii at depth during this month.
AVERAGE NUMBER OF LARVAE / 100L

A. 0.5 M, FLOOD

MEROPLANKTON KEY

- BIVALVIA
- POLYCHAETA
- GASTROPODA
- CIRRIPEDIA

B. 0.5 M, EBB

C. 8 M, EBB

D. 8 M, FLOOD
in the lower estuary. Molluscan bivalve veligers were most abundant from June through July, with a secondary peak in September and early October. Bivalve larvae were concentrated in the lower estuary, decreasing upriver. Prosobranch veligers were most abundant in the upper estuary, with peak larval populations occurring from late June to late July. Consistent patterns of seasonal succession were not observed in the distributions of nudibranch veligers, ectoproct larvae and the megalops and zoeal larvae of the crustaceans. These larvae occurred intermittently in low abundance at all stations. Except for the prosobranch populations which were decreasing from their July levels, others were found in concentrations less than 50 larvae/100 l and several phyla were lacking during August of all four years (see discussion p. 81). Results from Stations 3 and 4 were intermediate in all cases to the results from collections in the Harbor and Great Bay.

Annual Variation

The monthly distributions of meroplankton, described above, were consistent at all stations during the four years of this study (Figs. 12-16). The between-year variance in total meroplankton densities was not significant (Appendix B). Although annual densities of total meroplankton were similar, differences were observed in the larvae of certain species. In the lower estuary, densities of bivalve veligers were lowest in 1972 and Balanus balanoides nauplii were most abundant in 1973. In the upper estuary, highest densities of polychaete veligers were counted in 1973 plankton samples (Fig. 13). The time of appearance of prosobranch veligers in Great Bay was similar from 1971 through 1973, but larval densities were somewhat higher in May 1973 than in the other
in the lower estuary. Molluscan bivalve veligers were most abundant from June through July, with a secondary peak in September and early October. Bivalve larvae were concentrated in the lower estuary, decreasing upriver. Prosobranch veligers were most abundant in the upper estuary, with peak larval populations occurring from late June to late July. Consistent patterns of seasonal succession were not observed in the distributions of nudibranch veligers, ectoproct larvae and the megalops and zoeal larvae of the crustaceans. These larvae occurred intermittently in low abundance at all stations. Except for the prosobranch populations which were decreasing from their July levels, others were found in concentrations less than 50 larvae/100 l and several phyla were lacking during August of all four years (see discussion p. 81). Results from Stations 3 and 4 were intermediate in all cases to the results from collections in the Harbor and Great Bay.

Annual Variation

The monthly distributions of meroplankton, described above, were consistent at all stations during the four years of this study (Figs. 12-16). The between-year variance in total meroplankton densities was not significant (Appendix B). Although annual densities of total meroplankton were similar, differences were observed in the larvae of certain species. In the lower estuary, densities of bivalve veligers were lowest in 1972 and Balanus balanoides nauplii were most abundant in 1973. In the upper estuary, highest densities of polychaete veligers were counted in 1973 plankton samples (Fig. 13). The time of appearance of prosobranch veligers in Great Bay was similar from 1971 through 1973, but larval densities were somewhat higher in May 1973 than in the other
two years (Table 2).

Horizontal Distribution

Larval populations varied significantly over the 8 km distance from Portsmouth Harbor to Great Bay (Appendix B). During the four years of this study the total abundance of bivalve veligers as well as the densities of the individual species consistently decreased upriver to Great Bay (Appendices M and N). Veligers of *Anomia aculeata*, *Hiatella arctica*, *Mya arenaria*, *Modiolus modiolus* and *Mytilus edulis* decreased from the Harbor to Great Bay. On the other hand, the larvae of prosobranchs, polychaetes and the barnacle, *Balanus crenatus*, consistently decreased from Great Bay to the Harbor. Spionid trochophores and later stage larvae increased upriver (Table 2). Echinoderm larvae (bipinnaria, auricularia, ophiopluteus and echinopluteus) were found only in the lower estuary and decreased in abundance from Stations 1 to 4. Ectoproct larvae were not as definitive in their horizontal distributions.

There were consistent differences in the species composition of larvae between Harbor and Great Bay samples for the duration of the study (Figs. 12-15). This fact is most clearly presented on Figures 17 and 18 from data collected in 1971. Larvae of *Anomia aculeata*, *Hiatella arctica*, *Mya arenaria*, *Mytilus edulis*, *Modiolus modiolus*, *Balanus balanoides* and echinoderms comprise the lower estuarine community and all decrease upriver. Larvae of such species as *Crassostrea virginica*, *Modiolus demissus* and *Polydora* spp. comprise the upper estuarine community; larvae of *Polydora* decrease consistently downriver. The larvae of *C. virginica* and *M. demissus* were not collected in the upper
Table 2. Total and mean densities of meroplankton were calculated from data at four stations (Stations 1, 3, 4, and 7) during April through November of 1971-1973. All samples were collected at 8 m on near slack waters of flood tide.
### MEROPANKTON

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**TOTAL** 4939 617.38 4181 522.63 4840 605.00 3190 398.75 3604 450.50 3210 401.25
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Figure 17. Distributions of selected hydrographic parameters and meroplankton on high water of flood tide from four stations at 8 m during 1971.
Figure 18. Distributions of selected hydrographic parameters and meroplankton on low water of ebb tide from four stations at 8 m during 1971.
estuary where adult populations exist. Stations 3 and 4 were intermediate in larval density and composition to the lower and upper estuarine communities.

**Tidal Distributions**

Variations in larval distribution between high and ebb stages of tide were highly significant ($a \leq 0.001$) in the mid-estuary (Station 3) during the four years of this study (Appendix A). Consistently high densities of all bivalve veligers, echinoderm larvae, *Balanus balanoides* nauplii and cyprids occurred on high water stages of the tidal cycle (Figs. 12-15), their densities decreasing on low water stages. Such meroplankton as polychaete larvae, prosobranch veligers and *Balanus crenatus* nauplii were in low abundance or entirely lacking on high slack tides; but were abundant on low slack tides.

Comparisons of 1971 data, collected from the depth of 8 m on near slack water stages of flood and ebb tides showed consistent tidal variations of meroplankton of all stations (Figs. 17-18). Bivalve veligers which were abundant in the Harbor decreased from Stations 3 through 4 and were nearly lacking at Station 7 on flood tides. Bivalve larval densities on low tides in the Harbor were less than half those on the high tides and decreased substantially upriver. Larval densities of polychaetes, prosobranchs and *Balanus crenatus* nauplii were most concentrated on low tides in Great Bay, decreasing downriver to Station 4. The species forming the Great Bay community virtually disappeared at Station 3 (see Discussion p. 84).

Plankton collections from Station 3 at the surface (0.5 m) and
at depth (8 m) further substantiated the tidal differences observed in meroplankton density (Fig. 16). Bivalve veligers were in high concentration in late spring through early summer at the surface and at depth of high tides, but densities were much reduced on the low regardless of depth. Surface samples only were collected during March of 1973, accounting for the apparent anomaly of cirripede larvae (Balanus balanoides Stage I-III) with depth. It was not possible to collect 8 m samples as noted in the methods section. During 1971, April-May populations of cirripede larval stages (B. balanoides) were in highest concentration on high water, but July-August cirripedes (B. crenatus) were in highest concentration on low water.

Vertical Distribution

Densities of larvae collected from Station 3 at both 0.5 and 8 m depths were similar. Differences of abundance were not significant between the two depths using pooled data of total meroplankton, but interactions between depth and tide or between depth and month were significant (Appendix A). Bivalve veligers were always more abundant on high tides regardless of depth. Lowest densities of most phyletic groups occurred on low tides at 8 m (Fig. 16C). Polychaete larvae were most abundant during 1973 and were always more abundant in bottom waters regardless of tide.

Phyletic Considerations of Meroplankton

Ectoprocta

Adults of the Ectoprocta in the Piscataqua-Great Bay system were
abundant and varied comprising 22 species (Appendix 0); however, their larvae were not identifiable to the species level. Nine species of adults occurred in the lower estuary, ten species were collected just upriver of the General Sullivan Bridge and three were collected throughout the study area. Cyphonautes larvae were recorded in low densities (maximum 37 per 100 l) at all stations and their appearance in samples was sporadic from June through November (Appendices P-V). Larvae were collected more frequently in the lower estuary (Stations 1 through 4).

Annelida

Many of the 56 species of polychaetes described for the estuary were abundant in the estuarine benthos (Appendix 0) but only a moderate number of their larvae were taken in plankton samples. A lesser number were identified to species. Forty-two species of adults were collected intertidally and subtidally from the lower estuary, but all species were generally in low abundance. Populations which inhabit mud or sand substrates are limited within the lower estuary because most of the bottom is coarse sand or cobble. Polydora spp. and Fabricia sabella were dominant members of the periphyton community in the upper estuary; whereas, Ophelia bicornis, Heteromastus filiformis, Lumbrinereis tenuis, Nereis virens, and others inhabit the large areas of mud-sand substrates of the upper estuary. The inshore sediments of both bays, although not routinely sampled, had an abundance of adult polychaetes (personal observation).

Harmothoe imbricata, Eulalia viridis and Phyllodoce spp. larvae were collected sporadically (maximum of one larva per 100 l) from the lower estuary. The mitraria larvae of the oweniid polychaete, Myriochele
heeri, occurred in the lower estuary in low densities (a maximum of 20 per 100 l) from June through August. Adults of these four species inhabit the lower estuarine benthos. Likewise, low numbers of **Nephtys** spp. (a maximum of seven larvae per 100 l) and **Nereis** spp. larvae (maximum of 20 larvae per 100 l) were collected in the lower estuary. The majority of trochophore larvae occurred in the upper estuary from April through June, with maximum abundance during April and May. Highest densities were near low tide. Maximum densities of 60 trochophores per 100 l were tallied in the Harbor and 1917 per 100 l counted in Great Bay samples. Most trochophores probably developed into spionid larvae since peak densities of spionids followed the peak densities of the "unidentified trochophores" in Great Bay.

Spionid larvae were collected throughout the entire estuary during all years of this study, although they did not appear prior to June. Densities of spionid larvae ranged from 280 to 1555 per 100 l in Great Bay and from 21 to 86 per 100 l in Portsmouth Harbor. Adult **Polydora** spp. are most abundant in the upper estuary and larval distributions showed a similar distribution. Spionid larvae and unidentified trochophores were more abundant on the ebb than on flood tides. Polychaete cumulative totals were essentially those of the spionid larvae and unidentified trochophores (Figs. 12-15; Appendices M-N). Two major peaks were evident in all cumulative polychaete data, an early spring peak for the trochophore larvae and a slightly later peak for the more advanced spionid larvae.
Mollusca

The Mollusca form a major portion of the benthic and intertidal fauna within the Piscataqua Estuary. Thirty species of adult bivalves have been identified from the Harbor to Great Bay (Appendix 0); twenty-one species inhabit the lower estuary, three are essentially limited to the upper estuary and six have ubiquitous distributions within the study area. Adults and juveniles of the following are locally abundant in the lower estuary: Mya arenaria, Mytilus edulis, Modiolus modiolus, Placopecten magellanicus, Hiatella arctica, Ensis directus, Nucula proxima Macoma balthica and Tellina agilis. Adult distributions of these Harbor species decreased upriver. Adults of the following are locally abundant in the upper estuary but some of the juveniles are absent in certain years: Crassostrea virginica, Modiolus demissus, Mulinia lateralis, Gemma gemma and Macoma balthica. Adult distributions of Great Bay species decreased downriver.

Only a limited number of bivalve veligers have been identified to species in plankton samples. Although larvae of many of the Piscataqua bivalve species have been described (e.g., Sullivan, 1948), many of these are nearly identical to several closely related species and not certainly identifiable. This is the general difficulty with the identification of bivalve veligers in natural waters (personal observation from working with P. Chanley, J.D. Andrews, L. Wood). Wood and Hargis (1971) opted to count Crassostrea virginica larvae, (very distinctive) and identified the rest as "all others". Umbone stages which could not be identified to generic classification were listed as "unidentified umbone veligers" in the present study.
Anomia aculeata adults are moderately common throughout the subtidal benthos of the lower estuary on hard substrates. The juveniles of this species are common among the periphyton community of the lower estuary from late summer through autumn (Appendix 0). Although umbone stage veligers occurred at all stations, they further decreased upriver from a maximum density of the Harbor of 21 larvae/100 l (Appendices P-V). Seasonal abundance of their larvae was bimodal. Horizontal and high-low water distributions of *A. aculeata* veligers, plotted as monthly averages from 1971 to 1973, indicated that larvae were in the plankton from mid-May to mid-July, were absent in August and reappeared during September and October (Fig. 19). Differences between high-low stages of tide were not observed within monthly averages.

Little can be said about the quantitative larval distributions of *Mya arenaria*, since only the larvae of settlement size were distinguishable from *Hiatella arctica* larvae. Both species were present simultaneously in plankton samples. With regard to distinguishing planktonic larvae of *M. arenaria* from *Hiatella* sp., Savage and Goldberg (in preparation) determined that "specific identifying characters were lacking throughout much of larval life, from the early appearance of umbones at a shell length of approximately 155 μ until metamorphosis was approached in *M. arenaria* at a shell length of approximately 230-280 μ." The authors also noted that *Spisula solidissima*, *Macoma* sp. and *Cerastoderma pinna-tulum* were among species reared with *M. arenaria* which could be mistaken for *M. arenaria* at early stages of development. Attempts were made by Savage and Goldberg to use coloration and arrangement of pigment to separate these species in live plankton samples, but they found that color in *M. arenaria* varied from culture to culture and that *Hiatella* also displayed somewhat similar pigment characteristics.
Adults of *Hiatella arctica* are abundant among *Modiolus modiolus* mats in subtidal waters of the lower estuary and along the coast. Densities of larval *H. arctica* which were greater than 250 μ in length ranged from a maximum of 350 larvae per 100 l in the Harbor to a maximum of 5 per 100 l in Great Bay (Fig. 19). Maximum densities of larval *Hiatella* were collected at 8 m on high stages of tide. *Hiatella* larvae were most abundant in plankton samples from mid-June to mid-July, decreased to very low densities in August, then increased again during October. Juvenile *Hiatella* were moderately abundant in the periphyton community of the lower estuary from June through November, which conforms with planktonic seasonal occurrence.

Adults of *Mya arenaria* are abundant in certain intertidal habitats of the lower estuary, but young individuals predominate numerically. Late stage larval numbers of *M. arenaria* were always low, never more than 10 per 100 l, and these veligers occurred at all stations (Appendices P-V). *Mya arenaria* were observed to have a bimodal spawning pattern similar to that noted for *H. arctica* by monitoring seasonal presence of late stage larvae in samples and by gonadal condition of mature adults (Davis and Turgeon, 1971). *Mya* juveniles were not observed on settlement arrays from 1971 through 1973.

Although the straight hinge stage of mytilid veligers is easily separated from other straight hinge larvae by the length of hinge line, they were inseparable from each other within Piscataqua estuarine samples. Shell color and height are often used to separate early larval stages of *Mytilus* and *Modiolus*. However, these criteria were not useful for separating *Mytilus edulis* and *Modiolus modiolus* in preserved samples.
Figure 19. A. Seasonal distribution of the umbone stage veligers of *Hiatella arctica* and *Anomia aculeata* from Portsmouth Harbor (Station 1) to Great Bay (Station 7) on high water of flood tides at 8 m. B. Depth (0.5 and 8 m) and tidal (near slack water stages of flood and ebb tides) distributions of the umbone stage veligers *H. arctica* and *A. aculeata*, averaged monthly over the four year study period.
VELGERS/100 L

STATION 1

STATION 4

STATION 7

A. HORIZONTAL-SEASONAL DISTRIBUTION OF MEROPLANKTON

0.5 M, EBB

0.5 M, FLOOD

8 M, EBB

8 M, FLOOD

B. DEPTH-TIDAL-SEASONAL DISTRIBUTION AT STATION 3

KEY

- Hiostella orlilca
- Anomia osulenta
Recent culture work on *Mytilus edulis* and *Modiolus modiolus* larvae by de Schweinitz and Lutz (1976) showed that hinge line measurements do not overlap and can be used as diagnostic features to separate straight hinge stages of veliger larvae. More advanced stages of larval development (umbone larvae) also differed between species. Among other larval features, they concluded that the shell thickness was distinctive. *Modiolus modiolus* were more opaque and rounded than *M. edulis*. Opaqueness of shell was a prime feature used in separating these two nearly identical larval species within the present study. Straight hinge stages of *Modiolus demissus* larvae, although more distinctive, were not identified in samples collected from the upper estuary.

Mytilid straight hinge veligers ranged from 542 larvae per 100 l at Station 1 to 19 at Station 7 (Appendix P; Fig. 20). A large peak in density consistently occurred during June and July in the lower estuary and a much reduced one in September and October. Numbers were always higher on high tides than on low. *Modiolus* and *Mytilus* juveniles were not separated in periphyton studies by Normandeau Associates (1973).

Most *Modiolus modiolus* veligers were collected from the lower estuary during June and July (a maximum of 479 per 100 l); densities decreased upriver (Fig. 21). Larvae were most abundant on high stages of tide at 0.5 m and least numerous on low tides at 8 m (Appendix Q). Umbone stages of *Modiolus* veligers were never abundant in Great Bay. Veligers of *Modiolus demissus* were not collected from 1970 through 1973 even though their adults were in the upper estuary. This indicates either that spawning of *M. demissus* did not occur during these years or that
Figure 20. A. Average seasonal distribution of mytilid straight hinge and "other" straight hinge veligers from Portsmouth Harbor (Station 1) to Great Bay (Station 7) on high water of flood tides at 8 m. B. Depth (0.5 and 8 m) and tidal (near slack water stages of flood and ebb tides) distributions of mytilid and "other" straight hinge stages, averaged monthly over the four year study period.
**A. Horizontal-Seasonal Distribution of Meroplankton**

- **Station 1**
- **Station 3**
- **Station 4**
- **Station 7**

**Key**
- MYTILID STRAIGHT HINGE VELIGERS
- OTHER STRAIGHT HINGE VELIGERS

**B. Depth-Tidal-Seasonal Distribution at Station 3**

- 0.5 M, EBB
- 8 M, EBB
- 0.5 M, FLOOD
- 8 M, FLOOD
Figure 21. A. Average seasonal distribution of the umbone stage veligers of *Mytilus edulis* and *Modiolus modiolus* from Portsmouth Harbor (Station 1) to Great Bay (Station 7) on high water of flood tides at 8 m. B. Depth (0.5 and 8 m) and tidal (near slack water stages of flood and ebb tides) distributions of the umbone stage veligers of *M. edulis* and *M. modiolus*, averaged monthly over the four year study period.
larvae were produced but in lower densities than my sampling program could monitor.

*Mytilus edulis* adults were ubiquitous throughout the study area, but decreased considerably from the Harbor to Great Bay (Appendix 0). The umbone veligers of *M. edulis* occurred throughout the estuary, but the majority were collected at lower estuarine stations from June through July (Fig. 21). Larval concentrations decreased in August, then increased again in September and finally disappeared from plankton samples in November or December. *Mytilus* larvae were most abundant on high tides at 8 m during June and July.

I could not differentiate with certainty the many straight hinge veligers which have hinge lines from 50–65 μ. All were grouped into the category "other straight hinge veligers". The majority of these occurred from May through July of all years (Appendices P–V; Fig. 20). This category comprises two large classes of bivalves in the Piscataqua-Great Bay Estuary: 1) those with larvae that have not been reared and described adequately (e.g., *Solemya velum, Crenella decussata, Nucula proxima*), and 2) those with larvae that are so similar in shape, size and color that they cannot be consistently differentiated in preserved samples (e.g., *Mulinia lateralis, Macoma balthica, Cerastoderma pinnatulum, Ensis directus*). Straight hinge larvae were in greater concentrations in the Harbor during high tides and their numbers decreased upriver.

Ten species of adult Nudibranchia have been identified from the lower estuary during the four years of this study and L. Harris (personal communication) added nine species from his SCUBA survey of the Harbor benthos (Appendix 0). Adult nudibranchs were in low abundance
on hard substrata. Their larvae were not identifiable to the species level. Densities of nudibranch veligers were consistently low at all stations but were always more numerous in the lower estuary. Although their occurrence was sporadic they were collected in all months except January. An average of less than five nudibranchs were counted per sample in the weekly collections of live plankton from Station 3 in 1972 (Table 3).

The Prosobranchia is a prominent group in the Piscataqua-Great Bay Estuary. Adult populations of 18 different species (Appendix 0) were found in the intertidal zone and benthos from the Harbor to Great Bay. Adults and juveniles of *Lacuna vinca*, *Littorina littorea*, *Hydrobia minuta*, *Nassarius trivittatus*, and *Nucella lapillus* were locally abundant in the lower estuary and decreased upriver. Few of their larvae have been described adequately. Thus identifications of larvae to the species level were not achieved. Prosobranch veligers were abundant although their seasonal distributions were sporadic. Highest concentrations were recorded from Great Bay samples (over 2500 per 100 l). The majority of these larvae were probably *Nassarius obsoletus*, a numerically dominant form in Great Bay benthic communities. Larval prosobranch numbers consistently decreased downriver. At Station 3 prosobranch veligers were found in relatively high concentrations for periods of approximately two to three weeks, alternating with two week periods of low concentration. This pattern was consistent in the weekly data collected from live samples (Table 3) and probably represents individual spawnings of different species from subtidal and intertidal habitats. Prosobranch and polychaete larvae numerically dominated the meroplankton of Great Bay.
Table 3. Average densities (expressed as number/100 l) of meroplankton were summarized from replicate samples collected weekly at the same time of day (0900 hrs) on the same day for 1972. Samples were taken at a depth of 0.5 m, pumped for 5 minutes (approximately 150 l delivered) and counted alive.
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**N O M E R O P L A N K T O N**
Arthropoda

Benthic Crustacea with meroplanktonic stages are represented in the estuary by 12 species (Appendix 0). The adult standing stock of *Cancer irroratus* was estimated to be 10,000 in the lower estuary during 1972 and 1973 from mark and recapture studies by Normandeau Associates (1974). *Homarus americanus*, *Cancer irroratus* and *C. borealis* are presently harvested in the lower estuary. *Rhithropanopeus harrisi*, *Crangon septemspinosus* and *Carcinus maenas* are in high abundance along the shore throughout much of the estuary. Decapod zoeal and megalops stages of larvae, however, were in low abundance throughout the year. Zoea were present at all stations but appeared sporadically throughout the year (a maximum of 17 larvae per 100 l). Megalops larvae occurred sporadically also and did not exceed nine larvae per 100 l in any sample. They occurred at all stations on both tides and displayed no variability with tide, depth or season (Appendices P-V). Large crustacean larvae may have escaped the pump system of this study or may occur in moderately low concentrations in the water column.

Four species of adult barnacles (*B. balanoides*, *B. balanus*, *B. crenatus*, *B. improvisus*) were identified in the estuary. *Balanus balanus* was collected only occasionally on drift material. *Balanus balanoides* is the dominant barnacle of the rocky intertidal zone of the lower estuary. It also dominates the periphyton community of the lower estuary during May, after which its numbers diminish. Young *Balanus crenatus* appear in low numbers among larger *B. balanoides* in the submerged periphyton community during summer, but adult *B. crenatus* become more abundant than *B. balanoides* in the autumn. Adult densities of
both species decreased upriver. Balanus improvisus adults have been collected in Great Bay and Little Bay by the author, but they are scarce and their distributions are patchy. Larvae of B. improvisus were not collected during the study period.

The category "crustacean meroplankton" on Figures 12-15 and Appendices M-N is essentially the distribution of barnacles. Each peak correlates with the appearance of a species' cyprid or naupliar stages. Lowest concentrations were during mid-summer and winter.

Spring sampling began in April from 1970 through 1972, after B. balanoides larvae had maturated to late naupliar and cyprid stages. Consequently, distributional records of B. balanoides larvae are incomplete for these years. The live plankton data (Table 3) collected throughout 1972 revealed that Stages I and II of B. balanoides nauplii were in plankton samples by 15 February. Balanus balanoides nauplii were found from February to mid-May of 1973 in the lower to mid-estuary (maximum of 96 per 100 l at Station 4). Cyprid stage larvae occurred from late April to mid-May of all years (maximum of 32 at Station 4). No vessel was available for up-estuary sampling in March 1973 and this accounted for the lack of data for Stations 1 through 7 at 8 m at this time. Maximum densities of these larvae occurred during March in the Piscataqua system. Data from Station 3 surface samples indicated that densities were as high as 1390 Stage III nauplii per 100 l on 17 March 1973 (Appendix Z).

A maximum of 779 Balanus crenatus nauplii per 100 l occurred in Great Bay in mid-June of 1971. Densities of Balanus crenatus nauplii increased upriver, with peak densities occurring consistently in Great
Bay during June (Appendix R; Fig. 22). Nauplii of *B. balanoides* and *B. crenatus* were in plankton samples together from May through June. The nauplii of *B. balanoides* were consistently more abundant in the lower estuary, but *B. crenatus* were more abundant in the upper estuary (see discussion p. 97).

Densities of the cyprid stage larvae from both *B. balanoides* and *B. crenatus* were low (15 or less per 100 l) throughout the lower estuary. *Balanus balanoides* cyprids occurred from April through mid-June and those of *B. crenatus* from July through September.

**Echinodermata**

Six species of adult echinoderms were abundant in the Harbor and lower estuary — *Asterias vulgaris*, *Amphipholis squamata*, *Ophiopholis aculeata*, *Echinarchnius parma*, *Strongylocentrotus drobachiensis* and *Leptosynapta tenuis*. The adults of *Asterias forbesii* occur infrequently in the lower estuary. Juveniles of *A. vulgaris* were collected in low numbers on periphyton slides from September through November. None of their larval types, however, were identified to the species level. Low numbers of echinopluteus larvae were tallied during 1971 and 1972 even though adult and juveniles of *Strongylocentrotus drobachiensis* are dominant members of the lower estuarine benthos.

Both the auricularia and bipinnaria larvae occurred infrequently on high tides from the Harbor to mid-estuary (Appendices P-V). Auricularia larvae (maximum of 32 larvae per 100 l) were present in plankton samples from April through August; bipinnaria larvae (maximum of 39 per 100 l) were present from June through August.
Figure 22. A. Average seasonal distribution of the larval stages of *Balanus crenatus* and *B. balanoides* from Portsmouth Harbor (Station 1) to Great Bay (Station 7) on high water of flood tides at 8 m. B. Depth (0.5 and 8 m) and tidal (near slack water stages of flood and ebb tides) distributions of *B. crenatus* and *B. balanoides* larvae, averaged monthly over the four year study period.
Ophiopluteus larvae were abundant from April through June in the Harbor (a maximum of 532 per 100 l), but decreased rapidly upriver (only one larva was tallied at Station 4). Data from the live samples (Table 3) were similar to the preceding echinoderm larval distributions.

**Diel Variations in Selected Hydrographic Parameters and Meroplankton**

Consistent results were obtained from four 24-hour studies at Station 3. Samples were collected hourly at 0.5 m in July, 1970, September 1971, November 1972 and March 1973.

Surface salinity increased with flood tide to a maximum which occurred within the hour after high water, then decreased to a minimum that occurred just after full low tide. Summer temperatures increased on ebbing tides to a maximum on slack water, then decreased on the flooding tides. The maximum tidal range was 3.2 m for the four studies. Tidal currents consistently decreased to slack during the hour following maximum high and low tides; Secchi disc visibility increased consistently with slack tides. Current direction does not change in surface waters of this estuary until approximately 25 minutes after full high and low tides are measured on a tidal gauge. Dissolved oxygen and pH measurements changed little with tide.

Total abundance of bivalve, gastropod and ectoproct larvae increased substantially on flooding tides, reaching a maximum in surface waters within one hour after full flood, then decreased to a low which occurred within one hour after full low water (Figs. 23-26; Appendices W-Z). Polychaetae abundance was the reverse; these larvae increased on
Figure 23. Daily variations in distributions of bivalve larvae collected every three hours at 0.5 m on 30-31 July 1970. Dashed lines in the vertical axis represent times of high and low tides.
Figure 24. Daily variations in distributions of hydrographic parameters and meroplankton collected hourly at 0.5 m on 8–9 September 1971. Dashed lines in the vertical axis represent times of high and low tides.
Figure 25. Daily variations in distributions of selected hydrographic parameters and meroplankton collected hourly at 0.5 m on 17-18 November 1972. Dashed lines in the vertical axis represent times of high and low tides.
Figure 26. Daily variations in distributions of selected hydrographic parameters and meroplankton collected hourly at 0.5 m on 16-17 March 1973. Dashed lines in the vertical axis represent times of high and low tides.
the ebb tide near full low water and generally were not collected on the flood.

In the first 24-hour study (30-31 July 1970) the densities of umboned veligers of *Anomia aculeata*, *Modiolus modiolus*, *Mytilus edulis*, and *Hiatella arctica* were highest in samples collected just after full high tide (Fig. 23; App. W). Unidentified straight hinge and umbone veliger stages were in greatest abundance at this time. Other larval stages of meroplankton were not analyzed from this plankton series. Salinity was not measured during this preliminary study because the salinometer was inoperable. Temperature ranged from 16 to 19.5°C.

In the second 24-hour study (8-9 September 1971) cyphonautes larvae, prosobranch veligers, mytilid straight-hinge veligers, and the umbone veligers of *Anomia aculeata*, *Hiatella arctica*, *Modiolus modiolus* and *Mytilus edulis* were in highest concentration within one hour following full high tide (Fig. 24; App. X). Distributions of unidentified umbone veligers suggested a similar relationship with high tide, but larval numbers were generally too low to be definitive. Spionid polychaete larvae, however, were out of phase with this pattern and generally occurred in surface waters of ebb tides. Highest abundance of spionids was recorded approximately one hour following full low tide. Surface salinities ranged from 30.4 °/oo near low slack tide to 31.5 °/oo near high slack tide. Salinity differences between the depths of 0.5 and 8 m were negligible. Surface temperatures ranged from 15.8°C near high slack tide to 18.2°C near now slack tide. Temperature differences between the depths of 0.5 and 8 m were less than 0.4°C. Surface measurements of dissolved oxygen averaged approximately 8 mg/l and were lowest on slack tidal stages.
Measurements of pH ranged from 6.8 to 7.7 and did not vary with tidal stage.

The third 24-hour study (17-18 November 1972) indicated that cyphonautes larvae and the veligers of nudibranchs and prosobranchs were occurring in surface waters on high flood stages of tide although all meroplankton were in low concentration (Fig. 25; App. Y). Surface salinities ranged from 20.9 °/oo near low slack tide to 31.2 °/oo near high slack tide. Differences of approximately 1 °/oo separated the depths of 0.5 and 8 m. Surface temperatures ranged from 5.0°C near low slack tide to 7.0°C near high slack tide. Measurements of pH in surface waters ranged from 6.2 to 7.1 and were not related to tidal stage.

Results of the fourth 24-hour study (16-17 March 1973) showed that naupliar stages I, II and III of Balanus balanoides increased on flooding tides and reached maximal densities within one hour after full high tide (Fig. 26; App. Z). Early larval stages of spionids were in highest concentration near slack low water. Surface salinities ranged from 15.2 °/oo near slack low water to 28.9 °/oo near slack high water. Generally, less than 0.5 °/oo separated the depths of 0.5 and 8 m. Surface temperatures ranged from 2.4°C near high slack water to 3.4°C near low slack water, with similar temperatures recorded between the depths of 0.5 and 8 m. Measurements of pH ranged from 6.5 to 7.1 and did not relate to tidal stage.

A composite of the 24-hour data was prepared to present the most abundant species in the four diel studies. Average plankton distributions from the highest flood stage of tide were aligned and the remaining samples were plotted by number of hours following full high tide (Fig. 27).
Figure 27. Tidal variations in distributions of abundant larval types and total meroplankton.
TIDAL CYCLE

LARVAE PER 100 LITERS

30-31 July 1970
8-9 September 1971
Mylus Edulis Umbone Veligers

16-17 March 1973
Balanus Balanoides Naupliar Stages I-III

30-31 July 1970
8-9 September 1971
Anomia Aculeata Umbone Veligers

8-9 September 1971
Prosobranch Veligers

LARVAE PER 100 LITERS

8-9 September 1971
30-31 March 1973
TOTAL MEROPLANKTON
Individual species and total meroplankton increased consistently on flooding tides to maximal densities approximately one hour after full high tide, then decreased.
DISCUSSION

General Remarks

A four year study (1970-1973) of the meroplankton in the Piscataqua-Great Bay Estuary revealed that the seasonal, diurnal, annual, vertical, horizontal, diurnal and tidal patterns of distribution were consistent from year to year, despite variation in hydrographic parameters of the estuary resulting from temporal changes in run-off, phytoplankton composition and quantity, light penetration and the magnitude of change in salinity and temperature over a single tidal cycle. In fact, the estuary changes seasonally from a stratified system during periods of high runoff because of precipitation and snow melt to a well-mixed estuary during periods of reduced runoff.

For most species the time of appearance of the larvae and their duration in the water column were similar from year to year and consistently correlated with certain hydrographic parameters of the estuary. Larval populations of identified species were abundant in the meroplankton for approximately one month and then declined, to be replaced by another species. A dichotomy in the species composition of the meroplankton communities consistently occurred in the estuary; e.g., distinct meroplankton communities occupied Great Bay and Portsmouth Harbor waters, with reduced densities of Harbor and Bay species overlapping at intermediate stations. Harbor and Bay populations remained separate from each other and did not lose their identify with changing tides; Harbor populations were abundant on flood tides and Great Bay populations were abundant on ebb tides. To my knowledge, observations on this type of
community dichotomy and its relationship with hydrographic parameters have not been described previously, though certain aspects of meroplankton distributions have been investigated.

The hydrographic characteristics of this estuary differ substantially from others studied along the Western Atlantic. Certain parameters measurably differed between years, yet, the meroplankton results were consistent for four years.

Seasonal Distribution

The first meroplankton to appear in seasonal sequence were *Balanus balanoides* nauplii. Stage I and II nauplii were collected in the lower estuary during mid-February when water temperatures were approximately 2° C. Bousfield (1954) stated that nauplii were released at St. Andrews when water temperatures were beginning to rise from the daily average minimum of 1.2° C in February. The larvae of this Arctic-boreal marine species survive in waters from 0 to 13°C; waters above 15-16°C are probably lethal (Bousfield, 1954). Although deep water temperatures in the Piscataqua were near 0°C at the time when *B. balanoides* actually spawned, shallow water or air temperatures no doubt fluctuated appreciably above and below this. Barnes and Barnes (1967) found that time at which egg masses of *B. balanoides* are laid down and at which nauplii are released can be manipulated by controlling the period during which food is supplied. Thorson (1950) and Lucas (1961) suggested that the quality and quantity of food appearing in the phytoplankton blooms and the resulting release of ectocrines may be important in stimulating spawning. The majority of other planktotrophic species spawned in May and June when water temperatures were above 10°C.
In general, larval populations were most dense and species composition most varied from February through July and from September through November of each year. A seasonal pattern emerged: individual species spawned, their larvae reached a maximum density for a few weeks, then declined. Some larvae of each species remained in the plankton for a longer period than the population peak. This may be due either to sporadic emission of eggs or larvae have the main discharge from the population, to individual differences in maturation time, or to variation in finding a suitable substrate for metamorphosis. For example, Loosanoff and Davis (1963) demonstrated that even though bivalve larvae originated from the same spawning, were from the same parents, and were kept in the same vessel under identical conditions, individuals grew at widely different rates, and therefore, metamorphosed at different times. They found that a presumably homogeneous culture of oyster larvae under identical conditions began to set 18 days after fertilization and continued uninterrupted for a period of 27 days.

Although it is known that different physical and chemical stimuli will initiate spawning in laboratory populations of planktrotrophic species (Loosanoff and Davis, 1963; Chanley and Andrews, 1971), thermal stimulation remains a prime factor in in situ situations of temperate estuaries (Thorson, 1950; Kinne, 1963; Galtsoff, 1964; Carriker, 1967). Carriker (1961) suggested that Mercenaria mercenaria spawning was triggered principally near low tide in response to the warmer waters of ebbing tides. Spawning at this time would have the obvious advantage of transporting larvae up-estuary on
flooding tides, thus reducing initial loss seaward. Studies of bivalve larvae have suggested that spawning may even be related to lunar phases (Prytherch, 1929; Battle, 1932; Korringa, 1947; Knight-Jones, 1952).

Several consistent and interesting relationships were observed between seasonal meroplankton distributions and seasonal changes in hydrographic measurements of the Piscataqua Estuary (Figs. 12-15). Each year sharp increases in temperature were measured from April through June at all stations. Estuarine temperatures were moderate during June and July when the majority of larvae occurred, with maximal temperatures consistently occurring in August and September. Larval densities were much reduced in August and September. Larval densities increased again in October when temperatures were equivalent to those of June. Coincident to the spring-summer temperature increase was a general increase in estuarine salinity. This was most pronounced upriver. The maximum upriver salinity occurred in August or September and generally remained high until melting ice reduced salinity levels in late winter and early spring.

As noted in the results section, though the seasonal pattern remained the same, the maximum and minimum salinity varied considerably between the two wet years and the two dry years of this study. Salinity changes did not correlate with seasonal spawnings. Turbidity and pH data did not change seasonally in patterns similar to those of meroplankton seasonal succession.

Seasonal distributions of *Mytilus edulis*, *Hiatella arctica*, *Balanus balanoides* and *Balanus crenatus* in the Piscataqua system were
more similar to those compiled from the records of Maine and Canadian coastal waters than to those from more southerly water (e.g., Fish, 1925; Bigelow, 1926; Deevey, 1948; Bousfield, 1955; Shih, Figueira and Grainger, 1971). Distributions of *Asterias vulgaris* larvae differed slightly from those in Passamaquoddy Bay by Legare and MacLellan (1960). Auricularia larvae occurred from April through August and bipinnaria larvae from June through August in the Piscataqua–Great Bay Estuary. Seasonal distributions of *Anomia aculeata* differed in this study from the distributions of Fish and Johnson (1937), who noted that these larvae were widely distributed only in late August in the Gulf of Maine, and by Sullivan (1948), who noted that they only occurred in late June in Malpeque Bay. No mention was found in the literature of this boreal species having a bimodal distribution as it does in the Piscataqua system. *Anomia aculeata* larvae had two peaks in abundance, one in July and the other during October and November. Distributions of *Mya arenaria* larvae, likewise, appeared to be bimodal, even though abundances were low. Gonadal studies of *Mya arenaria* adults in the Piscataqua and Hampton–Seabrook estuaries (Davis and Turgeon, 1971) supported this suspected bimodal distribution. Distributions of several other species were similar. Spawning of such species ceases at the time when temperatures and illumination are highest, then resumes in early autumn when lower temperatures and a secondary diatom bloom again stimulate spawning in the Piscataqua–Great Bay estuary. Differences between seasonal distributions reported in the literature and those obtained for the Piscataqua populations may be due to: 1) incom-
plete monitoring studies on the part of other authors, 2) the Piscataqua populations may differ due to modification by inherent hydrological or biological conditions in the estuary, or 3) geographical variations may exist between these populations. Published seasonal distributional records for the larvae of Harmothoe imbricata, Eulalia viridis, Phyllodoce groenlandica and Myriochele heeri were not found for estuarine populations in northern Atlantic waters. Data on the seasonal distributions of the meroplankton in the Piscataqua–Great Bay Estuary are plotted on Figures 19–22 and are listed in Appendices P-V.

**Annual Variation**

Although total meroplankton abundance and the seasonal succession of populations were similar throughout this study, absolute densities of the larvae of certain larval species varied between 1970–1971 and 1972–1973. Larval densities summarized on Table 2, were higher for certain species from 1970 to 1971 (i.e., larvae of ectoprocts, Balanus balanoides, B. crenatus, miltids and echinoderms), but were higher for others during 1972 to 1973 (i.e., larvae of spionids and prosobranchs). Other larvae did not display any consistent pattern of density between these years. According to Normandeau Associates (1974), the densities of certain adult invertebrates varied from year to year in the Piscataqua–Great Bay Estuary. Higher densities of adult Lyonsia hyalina, Cerastoderma pinnatum, Mya arenaria and Botryllus schlosseri were recorded by the company in 1971 than in the following two years; but, densities of adult Tellina agilis and Balanus balanoides were higher in 1973 than in the pre-
ceding two years. In addition, an estuarine bloom of the tintinnid, *Stenosomella ventricosa* occurred in October and November of 1972 and 1973.

Coastal and Portsmouth Harbor waters were notably different during 1971, 1972 and 1973. A number of record appearances of southern, warm-water species were sighted in the Gulf of Maine and northern New England coastal waters during the summer of 1971 (Read, 1974). Near-shore waters were warmer during this year than during the other study years, with unusually warm water in September for bathing along the shores of New Hampshire and southern Maine. A coastal bloom of *Gonyaulax tamarensis* occurred in 1972 and 1973, extending from Maine to Massachusetts (blooms also occurred in 1974 and 1975). The bloom penetrated into Portsmouth Harbor as evidenced by measurable amounts of paralytic shellfish toxin within the tissues of certain species (J. Sasner, personal communication).

These data for 1970-71 reflected a period when the estuary was warm and summer salinity was high, but data from 1972-73 were collected when local precipitation was high and salinity in the estuary more reduced than in the previous two years. It should be noted that the up-estuary spring bloom of diatoms was much increased in 1972 and 1973 (especially *Chaetoceros debilis* and *Detonula confervacea*) when compared with 1970-71 (unpublished data). The annual averages of total precipitation for 1970 and 1971 were approximately 10 cm below the long-term annual average for Durham, New Hampshire; annual averages of total precipitation for 1972 and 1973 were 144 and 137 cm, respectively, above the long-term total average (U.S. Department of Commerce, National Wildlife Service, 1970-73). Surface precipitation
and, by inference, river flow varied considerably during these years, accounting for the between-year differences in estuarine salinities (see results section). The coastal bloom of dinoflagellates in 1972 and 1973 occurred after salinity was depressed and the terrigenous influx of minerals and nutrients was increased and precipitation was abnormally high. Furthermore, species which were noted in this study with between-year differences in distributions, such as B. balanoides, B. crenatus, Gonyaulax tamarensis, Stenosomella venticosa, may be indicators of salinity conditions in estuaries.

**Spatial Distribution**

A consistent dichotomy of the species composition in meroplanktonic (this study) and benthic (Normandeau Associates, 1974) communities within the estuary was described for collections from 1970 through 1973. Larvae of Anomia aculeata, Hiatella arctica, Mya arenaria, Modiolus modiolus, Mytilus edulis, Balanus balanoides and echinoderms always occurred in greatest concentrations at flood tides in the Harbor and lower estuary and were either lacking or scarce in Great Bay samples. Larvae of prosobranchs and spionids were most abundant at slack water of ebb tides in the upper estuary and Great Bay, with reduced densities of these extending downriver only as far as Station 4. If these species are transported further downriver, concentrations were too low to be recognizable as belonging to this community. Distributions of the adults and juveniles from the rocky intertidal zone were determined by trellis diagram analyses to be divisible into two distinct communities (Normandeau Associates,
1974). The Harbor and lower estuary has cold-water coastal fauna and the upper estuary and Great Bay has warm-water estuarine fauna. Great homogeneity was found in data from the lower estuary, with most pairs of stations demonstrating affinity indices above 90 percent (Normandeau Associates, 1974). This community dichotomy was evident, but not as pronounced in their data from the muddy intertidal habitat.

Even though the study area comprises only about 8 km in length and currents are strong, larval distributions were similar to their respective adult distributions. Lower and upper estuarine communities of benthic species remained separate even though tide potentially should scatter all planktonic larvae. Metamorphosed juveniles should colonize suitable substrata throughout the estuary unless there are barriers to larval dispersal, the juveniles cannot survive environmental extremes, or the recently settled young are eliminated by predators.

Lower estuarine faunal assemblages are not exposed to the seasonal and tidal extremes of temperature and salinity that the upriver fauna must survive in order to replenish adult stocks. Harbor salinity remained near 30 °/oo year-round regardless of tidal stage; temperatures ranged seasonally from 2 to 16°C. Hydrographic measurements were uniform despite the between-year differences which were discussed previously. Although ice or inundation by rains may kill exposed intertidal organisms, reproduction of non-exposed or subtidal populations could replenish this zone of the lower estuary. Both larval and adult densities of the stenotolerant species comprising the lower estuary decreased upriver. Salinity
in Great Bay ranged seasonally from 5 to 31 °/oo and temperatures from -0.5 to 25°C. Between-year differences in hydrographic measurements were noted for 1970-71 and 1972-73. Turbidity was consistently high. A sill separates Great Bay from the lower part of the estuary, reducing circulation of the water and allowing for increased temperatures above the "dam". Ice eliminates substantial portions of Great Bay shallow water and intertidal fauna in colder winters (Gable, 1973). Differences in salinity and temperature over the tidal cycle were greater in Great Bay than downriver. Only those species which can withstand the more rigorous environment of the upper estuary should survive in the shallow, turbid waters of Great Bay. If larvae or juveniles of a year class from the warm-water assemblage of the Great Bay benthos are eliminated from the upper estuary, then recruitment from downriver populations which occur in low densities if at all, is unlikely. For Great Bay species to survive, adult populations must be able to withstand discontinuous recruitment. Since adults of such species as Crassostrea virginica, Molgula manhattensis and Balanus improvisus are limited to the upper estuary, a barrier to their colonization must exist.

The benthic adult community of Great Bay must be tolerant of wide seasonal and tidal fluctuations in temperature and salinity. Conditions in the area may often be so extreme that the adults are stressed physiologically and spawn only intermittently. The following account of Crassostrea virginica can probably be applied to Balanus improvisus, Modiolus demissus and Molgula manhattensis
populations.

Although oysters are found both in Great Bay and the branch of the Piscataqua River that enters into the main estuary channel at Dover Point, no oyster larvae were collected at plankton stations during the four years of this study. K. Turgeon and the author, diving in Great Bay during the summers of 1971 and 1972, found no recent oyster spat and noted that the smallest oysters were 10 to 12 cm long. It was concluded that his population did not successfully reproduce between 1970 and 1972. Occasional spat were found intertidally in Great Bay during 1973 by Normandeau Associates (1974), indicating that at least some spawning occurred in that year. Ayer, Smith and Acheson (1970) mentioned that failure of spat settlement was a problem of this population in recent years and E. Swan (personal communication) reiterates that conditions are not always conducive for annual recruitment. Since summer temperatures were always high enough to allow spawning, some other factor or factors must inhibit spawning and/or larval survival. Results from this study show that pH and salinity are seasonally variable and are not the same from year to year. Variability of these two factors will presumably affect phytoplankton composition or quality. These in combination with fluctuations in predator populations, could have a significant impact on reproduction, larval survival and juvenile settlement.

The high turbidities of Great Bay may place a physiological stress on the ciliary action of respiration and feeding in all life
stages of some species. Newly set individuals are often coated with silt. Turbidity has increased greatly since 1931 (Jackson, 1944) when *Zostera marina* was eliminated by disease. Turbidities in the upper estuary are expected to decrease following recent reintroduction and establishment of *Zostera* beds (A. Mathieson, personal communication). If siltation is reduced, then spawning and settlement of such species as *C. virginica*, *M. demissus* and *B. improvisus* may increase.

The moderate salinity-temperature regime of the lower estuary and the extreme variability in salinity-temperature of the upper estuary are barriers to the distribution of certain species. Such species as *Asterias vulgaris*, *Modiolus modiolus*, *Cancer borealis*, and *Balanus balanoides*, considered to be cold-stenothermal species by Bousfield and Laubitz (1972), occupy the lower estuary and coastal waters. Summer temperatures in the warm-water bays (as high as 25°C) may be lethal to planktonic larval stages of lower estuarine species; however, summer salinities of the bays (up to 31 °/oo) would not be a barrier to the upriver extension of coastal species. The larvae of species which spawn in late spring or early summer may be found further upriver than their normal distribution. Distributions of *Balanus crenatus* are an example of this. Naupliar stages of this species penetrate upriver into Great Bay in June or July when salinities are not limiting. Unless older larval stages move back downriver, they may suffer mortality due to high summer temperatures (24°C was measured in the deeper water at Station 7). Cyprids, juveniles and adults of this species were not collected in Great Bay during the study period.
Species which spawn in the autumn after temperatures decrease in the bays may safely penetrate up-estuary because salinities remain high enough to allow larval survival and settlement before winter conditions prevail. Mortality of any adults would be high each spring when upriver salinities drop to around 5 ppt on ebbing tides. In addition, the reproductive requirements of any adults which remained would, presumably, not be met since salinities are lowest in the springtime when temperature and phytoplankton concentrations would be similar to downriver conditions. Such species as *Balanus improvisus*, considered to be a Mediterranean-boreal, brackish-water species by Bousfield (1955), and *Crassostrea virginica*, *Rhithropanopeus harrisi*, *Nassarius obsoletus*, *Modiolus demissus* and *Tellina agilis*, described as warm-water species by Bousfield and Laubitz (1972), occupy the upper estuary. Reproduction of brackish-water species in Great Bay may be adversely affected by the high salinities (up to 31 °/oo during summer) concurrent to the appropriate temperature regimes for spawning of this warm-water fauna. Bousfield (1954) noted that the Miramichi center of the occurrence of *B. improvisus* is in salinities ranging between 10 to 25 °/oo. Maximum water temperatures of the lower estuary are not high enough to allow reproduction of certain migrants from the upper estuary such as *Crassostrea virginica*. Spawning is induced in *C. virginica* between 20 and 32°C, after a rapid rise in temperature (Galtsoff, 1964).

What then is the origin of the isolated Great Bay fauna?

Bousfield and Laubitz (1972) stated that shallow water invertebrates from the Virginian Province (Cape Cod to Cape Hattaras) were isolated by large geographic areas of typically boreal populations along northern New England and eastern Canadian coastlines. Since 15,000 b.p. the climate changed from subarctic (ice covered most of the coastal region)
to a subsequent warm, "Hypsithermal" climate (10,000-6,000 b.p.), and then cooled to present conditions during the last 5,000 years (Bousfield and Thomas, 1975). These authors proposed that "warm-water" faunas of the Hypsithermal period were obliterated from many areas after the subsequent deepening and cooling of coastal seas from melting glaciers and the cooling climate. Animal populations formerly with extended and contiguous ranges were effectively isolated through time to summer-warm regions. This explanation for disjunct distributions of coastal species could reasonably account for the isolated warm-water fauna of the upper estuary. Jackson (1944), however, mentioned that the Great Bay oysters may have been introduced by man for commercial purposes, rather than representing post-glacial relict populations. Associated species such as Urosalpinx cinerea, Tellina agillis, Molgula manhattensis, Cliona sp. and Polydora sp. may also have been introduced, in oyster cultch. In addition, warm-water immigrants are known to occur in dock fauna near thermal effluents from power plants (Naylor, 1965; R. Turner, personal observation). Barnacles, spionids, oysters, mussels and others are known to be carried into the estuary as part of the fouling community on the hulls of ships. If warm-water reintroductions survived and reached Great Bay, then only geographical isolation of this community occurs and not isolation of the gene pools.

**High-Low Tidal Variation**

Ebb and flood tides averaging 5 kt peak currents did not destroy the homogeneity of the two meroplankton assemblages lying
only 8 km apart. This suggests that a method exists by which larval populations resist dissemination by tidal currents from their respective communities. Factors affecting dissemination include tidal currents, tidal exchange ratio of the estuary, reproduction rates, loss of populations through mortality and seaward transport, and the tidal distributions of various life stages.

Plankton analyses revealed large variations of meroplankton throughout the estuary with tide. Larval densities of such Harbor species as Balanus balanoides, Modiolus modiolus, Hiattella arctica, Anomia aculeata, Mya arenaria and Mytilus edulis were always highest on near high tides in this study. In contrast, larval densities of prosobranch veligers, spionid larvae and Balanus crenatus nauplii were highest on near low tides in Great Bay. Larval populations from upper and lower estuarine communities overlapped at the intermediate Stations 3 and 4, but densities at these intermediate stations were lower than at respective points of origin. If distributions were at all random or erratic, or if collection methods were inadequate, at least some samples would deviate from the above distributional patterns with tide, but none did.

One might attribute increased numbers of coastal organisms on the flood tide to influx of larvae into the estuary with incoming tides. Presumably, larvae would wash back out again with the change of tide unless they were killed or were able to resist drifting seaward. Results show that populations in the lower estuary were more abundant on near high tides than on near low (approximately
75% more abundant). A loss of over 75% of each species due to predation during a single tidal cycle seems highly improbable on the basis of Korringa's (1941 and 1942) findings that a loss of only ten percent was calculated for oyster larvae due to predation on both tidal cycles and an estimated 3-5 percent loss seaward per tidal cycle in the Oosterschelde, an estuarine embayment in Holland (Korringa, 1941 and 1952). For larvae of B. improvisus, Bousfield (1955) estimated a total loss of 14.5 percent per day. Seaward loss of larvae should be lower still in the Piscataqua-Great Bay system than for those in other systems because of the oscillating tidal flows and long residence time for water particles.

Meroplankton distributions of the upper estuarine populations indicated that larvae do not behave as inanimate particles. If the estimated time of four days for water particles from Station 3 to reach Great Bay (Ebasco Services, 1969) is assumed to be similar for particles moving from the Bay downriver, then Great Bay meroplankton could reach the Harbor after ten days if they behaved as inanimate particles. Because this sequence of events did not occur in meroplankton distributions over the study period, it is theorized that either larvae remain near the bottom or larval movements are controlled by individual swimming behavior in response to changing tides.

Tidal Distributions of Meroplankton

All 24-hours studies were conducted at an intermediate station (Station 3) which was shown in seasonal studies to contain
plankton from both the upper and lower estuarine communities. The sampling scheme was designed so that investigators were stationary (as are the respective benthic adults of most larval species identified in this study) and the water was moving beneath. Since oscillating currents characterize the estuary, plankton were collected from water moving downstream on the ebb tide and upstream on the flood, i.e. collection would be equivalent to moving the sample station downstream on flood tides and upstream on ebb tides. If a greater number of organisms are in the lower estuary, then it follows that flood samples should contain greater densities of lower estuarine species and these should be diluted by ebbing waters with their complement of upstream plankton. Inflowing waters should add coastal species to the resident complement of estuarine plankton. Unless these coastal species are eliminated from surface waters of the estuary by natural mortality, predation, or selective movement downward, then these plankton wash back past the investigator and plankton densities should be similar on ebb tides.

Sampling through approximately seven high and low tidal cycles revealed that the densities of lower estuarine larvae always increased on flooding tides to peak densities approximately one hour after high water (when tidal currents changed direction). Larval densities substantially decreased during the following hour on ebbing waters, continuing to decrease to the lowest values which always occurred within one hour after full low tide. Spionid larvae (members of the upper estuarine community), however, increased on the ebb tide and were lacking on flood tides. Seasonal studies
on near high and near low water stages (discussed above) and the 24-hour data indicated that natural mortality and predation were not adequate to explain such large changes of meroplankton density throughout the tidal cycle.

There are basically two theories which explain the preceding observations on tidal distributions of meroplankton in the Piscataqua estuarine system. Loosanoff (1949), Galtsoff (1964) and Normandeau Associates (personal communication) ascribe to a theory for passive transport of continuously swimming larvae. Larvae would not migrate within the water column but remain in overlying waters at the particular point representing the tidal stage upon which they were more spawned; these would not move further up-estuary than one tidal cycle would allow. Oscillating estuarine flow would entrap all entering meroplankton from egg emission until settlement. Using this theory, the paucity of lower estuarine larvae near low tide suggests that either eggs from estuarine adults are expelled only on flood tides or that all meroplankton are primarily from coastal adults or up-estuary brackish species. Passive transport sound simplistic but actually involves a series of assumptions for which evidence seems to be lacking in the literature and in this study. There is much evidence for a theory of active transport in which larvae migrate vertically and are subsequently carried horizontally by water currents (e.g., J. Nelson, 1912; Nelson and Perkins, 1930; Loosanoff, 1949; Carriker, 1951; T. Nelson, 1955; Kunkle, 1957; Wood and Hargis, 1971). If surface meroplankton behaved as passive particles, then they would be dispersed throughout the Piscataqua-Great Bay Estuary
from Portsmouth Harbor to Great Bay in ten days or less, according to particle transport studies by Ebasco Services, Inc. (1969). Oscillating flow and fast currents create a situation in which particle retention time is long, waters are horizontally and vertically well mixed for much of the year, and haloclines are formed in the spring from the high inflow of fresh water. Data collected on high-low tides by Normandeau Associates (1971 and 1972) and this author (Figs. 17 and 18) show that there are consistent, major differences in meroplankton density and composition throughout the study area on high and low slack water. For example, bivalve larvae are abundant from Station 1 (Portsmouth Harbor) to Station 4 on high slack tide, but are virtually nonexistent at Stations 3 and 4 on corresponding low slack tides and much less abundant at Station 1 than they are at Station 4 on high slack tides. Since 4.5 days are required for particles from Station 3 to be detected in Portsmouth Harbor, this evidence refutes passive transport. Results from weekly collection of plankton near Station 3 for a year at the same time of day, with tidal stage the variable, indicated that variations in larval densities with tidal stage were greater than those from time of day. Four year collections of data from different depths at Station 3 by Normandeau Associates (1971, 1972, 1973, 1974) and this author (Fig. 16) show that consistent differences in meroplankton density occur between the depths of 0.5 and 8 m on high slack (flood) and low slack (ebb) tides. Maximal densities of bivalve larvae on low slack water are consistently from half to a quarter less than those on high slack. Yet, this station, at the edge of the channel, is in
an area with much eddying (personal observations) and near shallow waters which have abundant adult bivalves (Normandeau Associates, 1972, 1973, 1974). In a series of 24-hour studies done in September 1971, November 1972 and March 1973, *Mytilus edulis* veligers, *Balanus balanoides* stage I-III nauplii and total meroplankton were in higher densities on the low to high half of each tidal cycle (Appendices x and z). These differences ranged from 19.2% in the September study (primarily bivalve veligers) to 8.1% in the March study (primarily barnacle nauplii). Thus, most meroplankton at this mid-estuarine station are abundant on the flooding half of the tidal cycle and highest densities are near high slack water. Additional evidence for active transport of meroplankton is derived from the occurrence of planktonic larvae well upriver of parental stocks. Naupliar stages of *Balanus crenatus*, the adults of which have a lower to mid-estuary center of distribution, were abundant in Great Bay. Passive transport by oscillating water masses cannot account for the transport of these larvae. Wood and Hargis (1971) concluded from tidal distributions of oyster larvae, which are found far upriver of parental spawning beds, that upward migration in the water column of larvae on flooding tides and subsequent downward migration on ebbing tides (active transport) accounts for upriver transport of larvae by estuarine currents. Therefore, the paucity of bivalve larvae on low water stages of tide, the concentration of bivalve larvae on high water stages of tide, the consistently greater numbers of bivalves on flooding cycles, the upriver penetration of *B. crenatus* nauplii, and the flow
characteristics of this estuary support the contention that some meroplankton undergo tidal migrations in the Piscataqua-Great Bay Estuary. The fact that Carriker (1951) collected oyster larvae from the bottom during low tide and found them abundantly in the plankton on flood tides led him to conclude oysters exhibited active transport.

Four 24-hour studies were conducted over different seasons and years to investigate the possibility that this mechanism was dependent on such tide-related factors as large changes of salinity or temperature over the tidal cycle. The estuary is stratified during the spring and autumn but is well mixed during the other seasons. Sampling when the estuary was not stratified would indicate if haloclines were a necessity for the tidal mechanism of selective swimming. Western Atlantic studies of meroplankton retention within estuaries were on coastal plain systems having well developed haloclines. In this study, salinity ranges over the tidal cycles were approximately 1 °/oo in the September study and as high as 14 °/oo in the March study. Temperature ranges over tidal cycles were similar for all studies, from 1 to 2°C. Average temperatures varied between studies from 17 to 18°C in July and September to 6°C in November to 3°C in March. Seasonal differences were noted in species composition but not in meroplankton behavior. In addition, different species and phyla were behaving similarly over the tidal cycle. Seasonal changes in magnitude of hydrographic extremes, discharge variations, solar insolation patterns and haloclines were not acting as limiting factors which inhibited meroplankton distributions with tidal oscillation.

Rather, these hydrographic parameters seem primarily to reflect the
seasonal species composition and absolute density of the meroplankton.

Most published accounts of meroplankton distribution over the tidal cycle dealt exclusively with oyster larvae. Conclusions were often contradictory, ranging from passive drifting of these larvae with water currents (Loosanoff, 1949; Galtsoff, 1964) to complex swimming behavior of larvae on specific stages of tide for maintenance within estuaries (J. Nelson, 1912; Nelson and Perkins, 1930; Carriker, 1951; T. Nelson, 1955; Wood and Hargis, 1971). The most complex theory of larval swimming behavior postulated that younger larval stages of oysters ebb and flow passively while older stages migrate up-estuary by swimming on the flood tide and settling to the bottom before ebb (Carriker, 1951; Wood and Hargis, 1971). Evidence that mature and eyed larvae were actually on the bottom during ebb tide was provided by Carriker (1951). Different observations by other authors led them to conclude that 1) larvae were most abundant on intermediate stages of tide (Prytherch, 1928); 2) older larvae congregated on or near the bottom during ebb tide and during both slack water periods (Kunkle, 1957); 3) larvae swam when tidal currents were minimal (Loosanoff, 1932); or 4) there was no relationship between stratification of larvae and tidal stages and no evidence that late stages were more common near the bottom (Loosanoff, 1949). Churchill and Gutsell (1921) found that tidal currents concentrated passively drifting larvae in definite areas within their study site. Oyster larvae were not collected in this study, but other bivalve veligers behaved like Carriker (1951) and Wood and Hargis (1971) said oyster
larvae do. This may be general for bivalve larvae in estuaries.

Few studies described tidal distributions of non-oyster meroplankton. Bousfield (1955) observed and concluded that early nauplii of *Balanus improvisus* were mainly near the surface toward the head of the bay, late nauplii were deeper toward the mouth of the estuary, and cyprids were deepest and again near the head. He described a three-dimensional distribution of larvae that changed with life stage and phase of tide. Larval stages which remained essentially below the mid-depth of the estuary were transported upriver by the net inflowing bottom waters of a stratified coastal plain type of estuary. By the same mechanism the later stages of *B. crenatus* were carried inward from the Gulf to the limit of their low salinity tolerance, but those of *B. balanoides*, swimming near the surface tended to be carried out of the estuary, especially during periods of freshet. DeWolf (1973) concluded that cyprids of *Balanus crenatus*, *B. improvisus*, *B. amphitrite*, and *Elminius modestus* sank to the bottom during periods of low current velocity and were redispersed again in the water column by increasing currents. A central point in DeWolf's review was his criticism of the work by Wood and Hargis (1971), e.g., that he could interpret their data as resulting from asymmetric tidal currents. Wood (personal communication) has replied that no such asymmetry of current speed (flood vs. ebb) or durations were observed. Results of the present study disagree with the conclusions of DeWolf. DeWolf's work is of limited application to the present study since he described only cyprid distribution in a pass between the NOrth and Wadden Seas.
Past investigations were primarily conducted on stratified estuaries with peak tidal currents of one knot or less. Studies were often of short duration and sampling depth varied between authors. Present observations on the distributions of Balanus balanoides and bivalve larvae in the Piscataqua system support those investigators who described oyster larvae as present in the upper water column on flood tides. Larval concentrations of the upper estuary meroplankton, however, were observed only near ebb slack tides. Wood and Hargis (1971) statistically demonstrated that the distribution of oyster larvae correlated positively with the increasing salinities of flooding tides, while coal particles correlated positively with the increasing currents of both flood and ebb tides. The present study concurs with their findings. These authors calculated that an oyster larva moving upward at its fastest rate (about 1 cm/sec) could negotiate a ten meter water column in about 15 minutes. Larval speeds of a similar order for other meroplankton would allow them to reach the surface during a single flooding cycle in the Piscataqua system.

Results from the larval distributions of barnacle species in my study were anticipated to be similar to those of Bousfield (1955), since both studies were on northern estuaries with fast tidal currents. The distribution of Balanus balanoides, B. crenatus and B. improvisus were different, however, from those described by Bousfield. In the Miramichi Estuary, Bousfield presumed that nauplii of B. balanoides were carried out of the estuary during periods of river flood. This may have been the case with some of the early larvae produced by estuarine adults residing in the Piscataqua system; however, Stage I-III
nauplii were most dense in flood samples from surface waters of the lower estuary. Inevitably, flooding tides carried *B. balanoides* larvae into the estuary in surface waters but subsequent ebbing waters did not carry equivalent concentrations of larvae seaward on ebbing tides. (This was true also of the bivalve larvae.) *Balanus balanoides* nauplii were selectively in the water column on flooding tides, and thus, carried into the estuary and moved toward headwaters. Estuarine spawned larvae are added to incoming planktonic populations, and still lower estuarine species were generally lacking on ebb tides. Distributions of later naupliar and cyprid stages were similar to those described by Bousfield (older stages were more concentrated in deeper waters and found further upriver). The larvae of *Balanus improvisus* were not collected in the upper estuary of the Piscataqua system, although their adults occurred in low abundance. This brackish-water sessile species may be similar to *C. virginica* in the Piscataqua system with intermittent larval recruitment. *Balanus improvisus* was predominant in suitable upriver habitats of the Miramichi Estuary. Such characteristics of the Piscataqua system as 1) seasonal and annual extremes of salinity, temperature and turbidity in shallow waters of Great Bay, 2) low freshwater inflow (only 1069 km² drainage area), and 3) the small area for estuarine endemics differ considerably from the Miramichi Estuary. As a result, low larval numbers or a lack of annual recruitment from all sessile brackish-water species were observed for Great Bay fauna (oyster larvae were not even collected although their adults were present). Dense concentrations of *Balanus brenatus* nauplii were collected in the upper estuary (Station
7), well above the main populations of spawning adults. This differed from the corresponding situation in the Miramichi Estuary.

Adult *B. crenatus* show a "trip effect" in the estuary in that larvae stay in channel waters and get drawn up toward the head of the estuary (at this time, upriver salinity is moderate and temperature is optimal).

As previously described, straight-hinge veligers of bivalve molluscs were concentrated primarily on flooding waters regardless of depth, but the late umbone stage of bivalve veligers, cyprid stage of barnacles, and larval stages and juveniles of spionid polychaetes were more dense at 8 m than in near-surface waters on specific stages of tide. Temporal and spatial distributions of the majority of bivalve larvae identified in this study have not been described for Western Atlantic estuaries (e.g., *Modiolus modiolus*, *Hiatella arctica*, *Anomia aculeata*). Tidal distributions of the larvae of all benthic invertebrates, excluding the barnacles, are presented in this study for the first time. In addition, annual, seasonal, and spatial distributions of certain species (e.g., *Myriochele heeri*, *Eulalia viridis*, *Anomia aculeata*) have not been described previously for estuarine waters.

The tidal migration pattern described for meroplankton in the Piscataqua-Great Bay Estuary differed by location within the estuary. Within the same system, the coastal aggregate of plankton was more abundant in flood waters while the Great Bay aggregate was more abundant in ebb waters. Generally speaking, each estuary has a different set of hydrographic characteristics and species assemblages. Additionally, the same species may behave differently in different estuaries as evidenced
by the conflicting oyster data. Future studies on estuarine distributions of species whose distributions are described for the first time within this study may find that meroplankton differ within estuaries as found for the different barnacle species or between estuaries for the same species as the oyster data indicates. Yet, the differing distributions of larval populations within this estuary allow speculation that differences in such characteristics as size of estuarine system and tidal flow modify distributions of larvae over tidal cycles and may account for differences between those investigators which described tidal differences in larval density of oysters, but on different stages of tide.

Numerous hydrological parameters have been investigated in the laboratory to determine which was responsible for eliciting tidal swimming behavior. Laboratory studies of salinity and current changes were initiated since they are most frequently cited in field investigations of fish larvae (Lewis and Mann, 1971; Wilkins and Lewis, 1971; Fore and Baxter, 1972) and oysters (Carriker, 1951; Wood and Hargis, 1971). Both T. Nelson (1952) and Haskin (1964) demonstrated that oyster larvae will rise from the bottom and actively swim in response to gradually increasing salinities. Other studies by T. Nelson (Nelson and Perkins, 1930; T. Nelson, 1931) demonstrated that oyster larvae which were on the bottom in still water, swam upward when a current was introduced. Changes in temperature (J. Nelson, 1915) and light intensity and quality (Haskin, 1964; Wood, unpublished data) have been investigated. Although Haskin (1964) stated that oyster larvae swam with changing light intensities, Wood (unpublished data) could not detect any significant changes in
swimming behavior with changing light intensity or quality. From these observations, it a-ppears that increasing salinities and changes in current are the most likely stimuli to larval swimming behavior in the estuary.

Pritchard's (1951) elucidation on the two layered drift transport system of stratified estuaries has been cited by several authors to account for larval distributions in coastal plain estuaries (Bousfield, 1955; Pearcy, 1962; Woods and Hargis, 1971; Graham, 1972). Larvae which remain below the level of "no net motion" in this type of estuary would be transported upstream, while larvae which remain in surface waters would be transported seaward. Smith (1964) suggests that response to non-tidal drift circulation may be widespread and Hulbert (1957) postulated that it may even extend to entirely pelagic species. The Piscataqua-Great Bay Estuary is stratified during only part of the year. Yet, larval distributions were similar on tidal cycles regardless of whether the estuary was stratified or not. Differences in larval densities between surface samples and 8 m samples were non-significant, but interactions between depth and tide were significant. Non-tidal drift circulation in the Piscataqua system is not a necessary factor for larval transport since this estuary is often well mixed from surface to depth.

Diel Variation

Analysis of the data from the four 24-hour stations indicated that meroplankton at Station 3 were not migrating on a diurnal cycle in response to day-night regimes. Weekly live samples collected at
the same time of day were not related to time but only to stage of the tide. Major faunal differences noted in these data were related to month and tide rather than to differences in solar intensity. Responses to light associated with stage of tide may exist, but they were not evident in this study.

There are exceptionally few studies on estuarine meroplankton which discuss any relationship between distribution of larvae and light as a triggering mechanism for migration. Williams and Porter (1971) stated that postmetamorphal bivalves were seasonally predictable in surface meroplankton of nocturnal waters on flooding tides. J. Nelson (1915) wrote that oyster larvae tended to stay near the bottom at night and rise when daylight appeared, but later investigators did not mention this behavior. Several studies of vertebrate larvae discuss estuarine distributions of the larval and juvenile fishes with correlations between day-night and tides (Lewis and Wilkins, 1971; Pacheco, 1973). Larvae were usually more abundant with flooding tides at night. An ichthyoplankton study in the Merrimack River Estuary, Massachusetts reached similar conclusions but attributed day-night differences to net avoidance in daylight hours (S. Peterson, unpublished data).

Although a large majority of planktonic species in oceanic and coastal waters undergo day-night migrations, few studies of estuarine meroplankton describe such migrations, and, as noted above, these are usually associated with tidal stages. A response by planktonic estuarine organisms to daily changes of insulation does not appear to be of selective advantage to the entire group or they would have evolved along similar lines as their oceanic counterparts. In fact, responses by
estuarine species to light variation may actually conflict with responses to tidal changes.

**Behavioral and Ecological Implications**

The following summation of observations are directly related to physiological responses of individuals to their variable estuarine environment: 1) a disjunct pattern of spawning occurred from February through October in which individual species spawned at different times; 2) planktonic larval life lasted for one month or less; 3) two distinct communities were maintained within the system; and 4) certain upper estuarine species may only spawn intermittently.

Behavioral responses in morphologically different species of meroplankton to tide accounted for their remaining near their respective estuarine benthic communities rather than being widely disseminated. By rising into the water column on flood stages of tide, lower estuarine larvae were transported upriver to their maximal limits of estuarine penetration. By rising in the water column with the minimal currents of ebb tide, upper estuarine larvae remained near parental spawning beds and resisted upriver transport. Many populations which inhabit Great Bay may already be at their furthest upriver extension for survival of larvae.

"Regularly recurring quantitative changes in some biological process, whether it takes place in a cell, tissue, organ, organism or population" is termed rhythm by Kleitman (1949). This definition categorizes the active transport mechanism described herein as tidal rhythm. Whether selective swimming with tide is an endogenous or
exogenous rhythm must be investigated in the laboratory. As Russell (1927) described for plankton: "It would seem that in fairly homogeneous waters light intensity may be the factor of prime importance governing the distribution of the different species, though other factors such as temperature and salinity may play their part, perhaps in altering the sensitivity of the animal to light. Rate of movement must be an important factor in the various sudden changes in vertical distribution exhibited, and the distribution of food is not to be ignored." Hardy (1956) discusses the matter in some detail and suggests that vertical migration may have evolved because it gave the animal concerned a continual change in environment, through horizontal transport by currents, which would otherwise be unattainable for a passively drifting creature. He also proposed an hypothesis of "animal exclusion" in which the distributional relationship between the animals and plants may be due to a modification in the vertical migration of the former in relation to dense concentrations of the latter. Most animals, it is supposed, come up to feed in the dense phytoplankton zone for a short time only at night possibly because this is sufficient for nutrition and minimizes exposure to visual predators.

Diurnal migrations have been described for many oceanic plankton as previously discussed, but are not well studied in estuaries. As Brown (1957) points out, "compared with the sun, the influence of the moon on illumination, temperatures, and humidity is slight. But in the intertidal regions of the shores of the oceans, the influence of the moon is twice as great as that of the sun." I wish to add that the effect of the moon and tides is even greater in estuaries because
the environmental differences between tidal cycles are more extreme during times of high river discharge. Reviews of tidal rhythmic activity in intertidal invertebrates by Cloudsley-Thompson (1961) and Bunning (1964) included the following rhythms which continued in aquaria without the tidal cycle: 1) the opening and closing of the valves in *Crassostrea virginica* (Brown, 1954) and *Mercenaria mercenaria* (Bennet, 1954), 2) the rate of water propulsion by *Mytilus edulis* (Rao, 1954), 3) rates of oxygen consumption in *Littorina littorea* and *Urosalpinx cinerea* (Sandeen, Stephens and Brown, 1954), and 4) spontaneous motor activity in *Uca* spp. (Brown, Fingereman, Sandeen and Webb, 1953; Bennet, Shriner and Brown, 1957) and *Carcinus maenas* (Naylor, 1958). As a final note from the literature, Brown, Webb, Bennett and Sandeen (1955) postulated that "endogenous diurnal and tidal rhythms may play an important role in regulating the frequencies and actual times of breeding periods including not only the synchronization of swarming, mating or spawning behavior, but also the synchronous anticipatory processes involved."

Planktonic larvae allow the dissemination of otherwise sedentary species, reduce inter- and intra-specific competition over benthic substrates and allow feeding on surface phytoplankton concentrations. If larvae remained near or on the bottom, they would be retained within estuaries and settle near parental spawning beds. Concentrations of bottom larvae, however, would be preyed upon by other benthic species and ingested by filter-feeding adults of their own species. If Hardy's (1956) theories are correct for plankton, then avoidance or "exclusion" may be the immediate, or direct causal factor for their
downward migration on certain tidal stages. Avoidance of ebb waters by lower estuarine meroplankton may be in response to dense concentrations of phytoplankton on flood slack tides, to such ebb-associated hydrographic factors as increased turbidity, or to the phytoplankton composition of ebbing tides. Avoidance of strong currents, silt, and the rapid transition from estuarine to freshwater conditions in the uppermost Bay could account for upriver species swimming on ebb slack tides. In addition, upper estuarine meroplankton must have adapted to feeding on the freshwater and brackish plankton which would be in highest concentration in surface waters at ebb slack tide. Because only low densities of coastal phytoplankton, are postulated to reach Great Bay waters on flooding tides, the greater concentrations of phytoplankton must be resident Bay or riverine plankton and would be present on ebb slack tides. The ultimate biological significance is the maintenance of estuarine larvae within the system. Another ultimate factor may be that older larvae, by moving near or onto the bottom of the estuary on each tidal cycle, increase their searching area for settlement on a preferred substratum. It has been suggested by Thorson (1957) that searching larvae discover suitable substratum only by actual contact. Larvae of many species of benthic invertebrates delay metamorphosis for an extended time if a suitable substrate is not encountered (Knight-Jones and Stephenson, 1950; deBlock, et al., 1959; Lynch, 1959; Scheltema, 1961; Thorson, 1957; Wilson, 1952; Carriker, 1967). If larval search time is shortened, then planktonic larval life is also shortened, by inference, increasing survival. Carriker (1967) stated that the average settling period of estuarine larvae seems to be one to two weeks, as opposed to more than three weeks for more
typically marine benthos.

The three-dimensional pattern of meroplankton swimming with tide poses two questions: 1) have other planktonic species adjusted to this tide-associated behavior; and, 2) have nektonic and benthic species which lack this behavior adapted to tidal migration of prey species. An analysis of other zooplankton taken in the tows suggested a similar response to tidal oscillation for holoplankton. Calanoids, harpacticoids, tintinnids and other holoplankters were in greatest abundance in surface water on the flooding tide at the mid-estuary station. Further studies on holoplankton and phytoplankton distribution in relation to tide would be desirable.

Tidal rhythms are not unique to the few well-studied meroplankton species (oyster and barnacle larvae); rather, fish larvae and juveniles, other meroplankton larvae, certain juvenile bivalves, some holoplankton and possibly dinoflagellates are all in highest concentration in surface water on flood tides. A three-dimensional meroplankton distribution that changes with time in estuaries poses interesting considerations for the remaining members of the community. Have they adjusted their feeding behavior in response to an oscillating food source? Fishermen and birds usually fish on flooding waters and cease catching fish after high slack water. It is hypothesized that nektonic primary, secondary and tertiary carnivores feed when their prey species are in highest concentration, i.e., on flood tides. Huntsman (1952) described a similar situation for the salmon of Passamaquoddy Bay, an arm of the Bay of Fundy in which tides of about 7 m occur twice each day. Small fish were in the surface waters of the Bay on flooding tides when the phyto- or zooplankton upon which they were feeding were...
carried inward from the Gulf of Maine. Since the fast currents pro-
duced turbulence and high turbidity, he postulated that phytoplankton
could not reproduce in surface waters of the Bay. Instead, large
concentrations of phytoplankton and zooplankton developed outside
the entrance of the Bay in the calmer, nutrient rich waters, then
moved into the Bay on flooding tides. Feeding forays of carnivores
which are linked to tide may also aid predator species by concentrating
them in estuarine waters for such physiological processes as mating or
spawning. Benthic carnivores and filter feeders prey on high concen-
trations of plankton near the bottom with each ebbing cycle. This
three-dimensional distribution of prey species serves to complicate
the food web of the estuarine community.

Previous studies of oyster and barnacle larvae, a number of
other plankton studies not described in terms of tidal transport, a
small number of tidal transport studies on vertebrate meroplankton
and this study of the Piscataqua-Great Bay lead to the conclusion
that behavioral responses to tide among estuarine species are common.
This proposed scheme for the estuarine plankton community involves
similar behavioral responses despite a diversity of morphotypes.

Day's (1951) comment, "the distribution of animals in estuaries
cannot be based on any single factor of the environment" is certainly
descriptive of the Piscataqua estuarine inhabitants and probably of all
estuaries. Prime factors effecting the distributions of the larvae
of benthic invertebrates in the Piscataqua-Great Bay Estuary include
temperature, salinity, tidal cycles, phytoplankton composition, size
of adult populations and their location, and size of estuary (i.e.,
Future Work

Future studies should be directed toward two avenues of investigation—(1) physiological studies to define the stimulus-reception-response mechanism and the immediate and ultimate reinforcement for tidal rhythm, and (2) field studies on other members of the estuarine community. The Piscataqua system is an excellent site for field studies. Weekly plankton collections taken on similar tidal stages yield the best seasonal monitoring data. Use of a more maneuverable vessel for 24-hour studies would allow diurnal drift studies to be conducted in the upper estuary to confirm the hypotheses generated in the present discussion. Studies in the upper estuary would be effected during April and either June or July when the barnacle and spionid larvae are abundant. Twenty-four hour studies conducted monthly or seasonally at several depths and from a lower and upper estuarine station will yield valuable data on larval distributions with tide in the Piscataqua-Great Bay estuarine system. Physiological studies might pursue the effects of slow step-wise changes of temperature, salinity, pressure, light or combinations of these on laboratory populations to simulate the subtle changes of each over a typical tidal cycle. Density measurements of laboratory populations should be taken hourly in standing aquaria to determine whether the rhythm persists and is thus endogenous.
SUMMARY

1. The purpose of this investigation was to determine the distributions of meroplankton in the Piscataqua-Great Bay Estuary in New Hampshire and Maine.

2. Previous work on seasonal, tidal, diurnal, vertical, and horizontal distributions of meroplankton and the effect of such environmental factors as salinity, temperature, light and pH on their distributions is discussed and evaluated.

3. The Piscataqua-Great Bay estuarine system is a coastal plain estuary which is stratified each spring and to a lesser extent in the autumn when river discharge is highest, but is vertically well mixed in summer and winter. The seaward part of the system has a narrow channel, 10 to 22 m in depth, with fast tidal cycles. Annual temperatures in the Harbor ranged from 2 to 16°C but salinities remained near 30 °/oo year round. Annual temperatures in Great Bay ranged from 0.5 to 25°C and salinities ranged from 5 to 31 °/oo. Great Bay waters are always turbid but the lower estuary waters are clearer.

4. Balanus balanoides was the first to spawn in the estuary (in February when water temperature was nearly 0°C); however, most meroplankton occurred in June and July, with a late fall-winter nadir in abundance. Meroplankton were not collected in the estuary during January.

5. Monthly variance in meroplankton distribution was highly significant. The high densities of meroplankton in June and July
decreased sharply in August of all years, then increased again in September or October. High summer temperatures of the upper estuary probably account for larval reduction.


7. Meroplankton distributions varied significantly between Portsmouth Harbor and Great Bay. A dichotomy of adult intertidal communities was described in which lower estuarine communities were significantly different from Great Bay communities; larval distributions were similar to those of their respective adults.

8. Great Bay populations of Crassostrea virginica, Modiolus demissus, Molgula manhattensis and Balanus improvisus did not produce larval swarms which were detectable with the sampling methodologies employed. It is hypothesized that these warm water species are stressed physiologically in Great Bay and annual spawning is intermittent.

9. Meroplankton distributions did not vary significantly with the 0.5 and 8 m depths, but interactions between depth and tide and between depth and month varied significantly.

10. There was no consistent pattern in day-night variation of mero-
plankton distributions.

11. In spite of the short length of the Piscataqua–Great Bay Estuary (8 km), the fast current speeds (average 5 kt peak on each tide), and the seasonal change in estuarine circulation type, estuarine species and their planktonic larval stages are maintained within the system.

12. Significant variance in meroplankton distributions occurred between high and low stages of tide from 1971 through 1973. All high tide samples from lower estuarine stations had a greater number of species and a higher density of bivalve larval species than low tide samples, but the larvae of spionids and prosobranchs were most abundant in low tide samples from the upper estuary.

13. *Balanus crenatus* nauplii (adults are subtidal, lower estuarine) were abundant on both stages of tide in Great Bay during 1971. It is postulated that these larvae extended further upriver when salinities in Great Bay were high (their cyprids are only in low abundance in the Bay), then high mortality reduced concentrations of late nauplii and cyprids or these nauplii were transported downriver on ebbing tides.

14. Although species composition changed with season, larval distribution with tide occurred throughout different seasons and years.

15. Results from this study suggest that larvae of the lower estuary are most abundant on flooding tides, while larvae of the upper estuary are most abundant on slack water of low tide.
16. Highest densities of fish larvae and juveniles, most meroplankton larvae, certain bivalve juveniles and holoplankton are in surface waters during flooding tides.
BIBLIOGRAPHY


Africa 33:53-91.


Nelson, J. 1912. Report of the Biological Department of the New Jersey Agricultural Experimental Station for the year 1911.


Appendix A. Three way analysis of variance with replication on Station 3 data between depths (0.5 and 8 m), months (April through November; averaged for 1971-1973) and tides (near slack water stages of flood and ebb).
Appendix A. Three way analysis of variance with replication on Station 3 data between depths (0.5 and 8 m), months (April through November; averaged for 1971-1973) and tides (near slack water stages of flood and ebb).

Grand Mean 285.79150

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<tr>
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<td>5</td>
<td>49508.1719</td>
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<tr>
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<td>1</td>
<td>109634.062</td>
<td>6.53 *</td>
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<tr>
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<td>306961.062</td>
<td>5</td>
<td>61392.2109</td>
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<td>1024.25000</td>
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<td>MDR</td>
<td>7844.00000</td>
<td>5</td>
<td>1568.79980</td>
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<td>TR (error)</td>
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<tr>
<td>MTR</td>
<td>11344.6641</td>
<td>5</td>
<td>2268.93262</td>
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</tr>
<tr>
<td>DTR</td>
<td>3333.33325</td>
<td>1</td>
<td>3333.33325</td>
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<tr>
<td>MDTR</td>
<td>12501.9023</td>
<td>5</td>
<td>2500.38037</td>
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</table>

TOTAL                         | 3348493.00      | 47                 |              |         |

*** means $\alpha \leq 0.001$       ** means $\alpha \leq 0.01$       * means $\alpha \leq 0.05$
Appendix B. Mixed-model, two way analysis of variance between years (1971-1973) and stations (Stations 1, 3, 4, and 7). Data from 8 m on flood tides.
Appendix B. Mixed-model, two way analysis of variance between years (1971-1973) and stations (Stations 1, 3, 4, and 7). Data from 8 m on flood tides.

<table>
<thead>
<tr>
<th>Stations</th>
<th>71</th>
<th>72</th>
<th>73</th>
<th>Total</th>
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<tbody>
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<td>1</td>
<td>4939</td>
<td>4181</td>
<td>4840</td>
<td>13960</td>
</tr>
<tr>
<td>3</td>
<td>3190</td>
<td>3604</td>
<td>3210</td>
<td>10004</td>
</tr>
<tr>
<td>4</td>
<td>2962</td>
<td>2805</td>
<td>2603</td>
<td>8370</td>
</tr>
<tr>
<td>7</td>
<td>1783</td>
<td>1619</td>
<td>1626</td>
<td>5028</td>
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<tr>
<td>Total</td>
<td>12874</td>
<td>12209</td>
<td>12279</td>
<td>37362</td>
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</table>

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Squares</th>
<th>F-Ratio</th>
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</thead>
<tbody>
<tr>
<td>Years</td>
<td>66762.5</td>
<td>2</td>
<td>33381.25</td>
<td>N.S.</td>
</tr>
<tr>
<td>Stations</td>
<td>13773179.7</td>
<td>3</td>
<td>4591059.9</td>
<td>59.396 ***</td>
</tr>
<tr>
<td>Error</td>
<td>463772.8</td>
<td>6</td>
<td>77295.47</td>
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</tr>
<tr>
<td>TOTAL</td>
<td>14303715.0</td>
<td>11</td>
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<td></td>
</tr>
</tbody>
</table>

*** means $\alpha \leq 0.001$
Appendix C. Vertical distribution of temperature and salinity measurements taken on flood tides in 1971 (solid lines represent temperature and dashed lines represent salinity).
Appendix D. Vertical distribution of temperature and salinity measurements taken on ebb tides in 1971 (solid lines represent temperature and dashed lines represent salinity).
Appendix E. Vertical distribution of temperature and salinity measurements taken on flood tides in 1972 (solid lines represent temperature and dashed lines represent salinity).
Appendix F. Vertical distribution of temperature and salinity measurements taken on ebb tides in 1972 (solid lines represent temperature and dashed lines represent salinity).
Appendix G. Vertical distribution of temperature and salinity measurements taken on flood tides in 1973 (solid lines represent temperature and dashed lines represent salinity).
Appendix H. Vertical distribution of temperature and salinity measurements taken on ebb tides in 1973 (solid lines represent temperature and dashed lines represent salinity).
Appendix I. Horizontal distribution of salinity from April through November of 1971 through 1973 on flood (solid lines) and ebb (dashed lines) tides.
Appendix J. Horizontal distribution of temperature from April through November of 1971-1973 of flood (solid lines) and ebb (dashed lines) tides.
Appendix K. Horizontal distribution of pH from April through November of 1971-1973 on flood (solid lines) and ebb (dashed lines) tides.
Appendix L. Horizontal distribution of depth of visibility (Secchi disc) from April through November of 1971-1973 on flood (solid lines) and ebb (dashed lines) tides.
Appendix M. Horizontal distribution of meroplankton from April through July of 1971-1973 at the depth of 8 m on flooding tides.
Appendix N. Horizontal distribution of meroplankton from August through November of 1971-1973 at the depth of 8 m on flooding tides.
Appendix 0. Species list of benthic adults with possible planktonic larval stages in the Piscataqua–Great Bay Estuary from 1970 to 1973. These are arranged by location within the estuary and include notes on their ecology.

1. Residents of Lower Estuary with Diminishing Densities Upriver.

2. Residents of Upper Estuary with Diminishing Densities Downriver.

3. Ubiquitous from Portsmouth Harbor to Great Bay, but densities decrease upriver.
Appendix 0. Species list of benthic adults with possible planktonic larval stages in the Piscataqua-Great Bay Estuary from 1970 to 1973.

1. Residents of Lower Estuary with Diminishing Densities Upriver

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNELIDA (Polychaeta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphitrite cirrata</td>
<td>1-4</td>
<td>subtidal, among kelp on hard substrata</td>
</tr>
<tr>
<td>Amphitrite johnstoni</td>
<td>1-3</td>
<td>subtidal, on sand substrata</td>
</tr>
<tr>
<td>Aricidea jeffreysi</td>
<td>1-4</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Cirratulus grandis</td>
<td>1-2</td>
<td>subtidal, taken infrequently on hard substrata</td>
</tr>
<tr>
<td>Dispio uncinata</td>
<td>1-4</td>
<td>subtidal, taken infrequently on hard substrata</td>
</tr>
<tr>
<td>Eteone lactea</td>
<td>1-5</td>
<td>muddy intertidal and subtidal, in Little Bay on sand substrata</td>
</tr>
<tr>
<td>Eteone longa</td>
<td>1-4</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Eulalia viridis</td>
<td>1-2</td>
<td>subtidal, taken infrequently on hard substrata</td>
</tr>
<tr>
<td>Glycera dibranchiata</td>
<td>1-2</td>
<td>subtidal, taken infrequently on hard substrata</td>
</tr>
</tbody>
</table>

a. Species list compiled from benthic, intertidal, and periphyton collections in the Piscataqua-Great Bay estuarine system from 1970-1973 by the staff of Normandeau Associates, Inc. and this author. Certain identifications confirmed by M. Abbott and J. Reinhart, curators of Gray Museum (Woods Hole, Massachusetts) and R. Turner of the Museum of Comparative Zoology (Harvard University, Cambridge, Massachusetts). Average densities determined by Normandeau Associates Inc. (1974) are employed herein as the only attempt to estimate adult abundances in this system.

b. Nudibranchia collected by L. Harris (unpublished data) during his SCUBA survey of the Portsmouth Harbor benthos and fouling communities.

c. Only species with average densities calculated to be greater than 10/m² from 1970-1973 were noted herein; species with lower abundance were reported without densities.
Appendix 0. Continued.

1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNELIDA (Polychaeta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goniada maculata</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Harmothoe extenuata</td>
<td>1-6</td>
<td>subtidal, on hard and sandy substrata</td>
</tr>
<tr>
<td>Harmothoe imbricata</td>
<td>1-6</td>
<td>subtidal, on hard and sandy substrata</td>
</tr>
<tr>
<td>Harmothoe spinulosa</td>
<td>1-2</td>
<td>subtidal, on hard and sandy substrata</td>
</tr>
<tr>
<td>Lumbrinereis fragilis</td>
<td>1-4</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Maldane sarsa</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Kyriochale heeri</td>
<td>1-3</td>
<td>subtidal, on mud substrata</td>
</tr>
<tr>
<td>Nephtys buccra</td>
<td>1-4</td>
<td>subtidal, on sand substrata</td>
</tr>
<tr>
<td>Nephtys caeca</td>
<td>1-5</td>
<td>muddy intertidal; subtidal, average density 24/m² decreasing to 2/m² in Little Bay on varied substrata, dominant by numbers in sand community</td>
</tr>
<tr>
<td>Nephtys incisa</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Nereis pelagica</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Orbinia ornata</td>
<td>1-3</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Parasonis sp.</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
</tbody>
</table>
### Appendix 0. Continued.

1. **Residents of Lower Estuary with Diminishing Densities Upriver, continued**

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>MOLLUSCA (Bivalvia)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Siliqua costata</em></td>
<td>2</td>
<td>subtidal, collected in 1972 on sand substrata</td>
</tr>
<tr>
<td><em>Solemya velum</em></td>
<td>1-2</td>
<td>subtidal, collected in 1971 and 1972 on sand substrata</td>
</tr>
<tr>
<td><em>Spisula solidissima</em></td>
<td>1-4</td>
<td>subtidal, small specimens on sand substrata</td>
</tr>
<tr>
<td><em>Thracia myopsls</em></td>
<td>2</td>
<td>subtidal, collected in 1971 on sand substrata</td>
</tr>
<tr>
<td><em>MOLLUSCA (Gastropoda, Nudibranchia)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acanthodoris pilosa</em></td>
<td>1-4</td>
<td>member of periphyton; subtidal on hard substrata</td>
</tr>
<tr>
<td><em>Aeolidia papillosa</em></td>
<td>1-4</td>
<td>member of periphyton; subtidal on hard substrata</td>
</tr>
<tr>
<td><em>Coryphella pellucida</em></td>
<td>1-4</td>
<td>subtidal on hard substrata</td>
</tr>
<tr>
<td><em>Coryphella salmonacea</em></td>
<td>1-4</td>
<td>subtidal on hard substrata</td>
</tr>
<tr>
<td><em>Coryphella stellata</em></td>
<td>1-4</td>
<td>in periphyton</td>
</tr>
<tr>
<td><em>Coryphella verrucosa</em></td>
<td>1-4</td>
<td>subtidal, on hard substrata; member of periphyton</td>
</tr>
<tr>
<td><em>Cratena pilata</em></td>
<td>1-4</td>
<td>member of periphyton</td>
</tr>
<tr>
<td><em>Cratena viridis</em></td>
<td>1-4</td>
<td>subtidal on hard substrata</td>
</tr>
<tr>
<td><em>Dendronotus frondosus</em></td>
<td>1-4</td>
<td>subtidal, on mud substrata; member of periphyton</td>
</tr>
</tbody>
</table>
1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
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</thead>
<tbody>
<tr>
<td>MOLLUSCA (Bivalvia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astarte undata</td>
<td>1-4</td>
<td>subtidal, on varied substrata</td>
</tr>
<tr>
<td>Crenella decussata</td>
<td>1-3</td>
<td>subtidal, on mud substrata</td>
</tr>
<tr>
<td>Crenella glandula</td>
<td>1-4</td>
<td>subtidal, on mud-sand substrata</td>
</tr>
<tr>
<td>Ensis directus</td>
<td>1-4</td>
<td>subtidal, on mud-sand substrata</td>
</tr>
<tr>
<td>Hiatella arctica</td>
<td>1-4</td>
<td>subtidal, on sand to mud substrata among kelp holdfasts; abundant in periphyton from June through November</td>
</tr>
<tr>
<td>Lyonsia hyalina</td>
<td>1-5</td>
<td>subtidal, on mixed substrata</td>
</tr>
<tr>
<td>Modiolus modiolus</td>
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<td>subtidal, on coarse sand substrata</td>
</tr>
<tr>
<td>Musculus niger</td>
<td>1-2</td>
<td>subtidal, collected in 1970 and 1971 on mud-sand substrata</td>
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<tr>
<td>Mya truncata</td>
<td>1</td>
<td>subtidal, collected three specimens in 1971 on hard substrata</td>
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<tr>
<td>Nucula proxima</td>
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<td>subtidal, average density 50/m² in sand and mud substrata</td>
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<td>Petricola pholadiformis</td>
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<td>muddy intertidal</td>
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<tr>
<td>Placopectin magellanicus</td>
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<td>subtidal, in sand-mud substrata</td>
</tr>
<tr>
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<td></td>
<td></td>
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<tr>
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Appendix 0. Continued.

1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
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<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
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<tr>
<td><strong>ANNELIDA (Polychaeta)</strong></td>
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</tr>
<tr>
<td>Pectinaria gouldii</td>
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<td>subtidal, lower estuary to Little Bay on sand-mud substrata</td>
</tr>
<tr>
<td>Pectinaria granulata</td>
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<td>subtidal, on sand-mud substrata</td>
</tr>
<tr>
<td>Phereus affinis</td>
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<td>subtidal, on sand-mud substrata</td>
</tr>
<tr>
<td>Phyllodoce groenlandica</td>
<td>1-3</td>
<td>muddy intertidal; subtidal on mud substrata</td>
</tr>
<tr>
<td>Phyllodoce maculata</td>
<td>1-4</td>
<td>subtidal, on mud-sand substrata</td>
</tr>
<tr>
<td>Phyllodoce mucosa</td>
<td>1-4</td>
<td>member of periphyton; subtidal, on sand substrata</td>
</tr>
<tr>
<td>Sabella crassicornis</td>
<td>2-4</td>
<td>subtidal, in sand substrata</td>
</tr>
<tr>
<td>Scolecolepides viridis</td>
<td>2-5</td>
<td>muddy intertidal; subtidal on mud substrata</td>
</tr>
<tr>
<td>Scolelepsis sp.</td>
<td>3-4</td>
<td>subtidal, in mud-sand substrata</td>
</tr>
<tr>
<td>Spirorbis spirillum</td>
<td>2-4</td>
<td>member of periphyton; subtidal, average density 20/m^2 attached to hard substrata and algae</td>
</tr>
<tr>
<td>Spirorbis borealis</td>
<td>2-4</td>
<td>subtidal on kelp fronds</td>
</tr>
<tr>
<td>Sternapinus acutata</td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td>Travisia carneae</td>
<td>1-2</td>
<td>subtidal, on hard substrata, collected only in 1970-1971</td>
</tr>
</tbody>
</table>
### 1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECHINODERMATA (Ophiuroidea)</strong></td>
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<td></td>
</tr>
<tr>
<td>Ophiopholis aculeata</td>
<td>1-3</td>
<td>subtidal, collected during 1971 and 1972 on hard substrata</td>
</tr>
<tr>
<td><strong>ECHINODERMATA (Echinoidea)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echinacanthus parma</td>
<td>1-4</td>
<td>subtidal, average density 60/m² on varied substrata, most common in muddy sand</td>
</tr>
<tr>
<td>Strongylocentrotus droebachiensis</td>
<td>1-4</td>
<td>subtidal, average density 10/m² on sand substrata</td>
</tr>
<tr>
<td><strong>ECHINODERMATA (Holothuroidea)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leptosynapta tenuis</td>
<td>1-2</td>
<td>subtidal, on varied substrata</td>
</tr>
<tr>
<td><strong>ECTOPROCTA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bugula spp.</td>
<td>1-5</td>
<td>in periphyton and on hard substrata</td>
</tr>
<tr>
<td>Cribilina annulata</td>
<td>1-2</td>
<td>subtidal, collected on algae in 1971 and 1972</td>
</tr>
<tr>
<td>Cribilina punctata</td>
<td>1-3</td>
<td>subtidal, collected in 1970 and 1971 on algae</td>
</tr>
<tr>
<td>Electra crustulenta</td>
<td>1-4</td>
<td>subtidal, on various hard substrata and algae</td>
</tr>
<tr>
<td>Electra pilosa</td>
<td>1-4</td>
<td>subtidal, collected on various substrata</td>
</tr>
<tr>
<td>Escharella immera</td>
<td>2-3</td>
<td>subtidal, collected in 1972 on hard substrata</td>
</tr>
<tr>
<td>Membranipora sp.</td>
<td>3-5</td>
<td>subtidal, collected on varied substrata</td>
</tr>
<tr>
<td>Microporella ciliata</td>
<td>1-2</td>
<td>subtidal, collected in 1971 on hard substrata</td>
</tr>
<tr>
<td>Parasmittina triapinosa</td>
<td>2-4</td>
<td>subtidal, collected in 1971 on hard substrata</td>
</tr>
</tbody>
</table>
Appendix 0. Continued.

1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOLLUSCA (Gastropoda, Nudibranchia)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Doto coronata</em></td>
<td>1-4</td>
<td>member of periphyton</td>
</tr>
<tr>
<td><em>Doto formosa</em></td>
<td>1-4</td>
<td>subtidal, on hard substrata</td>
</tr>
<tr>
<td><em>Eubranchus exigus</em></td>
<td>1-4</td>
<td>in periphyton</td>
</tr>
<tr>
<td><em>Eubranchus pallidus</em></td>
<td>1-4</td>
<td>member of periphyton community</td>
</tr>
<tr>
<td><em>Eubranchus muricata</em></td>
<td>1-4</td>
<td>subtidal, on hard substrata</td>
</tr>
<tr>
<td><em>Facelina bostoniensis</em></td>
<td>1-4</td>
<td>in periphyton</td>
</tr>
<tr>
<td><em>Onchidoris bilumellata</em></td>
<td>1-4</td>
<td>member of periphyton community during June, feeds on <em>Balanus balanoides</em></td>
</tr>
<tr>
<td><em>Onchidoris muricata</em></td>
<td>1-4</td>
<td>subtidal, on hard substrata</td>
</tr>
<tr>
<td><em>Tenellia fuscata</em></td>
<td>1-3</td>
<td>among algae on rocks</td>
</tr>
<tr>
<td><em>Tergipes tergipes</em></td>
<td>1-4</td>
<td>member of periphyton community from lower estuary to just above General Sullivan Bridge during June</td>
</tr>
<tr>
<td><strong>MOLLUSCA (Gastropoda, Prosobranchia)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Crepidula fornicata</em></td>
<td>1-5</td>
<td>subtidal, on hard substrata</td>
</tr>
<tr>
<td><em>Crepidula plana</em></td>
<td>1-3</td>
<td>subtidal on concave surfaces of shells</td>
</tr>
<tr>
<td><em>Haminoea solitaria</em></td>
<td>3-4</td>
<td>muddy intertidal</td>
</tr>
</tbody>
</table>
### Appendix O. Continued.

1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLLUSCA (Gastropoda, Prosobranchia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hydrobia minuta</em></td>
<td>1-5</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td><em>Lacuna viucta</em></td>
<td>1-4</td>
<td>member of periphyton, subtidal, on hard substrata and kelp fronds</td>
</tr>
<tr>
<td><em>Littorina littorea</em></td>
<td>1-5</td>
<td>muddy intertidal and rocky intertidal, average density 360/m²; subtidal, average density 10/m² on sand-hard substrata</td>
</tr>
<tr>
<td><em>Lunatia triseriata</em></td>
<td>1-5</td>
<td>muddy intertidal; member of periphyton; subtidal, average density 40/m² and decreases to 2/m² in Little Bay on mixed substrata</td>
</tr>
<tr>
<td><em>Mitrella lunata</em></td>
<td>1-4</td>
<td>subtidal, on varied substrata</td>
</tr>
<tr>
<td><em>Nassarius trivittatus</em></td>
<td>1-5</td>
<td>subtidal, average density 38/m² and decreases to 4/m² in Little Bay on varied substrata</td>
</tr>
<tr>
<td><em>Odostomia spp.</em></td>
<td>1-4</td>
<td>subtidal, on hard substrata among kelp</td>
</tr>
<tr>
<td><em>Polinices immaculatus</em></td>
<td>1-2</td>
<td>subtidal, collected infrequently on hard substrata</td>
</tr>
<tr>
<td><em>Nucella lapillus</em></td>
<td>1-5</td>
<td>muddy and rocky intertidal</td>
</tr>
<tr>
<td>ECHINODERMATA (Asteroidea)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Asterias forbesii</em></td>
<td>1-3</td>
<td>subtidal, on hard substrata</td>
</tr>
<tr>
<td><em>Asterias vulgaris</em></td>
<td>1-4</td>
<td>rocky intertidal; subtidal, on varied substrata; juveniles are members of periphyton</td>
</tr>
</tbody>
</table>
1. Residents of Lower Estuary with Diminishing Densities Upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTHROPODA (Crustacea, Decopoda)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancer borealis*</td>
<td>1-3</td>
<td>subtidal, collected infrequently</td>
</tr>
<tr>
<td>Cancer irratus</td>
<td>1-4</td>
<td>subtidal, estimated 10,000 population in lower estuary</td>
</tr>
<tr>
<td>Homarus americanus</td>
<td>1-4</td>
<td>subtidal, commercial fisheries but no population estimates available</td>
</tr>
<tr>
<td>Neopanopeus herbsti</td>
<td>2-3</td>
<td>subtidal, collected infrequently</td>
</tr>
<tr>
<td>Pagurus acadianus</td>
<td>1-3</td>
<td>subtidal, low intertidal on varied substrata</td>
</tr>
<tr>
<td>Rhizophropanopeus harrisi</td>
<td>1-5</td>
<td>subtidal, on varied substrata</td>
</tr>
<tr>
<td>ARTHROPODA (Crustacea, Thoracica)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanus balanoides</td>
<td>1-4</td>
<td>rocky intertidal, average density 1,980/m² in lower estuary; dominant in periphyton during May</td>
</tr>
<tr>
<td>Balanus balanus</td>
<td>1-2</td>
<td>occasionally collected on drift material</td>
</tr>
<tr>
<td>Balanus crenatus</td>
<td>1-5</td>
<td>subtidal, average density 926/m² in lower estuary, on hard substrates; dominant by number in periphyton community in autumn, extending to Little Bay in reduced abundance</td>
</tr>
<tr>
<td>MOLLUSCA (Bivalvia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anodonta scutelata</td>
<td>3-4</td>
<td>subtidal, on hard substrates; common among periphyton from late summer through autumn</td>
</tr>
<tr>
<td>Arctica islandica</td>
<td>1-2</td>
<td>subtidal, collected in 1970 and 1971 on sand substrata</td>
</tr>
<tr>
<td>Astarte borealis</td>
<td>1-5</td>
<td>subtidal, on sand-mud substrata</td>
</tr>
</tbody>
</table>
2. Residents of Upper Estuary with Diminishing Densities Downriver

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANnelida (Polychaeta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabricia sabella</td>
<td>5-7</td>
<td>dominant member of periphyton in Little Bay from October through November</td>
</tr>
<tr>
<td>Ophelia bicornis</td>
<td>5-6</td>
<td>subtidal, average density $32/m^2$ in Little Bay in sand substrata</td>
</tr>
<tr>
<td>Nereis diversicolor/virens</td>
<td>5-7</td>
<td>subtidal, muddy substrata</td>
</tr>
<tr>
<td>Polydora ligni</td>
<td>5-7</td>
<td>dominant by numbers in periphyton of Little Bay</td>
</tr>
<tr>
<td>Polydora spp.</td>
<td>4-5</td>
<td>dominant member of periphyton community at Adams Point from July through September</td>
</tr>
<tr>
<td>Scoloplos robusta</td>
<td>5-7</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Mollusca (Bivalvia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crassostrea virginica</td>
<td>7</td>
<td>rocky intertidal and subtidal in Great Bay, patchy distribution</td>
</tr>
<tr>
<td>Modiolus demissus</td>
<td>5-7</td>
<td>rocky intertidal, average density $15/m^2$</td>
</tr>
<tr>
<td>Mulinia lateralis</td>
<td>5-6</td>
<td>muddy intertidal; subtidal, collected infrequently</td>
</tr>
<tr>
<td>Thoracian (Cirripedia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanus improvisus</td>
<td>5-7</td>
<td>low intertidal, subtidal, patchy distribution on hard substrata</td>
</tr>
<tr>
<td>Ectoprocta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcyonidium sp.</td>
<td>4-5</td>
<td>member of periphyton in Little Bay</td>
</tr>
</tbody>
</table>
### 2. Residents of Upper Estuary with Diminishing Densities Downriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECTOPROCTA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bowerbankia gracilis</td>
<td>4-5</td>
<td>member of periphyton in Little Bay</td>
</tr>
<tr>
<td>Bugula stolonifera</td>
<td>5-6</td>
<td>member of periphyton in Little Bay and Great Bay</td>
</tr>
<tr>
<td>Cryptosula pallasiana</td>
<td>4-5</td>
<td>member of periphyton in Little Bay</td>
</tr>
<tr>
<td>Flustrellidra hispida</td>
<td>5-7</td>
<td>rocky intertidal, numerous but not counted</td>
</tr>
<tr>
<td>Hippothoa contracta</td>
<td>5-7</td>
<td>member of periphyton; subtidal on algae and other hard substrata</td>
</tr>
<tr>
<td>Hippothoa hyalina</td>
<td>4-6</td>
<td>member of periphyton in Little Bay; subtidal in low density within lower estuary</td>
</tr>
<tr>
<td>Schizoporella bisperta</td>
<td>5</td>
<td>member of periphyton in Little Bay</td>
</tr>
<tr>
<td>Scruparia ambiguus</td>
<td>5</td>
<td>member of periphyton in Little Bay</td>
</tr>
<tr>
<td>Schizopora errata</td>
<td>5</td>
<td>member of periphyton in Little Bay</td>
</tr>
</tbody>
</table>
### Appendix 0. Continued.

3. Ubiquitous from Portsmouth Harbor to Great Bay, but densities decrease upriver

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNELIDA (Polychaeta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clymenella torquata</td>
<td>1-7</td>
<td>muddy intertidal, average density 12/m² decreases upriver to 3/m² in Great Bay on variable substrata</td>
</tr>
<tr>
<td>Euclymene collaxis</td>
<td>1-7</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Heteromastus filiformis</td>
<td>1-7</td>
<td>muddy intertidal, lower estuary to Great Bay; subtidal, average density 14/m² in Little Bay to 4/m² in Great Bay on sand and hard substrata</td>
</tr>
<tr>
<td>Lepidonotus squamatus</td>
<td>1-7</td>
<td>subtidal, average density 8/m² in lower estuary to 2/m² in Great Bay around kelp holdfasts on sand and hard substrata; member of periphyton in lower estuary</td>
</tr>
<tr>
<td>Lumbrineris tenuis</td>
<td>1-7</td>
<td>muddy intertidal, lower to upper estuary; subtidal, average density 26/m² in lower estuary decreases to 18/m² in Little Bay to 10/m² in Great Bay on varied substrata</td>
</tr>
<tr>
<td>Nereis arenaceodonta</td>
<td>1-7</td>
<td>muddy intertidal</td>
</tr>
<tr>
<td>Nereis virens</td>
<td>1-7</td>
<td>muddy to rocky intertidal, lower to upper estuary; subtidal, on variable substrata</td>
</tr>
<tr>
<td>Scoloplos robustus</td>
<td>1-7</td>
<td>muddy intertidal; subtidal, average density 40/m² in lower estuary, 2/m² in Great Bay</td>
</tr>
<tr>
<td>Scoloplos fragilis</td>
<td>1-7</td>
<td>muddy intertidal; subtidal, average density 20/m² in lower estuary, 2/m² in mud substrata</td>
</tr>
<tr>
<td>Spio setosa</td>
<td>1-7</td>
<td>muddy intertidal, lower to upper estuary; subtidal, average density 4/m² in lower estuary to 6/m² in Little Bay to 2/m² in Great Bay on varied substrata</td>
</tr>
<tr>
<td>Streblospio benedicti</td>
<td>1-7</td>
<td>subtidal, mud substrata, low abundance throughout estuary</td>
</tr>
</tbody>
</table>
Appendix 0. Continued.

3. Ubiquitous from Portsmouth Harbor to Great Bay, but densities decrease upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARTHROPODA (Crustacea, Decapoda)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carcinus maenas</td>
<td>2-7</td>
<td>rocky intertidal</td>
</tr>
<tr>
<td>Crangon septemspinosus</td>
<td>3-7</td>
<td>muddy intertidal among <em>Spartina</em> and <em>Zostera</em></td>
</tr>
<tr>
<td><strong>MOLLUSCA (Bivalvia)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerastoderma pinnatulum</td>
<td>1-7</td>
<td>subtidal, average density 6/m² in lower estuary to 10/m² in Little Bay to 2/m² in Great Bay on varied substrata, but most abundant in muddy sand</td>
</tr>
<tr>
<td>Macoma balthica</td>
<td>1-7</td>
<td>muddy intertidal, average density 300/m² in lower estuary to 15/m² in upper estuary</td>
</tr>
<tr>
<td>Mya arenaria</td>
<td>1-7</td>
<td>muddy intertidal, average density 60/m² in lower estuary to 10/m² in upper estuary; subtidal, average density 10/m² in lower estuary to 1/m² in Great Bay on varied substrata</td>
</tr>
<tr>
<td>Mytilis edulis</td>
<td>1-7</td>
<td>muddy intertidal, rocky intertidal, (average density 230/m² in lower estuary); subtidal, average density 10/m² in lower estuary in near shore waters on hard substrata to 1/m² in Great Bay</td>
</tr>
<tr>
<td>Tellina agilis</td>
<td>1-7</td>
<td>muddy intertidal, lower to upper estuary; subtidal, 60/m² in lower estuary to 15/m² in Little Bay to 1/m² in Great Bay on mixed substrata, most common on muddy sand</td>
</tr>
<tr>
<td><strong>MOLLUSCA (Gastropoda)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acmaea testudinalis</td>
<td>1-7</td>
<td>muddy and rocky intertidal, subtidal average density 12/m² on hard substrata</td>
</tr>
<tr>
<td>Littorina obtusata</td>
<td>1-7</td>
<td>muddy intertidal and rocky intertidal (average density 2/m² in lower estuary to 40/m² in upper estuary)</td>
</tr>
<tr>
<td>Lunatia heroica</td>
<td>1-7</td>
<td>muddy intertidal, lower estuary; subtidal, average density 3/m² to 6/m² in Little Bay to 2/m² in Great Bay on mixed substrata</td>
</tr>
</tbody>
</table>
3. Ubiquitous from Portsmouth Harbor to Great Bay, but densities decrease upriver, continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Estuarine Location by Station</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLLUSCA (Gastropoda)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nassarius obsoletus</td>
<td>1-7</td>
<td>muddy intertidal, lower to upper estuary; subtidal, average density 5/m² in lower estuary to 10/m² in Great Bay on coarse sand</td>
</tr>
<tr>
<td>ECTOPROCTA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Callopora aurita</td>
<td>1-7</td>
<td>rocky intertidal, upper estuary; subtidal, on algae and hard substrata in lower estuary</td>
</tr>
<tr>
<td>Conopeum sp.</td>
<td>1-7</td>
<td>member of periphyton in Little Bay and Great Bay; subtidal on varied hard substrata from lower estuary to Great Bay</td>
</tr>
<tr>
<td>Crisia eburnea</td>
<td>1-7</td>
<td>member of periphyton in Little Bay and Great Bay; subtidal from lower estuary to Little Bay on varied substrata</td>
</tr>
</tbody>
</table>
Appendix P. Average density of meroplankton calculated monthly from April through November of 1971. Samples were collected from 8 m on near high water of flood tide at Stations 1, 3, 4 and 7.
<table>
<thead>
<tr>
<th>MEROPHANLONT</th>
<th>MONTH</th>
<th>Station 1</th>
<th>Station 3</th>
<th>Station 4</th>
<th>Station 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyphonatus larvae</td>
<td>A M J J A S O N</td>
<td>1 37 17 2</td>
<td>25 14 1</td>
<td>31 14 16 12</td>
<td>7</td>
</tr>
<tr>
<td>Harmothoe imbricata larvae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myriochele heeri mitaria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nectys spp. larvae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nereis spp. larvae</td>
<td>20</td>
<td>46 49 37</td>
<td>2 3 29 5 1 2</td>
<td>14 47 5</td>
<td>24 145 18</td>
</tr>
<tr>
<td>Calanid larvae</td>
<td>13 60</td>
<td>11 44</td>
<td>5 14 7 5</td>
<td>81 35 4</td>
<td></td>
</tr>
<tr>
<td>Polychaete trochospheres</td>
<td>15 3 6</td>
<td>21 10</td>
<td>4 2</td>
<td>5 5 3 4</td>
<td></td>
</tr>
<tr>
<td>Protula aculearum unbone</td>
<td>22 8 110 107</td>
<td>59</td>
<td>36 104</td>
<td>5 5</td>
<td>86 180 140 131 32 14</td>
</tr>
<tr>
<td>Other unbone veligers</td>
<td>19 20 5</td>
<td>25 17 2</td>
<td>4 2</td>
<td>5 5 3 4</td>
<td></td>
</tr>
<tr>
<td>Balanus balanoides nauplii</td>
<td>21 7</td>
<td>66 1</td>
<td>96 33</td>
<td>63 19</td>
<td></td>
</tr>
<tr>
<td>Balanus balanoides cyprids</td>
<td>1 25</td>
<td>21 7 1</td>
<td>32 12</td>
<td>5 1</td>
<td></td>
</tr>
<tr>
<td>Balanus crenatus nauplii</td>
<td>9</td>
<td>9 2</td>
<td>13</td>
<td>117 9</td>
<td></td>
</tr>
<tr>
<td>Balanus crenatus cyprids</td>
<td>4 1</td>
<td>11 1</td>
<td>5 1</td>
<td>1 1</td>
<td></td>
</tr>
<tr>
<td>Crustacean megalops larvae</td>
<td>1 1</td>
<td>1 1</td>
<td>1 6 4</td>
<td>1 2 1</td>
<td></td>
</tr>
<tr>
<td>Crustacean zoal larvae</td>
<td>1</td>
<td>1</td>
<td>7 17 1</td>
<td>1 1 1</td>
<td></td>
</tr>
<tr>
<td>Auricularia larvae</td>
<td>5 2</td>
<td>32</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Biplanaria larvae</td>
<td>12</td>
<td>28</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ophiopluteus larvae</td>
<td>50 233 39</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appendicularia larvae</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clioneid larvae</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fish eggs</td>
<td>10 4 3 4</td>
<td>16 1</td>
<td>5 1 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish larvae</td>
<td>52 15 1</td>
<td>104 238</td>
<td>193 189</td>
<td>104 63 902 760 365 88 25</td>
<td>164 739 948 615 198 200 77 35 102 248 707 250 96 202 139 19</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix Q. Average density of meroplankton calculated monthly from April through November of 1971. Samples were collected from 8 m on near high water of flood tide at Stations 1, 3, 4 and 7.
<table>
<thead>
<tr>
<th>MEROPHANLONTE MONTH</th>
<th>Station 1</th>
<th>Station 3</th>
<th>Station 4</th>
<th>Station 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyphonautes larvae</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Harmothoe imbricata larvae</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myriotrocha heeit mitraria</td>
<td>2</td>
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Appendix R. Average density of meroplankton calculated monthly from April through November of 1972. Samples were collected from 8 m on near high water of flood tide at Stations 1, 3, 4 and 7.
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Appendix S. Average density of meroplankton calculated monthly from April through November of 1973. Samples were collected from 8 m on near high water of flood tide at STation 1, 3, 4 and 7.
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Appendix T. Average density of meroplankton calculated monthly from April through November of 1971. Data were from 0.5 and 8 m collections on slack waters of flood and ebb tides at Station 3.
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**TOTAL**

|       | 133 | 516 | 599 | 454 | 166 | 141 | 79 | 15 | 104 | 639 | 902 | 760 | 330 | 365 | 88 | 25 | 80 | 112 | 79 | 103 | 65 | 78 | 22 | 15 | 103 | 247 | 263 | 200 | 106 | 75 | 46 | 44 |
Appendix U. Average density of meroplankton calculated monthly from April through November of 1972. Data were from 0.5 and 8 m collections on slack waters of flood and ebb tides at Station 3.
<table>
<thead>
<tr>
<th>MEROPLABONTON</th>
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<th>8 m, Flood</th>
<th>0.5 m, Ebb</th>
<th>8 m, Ebb</th>
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<td>AMJASON</td>
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**TOTAL**

|         | 144 | 306 | 368 | 924 | 494 | 357 | 107 | 10 | 131 | 593 | 933 | 1057 | 330 | 407 | 177 | 12 | 103 | 502 | 465 | 43 | 278 | 228 | 209 | 3 | 223 | 123 | 65 | 400 | 253 | 105 | 54 | 3 |
Appendix V. Average density of meroplankton calculated monthly from April through November of 1973. Data were from 0.5 and 8 m collections on slack waters of flood and ebb tides at Station 3.
<table>
<thead>
<tr>
<th>MEROPLANKTON</th>
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<th>8 m, Flood</th>
<th>0.5 m, Ebb</th>
<th>8 m, Ebb</th>
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Appendix W. Average density of meroplankton collected every three hours at Station 3 from 0.5 m on 30-31 July 1970.
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<th>2340</th>
<th>0240</th>
<th>0540</th>
<th>1040</th>
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<td>12</td>
<td>67</td>
<td>393</td>
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<td>8</td>
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<td>196</td>
<td>819</td>
<td>408</td>
<td>263</td>
<td>256</td>
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</table>
Appendix X. Average density of meroplankton collected hourly at Station 3 from 0.5 m on 8–9 September 1971.
| MEROPLANKTON       | TIME | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 | 0700 | 0800 | 0900 | 1000 | 1100 |
|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Cyphonautes larvae | 2    | 9    | 12   | 18   | 31   | 21   | 12   | 13   | 5    | 4    | 2    | 1    | 1    | 1    | 6    | 17   | 22   | 33   | 91   | 82   | 36   | 1    | 4    | 4    |
| Harmothoe larvae   |      |      |      |      |      |      |      |      |      |      |      |      |      | 2    |      |      |      |      |      |      |      |      |      |      |      |
| Nereis spp. larvae |      |      |      |      |      |      |      |      |      |      |      |      |      | 2    |      |      |      |      |      |      |      |      |      |      |      |
| Spionid larvae     | 4    | 2    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Other polychaete   |      |      |      |      |      |      |      |      |      |      |      |      |      | 2    |      |      |      |      |      |      |      |      |      |      |      |      |
| Anomia aculeata    | 2    | 8    | 10   | 51   | 102  | 94   | 36   | 27   | 14   | 12   | 8    | 7    | 1    | 3    | 14   | 25   | 28   | 187  | 129  | 48   | 1    | 4    | 8    |
| Nereis arctica     | 6    | 19   | 23   | 75   | 24   | 16   | 12   | 7    | 2    |      | 2    | 29   | 32   | 42   | 69   | 54   | 49   |      |      |      |      |      |      |      |
| Mytilus modiolus   | 1    | 1    | 2    | 46   | 22   | 5    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Hiatella arctica   |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Mytilus edulis     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Nudibranch veligers| 3    | 4    | 1    | 5    | 1    | 4    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Prosobranch veligers| 44  | 69   | 89   | 123  | 333  | 166  | 121  | 46   | 42   | 39   | 34   | 14   | 8    | 21   | 99   | 211  | 239  | 261  | 166  | 96   | 26   | 14   | 5    |
| Other umbone veligers| 4   | 8    | 26   | 32   | 27   | 3    | 4    | 3    | 1    | 1    | 1    | 5    | 9    | 29   | 41   | 5    | 6    |      |      |      |      |      |      |      |      |
| Other straight hinge| 1   | 27   | 1    | 1    | 4    | 9    | 1    | 6    | 6    | 21   | 43   | 4    | 3    |      |      |      |      |      |      |      |      |      |      |      |      |
| Zirphaea crispa     | 10   | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Balanus crenatus    | 1    | 2    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Crassostrea       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Megalopsis larvae  |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Zoea larvae        | 1    | 2    | 4    | 4    | 1    | 1    | 1    | 4    | 6    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Fish eggs          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TOTAL              | 456  | 675  | 1371 | 1845 | 4450 | 1511 | 1147 | 803  | 669  | 611  | 544  | 276  | 291  | 399  | 1217 | 1486 | 2058 | 3892 | 1327 | 1382 | 552  | 322  | 181  | 127  |
Appendix Y. Average density of meroplankton collected hourly at Station 3 from 0.5 m on 17-18 November 1972.
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<th>0440</th>
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<th>1740</th>
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