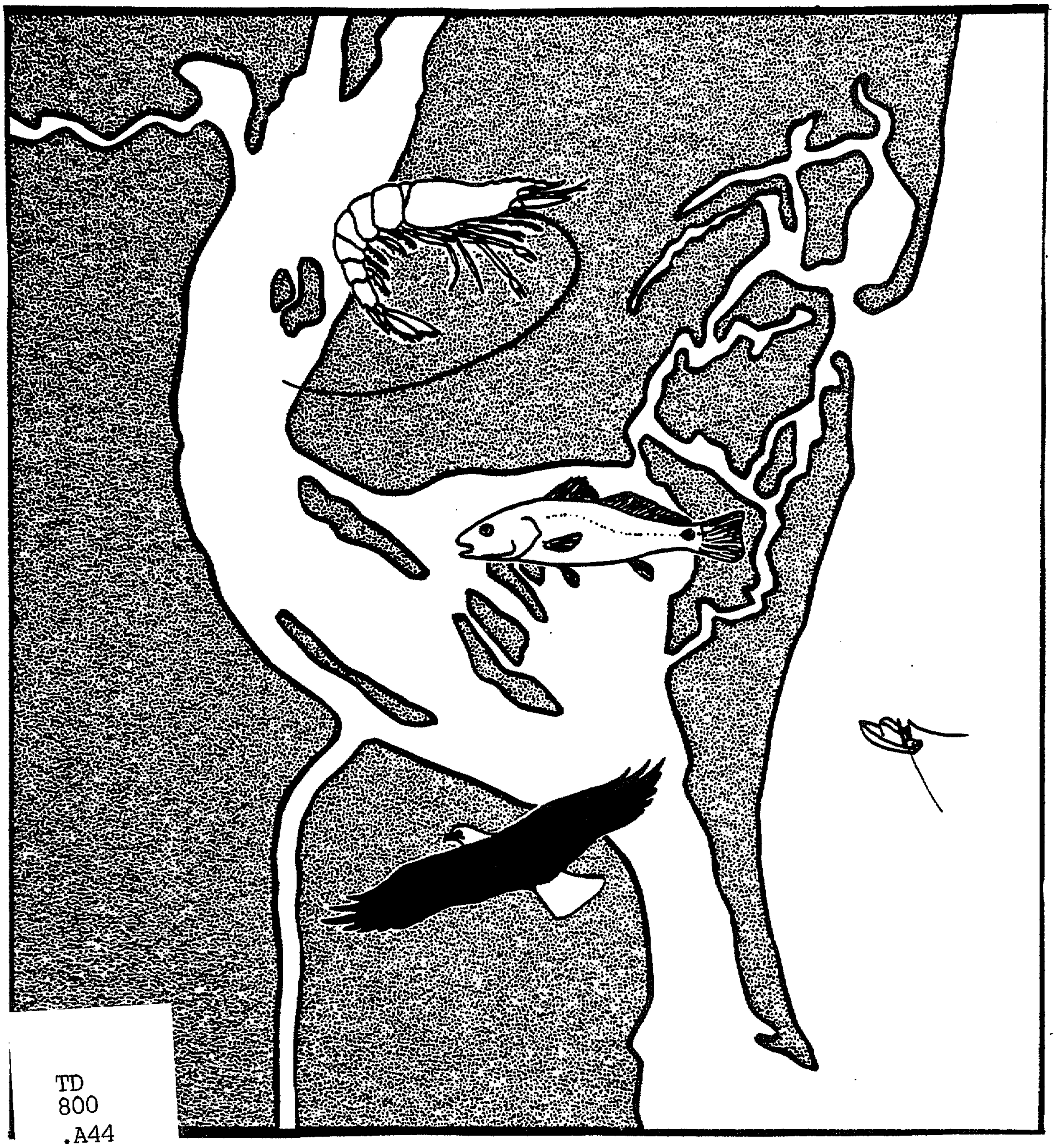
Pollution Ecology of Winyah Bay, SC: Characterization of the Estuary and Potential Impacts of Petroleum

Dennis M. Allen , William K. Michener , and Stephen E. Stancyk



Bel uch Institute for Marine Biology and Coastal Research

University of South Carolina Special Publication No. 84-1

POLLUTION ECOLOGY OF WINYAH BAY, SC: CHARACTERIZATION OF THE ESTUARY AND POTENTIAL IMPACTS OF PETROLEUM

Dennis M. Allen, William K. Michener, and Stephen E. Stancyk

Belle W. Baruch Institute for Marine Biology
and Coastal Research
University of South Carolina
Columbia, SC 29208

Final Report for Phases II and III

March 1984

Funds provided by the National Oceanographic and Atmospheric Administration U.S. Dept. of Commerce, through the Coastal Energy Impact Program (Grant No. NA-81-AA-D-CZ096). Awarded through the Division of Natural Resources, Governor's Office, State of South Carolina.

This report should be cited:

Allen, D.M., W.K. Michener, and S.E. Stancyk, Eds., 1984.
Pollution Ecology of Winyah Bay, SC: Characterization of the
Estuary and Potential Impacts of Petroleum.
Baruch Institute Special Publication No. 84-1
271pp.

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ACKNOWLEDGEMENTS

A study of this magnitude would not have been possible without the help of dozens of individuals who were dedicated to their work. The editors would like to express their special thanks to research specialists Bruce C. Lampright, T. Lance Ferrell, and Elizabeth Haskin for their efforts in making field measurements and processing zooplankton and epibenthic sled collections. Noel Alon also invested a great deal of time in collecting and processing samples and analyzing the zooplankton data. Beth Thomas was a regular member of the sampling team and was involved with data management and manuscript preparation throughout the study. William Johnson processed water samples and aided in the development of the nutrient study.

We also thank Wendy Allen, Doug Baughman, Lee Ann Clements, Mark Luckenbach, and Tom Wolaver for assistance in collecting samples, often under adverse conditions. D. Lynn Barker, Steve Hutchinson, Marvin Marozas, Robert McLaughlin, and Bobbie McCutchen contributed their time and expertise, especially during the analysis of collections and data in the laboratory. Don Caton and Paul Johnson are acknowledged for their keeping trucks, boats, and sampling equipment in operating condition.

We thank Yvonne Coakley and Shelley P. Elmore for typing this report, and F. John Vernberg and Virginia Smith for help in administrating this grant.

This study was funded by the National Oceanographic and Atmospheric Administration, U.S. Dept. of Commerce, through the Coastal Energy Impact Program (grant no. NA-81-AA-D-CZ096). We thank Michael Rowe and Trish Jerman of the Division of Natural Resources, Governor's Office, State of South Carolina for much help and encouragement in conducting this study.

EXECUTIVE SUMMARY

1. Phases II and III of our study of the Winyah Bay Estuary consisted of a series of 33 sampling excursions between September 1981 and September 1982 during which physical, chemical, and biological measurements were made along the salinity gradient. Data were obtained from 14 locations within the estuary. The study was an expansion of phase I of an investigation to characterize Winyah Bay and assess the potential impacts of petroleum pollution on the ecosystem.

2. Analyses of water samples indicated that concentrations of all nitrogen compounds (NO_3, NO_2, NH_4, TN) were consistently highest in the upper bay and decreased as a function of increasing salinity toward the ocean. A similar pattern was observed for phosphorus compounds. Concentrations were highest in winter when riverine inputs were greatest and utilization by phytoplankton was lowest. Previous studies have demonstrated that concentrations of nutrients in estuarine water are reduced in the presence of oil. Oiled sediments most likely affect rates of mineralization.

3. Phytoplankton production was lowest in the rivers and highest in the middle bay. A distinct seasonal trend with maximum phytoplankton activity in summer and minimum in winter was observed. Planktonic diatoms and dinoflagellates are generally less abundant in low salinity areas of estuaries, and the flushing activity of the freshwater input limits local populations. High chlorophyll concentrations in the middle bay are probably related to high nutrient densities and circulation patterns which encourage retention and production. The source of phytoplankton in the lower bay was the ocean. Effects of oil on phytoplankton are generally minimal once soluble (toxic) fractions leave the water column; however, indirect effects as a result of changes in nutrient availability and herbivore grazing pressure may have long term repercussions for the ecosystem.

4. Copepods were the dominant zooplankters throughout the estuary during all seasons. Maximum densities in excess of 10,000 individuals per cubic meter occurred during the warm months. *Acartia tonsa*, the most abundant species, dominated intermediate salinity areas. Other major species originated from the ocean and became more abundant in the middle bay as salinities increased. High salinity (marine) copepods were almost never present in the upper bay and several species of freshwater copepods rarely occurred seaward of the upper bay. Although copepods including *A. tonsa* may be eliminated by soluble toxic chemicals during an oil spill, they appear to be relatively tolerant of petroleum compounds in the water column and can quickly repopulate an area. Responses of copepod populations to oil pollution are highly variable and long term effects are not well understood.

5. Temporary members of the zooplankton including larvae of crustaceans, polychaetes, mollusks, and fishes were the most important constituents of the community during the warm months. Highest densities were near the ocean and many species were confined to high salinity, lower bay areas. Crab zoeae and barnacle larvae were sometimes abundant in the upper bay. Most of these developmental stages only occur for periods of days or weeks and may represent the entire year's reproductive effort of short lived estuarine species. Larval stages of invertebrates and fishes are often more sensitive to oil pollution than adults. A spill during a period of peak reproduction is likely to have major and long lasting effects on certain populations.

6. Amphipods, mysids, cumaceans, isopods and other small crustaceans which live on or near the bottom were widely distributed throughout the estuary, but highest diversity was near the ocean and highest densities were usually in the middle bay. Amphipod populations were consistently high in some rivers. Permanent members of the motile epibenthos are particularly susceptible to chronic oil pollution since oil accumulates at the sediment surface where these animals feed and reproduce. Long term reductions in these populations would result in loss of primary foods for juvenile fishes.

7. Shrimp, crab, and fish larvae comprising the motile epibenthos occurred throughout Winyah Bay, and their abundance was highly variable. Postlarval penaeid shrimp and dozens of commercially important species of larval fishes were most abundant during the warm months, especially in the middle bay. Relatively low densities of epibenthic larvae utilized upper estuary habitats. Due to patchy distribution, high motility, and preference for shallow marsh fringes and creeks, densities of larvae in epibenthic sled collections were large underestimates of the populations utilizing the estuary as a nursery area. Since most of these forms feed at the bottom, they would be very susceptible to post-spill or chronic oil pollution which results in oiled sediments. Fisheries would be adversely affected over long periods as a result of the destruction of larval forms and nursery habitats.

8. A major spill in the upper bay would have a less severe immediate impact on the organisms in the water column than a similar spill in the middle or lower bay; however, residuals from an upper bay spill would probably have a more severe long term effect. High densities of fine sediment particles which characterize the upper region of Winyah Bay would result in the rapid incorporation of oil into the sediments. Similarly, chronic discharges of relatively low concentrations of petroleum in the Sampit River would also result in oiled sediments. Microbial decomposition rates would probably not be sufficient to inactivate oiled sediments before they were redistributed by currents or runoff from spoil areas to the middle bay.

9. Circulation patterns within the estuary indicate that Mud Bay and other shallow backish areas in the middle bay would be a final destination of spilled oil (slick) and oiled sediments originating from an accident or chronic imputs in the upper bay. Since this region is also the location of highest overall phytoplankton, zooplankton, and larval fish production, severe ecological consequences would be inevitable. The presence of large intertidal marshes, vast shallow fine grained mudflats, and creeks which exchange water with the pristine North Inlet system suggest that a spill or the accumulation of polluted sediments in the middle bay would have the most severe impacts on the ecosystem as a whole.

10. Although the probability of a major oil spill in Winyah Bay is not high, it is likely that one or more significant spills would occur during the lifetime of a refinery. A major spill would have a devastating effect on the ecosystem. Regardless of whether or not a major spill occurs, chronic discharges of petroleum and refined products into the water and air would be allowed by law and would continue as long as the refinery was in operation. The presence of toxic petrochemicals in the refinery effluent, the accumulation of an oily sludge on the bottom, and the reduction of dissolved oxygen levels in the Sampit River will contribute to the degeneration, displacement, or elimination of plant and animal populations in the Sampit River and, eventually, other sections of Winyah Bay.

CHAPTER 1. ESTUARINE ECOLOGY AND THE SCOPE OF THE STUDY.

Coastal areas where significant amounts of freshwater runoff meet the sea are known as estuaries. Formally defined, an estuary is a semi-enclosed coastal basin which has an open connection to the ocean and within which saltwater is measurably diluted by freshwater. Major fluctuations in the volume of freshwater inflow coupled with more regular variations in tidal amplitude result in complex circulation patterns. Nutrients, organic materials, and sediments introduced from both the rivers and the ocean are distributed according to highly variable and complex current patterns. Patterns are difficult to describe because of the dynamic nature of the system and restrictions on the number of measurements that can be taken within any one combination of space and time. The motility of animals renders patterns of organism distribution within the estuary more difficult to describe than those for passive materials. Despite the dynamic character of an estuary such as Winyah Bay, there are distinct relationships between constituents of a parcel of water and its salinity. Changes in nutrient concentrations and small organism abundance can often be explained by changes in salinity. These relationships enable us to characterize an estuary in sufficient detail to be able to assess the potential impacts of pertubations such as oil pollution.

This study was developed: (1) to establish baseline information on specific physical, chemical, and biological characteristics of the Winyah Bay Estuary, (2) to determine the associations between the abiotic and biotic characteristics of the system, and (3) to assess the potential impacts of energy related development on organisms which inhabit Winyah Bay. The study represents the second and third phases of a three year field oriented research program. Results of the first phase were published in a report entitled: Ecology of Winyah Bay, SC and Potential Impacts of Energy Development (Allen et al., 1982). In that report, we described sampling programs and presented results of studies at No Man's Friend and South Jones Creeks. During the first phase, we also made collections along the axis of Winyah Bay. The second phase of our program involved an expansion of the initial set of sampling sites along the salinity gradient in Winyah Bay. The original series of six stations were sampled over a 28 month period, with five additional sites being added in the second year. At each sampling location, a complete set of physical measurements, water samples, and biological collections were made. Chemical analyses were conducted to determine nutrient concentrations, and chlorophyll was measured to determine the density of microscopic plants (phytoplankton). Microscopic animals were collected in the water column with fine mesh nets and somewhat larger, but still less than half inch long, organisms were collected near the bottom. The catch included the developmental stages of almost all commercially and recreationally important shrimps, crabs, and fishes as well as the small organisms upon which adults of these species prey.

The third phase of the project consisted of a series of short term field studies designed to investigate the magnitude of variability in physical, chemical, and biological components measured at one location over one or more tidal cycles.

The techniques used to collect and process samples during the second and third phases of this study were, in most cases, identical to those used in the first phase. In our first report, we provided many detailed descriptions and diagrams of the organisms that were collected in fine mesh nets. Only general information is used to preface the results of the analyses in this report. We hope that the interested reader will review and consult the appropriate section of the previous report.

During the second and third phases of our study we made approximately 280 sets of physical measurements, 570 zooplankton collections, and 480 epibenthic sled collections. Many hours were involved in the field collection, laboratory processing, and subsequent computer-aided analysis of <u>each</u> collection. Although hundreds of hours of effort have already been spent on data management and statistical analysis of this huge data set, the treatment of the results at this time is considered preliminary. This report contains several chapters which describe general trends which were determined by tabular and graphical comparisons of mean values. The final chapter presents a synthesis of the physical, chemical, and biological trends established during the two year study. It is important for the reader to recognize that only general patterns and associations are described in this report and that sophisticated statistical techniques are being developed to explore these interactions in more detail. The results of these analyses will constitute formal scientific publications during the next several years.

The vast size of Winyah Bay and the large variability characteristic of all measured components places limitations on the degree to which the estuary can be studied. The network of 14 regular stations was established to generate information on the differences between major habitat types, yet at least that many more different habitats occur within the system. We concentrated on subtidal habitats representing the most dominant bottom types along the salinity gradient. Productive intertidal and shallow subtidal habitats were not sampled. With the amount of technical help available, it was not possible to study benthic, fouling, or fish communities within Winyah Bay. Our focus was on the abundant small organisms which are close to the base of the estuarine food web. Even with these restrictions, the number of collections that we were able to make was limited by the rate at which we could process them in the laboratory. Nevertheless, sufficient information was generated to develop a description of the spatial and seasonal distributions of key zooplankton and motile epibenthic taxa. Several special short term studies were conducted to determine vertical distribution or patchiness near the bottom and to provide insight into the behavior of these organisms relative to tidal currents and salinity regimes.

The first report included a thorough review of scientific literature dealing with the effects of petroleum and refined fractions on estuarine organisms. Rather than repeat this effort, we have developed a final chapter in which we integrate our understanding of the physical, chemical, and biological characteristics of Winyah Bay with the known effects of oil pollution. Chronic and acute effects on the biota are assessed for the upper, middle, and lower bay. Particular emphasis is placed on effects on early life stages of fishes, crabs, and shrimps which utilize estuarine areas for nursery grounds. We believe that this is a realistic interpretation of the situation and hope that it will be useful in evaluating society's impact on Winyah Bay and determining the future of this estuary.

CHAPTER 2. THE STUDY AREA

A. Winyah Bay Estuary

The area considered in the present study includes the waterways and marshes which comprise Winyah Bay, South Carolina. Winyah Bay is one of the major estuarine ecosystems in the southeastern United States.

The axis of Winyah Bay is roughly oriented in a northwest-southeast direction (Fig. 2-1). The estuary is narrowest near its confluence with the ocean (0.8 miles) and widest in the center (4.2 miles). At the upper end of the bay where the two major rivers converge, the width is about 1.2 miles. Prominant features of Winyah Bay include the long rock jetties which project more than a mile into the ocean from North and South Islands, several large islands within the bay, and a large shallow midsection known as Mud Bay. Winyah Bay has a mean depth of only 15 ft. (4.2 m) and many hectares of open waterways are less than 6 ft. (2 m) in depth. A 27 ft. (8.2 m) ship channel runs along the axis of the bay from the end of the jetties to Georgetown Harbor. Details of the bathymetry of Winyah Bay are available from Coast and Geodetic Survey navigation map No. 787 and several U.S. Army Corps of Engineers documents (e.g. Trawle, 1969).

The entire Winyah Bay watershed is approximately 18,000 square miles (sq. mi.). Four major rivers drain into the system. More

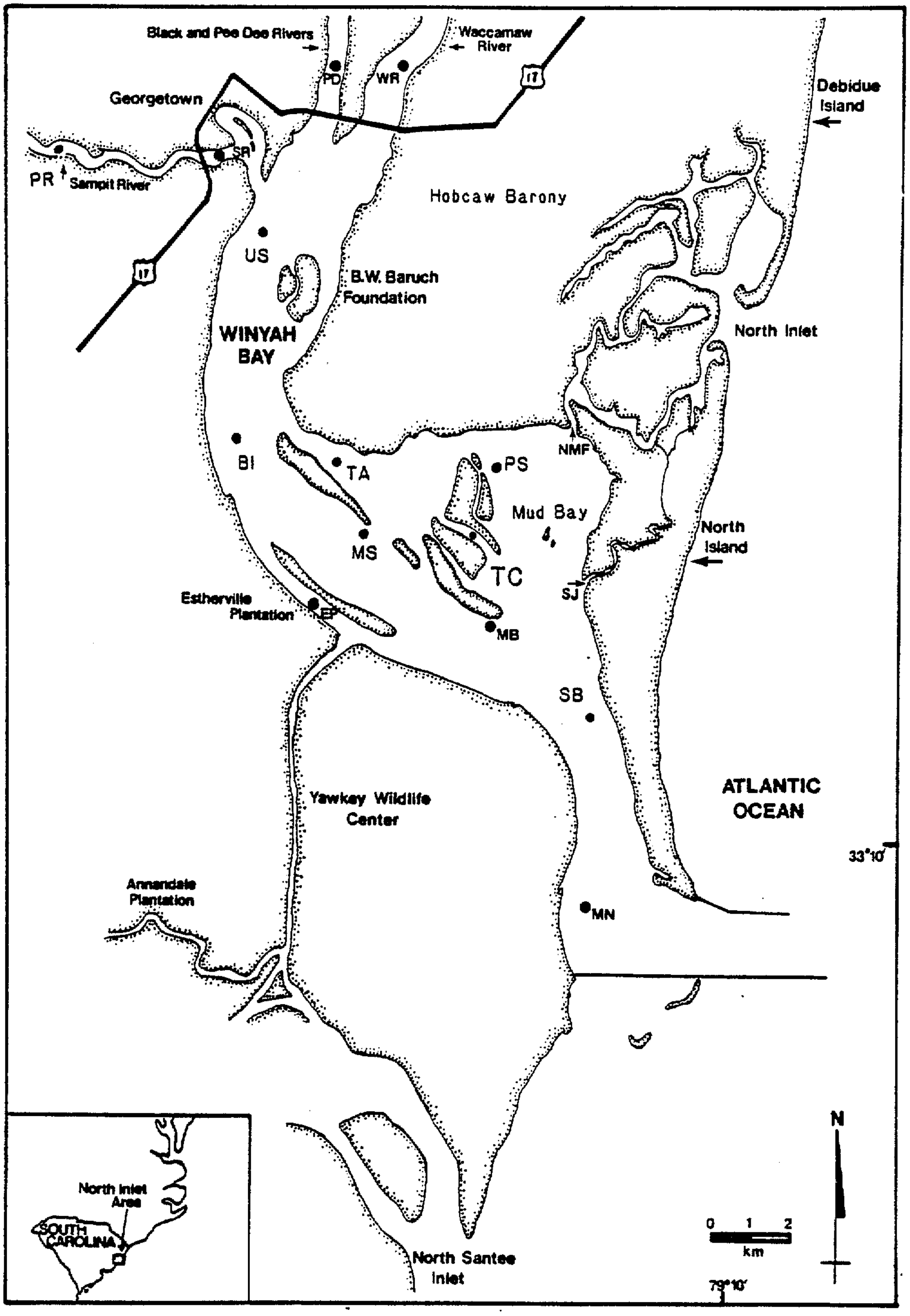


Figure 2-1. Location of sampling sites in Winyah Bay, SC. No Man's Friend (NMF) and South Jones (SJ) Creeks were the major study areas for Phase I of the study. Fourteen other stations were sampled during Phases II and III. They are described in Chapter 2 of this report.

Table 2-1. Locations, geomorphological characteristics, and salinity range for 14 stations in Winyah Bay which were sampled between August 1980 and September 1982.

STATION ABBREVIATION	LOCATION (LAT. - LONG.)	DEPTH (METERS) AT MLW	SEDIMENT TYPE	SALINITY RANGE (°/oo)
PR	33° 21' 44" N 79° 20' 18" W	6.2	Firm Mud/Clay	0-11.7
SR	33° 21' 28" N 79° 17' 10" W	8.0	Soft Mud	0-19.3
PD	33° 22' 29" N 79° 15' 40" W	3.0	Firm Mud/Clay	0-14.0
WR	33° 20' 30" N 79° 14' 45" W	9.5	Firm Mud/Clay	0-12.4
US	33° 20' 40" N 79° 16' 40" N	6.4	Sandy Mud	0-17.3
BI	33° 18' 42" N 79° 16' 57" W	6.7	Sandy Mud	0-22.0
TA	33° 17' 40" N 79° 15' 20" W	1.0	Mud	0-17.7
PS	33° 17' 30" N 79° 13' 28" W	0.8	Soft Mud	0-23.6
MS	33° 16' 20" N 79° 14' 22" W	5.0	Sandy Mud	2.7-32.4
TC	33° 17' 0" N 79° 13' 40" W	4.2	Sandy Mud	0-23.4
EP	33° 16' 7" N 79° 16' 17" W	4.5	Sandy Mud	2.0-30.6
MB	33° 15' 28" N 79° 13' 16" W	3.9	Muddy Sand And Shell	1.8-31.7
SB	33° 14' 36" N 79° 11' 40" W	4.2	Sand And Shell	3.8-33.9
MN	33° 12' 6" N 79° 11' 17" W	3.6	Sand And Shell	21.5-35.3

than 16,000 sq. mi. of this drainage area is associated with the Pee Dee-Yadkin River system which originates in the Blue Ridge Mountain area of North Carolina. Water from this area flows across the piedmont region of both North and South Carolina, over the coastal plain of eastern South Carolina,and into Winyah Bay through the Pee Dee River. The Waccamaw River also receives water from the Pee Dee as the poorly defined, shallow, wide, swampy waterways merge upstream of the Highway 17 bridges. The Black and Sampit Rivers drain much smaller watersheds. Other characteristics of these watersheds are given by the Conservation Foundation (1980).

According to Johnson (1972), the freshwater input to Winyah Bay Estuary ranges from 2000 to about 100,000 cubic feet per second (cfs), and mean runoff is approximately 15,000 cfs. Superimposed on this unidirectional freshwater flow toward the ocean is the regular semi-diurnal tidal pattern. Mean tidal amplitude is on the order of 4.6 ft. at the ocean end of Winyah Bay and 3.3 ft. at the Sampit River (5.4 ft. and 3.9 ft. on spring tides, respectively; Trawle, 1969). A salt wedge effect occurs as heavier salt water moves upestuary along the bottom with a flooding tide, even though the overlying freshwater may be flowing toward the ocean. During periods of low freshwater inflow, flooding tides move salt water more than 15 miles upstream of the Highway 17 bridges, but under average river flow, the penetration is usually within a mile of the bridges. Differences between surface and bottom salinities during these periods may be more than 20 ppt. Corps of Engineers (Trawle, 1969) measurements indicate that while surface waters are usually 29-32 ppt near the ocean entrance during most flow conditions, surface salinities in Georgetown Harbor range from about 0-10 ppt. Salinity patterns in the mixing zone between these ends of the system are highly variable as a result of changing freshwater inflow, tidal amplitude, wind conditions, and bottom topography. Further information on the hydrography of Winyah Bay is available in Trawle (1969), Johnson (1970), and Bloomer (1973).

Almost the entire shore of Winyah Bay is vegetated by marshes. Approximately 31,867 acres or 12,747 hectares of marsh are associated with this estuary. More than 77% of these marshes are regularly flushed through tidal action; the remaining 13% are impounded (Tiner, 1977). Some 80% of the marshes are vegetated by freshwater plants while most of the other 20% is inhabited by the brackish water grass (*Spartina cynosuroides*) and black rush (*Juncus roemerianus*). Of the 17 estuarine systems in South Carolina, Winyah Bay is most important in terms of freshwater marshes. In fact, about 35% of the state's freshwater marshlands occur here (Tiner, 1977). Relatively small stands of salt marsh cordgrass (*Spartinia alterniflora*) occur near the entrance of Winyah Bay, and a narrow band occurs adjacent to major waterways upstream to the middle bay.

B. Sampling Locations

Phases II and III of the Winyah Bay Study elucidated spatial and temporal patterns of the physical, chemical, and biological components of the estuary. A total of 14 sampling sites were visited on a regular basis. Their locations are shown in Figure 2-1.

Station location (latitude-longitude), depth, sediment type and salinity range are given in Table 2-1. Additional information on salinity patterns is presented in Chapter IV.

The Pennyroyal Creek (PR) station was located in the Sampit River several hundred meters downstream of the confluence with Pennyroyal Creek. Tows were made parallel to the marsh shoreline on the south side of the axis of the river. The bottom was relatively flat and composed of firm muds and clays. Current velocities were slow to moderate, but detrital accumulations on the bottom were low. Salinities were generally less than 5 ppt, but values to 12 ppt were recorded. There were no significant differences between surface and bottom salinities on any cruise.

The Sampit River (SR) station was downstream of the Highway 17 bridge and adjacent to the SC Ports Authority Terminal. Measurements were made at the south side of the turning basin and sled tows were along the ship channel toward the mouth of the river. Sediments were soft muds, and currents were generally moderate to slow. Salinities ranged from 0 to 19 ppt on the bottom, and bottom salinities were up to 10 ppt higher than surface values.

The Pee Dee River (PD) station was located approximately 1.3 km north (upstream) of the Highway 17 bridge. Water column measurements were made near mid channel. This area was the shallowest of the upestuary stations, and the bottom was characterized by high concentrations of marsh and terrestrial debris. Current velocities were moderate. Salinities were similar to those at other river stations; bottom salinities reached a maximum of 14 ppt. Surface and bottom values did not differ by more than 5 ppt on any cruise.

The Waccamaw River (WR) station was also situated about 1.3 km north of the Highway 17 bridge. Samples were collected near mid-channel in a large depression or basin which was more than 10 meters deep. The mud-clay bottom was usually free of organic detritus. Salinities were lower than those at PD on most cruises. Maximum bottom salinity was about 12 ppt and surface-bottom differences were less than 6 ppt.

The Upper Station (US) was located in Winyah Bay on the eastern side of the ship channel just downstream of the mouth of the Sampit River. Water samples were collected upstream of navigation marker "28", and sled tows were parallel to the channel upstream of this location. Current velocities in this area were stronger than at any of the river stations. The bottom was relatively hard. Salinity regimes were similar to the SR station with distinct stratification apparent during most cruises.

The Belle Isle(BI) sampling site was on the eastern side of the ship channel just upstream of the point where the channel curves to the southeast at Frazier Point. Water samples were taken near marker "24" and tows were made between markers "24" and "26". Moderate to strong currents and a hard clean bottom were typical. Salinities at the bottom ranged from 0 to 22 ppt and surface values were up to 10 ppt lower than bottom values on some cruises.

Thousand Acre (TA) station was situated adjacent to the western creek draining Thousand Acre marsh on Hobcaw Barony. This shallow soft bottom area usually had high accumulations of marsh detritus. Currents were low to moderate. Salinities were as variable between cruises as the other upestuary stations, but no significant stratification was apparent. Bottom values ranged from 0 to 18 ppt.

Pumpkinseed (PS) station was located in Mud Bay about 1 km west of the mouth of No Man's Friend Creek. The station was in shallow water at least 100 m from the eastern shore of the Marsh Islands. The sediment and current characteristics were similar to those at TA, but salinities were somewhat higher. The range at PS was from 0 to 24 ppt. No differences between surface and bottom salinities were observed.

Middle station (MS) was located on the eastern side of the ship channel near marker "20". Water samples were taken near the marker and net tows were toward marker "18". The sediment was a hard sandy mud, but detrital accumulations were often high on this side of the channel. Salinities ranged from 8 to 32 ppt on the bottom, but surface salinities were always much lower, sometimes by as much as 20 ppt.

The Cut (TC) is a northwest-southeast oriented channel which runs between the Marsh Islands. The channel lies between Mud Bay and the ship channel. Water column measurements were made midchannel where currents were moderate. Sediments were firm and detrital accumulations were low. Salinities ranged from 0 to 23 ppt on the bottom and differences between top and bottom were less than 4 ppt.

The Esterville Plantation (EP) station was located in the western channel just above the Intracoastal Waterway channel which connects Winyah Bay and the Santee System. Collections were made about midway between the mainland at Esterville Plantation and the large marsh island. The bottom was firm sand mud, and moderate to strong currents limited detrital accumulations in this area. Salinity ranges for both surface and bottom were from 2 to about 26 ppt. Bottom salinities were sometimes up to 20 ppt greater than at the surface.

The Mud Bay (MB) sampling site was on the eastern side of the ship channel across the channel from marker "17". Water samples were taken at the edge of the channel where current velocities were moderate to strong. The bottom was sandy and firm with little detritus. Salinities ranged from 4 to 33 ppt and differences between surface and bottom were as large as 11 ppt.

Shell Bank (SB) station was located between the shore of North Island and the small spoil islands east of the ship channel. This is upestuary from channel marker "16". Currents were often strong and the bottom was more irregular than at any of the previously described stations. Shell debris was common in sled tows. Salinities ranged from 6 to 34 ppt on the bottom, and there was usually little difference between surface and bottom.

Mother Norton (MN) Shoal station was the most seaward of the 14 stations. The samples were taken on the southern side of the ship channel near the base of the south jetty on South Island. Tows were parallel to the channel and seaward of marker "11". The bottom was entirely sand and subject to major changes between cruises as a result of strong tidal currents. Salinities at the bottom were always greater than 30 ppt and the lowest surface measurements were about 22 ppt. Surface-bottom differences were as great as 11 ppt.

CHAPTER 3. THE SAMPLING PROGRAM: METHODS AND MATERIALS

The field sampling program designed for the second phase of the Winyah Bay Study consisted of five major series. These series will be described in detail in this section following a description of the methods used for sampling the physical, chemical, and biological components of the estuary. Most of the physical-chemical, zooplankton, and epibenthic sled sampling procedures were similar to those described in our previous report on the first phase of the Winyah Bay Study (Allen et al., 1982).

A complete set of physical measurements was taken at each station on each cruise. Multiple sets were taken at each station on certain cruises so that changes in animal abundance could be related to changes in several characteristics of the water column. Water temperature, conductivity, and salinity were measured at increments of one meter from surface to bottom with a Bechman RS-5 induction salinometer. Water depth was determined from the weighted, calibrated probe cable on the salinometer. Vertical visibility was measured with a 25 cm diameter Secchi disk on daylight sampling cruises. Current direction and meterological conditions were recorded in conjunction with the temperature-salinity measurements. On the short-term sampling series, tidal current velocity was measured with a Teledyne Gurley vane type current meter.

During all cruises, water samples were collected for chemical nutrient and plant pigment analyses. A one liter water sample was collected from about 30 cm below the surface and 30 cm above the bottom with a Niskin-type cylindrical sampler which could be closed with a sliding messenger once the sampler was situated at the proper depth. Once the sample was collected, a 3 ml unfiltered volume was pipetted into a prewashed culture tube and a 15 ml sample was filtered (Gelman glass fiber filter, Type A/F, 25 mm), preserved with two drops of mercuric chloride, and stored in acid washed vials. After this field processing, the samples were frozen on dry ice and returned to the laboratory for analysis.

In the laboratory, nutrient concentrations were determined on a Technicon Auto Analyzer II. Filtered samples were used for the analysis of orthophsophate and (nitrate and nitrite) nitrogen. The basic method for analysis of orthophosphate followed that of Murphy and Riley (1962) as modified in Technicon Industrial Method No. 155-71W (1973) and described by Glibert and Loder (1977). The basic method for analysis of (nitrate and nitrite) nitrogen followed that of Technicon Industrial Method No. 158 71W (1972) as described by Glibert and Loder (1977). Unfiltered samples were used for the determination of total nitrogen and total phosphorous. Analysis was performed on a Technicon Auto Analyzer II and followed the basic procedure suggested by D'Elia et al., (1977) as modified by Edwards (unpublished).

Concentrations of chlorophyll a and phaeo-pigments were also determined from the bottom and surface water samples. From the one liter samples, 20 ml was pipetted to a filtration apparatus consisting of Gelman glass fiber filters (type, -A/E, 25 mm). The filters were placed in scintillation vials that were prewashed in 90% acetone. Saturated magnesium carbonate solution (1 ml) was added and the vials were frozen in the field.

In the laboratory, 9 ml of 100% acetone were added to the frozen samples resulting in a 90% acetone extraction solution. The samples were periodically agitated and stored at 5°C for 24 hours. A Turner flourometer was used to determine chlorophyll a and phaeo-pigments according to the method of Yentsch and Menzel (1963). Further information on the procedure is found in Holm-Hansen et al. (1965) and Strickland and Parsons (1972).

During the special chemistry transect and the 48 hour zooplankton series, water samples were analyzed for total and dissolved carbon, total dissolved phosphorus, total dissolved nitrogen, and ammonia (NH_4) in addition to the other parameters previously discussed. Two 15 ml samples (one filtered) were stored in acid-washed scintillation vials and refrigerated until they could be analyzed for dissolved and total organic carbon. Two 3 ml filtered samples were pipetted into pre-washed culture tubes and frozen on dry ice (for total dissolved nitrogen and total dissolved phosphorus). One 15 ml filtered sample was preserved with one drop of phenol and refrigerated for future ammonia analysis.

Analysis of total dissolved nitrogen and phosphorus was conducted on a Technicon Auto Analyzer II and followed the alkaline persulfate procedure as outlined by Gilbert et al. (1977). Ammonia analysis was also conducted on the Auto Analyzer and followed the "Berthelot reaction" method (Fiore, and O-Brien, 1962). Carbon samples were analyzed with a Beckman carbon analyzer (Model 915A) according to procedures recommended by the American Public Health Association (1981).

A variety of sampling gear and techniques were used to collect microscopic organisms in the water column. Three basic types of zooplankton nets were used. One set of nets consisted of 30 cm diameter ring nets. These nets were towed against the current for a total of 90 seconds. Boat speed was increased every 30 seconds so that samples could be collected for about 30 seconds at each of three levels (bottom, middle, and upper) of the water column. These collections, known as oblique tows, were used to obtain samples which represented the entire water column.

Another type of apparatus used to collect zooplankton was a square mouthed opening-closing net. These nets were deployed from an anchored boat during periods when tidal currents were sufficiently strong to push water and animals into the nets. To obtain a bottom sample, the apparatus would be lowered to the bottom, lifted up about 20 cm, and opened by means of a sliding messenger. On nets rigged with a double trip device, a second sliding weight was used to close the mouth of the net before hauling back to the surface. A surface sample was taken with the net mouth centered about 50 cm below the surface. Collections were made with both 153 μm and 365 μm mesh Nytex nets. All nets were fitted with General Oceanics Model 2030 torpedo type flowmeters to measure the volume of water filtered during the collection. Tows were usually for 90 seconds, but on some occasions, nets were set up to four minutes so that enough water would be filtered to yield a meaningful sample. Two sets of nets were usually deployed at the same time and place in order to assess the degree of patchiness in the water column.

When the collection was removed from the net, it was placed in a labelled jar and preserved in a 10% borax buffered formalin solution with rose bengal stain. In the laboratory, a 2 ml subsample was taken from each collection and examined under a microscope. Copepod crustaceans, which generally dominated the samples, were identified and counted to species. Other organisms were assigned to one of more than 50 other taxonomic categories. It usually took a trained technician about two hours to process a single zooplankton sample on the microscope. A complete list of zooplankton categories which occur in Winyah Bay was presented in Allen et al., 1982.

Small motile organisms including early developmental stages of fishes, crabs, and shrimps were collected with an epibenthic sled. This apparatus consisted of a steel frame which oriented a rectangular (51 X 30 cm) net mouth perpendicular to the bottom. A set of skis enabled the frame to be towed just high enough off the bottom so that the device did not dig into the substrate. Thus, small animals within 30 cm of the bottom would be swept into the

365 μm mesh net as the device was towed behind a boat. Occasionally, a second net which collected animals 30-60 cm above the bottom was mounted above the net which sampled on the 0-30 cm zone. The sleds were fitted with the flowmeters identical to those used in zooplankton nets. Tows were usually for six minutes in the direction that the tidal current was moving. Landmarks were used to identify the same tow path on each cruise. Two or three collections were made in each combination of time and space to provide replicate samples. Samples were removed and preserved on board. In the laboratory, entire samples were processed unless large volumes of detritus or organisms required that the sample be split. At least 12.5% of each sample was counted. Each collection required about two hours of processing time on the microscope. Details of the taxonomic categories for the zooplankton and motile epibenthos are given in other sections of this report.

A. Extensive Series

The first series of collections in this second phase of the Winyah Bay Study is referred to as the Extensive series. This series of seven cruises was an extension of the series of nine cruises completed between August 1980 and August 1981. The six stations (SR, PD, WR, MB, EP, and MN) sampled during the first phase were visited again during the second phase, and starting in September 1981 an additional six stations (PR, TA, BI, TC, PS, and SB) were sampled in the same manner. The dates on which the extensive stations were visited are listed in Table 3-1.

TABLE 3-1 Sampling dates for the Extensive and Intensive Series in Winyah Bay

Cruise dates: Extensive Series

September 29 and 30, 1981
November 31 and December 2, 1981
January 25 and 26, 1982
March 25 and 26, 1982
May 25 and 26, 1982
July 27, 1982
September 22, 1982

Cruise dates: Intensive Series

September 28, 1981
November 30, 1981
January 27, 1982
March 24, 1982
May 24, 1982
July 26, 1982
September 21, 1982

On each of the extensive cruises, single observations were recorded for atmospheric conditions, current direction, secchi visibility and depth at each station. Then a water temperature and salinity profile was taken. Water samples were collected from surface and bottom and later analyzed in the laboratory for total nitrogen, nitrate/nitrite, total phosphorus, orthophosphate, chlorophyll a, and phaeopigments.

Zooplankton collections were made with both 153 μm and 365 μm nets at each station. Two simultaneous 90 second oblique tows were made with each mesh size.

Two sequential six minute epibenthic sled tows were made with another boat at the same time that the zooplankton tows were being collected.

B. Intensive Series

This series of seven cruises was conducted during the same week as the extensive series, but the sampling plan on this series examined differences in the chemistry and biology at the surface and bottom. On the intensive cruises, more measurements were made at each station so that only three stations (one each in the lower (MN), middle (MS), and upper (US) portions of the estuary) were visited on that day. The cruise dates are given in Table 3-1.

At each station single observations were made for atmospheric conditions (air temperature, wind direction and speed, cloud cover), secchi visibility, depth, and current direction. Water temperature and salinity were recorded at one meter increments. Water samples were collected at the surface and bottom and later analyzed for total nitrogen, nitrate/nitrite, total phosphorus, orthophosphate, chlorophyll a, and phaeopigments.

A set of eight zooplankton collections was taken with opening-closing nets at each station. First, two simultaneous 153 μm mesh collections were taken at the bottom, then two simultaneous 153 μm mesh collections were taken at the surface. Two simultaneous 365 μm mesh collections were then made at the bottom and followed with a pair at the surface. All tows were made with moderate to strong ebbing tides and lasted about 90 seconds.

A set of twelve epibenthic sled collections was taken from another boat at the same time the zooplankton samples were being collected. Two sequential three minute tows were followed by two simultaneous three minute tows. Then, the same procedure was followed to obtain six minute and nine minute collections. All tows were in the direction of the ebbing tide and originated from the same starting point adjacent to the stationary zooplankton boat. The tows were approximately 300, 600, and 900 meters in length for the 3, 6, and 9 minute collections respectively.

C. 48 Hour Zooplankton Series

This special series was collected from September 18 (1000 hr) to September 20 (1200 hr), 1982 at the Mother Norton Shoal (MN) station near the mouth of Winyah Bay. Physical measurements and water samples were collected every hour for the 48 hour study. Wind conditions, air temperature, secchi visibility, and depth were recorded. Surface and bottom temperature, conductivity, salinity, and current velocity were measured. Water samples taken from the surface and bottom every hour were later analyzed for total nitrogen, nitrate/nitrite, ammonia, total dissolved nitrogen, total phosphorus, orthophosphate, total dissolved phosphorus, total organic carbon, total dissolved organic carbon, chlorophyll a, and phaeopigments.

Zooplankton collections were made with 153 µm opening-closing nets. Simultaneous collections were made at the bottom, then the surface from an anchored boat every two hours. Tow duration was estimated from a pre-collection flowmeter test to assure that sufficient time was allowed to filter a minimum volume of water. Most collections were for three minutes.

Laboratory analyses of the samples were similar to those used in the other series. Only dominant copepods were enumerated to the species level. Other copepods and meroplanktonic forms were counted at higher taxonomic levels.

D. Special multi-level epibenthos series

On September 17, 1982, organisms susceptible to capture in 365 µm mesh nets were sampled at the Mother Norton Shoal (MN) station. The complex sampling program was designed to allow comparisons: (1) between catches at the surface and bottom, (2) between single level sleds, double level sleds, and opening-closing nets, (3) between slow, moderate, and high velocity tidal currents, and (4) between passive (from a stationary boat) tows, with-the-tide tows, and against-the-tide tows.

During the 8 hr cruise, secchi visibility, water temperature, salinity, and current direction and velocity were measured at three levels. Measurements were made at 30 cm below the surface, middepth, and 90 cm above the bottom during each of the three stages of the tide.

All net collections were six minutes long. At each of the three tidal stages the following sequence of collections was made;

Stage 1 Boat 1: simultaneous double level sleds from an anchored position

Boat 2: simultaneous closing nets at bottom from an anchored position

Stage 2 Boat 1: simultaneous double level sleds towed against the tide

Boat 2: simultaneous closing nets at surface from an anchored position

Stage 3 Boat 1: simultaneous double level sleds towed with the tide

Boat 2: single sled towed with the tide

Stage 4 Boat 1: simultaneous single sleds towed with the tide

Boat 2: single sled towed with the tide

The first set of samples was taken around slack high tide in the morning. The four stages took approximately one hour to complete.

The second set started about an hour and one half after high tide and the last set started about two and one half hours into the ebb tide when tidal current velocities reached a maximum.

E. Special Chemistry Transect Series

These seven cruises were done during the same weeks as the extensive and intensive cruises. Sampling was initiated at Mother Norton Shoal (MN) near slack flood tide and samples were collected at stations along the ship channel in Winyah Bay. The first collection (at MN) was at the highest salinity station (usually about 34 ppt) and subsequent collections were made at locations where the salinity was 5 ppt less than at the previous station. Due to the highly variable nature of the salinity regime in the estuary, the number of stations sampled on each cruise was not consistent. Table 3-2 summarizes the sampling program and shows that during periods of maximum freshwater inflow (e.g. January) all collections were made within Winyah Bay. During low flow conditions, a number of stations were sampled upstream of the Highway 17 bridges in the Pee Dee and Waccamaw Rivers.

Meterological observations (air temperature, wind direction and velocity), secchi visibility, and depth were recorded at each station. Surface and bottom temperature, conductivity, and salinity were measured and a water sample was usually taken at each level. In the laboratory, water samples were analyzed for concentrations of total nitrogen, total dissolved nitrogen, nitrate/nitrite ammonia, total phosphorus, orthophosphate, total dissolved phosphorus,

Table 3-2 Sampling dates and distribution of collections taken during the Special Chemistry Transect Series in Winyah Bay.

Date	Total Samples In Winyah Bay	Total Samples In Pee Dee R.	Total Samples In Waccamaw R.	Total Samples On Cruise
Sep. 1, 1981	13	6	5	24
Dec. 10, 1981	12	5	5	22
Jan. 29, 1982	16	0	0	16
Mar. 27, 1982	16	1	1	18
May 28, 1982	12	5	5	22
Jul. 25, 1982	14	1	1	16
Sep. 23, 1982	10	4	8	22
Total in Series	93	22	25	140

dissolved organic carbon, total organic carbon, chlorophyll a and phaeophytin.

CHAPTER 4. PHYSICAL-CHEMICAL CHARACTERISTICS

Introduction

The following discussion of the results of the physical, chemical, and pigment sampling programs conducted within Winyah Bay is divided into three sections. The first section contains results and analyses of parameters measured during the extensive and intensive series of cruises and the special chemistry transect series. By presenting this information first, the reader is introduced to the patterns of spatial variability within the bay.

It should be reiterated that water samples for the extensive and intensive series of cruises were not necessarily collected on the same day nor during the same tidal stage. However, water samples for the special chemistry transect series were collected on the same day and generally within three hours of slack high tide. Sampling commenced at Mother Norton shoals at slack high tide and ended at the river stations approximately three hours later. Therefore, water samples were collected within a relatively short time span and during the same tidal stage.

One major advantage to the sampling program maintained during the special transect series is that nutrient and pigment concentrations are obtained along the entire salinity gradient. It is therefore possible to pinpoint sources and sinks of nutrients within the estuary as a whole. Also, by first understanding seasonal nutrient regimes for the entire estuary, it is possible to explain values obtained at individual stations during the extensive and intensive series of cruises.

The second section presents results and discussion of the parameters examined during the 48 hour zooplankton series. It provides a more detailed look at the short-term temporal variability at a single station.

The final section summarizes information presented in the first two sections and provides a general description of the temporal and spatial variability of nutrients and plant pigments within Winyah Bay estuary. Also, results from Winyah Bay are compared to conditions observed at No Man's Friend and South Jones Creeks.

Section I

In the first part of this section, general patterns identified during the special chemistry transect series for the chemical and pigment constituents are presented. Following this introduction is a more detailed discussion of concentration ranges, seasonal and spatial variability, and unusual trends exhibited at the stations sampled during the extensive and intensive series of cruises.

Data for individual chemical and pigment parameters from the special chemistry transect series were plotted against salinity to examine their behavior within the estuary. Four different mixing patterns were possible. A linear relationship of nutrients or pigments and salinity suggests that a constituent is mixing conservatively within the estuary. A negative linear trend is exhibited when freshwater inputs served as a source for the nutrient. Conversely, a positive linear trend is indicative of an oceanic source. Throughout the study, nutrient concentrations in freshwater were generally higher than those observed in high salinity samples. Unless otherwise noted, reference to a conservative mixing trend should be construed to mean that riverine inputs were the source of the nutrient and concentrations decreased in a linear fashion as salinity increased.

Two other mixing patterns were possible. A negative convex upward curve was obtained when the estuary served as a source for the nutrient. When the estuary acted as a sink, negative concave upward curves were obtained.

Although patterns illustrated by the plots are affected by numerous factors and should therefore be interpreted cautiously, this approach does provide a qualitative basis for understanding transport dynamics within the system. Also, this approach has been used in several other estuaries to examine mixing patterns of silicate, trace metals, dissolved oxygen, alkalinity, carbon, chemical nutrients, chlorophyll, and productivity. A more detailed explanation of this approach can be found in numerous publications (refer to Sharp et al., 1982, and references included therein).

Physical parameters are discussed first, followed by descriptions of the nutrient and pigment concentrations within Winyah Bay during the sampling period. A brief discussion (from Allen et al., 1982) of the importance of the individual nutrients and pigments to estuarine ecosystem dynamics is included. All data collected during the intensive and extensive series of cruises are tabulated by station in Appendix I. Physical/chemical and plant pigment data collected during the special chemistry transect series are tabulated by salinity in Appendix III.

Water Temperature

Surface and bottom water temperatures were highest from May through September 1982 (range; 22.8 - 30.8°C) at all stations sampled during the extensive and intensive series of cruises. Highest average water temperatures were recorded in July and ranged from 26.3 to 30.8°C. The annual trend consisted of decreasing temperatures from July through January and increasing temperatures thereafter. The January low temperatures ranged from 4.6 to 7.6°C.

Station differences in water temperature were small from September through January and no consistent unusual trends were observed. During March and May, riverine waters were warmer than oceanic waters. For example, during March a surface water temperature of 17.6°C was recorded at US. Surface temperatures were progressively cooler approaching MN. Values of 16.3 and 14.7°C were recorded at MS and MN respectively. A similar but less extreme trend was found in May when surface temperatures of 24.2 and 26.0°C were recorded at MN and US, respectively. Such behavior is to be expected during the spring months when increased solar radiation warms the more turbid riverine water faster than oceanic water. Depth is also an important factor since shallow bodies of water (rivers, lakes, etc.) can be warmed much faster than deeper oceanic water.

A reverse trend was observed in November and January when high salinity stations were slightly warmer than the freshwater stations. This trend was somewhat obscured by the warming that took place within Winyah Bay during this period. Increasing water temperatures within the bay were most noticeable during July when water temperatures were 1-2° C warmer within the Mud Bay area than at other sites. Shallow basins such as Mud Bay are particularly susceptible to extreme temperature variations. Flooding of warm exposed marsh surfaces and mud flats during the summer may significantly elevate water temperatures. Conditions or high turbidity also affect water temperature. Silt-laden water tends to warm much faster than clearer water.

Significant thermocline formation (temperature stratification within the water column) was not observed at most stations during any portion of the year. Surface and bottom temperatures rarely differed by more than 1°C. However, exceptions to this were recorded during May and July at the deepest stations where surface water temperatures were up to 2-3°C warmer than bottom temperatures. This feature is probably a predominant feature at deep high salinity estuarine stations during late spring and early summer when freshwater inputs are generally warmer than oceanic water. When this is the case, warmer less saline water tends to flow over cooler high salinity water and a salt wedge or halocline (salinity stratification within the water column) is formed. Haloclines were commonly observed in Winyah Bay channels, but such stratification was prevented by high wind and current velocities in shallow portions of the estuary.

Relatively large seasonal temperature fluctuations were observed at the stations. July temperatures averaged 20 - 25°C warmer than January temperatures. Temperature variations between stations within Winyah Bay were generally less than 3°C during a particular cruise. Diel temperature fluctuations will be addressed in Section II.

Salinity

Observed salinity values were primarily dependent on the degree of dilution of sea water by the riverine freshwater inputs. Inflow is related to the amount of freshwater entering the estuary as well as tidal intrusion of sea water. The amount of sea water entering the estuary is related to lunar phase (i. e. spring and neap tides), wind, and meteorological conditions. Figure 4-1 illustrates the surface salinity regime at three sites from MN (highest average salinity station) to progressively less saline areas (MS and US) throughout the sampling period. It is readily apparent that spatial variablility in salinity is large within Winyah Bay. The maximum range of salinities observed during a cruise was 33.3 g/l. Salinities were generally highest in November and lowest in January after a period of significant precipitation.

Salinity stratification was observed at all deep water stations during most of the year. Salinity differences of 10 - 15 g/l between surface and bottom water samples were common. This feature serves

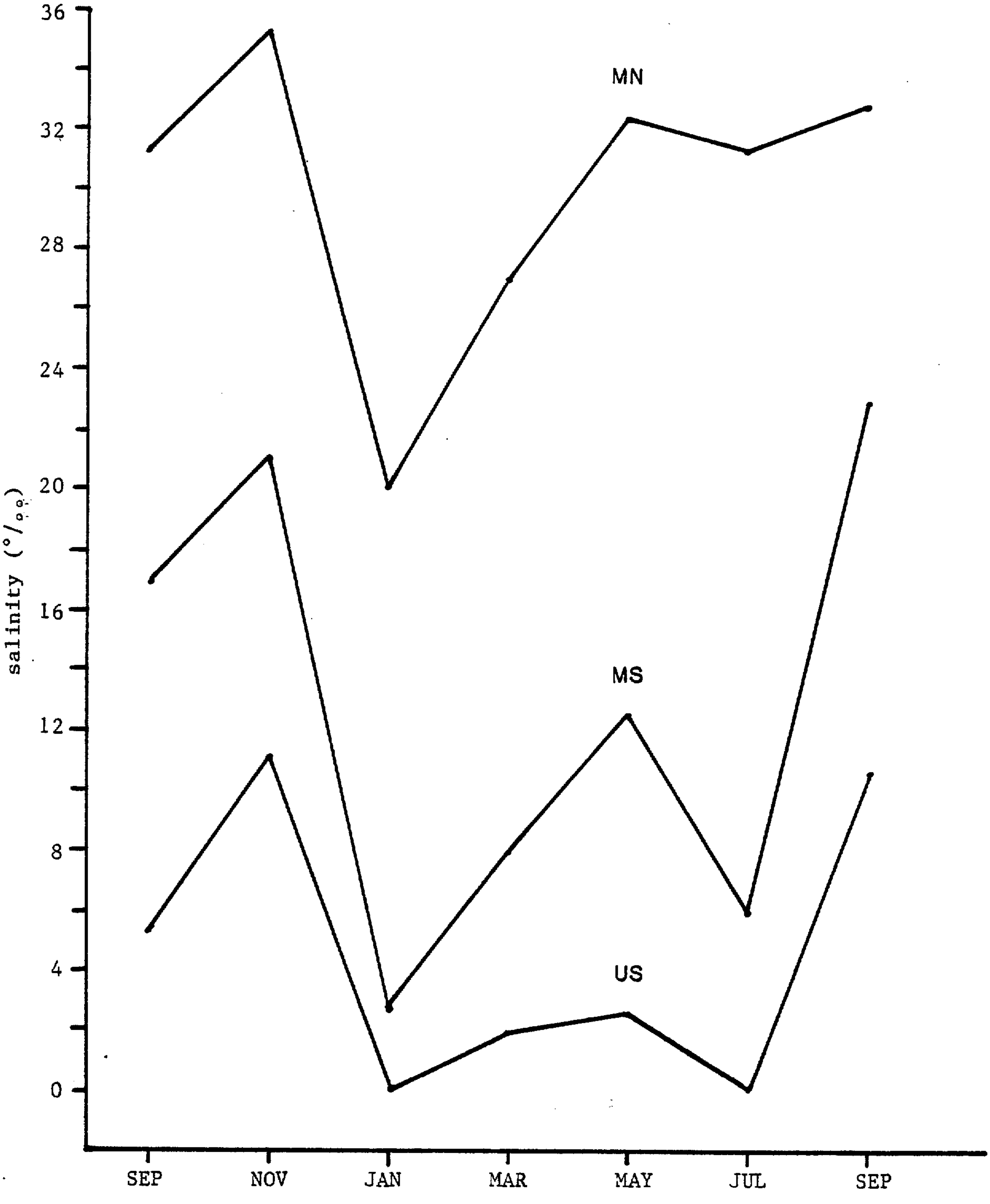


Fig 4-1. Surface salinity regime at three sites (MN, MS, and US) during the intensive series of cruises within Winyah Bay from September 1981-September 1982.

as a significant factor affecting the distribution of many organisms and the formation and maintenance of a permanent community structure. This relationship will be discussed in much greater detail in Chapters 5 and 6.

Persistance of a halocline can significantly affect nutrient and phytoplankton concentrations. When a halocline is present, phytoplankton can be effectively trapped within the lower more stagnant water body and this often results in decreased primary production. Also, decomposition within this water mass can result in depletion of oxygen reserves and, therefore, have potentially adverse consequences on animal community metabolism and structure.

Many factors affect the formation and maintenance of a halocline. High wind and current velocities break down or prevent stratification. Shallow areas (i. e. Mud Bay) rarely experience significant stratification since moderate to low wind velocities provide sufficient mixing to prevent such an occurrence.

The relationship of salinity to nutrients will be discussed individually under the appropriate category.

Secchi Disk Visibility

Vertical visibility was measured with a secchi disk. Secchi disk visibility is directly related to the vertical coefficient of light absorbtion which is the region from the surface to the depth at which 99% of the surface light has disappeared (Cole, 1975). This region is referred to as the euphotic zone, and is ecologically important because little or no photosynthesis can occur below this zone.

Average secchi disk visibility for all intensive and extensive stations increased from September 1981 (0.621 m) to a maximum value of 0.657 m in November 1981. The lowest average value was recorded in January 1982 (0.433 m) and was followed by a significant increase in March (0.592 m). Secchi disk visibility subsequently decreased from March to July (0.556 m) and increased slightly in September 1982 (0.598 m). The low visibility observed in January was a direct result of high levels of freshwater input to the system. Heavy freshwater input resulted in increased turbidity which was related to increased erosion and silt loading upestuary. Decreased visibility from March through July was influenced by increased densities of phytoplankton and detrital material in the water column as well as increased agricultural runoff associated with spring planting upstream.

Highest average secchi disk visibilities were recorded at MN and SB (0.689 and 0.706 m, respectively). These two stations represented the two most saline areas sampled. Dilution of silt laden freshwater at these locations resulted in a concomitant increase in secchi disk visibility. Phytoplankton and detrital concentrations are also usually lower in oceanic water. Several other factors influence the visibility at the more seaward stations including color of the water and tidal mixing.

Average annual secchi visibility was low at the river stations, ranging from 0.540 to 0.597 m at PD, SR, WR, and US. Lowest average visibilities were recorded at TA and PS (0.446 and 0.507 m, respectively). Both sites were located within the shallow Mud Bay area. Numerous factors are responsible for the low values. Wind velocity affects visibility within Mud Bay much more than at other sites. Low wind velocities can cause complete mixing of the water column at Mud Bay resulting in resuspension of silt, detritus, and phytoplankton. At the other deeper water sites, low wind velocities generally affect only the upper strata. Complete mixing of the water column is also indicated by the absence of salinity and temperature stratification within Mud Bay which contrasts with the extreme salinity stratification characteristic of deep water sites within Winyah Bay. Tidal mixing and phytoplankton production are also important factors contributing to the low secchi disk visibility within Mud Bay.

Phosphorus

Phosphorus is vital in the operation of cellular energy transfer systems. Phosphorus is typically scarce in unpolluted environments and is often a major limiting factor to aquatic productivity. Phosphorus, usually in the form of orthophosphate, is rapidly assimilated by phytoplankton as soon as it is made available and is then passed to higher trophic levels through herbivory and subsequent predation. Concentration of phosphorus in estuarine waters is primarily affected by basin morphometry, geochemistry of the watershed, input of organic matter, organic metabolism in the water column, and the rate of loss of phosphorus to the sediments (Reid and Wood, 1976).

Examination of composite plots of total phosphorus and total dissolved phosphorus in surface water samples versus salinity for the special chemistry transect series revealed a trend of conservative mixing from September 1981 through March 1982 (fall through spring). From May through September 1982, Winyah Bay appeared to act as a sink for both constituents, with the exception of May 1982 when total phosphorus followed a conservative mixing trend. Although values were low and extremely variable throughout the year, Winyah Bay generally acted as a sink for orthophosphate.

These results reflect the influence of phytoplankton on the nutrient regime within the bay. During cooler months when primary production is relatively low, total and total dissolved phosphorus mixing is conservative. As primary production increases within the bay, phosphorus tends to remain within the system. Mixing patterns and low concentrations of orthophosphate are the result of rapid assimilation of these nutrients by phytoplankton throughout the year.

During the extensive and intensive series of cruises, highest average concentrations of total phosphorus (3.1 μ At./l) and orthophosphate (1.1 μ At./l) were observed in January and March, respectively. These findings reflect the significant input of nutrient-rich freshwater to the system during January. High values of orthophosphate during March suggest that it was made available to the environment faster than it could be assimilated by the phytoplankton. Second highest average concentrations of total phosphorus (2.6 μ At./l) during July in Winyah Bay were caused by both high concentrations in the freshwater inputs and high primary productivity within the system. Lowest average total phosphorus concentrations (1.5 μ At./l) were recorded in November 1981 when freshwater inputs to the system were low and primary production was minimal.

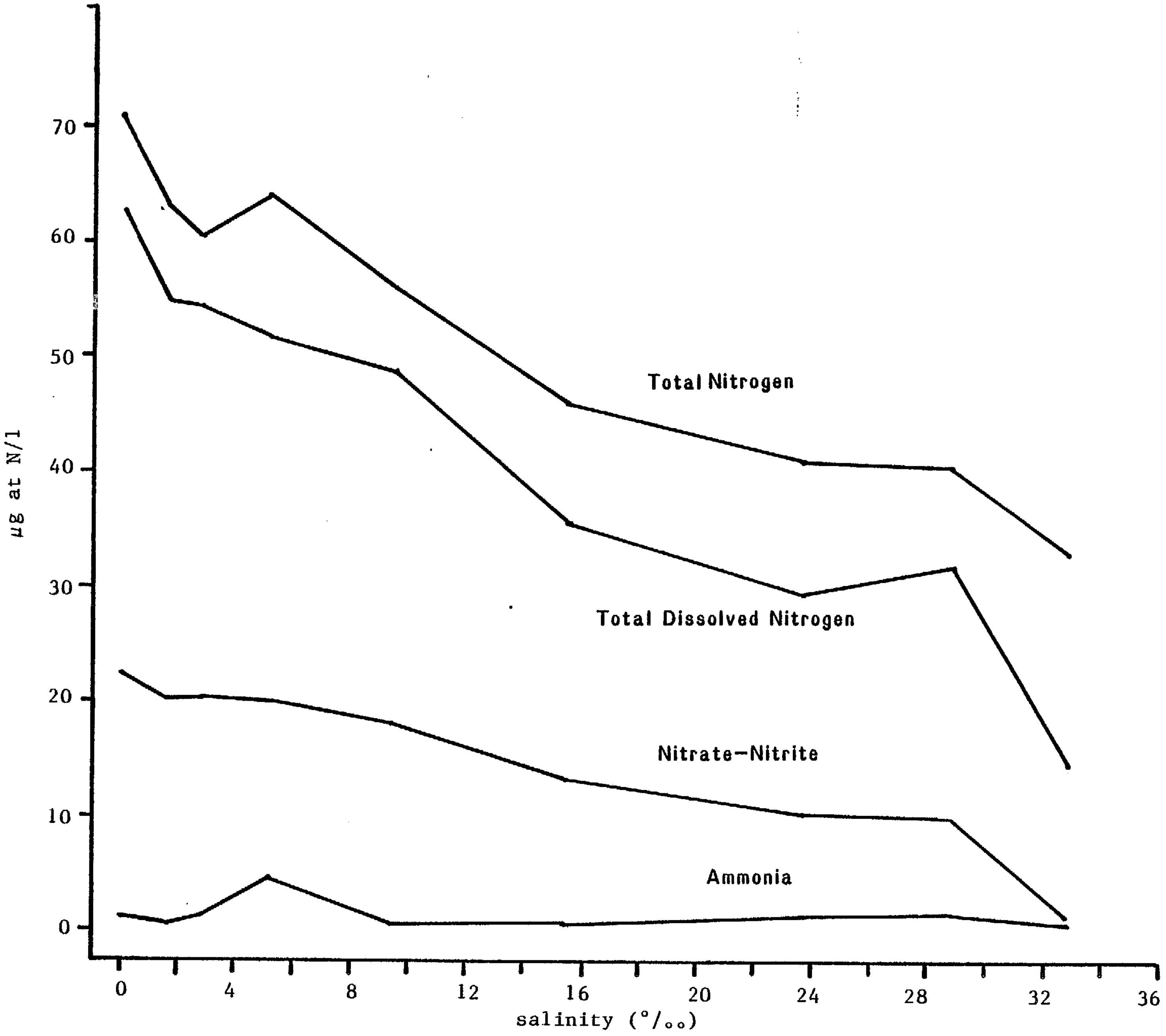
Average concentrations of total phosphorus in surface samples were generally higher at sites within Mud Bay than in other deeper water sites. For example, average surface concentration of total phosphorus at TA was 3.0 μ At./l compared to 1.8 μ At./l at MS. Ion exchanges between sediments and overlying water, and activity by microorganisms are probably responsible for this phenomenon (Gooch, 1968; Pomeroy et al., 1969). Circulation of phosphorus retained in the sediments by nearby extensive stands of Spartina alterniflora may also be important (Pomeroy et al., 1969).

Nitrogen

Nitrogen is used in the synthesis of protein which is a major constituent of living cells and, therefore, is essential to the existence of an ecosystem. Atmospheric nitrogen acts as a reservoir for a complex cycle involving plants, animals, and various forms of the element. Nitrogenous compounds are made available to the estuarine environment by bacterial fixation of elemental nitrogen, precipitation, surface runoff, riverine inputs, photochemical and lightning fixation, decomposing plant and animal tissues, and animal excretory products (amino acids, urea, uric acid, ammonia). Available nitrogen is transformed into nitrates through bacterial action. Ammonium-nitrogen and, to a lesser extent, nitrite-nitrogen can be utilized by some phytoplankton species, although nitrate-nitrogen is primarily taken up by the cells and transformed into complex proteins (Russell-Hunter, 1970). Concentrations of inorganic nitrogen compounds (ammonia, nitrite, nitrate) regulate the productivity of an aquatic ecosystem because they are used in the synthesis of plant proteins which form the basis of the aquatic food web.

Total nitrogen, total dissolved nitrogen, and nitrate-nitrite nitrogen generally followed a pattern of conservative mixing throughout the year. A composite plot of these three constituents plus ammonia from the July 1982 special chemistry transect cruise is presented in Figure 4-2. The apparent conservative mixing trends of total nitrogen, total dissolved nitrogen, and nitrate-nitrite nitrogen are representative of most other cruises. Total dissolved nitrogen constituted a significant portion of total nitrogen throughout the year. Although ammonia appears to be mixing conservatively during this particular cruise, this trend was not consistent. During September 1981, ammonia showed a distinct estuarine source. Ammonia concentrations were approximately 1 μ At./l at the freshwater and high salinity ends, but values averaging 5-6 μ At./l were recorded at mesohaline sites (10-26 g/l). During other cruises, ammonia values were usually low and highly variable, and no consistent trends were established. Conservative nitrogen behavior has been observed in nonurban tropical estuaries (Van Bennekom et al., 1978; Fanning and Maynard, 1978) and the Columbia River estuary (Stefansson and Richards, 1963).

Fig 4-2. Composite plot of total nitrogen and dissolved nitrogen fractions versus salinity for surface water samples collected during the July 1982 special chemistry transect cruise.



During the extensive and intensive series of cruises, maximum average concentrations of nitrate-nitrite nitrogen were recorded in January and March (17.4 and 25.0 μ At./l, respectively). This period corresponded to the period of maximum freshwater input to the estuary. High levels of nitrogen loading from freshwater sources as a result of surface runoff within the watershed, and heavy detrital loading followed by decomposition were important factors during this period. Maximum values reaching 33.38 μ At./l were usually recorded at upper estuary sites (WR and US).

Lowest average nitrate-nitrite nitrogen concentration (2.61 μ At./l) was obtained in September 1982 and corresponded to maximum densities of phytoplankton. Nitrate-nitrite nitrogen is rapidly assimilated by phytoplankton and a significant inverse relationship of phytoplankton to nitrate has been demonstrated (Tiner, 1981). Lowest nitrate-nitrite nitrogen concentrations were usually observed at the most seaward sites (MN and SB).

Average cruise concentrations of total nitrogen did not follow established trends which were observed in the previous study of No Man's Friend and South Jones Creeks where total nitrogen tracked phytoplankton abundance (Allen et al., 1982). Lowest average total nitrogen concentrations were recorded in September 1982 when chlorophyll a values were high. Highest average concentrations were recorded in November and January (81.0 and 74.9 μ At./l, respectively) when chlorophyll a values were low. Several factors were probably responsible for this anomalous behavior. The highest total nitrogen concentrations, ranging from 108-168 μ At./l, were recorded at mid-estuary stations (EP, US, BI). Dredging, which was observed adjacent to these sites, may have affected total nitrogen concentrations. Heavy freshwater inputs of nitrate-nitrite nitrogen and other forms of nitrogen were partially responsible for the high total nitrogen values observed during January.

Highest average total nitrogen concentrations for all cruises were observed at EP, BI, SR, and US. Lowest average values were most commonly recorded at MN.

Chlorophyll a, Phaeo-pigments, and Organic Carbon

Due to their capacity to photosynthesize, plants occupy the base of most food chains. There are two basic food chains in estuarine environments. In one, rooted angiosperms and epiphytes are the primary producers, and in the other, phytoplankton are the primary producers (Russell-Hunter, 1970). In either case, the generated plant tissues are fed upon directly by grazing (herbivory), or indirectly through the consumption of dead plant materials and decomposers (detritivory). There may be several steps involved in a single food chain. For example, a single food chain may include a diatom species (phytoplankton), a herbivorous zooplankton species, two predaceous zooplankton species, a small fish, and a larger fish. The production of fish and invertebrate tissue in an estuary or salt marsh is obviously directly related to the productivity of the green plants. Consequently, in order to understand fluctuations in the populations of zooplankton, epibenthic and benthic organisms, and fish, it is also necessary to understand primary productivity within the ecosystem.

Phytoplankton represent a high proportion of the standing crop of primary producers in estuaries and salt marsh creeks. Phytoplankton are microscopic aquatic plants which are primarily transported by tidal and wind driven currents.

Assessments of chlorophyll a concentrations were used as indicators of primary productivity in this study. Determination of chlorophyll a is a rapid chemical method for quantifying the amount of living plant matter in the water column, but the relationship between living organic plant material and the quantity of plant pigment is highly variable, depending upon the species composition of the phytoplankton in the water as well as their state of nutrition (Strickland and Parsons, 1972). Despite this limitation, assessment of chlorophyll a still serves as a useful tool, providing a relative index of seasonal and diurnal changes in the standing crop of phytoplankton.

Degradation products of chlorophyll may constitute a significant portion of the total green pigments in the water column. Typically, phaeophytin and phaeophorbide (collectively termed phaeo-pigments) represent the greatest percentage of chlorophyll degradation products (Strickland and Parsons, 1972). Determination of phaeo-pigments serves as a useful tool in determining relative rates of phytoplankton turnover.

Although chlorophyll a data collected during the special chemistry transect series was often highly variable, three distinct concentration patterns emerged (Figure 4-3). During September and November 1981,

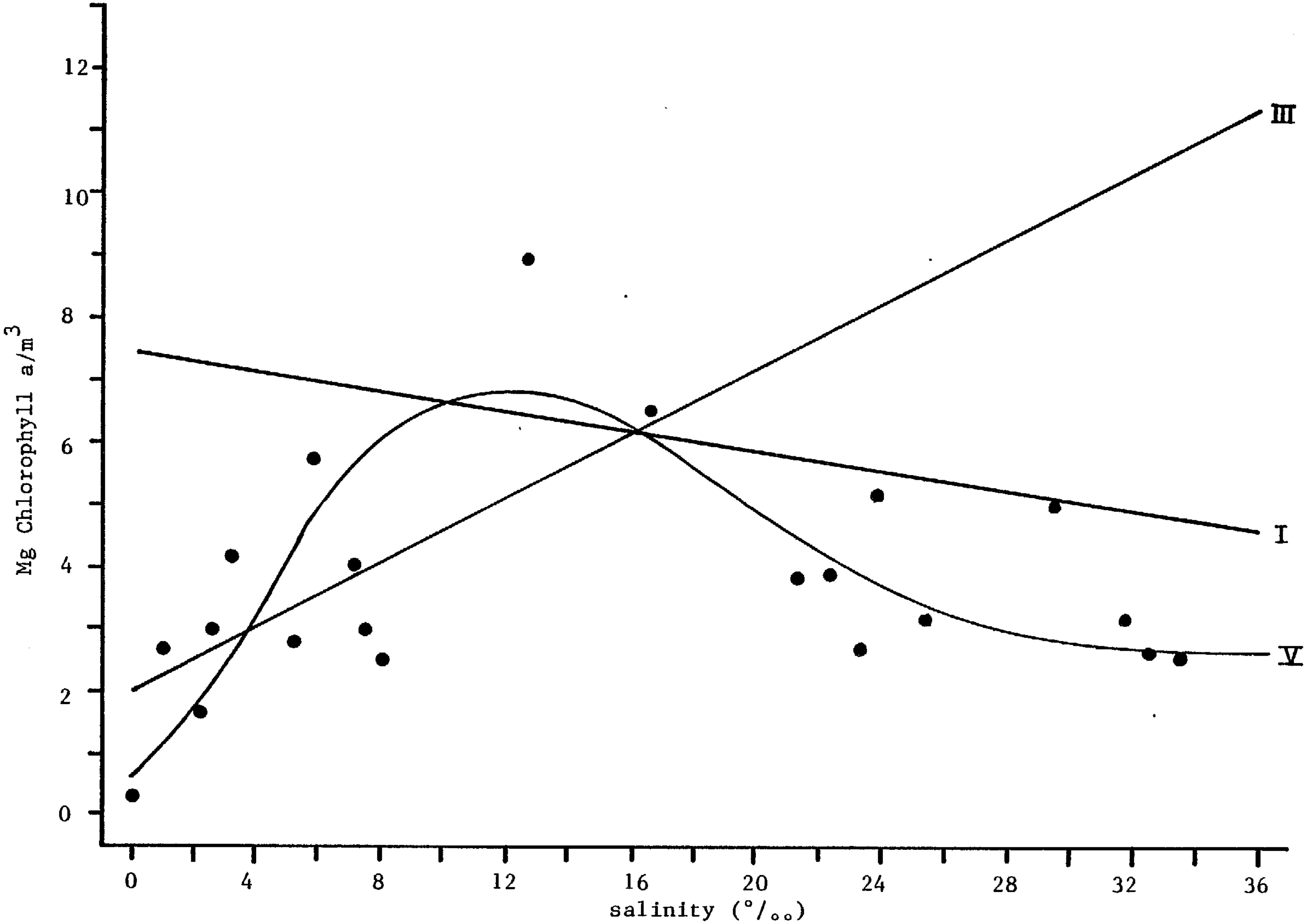


Fig 4-3. Concentrations of chlorophyll a versus salinity from surface and bottom water samples collected during special chemistry transect cruises. Best linear regression lines represent data recorded for cruises I (September, 1981) and III (January 1982). Actual values recorded during cruise V (May 1982) are included and the concentration curve drawn was visually determined. One anomalous chlorophyll a value (>29) was not included.

chlorophyll a concentrations appeared to decrease from freshwater to high salinity stations. Conversely, chlorophyll a concentrations increased from freshwater to high salinity areas during January 1982. From March through September 1982, the estuary was an apparent source of chlorophyll a; lowest values were observed at freshwater and high salinity areas. The usual pattern observed in January is likely related to the high degree of freshwater dilution throughout the estuary. Riverine and estuarine populations of phytoplankton were displaced toward the lower end of the bay.

The strong correlation of phaeo-pigment and chlorophyll a concentrations which is typically observed in estuarine systems (Allen et al., 1982), was not consistently observed in Winyah Bay. This was due to the highly variable nature of the phaeo-pigment data. During most special chemistry transect cruises, the data were so variable that few clear and consistent trends could be established. In March 1982, phaeo-pigment and chlorophyll a concentrations appeared to track each other (Figure 4-4). On this particular cruise and two others (September and November 1981), phaeo-pigments appeared to have an estuarine source.

Conservative mixing patterns were observed for total organic carbon and dissolved organic carbon throughout the year.

During the extensive and intensive series of cruises, average chlorophyll a concentrations decreased from a high value of 6.13 mg/m^3 in September 1982. A spring peak may have occurred in Winyah Bay between the March and May cruises.

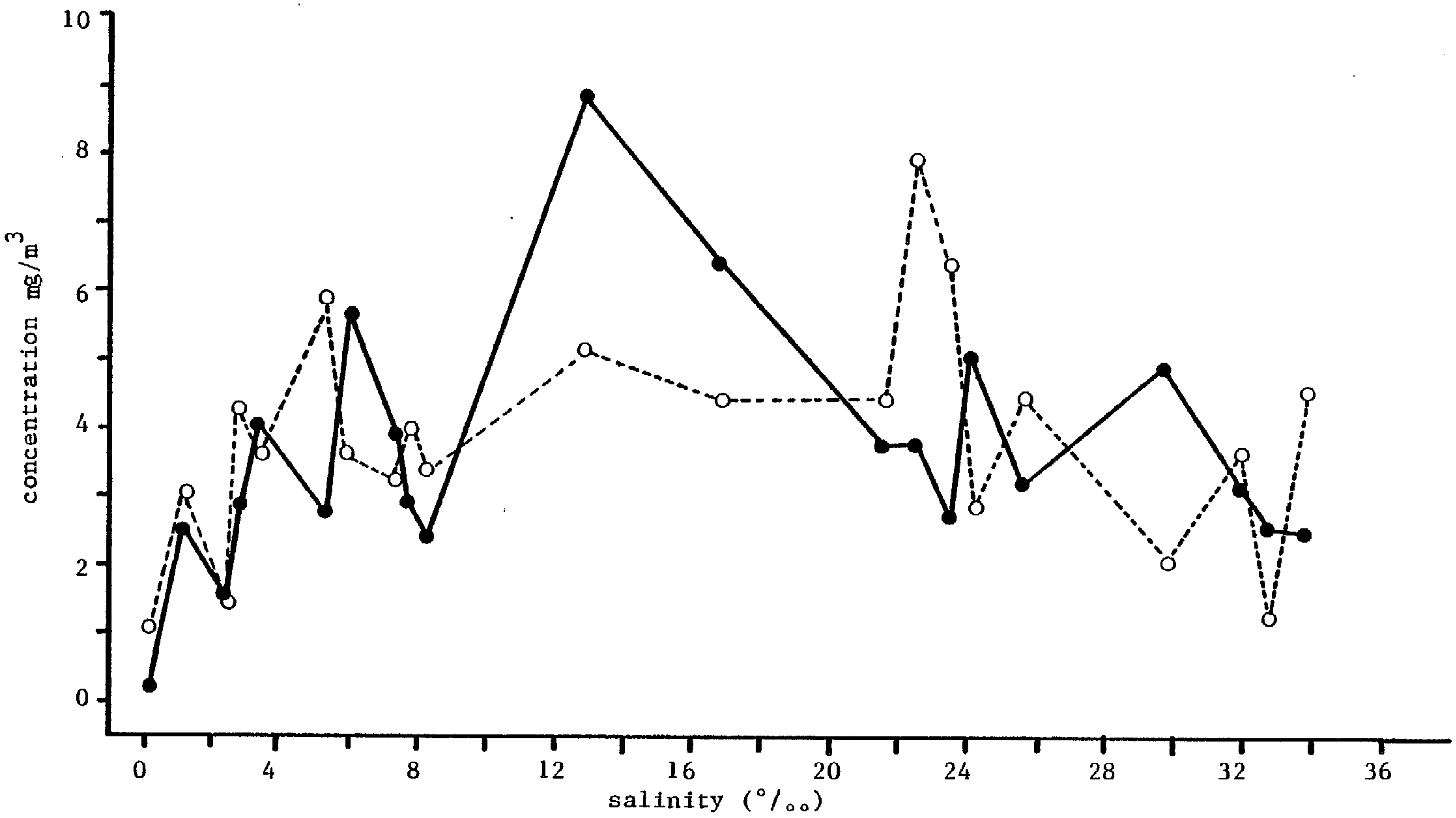


Fig 4-4. Composite plot of chlorophyll a and phaeo-pigment concentrations versus salinity for surface and bottom water samples collected during special chemistry transect cruise V (May 1982). One anomalous sample was not included.

Maximum chlorophyll a concentrations for individual sampling periods were observed at several locations (TA, BI, EP, US, and SR) and probably represented patches of phytoplankton. Minimum average concentrations for individual cruises were most commonly recorded at WR (3 of 7 cruises) although minimal values were also observed at PD, PR, US, and SB.

Average concentrations of phaeo-pigments for cruises generally tracked chlorophyll a concentrations. Phaeo-pigment concentrations decreased from an average value of 3.44 mg/m^3 in September 1981 at all stations to a minimum of 1.53 mg/m^3 in November 1981 and then increased to a maximum value of 5.04 mg/m^3 in September 1982. Since phaeo-pigments are a degradation product of chlorophyll and values are related to zooplankton grazing and natural attrition of phytoplankton, a close seasonal correlation of chlorophyll a and phaeo-pigments may be expected.

Section II

Spatial and seasonal variability of physical, chemical, and pigment parameters were presented in the previous section. During the 48 hour zooplankton study, hourly changes in the parameters were recorded over a two day period. Although caution should be exercised in interpreting temporal variation over a single two day period, by combining these data with observations recorded during the 24 hour cruises at adjacent No Man's

Friend and South Jones Creeks (Allen et al , 1982), it is possible to examine the relative importance of diel, diurnal, and seasonal variation in physical characteristics, and chemical and pigment concentrations.

The first day of sampling was characterized by relatively clear skies and low to moderate wind velocities. Percentage of cloud cover and wind velocity increased during the second day and a severe storm interrupted sampling for a two and one-half hour period. Cloud cover remained, but wind velocities decreased through the remainder of the cruise.

Specific data collected during the study are included in Appendix II. A description of physical, chemical, and pigment changes over the 48 hour period follows:

Temperature

Surface and bottom water temperatures only fluctuated from 25.8 to 27.4°C during the 48 hour study. During the first day, water temperature increased from a low of 25.8°C at 1000 hr to high values in late afternoon ranging from 27.1-27.4°C, and decreased thereafter to 26.6°C at 2300 hr. Patterns exhibited during the second day were opposite to those observed on the first day. Temperatures decreased from a high of 26.9°C in early morning (0600 hr) to a daily low of 25.9°C at 1200 hr. This decline was evidently caused by the movement of a frontal system across Winyah Bay.

Sampling was missed during the severe storm which occurred from 1300-1500 hr. Water temperatures subsequently increased to approximately 26.5°C after passage of the frontal system and remained relatively stable through the remainder of the sampling period (26.5 +/- 0.2°C). These minor fluctuations were probably not significant in terms of influences on chemical or biological processes measured during this period.

Salinity

Salinity of surface and bottom water ranged from 21.0 to 34.9 g/l through the 48 hour period (Figure 4-5). Salinity generally increased during the flooding tide and decreased during the ebbing tide. Salinity differences between surface and bottom samples were never greater than 3 g/l. The highest degree of salinity stratification occurred at times of low current velocity and was generally within one hour of slack tide. As current velocities increased, surface and bottom water mixed and this resulted in the breakdown of any halocline which had formed. A two-layered circulation pattern was observed around slack high tide when oceanic waters began to ebb. This pattern resulted in increasing bottom salinities and decreasing surface salinities. Salinity reductions of 3-4 g/l occurred during the 3 hour period preceeding and following the passage of the frontal system through Winyah Bay (1300-1500 hr, September 19, 1982). Thereafter, salinities resumed previous levels.

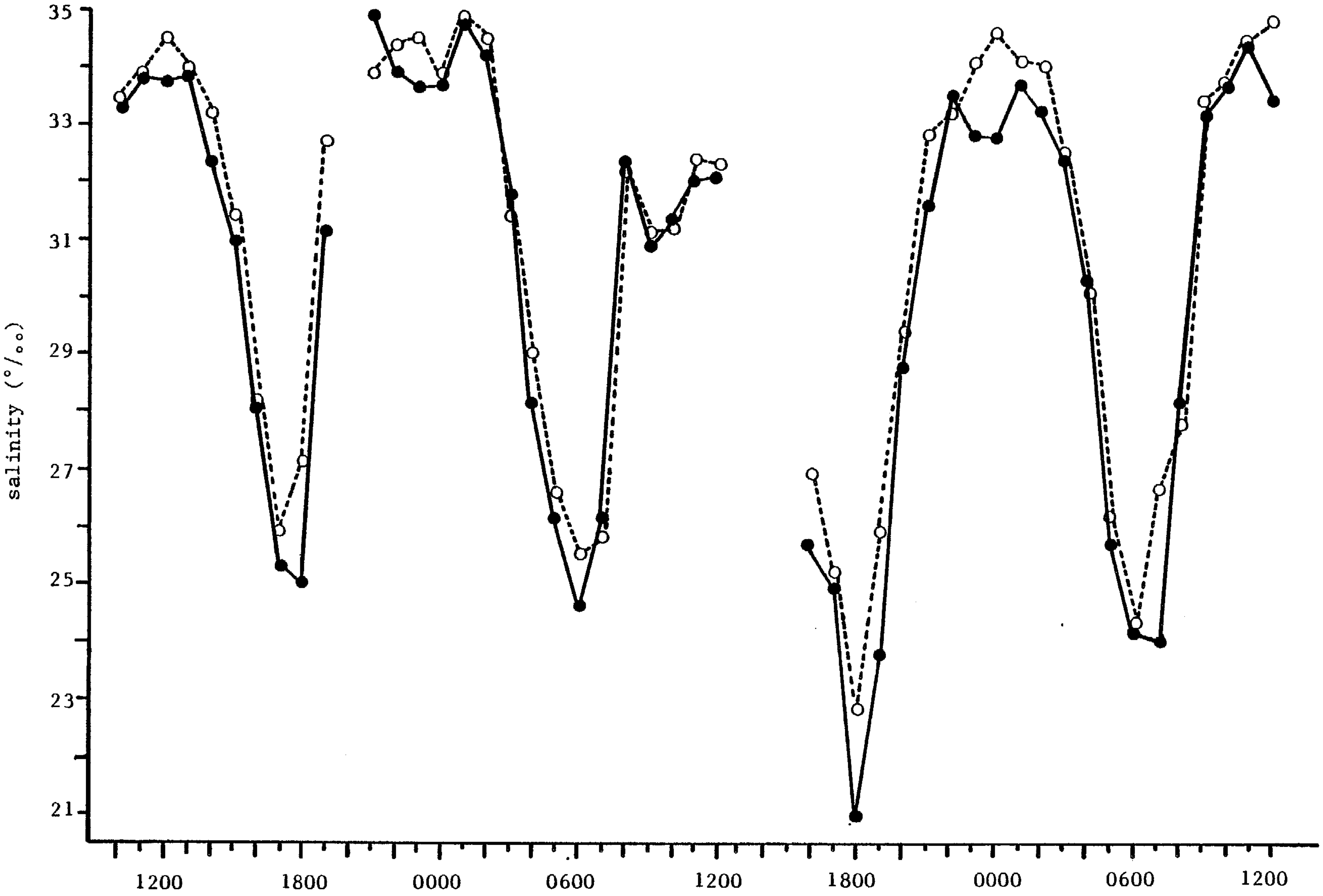


Fig 4-5. Salinity of surface (solid) and bottom (dotted) water during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

Phosphorus

Total phosphorus concentrations ranged from 0.2 - 4.2 μg At/l during the 48 hour study. Two dominant factors appeared to influence total phosphorus concentrations. Total phosphorus consistently increased during the ebbing tide to a maximum at slack low. This resulted from the input of phosphorus to the system from freshwater sources. Also, total phosphorus concentrations increased in bottom samples at slack low tide when salinity stratification was present. Ion exchanges between the pool of phosphorus in the sediments and overlying water was probably responsible for this phenomenon.

Orthophosphate concentrations ranged from less than 0.1 μg At./l to 2.5 μg At./l. Sediment resuspension appeared to be the dominant factor controlling orthophosphate concentrations in the water column. Maximum values for orthophosphate were observed at maximum current velocities (mid flood and mid ebb; refer to Figure 4-6). During these periods, sediment loading in the water column was at a maximum and secchi disk visibility was correspondingly low. It should be noted, however, that immediately following the thunderstorm (after 1500 hr on September 19, 1982), high concentration values of orthophosphate were recorded at low tide (1700-1800 hr). These findings are not totally inconsistent, and are probably the result of high wind velocities causing bottom sediment resuspension and surface runoff of sediment and nutrients from the surrounding watershed.

No consistent patterns were observed for total dissolved phosphorus.

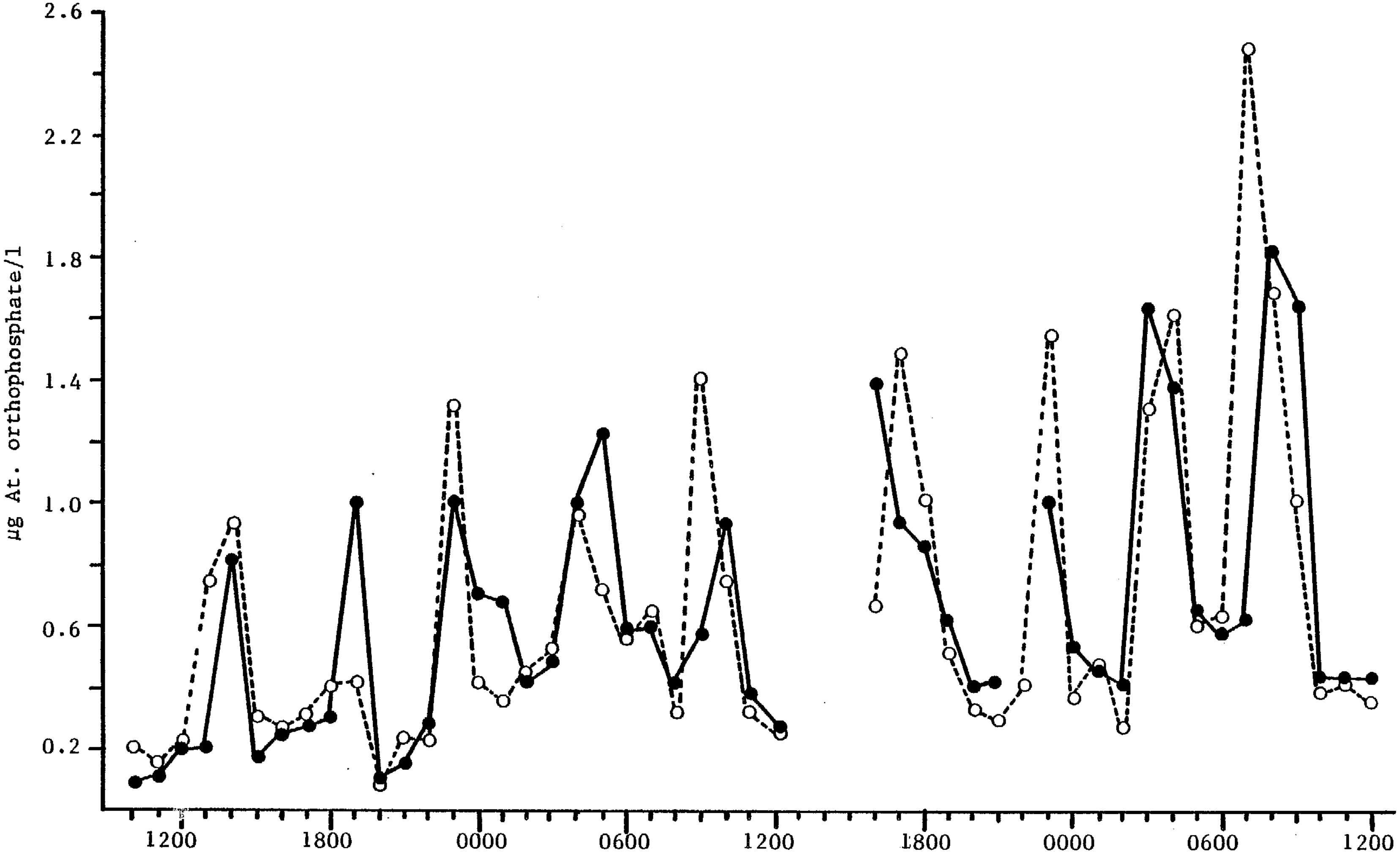


Fig 4-6. Orthophosphate concentrations in surface (solid) and bottom (dotted) water during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

Peaks at mid flood and mid ebb probably resulted from the significant contribution of orthophosphate to total dissolved phosphorus concentrations. High values at other times were likely related to increased biological activity which resulted in increases of dissolved organic phosphorus in the water column. Concentrations of total dissolved phosphorus ranged from less than 0.2 to 3.6 μg At./l.

Nitrogen

Total nitrogen concentrations ranged from approximately 8-68 μg At./l during the 48 hour period. Although numerous factors affect total nitrogen levels, a conservative mixing trend was discernible. Consequently, highest total nitrogen concentrations were recorded at low tide when salinities were lowest. Total nitrogen concentrations decreased as high salinity water entered the bay. A similar conservative mixing pattern was observed for nitrate-nitrite nitrogen (Figure 4-7). Nitrate-nitrite nitrogen values generally ranged from 0.3-3.0 μg At./l. The highest value (3.66 μg At./l) was recorded after the storm on the second day and was probably influenced siginficantly by precipitation and surface runoff.

Ammonia concentrations were typically in the range of 1-5 μg At/l. Although increases in ammonia concentration were observed at times when salinity stratification was present (most notably, slack high tide), a conservative mixing pattern was generally exhibited. However, the

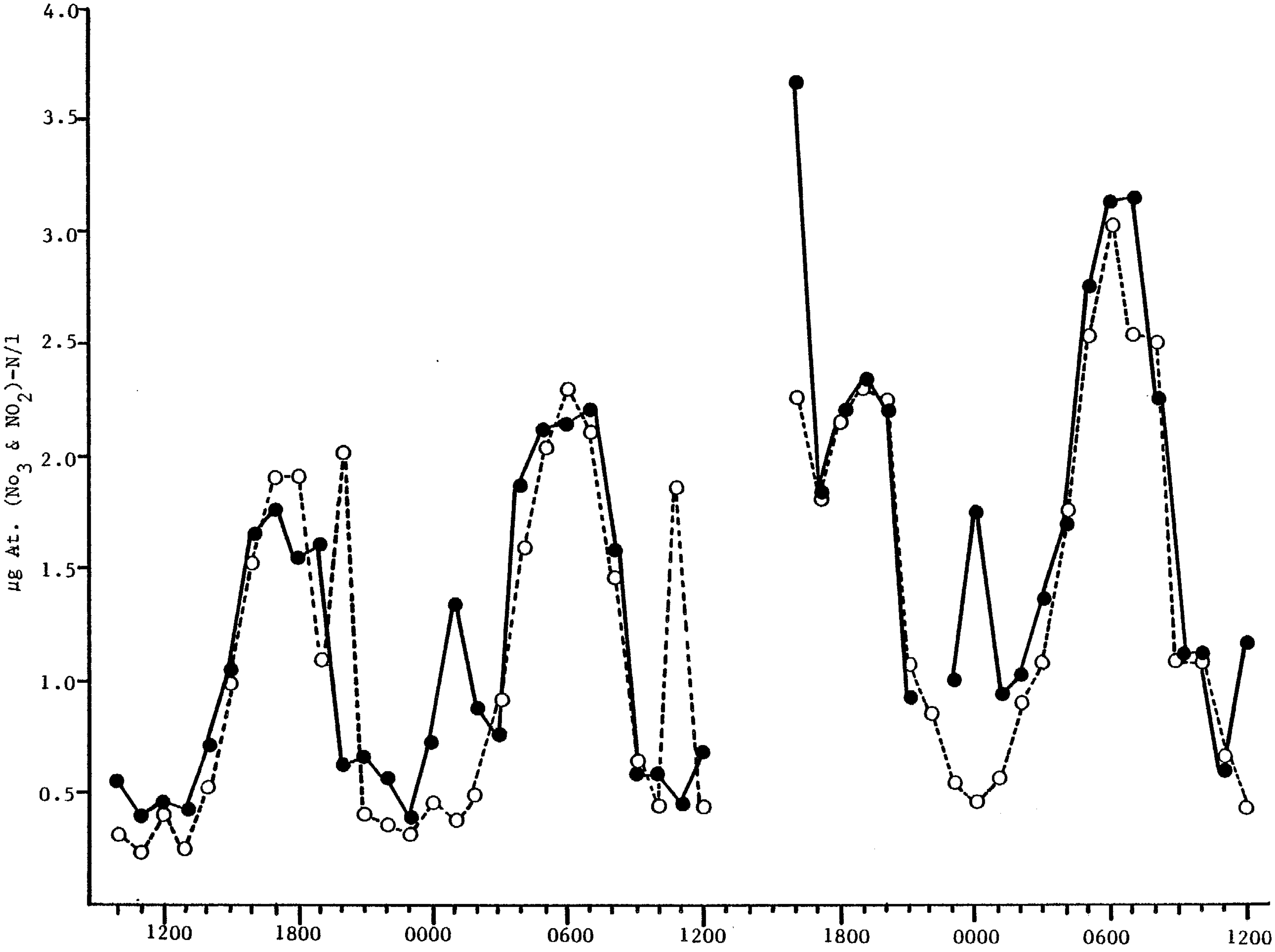


Fig 4-7. Nitrate-nitrite nitrogen concentrations in surface (solid) and bottom (dotted) water during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

data were highly variable and several other factors probably influenced ammonia availability in the water column.

The approximate concentration range for total dissolved nitrogen was 8-51 μg At./l. Dissolved fractions usually comprised nitrogen, and dissolved organic nitrogen fractions are constituents of total dissolved nitrogen. High values of ammonia and nitrate-nitrite nitrogen were usually reflected in total dissolved nitrogen concentrations. Other peaks in total dissolved nitrogen were presumably caused by dissolved organic fractions which often constitute a significant proportion of total dissolved nitrogen. Bacterial activity (decomposition) and animal excretion are two important biological sources of dissolved organic nitrogen.

Chlorophyll a, Phaeo-pigments, and Carbon

Maximum chlorophyll a concentrations (14.6 mg/m^3) were recorded near low tide during daylight hours on the first day (Figure 4-8). Subsequent daily low tide peaks were not as pronounced as those observed during the first day. Low values generally occurred at high tide and during night-time samples. Chlorophyll a concentrations as low as 1.9 mg/m^3 were recorded at high tide during the night. Temporally related variables, including tidal flushing and diurnal changes in photosynthetic rates, are often the most important determinants of phytoplankton abundance and primary production (Moll and Rohlf, 1981).

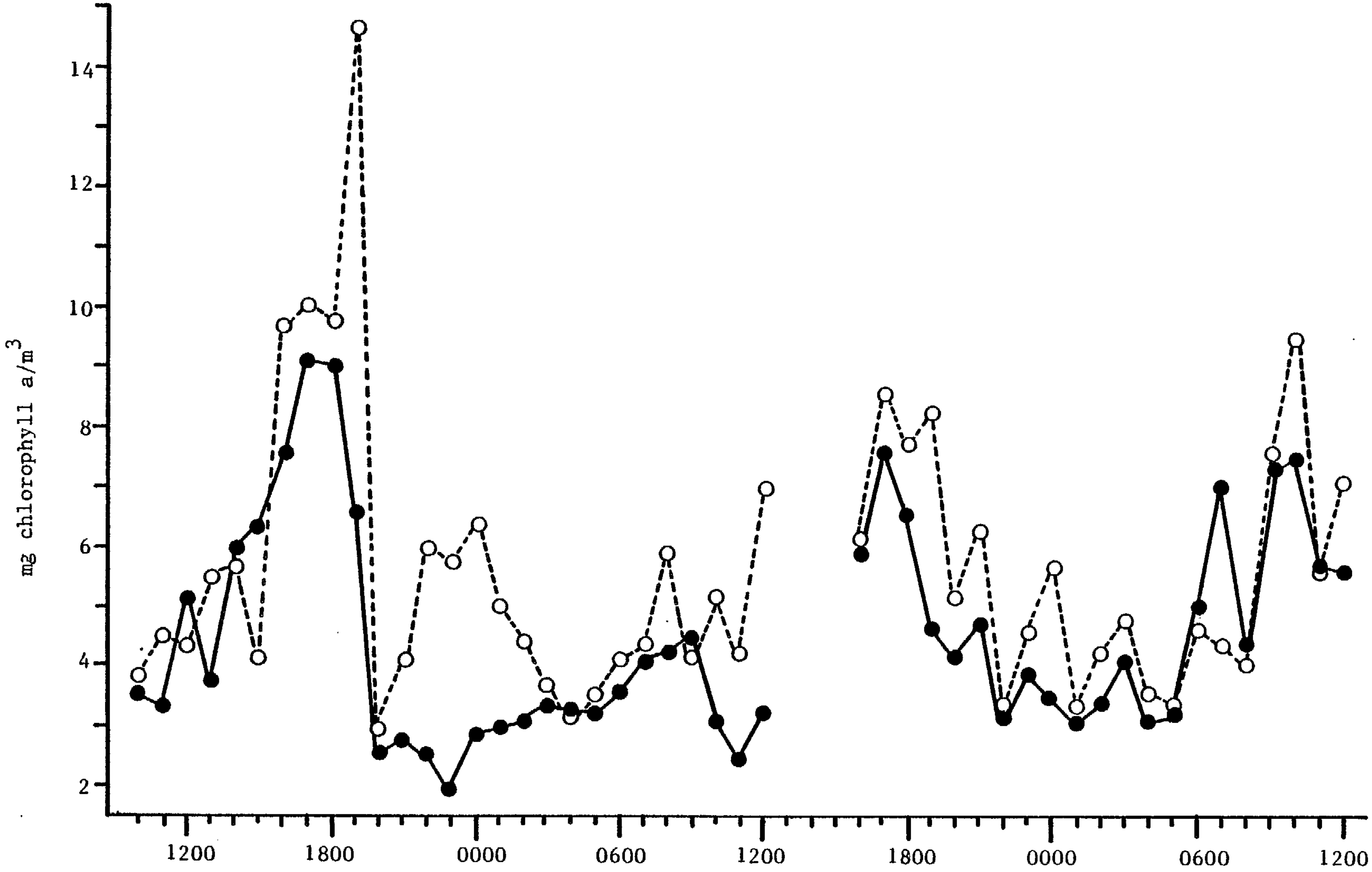


Fig 4-8. Chlorophyll a concentrations in surface (solid) and bottom (dotted) water during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

Phaeo-pigments closely tracked the pattern exhibited for chlorophyll a, which was probably related to the turnover of phytoplankton by zooplankton grazing and natural attrition. Since dead cells tend to settle to the bottom, surface phaeo-pigment concentrations were usually lower than bottom samples. Phaeo-pigment concentrations ranged from 0.5-12.8 mg/m^3.

Both dissolved and total organic carbon consistently exhibited highest values at low tide and lowest values at high tide throughout the 48 hour period. Total organic carbon values ranged from 2.6-6.4 mg/m^3 and dissolved organic carbon values were similar. Freshwater inputs and concentrations within the water column were responsible for the high values observed at low tide.

Section III

The annual temperature range for Winyah Bay was 4.6-30.8°C. The annual water temperature pattern was similar to that observed in No Man's Friend and South Jones Creeks. Diel and diurnal temperature changes were usually an order of magnitude less than those recorded on an annual basis. Within Winyah Bay, temperature extremes were most often recorded in Mud Bay and were related to the shallow depth of the basin. Vertical temperature stratification in the bay was not significant. Thermocline formation is probably less important ecologically to community structure and nutrient availability in the bay than the significant salinity stratification which was observed.

The salintiy regime within Winyah Bay is a highly significant factor affecting nutrient availability, phytoplankton density, and invertebrate and vertebrate community structure. Salinity stratification, especially at the deeper water stations, is generally present throughout the year. At individual stations, salinity changes over the tidal cycle were frequently large. Changes in salinity of 20-25 g/l over the tidal cycle were common in the middle bay. The salinity regime at the river sites is more stable than at stations in the middle bay.

Secchi disk visibility was usually most affected by biological activity. Generally, visibility decreased as primary productivity increased. However, physical factors dominated in January when extremely high levels of freshwater input caused erosion and sediment loading in the watershed. This resulted in the lowest secchi disk visibilities recorded during the study. With the exception of January, annual trends in vertical visibility were similar to those recorded in NMF and SJ Creeks.

Total phosphorus appears to mix conservatively within Winyah Bay during the cooler months when primary production is low. As primary productivity increases, Winyah Bay acts as a sink for total phosphorus. Orthophosphate is generally present in low concentrations throughout the year. Concentration of phosphorus in the system is significantly influenced by the amount of phosphorus entering the bay from riverine sources. The unusually high values observed in January were directly related to the high levels of freshwater input. Because of the January peaks in Winyah Bay, seasonal concentration plots were different from those recorded for NMF and SJ Creeks. It is likely, though, that seasonal trends in Winyah Bay closely resemble those observed for NMF and SJ Creeks when freshwater input is low to moderate. When this is the case, total phosphorus concentration is heavily influenced by phytoplankton in the water column.

Large changes in phosphorus concentrations can occur in a relatively short time period, and this was observed during the 48 hour study at Mother Norton Shoals. During this period, the range in total phosphorus concentration was greater than the average seasonal change for all stations.

Mud Bay appears to be a major processing area for phosphorus within Winyah Bay. Low current velocities, shallow depths, and a large surface area contribute to this behavior.

Nitrogen appears to mix conservatively in Winyah Bay throughout most of the year. Peak concentrations of total nitrogen in NMF and SJ Creeks appeared to coincide with phytoplankton densities. In Winyah Bay, however, nitrogen concentration was more closely related to the amount of nitrogen entering the bay from riverine sources. Short-term temporal variability in nitrogen concentration, as observed at Mother Norton Shoals during the 48 hour sampling period, was as large as seasonal variability.

Seasonal trends in chlorophyll a and phaeopigment concentrations were similar to those observed in NMF and SJ Creeks. Typically, chlorophyll a concentration and primary productivity is low in winter and high in summer. The absence of a spring peak in NMF and SJ Creeks and Winyah Bay was probably related to sampling frequency. In both studies, hourly changes in chlorophyll a concentration were often as large as seasonal changes.

CHAPTER 5. ZOOPLANKTON

The zooplankton community is comprised of a diverse assemblage of microscopic animals which are generally passively transported by water currents. The composition of the Winyah Bay zooplankton was discussed in considerable detail in the previous report (Allen et al., 1982). Information on the life histories, ecological roles, and spatial and temporal patterns of distribution was presented. This chapter summarizes the results of studies during Phase II and III of the project.

The Winyah Bay ecosystem contains a great diversity of both permanent and temporary planktonic forms. Among those species which spend their entire lives as plankton (holoplankton), copepods were generally the most abundant. The calanoid copepods, *Acartia tonsa*, *Parvocalanus crassisrostris*, *Eurytemora affinis* and *Pseudodiaptomus coronatus* are characteristic of eastern and southeastern coastal environments and were common in Winyah Bay (Bowman, 1971; Alden, 1977; Lonsdale and Coull, 1977; Sandifer et al., 1980). Other calanoid copepods occasionally found in the area were *Centropages hamatus*, *Centropages typicus*, *Centropages furcatus*, *Labidocera aestiva*, *Temora turbinata* and *Eucalanus* spp. Among the cyclopoid copepods collected in Winyah Bay, only *Oithona colcarva* and *Halicyclops* spp. were common. Other cyclopoid species belonging to the genera *Corycaeus*, *Cyclops*, *Eucyclops*, *Macrocyclops*, *Mesocyclops*, *Oncaea*, *Orthocyclops*, *Saphirella*, and Tropocyclops occurred only sporadically. Euterpina acutifrons, a cosmopolitan form, was the only harpacticoid copepod which regularly occurred in the bay.

Other holoplanktonic crustaceans found in the study area included ostracods and cladocerans; however, these were not nearly as abundant as copepods. Other crustacean groups such as small decapod shrimps, isopods, amphipods, mysids, cumaceans, and stomatopods were uncommon in the zooplankton collections.

Among the non-crustacean holoplankton, medusae, rotifers, appendicularians and chaetognaths commonly occurred in the samples. At times, these comprised a large percentage of the total organisms in the collections (Tables 5-1 and 5-2).

The temporary or meroplanktonic forms consisted largely of the eggs and larval stages of fish and benthic invertebrates. The most common larvae found in the zooplankton collections were barnacles (nauplii and cyprids), crabs (zoeae), polychaetes, and molluscs (primarily gastropod veligers and bivalve larvae). During periods of peak abundance, these larvae accounted for a large percentage of total organisms in a sample. However, due to the diversity of these groups in the area, it is unlikely that multiple peaks of abundance represented larvae of the same species. Larvae of other benthic organisms were occasionally found at low densities. Pilidium larvae of nemerteans, Muller's larvae of turbellarians, actinotroch larvae of phoronids, cyphonautes larvae of bryozoans, and bipinnaria or pluteus larvae of echinoderms, were

Table 5-1. Relative abundance of the three most dominant categories expressed as percentage (in parentheses) of total zooplankton at each station on each extensive cruise. Italicized numbers are total categories present in each sample. ALL = annual means for each station; TOTAL = means for each cruise for all stations.

STATION	SEP	NOV	JAN	MAR	MAY	JUL	SEP	ALL
PR	*13*	*11*	*15*	*10*	*17*	*12*	*12*	*13*
	AT (82)	BN (62)	RF (53)	EA (77)	AT (65)	EA (59)	BN (46)	AT (30)
	BN (7)	PL (14)	CY (16)	HA (6)	CZ (9)	CZ (21)	AT (28)	EA (28)
	CN (3)	AT (8)	EA (8)	HC (6)	GV (8)	HC (15)	ME (11)	BN (10)
SR	*12*	*9*	*19*	*9*	*10*	*12*	*9*	*11*
	AT (84)	AT (48)	RF (36)	EA (91)	AT (72)	CZ (43)	BN (83)	AT (40)
	BN (10)	PL (19)	CY (24)	CL (3)	CZ (20)	HC (19)	BC (7)	BN (32)
	CN (2)	BN (13)	HA (11)	CN (2)	BN (4)	AT (18)	AT (6)	EA (10)
PD	*12*	*10*	*20*	*14*	*13*	*18*	*13*	*14*
	AT (85)	AT (63)	CL (33)	EA (72)	AT (83)	HC (35)	AT (63)	AT (72)
	BN (10)	FE (19)	CY (32)	GV (8)	BC (6)	CZ (15)	BN (27)	BN (8)
	PL (2)	PL (12)	HA (7)	CY (5)	PL (4)	CN (15)	ME (8)	BC (4)
WR	*11*	*13*	*14*	*20*	*10*	*13*	*8*	*13*
	AT (90)	FE (71)	OS (44)	EA (37)	EA (46)	EA (67)	ME (38)	AT (43)
	BN (5)	AT (14)	CY (17)	CL (28)	AT (45)	HC (25)	AT (38)	EA (38)
	PL (2)	CN (5)	TP (9)	CY (10)	HC (6)	CZ (3)	BN (23)	HC (6)
BI	*10*	*14*	*22*	*15*	*15*	*19*	*13*	*15*
	AT (85)	AT (76)	CL (30)	EA (72)	AT (69)	AT (72)	BN (48)	AT (68)
	BN (11)	BN (8)	CY (14)	CN (14)	CZ (15)	HC (11)	AT (43)	BN (13)
	CN (1)	PL (4)	EA (11)	CL (8)	BC (7)	CN (5)	ME (4)	CZ (5)
TA	*15*	*16*	*20*	*14*	*11*	*12*	*9*	*14*
	AT (92)	AT (84)	EA (37)	EA (67)	AT (94)	AT (47)	AT (97)	AT (90)
	BN (3)	CN (7)	CL (15)	CN (15)	BC (2)	PL (25)	BN (2)	PL (2)
	PC (1)	PL (2)	CY (11)	CP (9)	PL (1)	EA (17)	ME (.2)	BC (2)
PS	*13*	*14*	*21*	*16*	*10*	*14*	*8*	*13*
	AT (79)	AT (81)	EA (35)	EA (38)	AT (93)	AT (94)	AT (97)	AT (90)
	PC (7)	PC (9)	OS (29)	CN (36)	PC (4)	PL (2)	BN (2)	PC (4)
	BN (6)	BN (4)	CL (7)	OC (9)	BN (1)	CZ (1)	PC (.5)	BN (2)
TC	*21*	*16*	*24*	*17*	*13*	*20*	*16*	*18*
	AT (69)	AT (43)	HA (20)	OC (37)	AT (73)	AT (44)	AT (67)	AT (62)
	BN (18)	BN (42)	OS (10)	EA (15)	BC (8)	CZ (22)	BN (21)	BN (13)
	PE (2)	PC (4)	EA (9)	PC (11)	PC (7)	GV (15)	GV (3)	CZ (6)
EP	*14*	*21*	*28*	*15*	*17*	*17*	*11*	*18*
	AT (79)	BN (69)	CH (31)	OS (31)	AT (64)	CN (29)	BN (50)	AT (53)
	BN (12)	PC (8)	AT (23)	EA (20)	PC (12)	HC (24)	AT (42)	BN (20)
	PE (3)	AT (5)	CN (13)	CY (14)	BN (10)	AT (23)	BC (6)	PC (2)
MB	*15*	*25*	*29*	*30*	*20*	*19*	*16*	*22*
	AT (75)	PC (24)	EA (23)	OC (27)	AT (42)	AT (54)	AT (75)	AT (55)
	BN (7)	BN (21)	BC (14)	OS (18)	BN (20)	BN (11)	BN (7)	BN (13)
	PC (7)	OC (11)	CL (8)	CN (11)	PC (11)	GV (9)	GV (4)	PC (8)
SB	*27*	*25*	*31*	*24*	*24*	*25*	*28*	*26*
	PC (33)	BN (24)	CP (28)	OC (41)	PC (42)	AT (33)	AT (31)	PC (29)
	BN (21)	PC (24)	CN (12)	CH (29)	BN (23)	BN (23)	PC (22)	BN (20)
	AT (12)	CP (16)	OC (8)	PC (8)	EU (8)	GV (10)	BN (8)	AT (14)
TOTAL	*15*	*16*	*22*	*17*	*15*	*16*	*13*	--
	AT (77)	AT (44)	RF (18)	EA (61)	AT (65)	AT (39)	AT (53)	AT (58)
	BN (13)	BN (22)	CY (12)	OC (9)	PC (7)	EA (14)	BN (32)	BN (13)
	PC (4)	PC (9)	EA (10)	CN (5)	EA (6)	CZ (12)	ME (3)	EA (5)

Organism abbreviations:

AT = *Acartia tonsa* adults & copepodids
BC = barnacle cyprids
BN = barnacle nauplii
CH = *Centropages hamatus*
CL = cladocerans
CN = copepod nauplii
CP = all other copepodids
CY = unidentified cyclopoid copepods
CZ = crab zoeae
EA = *Eurytemora affinis*
EU = *Euterpina acutifrons*
FE = fish eggs & larvae

GV = gastropod veligers
HA = unidentified harpacticoid copepods
HC = *Halicyclops* spp.
ME = medusae
OC = *Oithona colcarva*
OS = ostracods
PC = *Parvocalanus crassirostris*
PE = *Pseudodiaptomus coronatus*
PL = polychaete larvae
RF = rotifers
TP = *Tropocyclops prasinus*

Table 5-2. Relative abundance of the three most dominant categories expressed as percentage (in parentheses) of total zooplankton at each station on each intensive cruise. Italicized numbers are total categories present in each sample. S = surface tow; B = bottom tow; ALL = annual means for each station.

STATION	US		MS		LS	
TOW	S	B	S	B	S	B
CRUISE						
SEP	*15* AT (86) BN (6) CN (3)	*11* AT (59) GV (27) BN (5)	*21* AT (74) BN (7) PC (7)	*22* AT (52) PC (14) PL (7)	*29* PC (27) AT (14) PL (12)	*24* PC (32) AT (23) PL (16)
NOV	*11* AT (80) CN (8) PL (7)	*14* AT (87) CN (6) PL (5)	*22* AT (52) BN (17) PC (8)	*23* AT (60) PC (11) PL (6)	*26* PC (33) OC (20) PL (17)	*25* PC (34) OC (19) PL (12)
JAN	*21* CL (42) CY (18) RF (12)	*21* CL (42) CY (23) CN (6)	*30* FE (48) CL (9) CY (8)	*34* UC (11) FE (11) CY (10)	*16* CP (29) PC (19) AT (15)	*24* CP (25) PC (23) AT (13)
MAR	*15* CN (24) EA (20) CL (19)	*13* EA (53) CN (32) HA (6)	*19* OC (39) PC (16) BN (12)	*29* OC (37) CN (21) HA (10)	*16* OC (73) CH (12) PC (4)	*18* CH (67) OC (13) PC (7)
MAY	*11* AT (63) CZ (30) HC (3)	*15* AT (97) CZ (1) GV (1)	*17* AT (86) PC (4) CZ (3)	*21* AT (78) PC (10) BC (5)	*26* PC (52) CT (13) BC (6)	*29* PC (50) AT (9) BC (8)
JUL	*16* AT (36) CZ (28) HA (4)	*23* AT (59) CZ (17) GV (8)	*14* AT (41) BN (39) CZ (5)	*22* AT (52) OC (8) PC (8)	*23* PC (21) AT (19) BN (18)	*26* PC (24) AT (22) CN (12)
SEP	*6* AT (46) BN (45) ME (8)	*14* BN (54) AT (29) BC (5)	*19* BN (63) AT (19) PC (8)	*20* AT (36) GV (18) PC (14)	*22* BN (42) AT (18) PC (16)	*30* BN (25) AT (25) PC (22)
ALL	*14* AT (64) BN (9) CZ (6)	*16* AT (67) BN (11) GV (8)	*20* AT (57) BN (24) PC (6)	*24* AT (53) PC (12) GV (5)	*23* PC (25) OC (15) BN (13)	*25* PC (30) AT (18) PL (10)

Organism abbreviations:

AT = *Acartia tonsa* adults & copepodids
BC = barnacle cuprids
BN = barnacle nauplii
CH = *Centropages hamatus*
CL = cladocerans
CN = copepod nauplii
CP = all other copepodids
CT = chaetognaths
CY = unidentified cyclopoid copepods
CZ = crab zoeae
EA = *Eurytemora affinis*

FE = fish eggs & larvae
GV = gastropod veligers
HA = unidentified harpacticoid copepods
HC = *Halicyclops* spp.
ME = medusae
OC = ostracods
PC = *Parvocalanus crassirostris*
PL = polychaete larvae
RF = rotifers
UC = unidentified calanoid copepods

identified in some collections.

I. TAXONOMIC DIVERSITY

Zooplankton samples collected during both extensive and intensive series showed large spatial and temporal variations in organism density and composition throughout the bay. Although the common species were widely distributed, each station was usually dominated by only a few taxonomic categories. Generally, the three most abundant categories in a sample comprised from 70 to over 90% of the total organisms (Tables 5-1 and 5-2). Results from the extensive series showed that the most seaward stations (MB and SB) were generally the most diverse with 15 to 31 zooplankton categories represented in any given sample (mean ± S.D. : 24.1 ± 5.0). SB consistently had at least 24 categories in each sample. Results from the other stations were highly variable with patterns of seasonal occurrence (Table 5-1). Upper estuary stations (PR, SR, PD, and WR) were generally the least diverse with 8-20 categories in each sample (mean ± S.D. : 12.8 ± 3.3). The middle bay stations (BI, TA, PS, TC, and EP) had 8-28 categories (mean ± S.D. : 15.2 ± 5.1).

The intensive series revealed a similar pattern. The upper station (US) was the least diverse (6-23 categories, mean ± S.D. : 16.1 ± 4.3; Table 5-2). The middle intensive station (MS) had 14-34 categories, (mean ± S.D. : 24.7 ± 4.8), and the lower station (LS) had

16-30 categories (mean ± S.D. : 25.0 ± 3.9; Table 5-2).

In general, taxonomic diversity increased during the winter when low numbers (1-10/m^3) of freshwater species, especially cyclopoid copepods, occurred in the upper bay. This is in contrast to the findings for No Man's Friend and South Jones Creeks and North Inlet, where diversity was greatest during the warmer months when larval forms were introduced from high salinity areas (Allen et al., 1982; Barker unpublished). Most freshwater copepods never occurred in the vicinity of NMF and SJ in the middle bay.

II. TOTAL ZOOPLANKTON

Total zooplankton densities were generally much lower in the riverine extensive stations (PR, SR, PD, and WR with annual means of 6000 - 9500/m^3) for most of the year, except when one or two species occurred at exceptionally high densities (Fig. 5-1; Appendix III. A). With the exception of EP, which generally had low total zooplankton numbers (annual mean : 7700/m^3), all extensive stations had overall mean densities of 10000-13000/m^3 (Fig. 5-1). The mean densities for most stations were similar to those reported for No Man's Friend and South Jones Creeks (8100/m^3: Allen et al., 1982), but were much lower than the North Inlet LTER collections (two-year mean = 20,000/m^3: Barker, unpublished).

Total zooplankton densities were greatest during the warmer months; the highest overall density (26,000/m^3) occurred in May. Densities

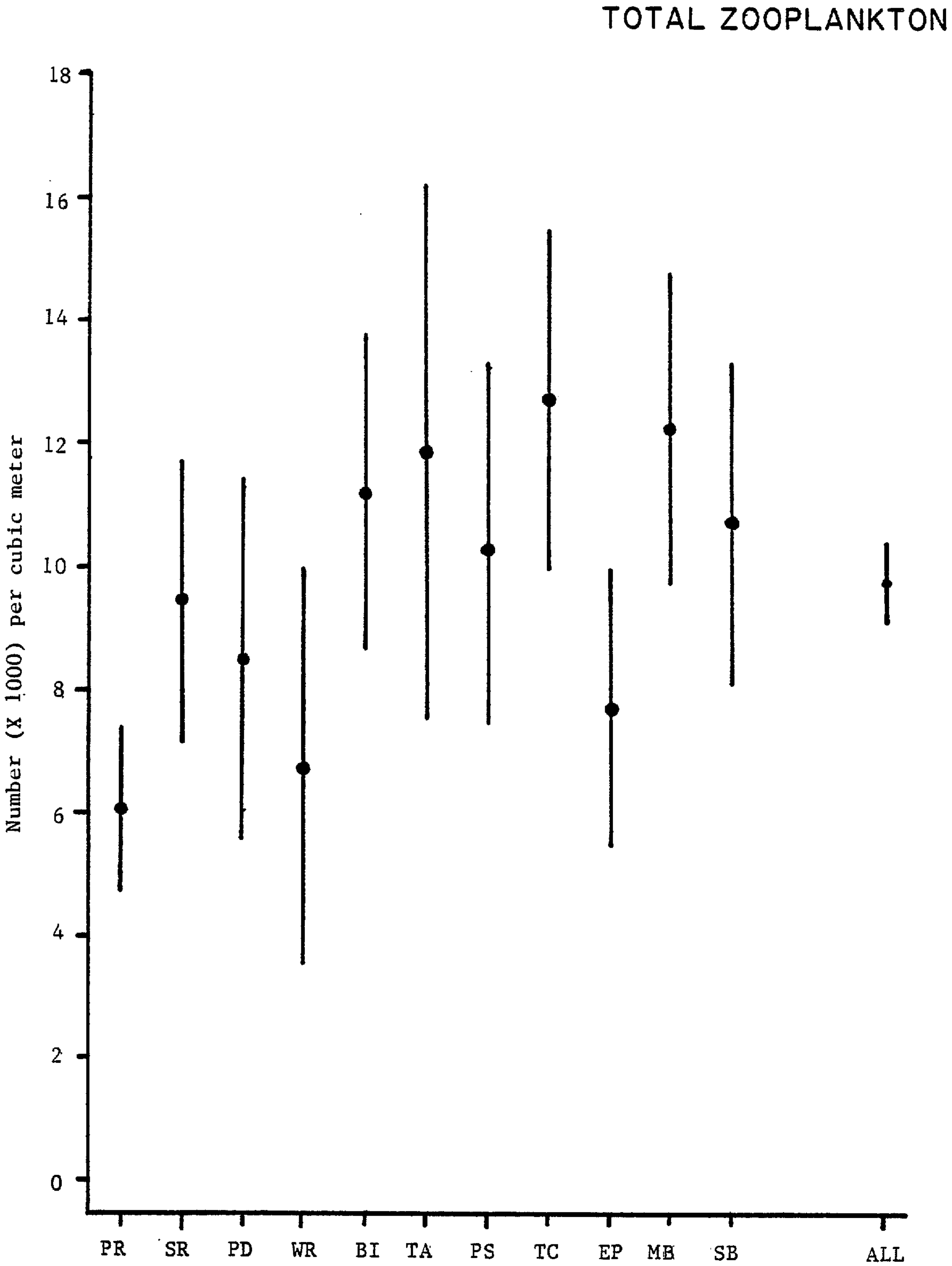


Fig. 5-1. Mean density (± 1 S.E.) of total organisms in zooplankton collections at 11 extensive series stations in Winyah Bay. Each mean is based on 14 samples taken over a 13 month period. A value based on all 154 collections is shown.

were generally about an order of magnitude lower during the winter months (Fig. 5-2). This was primarily due to the decrease in abundance or absence of dominant copepods such as Acartia tonsa and Parvocalanus crassirostris and the meroplankton. The exceptionally high total density rendered in May was the result of peak abundances of: (1) Acartia tonsa, Parvocalanus crassirostris, and meroplankton at most stations; (2) Eurytemora affinis and Halicyclops spp. at WR; and (3) Euterpina acutifrons and chaetognaths at SB.

A similar temporal pattern of total zooplankton abundance was observed during the intensive cruises (Figs. 5-3, 5-4, and 5-5). Values for both surface and bottom tows were about an order of magnitude lower during winter months. Average total zooplankton numbers were higher at the bottom than at the surface (Appendix IV.A). At the upper station (US), total density was much higher at the bottom that at the surface throughout the year, except in winter (Fig. 5-3). Surface densities of total zooplankton ranged from $170/m^3$ in January to $1200/m^3$ in May, while bottom densities ranged from $150/m^3$ in January to $41800/m^3$ in May. The large difference during May was due to exceptionally high bottom densities in Acartia tonsa adults and copepodids (Appendix IV.B).

At the middle station (MS), differences between surface and bottom densities were evident only in September 1981 and July 1982 when bottom numbers were almost double those at the surface (Fig. 5-4). This was due to much higher bottom densities of Acartia tonsa, Parvocalanus crassirostris, Oithona colcarva, polychaete larvae and gastropod veligers.

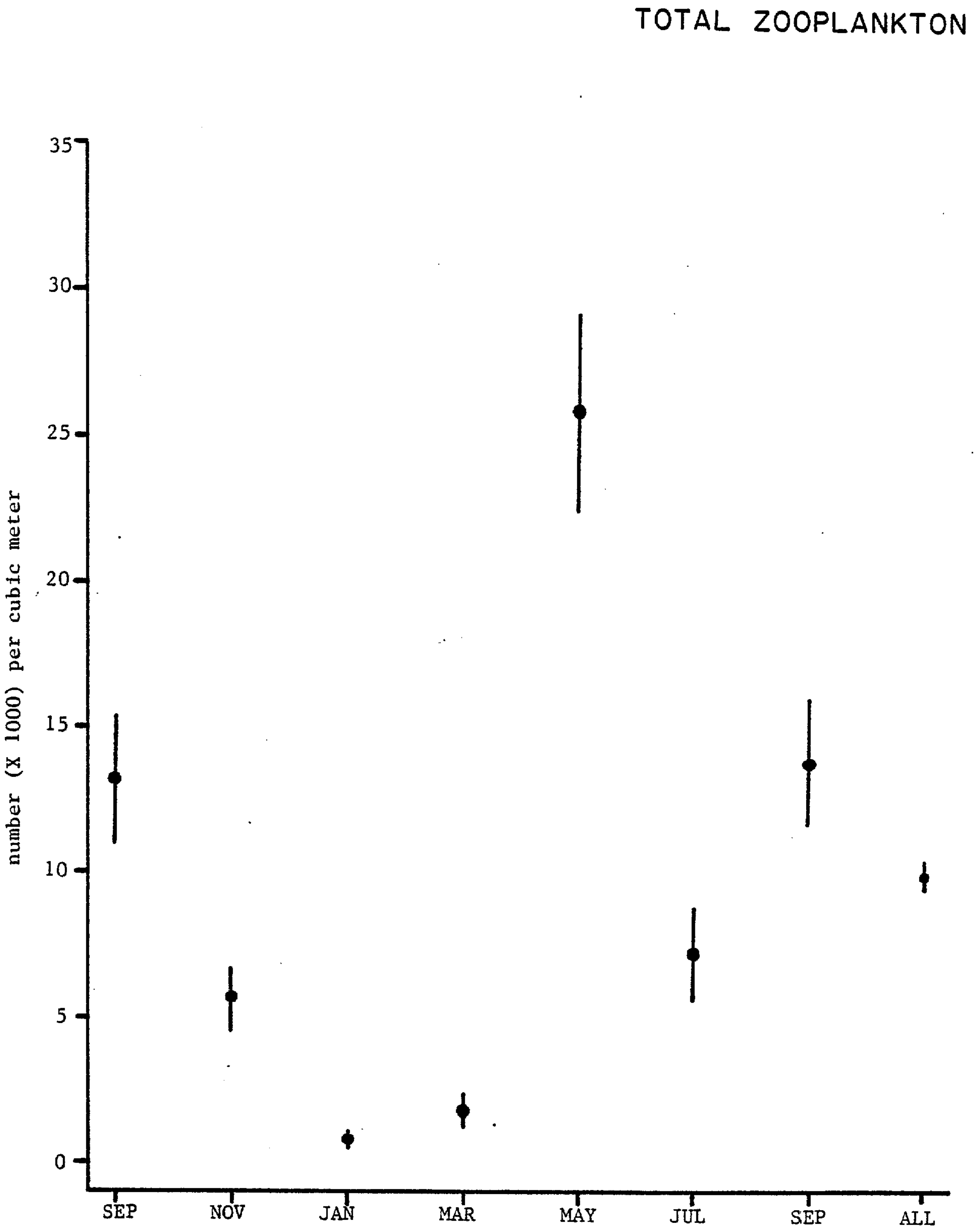


Fig. 5-2. Mean densities (± 1 S.E.) of total organisms in zooplankton collections for each extensive series cruise in Winyah Bay. Each mean is based on 22 samples taken at 11 stations on each cruise. A value based on all 154 collections is shown.

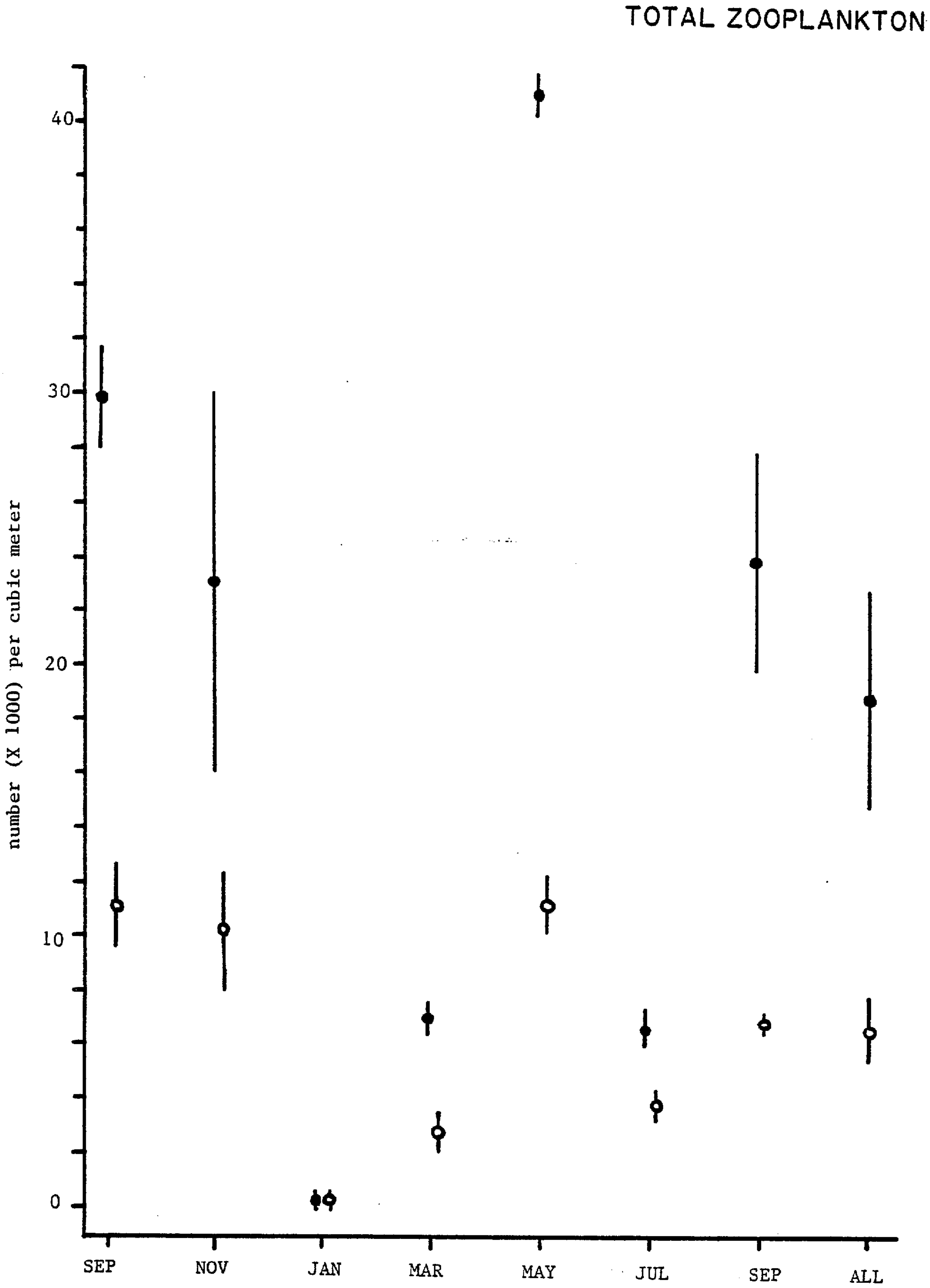


Fig. 5-3. Mean densities (± 1 S.E.) of total organisms in zooplankton collections at the upper station (US) during the intensive series cruises in Winyah Bay. Surface (°) and bottom (•) level values are shown for each of the seven cruises plus all cruises combined.

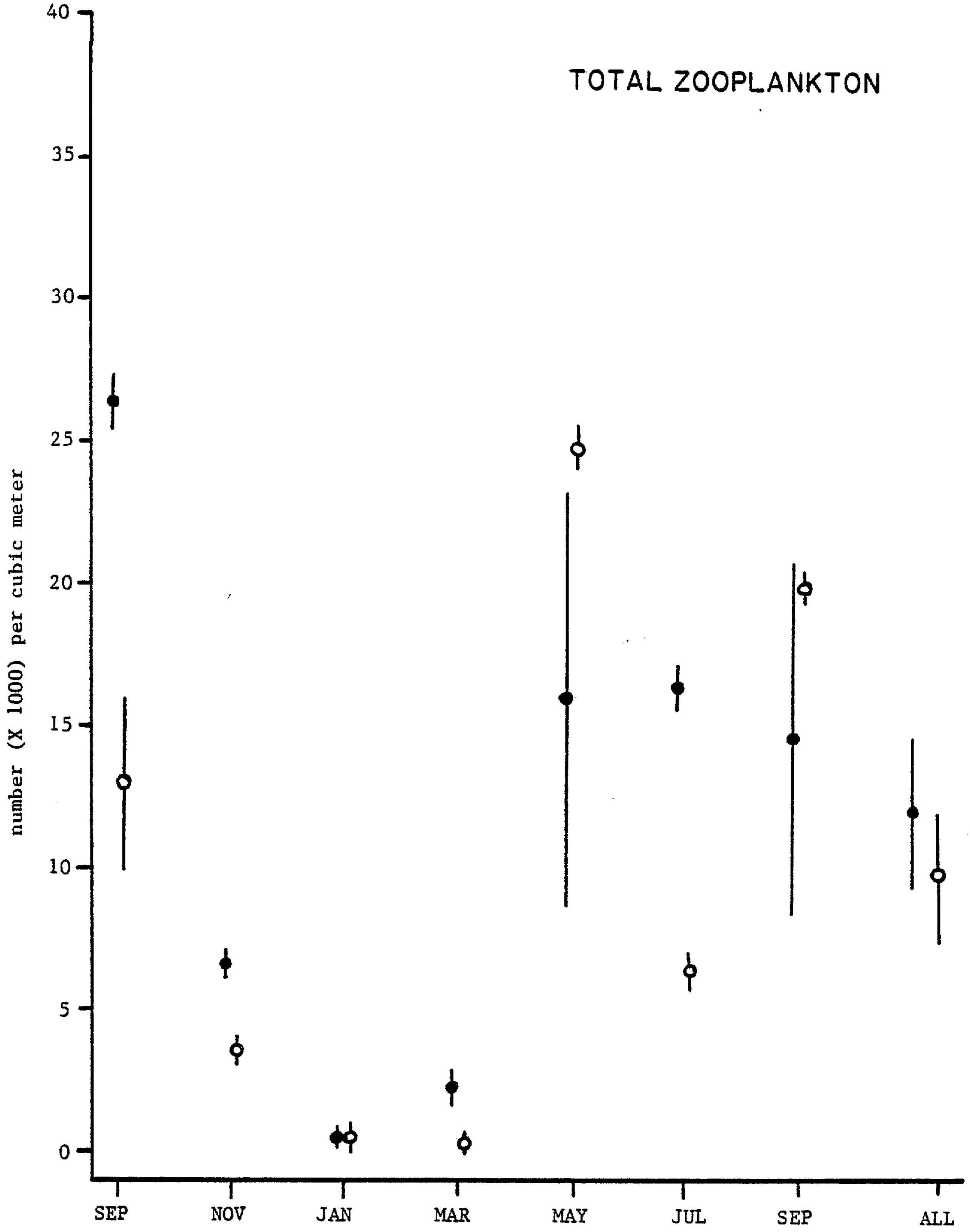


Fig 5-4. Mean densities (1. S.E.) of total organisms in zooplankton collections at the middle station (MS) during the intensive series cruises in Winyah Bay. Surface (°) and bottom (•) level values are shown for each of the seven cruises plus all cruises combined.

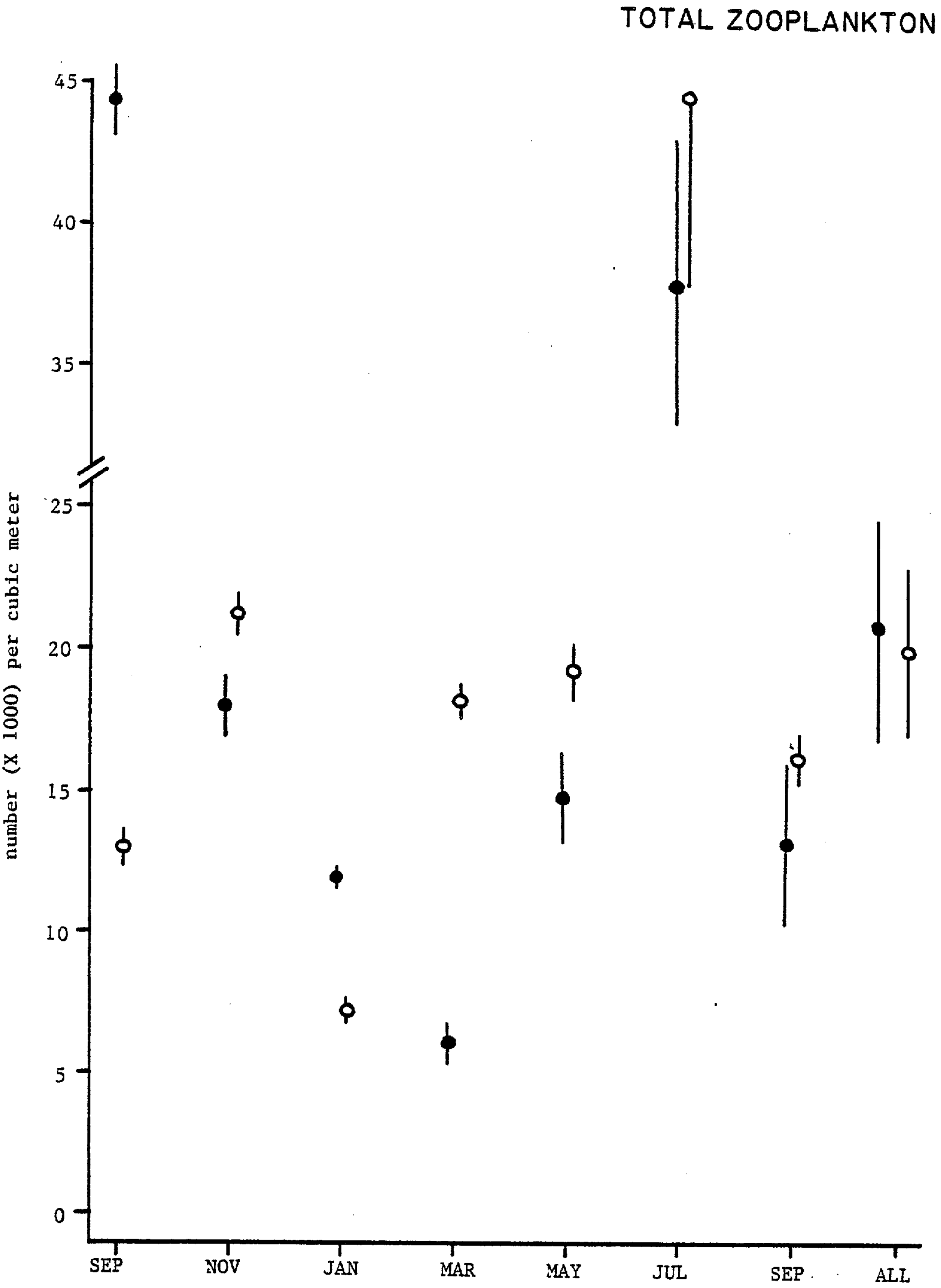


Fig. 5-5. Mean densities (1 S.E.) of total organisms in zooplankton collections at the lower station (MN) during the intensive series cruises in Winyah Bay. surface (°) and bottom(•) level values are shown for each of the seven cruises plus all cruises combined.

At other times, there were no significant differences between surface and bottom concentrations.

At the lower station (LS), differences between surface and bottom densities were less evident (Fig. 5-5). Bottom concentrations were higher only in September 1981 (44400/m^3 vs. 13000/m^3) and January 1982 (12000/m^3 vs. 72/m^3) due to greater numbers of *A. tonsa*, *P. crassirostris*, *O. colcarva*, polychaete larvae and bivalve larvae. During other periods, surface densities were generally higher (Fig. 5-5).

During the 48-hour sampling at Mother Norton, the bihourly trends of surface and bottom densities were similar, with peak abundance occurring shortly after high tides (Fig. 5-6). Although mean abundance of total zooplankton was higher for surface tows, the difference was not statistically significant (Table 5-3). Based on this single 48-hour sampling period, no apparent relationship was evident between total abundance and the time of day (day/night).

III. DOMINANT ZOOPLANKTON CATEGORIES

The zooplankton community in Winyah Bay was dominated by relatively few copepod and meroplanktonic species (Table 5-1 and 5-2). Although mean densities and the presence or absence of other minor categories varied, the stations generally had similar dominant species on any cruise. Copepods comprised at least half of the total zooplankton at each station

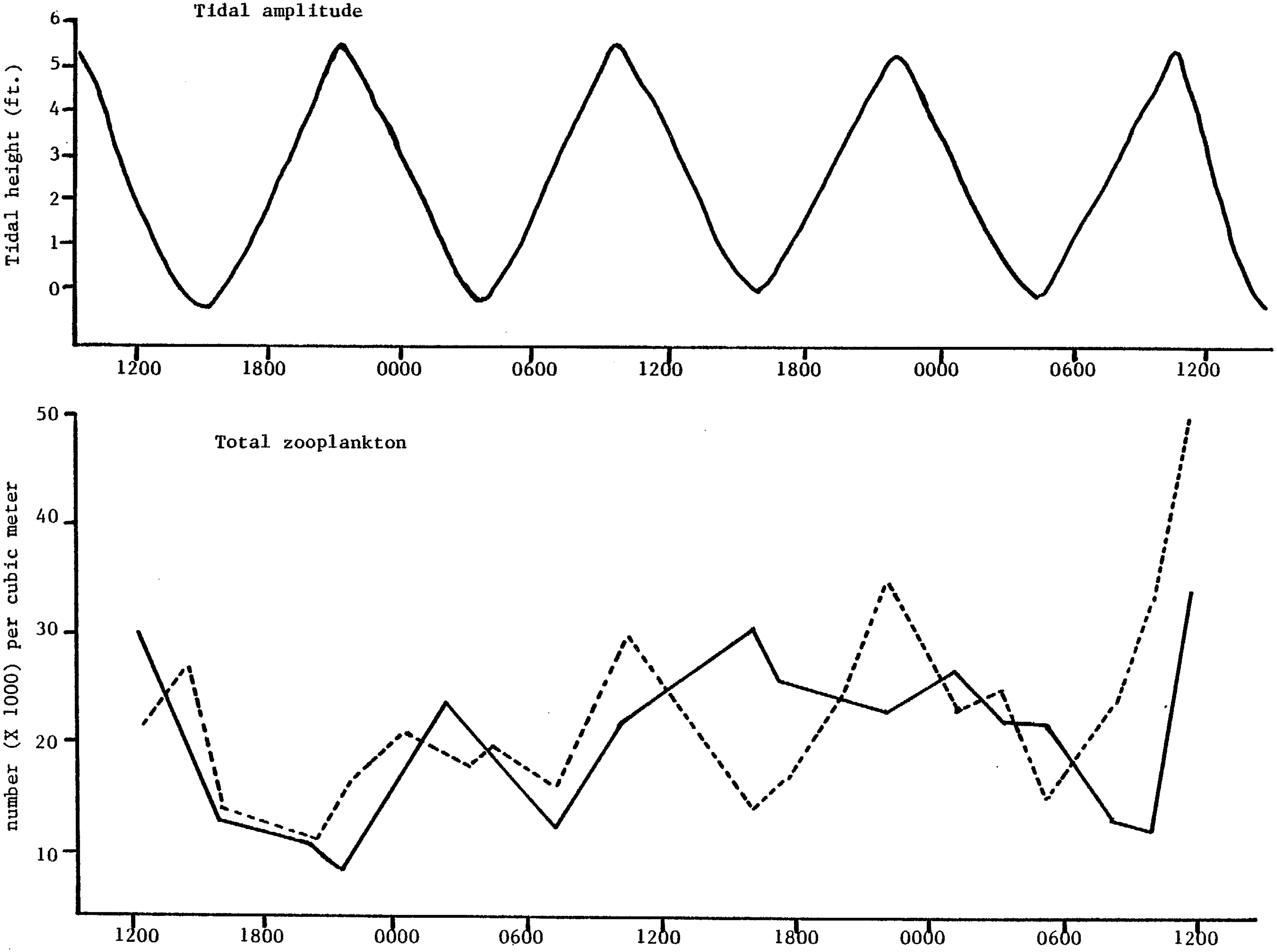


Fig 5-6. Mean densities of total zooplankton at surface (dotted) and bottom (solid) during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

Table 5-3. Comparative abundance (mean #/m^3 ± S.E.) of zooplankton from surface and bottom tows taken during the 48-hour sampling at Mother Norton.

Category	SURFACE	BOTTOM
Acartia tonsa	3146.78 ± 432.37	2495.56 ± 421.89
Acartia copepodids **	1719.65 ± 154.45	1092.46 ± 168.98
Paracalanus crassirostris	3371.75 ± 325.63	3021.79 ± 360.34
Euterpina acutifrons	1009.50 ± 81.08	860.71 ± 64.02
Oithona colcarva	695.98 ± 95.98	498.30 ± 59.94
Pseudodiaptomus coronatus *	274.85 ± 29.40	387.69 ± 40.14
Other copepods	993.86 ± 168.93	915.38 ± 125.00
Copepod nauplii	666.39 ± 95.02	421.86 ± 50.83
Other copepodids	447.72 ± 64.30	467.62 ± 77.94
[Total copepods *	12326.48 ± 788.58	10146.28 ± 802.65]
Barnacle nauplii *	4171.48 ± 850.49	2336.57 ± 382.76
Echinoderm larvae	822.98 ± 207.13	715.48 ± 189.81
Polychaete larvae	435.72 ± 56.97	445.53 ± 63.69
Gastropod veligers	744.00 ± 137.98	1028.67 ± 149.92
Crab zoeae	266.50 ± 51.20	169.66 ± 37.80
Other organisms	2904.42 ± 243.46	3921.46 ± 343.04
TOTAL ORGANISMS	23353.16 ± 1625.47	20374.31 ± 1224.38

N.B. Categories with asterisks show significant differences in surface and bottom abundances: * p=0.05, ** p=0.01.

(Fig. 5-7) throughout the year (Fig. 5-8). Total copepods (represented as a percentage of the total zooplankton) ranged from 53% at SR to 95% at PS (Fig. 5-7); in the North Inlet LTER study, copepods comprised 70-85% of the total catch over a two-year period (Barker, unpublished).

Some species of copepods were present throughout the year and they accounted for about 60% of total zooplankton in September to 90% in March (Fig. 5-2). Although they were not necessarily found in abundance at all stations, five copepod species (*A. tonsa*, *P. crassirostris*, *P. coronatus*, *E. acutifrons*, and *O. colcarva*) were year-round residents in the bay. Peak densities were observed during the spring and summer cruises. Other copepods appeared only during certain periods of the year. *E. affinis* and *Halicyclops* spp. were found only between January and July, while *Centropages hamatus* appeared only at the lower bay stations from November to July.

The most common larval forms were barnacle nauplii and cyprids, crab zoeae, polychaete larvae, gastropod veligers and bivalve larvae. These groups exhibited distinct seasonal patterns in abundance, generally reaching peak densities in spring and summer. Other seasonal non-copepod forms included medusae, chaetognaths and appendicularians which occurred in warmer months, and cladocerans, ostracods and rotifers which appeared during colder months (Table 5-1 and 5-2). Other planktonic organisms occurred sporadically and at very low densities.

Fig 5-7. Percent composition of zooplankton taxa at all 11 extensive series stations in Winyah Bay in 1981-82. The value for each taxa is a mean based on densities for all 7 cruises at that station.

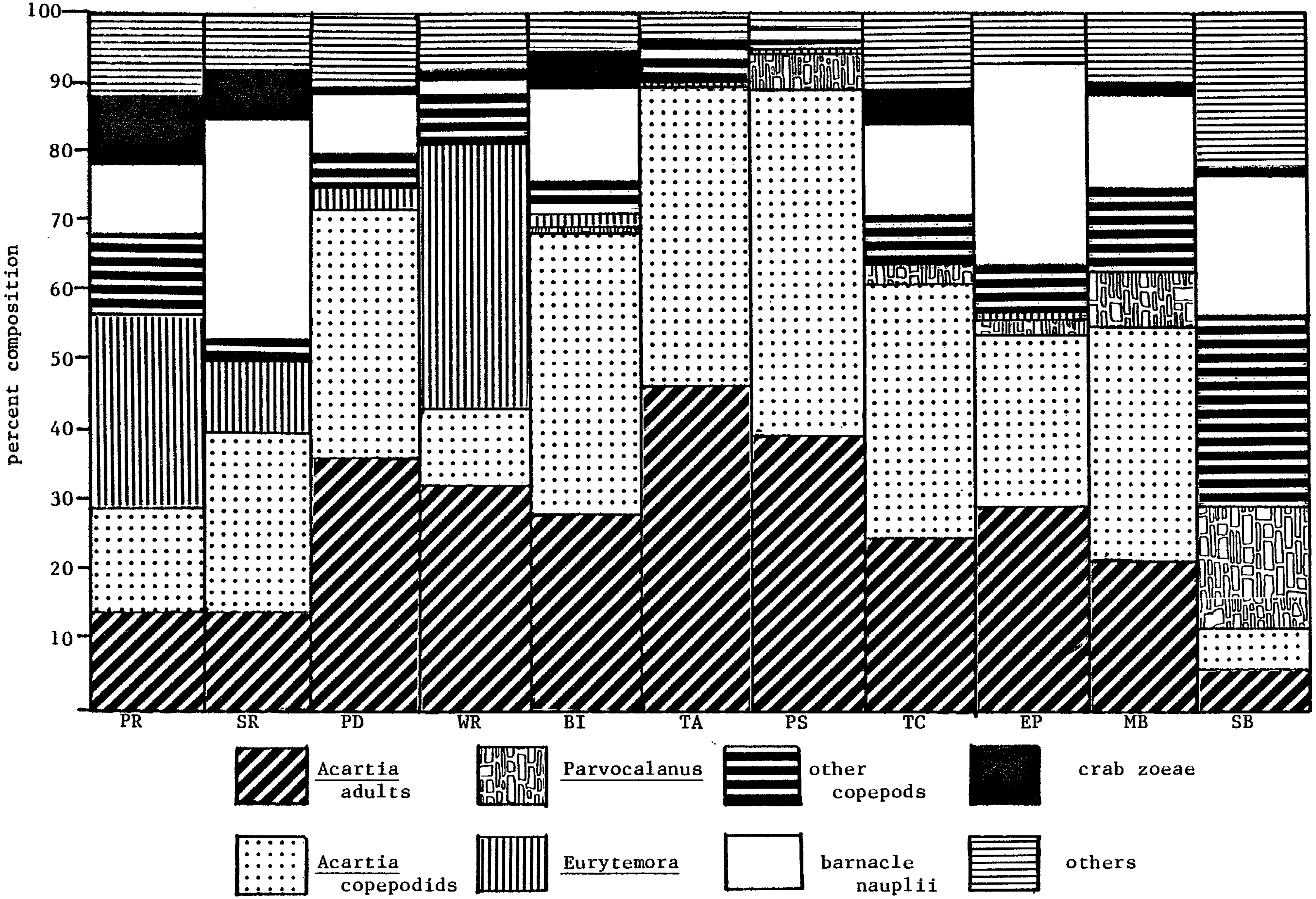
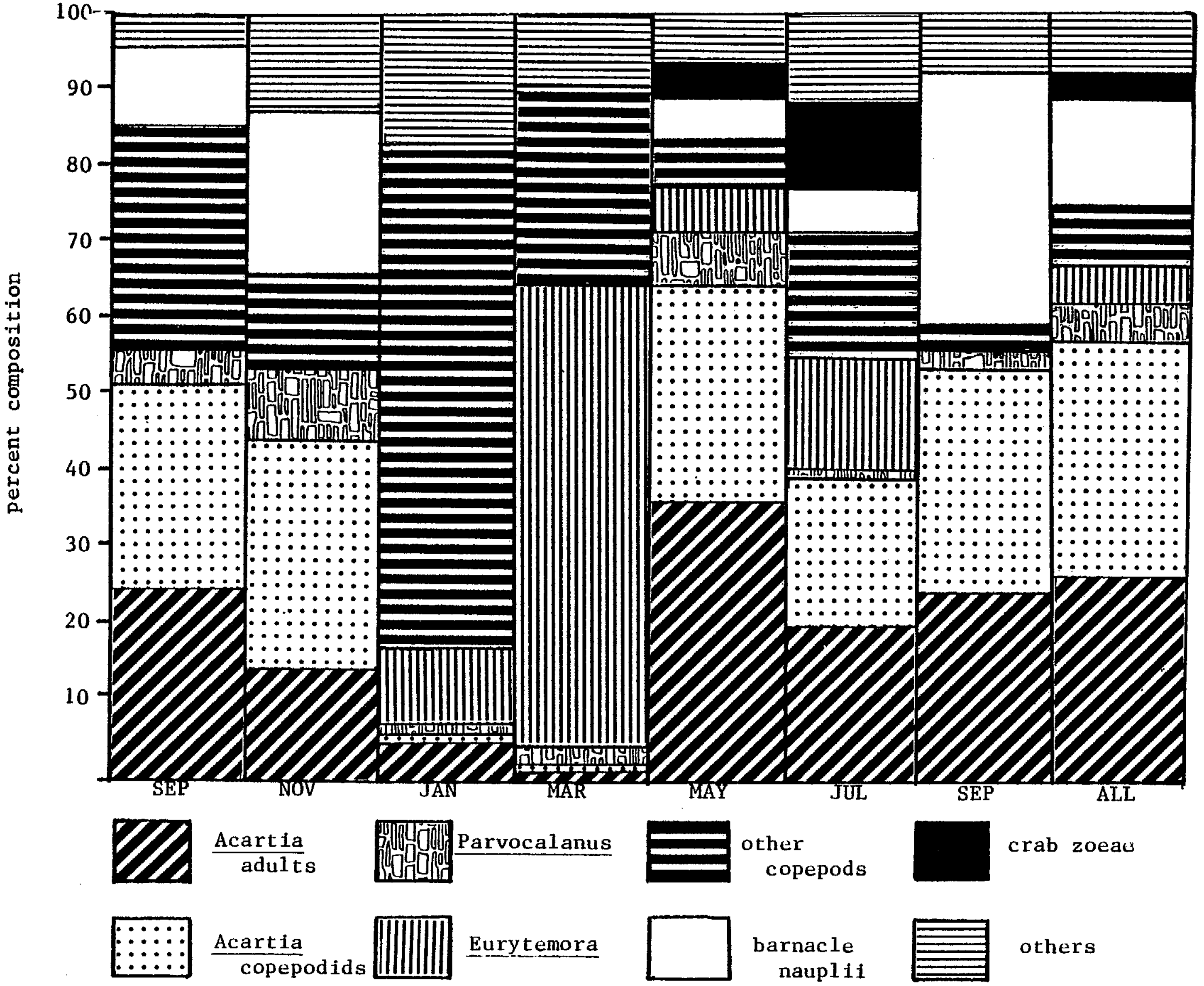


Fig 5-8. Percent composition of zooplankton taxa on all 7 extensive series cruises in Winyah Bay in 1981-82. The value for each taxa is a mean based on densities for all 11 stations on that cruise.



IV. COPEPODS

A. Acartia tonsa

Acartia tonsa dominated the Winyah Bay ecosystem. It accounted for nearly 60% of all zooplankton collected during the study (Table 5-1). Mean densities which ranged from 1500/m^3 at SB to 11000/m^3 at TA were similar to values reported for No Man's Friend and South Jones Creeks (Allen et al., 1982). Adults and copepodids of A. tonsa, when present, generally comprised a significant portion of total zooplankton at all stations (Table 5-1; Fig. 5-7). Average annual abundance of the species was generally higher at the middle bay stations, where adults and copepodids comprised about 90% of all zooplankton at TA and PS and 60 to 70% at BI and TC (Fig. 5-7). The abundance of A. tonsa ranged from 15-20% of total zooplankton at the seaward stations (MB and SB) to 40-70% at the riverine stations (PR, SR, PD, and WR). A true euryhaline species with broad salinity tolerance range, A. tonsa is generally more abundant in bays and rivers than in oceanic waters (Grice, 1960; Lance, 1963; Bowman, 1971; Sandifer et al., 1980).

Although A. tonsa was present year-round (especially at the lower bay stations), distinct seasonal variations in abundance occurred. It was absent at upper bay stations and was rare at the other stations during winter; highest densities occurred at all stations in spring and summer (Fig. 5-8; Appendix III.C,D). A warm-water species, A. tonsa comprised less than 5% of the zooplankton during winter months (January-

March), but accounted for 40-80% during other months. These temporal patterns are similar to those reported for other estuarine systems (Sutcliffe, 1948; Woodmansee, 1958; Lonsdale and Coull, 1977; Sandifer et al., 1980; Allen et al., 1982).

During the intensive sampling series, similar spatial and temporal patterns were observed for A. tonsa (Table 5-2). Both adults and copepodids reached peak densities at the three stations during the spring and summer months. With few exceptions, A. tonsa densities were higher at the bottom than at the surface during these months of peak abundance (Appendix IV.B). Surface densities were 1300, 3000 and 800/m^3 at US, MS and LS, respectively; corresponding bottom concentrations were 6100, 4000 and 2200/m^3.

In contrast to this pattern, a series of paired *t*-tests showed surface densities of Acartia copepodids during the 48 hour study to be significantly greater than bottom densities. Additionally, higher densities of adult Acartia occurred at the surface (Table 5-3). Combined adult and copepodid densities were significantly higher at the surface. Both surface and bottom peak abundances generally occurred shortly before low tides (Fig. 5-9).

B. Eurytemora affinis

This calanoid copepod comprised 5.5% of all zooplankton collected in the study, making it the second most abundant copepod in the Winyah Bay Estuary. When present, it was common at the upper and middle bay

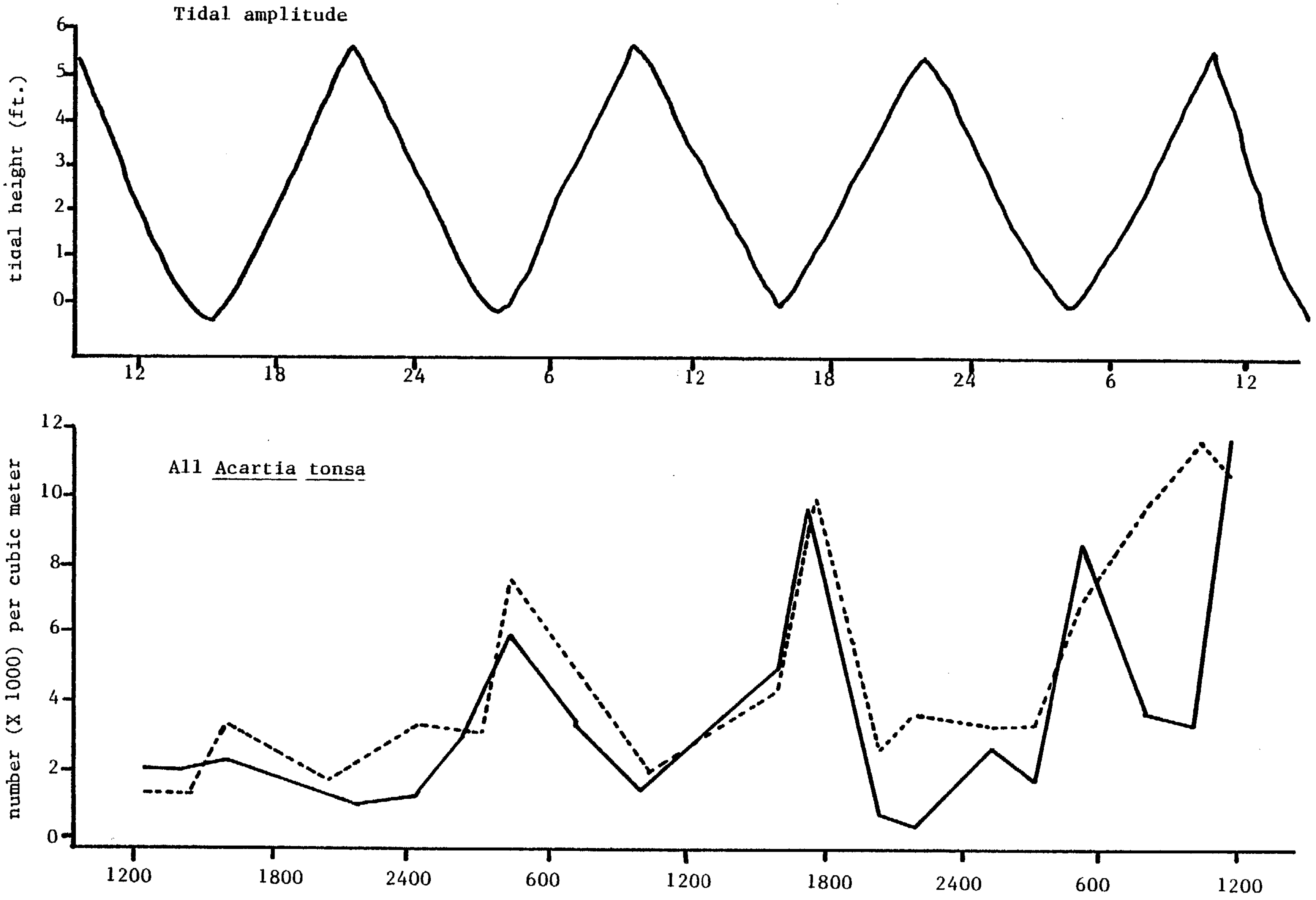


Fig 5-9. Mean densities of all *Acartia tonsa* (adults and copepodids) at surface (dotted) and bottom (solid) during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

stations and rare at the most seaward stations (Appendix III.E). Characteristic of fresh or less brackish waters, E. affinis was the most dominant copepod at PR and WR, where it accounted for 28% and 38% of all zooplankton, respectively (Fig. 5-7). It reached a peak density of 16000/m^3 at WR and 9000/m^3 at PR. E. affinis also comprised a sizable percentage of all zooplankton at SR, PD, BI and TA, where it was the second most dominant copepod (Fig. 5-7; Table 5-1). This large calanoid copepod was only occasionally collected in low densities at the lower bay stations (Appendix III.E). Its occurrence in low salinity waters was also noted at No Man's Friend and South Jones Creeks (Allen et al., 1982) and in North Inlet (Barker, unpublished).

A distinctly seasonal species, E. affinis first appeared at all stations (except WR) in January and reached peak abundances in late spring and early summer (Fig. 5-8; Appendix III.E). It became the most dominant organism in March when it accounted for over 60% of all zooplankton and was the second most abundant copepod in the system in July (Fig. 5-8).

During the intensive series, E. affinis most commonly occurred between January and July at the upper station (US), where it was the dominant copepod in March (Table 5-2). With the exception of a few individuals taken in bottom tows at MS in January and March, it was not collected at MS and LS (Appendix IV.C). At US, during peak abundance in March, bottom density (3700/m^3) was much higher than the surface density (600/m^3).

C. *Parvocalanus crassirostris*

Overall, *P. crassirostris* was the third most abundant copepod in the Winyah Bay Estuary. It comprised 5% of the total zooplankton on an annual basis. This is in contrast to observations at No Man's Friend Creek, South Jones Creek and North Inlet where it was the most abundant copepod (Allen et al., 1982; Barker, unpublished). *P. crassirostris* was generally most abundant at the stations nearest the ocean and was either rare or absent at the riverine stations (PR, SR, PD, WR) (Fig. 5-7). At station SB, *P. crassirostris* was the most abundant copepod, accounting for nearly 30% of all zooplankton. It was the second most abundant copepod at MB and comprised large percentages at BI, PS, TC, and EP. Densities at MB and SB were usually up to an order of magnitude higher than those at the other stations (Appendix III.F).

Although densities were generally low during winter months, *P. crassirostris* was present year-round, especially at the most seaward stations (Fig. 5-8). With the exception of May collections at SB when mean abundance was $13100/m^3$, mean densities during the warmer months ranged from 1000 to $3400/m^3$. These densities were similar to values reported for No Man's Friend and South Jones Creeks (about $3200/m^3$: Allen et al., 1982), but they were much lower than those at North Inlet ($15 - 20,000/m^3$: Barker, unpublished). Concentrations at the lower bay stations during winter months were an order of magnitude lower than during other periods.

On the intensive cruises, *P. crassirostris* was absent or rare at the upper station (US) and had highest densities at the lower station (LS) during all months (Appendix IV.C). When abundant, the species comprised similar proportions of total zooplankton in both surface and bottom tows (Table 5-2). On most cruises, surface and bottom densities were equivalent (Appendix IV.C).

A similarity between surface and bottom densities was also observed during the 48-hour sampling series at Mother Norton (Table 5-3). Peak densities tended to occur shortly after high tides (Fig. 5-10).

D. Pseudodiaptomus coronatus

P. coronatus, a relatively large calanoid species, was generally found at the lower bay stations (primarily TC, EP, MB and SB) where it comprised about 2% of all zooplankton at each station (Appendix III.G). At peak abundance, mean densities only ranged from 100 and 900/m^3. These were similar to values reported for No Man's Friend and South Jones Creeks (Allen et al., 1982).

Although it is considered a fall-winter species in the southern part of its range (Sutcliffe, 1948; Woodmansee, 1958; Sandifer et al., 1980), P. coronatus disappeared in winter form all stations except MB and SB where it was rare. Peak densities occurred in late spring and fall at most stations. The exception was at SB where highest concentrations were recorded during July. At the mouth of North Inlet, high densities occurred from late winter through summer (Lonsdale and Coull, 1977).

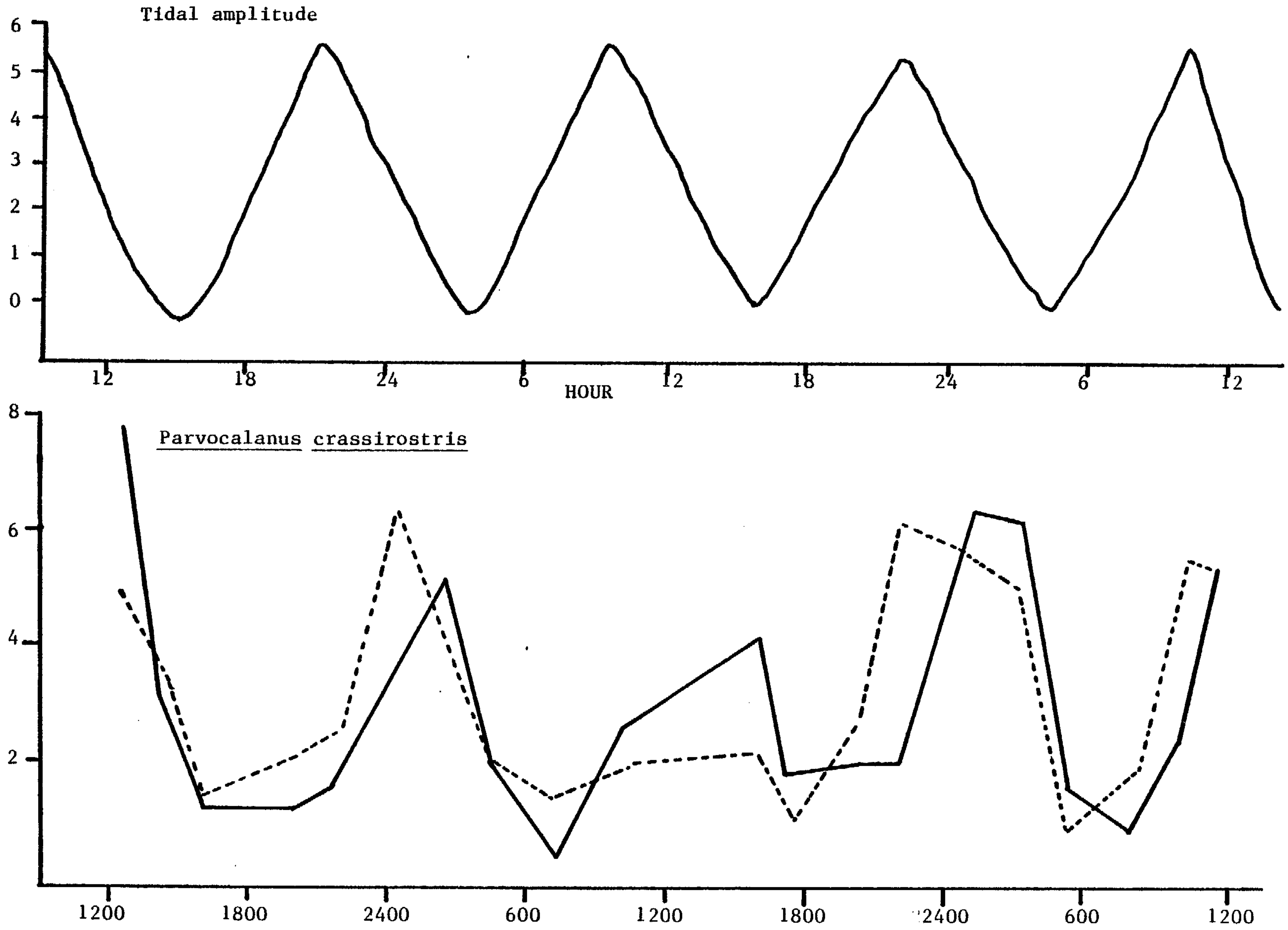


Fig 5-10. Mean densities of *Parvocalanus crassirostris* at surface (dotted) and bottom (solid) during the 48 hour sampling at Mother Norton Shoal (September 18-20, 1982).

Pseudodiaptomus coronatus showed some degree of vertical stratification. Densities were consistently higher at the bottom than at the surface during all intensive cruises (Appendix IV.D). This pattern was shown to be statistically significant during the 48-hour series at Mother Norton (Table 5-3). Jacobs (1961) found greatest densities of the copepodids of *P. coronatus* at the bottom of Georgia estuaries and contended that this species was not truly planktonic since it attached to suspended material.

E. *Euterpina acutifrons*

Euterpina acutifrons was the most abundant pelagic harpacticoid in the Winyah Bay Estuary. It primarily occurred at the most seaward extensive stations and was absent or rare at the uppermost stations (Appendix III.H). With peak densities of 1300 - 2500/m^3, *E. acutifrons* comprised 2% and 4% of the total zooplankton at MB and SB, respectively. Peak abundance was similar to that at North Inlet (Barker, unpublished), but it was higher than that at No Man's Friend and South Jones Creeks (Allen et al., 1982).

E. acutifrons was absent or rare at all stations during the winter months (January-March) and in July. It reached peak densities of up to 2500/m^3 at the lower estuary stations in spring. In contrast, peaks of abundance at NMF and SJ Creeks were in late fall (Allen et al., 1982). Peaks at North Inlet occurred in summer and early fall (Lonsdale and Coull, 1977; Barker, unpublished).

During the intensive series, *E. acutifrons* was also most abundant at the most seaward station (LS) throughout the year (Appendix IV.D). It peaked in abundance (2000/m^3) in fall at both the lower (LS) and middle (MS) stations. No clear-cut pattern in vertical distribution was evident during the intensive and 48-hour series (Table 5-3).

F. *Oithona colcarva*

The most abundant cyclopoid copepod in the lower estuary, *O. colcarva* primarily occurred at the most seaward stations and appeared only sporadically at riverine stations (Appendix III.I). With peak densities of 1000-1300/m^3, it was the third most abundant copepod at MB and SB. It accounted for about 2% and 6% of the total zooplankton at MB and SB, respectively.

O. colcarva was present at the most seaward stations year-round. Its highest abundance was in late winter - early spring (March) at the SB station and during fall (September-November) at the other stations (BI, TA, PS, TC, EP, MB). Similar temporal patterns of abundance were observed at NMF and SJ Creeks (Allen et al., 1982) and at North Inlet (Lonsdale and Coull, 1977; Barker, unpublished). *O. colcarva* was also the most dominant organism during March at stations TC, MB and SB, where it comprised 27-41% of the total zooplankton (Table 5-1).

During the intensive series, peak abundance of *O. colcarva* was observed in early spring at LS (14000/m^3) and in fall at MS (1500/m^3)

(Appendix IV.E). It occurred only at US in March, July, and September at relatively low numbers (< $360/m^3$). Although at LS during the spring peak, surface abundance was nearly twice that at the bottom, there was no consistent difference between surface and bottom densities.

During the 48-hour series, surface and bottom densities ($500\text{-}600/m^3$) were also similar (Table 5-3). There was no apparent relationship between *Oithona* abundance and tidal or daylight conditions.

G. *Halicyclops* spp.

Copepods of the genus *Halicyclops* were the most dominant cyclopoids at the less saline, upper bay stations. During periods of peak abundance, *Halicyclops* was one of the three most abundant categories at PR, SR, PD and WR (Table 5-3). This copepod was absent in late summer-fall (September-November), appeared in January, and reached a peak abundance of $2300/m^3$ in late spring and summer (May-July) (Appendix III.J). These cyclopoids were collected at similar densities in surface and bottom tows at the upper station on spring and summer intensive cruises (Appendix IV.E).

V. MEROPLANKTON

A. Barnacle larvae

Among the meroplankton, larval stages of barnacles were the most abundant larvae in the system. They were often one of the three most abundant categories in the collections (Tables 5-1 and 5-2). The two planktonic developmental stages of barnacles had similar spatial and temporal distributions.

Barnacle nauplii were generally found at all stations, and comprised from 2% to 32% of mean zooplankton densities (Fig. 5-7). They were present in the estuary throughout the year, except in January-March when they occurred in low numbers ($<50/m^3$) only at the most seaward stations (Fig. 5-8; Appendix III.K). Peak abundance (about $19000/m^3$) occurred in fall at most extensive stations. In contrast, densities of barnacle nauplii were highest from December through April in NMF and SJ Creeks (Allen et al., 1982) and between April and August in North Inlet (Lonsdale and Coull, 1977). Differences may be related to the different spawning times of the various species which occur within the system.

Barnacle cyprids were generally less abundant than the nauplii and sometimes constituted a sizable percentage of total organisms at some stations (Tables 5-1 and 5-2). Highest densities (from 600 to $2200/m^3$) were found during spring at most stations and in fall at the other stations (PR, SR, EP) (Appendix III.L). Cyprid densities were generally higher than those reported by Allen et al. (1982) for No Man's Friend and South Jones Creeks where peaks were around $200/m^3$.

With the exception of the September intensive collection in the upper bay, barnacle nauplii densities were higher at the surface than at the bottom (Appendix IV.F). At Mother Norton, barnacle nauplii densities were higher at the surface than at the bottom (Appendix IV.F). At Mother Norton, barnacle nauplii were significantly more abundant at the surface (Table 5-3). Cyprid densities were usually higher at the bottom.

B. Crab zoeae

Crab zoeae were common (up to 3600/m^3) at all stations (Fig. 5-7) during certain times of the year (Appendix III.M). They were most abundant at PR where they accounted for 10% of all zooplankton. When present, they were usually among the most abundant groups in the collections (Tables 5-1 and 5-2).

Zoeae occurred only during late spring and summer in both the extensive and intensive series. Densities tended to be higher at the surface than at the bottom (Appendix IV.G). During the 48-hour sampling, the difference between surface and bottom densities was not significant (Table 5-3).

C. Polychaete larvae

Polychaete larvae were found throughout the year at all extensive stations. Maximum densities were about 1400/m^3 (Appendix III.N). From spring through fall, they comprised one of the three most abundant categories at the riverine stations (Table 5-1).

During the intensive series, polychaete larvae were generally more abundant at the bottom than at the surface at US and MS (Appendix IV.G). Polychaete larvae densities were generally highest at LS; however, no consistent pattern between surface and bottom abundances could be discerned at this station. At Mother Norton, surface and bottom densities (about 440/m) were not significantly different (Table 5-3).

D. Molluscan larvae

Molluscan larvae also showed a distinct seasonal pattern of abundance. Gastropod veligers occurred from spring to early fall in the uppermost and lowermost extensive stations; they were rare or absent at stations TA and PS throughout the year (Appendix III.O). During peak densities in summer and fall, the most seaward stations had the greatest abundance of veligers (up to 2500/m^3 at the extensive stations; 9000/m^3 at the intensive stations). During these periods, bottom densities of gastropod veligers were up to one order of magnitude greater than those at the surface (Appendix IV.H). Bottom densities were also higher during the 48-hour series; however, the difference was not statistically significant (Table 5-3).

Bivalve larvae were most common at the seaward stations (Appendix III.P). Peak densities (70-470/m^3) occurred during May at all lower bay stations (TC, EP, MB, SB). They were only sporadically collected at the upper stations during spring and summer at densities less than 20/m^3. In the intensive series, bivalve larvae were found throughout most of the year at MS and LS (Appendix IV.H). Peak abundance was recorded during July at both MS (180/m) and LS (1800/m); bottom densities were usually higher than surface densities.

In summary, the zooplankton community in Winyah Bay was dominated by only a few species of copepods and the meroplanktonic larval stages of benthic invertebrates. In most cases, three taxonomic categories accounted for up to 90% of all organisms present. Taxonomic diversity was relatively low at all stations. Although there were distinct differences in patterns of occurrence and abundance, on each cruise the same taxa occurred at most stations in the estuary. While the most common groups occurred throughout the year, certain copepods and most larvae were seasonally abundant.

Many of the components of the Winyah Bay zooplankton play important roles in estuarine trophic dynamics, especially as food for young fishes and crustaceans. The zooplankton also serve as source of recruitment for benthic shellfish or fish populations. Perturbations adversely affecting the zooplankton constituents will ultimately involve other major components of the bay ecosystem. This is particularly significant since there are so few major taxa comprising the zooplankton community. Whatever affects the key species would surely affect the entire zooplankton community and subsequently other populations which depend upon the zooplankton for food sources. Destruction of year classes of fish and invertebrate larvae would have serious long term repercussions.

CHAPTER 6. MOTILE EPIBENTHOS

Organisms collected with an epibenthic sled (365 μm) include small crustaceans and fishes which either spend their entire lives within a few centimeters of the bottom or occur there only as developmental stages for relatively short periods of time. Since all of these organisms are motile and aggregative to some extent, the composition and abundance of the motile epibenthic community is highly variable in space and time. Although little information is available on the spatial and temporal distributions of motile epibenthic organisms in estuaries, it is clear that they play very important roles in these ecosystems. In this chapter, we present the first level analysis of data based on more than 450 epibenthic sled collections taken throughout Winyah Bay over a 13 month period.

More than 200 species of invertebrates and fishes have been collected with epibenthic sleds in the Winyah Bay - North Inlet area. Many of these forms only occur as incidental catches in the sled because they are either too large, small, or motile to be effectively collected with this sampling device. For this reason, copepods, crab zoeae, and other small invertebrates generally considered to be planktonic are not discussed in this chapter. Mollusks (clams and snails), polychaete worms, bryozoans, and other macroinvertebrates which are classified as benthic (living in the sediment) or fouling (attached to hard substrate) organisms are also deleted from the analysis. Softbodied invertebrates such as chaetognaths, medusae (jellyfish), and ctenophores (comb jellies) often dominated sled catches, but they were usually not enumerated in the collection analysis. Shrimps, crabs, and fishes more than about 20 mm in length are generally able to avoid the sled, so incidental catches of these individuals were not considered in the final analysis.

Most of the organisms collected were small ($\leqslant$ 20 mm) crustaceans and fishes. Although some of the most common forms were mysids, amphipods and other small adult crustaceans, many were developmental stages of more familiar shrimps, crabs, and fishes. Thus, the motile epibenthos represents a community comprised of larval crustaceans and fishes as well as important prey species for these and other estuarine predators.

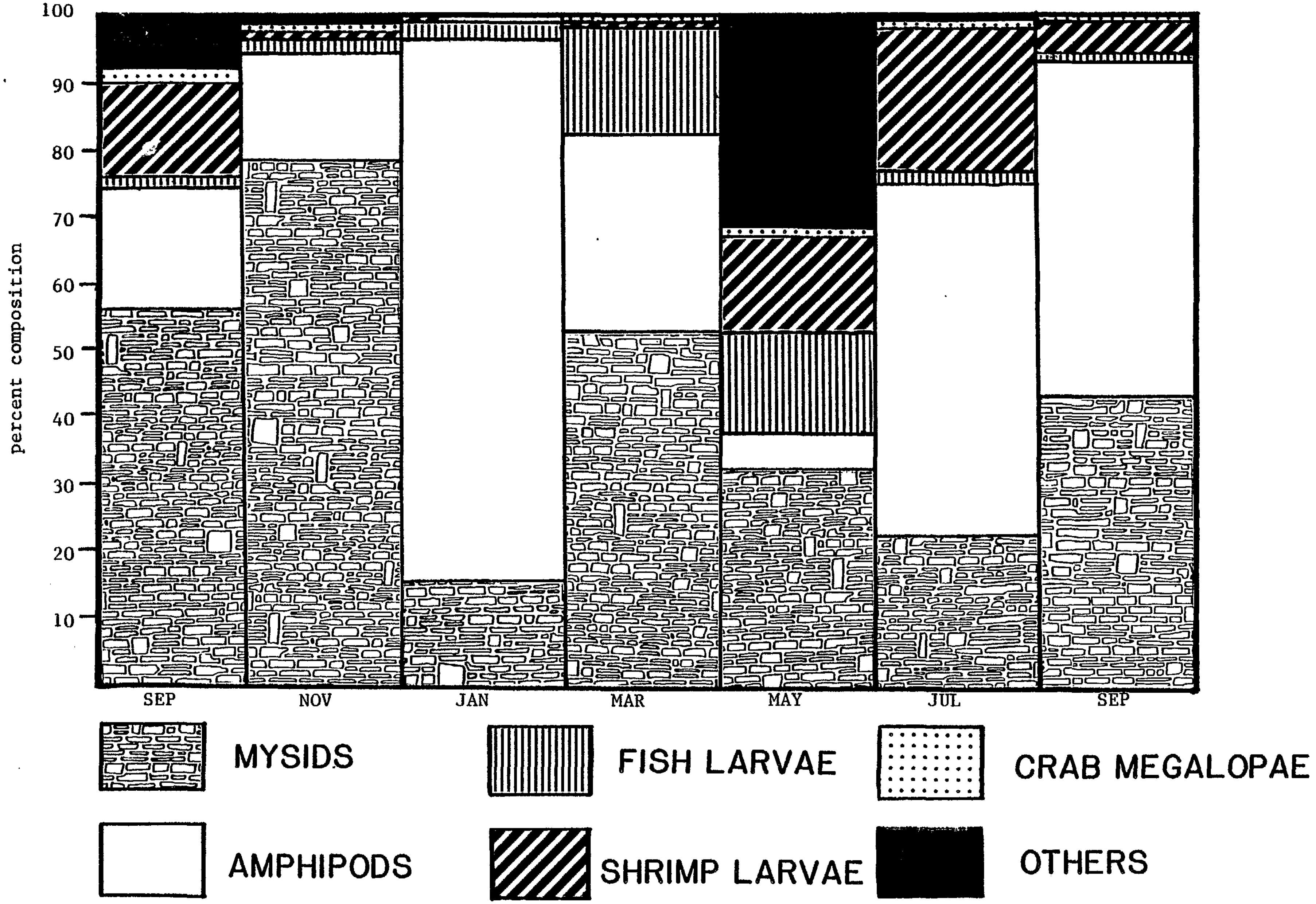
The taxonomic categories considered here are identical to those discussed in our report on earlier studies of No Man's Friend (NMF) and South Jones (SJ) Creeks (Allen et al., 1982). The reader should refer to this volume for additional information on these taxa (including drawings) and for specific scientific literature references. In the present report, summaries of the spatial and temporal distributions of each of the major taxa collected in Winyah Bay comprise the first section, and sections which address trends for total epibenthic organisms and the results of field experiments on sampling effectiveness follow. In the first section, entries for taxonomic groups include: (1) a summary of cruise to cruise variation based on the extensive series, (2) a summary of the spatial distribution based on the extensive series, (3) general trends with comparisons to NMF, SJ, and the 6 Winyah Bay stations sampled in 1980-81, (4) a summary of spatial and temporal patterns within the intensive series, (5) results of intensive series experiments to determine patchiness on the bottom in 3 regions of the Bay, and (6) a summary of changes in abundance on the bottom and throughout the water column within one tidal cycle.

A. MYSIDS

Mysid shrimps represented the single most important group of organisms collected during the study. *Neomysis americana* was the most common species in the lower bay and the only mysid collected at salinities less than about 25 ppt. It was present in Winyah Bay and nearshore coastal waters year round. *Mysidopsis bigelowi* was common and sometimes outnumbered *N. americana* in collections from the lower bay, but only during the warmest months. *Promysis atlantica*, *Metamysidopsis swifti*, *Bowmaniella floridana*, and *Brasilomysis castroi* only occurred during summer in high salinity areas, and none was abundant on any cruise. All species are included in the analysis of the spatial and temporal distribution within Winyah Bay.

Mysids comprised more than half of all organisms collected on the September 1981, November, and March cruises (based on the mean of all 11 extensive series stations (Fig. 6-1)). In November, mysids accounted for 80% of the catch. In January, when mysids were least abundant in the system, they accounted for 15% of all organisms collected (Fig. 6-1).

Fig. 6-1. Percent composition of major epibenthic taxa for each cruise in Winyah Bay. The value for each taxa is a mean based on densities of all 11 extensive series stations on that cruise.



Highest mysid densities were in September 1982 (about 11/m^3), and moderate densities were observed in November and May (about 6/m^3). Densities of less than 1/m^3 were found in January (Table 6-1).

The station with the highest density for all cruises combined was EP with 14/m^3. SR had the second highest densities (about 10/m^3), most stations had mean values of 3 to 7/m^3, and PR had the lowest densities (0.1/m^3) of all stations (Table 6-2). Mysids made up about 50% of the catch at 7 of the 14 stations sampled in the study (Fig. 6-2). They accounted for less than 10% of all organisms only at PR, PD, and PS.

The largest collection of mysids was 51/m^3 at EP in January. They were also very abundant at SR in September 1982 (42/m^3), (Appendix V. A.). Most collections yielded densities of less than 5/m^3. Differences between adjacent stations or consecutive cruises were often one to two orders of magnitude.

No mysids were collected in the rivers in January or March when water temperatures and salinities were lowest. However, moderate densities were determined at SR in July when the bottom water was about 6°/oo. In general, more mysids were found in brackish (Mud Bay) and high salinity areas, especially during winter and spring. The overall seasonal trend for the 11 station extensive series (1981-82) was very similar to that in the initial (6 station) study in the Bay during 1980-81, but mysids were up to 10 times more abundant during the earlier study (Allen, et al., 1982).

Table 6-1. Mean number of organisms per cubic meter plus or minus one standard error for each cruise in the Extensive Series from September 1981 through September 1982. Each value is a mean for collections made at all 11 stations on each cruise.

	SEP	NOV	JAN	MAR	MAY	JUL	SEP
Total Organisms	6.1 ± 1.6	7.6 ± 3.3	4.8 ± 2.0	8.3 ± 2.6	19.4 ± 4.3	10.5 ± 3.0	25.3 ± 9.2
Mysids	3.4 ± 1.2	5.9 ± 3.2	0.7 ± 0.3	4.3 ± 2.4	6.2 ± 1.8	2.2 ± 1.0	10.5 ± 3.1
Amphipods	1.0 ± 0.3	1.2 ± 0.5	4.0 ± 1.2	2.5 ± 0.8	1.1 ± 1.0	5.5 ± 2.2	13.0 ± 0.2
Shrimp Larvae	1.0 ± 0.4	0.1	0.1	0.8 ± 0.3	2.4 ± 0.3	2.4 ± 0.9	1.2 ± 0.2
Postlarval Penaeids	0.1	0.1	0	0	0.5 ± 0.1	0.1	0.1
Crab Megalopae	0.2	0.1	0	0.1	0.1	0.1	0.1
Fish Eggs	0.1	0.1	0	0.1	5.9 ± 2.2	0.1	0
Fish Larvae	0.1	0.2	0.2	1.3 ± 0.5	2.7 ± 1.0	0.1	0.1

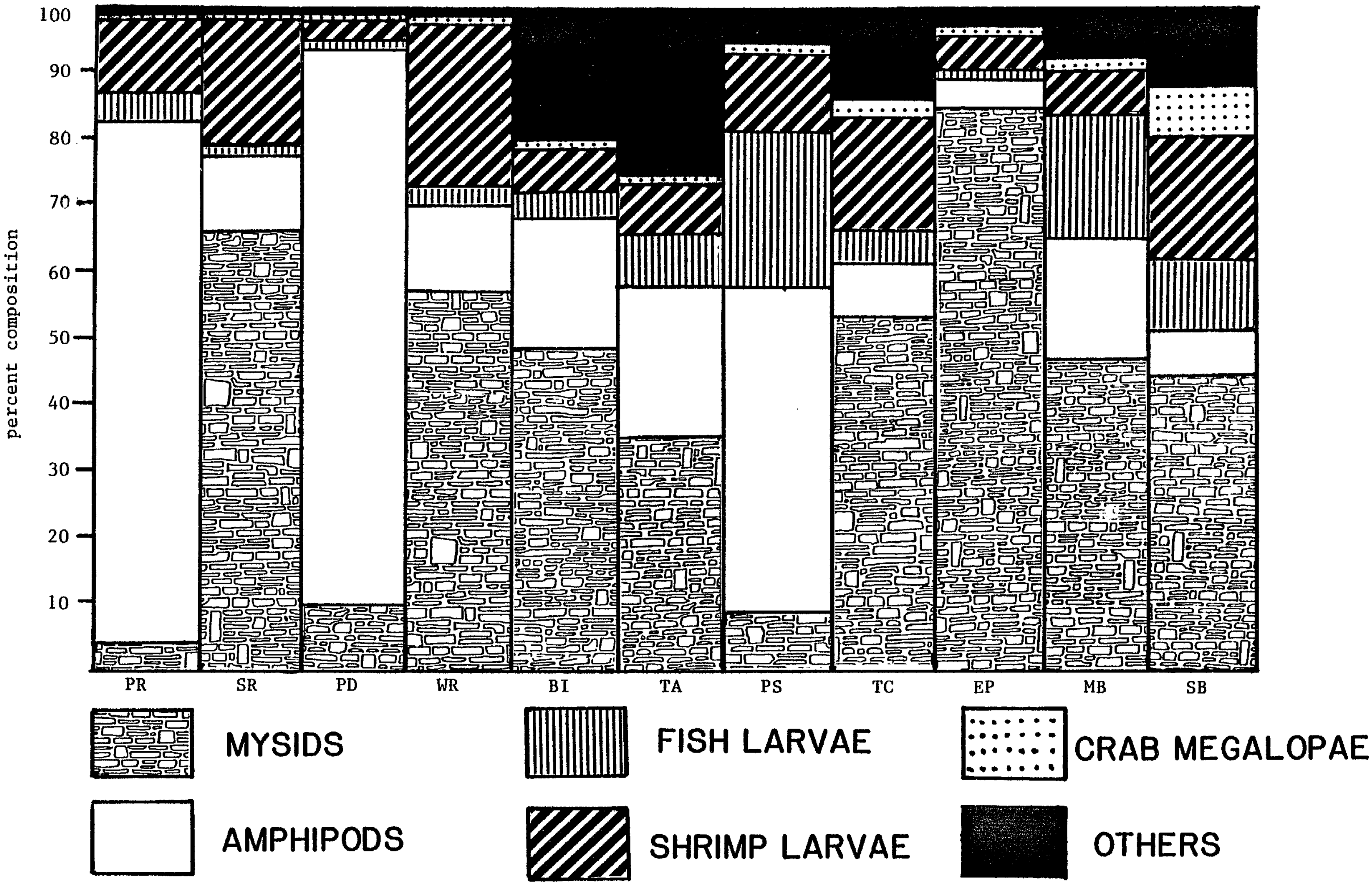
Table 6-2. Mean number of organisms per cubic meter plus or minus one standard error for all 11 Extensive and 3 Intensive stations. Extensive values are means of 14 collections and Intensive values are means of 60 collections taken during the 13 month study. + indicates presence at less than 0.1 per m^3.

	PR	SR	PD	WR	US	BI	TA
Total Organisms	3.5 ± 1.5	14.9 ± 5.0	30.6 ± 14.1	5.2 ± 2.6	5.2 ± 1.0	10.2 ± 4.2	18.1 ± 4.8
Mysids	0.1	9.9 ± 4.2	2.7 ± 1.1	3.0 ± 1.9	2.7 ± 0.6	4.9 ± 2.6	6.3 ± 2.7
Amphipods	2.7 ± 1.5	1.8 ± 0.7	25.9 ± 13.2	0.7 ± 0.2	0.9 ± 0.3	2.1 ± 0.8	4.1 ± 0.6
Shrimp Larvae	0.5 ± 0.2	2.9 ± 1.5	1.1 ± 0.5	1.2 ± 0.6	1.4 ± 0.3	0.7 ± 0.3	0.5 ± 0.1
Postlarval Penaeids	0	0.1	0.2 ± 0.1	0.1	0.1	0.1	0.8 ± 0.5
Crab Megalopae	+	0.1	0.2 ± 0.1	0.2 ± 0.1	0.1	+	+
Fish Eggs	+	+	+	+	0.1	2.0 ± 1.4	5.0 ± 3.5
Fish Larvae	0.2 ± 0.1	0.1	0.4 ± 0.2	0.1	0.1	0.2 ± 0.1	1.3 ± 0.5

Table 6-2. Continued

	PS	TC	MS	EP	MB	SB	MN
Total Organisms	7.0 ± 1.4	5.8 ± 1.4	12.3 ± 2.9	16.0 ± 5.1	12.9 ± 4.5	4.5 ± 1.0	9.0 ± 1.2
Mysids	0.6 ± 0.1	3.1 ± 0.3	7.0 ± 1.7	13.5 ± 2.4	6.1 ± 1.8	2.0 ± 0.3	2.1 ± 0.3
Amphipods	3.4 ± 0.8	0.4 ± 0.1	0.5 ± 0.1	0.7 ± 0.2	2.3 ± 0.6	0.4 ± 0.1	0.6 ± 0.2
Shrimp Larvae	0.8 ± 0.1	1.0 ± 0.2	1.0 ± 0.2	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.2	1.4 ± 0.3
Postlarval Penaeids	0.1	+	+	+	+	+	+
Crab Megalopae	+	0.1	0.2 ± 0.1	0.2 ± 0.1	0.1	0.3 ± 0.1	1.3 ± 0.2
Fish Eggs	0.3 ± 0.1	0.7 ± 0.2	2.6 ± 0.9	0.5 ± 0.2	0.6 ± 0.2	0.1	1.9 ± 0.6
Fish Larvae	1.6 ± 0.3	0.2 ± 0.1	0.6 ± 0.1	0.1	2.5 ± 0.8	0.5 ± 0.1	1.4 ± 0.4

Fig. 6-2. Percent composition for major epibenthic taxa for each station in Winyah Bay. The value for each taxa is a mean based on densities from all 7 extensive cruises at that station.



Although there are significant differences in abundance from year to year, a seasonal trend with a winter peak was observed during both years of sampling in the lower bay and at NMF and SJ.

A similar seasonal trend was seen in the intensive series. Overall densities were highest at MS (Fig. 6-3, Appendix VI. A.), but this is primarily related to the occurrence of densities of up to $96/m^3$ at MS in May. These high numbers occurred in the first two 3 minute tows, but not in any of the subsequent 3, 6, or 9 minute tows. Such variation is attributed to the patchy occurrence of mysids on the bottom. Additional statistical tests will be performed on these data, but the preliminary analysis indicates that mysids are widely distributed in low densities (especially in the middle and lower bay) and that high density aggregations occur in most areas for undetermined intervals that may range from hours to weeks.

Large short-term fluctuations in mysid densities were evident during the Special Series at MN in September 1982. Densities ranged from less than 1 to $20/m^3$ during the 5 hour study (Table 6-3). Mysids were more abundant in bottom than surface samples during all stages of the tide (Table 6-3). They always comprised a greater proportion of the catch at the bottom, although during turbulent strong tidal velocity conditions, 16% of the surface catch was mysids (Table 6-3). The density of mysids in all gear increased with increasing current velocity (Table 6-4).

Fig. 6-3. Mean densities (±1 S.E.) for 3, 6, 9 minute and all sled collections at 3 intensive series stations in Winyah Bay. Values are means of all 7 cruises.

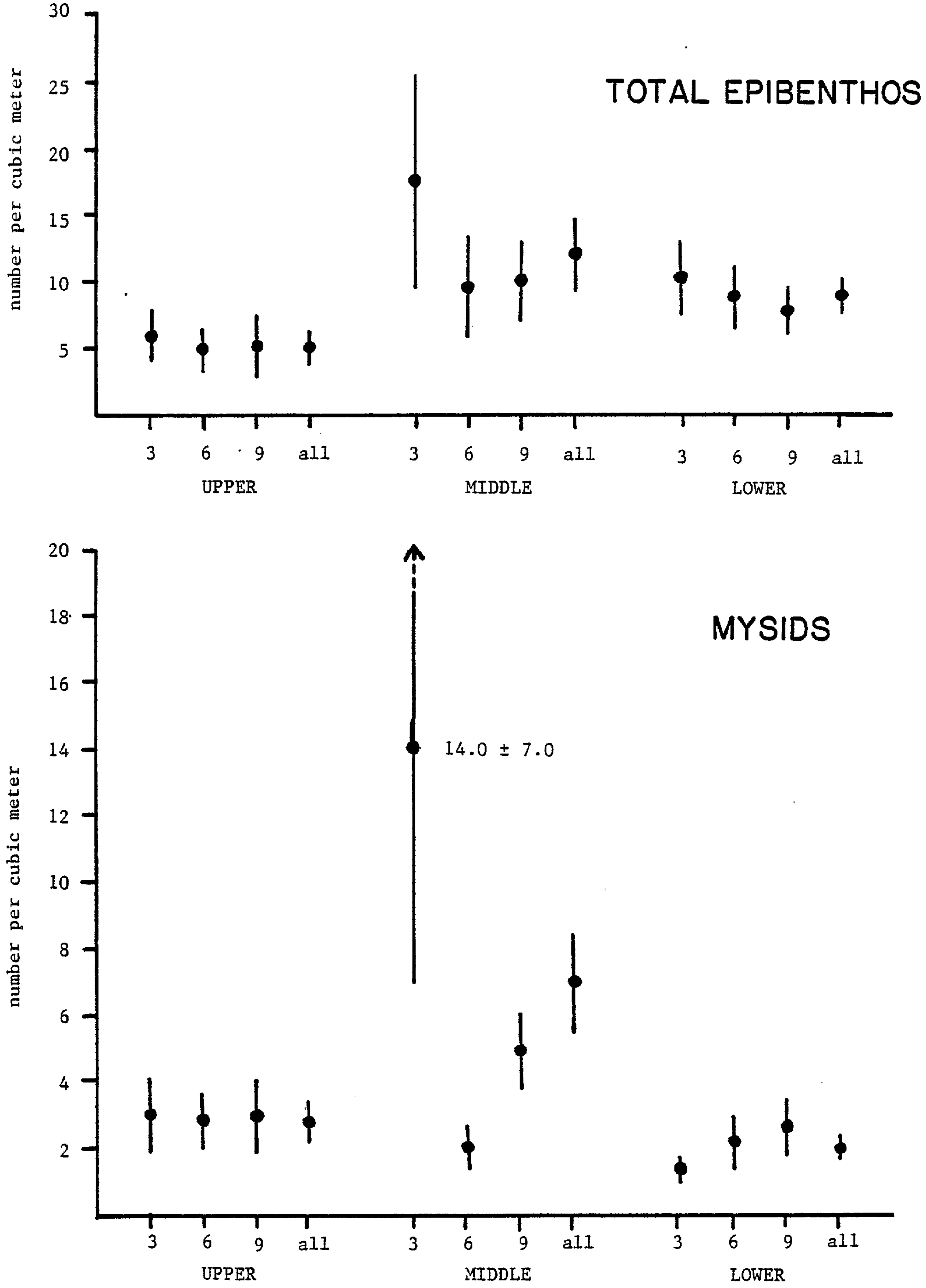


Table 6-3. Percentage of the total catch that each taxonomic group comprised during slack, moderate, and strong current conditions at MN on September 17, 1982. Values for surface (upper) and bottom (lower) 365 μm closing nets are given for each taxa.

	Slack	Moderate	Strong
Mysids	1 35	1 2	16 21
Amphipods	6 6	16 16	7 3
Shrimp Larvae	27 18	17 7	18 12
Crab Megalopae	21 3	1 3	1 1
Fish Larvae	47 3	10 6	1 1
Chaetognaths	10 23	24 51	38 52
Lucifer	8 12	9 3	7 4
Isopods	1 0	22 11	8 5
Others	7 0	0 3	4 1

Table 6-4. Summary of occurrence of taxonomic groups in a variety of sampling gear during the Special MN series on September 17, 1982.

Taxa	Range in density (#/m^3) for all gear	Density at surface(s) relative to bottom at all stages	Change in density with increase current
Total Organisms	7.2 - 66.4	B > S	increase
Mysids	0.2 - 19.8	B > S	increase
Amphipods	0.3 - 9.7	B > S	no change
Shrimp larvae	1.4 - 10.4	B > S	no change
Crab megalopae	0.1 - 1.2	B > S	increase
Fish larvae	0.1 - 6.9	S > B	decrease
Chaetognaths	1.4 - 33.8	B > S	increase
Lucifer	0.7 - 7.8	B = S	no change
Isopods	0.1 - 11.2	B > S	increase

B. AMPHIPODS

This group of small pericarid crustaceans was the second most important group of motile epibenthic organisms in Winyah Bay. Due to the amount of time necessary to identify all individuals to species, we were only able to deal with amphipods on the total amphipods level. Gammarids of the genera *Batea*, *Corophium*, *Erichthonius*, *Microprotopus*, *Unicola*, *Gammarus*, *Listriella*, *Elasmopus*, *Melita*, *Stenothoe*, and *Synchelidium* have been identified from various sled collections, but no specific information on occurrence is available at this time. Caprellids of the genera *Caprella* and *Paracaprella* were also identified. All comments on distribution are for total amphipods.

Amphipods were frequently the most abundant taxa in sled collections and often dominated the catches in the upper and middle bay (Fig. 6-2). More than half of all organisms collected in January, July, and September 1982 were amphipods (Table 6-1). Highest densities were in September 1982 ($13/m^3$). During all other months densities were from 1 to $6/m^3$ (Table 6-1).

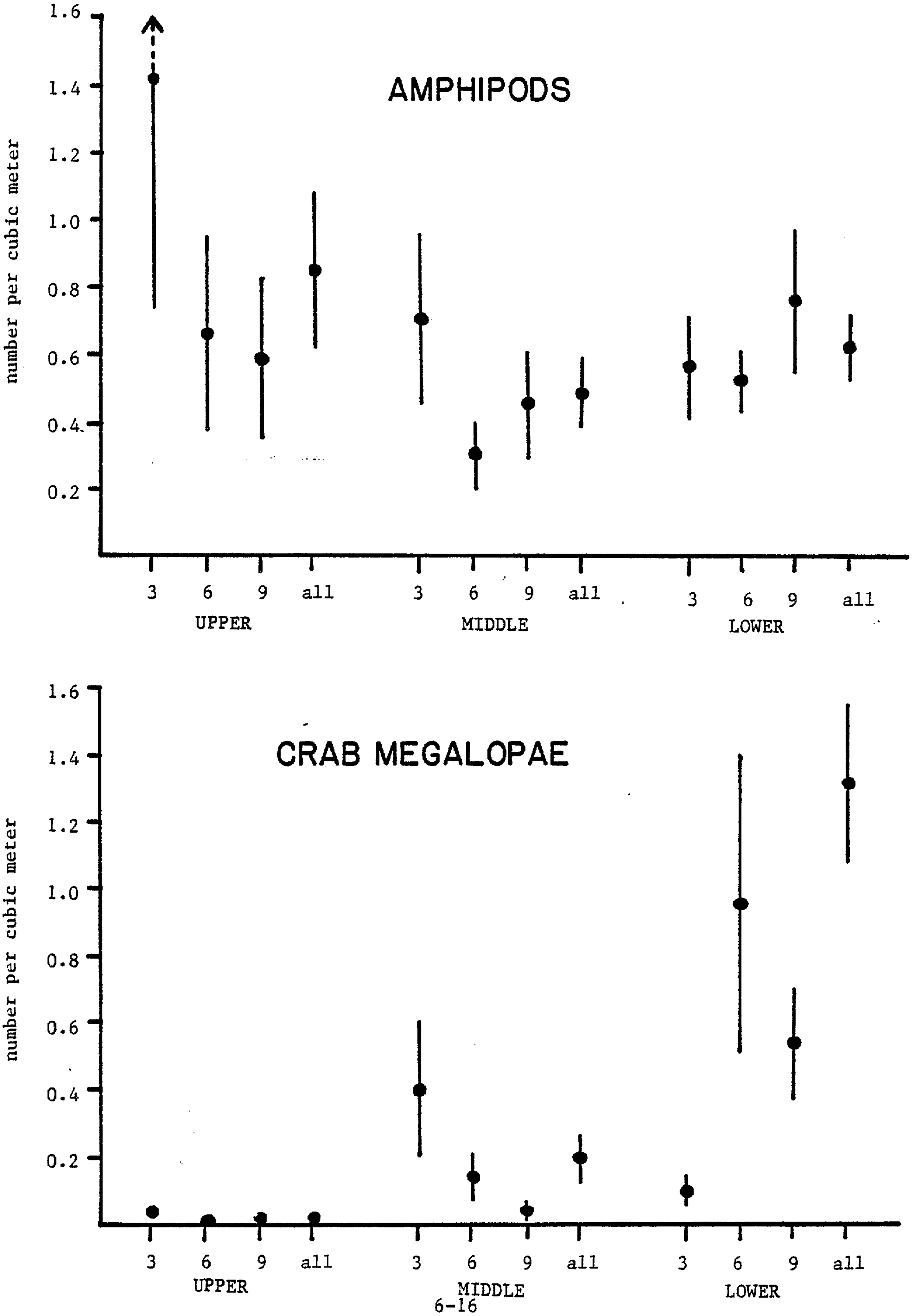
Overall densities were highest at PD ($26/m^3$) (Table 6-2). No other station had mean values greater than $4/m^3$. Amphipods accounted for more than 50% of the catch at PR, PD, and PS (Fig. 6-2). It is interesting that these are the 3 stations at which mysids were least important. Amphipods comprised less than 10% of the catch at most other stations.

The two largest catches were at PD in July (33/m^3) and September 1982 (134/m^3) (Appendix V. B.). The latter was the highest density of any epibenthic organisms determined in the study. In the previous study (Allen, et al., 1982), amphipods were generally more abundant in the upper bay, especially at the river stations. Densities at NMF and SJ were less than 1/m^3 throughout the year.

At the intensive series stations, overall densities were less than 1/m^3 (Fig. 6-4). They were somewhat higher at US than MS and MN; however, none were collected at US during November (Appendix VI. B.). Despite low temperatures and salinities, numbers of amphipods occurred in the US in January. Variability between consecutive 3, 6, and 9 minute collections was high, but there did not appear to be significant differences between tows of different lengths at any station when data from all cruises were combined. Further testing will reveal the extent of patchiness.

The amount of variation over only 5 hours at MN (< 1 to 10/m^3) was greater than that between most cruises (Table 6-3). Densities were greater on the bottom than near the surface (Table 6-3). Amphipods comprised equivalent proportions of the surface and bottom catch at slack and moderate tides, but like mysids, they were more important in surface catches during strong tidal current conditions (Table 6-4).

Fig. 6-4. Mean densities (±1 S.E.) for 3, 6, 9 minute and all sled collections at 3 intensive series stations in Winyah Bay. Values are means of 7 cruises.



Since many species of amphipods live in the sediment or are associated with fouling organisms (sponges, hydroids, etc), the epibenthic sled does not effectively sample all amphipod populations. All values are probably large underestimates of actual amphipod densities at most locations; however the trends described here are probably representative of the groups' distribution on open bottom of Winyah Bay. Amphipods are particularly abundant (> $100/m^3$) along shore zones, docks, and wherever hard substrates occur. There is a high diversity of species especially in the lower bay during the warm months, and other sampling gear and locations must be used to provide more specific information about this group. In general, amphipods are major sources of food for most predaceous fishes in the estuary.

C. ISOPODS

Isopods are also pericarid crustaceans that, with the exception of few species such as Aegathoa oculata, are closely associated with sediment and debris on the bottom. Crawling and burrowing forms such as Edotea montosa, Acinus depressus, Cassidinidea lunifrons, Sphaeroma spp. and Chiridotea spp. were identified from the collections. Aegathoa oculata was by far the most widely distributed species within the system. The patterns described are for total isopods.

Isopods occurred in only about 30% of all collections and, generally, only a few individuals were taken. The highest density was at SB in September 1981 ($1.3/m^3$) and most densities were less than $0.5/m^3$. They were present at all stations in September 1981, May, and September 1982 and occurred at some of the stations on every cruise. Densities were typically low in the rivers and upper bay since most species were high salinity forms. Aegathoa was collected at salinities as low as 6 ppt. Mud Bay stations TA and TC were consistently the locations of highest abundance for isopods.

In the intensive series, isopods were consistently most abundant at MN where all species occurred. A density of $1.3/m^3$ at MN in May was the highest for all stations on all cruises. US densities were clearly the lowest of the 3 stations. Insufficient numbers were collected to determine variation between 3, 6, and 9 minute tows at any location.

At NMF and SJ, isopods also usually occurred at densities less than $1/m^3$. They were collected throughout the year, but were most abundant during the warmest months. Isopods were most common in the lower bay during the 1980-81 study. Densities ranged from $10/m^3$ at MN in September to less than $1/m^3$ at other locations. Peak densities were during the warmest months.

Densities ranged from $0.1 - 11.2/m^3$ during the 5 hour special series study at MN (Table 6-3). Such a fluctuation indicates the high tidal variability associated with isopods. Bottom densities were higher than those near the surface (Table 6-3), but isopods made up a higher proportion of the surface catch, especially during moderate and strong current conditions (Table 6-4). Surface catches were dominated by *Aegathoa*. Densities of isopods increased with increasing current velocities (Table 6-3).

Although they were present at all locations during the study, isopods were not abundant enough in sled collections to consider them important components of the system. Sled determined densities are certainly underestimates of actual abundance for benthic forms and for *Aegathoa* which is a good swimmer capable of avoiding the net.

D. CUMACEANS

This last group of pericarid crustaceans includes *Leucon americanus*, *Cyclaspis varians*, *Oxyurostylis smithi*, and at least two unidentified species. As a group, cumaceans occurred in only 20% of the collections. Maximum density for the study was less than $0.5/m^3$.

Cumaceans were present in lower and middle bay collections on most cruises during the warm months. Middle bay stations TC, MB, and EP were the locations of maximum abundance throughout the year. None occurred in the rivers during most of the year; however, in September 1982 when bottom salinities were 10 to 15 ppt, significant numbers were collected at PD, SR, and WR. No cumaceans were taken at any stations in January or in July when salinities were low.

Among the intensive series stations, MN was consistently highest in cumacean densities. A maximum density of $0.8/m^3$ was observed in May and some cumaceans were taken at MN on every cruise. MS densities were comparable, but few were collected at US. Numbers were too low to test differences between 3, 6, and 9 minute tows at any station.

Low densities characterized the six Winyah Bay stations during the 1980-81 study. Peak densities were $4/m^3$ at MB, but lower bay collections were consistently highest. NMF and SJ densities were usually less than $1/m^3$.

Cumaceans were the least important of the pericarid crustaceans in the system, but since these organisms spend most of their lives buried in the sediment, they may be more abundant than sled catches would indicate.

E. DECAPOD SHRIMPS: ADULTS

At least 15 species of small adult decapod shrimps were collected with the sled. All 3 species of *Penaeus* and *Trachypenaeus constrictus* were collected as sub-adults and adults. Young *Sicyonia* spp. occurred in some summer collections at MN. Adult *Palaemonetes vulgaris* and *P. pugio* were widely distributed. These larger shrimps were considered incidental catches and not enumerated.

Smaller (< 15 mm) adult shrimp such as *Periclimenes americanus*, *Latreutes parvulus*, *Lysmata wurdemmani*, *Tozeuma carolinense*, *Neopontonides beaufortensis*, and *Ogyrides* spp. were occasionally collected in low numbers in the lower bay. These species were enumerated during sample processing, but are not discussed here. Snapping shrimps such as Alpheus spp. and the mud shrimps Upogebia affinis and Callianassa spp. were rarely encountered. Larval and small adult stomatopods or mantis shrimps (Squilla empusa) were also collected. None of these species is considered individually in this report, but the larvae of all decapod shrimps are considered as a group in another section.

Two small adult sergestid shrimps were studied in more detail. Acetes americanus is a coastal species which only occurred in the lower bay during the warm months. Among the extensive series stations, densities were always highest at SB. Maximum densities ($0.3/m^3$) were in September 1982. None were collected at any station in January and March. This pattern is similar to that determined in the 1980-81 study, but summer densities were higher (maximum $31/m^3$ at MN) during that year. SJ densities reached $5/m^3$ in August 1980 and NMF densities peaked at $1/m^3$ at that time.

Lucifer faxoni had a similar pattern of spatial and temporal distribution. Both sergestid species were often taken in the same collections. Lucifer was somewhat more abundant than Acetes with densities reaching $3.3/m^3$ at MB in March. Highest densities in Winyah Bay were at SB in September 1981 and November. None occurred at any station during January and July when salinities were lowest. With the exception of a few individuals in saline bottom waters at SR, none occurred in the rivers.

Lucifer was present at MN during the September 1982 special series sampling in sufficient numbers to comment on its short term distribution. Densities ranged from 0.7 to $7.8/m^3$ over the 5 hour period (Table 6-3). There was no difference between bottom and surface densities and abundance in the samples was not closely related to the stage of the tide (Table 6-3). *Lucifer* accounted for a larger portion of the surface catch at moderate and strong velocities (Table 6-4).

Both sergestid shrimps are high salinity warm water species which have a very limited distribution within the estuary. They may be considered indicator species for higher salinity water masses within Winyah Bay.

F. DECAPOD SHRIMPS: LARVAE

The taxonomic composition of the larval shrimp catch was not precisely determined because of the high diversity of species represented during the warm months. Most decapod shrimp species pass through 4-7 stages of development before they become small adults and most of these larval stages are difficult to identify to the species level. There is little doubt that the vast majority of early stage shrimp larvae in the upper bay were *Palaemonetes* spp. since grass shrimp are one of the few shrimps capable of reproducing in low salinity areas. Grass shrimp larvae were also collected at the most seaward stations along with other larvae belonging to species listed as small adults in the previous section.

The patterns described in this section are for total shrimp larvae.

A distinct seasonal trend with maximum densities occurring during the warmest months is consistent with previous studies in other temperate estuaries. In Winyah Bay, highest densities were in May and July ($2.4/m^3$) (Table 6-1). March and September (1981 and 1982) values were on the order of $1/m^3$. Densities less than $0.1/m^3$ were typical of the coldest months. Shrimp larvae were not a significant part of the epibenthic community from March to November, but they comprised 25% of the catch in July (Fig. 6-1).

Among the 14 stations sampled, SR had the highest mean density ($2.9/m^3$) (Table 6-2). Lowest densities were at PR and TA ($0.5/m^3$) and most other stations had mean values around $1/m^3$. During 1980-81, maximum densities ($3/m^3$) were found at WR and MN. Summer peak densities at SJ and NMF were from 4 to $6/m^3$.

Shrimp larvae comprised the largest portion of the catch (30%) at WR, although this group was also important at SR, PS, TC, and SB (Fig 6-2). They accounted for at least 5% of all organisms collected at every station.

The highest density determined in the study was $15/m^3$ at SR in July (Appendix V. C.). No shrimp larvae were taken in the rivers or upper bay in November, January, or March. TA was the only station with some shrimp larvae on the January cruise. Densities increased at all stations from March to May and decreased after September. Gravid adult shrimp were never collected during the coldest months.

Densities at intensive series stations US and MN were similar ($1.5/m^3$) and somewhat higher than those at MS (Fig 6-5). There did not appear to be significant differences in densities determined with 3, 6, and 9 minute tows but further statistical tests will be conducted to establish the degree of patchiness.

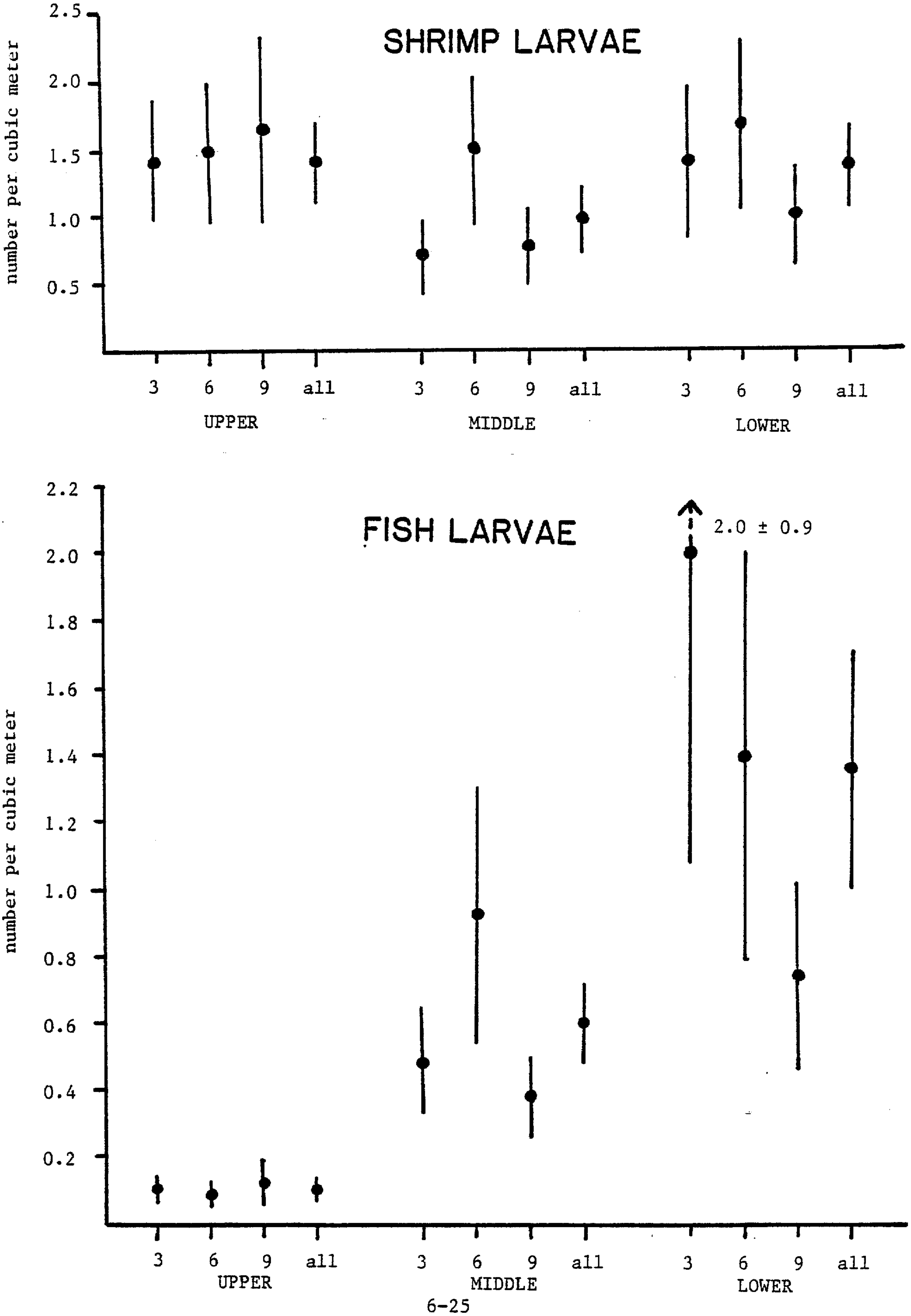
The seasonal pattern for the intensive series was identical to that determined in the extensive series with one notable exception. Some shrimp larvae occurred in every tow at US in March. July US densities were among the highest in the study (Appendix VI. C.)

Shrimp larvae densities ranged from 1.4 to 10.4 over the 5 hour study at MN in September 1982 (Table 6-3). There was no significant change in density as a function of tidal velocity. Even though larvae were more abundant in bottom than surface collections (Table 6-3), they accounted for a larger percentage of the surface catch at all stages of the tide. Shrimp larvae were the second most important group at the surface during slack and moderate stages of the tide.

G. DECAPOD SHRIMPS: POSTLARVAL PENAEIDS

Late larval stages of the penaeid shrimps are readily recognized in epibenthic sled collections and because of the commercial importance of this group of shrimps, they were enumerated in the analyses. The spatial and seasonal patterns of distribution described here are for larval shrimps belonging to the genus Penaeus (or

Fig. 6-5. Mean densities (±1 S.E.) for 3, 6, 9 minute and all sled collections at 3 intensive series stations in Winyah Bay. Values are means of all 7 cruises.



Trachypeneaus). No attempt was made to separate the individuals to species. Although there is no doubt that huge numbers of these larvae migrate from the ocean to estuarine nursery areas in Winyah Bay, they grow very rapidly and are probably only susceptable to capture by the sleds for days or weeks. For this reason and because of the likelihood that postlarval pendeids reside in habitats other than those routinely sampled with the sleds, it is not surprising that densities in the collections were so low. Nevertheless, information given for the general seasonal and spatial distribution of these larvae represents the only data of its kind.

Extensive series station densities were usually less than $0.5/m^3$. Highest densities were in May and none were collected in January or March (Table 6-1). Among all stations, TA had the highest mean density ($0.8/m^3$) (Table 6-2). Most stations had mean densities of less than $0.1/m^3$. None were collected at PR on any cruise.

The highest density of postlarval penaeids determined in the study was $5.2/m^3$ at TA in May (Appendix V. D.). None had been collected at any station during the two previous cruises (January and March) and penaeid larvae were only collected at two other stations on the May cruise. They were more common in the lower and middle bay in July and occurred at all stations except PR in September 1982. However, densities were always less than $0.3/m^3$ whenever they were present.

No penaeid postlarvae were collected at the intensive stations from September through March (Appendix VI. D.). Some occurred in the US in May, the US and MS in July, and the LS and MS in September 1982. Generally, densities were less than $0.1/m^3$. Too few were captured at the ship channel stations to compare differences between the 3, 6, and 9 minute tows.

None were collected during the special series at MN.

H. DECAPOD CRABS: MEGALOPAE

At least 7 species of anomuran and 14 species of brachyuran crabs were collected during the sled study in Winyah Bay. As was the case with the shrimps, the occurrence of individuals larger than about 15 mm was considered incidental. Hermit crabs (*Pagurus* spp. and *Clibanarius vittatus*) were occasionally present in collections, but the sled did not effectively sample these common forms. Other anomurans including *Euceramus*, *Porcellana*, *Emerita*, and *Hypoconcha* were also incidentals. Among the brachyurans, *Callinectes*, *Portunus*, *Ovalipes*, *Calappa*, *Libinia*, and *Cancer* were sometimes represented by juveniles and small adults. *Menippe*, *Neopanope*, *Rhithropanopeus*, and *Pinnixa* were also collected, usually in association with bottom debris or shell. Almost all of these species were most commonly encountered in the lower bay. Fiddler crabs of the genus *Uca* were never taken as adults in the sled, but megalopa stage larvae of this group were common in summer collections. The analysis of the distribution of megalopae that follows is for total crab megalopae

Crab megalopae densities were uniformally low throughout the year. None occurred on the January cruise, and the highest overall density was only 0.2/m^3 in September 1981 (Table 6-1). Megalopae never accounted for more than 2% of the total catch for any cruise (Fig. 6-1).

Among the stations, MN had the highest overall density of 1.3/m^3. All other stations had mean values of 0.3/m^3 or less (Table 6-2). Megalopae did not account for more than 5% of the catch at any station except SB (8%) (Fig 6-2).

Megalopae were present at most stations on all cruises except January, when none occurred anywhere, and March (Appendix V. E.). The highest density was at SB in May (1.4/m^3), but most values were less than 0.5/m^3. Densities were consistently low at PR, TA, and PS even during the warmest months when magalopae were most abundant.

Although the same seasonal pattern was found during the 1980-81 studies at NMF, SJ, and 6 Winyah Bay stations, megalopae were less abundant during 1981-82. Maximum densities in the previous study were greater than 50/m^3 (MB, June).

Since the megalopa is a relatively short-lived developmental stage, sampling intervals on the order of weeks or months are too long to generate a good understanding of temporal patterns of abundance. Additional short term studies at locations in the lower bay are necessary to elucidate these patterns.

The seasonal pattern for crab megalopae in intensive series collections was identical to that in the extensive series. None were taken anywhere on the January cruise and few were collected in the US on most cruises (Appendix VI. E.). Low densities made it difficult to determine whether their distribution on the bottom was patchy.

Densities were also low on the special series cruise at MN in September 1982. The range was from 0.1 to 1.2/m^3 (Table 6-3). Bottom densities were higher than those at the surface (Table 6-3), but megalopae accounted for 21% of the surface catch at slack tide (Table 6-4). The proportion of the surface catch was negligable at moderate and strong velocities. All megalopae examined in these samples were *Uca* spp.

I. FISHES: EGGS

The identification of fish eggs to even the family level is a very difficult and tedious task. It was beyond the scope of this study to process samples on this level, so the discussion below is restricted to total fish eggs. Interpretation of the patterns is complex because: (1) fish eggs exist on time scales of hours to days, (2) many species produce eggs that are too small to be retained in 365 μm nets, and (3) some species produce eggs that are attached to the bottom and others have various degrees of buoyancy. There is no doubt that the sled collects only a small portion of the available eggs in that section of the water column which is least likely to have high densities of eggs.

The only cruise on which fish eggs were present in high densities was May when values were 5.9/m^3 (Table 6-1). None were taken in January and September 1982; other months had overall densities on the order of 0.1/m^3.

TA had the highest overall densities (5.0/m^3). The next highest values were at MS (2.6/m^3). Only small numbers were collected in the rivers, but some were present at all stations (Table 6-2).

No eggs were collected at any station in January or September 1982 and the only ones collected in September 1981, November, and March were in the lower estuary (Appendix V. F.). May was the only cruise on which fish eggs occurred at every station. The highest densities of the study were 35/m^3 at TA and 14/m^3 at BI in May. A similar low density pattern was found at NMF, SJ, and the Winyah Bay stations in 1980-81.

A similar seasonal pattern was observed during the intensive series. Among these stations, densities were also highest in the middle bay in May. Densities were too low to determine differences between 3, 6, and 9 minute tows (Appendix VI. F.). Similarly, numbers of fish eggs in the special series were too low to comment on vertical distribution or the effect of tide stage.

J. FISHES: LARVAE

Most of the problems associated with the identification and quantification of fish eggs in estuarine waters also apply to fish larvae. Certainly more than 180 species of fishes are represented by eggs and larvae (or postlarvae) in South Carolina estuaries. Early yolk-sac stages cannot be easily identified beyond the family level; however, older larvae were distinguished to lower taxonomic levels during sample processing. Following verification of the identification and the measurement of all individuals, further information on how various species utilize Winyah Bay will be available. Preliminary information based on the analyses of sled collected larvae at NMF and SJ Creeks is available in Chapter 7 of the first report (Allen et al., 1982). A list of fish larvae identified from Winyah Bay sled collections in 1981-82 is presented in Table 6-5. In this section, spatial and temporal distributions for total fish larvae are described.

Fish larvae were most abundant on the May cruise ($2.7/m^3$) (Table 6-1). The mean density for March was $1.3/m^3$, and values for all other months were $0.2/m^3$ or less. Larvae were important constituents of the catch in March and May (15%), but they were less abundant on all other cruises (Fig. 6-1).

Among all stations, MB had the highest densities ($2.5/m^3$). Values at TA, PS, and MN were less than $1/m^3$, and all other stations had much lower mean densities (Table 6-2). Fish larvae accounted for more than 10% of the catch at TA, PS, MB, and SB in the middle and lower bay (Fig. 6-2).

Table 6-5. List of species of fishes represented by larvae or postlarvae in epibenthic sled collections in Winyah Bay Estuary.

FAMILY	GENUS-SPECIES	COMMON NAME
Elopidae	Elops saurus	ladyfish
Anguillidae	Anguilla rostrata	American eel
Ophichthidae	Myrophis punctatus	speckled worm eel
Clupeidae	Alosa spp.	blueback herring and/or American shad
	Brevoortia tyrannus	Atlantic menhaden
	Dorosoma spp.	gizzard shad and/or threadfin shad
Engraulidae	Anchoa mitchilli	bay anchovy
	Anchoa hepsetus	striped anchovy
Synodontidae	Synodus foetens	inshore lizardfish
Ariidae	Arius felis	hardhead (juveniles)
Ictaluridae	Ictalurus spp.	brown bullhead and/or channel catfish
Batrachoididae	Opsanus tau	oyster toadfish (juveniles)
Gobiesocidae	Gobiesox strumosus	skilletfish
Gadidae	Urophycis spp.	southern hake and/or spotted hake
Atherinidae	Menidia menidia	Atlantic silverside
Syngnathidae	Syngnathus spp.	northern pipefish and/or chain pipefish (juveniles)
Percichthyidae	Morone spp.	striped bass and/or white perch
Serranidae	Centropristis striata	black sea bass
	Centropristis philadelphica	rock sea bass
Carangidae	Caranx spp.	crevalle jack and/or horseeye jack
	Chloroscombros chrysurus	Atlantic bumper

Table 6-5 Cont.

FAMILY	GENUS-SPECIES	COMMON NAME
Centrarchidae	*Lepomis* spp.	redear and/or redbreast sunfish
Lutjanidae	*Lutjanus griseus*	gray snapper
Gerreidae	*Eucinostomus* spp.	spotfin mojarra and/or silver jenny
Pomada syidae	*Orthopristis chrysoptera*	pigfish
Sparidae	*Lagodon rhomboides*	pinfish
Sciaenidae	*Bairdiella chrysura*	silver perch
	Cynoscion regalis	weakfish
	Leiostomus xanthurus	spot
	Menticirrhus spp.	northern kingfish and/or southern kingfish
	Micropogonias undulatus	Atlantic croaker
	Sciaenops ocellata	red drum
	Stellifer lanceolatus	star drum
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish (juveniles)
Mugilidae	*Mugil cephalus*	striped mullet (juveniles)
Blenniidae	*Hypsoblennius hentzi*	feather blenny
Gobiidae	*Gobiosoma* spp.	naked goby and/or seaboard goby
Stromateidae	*Peprilus alepidotus*	harvestfish (juveniles)
	Peprilus triacanthus	butterfish (juveniles)
Triglidae	*Prionotus* spp.	bighead searobin and/or leopard searobin
Bothidae	*Ancyclopsetta quadrocellata*	ocellated flounder

Table 6-5 Cont.

FAMILY	GENUS-SPECIES	COMMON NAME
	Citharichthys spilopterus	bay whiff
	Etropus crossotus	fringed flounder
	Paralichthys lethostigma	southern flounder
	Paralichthys dentatus	summer flounder
Soleidae	*Trinectes maculatus*	hogchoker
Cynoglossidae	*Symphurus plagiusa*	blackcheek tonguefish
Balistidae	*Monacanthus hispidus*	planehead filefish (juveniles)

The highest density determined in the program was about $16/m^3$ at MB in May (Appendix V. G.). The only other major catches were at TA and PS in March and May. River densities were typically low. Densities were usually less than $1/m^3$, and none were collected anywhere in January. In general, highest numbers occurred in the middle bay in spring (Appendix V. G.).

Densities at NMF and SJ Creeks were higher than most Winyah Bay Stations. Winter values of about $3/m^3$ and summer densities from 6 to $12/m^3$ in these creeks may indicate that such habitats are more important nursery areas than open waterways. During 1980-81, Winyah Bay densities were usually about $1/m^3$.

Intensive series patterns of abundance were similar to the extensive series patterns in that US densities were lowest. Densities at MS and MN were comparable to extensive series station values. Generally, highest densities were in the spring (Appendix VI. G.). Some differences in the densities determined in 3, 6, and 9 minute tows may indicate the extent to which larvae occur in patches on the bottom (Fig. 6-5).

On the special series MN cruise, fish larvae densities ranged from 0.1 to 6.9 (Table 6-3). The range in densities during a 5 hour study at one location was greater than the differences between adjacent stations or cruises in the extensive cruises. Such variability is common among these motile organisms. During the special series, fish larvae densities decreased as velocity increased (Table 6-3). Surface densities were greater than bottom densities (Table 6-3) and larvae accounted for a larger percentage of the surface catch during slack and moderate current conditions (Table 6-4). Fish larvae were the most important (45%) group in surface collections at slack tide; they became less important at the surface as current velocities increased (Table 6-4).

K. CHAETOGNATHS

Chaetognaths or arrow worms are very abundant in Winyah Bay, especially in the lower bay during the warm months. During the 1980-81 study of motile epibenthos, chaetognaths dominated 7 of the 9 cruises at MN. Densities of these elongate (< 10 mm) zooplankton predators were often on the order of $100/m^3$. At least 3 species of the genus Sagitta were identified in lower bay collections. A similar seasonal pattern was found at NMF and SJ during 1980-81, and densities were equivalent to those in the lower bay at the same time. Chaetognaths are high salinity coastal species which are moved toward the upper bay with the salt wedge and, thus, may serve as indicators of salt water penetration and water mass residence time in the upper bay.

Since sample processing time was more than doubled when chaetognaths were present, it was difficult to justify counting all individuals. Problems with retention of small individuals in 365 μm nets, their wide vertical distribution within the water column, and the apparent insignificance of chaetognaths in the diets of estuarine fishes all contributed to the decision not to count chaetognaths in either the sled or zooplankton collections during the 1981-82 extensive or intensive series.

Chaetognaths were counted in the special series collections at MN. Densities ranged from 1 to $34/m^3$. Bottom densities were greater than surface densities and they increased with increasing current velocity (Table 6-3). They were the most important organisms in the collections at all stages of the tide, but accounted for a larger proportion at the bottom than the surface (Table 6-4).

L. MEDUSAE AND CTENOPHORES

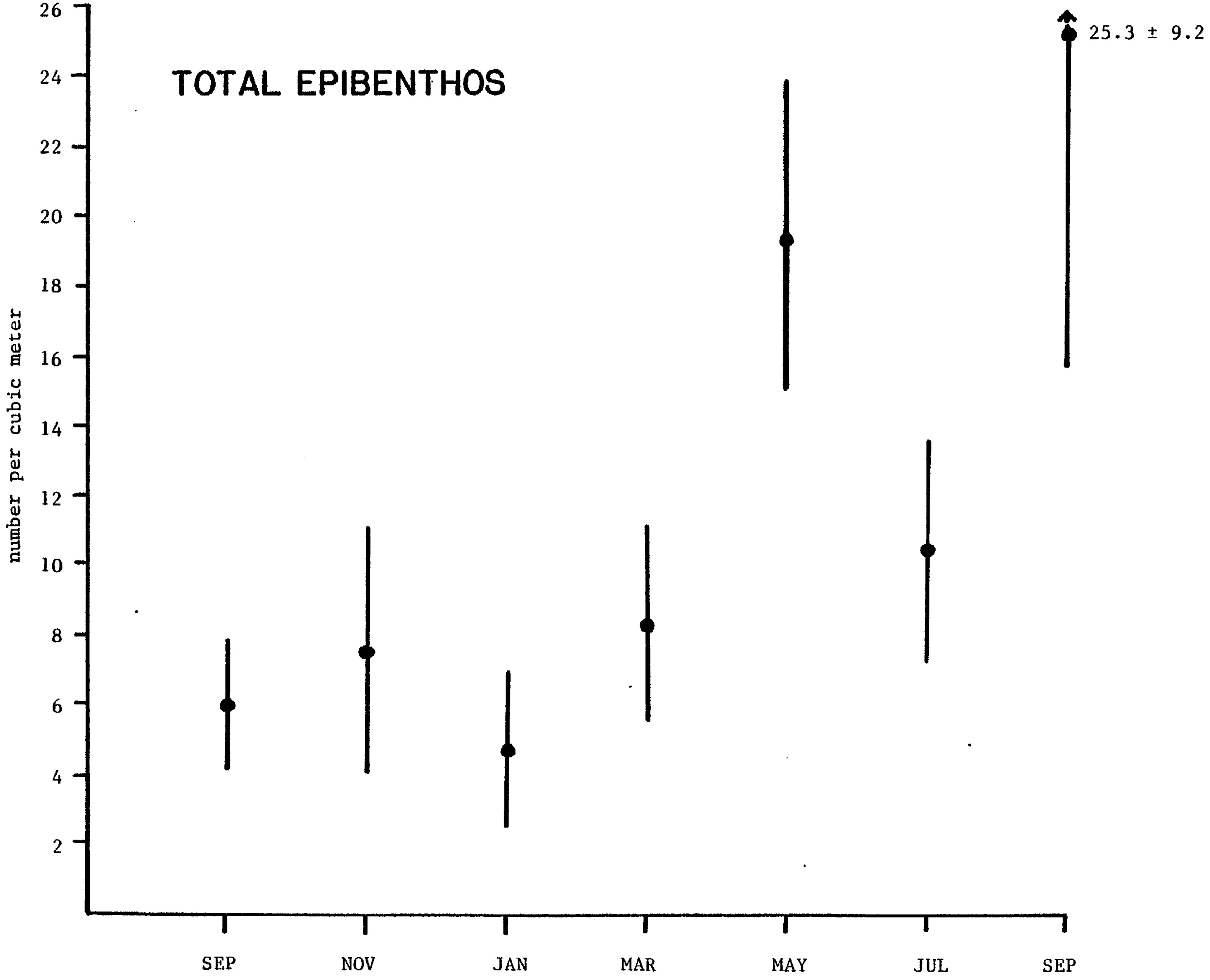
Medusae representing many hydrozoan families (especially F. Bougainivilliidae) were collected in most samples during most of the year. Larger jellyfish such as Stomolophus meleagris, Chrysaora quinquecirrha, and Rhopilema verrilli were incidentals in the sleds. Ctenophores commonly collected were Mnemiopsis leidyi and Beroe ovata. Sometimes small (< 15 mm) jellyfish were so dense that sample volumes were more than one liter. The first attempt to conduct the special series in September 1982 at MS was cancelled after 2 hours because medusae fouled the nets. Medusae were not enumerated in any of the samples for the same reasons that chaetognaths were not counted; however, a distinct pattern was observed. Small medusae were most abundant in the middle bay in summer and fall. Whereas chaetognaths were major zooplankton predators near the ocean, medusa dominated near the bottom further up the bay especially in the channel. Few medusae were found in the river or at the lower bay stations near flood tide. Other sampling gear and procedures must be used to determine more specific patterns of medusae and ctenophore distribution within Winyah Bay. There is no doubt that medusae play a major role in the estuarine food web and may be a major factor influencing zooplankton abundance and community structure. When medusae were abundant, densities of all motile epibenthos, especially mysids, were near zero.

M. TOTAL ORGANISMS

In this section trends for total epibenthic organisms are discussed. The category includes mysids, amphipods, isopods, cumaceans, decapod shrimp larvae, postlarval penaeids, *Acetes*, *Lucifer*, crab megalopae, fish eggs and fish larvae. None of the incidental forms (e.g. chaetognaths, medusae, crab zoeae or copepods) was considered in this analysis even though such forms often totally dominated the sled collections.

Overall densities for total organisms were on the order of 5 to $10/m^3$ during September 1981, November, January, March, and July and reached their highest levels in May ($19/m^3$) and September 1982 ($25/m^3$) (Fig 6-6). An abrupt increase in density occurred in May after relatively low densities persisted through the winter. The lower density on the July cruise was probably related to the major freshwater runoff at this time. Low upper and middle bay salinities in July are thought to have displaced the high salinity forms, which dominate the summer community, toward the ocean. During

Fig. 6-6. Mean densities (±1 S.E.) of total epibenthic organisms on all 7 extensive series cruises in Winyah Bay in 1981-82. Each value is the mean for all 11 stations on that cruise.



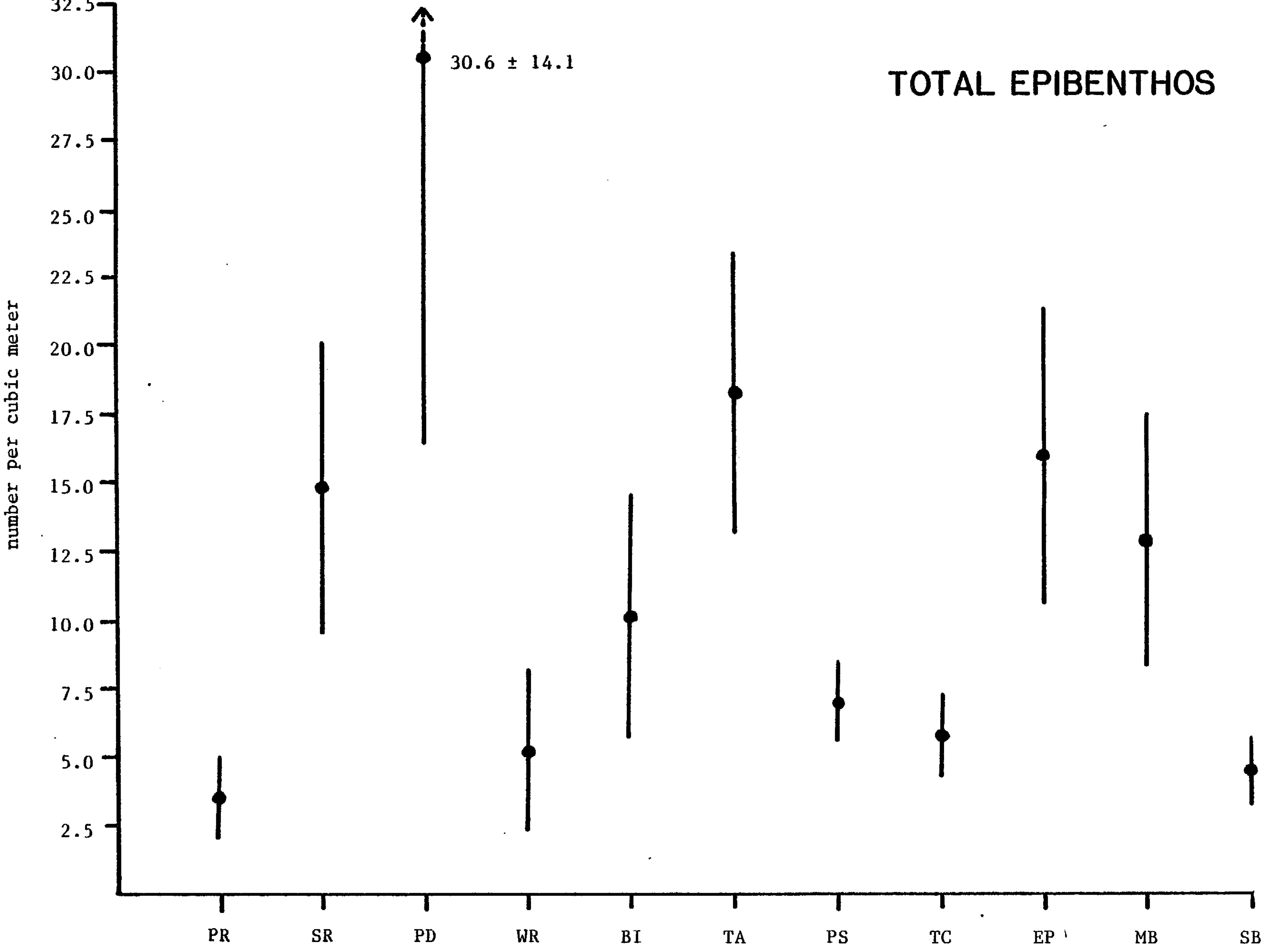
the 1980-81 study of 6 stations, total organism densities ranged from 4 to 25/m^3 with a peak of 55/m^3 in June (Allen et al., 1982). The seasonal pattern and overall abundance at NMF and SJ Creeks was comparable to the middle bay stations.

Of the 14 stations sampled in 1981-82, PD had the highest density of total organisms (31/m^3) (Table 6-7). This was almost entirely due to the occurrence of high densities of amphipods during summer and fall. At most stations mean densities were 10 to 100 organisms/m^3 (Fig. 6-6). Lowest values (about 5/m^3) were found at PR, WR, US, TC, and SB. Highest variability between cruises was at the river stations, where salinity fluctuations between cruises were highest.

Total organism density tended to be highest in the middle bay, especially at TA, MS, and EP (Fig. 6-7). Mud Bay stations PS and TC were more comparable to lower bay stations SB and MN. PR had the lowest mean density, but WR and US were also low. The density at SR was significantly higher than at the other river stations with the exception of PD.

The highest density of total organisms collected in the study was 147/m^3 at PD in September 1982 (Appendix V. H.). The second highest density was at TA in May. Most collections had 2 to 15 organisms/m^3, but no motile epibenthic organisms occurred at PR in November or WR in January. Generally, total organism densities throughout the bay were lowest in winter and when salinities were lowest (Appendix V. H.).

Fig. 6-7. Mean densities (±1 S.E.) of total epibenthic organisms at all 11 extensive series stations in Winyah Bay in 1981-82. Values are means of all collections taken at that location on the seven cruises.



The range in densities between intensive series cruises was from 5 to 15/m^3 and the seasonal pattern of distribution was consistent with the summary based on the extensive series (Fig, 6-3). US densities were generally lower than MS and MN densities, with the exception of the May cruise on which very high densities of mysids were caught in a few of the US tows (Appendix VI. H.).

Total organism densities on the special series cruise at MN in September 1982 ranged from 6 to 66/m^3 over the 5 hour period (Table 6-6). Higher densities occurred on the bottom than surface especially during strong current conditions (Table 6-3 and 6-5). There was a trend toward increasing abundance with increasing current velocity (Table 6-3).

N. SAMPLING CONSIDERATIONS

One of the purposes of the special series cruise was to examine the differences in the performance of various sampling gear. A comparison of total organisms in closing nets deployed at the surface and bottom showed significantly more animals occurred at the bottom during slack and strong current conditions; more were in surface tows during moderate currents (Table 6-4). Unfortunatly, values at both levels at slack and moderate tides may be misleading because such low volumes of water were filtered. There were no significant differences in the size of the catch between the 0 to 30 cm level and the 30 to 60 cm level sled nets at any stage of the tide (Table 6-6). Single level sled values were very similar to those in both levels of the double sleds.

Table 6-6. Comparison of densities of total organisms collected in different gear types at slack, moderate, and strong current conditions. Values are mean number per cubic meter plus or minus one standard error.

	Slack	Moderate	Strong	All
Surface closing net	14.5 ± 3.6	49.5 ± 19.0	17.2 ± 1.4	26.4 ± 9.2
Bottom closing net	57.1 ± 23.1	23.3 ± 5.5	57.6 ± 8.0	45.9 ± 10.5
Upper level sled	12.7 ± 1.4	28.9 ± 2.8	66.4 ± 6.2	33.8 ± 6.9
Lower level sled	12.1 ± 1.3	36.6 ± 4.4	56.0 ± 5.0	33.3 ± 6.2
Single level sled	7.2 ± 0.6	47.6 ± 2.3	52.2 ± 1.9	34.9 ± 7.5

Densities of total organisms increased in all sleds as current velocities increased (Table 6-6). This trend was also evident when all gear were considered together (Table 6-7).

By far the highest densities ($95/m^3$) were collected when nets were towed against a strong tide; however, the mean density for tows in the direction of the strong tide ($54/m^3$) was also high (Table 6-7). All of this evidence indicates that sleds are most effective in collecting organisms during peak tides, presumably when many swimming forms remain near the sediment - water interface where current velocities are lowest. Changes in the vertical distribution of organisms susceptible to capture in 365 μm nets and/or changes in the effectiveness of the sampling device in capturing the organisms are two major problems which complicate the interpretation of field survey data. Since there was no way to collect samples at the same stage of the tide at all stations on each cruise, care had to be taken to sample the stations in the same sequence on each cruise. Starting time, time on station, and travel time between stations were consistent between cruises. On extensive cruises, lower bay stations were sampled at the beginning of ebb tide. Middle bay stations were sampled around peak tides, and upper bay stations were sampled near low tide. On intensive series cruises, lower and upper bay stations were sampled at moderate ebbing velocities and middle bay samples were taken near peak velocities. Mud Bay and PR velocities were always low. Further analyses will be conducted using all available data to determine the extent to which stage of tide may have influenced patterns of abundance.

Table 6-7. Comparison of densities of total organisms collected at slack, moderate, and strong tidal velocities. Mean values (± S.E.) are given for (1) all gear towed in the direction the tide was flowing, (2) all gear towed against the tide, and (3) all gear deployed from an anchored boat.

	Towed With Tide	Towed Against Tide	Stationary	All Methods
Slack	5.7 ± 0.9	17.2 ± 5.2	25.4 ± 8.7	18.3 ± 5.0
Moderate	28.9 ± 6.3	26.9 ± 1.1	46.9 ± 7.9	33.7 ± 5.4
Strong	53.5 ± 2.3	94.5 ± 9.3	31.3 ± 6.1	53.0 ± 7.6

O. SUMMARY

Motile epibenthic crustaceans and fishes constitute an essential link in the estuarine food web. Most of these small animals assimilate plant material, algae, and microorganisms and make this energy available to higher trophic levels. Other species are represented in the community by developmental stages of forms which grow and eventually feed on smaller epibenthic crustaceans. Mysids, amphipods, and small decapods are major sources of food for most commercially and recreationally important fishes in Winyah Bay.

Petroleum pollutants threaten the motile epibenthos through several mechanisms, but the most significant potential harm involves the accumulation of hydrocarbons in fine grained sediments. Since these organisms live near the bottom, they are particularly susceptible to the ingestion of polluted particles. Lethal and sublethal effects on respiration, growth, feeding, and reproduction are known for common epibenthic forms. Low concentrations of toxic petrochemicals associated with the effluent of a refinery are likely to have adverse long term effects on these organisms. Due to their critical ecological role, destruction of motile epibenthic forms will have severe repercussions for the entire estuary.

CHAPTER 7. ECOLOGY OF WINYAH BAY AND POTENTIAL IMPACTS OF CHRONIC AND ACUTE OIL SPILLAGE

It is estimated that tens of thousands of scientific papers describing the effects of petroleum on the marine environment have been published in the past twenty years (Gunkel and Gassmann, 1980). Fortunately, it is not necessary to examine the entire literature base available to achieve an understanding of the impacts of petroleum on temperate marine environments. Numerous literature reviews by respected authorities in the field have been published recently which summarize this voluminous literature and attempt to integrate information which may often appear to be contradictory and confusing (NAS, 1975; Clark, 1982; Olsen et al., 1982). Also, a review of literature more pertinent to the habitats and species assemblages present within Winyah Bay has been previously prepared (Allen et al., 1982).

Since further extensive review of the literature would be extremely time consuming and repetitive, it is the intent of the authors to only present examples from the most recent literature which add to our understanding of oil impacts in the marine environment. Following a survey of the most recent literature, we will attempt to integrate probable impacts with what is now known about the ecology of Winyah Bay. Emphasis will be placed upon the effects of oil on primary producers, zooplankton, and epibenthic organisms (including early life history stages of fishes, crabs, and shrimps) since this was the focus of phases II and III of the study.

A proposal to construct and operate a crude oil refinery on the Sampit River in upper Winyah Bay has generated considerable interest in the potential impacts of the industry on the Winyah Bay Estuary. In addition to the three phase study reported in Allen et al. (1982) and the present document, the Coastal Energy Impact Program (NOAA) supported three other investigations of oil pollution in Winyah Bay. Our studies describe physical, chemical, and biological characteristics of the estuary and assess potential impacts of petroleum, especially on zooplankton and early life stages of crustaceans and fishes which inhabit the system. Thebeau et al. (1982) developed an Environmental Sensitivity Index which classifies each coastal habitat type according to its vulnerability to spilled oil. They found that more than 80% of the shoreline of Winyah Bay falls within the most sensitive categories. May (1982) developed an oil spill trajectory model for Winyah Bay. Difficulties in predicting the fate of spilled oil and deploying effective containment and clean-up equipment in a large and physically dynamic estuary such as Winyah Bay are formidable. Bidleman and Svastits (1983) conducted baseline measurements of petroleum hydrocarbons in water samples from locations within Winyah Bay and found present levels were low.

FATES AND IMPACTS OF OIL IN THE MARINE ENVIRONMENT; A SURVEY OF RECENT LITERATURE

It is estimated that half of the petroleum discharged by the United States into the marine environment enters estuaries from coastal metropolitan areas and rivers (NAS, 1975). Concentrations of petroleum hydrocarbons in the water column typically approach 0.1 ppm near these metropolitan areas. Although water column "concentrations decline rapidly with distance from the source, surface sediment concentrations of 500 ppm or greater appear to be present over large portions of urbanized estuaries" (Olsen et al., 1982). Recent research suggests that "major environmental impacts may be expected when water column concentrations are sustained at 0.1 ppm and more and when surface sediment concentrations attain 500 ppm" (Olsen et al., 1982).

It is impossible to precisely determine the fate of oil from specific discharges (Wheeler, 1978) because of highly variable environmental conditions; however, it is now known that all but the most volatile fractions are incorporated into the bottom sediments (Olsen et al., 1982). Most of the serious long term effects associated with oil discharges are reported for low energy environments (lagoons, estuaries, and marshes) where oil tends to persist for long periods (Vandermeulen, 1982). In general, substantial restoration to pre-spill conditions in acutely polluted areas occurs within two years (Clark, 1982). However, subtle changes in sensitive areas may persist for decades (Southward and Southward, 1979; Sanders et al., 1980; Vandermeulen, 1982).

Effects of chronic discharges are often difficult to determine since these subtle changes may be masked by natural changes (Lewis, 1982). Generally, intertidal and subtidal benthic communities respond most dramatically. Temporal changes after an acute spill are similar to spatial changes observed around chronic discharges. Such effects are generally seen as "a simplification of the ecosystem with dominance of a few species" (Southward, 1982).

Three approaches have been used to determine the effects of oil on marine ecosystems. The first approach employs bioassays which determine the minimum concentrations of petroleum or its constituents necessary to kill the test organisms. Table I summarizes results of some 96 hour bioassays which have been conducted on a variety of marine organisms (from Olsen et al., 1982). Although the lethal concentration is influenced by numerous factors (including the type of oil, the manner in which the oil is presented, and the sensitivity of the species) bioassays provide important information about the relative toxicity of hydrocarbons to different species and life stages in a community (Olsen et al., 1982). Generally, juveniles are more sensitive than adults and larval crustaceans appear to be among the most sensitive groups of organisms to hydrocarbons (Rice et al., 1977).

In the second approach, field observations are used to report the actual effects of chronic and acute oil pollution. Hundreds of scientific papers describe significant reductions in zooplankton,

Table 7-1. Lethal Concentrations of Crude and No. 2 Fuel Oil Determined Through 96-Hour Bioassays in Which Hydrocarbon Concentrations Were Measured Directly (Adapted from Rice et al., 1977a)

	Crude Oils (ppm)	No. 2 Fuel Oil (ppm)	Source
6 Species Shrimp and Crab Stage I Larvae	0.9-1.8	-	Brodersen et al., 1977
4 Shrimp Species	-	1-6.6	Neff et al., 1976
6 Crustacean Species	0.6-4.2	0.5-1.7	Rice et al., 1977b
4 Limpet and Chiton Species	3.6-9.6	0.4-5.6	Rice et al., 1977b
3 Fish Species	5.5-19.8	3.9-6.3	Anderson et al., 1975
4 Fish Species	1.2-2.9	0.8-2.1	Rice et al., 1977b
3 Polychaetes	9.5-12.5	2.3-2.7	Rossi et al., 1976
Polychaete	12.5-19.8	2-8.4	Rossi and Anderson, 1976

shellfish, fish, bird, and benthic populations following an oil spill. Much of this literature was reviewed previously (Allen et al., 1982) and will not be repeated here. Chronic oil pollution in rivers can also result in significant declines in commercial catches of fishes and crustaceans in adjacent bays (Spears, 1971). Medium and long term changes to fisheries stocks may be much more significant than any immediate effects which are reported (Cnexo, 1981).

The newest approach to studying oil pollution in the marine environment entails the use of microcosms which are built to mimic the marine ecosystem. A recent series of experiments which integrated pelagic and benthic ecosystems was conducted by researchers at the University of Rhode Island (Olsen et al., 1982). Water accomodated No. 2 fuel oil was added to three microcosms and a concentration of 0.2 ppm was maintained throughout the experiment (February 1977 through October 1977). Effects were compared to three un-oiled control microcosms. A second set of experiments was conducted from March 1978 through July 1979 in a manner similar to the first, but a lower concentration of 0.1 ppm was maintained. Recovery of the ecosystem was monitored for one year after oil additions ceased. Results of the experiments which measured effects on the experimental ecosystem are presented in Table II. The researchers' interpretation of the results is extracted verbatim from published literature and is presented in summary form below (from Olsen et al., 1982):

1. General conclusions:

"The chronic-addition experiments led to several major

Table 7-2. The Impacts of Sustained, Low Concentrations of No. 2 Fuel Oil (0.2 and 0.1 ppm) on Principal Trophic Components, Species, and Nutrients in MERL Microcosms Expressed as Percentages of Mean Oiled Compared to Mean Control Microcosms (from Oviatt et al., 1982)

	0.2 ppm	0.1 ppm	Recovery from 0.1 ppm
A. Water Column			
C_{14} Productivity	+179%[b]	+ 37%	+ 4%
Chla	+120%[a]	+ 67%	+ 25%
NH_3	- 77%[b]	- 19%	- 42%
$NO_2 + NO_3$	- 71%[b]	- 63%	- 58%
PO_4	- 14%	- 40%	- 63%
SiO_4	- 3%	- 74%[a]	- 63%
Zooplankton Biomass	- 43%	- 23%	- 9%
Total Zooplankton	- 78%[b]	- 16%	- 10%
Acartia tonsa	+633%[c]	+463%[a]	+ 81%
Acartia clausi	- 69%[a]	+ 2%	+ 58%
B. Macrofauna			
Total Macrofauna	- 30%[a]	- 42%[b]	- 64%
Mediomastus ambiseta	- 35%	- 55%[b]	- 83%
Nucula annulata	- 37%[a]	- 13%	- 36%
Ampelisca abdita	-100%	- 93%[a]	- 98%
Chaetozone sp.	+221%	+203%	+276%
C. Meiofauna			
Total Meiofauna	- 38%[b]	+ 23%	- 18%
Nematodes	- 46%[b]	+ 9%	- 23%
Harpacticoids	- 57%	- 35%[a]	+ 19%
Foraminifera	+257%	+202%[a]	- 14%
Ostracods	-100%	- 94%[b]	- 68%[a]
Juvenile Bivalves	- 3%	- 90%	- 37%
Juvenile Polychaetes	+223%	+ 18%	+277%

a. Statistically significant at the 90 percentile

b. Statistically significant at the 95 percentile

c. *Acartia tonsa* flourished in only one of the three oiled tanks; time-averaged numbers in each tank during oiling were 5242, 18, and 38.

conclusions. The first is that the key factors affecting the magnitude of the impact of oil on major components of the ecosystem are the generation times of species and the length of time organisms are in contact with the oil. Since the oil disappeared rapidly from the water column, populations of short-lived planktonic species sensitive to the low oil concentrations recovered days or weeks after oiling ceased. Approximately half the oil added to the water column became incorporated in surface sediments, and here it persisted and had severe, long-lasting effects on the longer-lived benthos."

2. Water column nutrients:

   "All principal nutrients were lower in the waters of oiled tanks than in controls. During the recovery experiment, for example, ammonia, nitrate, nitrite, phosphate, and silicate were all reduced by approximately 50 percent. This too is attributed to the radical decline in the benthic community, which therefore produced a slower rate of remineralization of nutrients to the water column."

3. Phytoplankton:

   "The phytoplankton flourished at sustained concentrations of both 0.1 ppm and 0.2 ppm and during the recovery experiment. Primary productivity, for example, increased by 179 percent at 0.2 ppm and by 37 percent at 0.1 ppm. Since many of the animals killed by the oil were herbivores, the reduction in their numbers is the most likely reason for increases in the populations of phytoplankton. Experiments on the effects of similar concentrations of oil on isolated phytoplankton populations confirmed that the oil itself does not cause increases in plant biomass. Increases were also seen in the populations of benthic microflora in the oiled microcosms".

4. Macroalgae:

   "A visually obvious difference between the oiled and control microcosms during both experiments was the virtual absence of the fouling community of primarily subtidal species of macroalgae that grew and had to be removed from the walls on the control tanks".

5. Benthic Fauna:

   "Once the concentration of hydrocarbons in the top one centimeter of sediments reached approximately 500 ppm benthic populations that were sampled every month during the experiment began to decline rapidly. The only exception was on _Chaetozone_ species that was tolerant of the oil and became twice as abundant in oiled tanks. The normally abundant populations of amphipods (primarily _Ampelisca_) and ostracods were particularly sensitive. The recovery experiment demonstrated that the benthic community was as severely depressed during the year after oiling had ceased as it was during the highest oil addition experiment".

6. Zooplankton:

"Chronic additions that produced mean concentrations of 0.1 ppm and 0.2 ppm in both experiments caused reductions in the total biomass and numbers of zooplankton. At the higher concentration, zooplankton numbers declined by 78 percent and biomass by 43 percent. The drastic effect of the oil on the total zooplankton population was softened by the tolerance for oil at both concentrations shown by one species (*Acartia tonsa*). This large [copepod] crustacean took advantage of the abundant phytoplankton and was 633 percent more abundant in oiled tanks during the first oiling experiment and 463 percent more abundant in the second experiment, relative to the controls. After oiling ceased, the entire zooplankton population rebounded rapidly and was more abundant during the year-long recovery experiment in previously oiled tanks than in controls. This is attributed to the decreased grazing pressure of the benthic community".

Ecological Consequences Of Oil Discharge Into Winyah Bay

The physical complexity of an estuary such as Winyah Bay cannot be overemphasized in any discussion of the spatial and temporal distributions of the organisms which inhabit it. At any location between the ocean entrance and the source of freshwater input, large changes in salinity, turbidity, current characteristics, nutrient concentrations, and organism abundance occur over short intervals of time (minutes and hours). Variability over a single tidal cycle may be as large as that measured during an entire year. Because of the dynamic nature of estuaries, it is difficult to describe patterns of distribution for most components; however, during the present study several general trends were observed and these patterns will be described in this section of the report.

The major characteristic used to distinguish water masses within an estuary is salinity. In the following discussion, three salinity zones are identified and used to describe distributional patterns of chemical and biological components within Winyah Bay. The upper bay is dominated by freshwater input from the rivers. The middle bay is the primary mixing zone, and the lower bay is dominated by saltwater input from the ocean. During periods of low and moderate freshwater inflow, the salinity gradient from 0 to 35 ppt is gradual, but during major flooding periods most of Winyah Bay will be less than 10 ppt and a steep gradient occurs near the ocean entrance. Preliminary analyses of the relationships between the physical properties of the water column, especially salinity, and those chemical and biological characteristics measured simultaneously indicates that there are predictable associations. The following characterization of the three regions within Winyah Bay stresses the interactions between components. An assessment of potential impacts within each of the regions will follow the ecological characterization. Impact predictions will be based upon: (1) the literature reviewed in the previous section (2) other literature sources with which we are most familiar (Allen et al., 1982, NAS, 1975; and many of the references described therein) and (3) our current understanding of the ecology of Winyah Bay.

The Upper Bay

Tidal amplitude is lowest in the upper bay. The predominant direction of water flow is toward the ocean, especially following major storms when freshwater inflow is at the maximum level. Although the effect of the flooding tide may be detected many miles upstream, increases in river depth are more often the result of a backing up of the freshwater inlfow than to a penetration of salt water. Little vertical salinity stratification was evident at any of the river stations except in the lower Sampit River where relatively high salinity water remained near the bottom. Salinity near the bottom of the ship channel outside of the Sampit River was often lower than that at the bottom of Georgetown Harbor.

There appears to be little doubt that the source of nitrogen for the estuary is the rivers. High concentrations of phosphorus also occurred in the upper bay. Despite high levels of nutrients, chlorophyll a and carbon concentrations in this region were low relative to the middle and lower bay. Decreased secchi disk visibility in the upper bay was primarily due to high concentrations of fine mud/clay particles and tannins which originated from further upstream. Low light penetration and low salinity apparently minimize phytoplankton production even in the presence of high nutrient concentrations. Additionally, the oceanward flow of surface water prohibits the establishment and maintenance of resident phytoplankton populations in this area. Attached benthic diatoms are, however, abundant along the shore zone and on the marsh surface. Total zooplankton densities were also lowest in the upper bay, especially during major periods of freshwater inflow. There are relatively few freshwater zooplankton species in South Carolina's coastal rivers, and those that were collected in the upper bay during high flow conditions were not abundant. Freshwater cladocerans, rotifers, and insect larvae were collected when the upper bay was essentially freshwater, but during lower flow conditions, the copepods Halicyclops and Eurytemora were more abundant in the upper bay than anywhere else in the estuary. Acartia, the most important copepod in the estuary, was usually present in the upper bay, but densities decreased to zero during periods of high freshwater inflow. Conspicuously absent from the upper bay, even when salinities were highest, were at least four other copepod species which were abundant near the ocean. Each species of copepod was more abundant in one region than another, but their abundance in all regions varied significantly from season to season.

With the exception of the larvae of a few low salinity invertebrates, meroplankton was never abundant in the upper bay. Crab zoea (*Uca* and *Rithropanopeus*) were important summer constituents of the upper Sampit River zooplankton. Barnacle nauplii and polychaete larvae densities were also high at the river stations at times. Short lived peaks of high densities of only a few species characterized the upper bay meroplankton.

Among the epibenthic crustaceans, amphipods were most important in the rivers and upper bay. Gammarid amphipods were patchy in their distribution, but local populations such as those in the Pee Dee River were apparently large. Habitat specificity accounts for large differences in abundance between adjacent areas. Amphipod species composition in the upper bay is different than that in high salinity areas, and it is unlikely that populations move between regions of Winyah Bay.

Mysids were also abundant in the upper bay, especially in the bottom waters of the lower Sampit River. The marine-brackish water mysid *Neomysis* was most abundant at this location when river flow was minimal, and it was absent only when salinities were below about 5 ppt. No other mysid species were collected in the upper bay. Aggregations of *Neomysis* are highly motile and are capable of selecting suitable habitats within the region. Deep relatively high salinity bottom water in Georgetown Harbor was inhabited by higher densities of mysids than surrounding river and ship channel habitats.

Shrimp larvae densities were higher in the lower Sampit River than anywhere else in Winyah Bay possibly because of the presence of saltier water. Larvae of the grass shrimp *Palaemonetes*, which occurs in high densities along the river banks, piers, and ricefield ditches, dominated all shrimp larvae collections in this area. Densities in the ship channel were somewhat lower.

Upper bay densities of fish eggs and larvae were lower than those from more saline areas. Few species of freshwater or marine fishes produce early life stages which develop in low salinity regions of an estuary. Although some species such as catfishes, gars, and minnows reproduce in the upper bay, they do not produce young which inhabit river bottoms or major channels. Fish larvae and juvenile fishes are much more abundant in shore zone and ricefield ditch habitats, but these areas were not sampled in the present study. Sciaenid and other brackish-marine fishes move to low salinity areas only after completing their early life stages in more saline regions. It is also likely that the low densities of larval fishes in upper Winyah Bay are related to low concentrations of chlorophyll and low zooplankton densities.

Potential Impacts in the Upper Bay

Effects of chronic oil pollution within the Sampit River would probably be minimal during the first 1-2 years of plant operation. Baseline studies within Winyah Bay indicate that current water column concentrations in the rivers and bay are very low (Bidleman and Svastits, 1983). It is possible, though, that hydrocarbons and other pollutants normally associated with runoff from municipal areas are having some effect upon localized benthic populations within the Sampit River. However, sampling of benthos within several locations in the Sampit River must be conducted before any such effects can be quantified. Since so little information is currently available, we consider a thorough study of the benthos and sediment chemistry of the Sampit River absolutely essential to the assessment of potential impacts of an oil refinery.

Routine discharges from plant operation will result in the buildup of hydrocarbons in bottom sediments of the Sampit River to levels which would have detrimental effects upon local biota. High turbidity in the rivers (especially the presence of fine mud and clay particles in the water column) will only exacerbate the process since heavier oil fractions will floculate with particles and accumulate on the bottom. Effects of routine operation will be most noticeable in areas nearest the effluent discharge. However, these effects will be detected throughout the Sampit River system as oiled sediments spread along the bottom. Suspension of bottom sediments by tidal action and river flow will eventually result in a patchy distribution of oiled sediments throughout much of the Sampit River system and portions of the upper bay. Oiled particles will also enter the upper bay as a result of runoff from dredged sediments (from Georgetown Harbor and the ship channel) which are deposited in spoil areas between the Waccamaw and Pee Dee River bridges and on Hobcaw Barony, across the bay. Through this mechanism, petroleum pollutants will become widely distributed within the estuary.

Acute oil spills, depending upon the size and location of the spill,could possibly affect much of the Sampit River system and portions of the upper estuary. Large oil spills in the upper portion of Winyah Bay would affect the middle and lower regions of the estuary. Because of the net flow of water toward the ocean, oil spills in the upper bay are more likely to impact lower portions of the bay than riverine habitats far up the Waccamaw and Pee Dee Rivers. However, under certain conditions spills would be transported to marshes upstream of the bridges.

Chronic and acute oil pollution in the upper bay would also result in decreased nutrient concentrations within the system. Benthic communities would experience drastic declines. Concomitant declines in rates of remineralization of nutrients by the benthos would result in decreased nutrient availability. Such effects would be most noticeable in the Sampit River since its watershed is much smaller and receives less phosporus and nitrogen nutrients from agricultural runoff than the other rivers.

Primary production in the water column would probably increase as a result of the destruction of herbivore populations. Some restructuring of the phytoplankton community would be expected as highly sensitive species are destroyed and other less sensitive species experience significant increases. The most dramatic detrimental effects upon primary producers would be the destruction of intertidal marsh plants which receive direct oiling. Plant communities along the shore zone and adjacent to the rice field ditches would be expected to experience the most drastic declines. Pertubation of the marshes would not only result in the overall reduction of primary production, but it would eliminate irreplacable habitats for major estuarine invertebrates, fishes, and birds.

Species diversity in the zooplankton community would decrease since most species are very sensitive to hydrocarbons. Less sensitive species such as Acartia tonsa, which is generally least abundant in upper portions of the estuary, may assume a greater role throughout much of the year as other species are reduced in numbers. However, total zooplankton numbers and biomass in the upper regions of the bay may decrease by as much as 70-80 %. The zooplankton community would be dominated by only a few species which may be abundant seasonally. Amphipod populations, which were most abundant in the rivers and upper bay, would probably be eliminated or severely reduced since they are extremely sensitive to hydrocarbons.

Crustacean larvae, especially shrimp larvae which were more abundant in the Sampit River than any other site sampled in Winyah Bay, are generally very sensitive to petroleum and would probably experience dramatic decreases in abundance. Crab zoeae, which are important constituents in the upper Sampit River, would also be affected. Barnacle nauplii and other members of the meroplankton which are important at the river sites would probably not be affected as severely as other groups since they spend less of their lives as plankton and are generally, as a group, less sensitive to hydrocarbons.

Mysids were very abundant in the upper bay and often dominated the epibenthic community. Although mysids are highly motile, their proximity to contaminated bottom sediments throughout their entire life cycle make them particularly susceptible to oil pollution.

Damage to larval and juvenile fish populations would be greatest in the shore zone and rice field ditch habitats where they are known to be most abundant. Extensive acute oil pollution would result in massive depletions of fishery stocks. Affects of chronic oil pollution would inevitably result in a decline of commercial and recreational catches. Tainting of fish flesh from ingestion of oiled prey items and direct exposure to oil could become a serious problem and result in severe financial hardship to local fishermen (McIntyre, 1982). Many of the hydrocarbons associated with refinery effluents are known to be carcinogenic and may constitute a significant long term human health hazard.

The Middle Bay

The region which extends from the Belle Isle-Frazier's Point constriction of Winyah Bay to the Shell Banks near the narrow ocean end is physically the most complex region. Subsections of the middle bay such as the shallow expanse of Mud Bay, the narrow high velocity ship channel, and secondary channels indicate the diversity of habitats in this region. The extent to which freshwater inflow and saline tidal waters mix at any location is the result of many interacting factors including bathymetry, runoff, tide stage, tide amplitude, and winds conditions. Riverine inflow generally moves seaward along the surface, even when more saline bottom waters are moving upstream with the flooding tide. Salinity stratification is most distinct in the ship channel. More thoroughly mixed water occurs around the marsh islands and in Mud Bay. Low current velocities, low secchi disk visibility, and high sedimentation rates characterize the Mud Bay area and these features contrast sharply with the dynamic tidal patterns of the major creeks which connect the northern side of Mud Bay to North Inlet.

Mud Bay had higher concentrations of nitrogen and phosphorus than the central portion of the middle bay where amounts of all constituents were highly variable. Chlorophyll a and carbon concentrations were generally highest in the middle bay where high nutrient concentrations and complex circulation patterns probably enhanced production. Due to the lower salinity of the surface waters along the axis of the estuary, primary production was lower in the channels than in the shallows.

Overall densities of total zooplankton in the middle bay were intermediate between the rivers and ocean; densities and species composition were also most variable here. _Acartia_, a truly euryhaline copepod, usually dominated collections throughout the middle bay and was more abundant there than in other regions of the estuary. During periods of major inflow, _Acartia_ densities decreased and _Eurytemora_ and _Halicyclops_ densities increased. During medium and low freshwater inflow conditions, the marine copepods Parvocalanus, Pseudodiaptomus, Oithona, and Euterpina were more abundant in the middle bay.

Marine forms were usually most abundant in the high salinity bottom waters in the ship channel. Densities of copepods, particularly Acartia, were often highest at the shallow open water stations in Mud Bay, but densities of meroplankton such as crab zoeae, barnacle nauplii and cyprids, and polychaete and mollusk larvae were often low in these areas. Densities of these invertebrate larvae were usually higher in secondary channels such as EP and TC. Seasonal fluctuations in abundance were significant for all zooplankton constituents, but distributions within the estuary at any time were closely related to the salinity regime.

Epibenthic sled studies indicated that Mud Bay was of primary importance to the estuary as a nursery ground for fishes and shrimps. Highest densities of fish eggs and penaeid shrimp postlarvae and second highest densities of fish larvae and amphipods were found in this area. The tidal creeks NMF and SJ were equally important. Channel stations in the middle bay yielded the highest densities of mysids and fish larvae. Almost all species of fish larvae were collected in all of the middle bay habitats, but species composition and abundance were highly variable.

The high densities of pericarid crustaceans and copepods in the middle bay are most likely related to the high chlorophyll concentrations typical of this region. Rich benthic communities and high numbers of planktivorous medusae, menhaden, and mullet are related to the high productivity of this brackish area. Despite the complexity of the middle bay, biological activity appears to be greater than elsewhere in the system. This productivity is manifest in the ability of a small number of species which tolerate a wide range of physiological conditions to utilize the large amounts of organic material which are synthesized and accumulate in this region of the estuary.

Potential Impacts in the Middle Bay

The impacts of acute oil spillage in the middle region of the bay would probably have the most disastrous effects of any area in the Winyah Bay system. The presence of large expanses of complex and highly productive habitats make this region particularly susceptible to petroleum impacts. High current velocities near the ship channel would result in the rapid spreading of oil from a spill throughout the middle and lower bay. Vast areas of aquatic macrophytes are present within the Thousand Acre Ricefield complex and along the periphery of Mud Bay. Water entering No Man's Friend and South Jones Creeks inundate hundreds of acres of *Spartina alterniflora* marsh within the North Inlet system. An oil spill in the middle bay could seriously affect this highly productive community and significantly reduce the valuable habitat it provides for the biotic community.

High sedimentation rates and low current velocities within Mud Bay would rapidly increase the rate at which oil is incorporated into the bottom sediments. Mud Bay appears to harbor a highly productive benthic community as evidenced by the higher nutrient concentrations in the area. Remineralization of nutrients by benthic organisms would be severely depressed by oil pollution and result in lower availability of nutrients to primary producers and consumers. Phytoplankton may experience rapid population increases in this area as a result of decimation of herbivore populations. Acartia tonsa populations would likely continue to dominate in the middle region of the estuary after an oil spill. However, species diversity would decrease drastically as other more sensitive zooplankton species are reduced in numbers. Temporary members of the zooplankton community such as crab zoea, barnacle nauplii and cyprids, and molluskan larvae would probably be most affected at areas near mid-channel and EP.

Mud Bay also plays an extremely important role as a nursery ground for fishes, crabs, and shrimps. The high population densities normally encountered in this area would be severely reduced following an oil spill. Such an occurrence would have estuary-wide implications. Continued resuspension of bottom sediments in Mud Bay would serve as a mechanism for long-term contamination of the local plant and animal communities. The abundant amphipod populations in Mud Bay would be particularly susceptible to oil pollution and may be substantially reduced.

Mysids and fish larvae which were most abundant in the middle bay would decline in numbers. Although densities would be expected to increase during recovery from an oil spill, some species which are exposed to contaminated bottom sediments throughout their life cycles may take several years to return to normal levels.

Perhaps the greatest danger of an oil spill in this area relates to the trapping of oiled sediments in Mud Bay. Such an event could be expected to cause impacts for many years or decades as a result of resuspension in the water column. Also, damage to the region would inevitably be reflected in decreased catches of commercially important fishes, crabs, and shrimps. Damage to shellfish resources and fishery nursery habitats in North Inlet would result from the transport of oil residues and sediments through NMF and SJ Creeks. Because of the special characteristics of the middle bay, even a relatively small spill or the persistence of low concentrations of petroleum hydrocarbons would have serious adverse effects.

The Lower Bay

Tidal amplitude and current velocities are greatest in the ocean dominated lower region. During periods of major freshwater inflow, surface water masses with salinities below 20 ppt flow to the ocean entrance to Winyah Bay, but strong tidal currents inhibit stratification in this region. Water clarity was always greatest in the lower bay, a feature probably related to low suspended particle and chlorophyll concentrations. Nitrogen and phosphorus concentrations were consistently lower in this region, which indicates that ocean waters are relatively poor in nutrients and riverine nutrient inputs are depleted or diluted before reaching the ocean. Physical and chemical characteristics are similar to those at the mouth of North Inlet.

Total zooplankton densities were generally higher in the lower bay than further upestuary. Copepods were also the most important taxa near the ocean, but the diversity of species was much greater. *Acartia* was not nearly as important as it was in the middle bay except when it was displaced to the more seaward regions during major inflow. *Halicyclops*, a low salinity copepod, only occurred during the major runoff in January. During most flow conditions, marine copepods such as *Parvocalanus*, *Oithona*, *Pseudodiaptomus*, *Euterpina*, and *Centropages* were present in densities which changed from season to season.

Barnacle larvae densities were usually high especially during periods of salinity stratification. Nauplii densities were higher at the surface and cyprids were more abundant near the bottom. Relatively low numbers of zoeae were present in the lower bay, but megalopae densities near the bottom were the highest of any region. Peak densities of mollusk and polychaete larvae were observed near the ocean. The lower bay was also the highest density area for chaetognaths, echinoderm larvae, and appendicularians. In general, summer species diversity was highest near the ocean.

Total motile epibenthos densities were also highest in the lower bay. The largest variety of pericarid and decapod crustaceans occurred in high salinity areas throughout the year. Lowest density and diversity values were recorded during periods of maximum inflow. Intermediate densities of mysids, amphipods and fish larvae occurred there. Although shrimp larvae densities in the lower bay were the lowest in the estuary during the 1981-82 cruises, peak densities occurred there during the 1980-81 cruises. Isopods, cumaceans, sergestid shrimps, and postlarval penaeid shrimps were usually most abundant in lower bay collections. Although early developmental stages of most fishes, crabs, and shrimps were collected in relatively high densities during the warmest months, it is likely that most motile forms moved to more productive, less turbulent habitats such as those described for the middle bay. Adults of most crustacean and finfish species of commercial importance reproduce in the ocean. Larval white and brown shrimp, blue crabs, mullet, spot, croaker, and flounder enter the estuary and move to nursery areas within the system. Young shad, sturgeon, and striped bass, spawned well up the rivers, move to more saline nursery areas as they develop. There appears to be little doubt that middle bay habitats are essential for the completion of the life cycles of almost all major coastal fishery species. Although there is a great deal of biological activity in the lower bay, this area may be best categorized as the corridor of movement between ocean and middle bay habitats. Few motile forms appear to reside in the dynamic lower bay region.

Potential Impacts in the Lower Bay

High current velocities in the lower bay would rapidly spread any oil from a spill over a large distance upestuary or to the nearshore coastal environment depending upon tide and wind conditions. Low nutrient concentrations and phytoplankton densities near mid-channel in the lower portion of the estuary would probably not be significantly affected by oil spillage. The greatest damage to primary producers and nutrient regimes in the lower bay would be felt if oil entered marshes on Cat, South and North Islands. Oiled vegetation would experience massive mortality and nutrient concentrations would concomitantly decrease. Rich benthic communities which are present in these areas would be seriously damaged. Recovery from a major spill would take more than a decade.

High species diversity of zooplankton in the lower bay would decrease as more sensitive species were replaced by those less sensitive. However, zooplankton populations would not be expected to experience serious long-term effects since recruitment from adjacent near shore and upper estuary sites would be rapid. Effects on the abundant meroplankton in the lower estuary including crab magalopae, barnacle nauplii, and echinoderm larvae would be similar to those observed for other members of the zooplankton community; however, if a spill occurred during the peak reproductive period of some species, long term effects on the populations would result.

Populations of crustacean larvae including shrimps and crabs which were very abundant in the lower bay would be affected by an oil spill. Since most shrimps, crabs and larval fishes migrate to more suitable nursery grounds near the middle of the estuary and do not feed for prolonged periods in the lower bay, impacts to these organisms would probably be less severe here than at sites located further up the estuary. Also, low turbidity and high current velocities would likely reduce the buildup of hydrocarbons in the sediments at the ocean end of the estuary. Therefore, unless oil entered low-energy marsh habitats and protected shore areas, severe and long-term ecological damage to benthos and plankton in the lower bay would not be expected. Oil deposited on the jetties and sandy beaches would have severe repercussions for populations peculiar to these habitats.

A survey of the recent literature and integration with our present knowledge of Winyah Bay indicate that highly productive areas in the middle bay / North Inlet and similar areas adjacent to the river sites (especially the shore zone and ricefield ditch habitats) would experience the most severe effects to the invertebrate and vertebrate populations should an oil spill occur. Effects from chronic oil pollution may not be detected during the first year or two of plant operation; however, significant environmental degradation including substantial decreases in local commercial and recreational fisheries will eventually result from the chronic discharge of petroleum into the upper bay.

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KEY TO APPENDICES I-VII

Parameter	Unit of Measurement
Water Temperature	degrees Centigrade (C)
Air Temperature	degrees Centigrade (C)
Salinity	grams/liter (g/l,o/oo ,or ppt)
Secchi Disk	meters
Wind Velocity	miles per hour
Wind Direction	degrees
Water Velocity	meters/second
Conductivity	millimhos/cm
Total Nitrogen	microgram Atoms Nitrogen/liter (ug At. N/l)
Total Dissolved Nitrogen	
Nitrate-Nitrite	
Ammonia	
Total Phosphorus	microgram Atoms Phosphorus/liter (ug At. P/l)
Total Dissolved Phosphorus	
Orthophosphate	
Chlorophyll a	milligrams/cubic meter (mg/m3)
Phaeo-pigments	
Dissolved Organic Carbon	
Total Organic Carbon	

Organism abundance (Appendices IV-VII) is expressed as number/cubic meter.

Appendix I. A. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Pennyroyal Creek

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.8	14.3	7.5	17.7	26.4	29.0	26.9
Bottom	24.6	13.8	7.6	17.5	26.3	28.9	26.9
Salinity							
Surface	8.0	11.4	0.0	0.2	5.7	1.0	10.6
Bottom	8.3	11.7	0.0	0.5	5.9	1.1	10.6
Secchi Disk	0.65	0.70	0.45	0.58	0.52	0.50	0.40
Total Nitrogen							
Surface	71.7	77.6	-	87.3	-	63.4	54.5
Bottom	51.1	72.3	54.9	86.8	-	64.9	51.2
Nitrate-Nitrite							
Surface	14.16	8.23	8.59	26.61	12.97	13.55	0.57
Bottom	14.15	8.18	7.91	26.48	12.79	13.47	0.76
Total Phosphorus							
Surface	3.0	1.9	-	2.5	-	3.1	1.6
Bottom	3.0	2.1	1.5	2.8	-	3.2	1.4
Orthophosphate							
Surface	0.56	0.59	0.39	1.01	0.62	0.86	0.81
Bottom	0.49	0.51	0.40	1.04	0.57	1.02	0.95
Chlorophyll a							
Surface	0.59	2.75	1.06	1.88	2.95	2.55	5.16
Bottom	1.45	1.93	1.30	2.10	2.70	2.36	5.16
Phaeo-pigments							
Surface	1.62	1.96	1.84	2.25	3.18	2.69	5.17
Bottom	2.00	2.06	2.50	3.37	3.77	4.08	5.67

Appendix I. B. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Sampit River

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.8	14.1	5.7	16.9	27.2	29.5	27.0
Bottom	24.3	13.3	6.0	16.8	25.5	28.1	26.7
Salinity							
Surface	7.3	10.3	0.0	0.5	3.9	0.8	9.4
Bottom	11.1	16.4	0.0	4.0	17.1	6.2	19.3
Secchi Disk	0.65	0.65	0.48	0.52	0.50	0.43	0.55
Total Nitrogen							
Surface	65.7	66.7	87.9	124.1	-	62.2	48.1
Bottom	100.6	93.5	77.5	115.2	-		44.9
Nitrate-Nitrite							
Surface	13.73	9.67	16.28	28.65	14.15	15.42	0.77
Bottom	11.66	7.99	16.09	28.92	9.86	16.14	0.63
Total Phosphorus							
Surface	2.8	1.6	1.7	2.0	-	3.2	0.8
Bottom	5.7	9.5	2.6	3.1	-	10.4	1.6
Orthophosphate							
Surface	0.44	0.37	0.38	1.28	0.66	0.83	0.62
Bottom	0.45	0.47	0.49	1.23	0.53	0.84	0.65
Chlorophyll a							
Surface	2.80	1.74	1.16	1.88	6.08	4.68	11.97
Bottom	10.03	3.93	1.64	2.71	4.30	20.09	8.60
Phaeo-pigments							
Surface	2.40	1.30	1.29	1.79	4.20	2.27	4.28
Bottom	14.45	7.96	3.48	3.88	5.64	20.19	6.93

Appendix I. C. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Pee Dee River

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.7	13.8	5.8	17.0	26.4	29.3	26.8
Bottom	24.3	13.5	5.8	16.0	26.1	28.6	26.4
Salinity							
Surface	9.6	9.0	0.0	0.0	4.0	0.9	12.5
Bottom	10.6	9.0	0.0	0.0	5.6	1.7	14.0
Secchi Disk	0.55	0.55	0.70	0.58	0.52	0.40	0.58
Total Nitrogen							
Surface	91.3	86.2	65.8	63.6	-	58.3	53.5
Bottom	65.5	89.2	-	85.3	-	64.9	42.4
Nitrate-Nitrite							
Surface	13.91	9.44	18.50	29.00	13.96	18.89	5.16
Bottom	13.38	9.54	18.03	28.72	13.46	17.27	4.73
Total Phosphorus							
Surface	2.2	1.9	1.7	0.1	-	3.0	1.4
Bottom	4.3	2.3	-	2.2	-	3.5	1.1
Orthophosphate							
Surface	0.36	0.36	0.42	0.71	0.48	1.09	0.76
Bottom	0.40	0.38	0.42	0.91	0.48	0.76	0.76
Chlorophyll a							
Surface	5.77	1.88	0.64	1.79	2.77	2.44	13.39
Bottom	5.65	2.27	0.90	1.74	5.45	3.78	11.36
Phaeo-pigments							
Surface	3.23	1.56	0.67	2.05	3.53	2.01	4.88
Bottom	4.74	2.17	1.11	2.12	12.57	3.04	5.81

Appendix I. D. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Waccamaw River

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.2	13.4	5.7	16.4	26.7	29.6	26.7
Bottom	23.8	13.1	5.4	16.2	26.0	28.3	26.6
Salinity							
Surface	3.4	4.8	0.0	0.2	1.1	0.0	6.0
Bottom	8.1	7.7	0.0	0.2	3.9	0.0	12.4
Secchi Disk	0.45	0.75	0.75	0.60	-	0.43	0.60
Total Nitrogen							
Surface	88.6	100.6	73.4	-	-	63.3	47.4
Bottom	66.6	84.7	88.6	-	-	67.3	62.1
Nitrate-Nitrite							
Surface	16.22	11.48	18.85	27.78	16.86	22.02	3.39
Bottom	14.51	11.26	18.62	28.19	14.95	22.24	5.36
Total Phosphorus							
Surface	2.6	1.7	1.4	-	-	3.0	1.4
Bottom	5.7	3.1	0.8	-	-	3.4	3.1
Orthophosphate							
Surface	0.38	0.49	0.37	0.57	0.54	1.74	0.50
Bottom	0.40	0.43	0.58	1.38	0.46	1.42	0.64
Chlorophyll a							
Surface	2.58	1.04	0.75	1.52	3.93	0.55	10.75
Bottom	6.63	2.02	0.83	1.47	5.45	0.99	17.86
Phaeo-pigments							
Surface	7.47	0.83	0.68	1.74	3.11	1.10	5.31
Bottom	6.65	3.23	0.70	2.04	18.36	2.61	14.09

Appendix I. E. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Upper Station

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.9	12.0	4.6	17.6	26.0	28.2	26.6
Bottom	24.7	12.6	4.6	17.1	25.7	27.8	26.7
Salinity							
Surface	5.3	11.2	0.0	1.9	2.6	0.0	10.6
Bottom	10.1	17.3	0.0	3.0	7.5	10.5	16.7
Secchi Disk	0.65	0.75	0.45	0.65	0.50	0.55	-
Total Nitrogen							
Surface	62.9	124.0	66.7	71.2	-	53.4	58.3
Bottom	64.7	86.6	82.9	70.8	-	62.7	59.2
Nitrate-Nitrite							
Surface	16.56	9.82	24.40	33.38	14.79	19.90	0.09
Bottom	14.09	10.47	24.83	31.14	13.46	17.33	2.03
Total Phosphorus							
Surface	2.9	1.9	2.0	2.9	-	2.8	1.3
Bottom	3.0	2.6	1.5	1.8	-	4.0	2.2
Orthophosphate							
Surface	0.42	0.60	0.46	1.61	0.53	0.80	0.64
Bottom	0.36	0.95	0.44	1.87	0.60	0.74	0.69
Chlorophyll a							
Surface	6.76	1.69	1.00	1.91	5.35	3.58	52.36
Bottom	5.90	2.41	0.77	2.31	3.63	11.77	2.31
Phaeo-pigments							
Surface	2.66	1.44	0.98	2.31	4.59	3.06	-
Bottom	3.34	2.94	0.68	3.01	4.46	6.88	13.78

Appendix I. F. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Belle Isle

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.8	13.6	5.4	16.8	26.8	28.7	26.5
Bottom	24.7	13.1	5.2	16.3	25.0	28.0	26.3
Salinity							
Surface	12.1	16.2	0.0	1.0	8.9	3.5	16.9
Bottom	19.3	22.0	0.4	6.0	20.1	13.9	20.8
Secchi Disk	0.65	0.50	0.40	0.43	0.64	0.60	0.58
Total Nitrogen							
Surface	96.8	78.1	82.2	65.1	-	60.4	42.9
Bottom	87.9	168.6	76.8	127.9	-	69.0	49.2
Nitrate-Nitrite							
Surface	7.50	8.11	17.53	31.72	11.92	18.71	2.39
Bottom	10.27	5.67	18.56	27.65	6.92	17.39	5.45
Total Phosphorus							
Surface	2.0	1.6	1.5	2.7	-	2.7	1.1
Bottom	3.5	11.7	1.8	11.5	-	4.7	2.6
Orthophosphate							
Surface	0.57	0.60	0.36	1.08	0.46	0.54	0.61
Bottom	0.39	0.58	0.30	0.86	0.53	0.63	0.72
Chlorophyll a							
Surface	6.14	1.25	1.25	3.57	7.50	4.54	17.67
Bottom	5.28	5.63	0.75	3.87	3.44	9.34	9.93
Phaeo-pigments							
Surface	3.33	1.56	1.65	3.42	4.98	3.09	4.93
Bottom	5.57	15.53	1.00	18.62	9.15	8.76	6.86

Appendix I. G. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Thousand Acre

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	22.9	12.8	5.3	15.9	25.5	30.8	26.5
Bottom	23.9	12.8	5.3	15.9	25.5	29.5	26.3
Salinity							
Surface	13.2	16.8	0.0	2.1	17.2	3.2	17.2
Bottom	16.4	17.7	0.0	5.0	17.1	4.3	17.3
Secchi Disk	0.35	0.45	0.55	0.42	0.32	0.40	0.63
Total Nitrogen							
Surface	53.2	72.3	83.5	62.0	-	63.6	50.8
Bottom	47.5	83.0	42.7	68.3	-	64.5	48.5
Nitrate-Nitrite							
Surface	10.97	8.41	19.36	30.05	11.65	18.54	1.62
Bottom	10.39	7.67	19.83	27.74	11.50	18.06	1.10
Total Phosphorus							
Surface	3.6	2.0	1.3	2.3	-	3.3	5.3
Bottom	3.6	2.2	2.3	3.0	-	3.2	1.8
Orthophosphate							
Surface	0.33	0.53	0.36	0.79	0.36	0.31	0.74
Bottom	0.40	0.59	0.35	0.98	0.50	0.24	0.61
Chlorophyll a							
Surface	13.01	2.27	1.20	2.34	8.97	9.94	12.38
Bottom	5.90	1.69	1.11	3.44	8.17	8.33	18.67
Phaeo-pigments							
Surface	4.84	1.50	1.15	2.81	4.92	5.75	5.35
Bottom	3.11	2.30	1.02	4.41	6.21	6.39	6.81

Appendix I. H. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Pumpkinseed Island

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.2	12.9	5.0	15.5	25.5	30.0	27.1
Bottom	24.2	12.6	5.1	15.4	25.4	29.6	26.8
Salinity							
Surface	17.4	22.1	0.0	5.5	16.6	6.4	18.8
Bottom	18.9	23.6	0.0	7.9	18.2	6.2	20.1
Secchi Disk	0.45	0.65	0.25	0.70	0.50	0.45	0.55
Total Nitrogen							
Surface	80.9	-	63.0	82.7	-	57.9	37.3
Bottom	69.9	82.4	78.2	53.9	-	60.3	38.9
Nitrate-Nitrite							
Surface	8.17	6.55	20.09	27.27	8.48	15.97	1.51
Bottom	8.77	5.71	19.20	25.23	7.98	15.82	5.40
Total Phosphorus							
Surface	2.1	-	2.6	1.7	-	2.7	0.8
Bottom	1.8	1.6	1.3	1.6	-	2.9	1.3
Orthophosphate							
Surface	0.43	0.55	0.32	1.58	0.44	0.28	0.71
Bottom	0.37	0.70	0.33	1.11	0.44	0.59	0.67
Chlorophyll a							
Surface	8.35	1.64	1.84	1.64	6.08	8.46	9.29
Bottom	7.37	1.78	2.09	2.34	7.99	9.94	10.95
Phaeo-pigments							
Surface	3.54	1.44	5.78	2.35	5.64	4.69	3.36
Bottom	4.41	1.66	5.19	2.26	8.69	4.46	3.83

Appendix I. I. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Middle Station

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	25.1	12.6	4.9	16.3	26.2	28.9	26.8
Bottom	24.7	13.2	5.1	15.2	24.7	27.5	26.4
Salinity							
Surface	16.9	21.1	2.7	7.9	12.5	5.9	23.0
Bottom	26.7	31.3	8.4	23.8	25.0	25.5	32.4
Secchi Disk	0.55	0.65	0.35	0.78	0.47	1.00	0.75
Total Nitrogen							
Surface	76.5	72.4	84.3	55.1	-	48.3	30.0
Bottom	88.5	67.8	76.7	44.2	-	48.0	19.7
Nitrate-Nitrite							
Surface	9.65	6.69	19.23	26.06	9.09	14.36	4.04
Bottom	7.68	3.18	15.40	9.38	4.41	4.42	1.79
Total Phosphorus							
Surface	1.7	1.4	2.8	1.9	-	1.8	0.90
Bottom	1.7	1.5	2.4	0.7	-	1.8	0.60
Orthophosphate							
Surface	0.42	0.69	0.24	1.28	0.35	0.46	0.51
Bottom	0.35	0.36	0.26	0.93	0.41	0.45	0.49
Chlorophyll a							
Surface	6.88	2.02	1.30	1.81	9.85	10.75	14.00
Bottom	3.56	2.94	4.05	2.58	2.87	8.94	5.64
Phaeo-pigments							
Surface	2.71	1.65	1.19	2.16	4.87	5.31	3.54
Bottom	3.02	2.86	2.30	1.80	2.43	5.84	3.37

Appendix I. J. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: The Cut

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.6	13.3	5.6	15.7	26.2	29.5	26.3
Bottom	24.6	13.0	5.6	15.5	25.3	28.5	26.1
Salinity							
Surface	17.8	22.2	1.5	9.0	17.8	6.2	20.9
Bottom	21.1	23.4	0.0	12.0	20.0	7.1	22.0
Secchi Disk	0.55	0.55	0.30	0.75	0.70	0.65	-
Total Nitrogen							
Surface	92.2	81.9	77.3	50.7	-	-	37.0
Bottom	81.6	70.2	79.7	57.1	-	-	40.1
Nitrate-Nitrite							
Surface	8.35	6.05	18.91	23.94	8.00	16.71	5.53
Bottom	7.88	5.59	18.47	20.82	6.77	16.59	5.45
Total Phosphorus							
Surface	1.9	1.5	4.1	-	-	-	3.4
Bottom	1.6	2.0	4.9	2.2	-	-	3.8
Orthophosphate							
Surface	0.33	0.73	0.23	1.31	0.48	0.28	0.57
Bottom	0.29	0.66	0.26	0.78	0.51	0.88	0.71
Chlorophyll a							
Surface	9.58	2.41	1.59	2.05	4.49	6.81	8.88
Bottom	4.79	1.93	1.78	2.10	3.01	7.23	9.33
Phaeo-pigments							
Surface	4.16	1.71	3.03	1.78	3.66	4.08	4.96
Bottom	3.29	2.96	3.74	4.27	4.96	5.67	10.05

Appendix I. K. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Esterville Plantation

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	25.2	13.8	6.1	18.9	26.9	28.7	26.0
Bottom	24.6	13.1	7.1	15.5	24.9	28.0	26.0
Salinity							
Surface	11.2	24.8	3.7	2.2	22.2	2.0	13.0
Bottom	20.5	26.8	25.5	22.1	24.9	2.3	16.7
Secchi Disk	0.45	0.65	0.35	0.58	0.58	0.45	0.73
Total Nitrogen							
Surface	60.9	108.2	67.3	63.4	-	63.0	-
Bottom	86.6	76.4	192.1	-	-	69.1	57.1
Nitrate-Nitrite							
Surface	12.72	5.09	15.84	30.10	6.69	18.37	4.32
Bottom	7.21	4.07	7.01	11.17	4.33	18.62	2.37
Total Phosphorus							
Surface	2.8	1.5	2.0	2.2	-	3.2	-
Bottom	6.7	1.3	14.2	-	-	5.1	2.9
Orthophosphate							
Surface	0.37	0.71	0.22	0.77	0.47	0.47	0.50
Bottom	0.37	0.74	0.34	0.72	0.51	1.11	0.42
Chlorophyll a							
Surface	8.44	2.27	1.78	3.13	10.38	3.40	13.39
Bottom	8.79	2.31	17.59	2.29	3.63	3.92	13.79
Phaeo-pigments							
Surface	6.11	1.72	1.98	2.06	4.67	3.01	4.70
Bottom	14.02	2.04	25.73	2.29	5.21	8.29	10.02

Appendix I. L. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Mud Bay

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	25.1	13.9	6.0	16.8	27.0	28.5	25.7
Bottom	24.7	13.5	6.0	16.5	23.8	28.1	26.0
Salinity							
Surface	16.9	31.9	1.8	10.0	21.5	8.8	23.6
Bottom	26.7	32.7	4.0	11.5	32.4	9.3	23.8
Secchi Disk	0.55	0.75	0.30	0.60	0.62	0.42	0.48
Total Nitrogen							
Surface	76.5	48.2	74.4	51.7	-	50.8	33.9
Bottom	88.5	75.4	78.1	53.0	-	67.8	41.9
Nitrate-Nitrite							
Surface	9.65	2.00	18.07	21.90	6.83	15.36	4.42
Bottom	7.68	1.38	12.37	21.01	1.25	15.25	4.24
Total Phosphorus							
Surface	1.7	0.9	8.8	1.9	-	2.2	1.1
Bottom	1.7	1.4	5.0	2.2	-	4.6	1.8
Orthophosphate							
Surface	0.42	0.41	-	0.78	0.51	0.59	0.64
Bottom	0.35	0.39	0.48	0.83	0.38	0.66	0.59
Chlorophyll a							
Surface	6.88	2.60	2.70	2.05	3.32	2.66	5.92
Bottom	3.56	2.80	9.50	2.56	2.70	4.46	8.81
Phaeo-pigments							
Surface	2.71	1.84	4.34	2.89	2.69	4.55	8.11
Bottom	3.02	2.51	12.33	3.49	3.53	15.29	8.28

Appendix I. M. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Shell Bank

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	24.8	13.9	5.6	15.2	24.1	28.6	26.1
Bottom	24.7	13.5	5.8	14.8	23.0	27.9	26.3
Salinity							
Surface	32.2	33.2	3.8	22.5	32.7	14.1	31.7
Bottom	32.2	33.9	6.3	25.5	33.5	19.3	31.5
Secchi Disk	1.15	0.85	0.30	0.63	0.88	0.55	0.58
Total Nitrogen							
Surface	-	60.9	73.5	41.6	-	48.5	27.2
Bottom	65.9	75.0	96.6	44.8	-	43.9	27.8
Nitrate-Nitrite							
Surface	0.14	1.67	17.45	8.88	1.47	13.90	1.77
Bottom	0.85	0.96	17.12	7.38	0.66	9.17	1.75
Total Phosphorus							
Surface	-	0.8	7.8	0.9	-	2.0	1.0
Bottom	1.2	1.4	6.1	0.7	-	2.3	1.1
Orthophosphate							
Surface	0.16	0.43	0.27	2.27	0.29	0.59	0.62
Bottom	0.29	0.33	0.29	0.87	0.83	0.63	0.56
Chlorophyll a							
Surface	4.42	1.88	3.56	2.87	2.00	1.78	2.96
Bottom	3.69	2.22	5.77	2.92	1.81	1.31	2.96
Phaeo-pigments							
Surface	1.81	1.47	6.48	1.91	1.36	4.67	5.62
Bottom	2.32	2.49	10.16	2.14	1.59	8.09	6.18

Appendix I. N. Physical/chemical characteristics and plant pigments during extensive and intensive series of cruises within Winyah Bay (1981 - 1982).

Location: Mother Norton

	Sep	Nov	Jan	Mar	May	Jul	Sep
Water Temp.							
Surface	25.4	13.3	5.8	14.7	24.2	29.0	26.5
Bottom	25.0	13.3	6.6	14.6	22.8	26.3	26.5
Salinity							
Surface	31.4	35.3	21.5	27.0	32.4	31.3	32.8
Bottom	33.6	35.3	33.3	30.0	34.1	34.2	33.3
Secchi Disk	1.05	0.75	0.28	0.47	0.57	0.95	0.75
Total Nitrogen							
Surface	51.1	76.2	74.5	31.2	-	27.0	25.0
Bottom	38.5	49.0	64.9	34.4	-	28.6	23.5
Nitrate-Nitrite							
Surface	1.60	1.23	10.13	5.04	0.75	3.22	1.01
Bottom	0.72	1.31	1.53	2.53	0.32	0.55	0.96
Total Phosphorus							
Surface	1.3	1.0	3.0	0.7	-	0.9	1.0
Bottom	1.3	0.8	3.4	0.8	-	1.6	1.0
Orthophosphate							
Surface	0.11	0.22	0.17	0.40	0.35	0.12	0.36
Bottom	0.08	0.17	0.14	0.40	0.22	0.24	0.43
Chlorophyll a							
Surface	3.56	3.69	8.11	2.82	5.47	4.27	8.47
Bottom	6.39	3.81	7.99	3.14	5.10	9.94	9.91
Phaeo-pigments							
Surface	1.63	1.40	3.67	1.83	2.44	3.56	5.25
Bottom	2.73	1.62	6.33	3.10	3.05	7.60	5.37

Appendix II. A. Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Air Temp.	Wind Vel.	Wind Dir.	Tide	Water Velocity	
						S	B
9-18	1000	27.0	5.0	225	Flood	0.53	0.17
	1100	28.0	7.0	180	Flood	0.25	0.10
	1200	28.0	11.0	190	Ebb	0.85	0.40
	1300	29.0	11.5	190	Ebb	1.05	0.90
	1400	29.0	13.0	230	Ebb	1.40	1.10
	1500	28.0	13.5	190	Ebb	-	-
	1600	27.5	14.0	190	Ebb	1.15	0.95
	1700	28.0	15.0	190	Ebb	0.58	0.52
	1800	27.5	15.0	190	Flood	0.10	0.20
	1900	26.0	15.0	202	Flood	0.65	0.55
	2000	26.0	10.0	180	Flood	-	-
	2100	26.0	17.0	180	Flood	-	-
	2200	26.0	12.5	180	Flood	0.60	0.45
	2300	26.0	9.0	190	Slack	0.25	0.10
9-19	0000	26.0	15.5	202	Ebb	0.55	0.40
	0100	25.0	13.5	247	Ebb	1.05	0.80
	0200	25.0	10.0	225	Ebb	1.45	1.05
	0300	25.0	5.0	202	Ebb	-	-
	0400	25.0	5.0	202	Ebb	1.15	0.85
	0500	24.0	<5.0	Var.	Ebb	0.55	0.35
	0600	24.0	<5.0	Var.	Slack	-	-
	0700	24.0	<5.0	Var.	Flood	-	-
	0800	25.0	0.0	-	Flood	-	-
	0900	25.0	<5.0	Var.	Flood	-	-

Appendix II. A. (continued) Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Air Temp.	Wind Vel.	Wind Dir.	Tide	Water Velocity S	Water Velocity B
9-19	1000	26.0	<5.0	Var.	Flood	-	-
	1100	27.5	7.0	60	Flood	-	-
	1200	29.0	10.0	180	Slack	-	-
	1600	25.0	15.0	220	Ebb	-	-
	1700	25.0	15.0	180	Ebb	-	-
	1800	25.5	15.0	90	Ebb	-	-
	1900	25.2	11.0	215	Flood	-	-
	2000	25.0	11.5	225	Flood	-	-
	2100	25.0	10.0	200	Flood	-	-
	2200	25.0	11.5	210	Flood	-	-
	2300	25.0	12.5	180	Flood	-	-
9-20	0000	25.0	14.5	190	Flood	-	-
	0100	26.0	13.0	190	Ebb	-	-
	0200	25.5	14.0	210	Ebb	-	-
	0300	25.5	14.5	210	Ebb	-	-
	0400	25.0	13.0	210	Ebb	-	-
	0500	25.0	11.0	230	Ebb	-	-
	0600	25.5	11.5	220	Ebb	-	-
	0700	25.0	12.0	190	Flood	-	-
	0800	25.0	11.0	170	Flood	-	-
	0900	26.0	13.0	170	Flood	-	-
	1000	26.0	13.0	170	Flood	-	-
	1100	27.0	13.0	170	Flood	-	-
	1200	27.0	14.0	210	Flood	-	-

Appendix II. B. Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Temperature		Conductivity		Salinity	
		S	B	S	B	S	B
9-18	1000	25.8	26.3	52.1	52.3	33.4	33.5
	1100	26.2	26.3	52.5	53.0	33.8	33.8
	1200	26.4	26.1	53.2	53.5	33.8	34.5
	1300	26.1	26.1	53.0	53.1	33.9	34.0
	1400	26.8	26.6	51.4	52.2	32.4	33.2
	1500	26.9	26.9	49.1	50.0	30.9	31.4
	1600	27.3	27.2	45.0	45.2	28.1	28.2
	1700	27.2	27.3	41.1	42.1	25.3	25.9
	1800	27.1	26.9	40.7	43.8	25.1	27.1
	1900	27.4	26.7	-	-	31.2	32.7
	2000	-	-	-	-	-	-
	2100	27.0	27.0	54.2	54.2	34.9	33.9
	2200	26.9	27.0	54.0	54.2	33.9	34.4
	2300	26.7	26.6	53.6	53.6	33.7	34.5
9-19	0000	26.7	25.8	53.4	53.5	33.7	33.9
	0100	26.8	26.6	53.6	53.9	34.8	34.9
	0200	26.6	26.7	53.1	53.7	34.2	34.5
	0300	26.8	26.9	49.9	49.9	31.8	31.4
	0400	26.6	26.7	45.0	46.0	28.2	29.0
	0500	26.9	26.8	41.2	42.0	26.2	26.6
	0600	26.5	26.9	39.4	40.3	24.6	25.5
	0700	26.7	26.4	41.4	41.8	26.1	25.8
	0800	26.5	26.5	51.0	50.8	32.3	32.2
	0900	26.2	26.2	48.8	49.0	30.9	31.1

Appendix II. B. (continued) Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Temperature		Conductivity		Salinity	
		S	B	S	B	S	B
9-19	1000	26.1	26.1	50.3	49.1	31.4	31.2
	1100	26.3	26.1	50.3	50.9	32.0	32.4
	1200	26.2	25.9	50.7	51.2	32.1	32.3
	1600	26.4	26.1	42.3	43.4	25.7	26.9
	1700	26.5	26.7	40.5	40.4	24.9	25.2
	1800	26.4	26.2	35.2	37.5	21.0	22.8
	1900	26.0	26.4	38.8	40.3	23.8	25.9
	2000	26.7	26.6	45.7	46.7	28.8	29.4
	2100	26.5	26.7	51.2	51.4	31.6	32.8
	2200	26.4	26.4	51.9	52.2	33.5	33.2
	2300	26.4	26.5	51.6	53.3	32.8	34.1
9-20	0000	26.6	26.7	51.7	54.0	32.8	34.6
	0100	26.5	26.5	52.8	53.3	33.7	34.1
	0200	26.4	26.6	51.8	52.6	33.3	34.0
	0300	26.5	26.5	50.2	50.6	32.4	32.5
	0400	26.7	26.5	47.2	47.4	30.3	30.1
	0500	26.7	26.7	41.0	41.8	25.7	26.2
	0600	26.7	26.4	38.8	40.0	24.2	24.3
	0700	26.7	26.7	38.5	42.2	24.0	26.7
	0800	26.5	26.7	49.2	43.4	28.2	27.8
	0900	26.2	26.4	52.0	52.0	33.2	33.4
	1000	26.3	26.5	52.5	52.5	33.7	33.7
	1100	26.5	26.5	53.6	53.6	34.4	34.4
	1200	26.6	26.6	54.6	54.1	33.4	34.8

Appendix II. C. Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Nitrate-Nitrite		Ammonia		Total Dissolved Nitrogen		Total Nitrogen	
		S	B	S	B	S	B	S	B
9-18	1000	0.56	0.32	2.49	1.30	20.2	10.8	-	18.9
	1100	0.40	0.24	1.09	2.38	18.4	8.8	9.1	24.1
	1200	0.45	0.40	1.79	1.98	-	14.5	19.2	17.6
	1300	0.42	0.25	1.01	1.34	13.3	-	19.6	18.1
	1400	0.71	0.52	1.28	1.88	14.8	-	22.6	18.8
	1500	1.04	0.98	1.26	1.84	12.1	13.2	28.3	14.2
	1600	1.63	1.51	1.74	1.68	20.0	16.5	30.6	31.9
	1700	1.77	1.87	2.32	1.61	17.0	22.4	27.6	24.1
	1800	1.55	1.90	1.48	2.39	23.9	22.6	32.3	30.1
	1900	1.61	1.07	2.00	1.41	15.2	22.7	21.2	27.6
	2000	0.61	2.03	1.20	1.35	18.9	-	14.6	18.1
	2100	0.64	0.42	1.79	1.42	27.9	-	16.0	16.0
	2200	0.57	0.36	1.32	1.60	20.9	14.7	-	22.8
	2300	0.41	0.32	7.70	2.19	13.4	19.3	16.4	32.1
9-19	0000	0.72	0.45	1.22	6.48	23.0	51.2	17.9	22.9
	0100	1.34	0.37	5.08	0.85	48.5	21.8	16.2	19.7
	0200	0.88	0.48	9.63	2.50	23.8	19.2	29.0	18.1
	0300	0.75	0.91	1.89	2.00	17.5	26.7	18.2	21.7
	0400	1.85	1.58	4.36	6.02	41.9	30.9	23.0	26.4
	0500	2.12	2.04	2.60	2.40	29.5	28.4	25.7	26.0
	0600	2.13	2.28	2.08	3.28	29.6	25.5	27.6	31.1
	0700	2.21	2.09	3.40	4.48	39.6	31.6	27.1	36.1
	0800	1.57	1.46	4.16	2.73	36.6	30.7	23.5	23.1
	0900	0.60	0.63	0.00	4.03	13.3	13.7	22.9	20.0

Appendix II. C. (continued) Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Nitrate-Nitrite		Ammonia		Total Dissolved Nitrogen		Total Nitrogen	
		S	B	S	B	S	B	S	B
9-19	1000	0.58	0.44	0.43	0.29	17.4	26.0	19.2	11.2
	1100	0.45	0.45	0.72	0.58	15.0	17.0	19.0	22.8
	1200	0.69	0.45	2.28	0.31	25.6	22.5	19.6	18.3
	1600	3.66	2.26	0.00	4.84	-	29.1	29.1	30.2
	1700	1.85	1.85	4.89	1.99	30.4	24.6	33.4	30.7
	1800	2.19	2.15	2.43	4.18	23.5	27.0	24.0	31.9
	1900	2.31	2.23	1.68	2.33	31.0	29.2	27.8	31.8
	2000	2.20	2.24	2.58	2.43	27.2	29.0	26.0	32.2
	2100	0.93	1.07	1.20	0.78	21.6	13.2	31.1	27.2
	2200	-	0.84	1.22	1.76	17.0	27.7	18.7	15.2
	2300	1.02	0.53	3.36	0.79	19.6	21.3	19.1	25.5
9-20	0000	1.71	0.46	1.28	1.07	17.1	19.7	19.2	26.1
	0100	0.93	0.56	1.41	1.36	26.7	19.3	25.8	17.0
	0200	1.01	0.89	1.48	2.48	20.1	21.1	23.7	25.2
	0300	1.35	1.06	2.07	1.99	18.3	22.4	28.4	31.6
	0400	1.69	1.74	2.16	2.51	23.3	21.4	28.6	26.5
	0500	2.75	2.52	2.82	2.11	25.6	22.8	28.6	32.6
	0600	3.13	3.02	2.26	2.36	34.8	35.5	33.0	41.2
	0700	3.14	2.53	2.49	3.46	29.7	24.9	33.0	54.6
	0800	2.26	2.49	2.49	1.97	39.7	29.4	36.4	38.7
	0900	1.10	1.10	1.22	1.28	24.5	23.6	36.3	60.1
	1000	1.11	1.08	1.27	1.79	30.9	16.4	42.4	54.2
	1100	0.60	0.65	0.75	1.11	25.7	22.2	35.4	36.4
	1200	1.15	0.43	1.77	1.02	35.0	19.4	26.5	68.6

Appendix II. D. Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Orthophosphate		Total Dissolved Phosphorus		Total Phosphorus	
		S	B	S	B	S	B
9-18	1000	0.089	0.208	0.3	0.3	-	0.6
	1100	0.118	0.154	0.2	0.4	0.2	0.8
	1200	0.214	0.225	-	1.1	0.7	0.9
	1300	0.224	0.750	0.9	-	1.0	0.8
	1400	0.818	0.939	2.6	-	0.9	1.0
	1500	0.177	0.303	0.2	0.2	1.1	0.5
	1600	0.250	0.271	0.4	0.2	1.2	1.3
	1700	0.284	0.315	0.3	0.6	1.0	1.1
	1800	0.314	0.404	0.3	0.4	0.8	1.4
	1900	1.041	0.418	0.2	0.2	0.7	1.7
	2000	0.099	0.084	0.5	-	0.6	0.8
	2100	0.162	0.241	1.1	-	0.6	0.4
	2200	0.285	0.233	0.5	0.3	-	0.9
	2300	1.061	1.320	0.0	0.5	0.4	1.7
9-19	0000	0.712	0.420	0.0	2.8	0.4	1.1
	0100	0.679	0.356	1.3	0.7	0.5	1.0
	0200	0.422	0.446	0.2	0.3	0.8	0.7
	0300	0.490	0.531	0.7	0.6	0.8	1.0
	0400	1.019	0.971	1.1	1.9	0.7	1.0
	0500	1.225	0.717	1.0	0.8	1.1	1.3
	0600	0.582	0.572	0.8	0.7	1.0	1.6
	0700	0.602	0.647	1.0	0.7	1.0	1.6
	0800	0.416	0.331	1.2	0.6	1.0	4.2
	0900	0.585	1.141	0.2	0.1	1.0	0.5

Appendix II. D. (continued) Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Orthophosphate		Total Dissolved Phosphorus		Total Phosphorus	
		S	B	S	B	S	B
9-19	1000	0.930	0.751	0.1	0.0	0.5	0.3
	1100	0.385	0.325	0.0	0.1	0.6	1.1
	1200	0.266	0.250	0.1	0.0	0.6	0.6
	1600	1.395	0.670	-	1.1	0.9	1.0
	1700	0.943	1.490	0.5	0.3	1.2	1.4
	1800	0.866	1.129	0.4	1.1	1.0	1.3
	1900	0.624	0.517	0.5	0.8	1.1	1.1
	2000	0.412	0.329	1.2	0.5	1.3	1.1
	2100	0.421	0.348	0.4	0.2	1.2	1.3
	2200	-	0.406	0.1	3.6	0.6	1.0
	2300	1.023	1.554	1.0	0.3	0.4	1.0
9-20	0000	0.539	0.368	0.9	0.4	1.2	1.2
	0100	0.461	0.462	0.5	1.6	1.1	0.7
	0200	0.416	0.277	0.3	0.4	0.5	0.7
	0300	1.635	1.312	0.5	0.5	1.2	1.2
	0400	1.384	1.614	0.4	0.6	0.9	1.0
	0500	0.655	0.600	0.6	1.0	0.9	1.2
	0600	0.578	0.635	1.3	1.4	1.2	1.8
	0700	0.621	2.481	1.0	0.7	1.3	1.7
	0800	1.823	1.687	0.9	0.6	1.2	2.1
	0900	1.640	1.091	2.6	0.6	2.2	2.6
	1000	0.444	0.391	0.7	2.2	2.7	2.6
	1100	0.442	0.419	0.7	0.6	1.7	1.4
	1200	0.419	0.359	0.8	0.6	1.8	2.3

Appendix II. E. Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Dissolved Organic Carbon		Total Organic Carbon		Chlorophyll a		Phaeo-pigments	
		S	B	S	B	S	B	S	B
9-18	1000	2.7	2.3	3.7	2.9	3.59	3.80	2.36	2.19
	1100	2.7	4.3	2.9	2.8	3.37	4.48	1.86	3.22
	1200	3.9	3.8	3.3	3.0	5.16	4.33	2.92	3.93
	1300	2.3	2.5	3.6	3.6	3.79	5.43	4.91	4.27
	1400	2.6	2.5	3.4	3.4	5.98	5.64	3.59	3.25
	1500	3.4	3.6	4.4	4.2	6.33	4.12	2.75	7.01
	1600	3.4	3.5	4.2	4.4	7.57	9.63	4.00	3.51
	1700	3.8	4.2	4.8	5.2	9.08	9.98	3.88	4.43
	1800	4.4	4.8	4.5	4.8	9.01	9.75	6.77	5.64
	1900	3.8	3.5	4.2	4.2	6.54	14.61	2.61	11.98
	2000	2.8	4.0	2.6	2.7	2.55	2.89	4.23	2.57
	2100	3.3	2.8	2.6	2.6	2.76	4.10	3.43	0.94
	2200	2.6	3.2	3.1	3.2	2.54	5.92	2.52	7.86
	2300	3.1	3.4	2.9	5.6	1.93	5.71	2.12	6.88
9-19	0000	3.7	4.0	3.2	4.6	2.92	6.34	1.91	4.91
	0100	-	3.0	3.4	3.3	2.97	4.98	2.51	5.87
	0200	3.6	3.8	3.6	3.3	3.06	4.40	2.82	4.74
	0300	4.9	4.5	4.0	3.6	3.37	3.65	3.77	4.45
	0400	5.1	3.8	4.5	4.5	3.30	3.24	4.15	3.96
	0500	4.5	4.6	4.2	5.2	3.21	3.51	3.02	4.19
	0600	4.6	5.0	5.0	5.1	3.56	4.06	2.99	5.08
	0700	4.2	4.2	4.6	5.0	4.06	4.33	1.95	4.18
	0800	-	2.9	4.8	3.9	4.27	5.85	4.69	10.25
	0900	2.5	2.5	3.3	3.2	4.47	4.13	3.04	3.01

Appendix II. E. (continued) Physical/chemical characteristics and plant pigments during intensive 48-hour sampling program at Mother Norton Shoals (September 1982).

Date	Time	Dissolved Organic Carbon		Total Organic Carbon		Chlorophyll a		Phaeo-pigments	
		S	B	S	B	S	B	S	B
9-19	1000	2.8	2.5	3.2	3.1	3.16	5.16	1.91	3.42
	1100	2.6	3.1	3.5	3.5	2.46	4.20	4.48	4.40
	1200	2.8	2.7	3.4	3.3	3.27	6.95	2.63	0.50
	1600	-	3.8	4.3	4.8	6.40	6.54	3.24	4.55
	1700	3.5	3.8	4.5	4.6	7.57	8.53	4.58	6.31
	1800	4.3	4.2	4.8	4.9	6.54	7.71	3.85	4.63
	1900	4.3	4.5	5.0	5.4	4.68	8.19	3.08	5.46
	2000	4.4	4.1	4.5	4.1	4.19	5.10	4.06	3.30
	2100	3.1	2.9	3.5	4.3	4.75	6.26	4.46	8.83
	2200	2.8	3.2	3.2	3.2	3.23	3.31	3.97	2.38
	2300	3.1	3.1	3.2	3.8	3.92	4.54	3.15	5.54
9-20	0000	2.6	2.5	3.5	3.2	3.51	6.13	3.50	4.08
	0100	3.5	3.2	3.1	3.2	3.15	3.30	3.25	3.74
	0200	2.5	3.1	4.3	3.5	3.40	5.23	3.34	4.36
	0300	3.1	3.5	4.4	4.3	4.06	4.75	3.90	6.15
	0400	5.4	6.2	4.9	4.2	3.17	3.51	4.60	4.75
	0500	7.5	6.0	6.4	5.5	3.30	3.37	5.15	5.14
	0600	7.5	8.0	5.9	5.8	5.02	4.61	4.56	4.72
	0700	6.8	6.3	5.0	5.0	7.01	4.33	4.38	6.12
	0800	6.9	7.1	4.5	4.8	3.85	3.51	5.48	5.57
	0900	5.5	4.9	4.8	4.8	7.23	7.51	9.18	10.04
	1000	6.9	5.5	4.8	5.7	7.44	9.44	9.55	12.82
	1100	3.4	5.4	3.5	3.4	5.71	5.71	5.94	6.12
	1200	4.5	3.2	3.5	3.7	5.57	7.02	3.88	6.19

Appendix III. A. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 1. (October, 1981)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	0.0	-	0.92	2.0	2.3
0.0	S	0.0	-	1.15	2.8	4.2
2.2	S	3.7	25.6	0.46	1.9	2.4
3.5	S	6.0	25.6	0.40	2.2	2.9
4.6	B	7.7	24.1	0.43	1.4	3.8
4.7	B	8.0	24.5	0.37	1.7	2.7
5.3	S	9.1	25.6	0.39	1.5	2.2
5.4	S	9.2	24.6	0.35	1.6	2.2
6.8	B	11.3	24.5	0.37	1.8	4.6
6.9	S	11.6	24.6	0.33	1.4	2.2
6.9	B	11.6	24.6	-	-	-
7.5	B	12.4	24.5	0.41	1.4	4.6
11.0	S	17.9	25.0	0.41	1.4	2.0
11.7	S	19.2	25.1	0.36	1.2	2.5
15.6	B	25.0	24.8	0.40	1.7	2.2
15.7	S	25.6	25.6	0.33	1.0	2.2
18.8	B	29.7	24.8	0.40	1.0	2.4
23.6	S	37.8	26.2	0.27	1.0	1.4
24.9	B	38.9	25.0	0.33	0.9	1.4
25.7	S	40.6	26.0	0.28	0.7	1.2
32.0	B	48.9	25.0	0.16	0.4	1.4
32.5	S	29.8	25.2	0.12	0.4	0.9
33.2	B	50.5	25.1	0.50	0.3	1.3
33.5	B	51.1	25.0	0.20	0.5	1.8
34.3	S	51.8	25.4	0.08	0.4	0.6

Appendix III. A. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 1. (October, 1981)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	5.75	14.45	68.4	72.1
0.0	S	1.15	6.85	71.3	83.3
2.2	S	2.59	16.95	64.8	76.2
3.5	S	1.71	13.41	70.5	72.8
4.6	B	2.88	15.94	59.9	87.8
4.7	B	2.11	13.44	72.6	87.5
5.3	S	2.90	16.01	64.1	79.6
5.4	S	2.05	15.34	64.6	77.2
6.8	B	2.85	14.89	63.5	95.4
6.9	S	2.24	14.41	61.5	71.2
7.5	B	3.77	14.97	64.4	87.3
11.0	S	4.91	14.74	59.4	68.4
11.7	S	6.14	13.69	57.0	62.5
15.6	B	5.71	11.30	54.2	62.2
15.7	S	4.92	12.61	53.1	54.2
18.8	B	3.96	8.32	39.4	66.2
23.6	S	5.22	6.38	46.9	46.9
24.9	B	6.83	6.56	41.4	40.5
25.7	S	4.77	4.39	39.0	43.9
32.0	B	2.63	1.51	-	39.3
32.5	S	2.15	0.51	34.4	40.5
33.2	B	3.81	0.86	29.1	35.3
33.5	B	0.96	0.61	21.1	46.0
34.3	S	1.55	0.40	32.4	34.5

Appendix III. A. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 1. (October, 1981)

Salinity	Depth S/B	Chloro- phyll a	Phaeo- pigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	0.83	0.73	21.0	-
0.0	S	1.01	1.98	32.0	-
2.2	S	8.35	3.08	8.5	-
3.5	S	7.74	2.42	21.5	-
4.6	B	6.63	1.68	25.0	-
4.7	B	6.51	2.61	19.0	-
5.3	S	8.60	2.72	5.5	-
5.4	S	7.37	2.91	20.5	-
6.8	B	6.63	5.49	18.5	-
6.9	S	5.90	5.42	17.0	-
7.5	B	6.14	8.29	10.0	-
11.0	S	4.30	2.51	15.0	-
11.7	S	9.46	4.63	16.5	-
15.6	B	4.18	2.87	9.5	-
15.7	S	8.11	3.21	12.5	-
18.8	B	3.69	4.28	12.0	-
23.6	S	5.41	2.56	10.0	-
24.9	B	3.93	2.42	10.5	-
25.7	S	2.70	1.60	9.5	-
32.0	B	5.77	3.00	8.5	-
32.5	S	3.93	0.71	6.5	-
33.2	B	6.14	4.71	5.5	-
33.5	B	8.72	5.94	6.5	-
34.3	S	3.47	1.20	8.0	-

Appendix III. B. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 2. (December, 1981)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	-	-	0.07	-	6.2
0.0	S	-	-	0.20	-	4.4
0.0	S	-	-	-	1.0	3.7
4.4	S	5.5	9.2	0.49	1.7	2.4
6.0	S	7.5	9.0	0.30	1.2	3.4
6.9	S	8.4	9.1	0.47	1.2	2.2
9.1	B	11.0	9.2	0.42	1.2	4.8
9.3	S	11.2	9.3	0.41	1.0	3.9
9.8	B	11.6	9.1	0.43	1.4	8.4
11.3	S	13.5	8.9	0.41	1.1	9.6
12.0	S	14.2	9.2	0.37	0.8	2.8
14.4	S	16.8	9.0	0.38	0.9	2.5
17.5	S	19.3	8.3	0.45	0.7	3.9
22.2	B	25.0	8.9	0.51	0.6	3.2
28.1	S	31.2	8.8	0.35	0.6	2.4
31.4	B	34.6	9.3	0.30	0.5	2.5
32.6	B	36.0	9.5	0.24	0.4	1.3
33.2	S	36.7	9.5	1.84	0.4	1.1
33.2	S	36.6	9.7	-	0.2	1.2
33.2	B	36.7	9.7	-	0.3	1.1
33.2	B	36.8	10.0	0.15	0.4	1.1
33.3	S	36.8	9.9	0.20	1.5	1.2
33.6	B	37.0	9.5	0.43	-	1.0

Appendix III. B. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 2. (December, 1981)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	6.88	11.73	-	159.4
0.0	S	1.67	6.01	-	107.8
0.0	S	0.96	-	64.9	95.4
4.4	S	0.14	10.83	65.3	93.0
6.0	S	3.14	8.81	61.4	80.3
6.9	S	0.53	10.46	76.2	64.8
9.1	B	0.20	9.95	61.5	92.9
9.3	S	0.02	9.30	78.3	84.0
9.8	B	0.28	9.00	69.6	93.0
11.3	S	0.62	8.86	72.9	110.8
12.0	S	0.09	8.19	67.4	67.8
14.4	S	0.02	7.20	65.5	82.8
17.5	S	3.86	7.38	49.2	70.1
22.2	B	-	6.85	53.3	71.9
28.1	S	0.15	5.65	70.0	76.8
31.4	B	1.24	2.68	70.6	66.6
32.6	B	-	1.29	66.1	73.8
33.2	S	0.15	1.41	60.9	75.7
33.2	S	0.12	-	35.2	83.6
33.2	B	0.21	-	39.6	59.3
33.2	B	0.47	0.74	41.0	43.7
33.3	S	-	0.78	66.3	50.1
33.6	B	-	0.94	-	59.0

Appendix III. B. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 2. (December, 1981)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	7.39	13.44	13.6	20.6
0.0	S	3.07	3.40	-	18.2
0.0	S	1.64	1.71	12.1	9.4
4.4	S	3.93	1.96	7.9	10.3
6.0	S	5.77	4.39	10.3	10.8
6.9	S	3.56	1.75	8.8	9.1
9.1	B	4.05	5.65	9.7	10.9
9.3	S	5.16	4.77	8.8	11.5
9.8	B	6.63	9.53	9.1	17.3
11.3	S	6.39	10.70	9.7	16.3
12.0	S	3.07	3.51	8.8	10.3
14.4	S	3.44	2.68	7.6	8.5
17.5	S	4.42	5.16	7.3	10.0
22.2	B	3.81	4.62	6.7	8.8
28.1	S	3.81	3.12	7.0	8.8
31.4	B	4.42	3.78	8.8	6.1
32.6	B	4.30	2.63	6.7	5.8
33.2	S	4.67	2.03	6.2	5.5
33.2	S	4.30	2.86	6.8	5.6
33.2	B	4.30	2.98	5.4	6.1
33.2	B	4.55	3.08	7.0	6.9
33.3	S	4.18	3.44	6.8	5.8
33.6	B	3.69	2.32	5.7	5.8

Appendix III. C. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 3. (January, 1982)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	0.0	5.8	-	0.9	2.0
0.0	S	0.0	5.2	0.51	0.7	1.1
0.0	S	0.0	4.7	2.44	-	2.1
0.0	B	0.0	4.9	0.96	-	1.5
2.1	S	2.5	5.9	0.50	1.1	2.0
5.6	S	6.4	6.1	0.35	1.1	1.6
11.6	B	12.7	5.8	0.26	0.6	6.5
17.5	S	19.2	6.7	0.22	0.7	1.6
22.5	B	23.8	6.3	0.27	0.3	2.4
24.2	S	25.8	7.2	0.11	0.4	1.5
26.4	S	28.1	7.2	0.11	0.3	1.3
26.4	B	27.6	6.4	0.11	0.2	1.6
27.7	B	29.0	6.5	1.15	0.3	2.1
31.0	B	32.0	7.1	0.12	0.2	2.5
31.2	B	32.6	6.6	0.36	0.1	-
31.6	B	32.8	6.8	0.08	0.2	2.4

Appendix III. C. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 3. (January,1982)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	0.88	18.17	86.1	82.6
0.0	S	0.29	23.26	71.4	91.2
0.0	S	0.15	27.66	77.3	85.4
0.0	B	0.51	29.03	97.7	85.3
2.1	S	0.60	14.99	74.5	73.9
5.6	S	4.21	18.51	64.4	71.5
11.6	B	0.02	9.44	68.9	109.9
17.5	S	0.10	13.54	70.7	61.9
22.5	B	-	6.98	73.0	63.1
24.2	S	0.22	5.83	92.0	53.0
26.4	S	0.66	4.16	64.6	70.4
26.4	B	1.56	4.20	54.7	51.0
27.7	B	0.77	3.49	77.7	55.0
31.0	B	4.94	2.09	56.8	56.4
31.2	B	-	0.93	57.9	-
31.6	B	0.34	0.66	50.2	51.5

Appendix III. C. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 3. (January, 1982)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	1.20	1.33	10.6	10.3
0.0	S	1.88	3.65	10.0	15.7
0.0	S	1.06	1.07	10.3	10.6
0.0	B	0.98	1.17	4.9	10.6
2.1	S	1.40	1.77	11.7	11.4
5.6	S	7.00	5.35	12.6	12.6
11.6	B	9.14	10.03	7.3	14.9
17.5	S	2.99	1.95	8.0	10.0
22.5	B	7.98	5.64	5.4	11.1
24.2	S	7.99	3.10	6.0	6.0
26.4	S	5.65	2.32	5.4	5.1
26.4	B	8.23	4.12	4.8	7.7
27.7	B	10.55	5.98	6.3	8.0
31.0	B	2.32	5.46	9.4	5.5
31.2	B	9.15	7.06	5.5	8.5
31.6	B	9.15	6.72	4.0	7.7

Appendix III. D. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 4. (March, 1982)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	0.0	16.9	1.02	-	0.5
0.0	S	0.0	16.1	1.52	-	0.2
1.0	S	0.5	15.3	0.89	1.4	3.5
2.0	S	1.1	16.2	0.89	1.1	2.4
5.5	S	7.9	15.4	0.83	1.0	2.0
8.0	S	13.8	15.9	0.93	0.6	1.7
10.8	B	12.0	15.9	1.01	1.0	-
15.5	S	22.9	15.0	0.50	0.4	0.8
20.0	S	28.4	14.6	0.54	0.4	-
21.6	B	29.2	14.6	0.51	3.2	1.8
29.0	B	38.4	14.2	0.26	0.2	0.7
29.0	B	37.7	14.2	0.33	0.3	0.6
29.1	B	37.0	14.3	0.37	0.2	0.6
30.8	B	40.4	14.0	0.42	0.1	0.8
32.0	S	40.3	13.9	0.45	0.1	0.9
32.0	S	39.7	14.1	0.42	-	0.7
32.0	B	40.3	14.2	0.15	0.2	0.2
32.1	B	40.4	14.2	0.65	-	0.7

Appendix III. D. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 4. (March, 1982)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	6.40	15.57	65.1	131.3
0.0	S	5.10	23.85	-	98.0
1.0	S	0.80	27.67	54.9	88.3
2.0	S	3.20	25.23	62.1	80.1
5.5	S	3.30	22.28	52.9	73.1
8.0	S	0.40	22.78	42.5	61.6
10.8	B	3.90	19.52	44.5	-
15.5	S	7.40	15.44	39.5	55.4
20.0	S	2.40	12.53	40.9	65.7
21.6	B	0.40	11.79	33.6	106.2
29.0	B	3.50	2.18	60.8	46.7
29.0	B	1.00	3.15	34.7	34.0
29.1	B	5.20	4.39	25.3	37.7
30.8	B	3.10	0.49	36.4	50.7
32.0	S	1.20	1.78	20.9	42.4
32.0	S	3.50	1.58	24.0	50.6
32.0	B	2.50	1.07	22.4	41.4
32.1	B	1.60	0.76	20.2	60.1

Appendix III. D. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 4. (March, 1982)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	1.69	2.12	13.6	13.9
0.0	S	1.16	2.11	14.4	12.8
1.0	S	3.69	4.86	12.9	17.2
2.0	S	1.93	2.06	13.3	16.1
5.5	S	2.22	1.68	11.9	11.1
8.0	S	4.67	2.03	11.1	11.9
10.8	B	4.57	28.49	9.7	-
15.5	S	1.98	1.38	8.3	10.0
20.0	S	2.07	1.60	6.9	10.0
21.6	B	2.95	4.67	7.2	11.4
29.0	B	2.51	1.89	4.7	6.9
29.0	B	2.36	1.76	5.0	5.6
29.1	B	2.60	2.02	5.3	6.1
30.8	B	2.70	2.42	4.2	9.7
32.0	S	2.94	2.22	3.9	21.9
32.0	S	2.80	2.19	5.0	-
32.0	B	2.02	1.87	3.9	10.0
32.1	B	2.51	2.30	4.4	7.3

Appendix III. E. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 5. (May, 1982)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	0.0	-	1.18	2.4	3.3
1.0	S	1.8	26.5	0.67	2.1	2.8
2.2	S	4.0	26.8	0.57	1.9	2.8
2.6	S	4.6	26.5	0.58	1.7	2.9
3.2	S	5.7	26.7	0.52	1.7	2.4
5.1	B	8.8	26.0	0.50	1.5	3.5
5.8	S	10.1	26.5	0.44	1.5	2.4
7.1	S	12.3	26.5	0.49	1.5	2.1
7.5	B	12.8	26.0	0.53	1.4	2.5
8.1	B	13.6	26.1	0.80	1.3	2.1
10.8	S	18.2	26.4	0.37	1.0	3.7
12.7	S	21.1	26.2	0.28	0.9	2.0
16.7	S	27.4	26.2	0.28	0.8	2.1
21.3	B	33.9	25.4	0.48	1.5	2.2
22.3	B	35.3	25.5	0.34	0.6	3.8
23.2	B	36.5	25.6	0.37	0.8	2.8
23.7	S	37.8	25.8	0.38	0.7	1.3
25.3	B	39.5	25.3	0.36	0.3	1.4
29.5	S	45.6	25.1	0.54	0.6	1.1
31.7	B	47.9	25.4	0.24	0.6	1.7
32.5	S	50.0	25.7	0.23	1.0	1.8
33.5	B	51.5	25.7	0.19	0.5	1.2

Appendix III. E. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 5. (May, 1982)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	0.23	8.00	63.5	68.0
1.0	S	0.25	16.13	51.9	58.6
2.2	S	1.41	15.31	51.7	59.4
2.6	S	0.19	11.83	56.7	64.1
3.2	S	0.20	13.45	51.5	55.9
5.1	B	0.16	13.13	50.5	66.8
5.8	S	0.20	13.64	49.1	58.1
7.1	S	0.29	12.63	48.8	53.6
7.5	B	0.13	12.51	48.1	56.5
8.1	B	0.14	12.27	49.2	53.3
10.8	S	0.21	11.05	41.5	66.2
12.7	S	0.21	10.40	38.8	50.8
16.7	S	2.51	8.29	31.7	48.6
21.3	B	0.13	9.17	37.6	48.4
22.3	B	0.16	5.91	32.0	62.3
23.2	B	0.15	5.36	30.9	50.4
23.7	S	0.08	5.36	27.0	36.2
25.3	B	0.40	4.30	24.2	34.3
29.5	S	0.54	3.12	21.8	32.9
31.7	B	0.45	1.44	23.1	36.2
32.46	S	0.49	1.24	22.3	28.3
33.5	B	0.55	0.38	14.9	31.8

Appendix III. E. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 5. (May, 1982)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	0.59	1.22	17.4	19.1
1.0	S	2.65	3.15	10.3	10.9
2.2	S	1.64	1.58	11.1	11.1
2.6	S	2.95	4.44	14.3	13.7
3.2	S	4.30	3.67	11.4	11.4
5.1	B	2.83	5.95	11.7	13.7
5.8	S	5.77	3.70	11.2	12.4
7.1	S	3.93	3.34	10.9	11.1
7.5	B	3.07	4.20	10.9	12.4
8.1	B	2.46	3.48	11.1	11.1
10.8	S	29.20	8.50	10.0	11.2
12.7	S	8.85	5.24	9.4	10.0
16.7	S	6.51	4.46	9.4	9.7
21.3	B	3.81	4.51	8.5	10.3
22.3	B	3.93	7.96	7.1	12.4
23.2	B	2.70	6.54	6.5	9.1
23.7	S	5.16	2.92	6.5	7.4
25.3	B	3.19	4.54	5.6	7.1
29.5	S	5.04	2.12	5.3	5.6
31.7	B	3.19	3.73	6.5	5.9
32.5	S	2.70	1.29	7.4	5.1
33.5	B	2.58	4.58	3.8	5.7

Appendix III. F. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 6. (July, 1982)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	0.0	28.4	0.58	2.8	3.5
1.7	S	3.3	28.1	0.81	2.1	3.4
2.8	S	5.5	28.1	0.77	1.5	2.7
5.1	S	9.5	29.2	0.23	1.3	2.9
9.5	S	16.7	28.5	0.34	1.0	2.0
15.0	B	25.4	27.7	0.22	0.7	0.0
15.4	S	26.1	27.5	0.42	0.6	1.7
16.3	B	27.5	27.4	0.51	2.0	3.8
17.3	B	28.5	27.6	0.38	0.5	4.1
19.6	B	32.6	27.2	0.82	0.3	2.8
23.6	S	38.1	27.9	0.41	0.3	1.5
28.8	S	45.7	27.2	0.86	0.3	1.4
30.1	B	47.7	26.4	0.26	0.0	2.1
32.3	B	50.2	25.9	0.22	0.0	2.1
32.8	S	51.6	27.3	0.24	0.2	1.9
32.9	B	51.6	27.3	0.21	0.0	1.9

Appendix III. F. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 6. (July, 1982)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	1.21	22.41	62.4	70.7
1.7	S	0.62	20.19	54.5	62.6
2.8	S	1.32	20.27	54.2	60.3
5.1	S	4.73	19.87	51.5	63.9
9.5	S	0.70	18.15	48.4	55.9
15.0	B	1.36	14.10	40.1	0.0
15.4	S	0.72	13.24	35.5	45.9
16.3	B	1.18	19.68	50.0	60.4
17.3	B	0.88	13.39	35.4	60.5
19.6	B	0.95	10.37	29.4	51.9
23.6	S	1.43	10.31	29.4	40.8
28.8	S	1.55	10.07	31.7	40.4
30.1	B	0.47	3.44	18.6	39.1
32.3	B	0.35	1.82	14.5	41.2
32.8	S	0.40	1.40	14.8	33.0
32.9	B	0.57	1.18	11.5	37.9

Appendix III. F. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 6. (July, 1982)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	-	-	11.4	10.8
1.7	S	4.40	6.87	10.6	11.0
2.8	S	7.16	4.49	10.3	12.7
5.1	S	7.98	6.04	9.4	11.9
9.5	S	8.26	5.77	9.2	10.4
15.0	B	23.54	68.80	8.1	30.0
15.4	S	8.81	4.22	7.5	9.6
16.3	B	8.95	4.83	9.5	13.3
17.3	B	9.34	9.13	7.1	10.6
19.6	B	8.40	7.01	6.3	9.3
23.6	S	7.98	4.67	6.4	6.4
28.8	S	4.40	10.50	8.7	8.1
30.1	B	11.36	9.69	3.8	5.8
32.3	B	14.61	14.57	3.5	6.7
32.8	S	8.40	7.51	3.8	6.7
32.9	B	9.74	9.83	3.5	6.6

Appendix III. G. Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 7. (September, 1982)

Salinity	Depth S/B	Conductivity	Water Temp.	Orthophosphate	Total Dissolved Phosphorus	Total Phosphorus
0.0	S	-	-	0.62	1.6	0.0
2.3	S	4.1	26.6	0.57	0.9	2.2
3.3	S	6.0	26.8	0.57	0.8	1.4
5.0	S	8.7	26.2	0.38	0.5	2.1
5.1	S	9.0	26.5	0.50	1.0	1.2
7.3	S	12.5	26.0	0.38	0.6	0.9
8.5	B	14.3	26.3	0.38	0.6	2.7
12.0	S	20.1	26.1	0.43	0.3	0.7
12.6	S	21.1	26.7	0.37	-	1.0
13.9	B	22.9	25.8	0.44	0.5	1.2
15.3	B	24.9	26.0	0.41	0.2	1.0
15.9	S	25.9	25.5	0.41	0.0	0.7
17.7	B	28.4	25.6	0.38	1.6	8.7
21.9	B	34.9	25.8	0.47	0.4	2.0
23.3	B	26.7	25.3	0.44	0.2	2.3
24.6	S	38.9	25.7	0.45	1.0	0.6
26.3	B	40.8	25.3	0.45	1.2	1.2
28.9	S	45.2	25.7	0.38	0.3	0.6
32.9	B	50.5	25.7	0.35	0.1	1.3
33.3	S	51.2	25.6	0.40	0.1	0.7
35.0	B	53.4	25.4	0.35	0.0	1.4

Appendix III. G. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 7. (September, 1982)

Salinity	Depth S/B	Ammonia	Nitrate-Nitrite	Total Dissolved Nitrogen	Total Nitrogen
0.0	S	5.41	2.98	44.1	10.2
2.3	S	1.44	0.50	39.4	48.2
3.3	S	1.31	-	40.7	54.5
5.0	S	3.87	2.21	39.3	60.0
5.1	S	2.02	4.64	44.3	48.2
7.3	S	2.59	1.77	37.5	47.0
8.5	B	2.88	0.19	40.5	55.1
12.0	S	1.69	1.06	36.8	44.4
12.6	S	1.45	4.94	35.3	36.5
13.9	B	2.48	4.38	40.4	63.2
15.3	B	3.36	3.40	31.8	58.9
15.9	S	1.59	3.12	26.0	42.3
17.7	B	3.08	2.45	34.1	82.1
21.9	B	3.03	0.85	26.1	46.1
23.3	B	2.61	0.18	25.8	53.7
24.6	S	3.08	4.89	33.6	27.2
26.3	B	2.97	4.35	27.5	34.6
28.9	S	2.36	2.49	21.1	31.6
32.9	B	1.92	1.40	12.8	32.4
33.3	S	1.53	1.21	15.9	22.9
35.0	B	1.43	0.55	11.4	30.3

Appendix III. G. (continued) Physical/chemical characteristics and plant pigments tabulated by salinity for the special chemistry transect series.

Cruise 7. (September, 1982)

Salinity	Depth S/B	Chlorophyll a	Phaeopigments	Dissolved Organic Carbon	Total Organic Carbon
0.0	S	3.72	3.48	6.5	6.9
2.3	S	11.77	5.22	6.2	6.8
3.3	S	19.28	5.46	6.5	7.1
5.0	S	5.78	7.06	8.8	10.0
5.1	S	10.32	4.21	6.0	6.5
7.3	S	13.59	5.79	6.9	7.1
8.5	B	7.91	5.80	6.2	7.5
12.0	S	16.64	4.78	6.3	6.2
12.6	S	22.12	5.03	6.2	7.4
13.9	B	14.00	10.01	5.8	8.2
15.3	B	11.77	9.10	5.7	8.5
15.9	S	20.70	5.52	5.5	6.2
17.7	B	8.88	4.96	6.0	6.3
21.9	B	9.95	11.11	5.1	7.5
23.3	B	4.13	13.40	4.8	8.9
24.6	S	4.41	2.92	4.3	5.2
26.3	B	4.34	5.93	3.8	5.4
28.9	S	3.51	4.81	3.4	4.6
32.9	B	4.34	2.74	2.8	4.2
33.3	S	3.10	5.05	2.8	3.5
35.0	B	6.06	7.66	2.3	4.5

Appendix IV. A. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Total Zooplankton

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	4548	1386	2212	2618	10146	15278	6070	6036
SR	12210	3344	934	6958	17462	2270	23026	9458
PD	9098	2367	307	1516	32310	2938	11245	8540
WR	3240	1654	122	998	34463	1834	4592	6700
BI	26625	5360	224	2080	20948	9322	14452	11287
TA	21344	8090	364	848	46268	2646	3400	11852
PS	8702	8690	665	440	30658	5177	17877	10316
TC	11707	10852	476	339	28499	16106	21196	12739
EP	18409	4866	1948	98	7896	1900	18692	7687
MB	19082	8818	374	860	24456	10330	21947	12267
SB	10294	7724	1340	3176	31530	11524	9692	10754
ALL	13205	5741	815	1812	25876	7211	13835	9785

Appendix IV. B. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Total Copepods

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	3899	136	896	2454	7705	11706	1827	4089
SR	10733	1996	468	6646	12949	1064	1524	5054
PD	7904	1539	184	1338	27198	2426	7151	6820
WR	2983	342	60	604	33616	1708	1758	5867
BI	23723	4558	133	1892	15731	8300	6418	8679
TA	20494	7496	256	828	43950	1808	3316	11164
PS	8037	8298	408	419	30062	4978	17498	9957
TC	9242	6038	242	280	24378	8158	15396	9105
EP	15444	1016	1851	66	6440	1690	7942	4921
MB	16876	5758	226	560	15754	6933	18526	9233
SB	5832	5008	1082	2881	20416	6260	6823	6900
ALL	11379	3835	528	1633	21654	5248	8016	7435

Appendix IV. C. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Acartia tonsa

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	793	26	0	0	4430	157	658	866
SR	3056	96	0	0	5292	296	318	1294
PD	2091	794	0	0	15642	44	3036	3087
WR	830	142	0	0	13238	2	934	2164
BI	6612	1670	1	3	8598	3112	1840	3120
TA	6566	2208	0	12	18142	772	1186	5555
PS	2310	2004	0	14	10648	2966	10238	4026
TC	1410	1082	8	2	10242	4027	5898	3239
EP	6587	149	434	4	3840	154	4332	2214
MB	5416	391	4	6	4994	2230	5926	2710
SB	772	96	8	56	947	1924	1073	696
ALL	3313	787	41	9	9638	1426	3222	2634

Appendix IV. D. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Acartia copepodids

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	2922	90	0	0	2210	156	1058	920
SR	7222	1514	0	0	7278	108	1085	2458
PD	5600	690	0	0	11090	26	4010	3059
WR	2101	98	0	0	2170	0	809	740
BI	16015	2420	0	0	5958	3564	4320	4611
TA	13082	4600	0	28	15280	473	2116	5083
PS	4568	5030	0	16	17962	1913	7139	5233
TC	6716	3550	0	16	10591	3132	8259	4609
EP	7933	82	22	8	1226	283	3450	1858
MB	8918	562	3	10	5338	3347	10436	4088
SB	441	280	22	122	637	1876	1919	757
ALL	6865	1720	4	18	7249	1352	4055	3038

Appendix IV. E. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Eurytemora affinis

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	182	2027	598	8954	0	1680
SR	0	0	13	6352	0	104	0	924
PD	0	0	1	1086	98	411	0	228
WR	0	0	0	366	15999	1233	0	2514
BI	0	0	25	1505	0	11	0	220
TA	0	0	136	568	0	453	0	165
PS	0	0	232	166	0	51	0	64
TC	0	0	44	52	0	18	0	16
EP	0	0	60	20	0	221	0	43
MB	0	0	84	6	0	0	0	13
SB	0	0	90	0	0	0	10	14
ALL	0	0	79	1104	1518	1041	1	535

Appendix IV. F. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Paracalanus crassirostris

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	6	0	0	0	11	0	8	4
SR	81	2	0	0	0	0	0	12
PD	17	2	0	0	26	0	0	6
WR	10	0	0	0	0	0	0	1
BI	180	122	0	0	530	26	100	137
TA	264	27	0	1	66	0	0	51
PS	630	768	0	16	1200	14	80	387
TC	218	408	1	38	1970	58	332	432
EP	165	384	74	0	967	0	34	232
MB	1352	2146	4	74	2594	110	730	1000
SB	3368	1858	22	243	13086	1066	2090	3105
ALL	572	519	9	34	1859	116	307	488

Appendix IV. G. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

<u>Pseudodiaptomus coronatus</u>

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	4	2	0	0	0	0	32	5
SR	86	0	0	0	16	0	0	14
PD	27	0	0	0	0	0	0	4
WR	10	2	0	0	0	0	0	2
BI	307	115	0	0	279	0	0	100
TA	157	28	0	0	129	0	0	45
PS	43	37	0	0	0	0	0	11
TC	291	125	0	0	872	152	225	238
EP	550	4	0	0	207	0	57	117
MB	795	50	0	2	172	272	465	246
SB	141	66	2	16	142	582	326	182
ALL	216	39	0	2	165	91	100	88

Appendix IV. H. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Euterpina acutifrons

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	0	0	0	0	8	1
SR	0	0	0	0	0	0	0	0
PD	0	0	0	0	0	0	13	2
WR	0	0	0	0	0	0	0	0
BI	0	16	0	0	37	0	43	14
TA	0	0	0	0	70	0	0	10
PS	0	0	0	0	78	0	20	14
TC	11	127	0	0	385	0	216	106
EP	0	44	9	0	96	0	0	21
MB	0	244	1	1	1264	0	506	288
SB	156	107	2	0	2456	31	292	435
ALL	15	49	1	0	399	3	100	81

Appendix IV. I. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Oithona colcarva

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	14	0	0	0	0	0	0	1
SR	86	0	0	0	0	0	0	12
PD	72	0	0	78	0	4	14	13
WR	0	0	0	0	0	0	0	0
BI	280	38	0	4	37	26	28	59
TA	134	40	0	4	94	3	0	39
PS	282	90	0	38	78	4	20	73
TC	288	209	2	125	97	64	100	126
EP	104	153	6	4	18	2	40	47
MB	214	978	20	236	192	66	182	270
SB	627	684	110	1316	826	368	354	612
ALL	191	199	13	157	122	49	67	114

Appendix IV. J. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

<u>*Halicyclops*</u> <u>spp</u>.

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	72	148	412	2300	0	419
SR	0	0	39	82	136	426	0	98
PD	0	0	2	70	220	1041	0	190
WR	0	0	1	85	2062	454	0	372
BI	0	0	2	30	0	1036	0	152
TA	0	0	4	0	0	39	5	7
PS	0	0	30	0	0	0	0	4
TC	0	0	6	0	0	485	32	75
EP	0	0	5	1	0	454	0	66
MB	0	0	4	1	0	10	0	2
SB	0	0	12	0	0	0	0	2
ALL	0	0	16	38	257	568	3	126

Appendix IV. K. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Barnacle nauplii

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	336	855	70	0	344	0	2816	632
SR	1280	444	0	0	610	2	19040	3054
PD	934	56	0	0	670	0	2986	664
WR	164	17	0	0	34	0	1042	180
BI	2801	434	0	0	370	92	6918	1516
TA	540	164	0	0	488	52	68	187
PS	514	312	0	12	174	12	338	195
TC	2074	4514	2	16	170	590	4480	1692
EP	2174	3362	14	1	753	35	9295	2233
MB	1421	1848	2	48	4972	1173	1578	1577
SB	2116	1882	2	34	7214	2666	822	2105
ALL	1305	1262	8	10	1436	420	4490	1276

Appendix IV. L. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Barnacle cyprids

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	42	3	35	0	256	0	266	86
SR	0	16	12	0	306	0	1703	291
PD	8	19	0	0	2092	4	132	322
WR	0	25	0	0	457	0	25	72
BI	25	87	0	0	1430	88	500	304
TA	43	168	4	3	1093	24	0	191
PS	7	18	6	2	154	30	20	34
TC	28	25	39	18	2248	491	446	471
EP	45	14	24	1	294	34	1126	220
MB	70	79	52	28	643	212	608	242
SB	34	54	90	10	830	538	64	231
ALL	28	46	24	6	891	129	444	221

Appendix IV. M. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Crab zoeae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	0	0	898	3258	118	610
SR	0	0	0	0	3446	974	18	634
PD	0	0	0	0	293	451	13	108
WR	0	0	0	0	134	64	10	30
BI	0	0	0	0	3201	372	0	510
TA	23	0	0	0	266	88	0	54
PS	0	0	0	0	154	52	0	29
TC	10	0	0	0	1533	3530	21	728
EP	0	5	0	0	127	14	0	21
MB	0	0	0	0	2078	266	0	335
SB	12	0	0	0	294	238	10	79
ALL	4	1	0	0	1130	846	17	285

Appendix IV. N. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Polychaete larvae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	128	198	0	0	90	140	16	82
SR	112	667	1	0	135	104	16	146
PD	208	296	1	0	1386	14	13	274
WR	76	79	0	0	188	2	5	50
BI	51	226	0	0	21	301	0	86
TA	156	172	0	0	470	662	0	208
PS	88	8	0	1	116	84	0	42
TC	199	188	1	2	0	672	62	160
EP	76	212	0	0	116	62	28	70
MB	536	776	0	32	364	108	162	283
SB	408	512	4	125	570	146	214	283
ALL	185	303	1	14	314	209	46	153

Appendix IV. O. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Gastropod veligers

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	128	0	0	42	809	35	337	193
SR	40	0	0	80	16	0	96	33
PD	25	0	0	114	647	0	40	118
WR	0	2	0	78	34	12	5	19
BI	0	0	0	0	18	44	14	11
TA	0	9	0	0	0	0	0	1
PS	0	0	0	0	0	9	0	1
TC	11	0	0	1	0	2472	574	437
EP	520	0	0	0	84	40	138	112
MB	0	76	0	2	108	964	973	303
SB	12	12	0	31	369	1178	502	301
ALL	67	9	0	32	190	432	244	139

Appendix IV. P. Zooplankton abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Bivalve larvae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	0	0	0	0	0	0
SR	0	0	0	0	0	0	0	0
PD	0	0	0	0	0	4	0	1
WR	0	0	0	2	0	6	0	1
BI	0	0	0	0	18	0	0	3
TA	0	0	0	0	0	0	2	0
PS	0	0	0	0	0	4	0	1
TC	38	0	1	0	122	18	0	26
EP	0	0	18	0	64	0	0	12
MB	0	40	10	2	129	80	61	46
SB	59	18	28	40	466	248	33	127
ALL	9	5	5	4	73	33	9	20

Appendix V. A. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Total Copepods

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	10452	9008	72	1884	7566	1562	3182	4818
bot.	19572	21336	69	6776	40654	4086	7731	14318
MS								
surf.	11298	2406	211	187	23033	3088	6360	6655
bot.	20430	5342	372	2260	14983	13170	9875	9490
LS								
surf.	8616	14652	6716	16579	13876	27784	7344	13652
bot.	31469	12670	10464	5656	12040	25401	7906	15086

Total Zooplankton

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	11538	10196	176	2892	11176	3832	6773	6655
bot.	29874	22906	152	7062	41782	6536	23461	18825
MS								
surf.	12964	3640	688	236	24708	6353	19902	9784
bot.	26428	6730	626	2494	16100	16674	14572	11947
LS								
surf.	13040	21165	7239	18122	19259	44344	16183	19908
bot.	44352	17949	11967	6105	14860	37746	13226	20887

Appendix V. B. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Acartia tonsa

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	2160	2616	0	3	2704	838	942	1313
bot.	5203	10276	0	12	21705	2343	3222	6109
MS								
surf.	3989	1092	12	4	12778	604	2656	3020
bot.	9220	2556	12	42	9890	3885	2482	4012
LS								
surf.	1139	96	840	60	585	1972	942	805
bot.	7996	334	1229	72	981	3556	1556	2246

Acartia copepodids

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	7774	5514	0	0	4388	556	2158	2913
bot.	12294	9544	0	0	18658	1482	3622	6514
MS								
surf.	5590	818	6	3	8480	1996	1184	2582
bot.	4601	1498	3	20	2698	4820	2734	2339
LS								
surf.	668	384	244	66	456	6390	1940	1450
bot.	2376	686	352	17	322	4892	1792	1491

Appendix V. C. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Eurytemora affinis

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	0	0	0	584	70	16	0	96
bot.	0	0	2	3744	42	54	0	549
MS								
surf.	0	0	0	0	0	0	0	0
bot.	0	0	44	34	0	0	0	11
LS								
surf.	0	0	0	0	0	0	0	0
bot.	0	0	0	0	0	0	0	0

Paracalanus crassirostris

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	8	18	0	0	0	0	0	4
bot.	336	16	0	0	42	6	98	71
MS								
surf.	902	296	10	38	934	220	1535	562
bot.	3604	722	38	235	1664	1310	2060	1376
LS								
surf.	3471	6896	1398	651	10090	9384	2566	4922
bot.	14368	6118	2747	448	7494	9072	2889	6162

Appendix V. D. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Pseudodiaptomus coronatus

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	94	0	0	0	0	0	0	13
bot.	332	140	0	0	42	0	492	144
MS								
surf.	224	55	8	1	304	101	182	125
bot.	548	48	0	6	352	828	494	325
LS								
surf.	47	55	0	16	466	134	72	113
bot.	200	106	0	22	983	369	78	251

Euterpina acutifrons

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	0	0	1	0	0	0	0	1
bot.	0	16	0	0	42	0	98	22
MS								
surf.	16	46	4	0	224	0	433	103
bot.	0	14	0	0	132	51	1750	278
LS								
surf.	236	1298	27	0	690	493	350	236
bot.	160	722	26	0	636	480	248	160

Appendix V. E. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

__Oithona colcarva__

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	16	0	0	2	0	5	0	3
bot.	358	0	0	9	0	8	172	78
MS								
surf.	262	46	32	92	29	28	202	99
bot.	1274	176	40	917	54	1404	136	571
LS								
surf.	916	4138	470	13211	555	1988	230	3073
bot.	2307	3412	838	783	314	2021	236	1416

__Halicyclops__ spp.

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	0	0	4	192	362	142	0	100
bot.	0	0	4	238	84	100	0	61
MS								
surf.	0	0	3	0	0	0	0	<1
bot.	0	0	5	2	0	0	0	1
LS								
surf.	0	0	0	0	0	0	0	0
bot.	0	0	13	0	0	0	0	2

Appendix V. F. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Barnacle nauplii

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	708	200	0	384	20	18	3030	623
bot.	1424	98	0	16	42	283	12701	2080
MS								
surf.	902	604	12	28	30	2494	12555	2376
bot.	871	352	14	12	10	214	308	254
LS								
surf.	1008	2126	0	265	79	7814	6758	2578
bot.	676	1714	26	0	98	735	3365	945

Barnacle cyprids

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	15	168	1	0	188	38	30	63
bot.	101	73	1	0	167	62	1084	212
MS								
surf.	33	262	6	4	623	262	488	240
bot.	186	295	10	10	820	788	448	210
LS								
surf.	30	18	0	0	1060	242	488	193
bot.	0	95	78	0	1208	45	448	210

Appendix V. G. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Crab zoeae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	0	0	0	0	3324	1040	0	624
bot.	0	0	0	0	418	1128	0	221
MS								
surf.	0	0	0	0	812	300	62	168
bot.	0	0	0	0	113	264	22	57
LS								
surf.	44	0	0	0	456	304	48	122
bot.	50	0	0	0	56	300	12	60

Polychaete larvae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	246	743	1	0	30	21	0	149
bot.	634	1176	1	0	0	116	74	286
MS								
surf.	288	254	0	6	16	42	0	87
bot.	1796	370	6	44	0	871	174	466
LS								
surf.	1588	3604	280	576	458	4302	445	1607
bot.	7314	2166	732	64	408	3896	350	2133

Appendix V. H. Zooplankton abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, depth, and month. The annual average for each station and depth is also presented.

Gastropod veligers

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	76	0	1	29	29	28	0	23
bot.	8144	0	1	49	292	508	1009	1429
MS								
surf.	207	4	2	1	48	14	126	57
bot.	1343	7	1	0	15	342	2675	626
LS								
surf.	40	94	0	184	54	44	48	66
bot.	374	60	26	14	80	78	34	95

Bivalve larvae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
US								
surf.	0	0	1	0	0	0	0	<1
bot.	0	42	4	0	0	6	24	11
MS								
surf.	12	4	3	0	14	23	43	14
bot.	83	0	16	10	24	152	101	55
LS								
surf.	164	78	198	144	312	501	256	236
bot.	621	35	496	106	219	1338	360	454

Appendix VI. A. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Mysids

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0.16	0	0	0	0.24	0.23	0.26	0.13
SR	1.13	0.01	0	0	9.21	16.32	42.31	9.85
PD	8.91	0.19	0	0	0.44	1.21	8.09	2.69
WR	18.24	0.23	0	0	0.44	0	1.74	2.95
BI	0.60	1.78	0.10	0.51	26.22	0.16	5.11	4.93
TA	1.27	1.23	0	0.64	15.05	0	25.90	6.30
PS	1.50	0.79	0	0.39	0.09	0.07	1.79	0.66
TC	1.68	4.32	0.26	4.68	6.77	3.90	0.37	3.14
EP	2.74	51.31	0.42	2.61	7.25	1.54	28.91	13.54
MB	0.59	0.20	1.66	38.12	1.53	0.16	0.16	6.06
SB	0.97	4.96	4.77	0.45	1.05	0.37	1.10	1.95
ALL	3.44	5.91	0.66	4.31	6.21	2.18	10.52	

Appendix VI. B. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Amphipods

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0.06	0	3.38	0.46	0.01	15.09	0.17	2.74
SR	0.15	0	5.14	0.04	0.01	6.22	0.89	1.78
PD	1.27	0.15	0.32	11.41	0.08	33.42	134.81	25.92
WR	1.20	0.86	0	0.15	0.21	2.12	0.12	0.67
BI	0.68	0	0.25	8.40	0.09	1.23	3.93	2.08
TA	3.99	8.29	2.73	1.59	8.21	1.80	1.85	4.07
PS	3.55	1.99	17.78	0.07	0.16	0.09	0.29	3.42
TC	0.30	0.66	1.04	0.06	0.71	0.11	0	0.41
EP	0.05	0.62	0.02	0.87	2.26	0.71	0.41	0.71
MB	0.13	0.10	11.82	4.11	0	0.02	0.03	2.32
SB	0.04	0.78	1.21	0.24	0.07	0	0.16	0.36
ALL	1.04	1.22	3.97	2.49	1.07	5.53	12.97	

Appendix VI. C. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Decapod shrimp larvae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	1.78	0	0	0	0.86	0.42	0.06	0.45
SR	0.53	0	0	0	3.91	15.46	0.69	2.94
PD	0.20	0	0	0	4.35	0.26	2.78	1.08
WR	5.98	0	0	0	0.03	0.01	2.58	1.23
BI	0.26	0	0	0	3.28	1.03	0.49	0.72
TA	0.14	0.02	0.03	0.02	1.41	1.46	0.43	0.50
PS	0	0.03	0	0.60	1.81	0.26	3.05	0.82
TC	0.06	0.01	0	0.13	2.57	3.89	0.49	1.02
EP	0.91	0	0	0.06	0.50	2.73	1.13	0.76
MB	0.38	0.02	0	0.06	3.41	0.51	0.72	0.73
SB	0.25	0.08	0	0.04	4.33	0.19	0.48	0.77
ALL	0.95	0.01	0.01	0.08	2.41	2.38	1.17	

Appendix VI. D. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Postlarval penaeid shrimp

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	0	0	0	0	0	0
SR	0	0	0	0	0	0	0.06	0.01
PD	0	0	0	0	0.01	0	0.14	0.02
WR	0	0	0	0	0	0	0.02	0.01
BI	0	0	0	0	0	0	0.03	0.01
TA	0.07	0.11	0	0	5.17	0.09	0.15	0.80
PS	0.08	0.02	0	0	0.01	0.02	0.27	0.06
TC	0	0	0	0	0	0.02	0.18	0.03
EP	0	0	0	0	0	0	0.12	0.02
MB	0	0	0	0	0	0.02	0.10	0.02
SB	0	0	0	0	0	0.05	0.18	0.03
ALL	0.01	0.01	0	0	0.47	0.02	0.11	

Appendix VI. E. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Crab megalopae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0.04	0	0	0	0	0.01	0.02	0.01
SR	0.07	0	0	0	0.02	0.12	0.34	0.08
PD	0.62	0.02	0	0	0.01	0.40	0.46	0.22
WR	0.72	0	0	0	0.01	0.14	0.27	0.16
BI	0.05	0.02	0	0	0.23	0	0.02	0.05
TA	0	0.05	0	0	0.05	0	0	0.01
PS	0	0.09	0	0	0	0	0	0.01
TC	0.15	0.23	0	0	0.20	0.33	0	0.13
EP	0.51	0.15	0	0	0.08	0	0.33	0.15
MB	0.03	0.01	0	0.08	0.31	0.02	0.01	0.07
SB	0.07	0.45	0	0	1.35	0.13	0.13	0.30
ALL	0.21	0.09	0	0.01	0.21	0.10	0.14	

Appendix VI. F. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Fish eggs

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0	0	0	0	0.02	0	0	0.01
SR	0	0	0	0	0.02	0	0	0.01
PD	0	0	0	0	0.16	0	0	0.02
WR	0	0	0	0	0.01	0	0	0.01
BI	0	0	0	0	14.16	0	0	2.02
TA	0	0	0	0	34.78	0.02	0	4.97
PS	0	0	0	0	1.93	0	0	0.28
TC	0	0	0	0	4.81	0	0	0.69
EP	0	0	0	0	3.62	0	0	0.52
MB	0.06	0	0	0.03	3.96	0	0	0.58
SB	0	0.01	0	0	1.00	0	0	0.14
ALL	0.01	0.01	0	0.01	5.86	0.01	0	

Appendix VI. G. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Fish larvae

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	0.01	0	0	0.57	0.28	0.20	0	0.15
SR	0.01	0	0	0.11	0.67	0.06	0.02	0.12
PD	0.03	0.14	0	0.02	2.37	0.22	0	0.40
WR	0.04	0.20	0	0.07	0.35	0.02	0.02	0.10
BI	0.02	0.04	0.03	0.70	0.70	0.07	0.03	0.23
TA	0.14	0.50	0.12	5.52	1.98	0.06	0.43	1.25
PS	0.12	0.20	0.27	6.83	3.06	0.65	0.17	1.61
TC	0.01	0.09	0.27	0.04	0.93	0.10	0.04	0.21
EP	0.01	0.02	0.04	0.05	0.79	0	0.04	0.14
MB	0	0.03	0.65	0.51	16.12	0.09	0.05	2.49
SB	0.01	0.81	0.37	0	2.32	0.12	0	0.52
ALL	0.04	0.18	0.16	1.31	2.69	0.14	0.07	

Appendix VI. H. Epibenthos abundance during extensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station and month. The annual average for each station and the average abundance for all stations within a specific sampling period are also presented.

Total Organisms

Station	Date							
	Sep	Nov	Jan	Mar	May	Jul	Sep	All
PR	2.18	0	3.41	1.03	1.51	16.00	0.54	3.52
SR	2.22	0.02	5.17	0.15	13.97	38.38	44.64	14.94
PD	11.38	0.53	0.32	11.43	7.46	35.51	147.30	30.56
WR	26.49	1.33	0	0.22	1.09	2.44	5.00	5.22
BI	1.88	1.89	0.40	9.61	44.87	2.61	9.93	10.17
TA	5.80	10.64	2.92	7.78	66.96	3.49	28.95	18.08
PS	5.75	3.28	18.05	7.91	7.22	1.25	5.73	7.03
TC	2.70	5.53	1.57	5.11	16.14	8.41	1.12	5.80
EP	4.39	52.57	0.50	3.61	14.62	4.98	31.12	15.97
MB	1.47	0.46	14.55	43.05	28.67	0.95	1.41	12.94
SB	2.70	7.46	6.38	0.80	10.82	1.06	2.47	4.53
ALL	6.09	7.61	4.84	8.25	19.39	10.46	25.29	

Appendix VII. A. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Mysids

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0.92	0.04	0.01	0.10	9.17	10.39	0.26	2.98
6 min.	1.46	0.14	0	0.05	7.85	6.84	-	2.72
9 min.	0.43	0	0	0.04	12.98	4.47	-	2.99
Mean	0.94	0.06	0.01	0.06	10.00	7.24	0.26	2.65
Middle								
3 min.	0.20	0.04	0.59	1.04	96.17	0.03	0.13	14.03
6 min.	0.84	2.39	4.76	0.53	5.92	0.06	0.27	2.11
9 min.	1.89	2.95	4.57	14.30	10.45	0.23	0.06	4.92
Mean	0.98	1.79	3.31	5.29	37.51	0.11	0.15	7.02
Lower								
3 min.	0.76	0.16	1.65	2.47	0.02	0.05	4.33	1.35
6 min.	0.39	0.13	4.30	1.57	0.74	0	9.12	2.32
9 min.	0.25	0.08	6.34	10.11	2.13	0.01	0.10	2.72
Mean	0.47	0.12	4.10	4.72	0.96	0.02	4.51	2.13

Appendix VII. B. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Amphipods

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0.16	0	0.33	0.03	0	9.37	0.06	1.42
6 min.	0.09	0	0.38	0.01	0.04	3.42	-	0.66
9 min.	0.07	0	0.55	0.01	0.01	2.81	-	0.58
Mean	0.10	0	0.42	0.18	0.02	5.20	0.06	0.85
Middle								
3 min.	0.34	0.08	3.45	0.11	0.28	0.49	0.14	0.70
6 min.	0.85	0.07	0.82	0.15	0.12	0.02	0.05	0.30
9 min.	0.35	0.01	1.98	0.62	0.16	0.01	0.01	0.45
Mean	0.51	0.05	2.09	0.30	0.19	0.17	0.06	0.48
Lower								
3 min.	0.52	0.43	0.08	2.00	0.40	0.24	0.24	0.56
6 min.	0.56	0.25	0.12	0.91	1.63	0.01	0.15	0.52
9 min.	0.22	0.40	0.85	1.27	2.50	0.03	0.11	0.77
Mean	0.44	0.36	0.35	1.40	1.50	0.09	0.17	0.62

Appendix VII. C. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Decapod shrimp larvae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	1.05	0	0	0.02	4.00	4.33	0.54	1.42
6 min.	0.80	0	0	0.01	1.68	6.33	-	1.47
9 min.	0.26	0	0	0.01	1.32	8.31	-	1.65
Mean	0.70	0	0	0.01	2.34	6.32	0.53	1.41
Middle								
3 min.	0.14	0	0	0.01	1.22	0.47	2.97	0.69
6 min.	1.15	0	0	0.03	7.17	0.24	1.97	1.51
9 min.	0.70	0.01	0	0.03	3.48	0.11	0.97	0.76
Mean	0.66	0.01	0	0.02	3.95	0.28	1.97	0.98
Lower								
3 min.	0.47	0.01	0	0.01	0.89	1.29	7.23	1.41
6 min.	0.45	0.01	0	0.01	2.49	0.36	8.38	1.67
9 min.	0.29	0.01	0	0.03	3.01	0.25	3.62	1.03
Mean	0.40	0.01	0	0.01	2.13	0.64	6.41	1.37

Appendix VII. D. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Postlarval penaeid shrimp

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0	0	0	0	0	0.01	0	0.01
6 min.	0	0	0	0	0	0	-	0
9 min.	0	0	0	0	0.01	0	-	0.01
Mean	0	0	0	0	0.01	0.01	0	0.01
Middle								
3 min.	0	0	0	0	0	0.02	0.03	0.01
6 min.	0	0	0	0	0	0.01	0.01	0.01
9 min.	0	0	0	0	0	0.02	0	0.01
Mean	0	0	0	0	0	0.02	0.01	0.01
Lower								
3 min.	0	0	0	0	0	0	0.11	0.02
6 min.	0	0	0	0	0	0	0.06	0.01
9 min.	0	0	0	0	0	0	0	0
Mean	0	0	0	0	0	0	0.06	0.01

Appendix VII. E. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Crab megalopae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0.14	0	0	0	0	0.05	0.12	0.04
6 min.	0.01	0	0	0	0.01	0.04	-	0.01
9 min.	0.03	0	0	0	0.02	0.07	-	0.02
Mean	0.06	0	0	0	0.01	0.05	0.12	0.03
Middle								
3 min.	0	0	0	0	2.68	0.04	0.08	0.40
6 min.	0	0.02	0	0.01	0.85	0.02	0.18	0.15
9 min.	0.06	0.01	0	0.01	0.23	0.04	0.01	0.05
Mean	0.02	0.01	0	0.01	1.25	0.03	0.09	0.20
Lower								
3 min.	0.23	0	0	0.03	0.16	0.03	0.24	0.10
6 min.	0.16	0.01	0	0.06	0.45	0.01	0.06	0.96
9 min.	0.14	0.02	0	0.02	0.60	0.01	0.01	0.54
Mean	0.18	0.01	0	0.04	0.40	0.02	0.11	1.32

Appendix VII. F. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Fish eggs

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0	0	0	0	0.22	0.11	0	0.05
6 min.	0	0	0	0	0.06	0.08	-	0.02
9 min.	0	0	0	0	0.07	0.03	-	0.02
Mean	0	0	0	0	0.12	0.07	0	0.03
Middle								
3 min.	0	0	0	0	5.95	0	0.01	0.99
6 min.	0	0	0	0	29.03	0.01	0.01	4.15
9 min.	0	0	0	0	20.42	0.01	0.01	2.92
Mean	0	0	0	0	18.47	0.01	0.01	2.64
Lower								
3 min.	0	0.01	0	0	23.05	0	0	3.29
6 min.	0.02	0.01	0	0	10.55	0.02	0.01	1.52
9 min.	0.01	0.01	0	0	5.34	0.02	0.01	0.77
Mean	0.01	0.01	0	0	12.98	0.01	0.01	1.86

Appendix VII. G. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Fish larvae

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	0	0	0.02	0.08	0.47	0.16	0.01	0.11
6 min.	0.02	0	0.01	0.08	0.23	0.19	-	0.09
9 min.	0.02	0	0.01	0.05	0.62	0.06	-	0.13
Mean	0.01	0	0.01	0.07	0.44	0.14	0.01	0.10
Middle								
3 min.	0.02	0.02	0.16	0.20	2.27	0.65	0.06	0.48
6 min.	0	0.02	0.89	0.01	5.30	0.17	0.03	0.92
9 min.	0.03	0.07	0.64	0.02	1.76	0.08	0.09	0.38
Mean	0.02	0.04	0.56	0.08	3.11	0.30	0.06	0.60
Lower								
3 min.	0.09	0.03	0.19	0	12.77	0.74	0.08	1.99
6 min.	0.33	0.01	0.25	0.03	8.44	0.54	0.12	1.39
9 min.	0.01	0.01	0.15	0.03	3.71	0.91	0.40	0.75
Mean	0.14	0.02	0.20	0.02	8.30	0.73	0.20	1.37

Appendix VII. H. Epibenthos abundance during intensive series of cruises within Winyah Bay (1981 - 1982). Mean abundance is presented by station, month, and length of tow. Mean represents the average of the three tows. Abundance is expressed as number per cubic meter.

Total Organisms

Station	Sep	Nov	Jan	Mar	May	Jul	Sep	All
Upper								
3 min.	2.44	0.07	0.37	0.26	13.93	24.47	1.30	6.12
6 min.	2.70	0.16	0.41	0.17	9.94	16.96	-	5.06
9 min.	1.06	0.02	0.57	0.12	15.09	15.79	-	5.44
Mean	2.06	0.08	0.45	0.19	12.99	19.08	1.30	5.16
Middle								
3 min.	0.85	0.39	4.45	1.73	108.91	2.55	3.78	17.52
6 min.	3.19	2.65	6.59	0.89	48.89	0.82	3.23	9.47
9 min.	3.16	3.21	7.41	15.28	36.75	0.69	3.33	9.98
Mean	2.40	2.08	6.13	5.97	64.85	1.36	3.45	12.32
Lower								
3 min.	4.00	1.40	1.96	5.98	37.95	5.79	15.65	10.39
6 min.	2.79	0.72	4.75	3.22	27.38	1.73	20.66	8.75
9 min.	1.35	0.78	7.66	13.69	21.53	1.61	8.51	7.88
Mean	2.72	1.00	4.79	7.63	28.95	3.04	14.94	9.01