ABSTRACT

Steven E. Reed. THE DISTRIBUTION AND SEASONALITY OF THE BENTHIC AQUATIC MACROPHYTES OF THE PAMLICO RIVER ESTUARY, NORTH CAROLINA. (Under the direction of Dr. Graham J. Davis) Department of Biology, January, 1979.

The distribution and seasonal dynamics of the submersed vascular plants and macroscopic algae of the Pamlico River estuary, North Carolina, were studied from July 1973 through August 1974. Plants were restricted mainly to the sandy shallow margins in the upper two-thirds of the estuary with most of the biomass around 1 m depth. The estuary was divided into oligo-, meso- and polyhaline zones based on a rather unstable salinity gradient. In the oligohaline zone macrophyte communities consisted of *Vallisneria americana*, *Potamogeton perfoliatus* var. *bupleuroides*, *Najas guadalupensis*, and the muskgrasses *Chara* sp. and *Nitella* sp.; the mesohaline zone included *V. americana*, *P. perfoliatus* and *Ruppia maritima*; and some sheltered low energy environments of the polyhaline zone had small amounts of *R. maritima*.

Line transects were used to sample biomass and community species composition during the seasonal studies. Salinity varied between 1 and 16^{o}/oo depending on the rate of freshwater discharge from the Tar River, the principal tributary. Water temperature closely paralleled air temperature, ranging between 5° and 30°C. During the summer and early fall, the

dominant macrophyte was *Vallisneria americana*, accounting for 80-90% of the total macrophyte biomass in the estuary. *Ruppia maritima* was dominant during the low temperatures of the winter months and in regions of high salinity, but at low biomass levels. Maximum biomass was recorded in September and October with minimal biomass occurring in February. *Compsopogon coeruleus*, a red filamentous alga, appeared in nuisance proportions in the oligo-mesohaline area during early summer; the green algae *Cladophora* sp. and *Enteromorpha* sp., reached maximum biomass later in the season. A direct relationship was found between water temperature and the biomass of all major species.

THE DISTRIBUTION AND SEASONALITY OF THE BENTHIC AQUATIC MACROPHYTES OF THE PAMLICO RIVER ESTUARY, NORTH CAROLINA

A Thesis
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In Partial Fulfillment
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Master of Science in Biology

by
Steven E. Reed
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by

Steven E. Reed

APPROVED BY:

SUPERVISOR OF THESIS

Graham J. Davis

Dr. Graham J. Davis

THESIS COMMITTEE

Mark M. Brinson

Dr. Mark M. Brinson

Charles W. O'Rear

Dr. Charles W. O'Rear

Richard A. Stephenson

Dr. Richard A. Stephenson

CHAIRMAN OF THE DEPARTMENT OF BIOLOGY

Edward P. Ryan

Dr. Edward P. Ryan (acting)

DEAN OF THE GRADUATE SCHOOL

Joseph G. Boyette

Dr. Joseph G. Boyette

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The estuaries of the United States are among our richest resources and are undergoing tremendous strains due to the activities of man. Most studies on estuarine ecosystems have emphasized the nekton, plankton, epifauna, or infauna with little mention of the submersed plants. These vascular plants are rooted in the substrate and flourish in the littoral of most estuaries.

Benthic aquatic macrophytes play many important roles in estuarine ecosystems. The classical concept of the macrophyte community is one of primary production and as a nursery area for young fish and other organisms. In relation to other ecosystem components, macrophytes function in support, shelter and oxygen production (Boyd, 1971). Without this vital component, the production and diversity of many estuarine systems would be tremendously reduced. Macrophytes also accumulate nutrients from the water thereby decreasing the possibility of algal blooms. They play a vital role in the nutrient cycling of carbon, nitrogen, and phosphorous as they accumulate these nutrients in the spring and early summer when the nutrient concentration is high. The nutrients are then released through decay, especially in the fall and winter (Davis and Brinson, 1976). As these aquatic plants die or become uprooted, degradation or the process of detritus formation begins. These benthic aquatic macrophytes may provide an important winter input into the detritus food chain. The importance of vascular plant detritus to estuaries has been reviewed by Odum et al. (1973).

Aquatic macrophytes are also important in the recreational opportunities of an area. The best hunting areas for waterfowl are those which sustain large stands of benthic plants. *Potamogeton*, *Ruppia*, and *Najas* were found to be the most important foods for the primary game species of waterfowl in Currituck Sound, North Carolina (Quay and Critcher, 1965). Macrophytes provide cover for the young of many game fish that breed in the estuaries. These "weed beds" are frequented by anglers in search of species from largemouth bass to speckled trout.

Stands of aquatic plants cause an increase in the rate of sedimentation. The leaves and stems slow the water down as it passes through the plant bed and thereby the finer particles settle out creating clearer water. Plant stands also may absorb wave energy and stabilize the bottom, thus helping to retard the rate of shoreline erosion in areas where they are present.

This study was designed to describe the distribution and seasonality of the benthic aquatic macrophytes of the Pamlico River estuary. These are rooted plants and their presence in an area is the result of the integration of a number of environmental parameters over a given period of time. Macrophyte distribution, biomass, and community composition as related to the environmental parameters of temperature, salinity, depth, turbidity, and season will be discussed. The results of this research will be compared to studies of other estuaries in North Carolina and Virginia.

Most of the biological studies on the Pamlico River have been by biologists of N.C. State University working out of the Pamlico Marine Laboratory near Aurora, N.C. This is now the Pamlico Estuarine Laboratory of the Institute for Coastal and Marine Resources of East Carolina University. Past research on the estuary was concerned with its hydrography (Hobbie, 1970), phytoplankton (Hobbie , 1971), nutrients (Hobbie, 1974 and others), benthos (Tenore, 1972), and epifauna (Dean, 1973). Research sponsored by the Water Resources Research Institute of the University of North Carolina on the ecology and productivity of the submersed macrophytes of the estuary is the subject of a recent report (Davis and Brinson, 1976). A summary of the results of this work is included in this report.

DESCRIPTION OF THE STUDY AREA

The Tar River flows through northeastern North Carolina generally southeastward to Washington, North Carolina where it becomes the Pamlico River. From Washington, the estuary extends some 60 km east-southeast where it joins the Pamlico Sound (Figs. 1 and 2).

The width of the estuary varies from 3 to 13 km and it has a mean depth of about 3.5 m with wide sandy littoral margins. Lunar tides are slight (ca. 15 cm) due to the dampening effect of the outer banks and shallow Pamlico Sound. More important in the estuary are the wind tides which can have an amplitude of more than 1 m (Debbie Landy, personal communication). Because of the width and shallowness of the estuary, the wave action keeps large quantities of particulate matter in suspension resulting in high turbidity, especially in the upper reaches.

The water has a light brown color due to many of its inputs coming from tannin laden swamp waters (Hobbie, 1971). The Tar River flows through an agricultural region and carries a tremendous suspended sediment load which, during periods of elevated flow, can muddy the upper half of the estuary for days.

Davis and Brinson (1976) recorded salinities in the estuary from 0 - 15^{o}/oo. There is usually a difference in salinity readings of 1 - 4^{o}/oo between the two sides of the

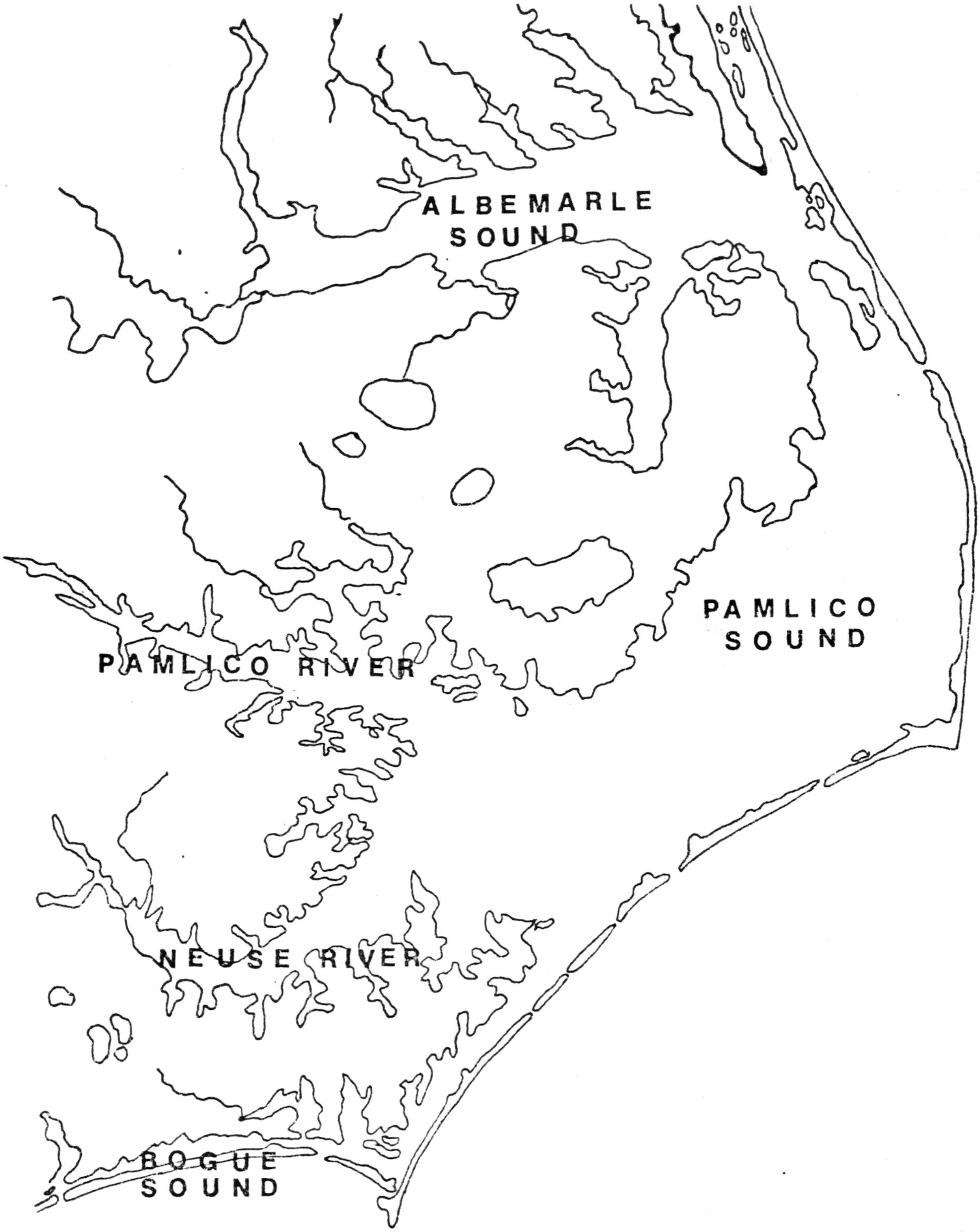

Figure 1. The Pamlico and Albermarle Sounds and their tributaries.

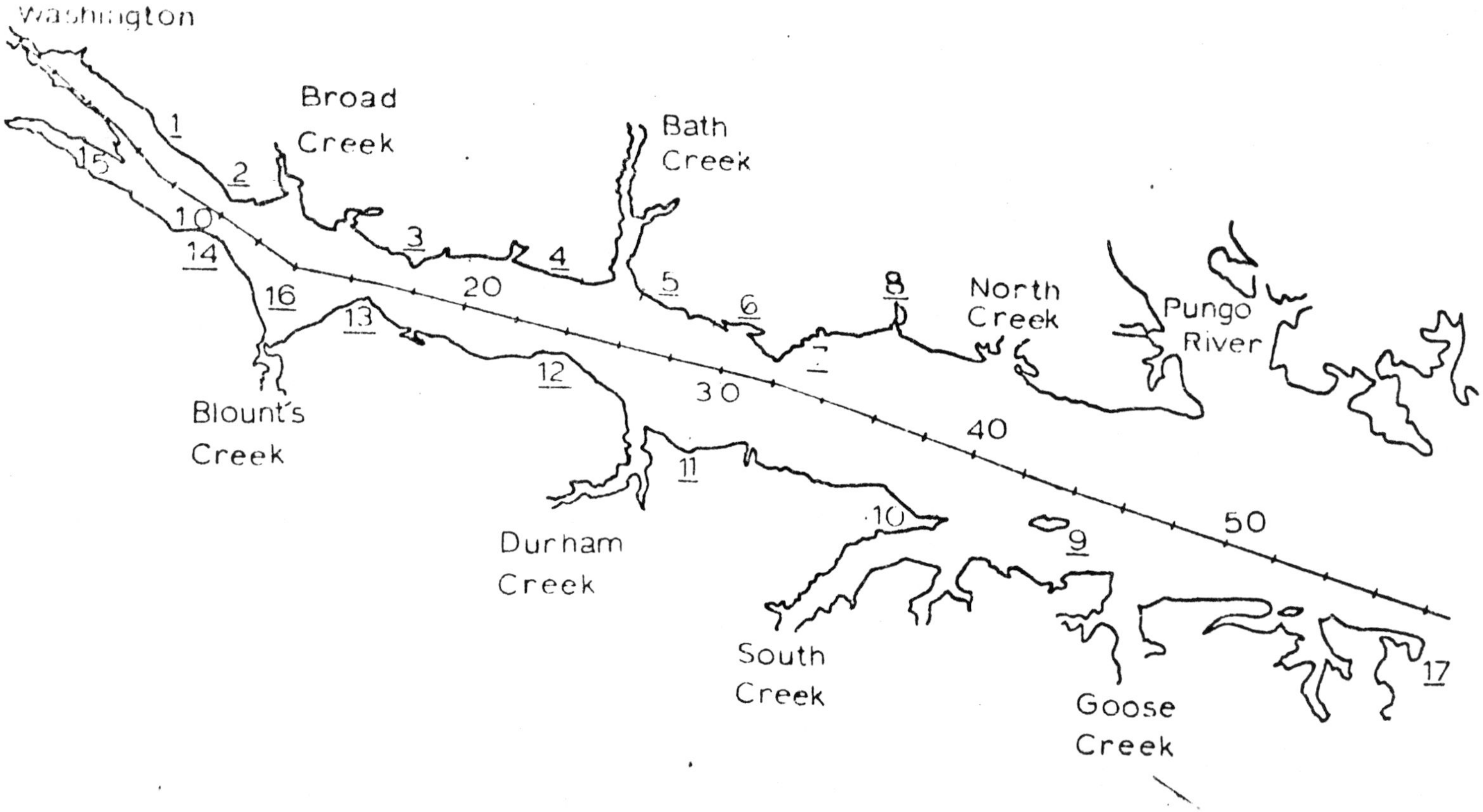

Figure 2. The Pamlico River estuary, North Carolina. River km as shown begin at the Pamlico River estuary-Tar River confluence and generally follow channel markers. Locations: 1-Austin Pt., 2-Broad Creek Pt., 3-Ragged Pt., 4-Hawkins Ldg., 5-Bayview, 6-Mixon Ck., 7-Gaylord Bay, 8-St. Clair Cr., 9-Indian Island, 10-Hickory Pt., 11-Texasgulf Inc., 12-Core Pt., 13-Maul's Pt., 14-Hill's Pt., 15-Chocowinity Bay, 16-Blount's Bay, 17-Pamlico Pt. (by T. Vicars).

estuary. In the northern hemisphere, freshwater tends to flow out of estuaries on the right side facing the ocean and saline waters move in on the left due to Ferrell's Law and is the reason that salinities are usually lower along the south shore of the Pamlico River.

The upper Pamlico River estuary is classified as an oligohaline system with a saltwater shock zone and a winter cold period (Odum et al. 1974). Stratification in the up-river areas usually occurs during the summer, and then for only short periods. An inflow of freshwater must be coupled with a period of calm winds and high temperatures to set up haloclines or thermoclines. Davis et al. (1978) found that when stratification does occur, the vertical differences can reach 4°C and 7°/oo salinity, and if these conditions persist for a week or more, the deeper waters will become deoxygenated. This stratification associated with haloclines makes the water column stable and considerable wind energy is required to mix the estuary.

Copeland and Hobbie (1972) noted the absence of the intertidal *Juncus* and *Spartina* marshes along the "tideless" Pamlico River which, in tidal estuaries of North Carolina, may be primary contributors to the detritus food chain. They stated that detritus in the Pamlico River comes instead from the large beds of *Ruppia* and *Potamogeton* which are rooted along the shallow shoreline. Among the rooted aquatic macrophytes, the primary detrital contributor is *Vallisneria ameri-*

cana, the dominant macrophyte of the Pamlico River estuary (Davis and Brinson, 1976).

The dominant phytoplankers are diatoms and the dinoflagellate Peridinum triquetrum which may reach red tide proportions during the winter months (Hobbie, 1970). Also, Hobbie found nitrogen to be the limiting nutrient in phytoplankton productivity as phosphorous concentrations were high throughout the estuary. During the growing season, the macrophytes accumulate nutrients and are probably not limited by the availability of nitrogen at least in the upper reach. In colder periods, these nutrients may be used in increased phytoplankton production and contribute to winter algal blooms. As more nitrogen enters the estuary it may lead to increased macrophyte production, major algal blooms during warmer months, and possibly lowered dissolved oxygen levels throughout the estuary (Davis et al. 1978).

The Pamlico River estuary is an important resource for North Carolina. It serves as a recreation area for boating and sport fishing and also supports a small commercial fishery. How the estuary affects the Pamlico Sound and shallow nearshore waters through export of inorganic and organic nutrients is poorly understood.

MATERIALS AND METHODS

Two tributaries of the Pamlico River estuary, Durham Creek and South Creek, were the first areas surveyed in the field study. In each creek, 30 random sampling stations were established on an enlarged navigation chart using the area from shore out to a depth of 2.5 m. Sampling was in triplicate at each site to assess the sampling error in the creek surveys.

During July 1973, a preliminary sampling program identified and defined the habitat of the benthic aquatic macrophytes of the Pamlico River estuary, North Carolina. The estuary was divided into six sampling strata as utilized by Tenore (1972) in his study of the macrobenthos (Fig. 3). Each stratum was further divided into two substrata, the north substratum or side of the river, and the south substratum. Each substratum ranged from the shore out to a depth of 2.5 m. This preliminary sampling design had an equal random allocation of 30 samples taken in each substratum or a total of 60 samples per stratum.

The preliminary sampling program gave some insight into the representative species and biomass in each stratum as well as the depth ranges of maximum biomass occurrence. On this basis, a gradient analysis transect was run at a depth of 1 m, as close to shore as possible, on the south side of the estuary from Hill Point (10 km S) to Pamlico Point (58 km S)

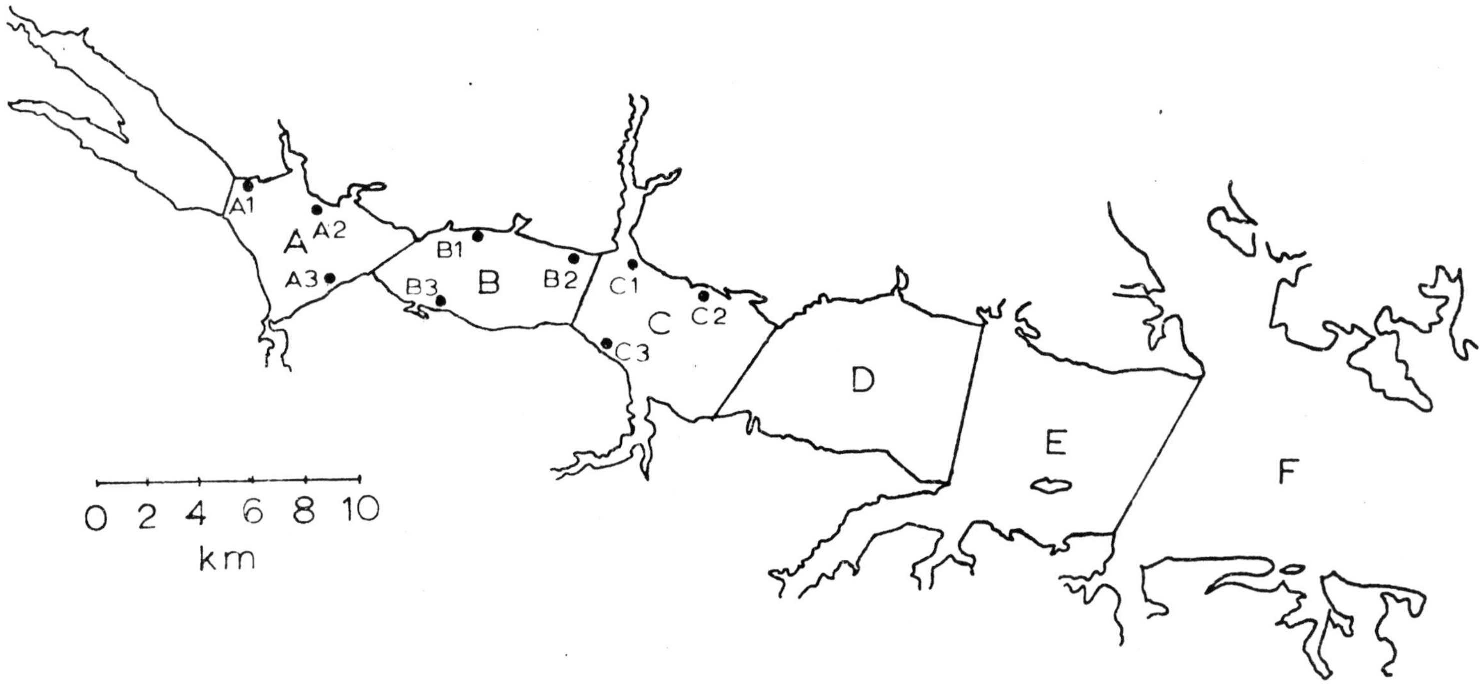

Figure 3. Pamlico River estuary sampling strata used in the survey of aquatic macrophytes July 1973, and transect locations (●) for the 1973-74 seasonality study.

where the river joins the Pamlico Sound. Two samples were taken every 200 m.

Next, the seasonality of submersed macrophytes of the estuary were studied. Since the preliminary studies had revealed that the majority of the macrophyte biomass was located in the upper three strata, a seasonal sampling program was designed and carried out in this region from August 1973 to August 1974. Three random transects were established for each of the three strata for this study (Fig. 3) and there was an equal random allocation of 10 samples taken along each transect. Each transect began at a random point from 1 - 10 m from shore with the other 9 samples being taken at regular intervals (1/10 transect length) to the end of the transect. There transects ran from shore out to a depth of 2 m or to the end of well defined plant beds. Samples were collected from each transect on a monthly basis except during the winter months when sampling was bimonthly.

A pair of modified oyster tongs was used as the sampling apparatus for all studies (Fig. 4) which sampled an area of 0.5 m^2. The oyster tongs were used because they provided a rapid efficient means of sampling the macrophytes which in most cases were rooted in a hard sandy substrate. The standing crop sampling efficiency of the tongs was found to be greater than 85% for all species in all seasons (Harwood et al. 1976).

The sampling site was located and the water depth was

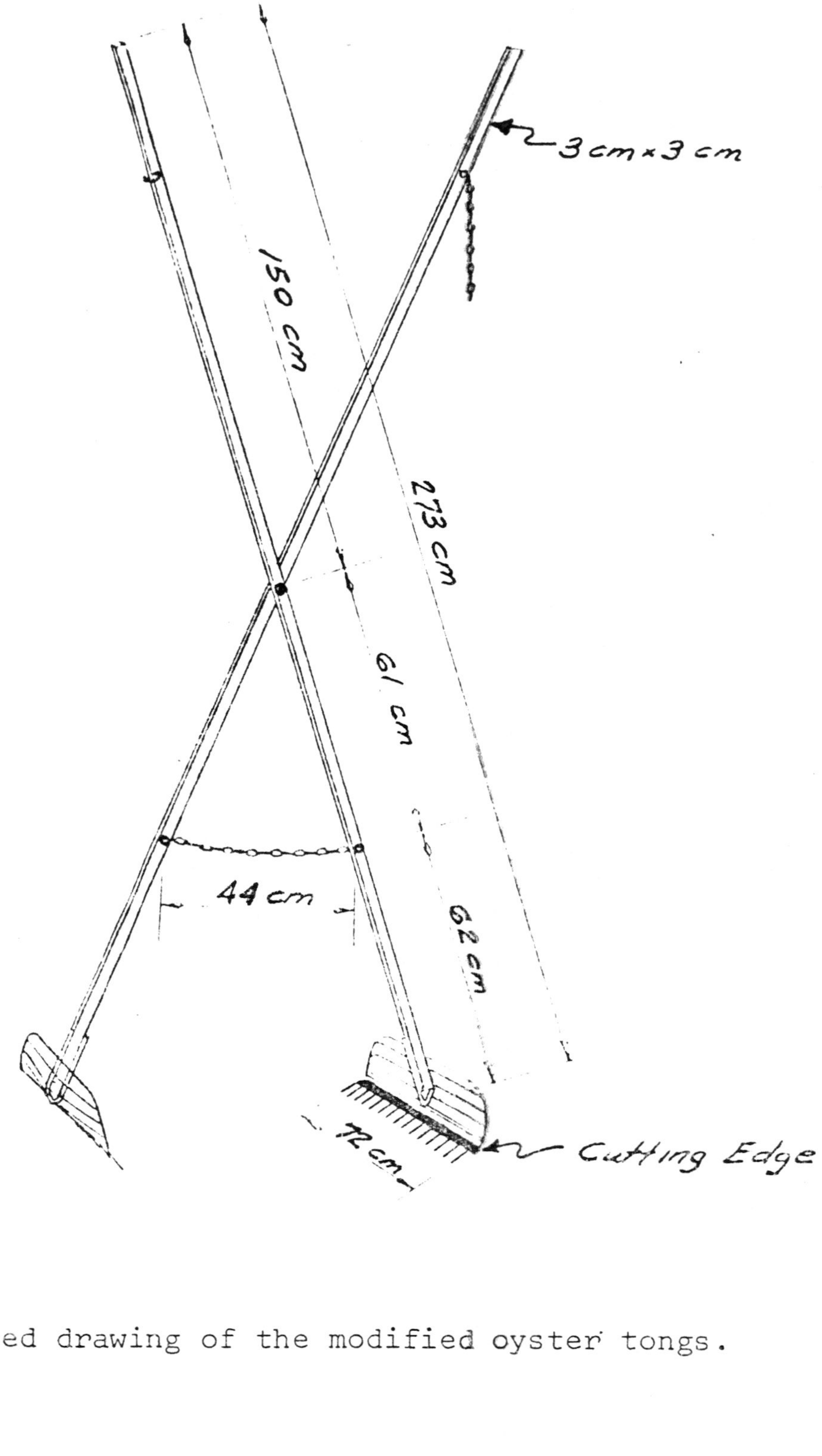

Figure 4. Scaled drawing of the modified oyster tongs.

checked to insure that it did not exceed the 2.5 m range of the tongs. The tongs were opened fully, lowered slowly to the bottom, and allowed to settle momentarily into the substrate. It was necessary to maintain the tongs perpendicular to the substrate and apply a downward force while closing them to insure a constant sediment sampling depth. The closed tongs were secured with a chain lock near the top of the handles, and slowly raised to the surface where the sample was carefully transferred to a container. A sieve was utilized to separate the macrophyte material from the substrate. The collected material was tagged, placed in a container with estuarine water, and returned to the laboratory for further analysis.

In the laboratory, the plants were floated in large trays of water and separated by species. The separated plants were placed in a large bucket, washed with a strong jet of water, and drained; this process was repeated twice. This procedure removed most of the loosely attached epiphytes and sediment, but did not remove encrusting diatoms on older plants. The samples were placed in mesh bags and spun dry (5 - 7 min.) with a domestic clothes washer on spin cycle to remove adherent water. When the spinning was complete, the bags were removed and placed in a covered holding bucket until they could be weighed. Small samples were blotted dry on paper towels and fresh weight recorded to the nearest 0.1 g. Material not processed on the day collected was placed in a cold room at 5°C until processed, usually within 24 h.

Special collections were made for the dominant species of each stratum on a seasonal basis for determination of tong efficiency. Triplicate samples of each species were obtained in each stratum. After sampling, three random cores (diameter 11 cm, 20 cm deep) were removed from the sample area. The amount of plant material found in the cores was extrapolated to the entire sampling area and added to the amount recovered by the tongs. In this matter, we were able to extrapolate to the total biomass present and not just the amount collected. The material from the special collections was analyzed in the laboratory and calculations made for percent dry weight, percent ash weight, and root/shoot ratios.

At each sampling site, the depth was taken with a graduated depth stick and recorded in cm. At the end of each transect, salinity was measured by a refractometer (American Optical Co.) in parts per thousand ($^{o}/oo$), transparency was measured with a Secchi disc in cm, and water temperature was recorded in °C.

RESULTS AND DISCUSSION

Floristics

During this project, 1800 samples were collected for a total of 11 different species of macrophytes encountered. There were six species of vascular plants and five species of algae as follows:

- Vascular plants
  - Monocotyledoneae
    - Hydrocharitaceae
      - *Vallisneria americana* Michaux (wild celery)
    - Potamogetonaceae
      - *Potamogeton perfoliatus* var. *bupleuroides* (Fernald) Farwell (redhead grass)
      - *Potamogeton pectinatus* L. (sago pondweed)
      - *Potamogeton foliosis* Radford (pondweed)
    - Ruppiaceae
      - *Ruppia maritima* L. (widgeon grass)
    - Najadaceae
      - Najas guadalupensis (Sprengel) Magnus (bushy pondweed)
- Algae
  - Chlorophyta
    - Characeae
      - *Chara* sp. (muskgrasses)
      - *Nitella* sp. (muskgrasses)

Cladophoraceae

Cladophora glomerata (L.) Kutz

Ulvaceae

Enteromorpha intestinalis Link

Rhodophyta

Erythrotrichiaceae

Compsopogon coeruleus (Balbis) Montagne

Subsequently, these Pamlico River species will be referred to by their generic names except for *Potamogeton pectinatus* and *P. foliosus*. This floristic summary only includes the benthic aquatic macrophytes found in the main body of the Pamlico River estuary and excludes all tributary areas and any emergent vegetation growing along the margins. The taxonomic references were Radford et al. (1968) for vascular plants and Whitford and Schumacher (1969) for the algae.

SURVEYS: SUMMER 1973

Creek Surveys

The Durham Creek (27 km S) study is summarized in Table 1. A total of 38 (42%) of the quadrats sampled were empty. *Najas* had the highest percent occurrence and *Vallisneria* had the highest mean wet weight of all species present. The aquatic moss, *Fontinalis* sp. was not present in the main body of the estuary. The survey of South Creek (40 km S) produced all empty quadrats except for two upstream sites which were located in a bend where Compsopogon was flourishing.

Table 1. Wet weights and frequency of macrophytes in the Durham Creek Survey, July 1973. Quadrats of 0.5 m^2 were sampled with modified oyster tongs.

Species	Wet weight (g)	Percent occurrence	Mean wet weight (g)	Percent of total biomass
Vallisneria	2105.6	13	175.5	83
Najas	262.0	38	7.7	10
P. perfoliatus	2.0	2	1.0	1
Ruppia	43.8	13	3.6	2
Muskgrasses	111.0	29	4.3	4
P. Foliosus	24.8	26	1.1	1
Fontinalis sp.	0.3	1	0.3	1
Total	2550.4[a]			

[a] For all species combined; $\bar{x}$=28.34g; S.D.=10.8

Durham Creek had a more heterogeneous macrophyte community than in any of the Pamlico River strata. Random sampling in the Pamlico River resulted in empty quadrats 78% of the time as compared to 42% for Durham Creek. This difference in growth pattern is attributable to the difference in exposure of the two localities. The creek is more curving and much narrower and therefore more protected from damaging waves which can prevent the establishment of benthic plants. The muddy bottom of the medium depth areas (1.5 - 3 m) of

Durham Creek is suitable for growth of the thin leafed species which seem to grow best, or with less competition, on muddy substrate at depths where light intensity is reduced. This is exemplified by the fact that *Najas*, a thin leafed species, had the highest frequency and was followed by the other thin leafed species, the muskgrasses and *P. foliosus* in decreasing order. *Vallisneria* and *Potamogeton* had two of the lower frequency values, but *Vallisneria* accounted for 83% of the total biomass collected. The leaves of *Vallisneria* and *Potamogeton* are much thicker and larger than those of *Najas* and the other thin leafed species which resulted in the higher biomass. Most of this *Vallisneria* was located in the sandy shallows in the vicinity of the mouth of the creek where the water was clearer and more light was available. The root and rhizome system of *Vallisneria* is probably responsible for its survival in more exposed areas.

The portion of South Creek studied, as compared to Durham Creek, is much straighter and wider and therefore, more exposed. Its mouth is larger and it is located downriver where the whole estuary is wider. Hence, South Creek is subject to larger waves coming in from the river uprooting any macrophytes that might have become established. The portion of the creek studied was a straight stretch (flowing east-southeast) as compared to the meandering Durham Creek. The *Compsopogon* that was collected in a bend probably washed down from upstream and the *Ruppia* was located in protected embayments. The *Ruppia* and other species were located outside of the random quadrats. The increased exposure and higher salinity were apparently the factors responsible for the tremendous number of empty quadrats in the South Creek Survey.

Preliminary Survey

The distribution of macrophytes by strata as determined by the preliminary survey is shown in Fig. 5. In the lower, wider two strata (Strata E & F), no macrophytes were found. The increased exposure to fetch, higher wave energies, and higher salinities may be the reasons that no macrophytes were collected in these two strata.

Potamogeton pectinatus was found only in Stratum D. This species was collected in a small patch near the mouth of the Lee Creek diversion at Texasgulf. The water in this area was frequently murky and the substrate is a chalky mud. *Potamogeton pectinatus* has been reported to grow well in sediments with high phosphate concentrations and be a "polluted water plant" (Hynes, 1974).

Vallisneria was the dominant macrophyte in Strata A, B, and C with the greatest biomass in Stratum B. *Potamogeton* had a similar distribution with a peak in Stratum B also. In Stratum B, the salinity was higher than upriver so there would be less competition from the more fresh water adapted species. The water was usually clearer as compared

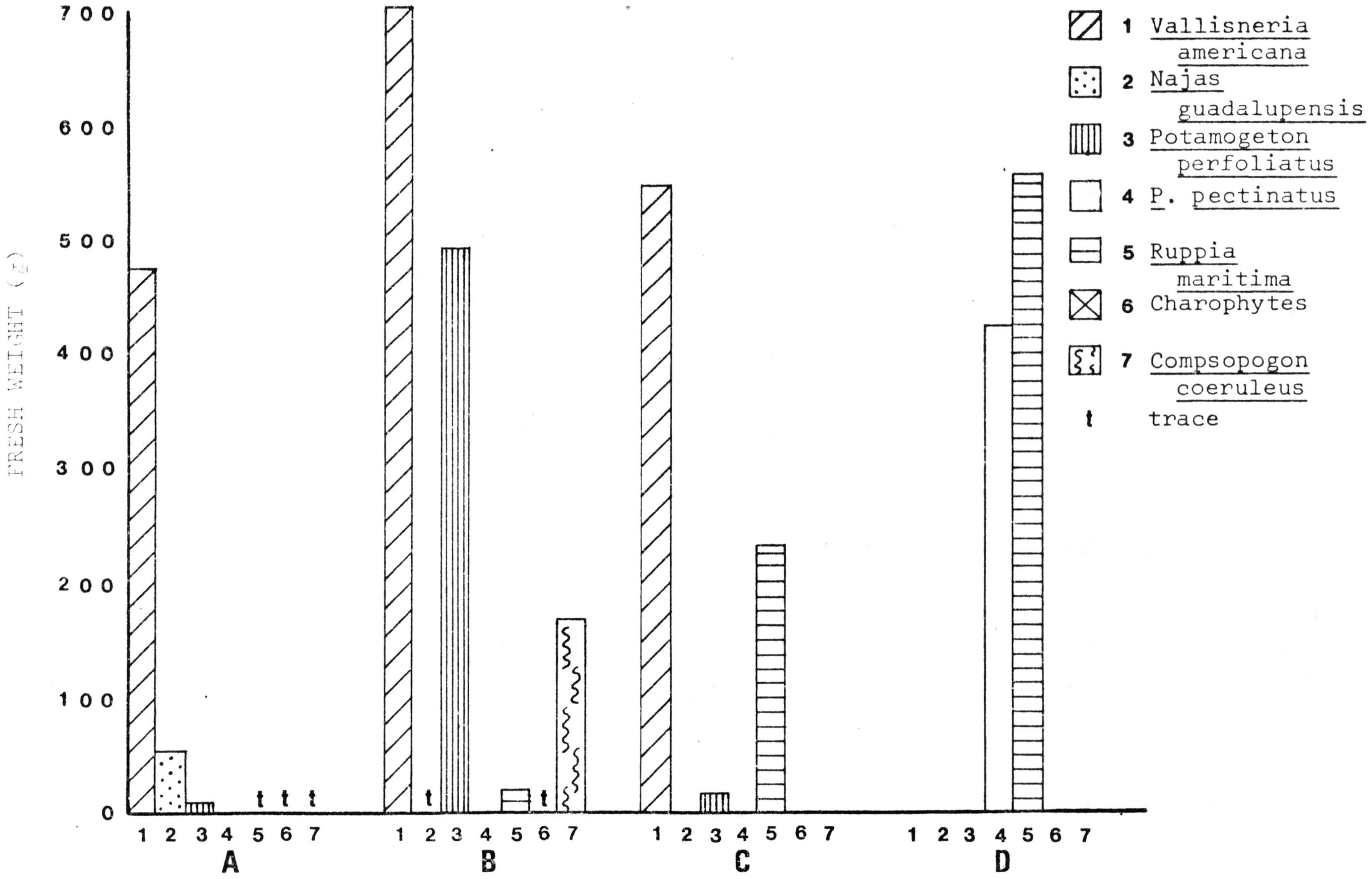

Figure 5. Fresh weights and species distribution by strata for preliminary survey, in the Pamlico River estuary, North Carolina.

to neighboring strata thereby causing less light attenuation. Turbulence in this section may tend to prevent the establishment of the shallow rooted macrophytes such as Najas and the muskgrasses. Potamogeton and especially Vallisneria are best adapted to the environmental conditions in Stratum B.

Vallisneria was the dominant macrophyte in Stratum A. Najas had the second highest biomass as it appears to be adapted to fresher more turbid water. Small amounts of Potamogeton were collected here along with trace quantities of Ruppia, Compsopogon, and the muskgrasses.

Ruppia was found in all four strata beginning with only a trace in Stratum A, and increasing amounts downriver until it became the dominant macrophyte in the higher salinity of Stratum D. Potamogeton pectinatus also survived the higher salinities there.

The upper four strata (Strata A,B,C, and D) had a mean value of 82% empty quadrats. The higher individual sample biomass values occurred in the strata with the greatest fetch (Strata C & D). The results of the Preliminary Survey indicate that the macrophyte community is overdispersed and a more intensive sampling program probably would yield similar results.

Southside Transect

To study variations in macrophyte biomass along the estuarine gradient, a southside transect was run from Hill's

Pt. (10 km S) to Pamlico Pt. (58 km S) (Fig. 2) at a constant depth of 1 m as close to shore as possible during July 1973. The results of this study are shown graphically in Fig. 6. The figure represents the river from Hill's Pt. to Durham Creek. Macrophyte beds stopped abruptly just east of Durham Creek, and no plants were encountered between there and Pamlico Pt.

The most widely distributed macrophyte was *Vallisneria* and it also accounted for most of the high biomass peaks in Fig. 6. The red filamentous algal, *Compsopogon*, appeared to be localized around salinity 4.5 to 6.5^{o}/oo as in (lower Stratum B) in this survey. The widely separated stands of *Potamogeton* were overshadowed by the higher wet weight values of *Vallisneria* and *Compsopogon*. *Najas* occurred in relatively small quantities and was restricted to Stratum A (1 - 3^{o}/oo) except for some trace amounts downriver in the vicinity of the mouth of Nettle's Creek (19 km S). The southside study produced only one small sample of *Ruppia* which appeared just east of Durham Creek in Stratum D in the preliminary survey, but these were growing in shallower water than the 1 m depth of the southside transect.

The southside transect further substantiated the distribution results of the preliminary survey. At low salinities (0 - 3^{o}/oo) the species present were *Vallisneria*, *Potamogeton*, *Najas*, and small amounts of muskgrasses. With

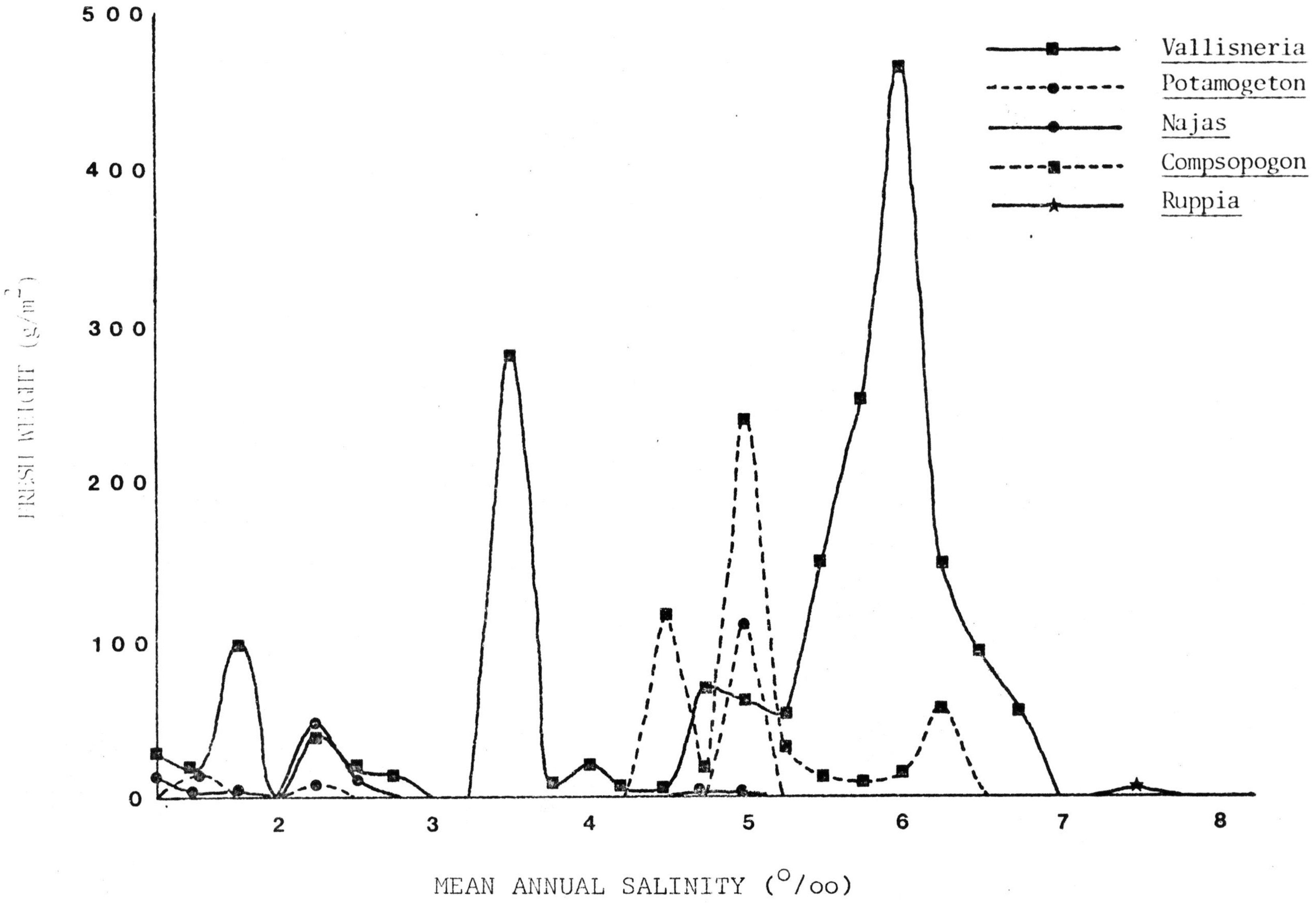

Figure 6. Southside transect from Hill Pt. (1°/oo) to Durham Creek (8°/oo) at 1 m depth with samples taken every 200 m. Fresh weights (g/m^2) for most abundant species along the salinity gradient (°/oo) in the Pamlico River estuary 1973-74.

increasing salinity (4 - 7°/oo) the composition changed to Vallisneria, Potamogeton and Ruppia. At mean annual salinities above 8°/oo Ruppia was the only macrophyte present and then only in protected areas. Compsopogon was found in different areas in both studies, but its distribution was highly dependent on wind direction.

Every time the transect crossed a prominent point, such as Maul's Pt. (17 km S) or Core Pt. (38 km S), there were almost continuous empty quadrats. These points are areas of maximum exposure with rapid erosion, sand burial, or fragmentation and abrasion of any macrophytes that might colonize there. The number of empty quadrats increased downriver, but the quadrats with macrophytes contained a much higher mean biomass than those upstream. The further downriver the greater the fetch or potential wave energy that could damage macrophytes and the larger the area without any macrophytes. It is difficult for macrophytes to remain attached in this area, but the ones that do have little competition and form circular beds of tremendous biomass. Two samples 1 m apart might yield 0 g/m^2 and 1200 g/m^2 fresh weight (inside a circular bed) showing the amplification of overdispersion in downriver areas.

SEASONAL STUDIES

Transect Variation on a Single Sampling Date

The preliminary survey and southside transect provided some indication of the general distribution and relative biomass of macrophytes throughout the estuary. This information was used to describe the community composition of macrophytes in each stratum. These strata are far from being individual homogeneous systems with regard to the biomass distribution of a specific macrophyte as is shown in Fig. 7. This figure represents the organic weight (g/m^2) of <u>Vallisneria</u> collected from each transect (see Fig. 3 for locations) during August 1973.

Transects A1 and A2 were roughly 2 km apart on the same side of the river yet their difference in biomass was high (11.9 g/m^2). Transect A1 was protected in the embayment produced by Broad Creek Point (10 km N) as opposed to Transect A2 which was in an exposed area just downriver of Broad Creek (12 km N). Transects B1 and B2, roughly 5 km apart on the north side of the river, showed a large difference in biomass (13.6 g/m^2). Transect B1 was in the vicinity of a private camp and might have been subject to increased fragmentation or uprooting by swimmers or boat traffic. The values for the transects in Stratum C are relatively close together. General trends in relative biomass values and species distribution can be established for each stratum, but individual transect variations show that it would be difficult to find a representative area.

<u>Hydrographic Data</u>

Monthly hydrographic data are in Fig. 8. The values

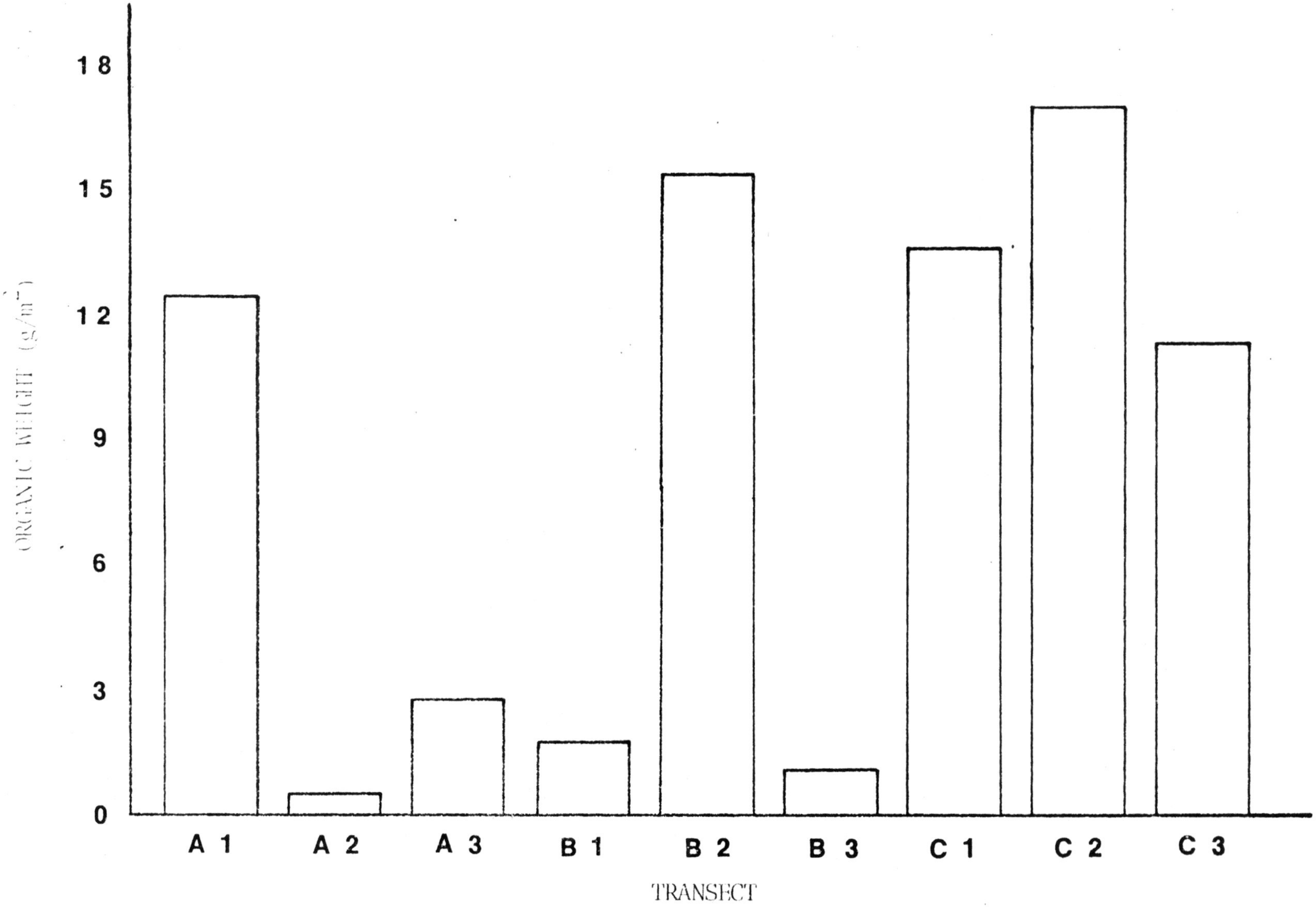

Figure 7. Organic weight of Vallisneria americana for seasonal transects on a single sampling date in the Pamlico River estuary, N.C. August 1973.

represent the mean of the three transects for each stratum. Salinity peaked in November and again in July with a downriver gradient usually apparent. The freshwater inflow of the Tar River is a major factor affecting salinity. Most of this freshwater flows out of the estuary along the south shore and creates a difference of up to $3^{o}/oo$ between transects on opposite sides of the river (B1 & B3) due to Ferrell's Law. Wind tides in the estuary also have an influence on the salinity distribution.

Water temperature of the estuary closely followed ambient air temperature. The coldest period occurred during December when some daytime readings were below 6°C, and the warmest month was August 1974 when the temperature at Transect B1 was 32.5°C. Between September and October, the water temperature started decreasing and dropped sharply during November. The Pamlico River began to warm in March with a rapid rise in April that continued increasing more slowly through the summer.

Secchi disc transparency depth showed influence of the Tar River. During rainy periods, the Tar River carries a heavier suspended sediment load into the Pamlico River estuary. This is shown in Fig. 8 where, after spring rains, transparency in all three strata reached the lowest values for the year. Wind and waves have the effect of increasing turbidity as the waves resuspend the sediment shallow water. This effect was amplified downriver where, with greater fetch,

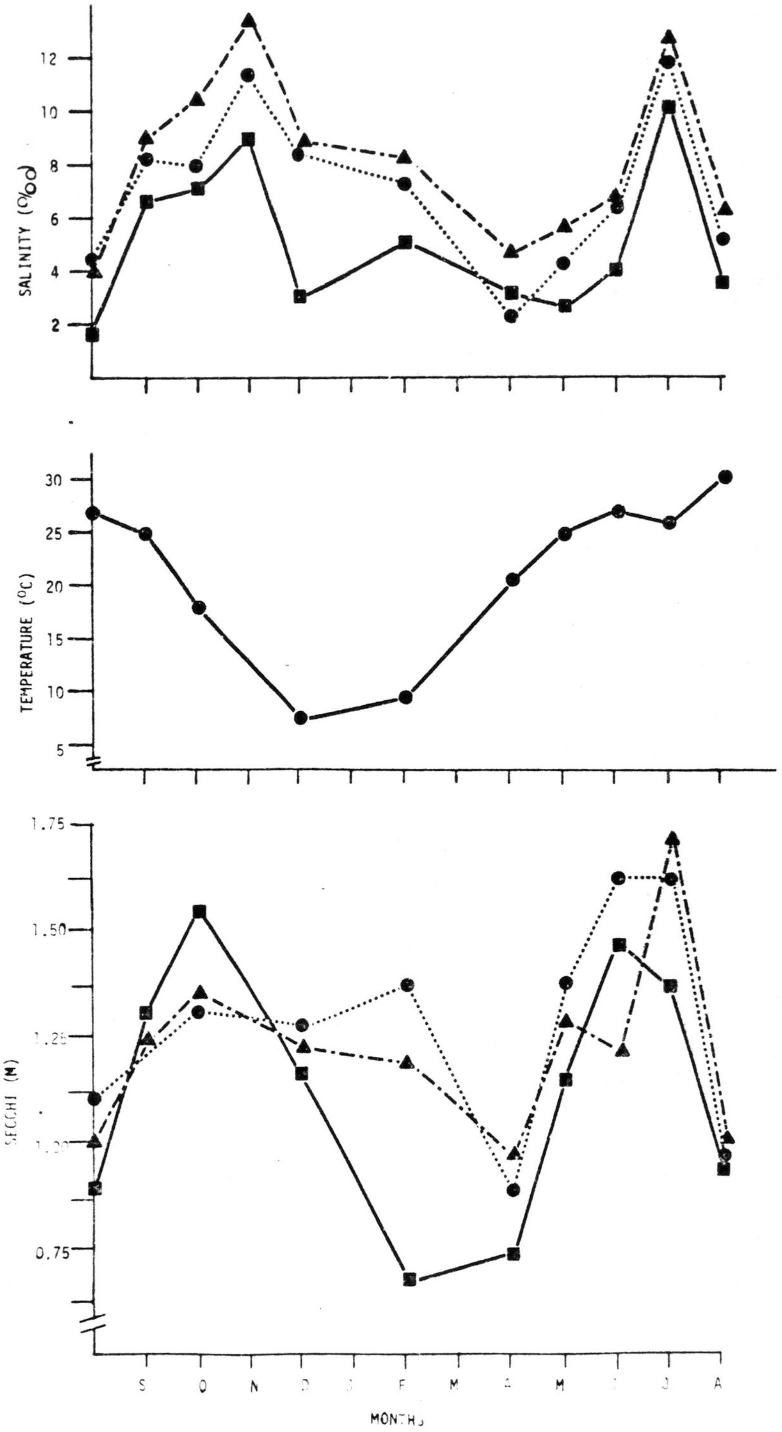

Figure 8. Hydrographic data for seasonal studies in the Pamlico River estuary 1973-74. Upper-Salinity (°/oo). Each point is the average for all transects in the stratum (—■— Stratum A, ----●---- Stratum B, —·▲·— Stratum C). Middle-Temperature (°C). Each point is the average for all transects. Lower-Secchi disc transparency (m). Each point is the average for all transects in the stratum. Strata are as for upper graph.

the waves were larger and thus stirred up increased amounts of sediment resulting in greater turbidity.

Seasonal Transects

The monthly fluctuations of the biomass of the three major macrophytes collected in this study (Vallisneria, Potamogeton, and Ruppia) are plotted in Fig. 9 along with monthly variations in water temperature and salinity. The hydrographic parameters as well as the organic weight values (g/m^2) represent the mean values for all transects (Strata A, B,and C). The terminal or peak biomass of the dominant macrophyte, Vallisneria, during 1973 occurred in September when the water temperature was just beginning to cool after the hot summer. Potamogeton peaked with October growth. Ruppia seemed to peak in October and April, but biomass was very low. From October through January, the water temperatures continued to decrease and the biomass of Vallisneria and Potamogeton was drastically reduced. The "carry over" biomass of Vallisneria was less than 0.1 g/m^2 and consisted of only winter buds buried in the substrate. Potamogeton was reduced to stubbly epiphyte-covered stands with a "carry over" value of about 1.1 g/m^2. Ruppia appeared to be more abundant during the cooler periods. It was the dominant macrophyte during the early spring when it reached one of its peaks at about 1.2 g/m^2 in April.

Water temperature increased from 9° to 20°C from February to April and rose another 5°C during the month of

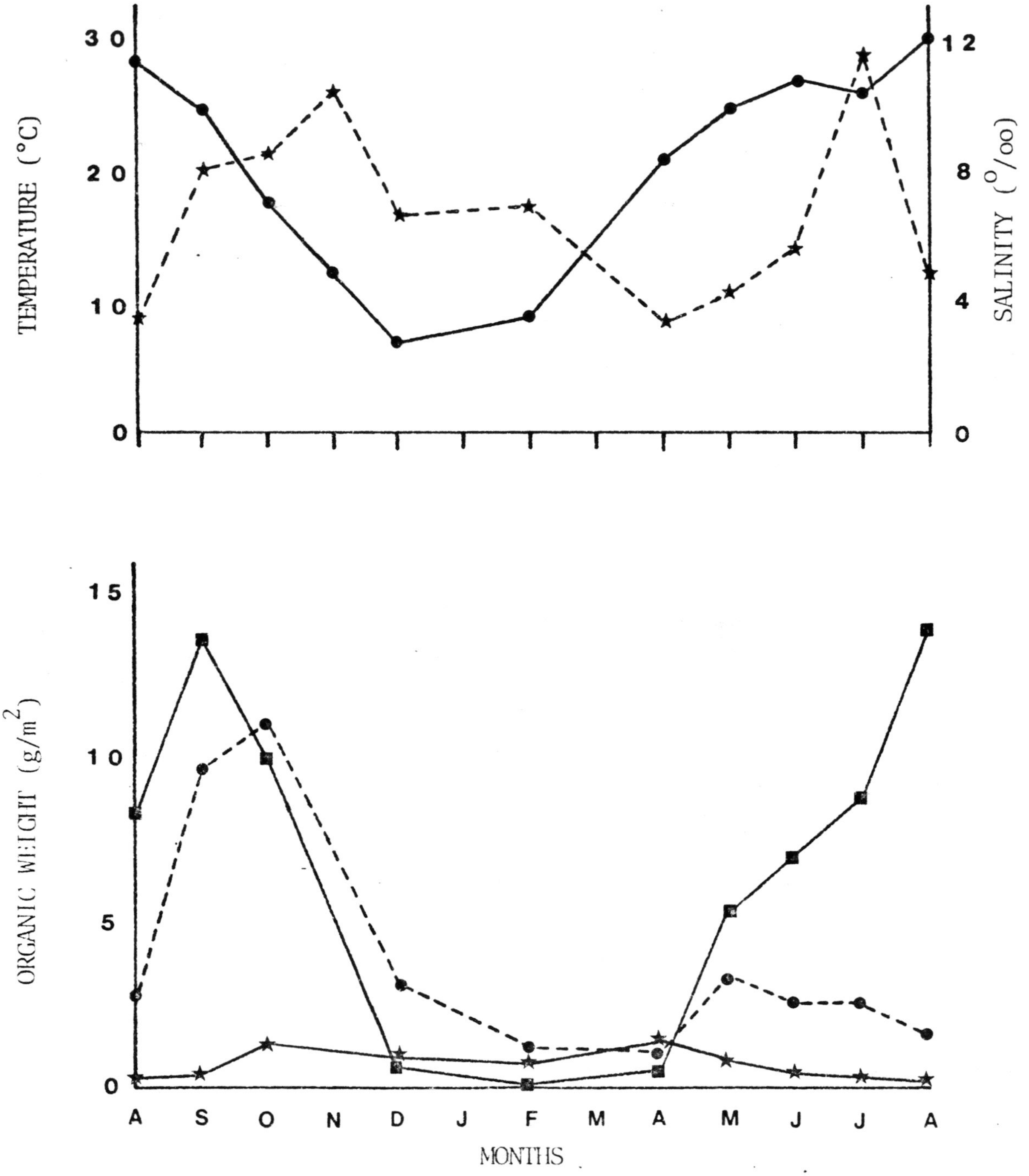

Figure 9. Upper-Monthly mean temperatures (°C) and salinities (°/oo) for all transects in the seasonal study in the Pamlico River estuary 1973-74 (——●—— temperature, ---★--- salinity). Lower-monthly mean biomass of the three most abundant species for the nine transects in the seasonal study in the Pamlico River estuary 1973-74. (——■—— *Vallisneria*, ---●--- *Potamogeton*, ——★—— *Ruppia*).

May. In April, the winter buds of *Vallisneria* had germinated and their shoots were above the substrate. The truncated stands of *Potamogeton* had new shoots from axillary buds. Both of these major species had their most rapid rates of growth during the month of April while water temperature was continuing to increase rapidly. *Vallisneria* continued to show increases in biomass in May and June at a somewhat slower rate, but returned to its rapid rate of growth during July. Zamuda (1976) noted renewed growth of *Vallisneria* in midsummer in studies of growth dynamics of this species. This appeared to follow flowering. The biomass values for *Potamogeton* were low in 1974 compared to 1973 and varied little seasonally.

The seasonal transect study (Fig. 8) showed that *Vallisneria* was the dominant macrophyte during all months except for the winter period. During this cold period (6 - 8°C), the dominants were *Potamogeton* and *Ruppia*, but with low biomass. *Vallisneria* was apparently the least tolerant of decreases in temperature as it declined in biomass as the temperature dropped to 18°C, while *Ruppia* and *Potamogeton* decreased as the temperature dropped from 18°-12°C. There was a direct relationship between plant growth and water temperature. Between the months of February and August, while the water temperature was increasing, plant biomass also increased. The most rapid increases in biomass lagged behind rapid temperature increases.

Salinity apparently had little relationship to the seasonal biomass fluctuations in the Pamlico River estuary. During the 1973-74 study, salinity reached its maximum mean levels for the river (11 - 12°/oo) twice. The first salinity peak occurred in November when all species were decreasing in biomass and the second came in July when Vallisneria was rapidly increasing, Potamogeton was remaining the same, and Ruppia was slightly decreasing. Salinity was more readily related to the distribution of aquatic macrophytes down the gradient. Secchi disc transparency depth increased throughout the study area during most of the growing season in 1974, but a drastic decrease was recorded for August.

Annual Variations

The mean weight of Vallisneria for the transects increased from 8.4 g/m^2 in 1973 to 13.9 g/m^2 in 1974 (Table 2). The biomass of Potamogeton decreased during the same period from 2.6 to 1.7 g/m^2. Ruppia also showed a decrease from 0.2 to 0.1 g/m^2. These mean values from all transects show only moderate annual variations in biomass, but annual fluctuations on a transect basis were often large.

Vallisneria increased between 8 - 27 g/m^2 on all transects in Stratum A and on Transects B1 and B3. All transects in Stratum C along with B2 showed decreases ranging from 5 - 16 g/m^2. Annual biomass fluctuations of Potamogeton both increased and decreased in Strata B and C with

Table 2. Annual biomass (organic weight - g/m^2) of the three dominant macrophytes, by transect, for August 1973 and August 1974.

Transect[a]	Vallisneria		Potamogeton		Ruppia	
	1973	1974	1973	1974	1973	1974
A1	12.3	39.1	0.7	7.3	0	0
A2	0.5	14.7	0.7	1.4	0	0
A3	2.8	10.9	0	0.3	0	0
B1	1.8	12.7	1.8	0.9	0	0.3
B2	15.4	10.1	3.7	0.1	0.2	0.2
B3	1.1	28.9	0.1	1.4	0	0.2
C1	13.7	2.4	0	0	0.7	0
C2	17.0	0.5	16.4	0.7	0.8	0
C3	11.3	5.8	0	3.0	0.2	0.2
Mean for River	8.4	13.9	2.6	1.7	0.2	0.1

[a] Transects as in Fig.3.

increases in Stratum A. Ruppia was absent in Stratum A, increased or remained the same in Stratum B, and decreased or remained the same in Stratum C.

Mean salinity during August 1974 was 1.7^{o}/oo higher than August 1973. The water temperature was 2°C warmer in 1974, and the transparency depth measurements for both sampling periods were similar.

The most fundamental difference in the annual transect variations were associated with Vallisneria and Potamogeton; there was a major change in the biomass of every transect. This change on a relative basis was usually in the opposite direction of the 1973 biomass figure. If the biomass was low in 1974, there was an increase and if the 1973 biomass was high, 1974 showed drastic decrease. In the fall of 1973, the salinity of the lower portion of the study area (Stratum C) was abnormally high (17 - 18^{o}/oo) for a month or more and may have been responsible for the decrease in biomass in this area.

Special Collections

Collections for more detailed analyses for the dominant species were made in the late spring and winter of 1973 and the spring of 1974. Representative samples of Vallisneria, Potamogeton, and Ruppia were collected from all strata where they were present. Analyses for percent dry weight, percent ash, and root/shoot ratios (Tables 3,4, and 5) were made for each species.

Table 3. Seasonal percent dry weight for dominant macrophytes.

Species	3-6 June	12-16 December	8-11 May	Yearly Mean
<u>Vallisneria</u>	7	7*	8	7
<u>Potamogeton</u>	13	15	11	13
<u>Ruppia</u>	10	15	11	12

* This sample consisted of only winter buds and rhizomes.

<u>Vallisneria</u> had the lowest yearly mean percent dry weight as well as during each sampling period. <u>Ruppia</u> had the second lowest percent with <u>Potamogeton</u> having the highest. All species had percentages around 10 which is similar to other macrophyte species found in North Carolina (Dillon, 1968). Vicars (1976), in his work on the Pamlico River, recorded summer dry/wet weight ratios for <u>Vallisneria</u> of 0.066, for <u>Potamogeton</u> 0.13, and 0.125 for <u>Ruppia</u>.

Table 4. Seasonal percent ash for dominant macrophytes.

Species	3-6 June	12-16 December	8-11 May	Yearly Mean
<u>Vallisneria</u>	27	36	46	36
<u>Potamogeton</u>	16	25	33	25
<u>Ruppia</u>	22	21	42	28

Factors other than normal seasonal differences apparently affect the percent ash weight. In June 1973 the percent ash weight of each species was about half that of May 1974. Potamogeton had the lowest yearly mean percent ash weight and was followed in increasing order by Ruppia and Vallisneria. Vicars (1976) reported summer percent ash weights of 25 for Vallisneria, 21 for Potamogeton, and 28 for Ruppia.

Table 5. Seasonal root/shoot ratios for dominant macrophytes.

Species	3-6 June	12-16 December	8-11 May	Yearly Mean
Vallisneria	0.44	-	0.65	0.54
Potamogeton	0.17	0.89	0.29	0.45
Ruppia	0.54	2.91	0.67	1.37

The accumulation of root material reaches its maximum at the end of the fall growing season and the shoot systems are drastically reduced by late fall. All species except for Vallisneria, which was absent during the winter except for a few winter buds, showed a drastic increase in the root/shoot ratio between summer and winter. Zamuda (1976) reported a summer mean root-rhizome/shoot ratio of 0.74 for Vallisneria. Ruppia had by far the highest mean root/shoot ratio of the three species studied.

PHYSICAL FACTORS

Physical factors acting on the Pamlico River estuary are the variables which control the biomass variations and distribution patterns of the aquatic macrophytes. This study, which focused on the factors of salinity, temperature, turbidity, and depth, will be compared to results from other oligo-, meso-, and polyhaline estuarine macrophyte studies. The physical characteristics of the estuaries considered are shown in Table 6.

Salinity

Salinity is one of the most important physical factors affecting macrophyte distribution within the Pamlico River estuary. All other factors being equal, a species will grow best in the salinity regime to which it is best adapted. The salinity of the estuary, as described previously, is controlled primarily by the amount of freshwater inflow from the Tar River and influenced somewhat by wind tides. The differences in salinity within the study area (between Hill's Point (S 11 km) and Bayview (N 29 km)) ranged from $1^{o}/oo$ following periods of heavy runoff to $8^{o}/oo$ during dry periods. In some areas, (e.g., Transects C2 and C3) (Fig. 3) the difference in salinity extremes during the year was over $10^{o}/oo$ (Fig. 8). This wide range of salinities in the lower strata may be one cause of the lower number of species there. Salinities in the study area ranged from $1^{o}/oo$ to $18^{o}/oo$; therefore, there were sectors which de-

Table 6. Physical characteristics of various estuarine ecosystems.

Estuary	Salinity range (°/oo)	Mean transparency (m) (growing season)	Temperature range (°C)
Pamlico River[1]			
Stratum A	0.7-10	0.9	6-33
Stratum B & C	1.0-13	1.2	6-33
Currituck Sound-Back Bay[2]	0-4	0.7	0-36.3
Kitty Hawk Bay[3]	1-3	good, bottom visible, at most times	
Bogue Sound[4]	27-33	turbid	8.3-33.5
Chesapeake Bay			
Susquehanna Flats[5]	0-3	1.5	
Rhode River[6]	<2-12	(2% incident radiation)	

Sources:

[1] Reed, 1979

[2] Sincock, 1965

[3] Getsinger, 1976

[4] Dillon, 1968.

[5] Steenis, 1970

[6] Southwick and Pine, 1975

pending on the season could be classified as oligohaline (0.5 - 5^{o}/oo) and mesohaline (5 - 18^{o}/oo) according to Reid (1961).

The time over which changes in salinities occur is likewise important. A 10^{o}/oo change might be withstood by a species if the increase were over a period of a few months. A change of this magnitude in only a few days could obliterate or reduce a macrophyte community. For example, *Vallisneria* biomass for Transects C1 and C2, where the salinity values rose rapidly to a very high level (16 - 18^{o}/oo) during the late fall, was reduced there by 80 - 95% the following summer. *Vallisneria* would not have survived salinities of this magnitude even with a gradual change (see Table 7). This suggests an inhibitory effect of the high salinities. Steenis (1970) noted that increased salinities during the growing season "pushed back" the growth of *Vallisneria* in the Chesapeake Bay area.

The salinity gradient and other factors such as wave energy are reflected in macrophyte distribution throughout the estuary. The oligohaline community around Blount's Bay (S 14 km) consisted of *Vallisneria*, *Najas*, *Potamogeton*, muskgrasses, and a trace of *Ruppia*. Components of the mesohaline community were *Vallisneria*, *Potamogeton*, and *Ruppia*. In the polyhaline region (18 - 30^{o}/oo) *Ruppia* was found in some sheltered areas.

Steenis (1970) established salinity tension zones in the Chesapeake Bay area for various macrophytes found there (Table 7). Anderson (1972) reported that salinity and bottom type were the major physical factors affecting macrophyte distribution in the Chesapeake Bay area. He found the salinity ranges were: freshwater only for *Vallisneria americana*, 5 - 25°/oo for *Potamogeton perfoliatus* var. *bupleuroides* and 5 - 40°/oo for *Ruppia maritima*. The findings for *Vallisneria* and *Ruppia* are somewhat different than those reported by Steenis and also those of this study for *Vallisneria*.

In Kitty Hawk Bay, N.C., Getsinger (1976) found *Vallisneria americana*, *Potamogeton perfoliatus* var. *bupleuroides*, *Ruppia maritima*, and *Najas guadalupensis* as well as *Myriophyllum spicatum*, *Potamogeton pectinatus*, and *Potamogeton foliosus*. The salinity in this area is usually around one to a few °/oo. As compared with the Pamlico River estuary, the greater species richness appears to be related to a more stable environment in the bay, especially with regard to salinity.

All the species found in the Pamlico River estuary, plus four additional ones, were listed in a U.S. Fish & Wildlife Service Report (Sincock, 1965) for Back Bay-Currituck Sound. This work involved some experimental work in drums on shore where they found the greatest growth of total vegetation at 3.6°/oo. *Vallisneria americana* had the highest tuber production at 14°/oo but a reduction in individual

Table 7. Salinity tension zones for selected macrophytes-Chesapeake Bay (Steenis, 1970).

Salinity (°/oo)	Species
<3	*Najas guadalupensis* & *Nitella* sp.
3-5	*Vallisneria americana* & *Chara* sp.
20-25	*Potamogeton perfoliatus* var. *bupleuroides*
30+	*Ruppia maritima* & *Zostera marina*

plant size above 7°/oo. *Potamogeton perfoliatus* var. *bupleuroides* had good yields at all salinities (0 - 14°/oo), but most rapid growth was on silt soils at 0 - 5°/oo. *Najas guadalupensis* did not survive 9°/oo and its yield was reduced between 3.5 - 7°/oo. *Ruppia maritima* yields increased at 5°/oo and peaked at 7°/oo but showed good production up to 14°/oo. *Nitella* sp. did not survive above 7°/oo and may be retarded at 3.5°/oo.

Bourn (1932), in one of the earliest investigations of the ecology of coastal North Carolina macrophytes, found the Back Bay-Currituck Sound, N.C. area salinities to be around 2 - 3°/oo with increases up to 7°/oo during dry periods. He stated that salinity was most affected by rainfall, but wind was also important. He did not describe any distribution of species along a salinity gradient but did conduct greenhouse growth studies on the effects of salinity in tanks. He found *Vallisneria americana* productivity greatest at 4^{o}/oo and was lowest at 13^{o}/oo. Production of *Najas guadalupensis* was highest at 1.5^{o}/oo and was reduced at 9^{o}/oo. *Potamogeton pectinatus* growth was greatest at 7^{o}/oo and least at 34^{o}/oo.

Bourn found *Potamogeton pectinatus* to be the dominant macrophyte of the sound, accounting for 60% of total standing crop. He also found in order of abundance: *Najas guadalupensis*, *Vallisneria americana*, *Potamogeton perfoliatus* var. *bupleuroides*, *Ruppia maritima*, *Ceratophyllum demersum*, *Potamogeton foliosus*, and the muskgrasses. The salinity gradient was less pronounced and the annual fluctuations are on the order of 2 - 4^{o}/oo rather than the 10^{o}/oo in the Pamlico. This, as well as lower turbulence, probably accounts for the higher diversity described in these data by Bourn (1932) and Sincock (1965).

In the Pamlico River estuary, *Vallisneria* and *Potamogeton* had their highest biomass in Stratum B, where salinity ranged during 1973-74 from 2 - 12^{o}/oo with an annual mean of 6.6^{o}/oo. Both species were found in other strata where salinity was 0^{o}/oo and 14^{o}/oo, but their biomass was lower. The highest biomass of *Najas* and the muskgrasses was in Stratum A, where salinity ranged from 1 - 11^{o}/oo with an annual mean of 4.7^{o}/oo. These species were also found in Stratum B, but they were growing near a creek mouth where the creek's freshwater input could reduce the higher salinities there. In

Strata C, *Ruppia* had its highest biomass and salinity there ranged from 3 - 13^{o}/oo with an annual mean of 7.6^{o}/00. *Ruppia* was found in the lower salinities of Stratum B (2 - 12^{o}/oo) and trace amounts were collected in Stratum A where salinity is 1^{o}/oo during some periods of the year.

Dillon (1968) in his work on Bogue Sound, N.C. found the annual salinity there to be 31 - 33^{o}/oo with a 1 - 2^{o}/oo gradient from east to west. He also mentioned the low salinity at Morehead City was 24^{o}/oo with 27 - 29^{o}/oo not uncommon. These salinities, according to Reid (1961), make this a polyhaline to marine system. He found two vascular and nine non-vascular macrophytes. The vascular macrophytes were *Zostera marina* which was responsible for 87% of total standing crop and a small amount of *Halodule beaudettei*. The extremely high salinity of this estuary is the reason that none of the species found in the Pamlico are found in Bogue Sound. The fairly constant salinity in this polyhaline environment is apparently related to fewer vascular species found and the overall higher diversity for the non-vascular species.

Seasonal Variations and Temperature

Another important physical factor affecting macrophyte growth is water temperature. The mean temperature of Pamlico River estuary between August 1973 and August 1974 fluctuated from a high of 30°C in August to 5°C in January. There is a direct relationship between temperature and macrophyte biomass (Fig. 9).

Sincock (1965) found that *Potamogeton* in Currituck Sound-Back Bay was one of the early spring dominants and it appeared to die back in mid-summer. These findings are similar to those in the Pamlico River where, from December through April (Fig. 9), *Potamogeton* was at low levels. It also had a small reduction in biomass during July and peaked in October. Muskgrasses in Currituck Sound-Back Bay were scarce during the spring with great increases between August and November. *Najas* was dominant in late winter and early spring. In the Pamlico, *Najas* reached its peak in the oligohaline zone during October and existed in only minimal quantities in winter and spring.

Vallisneria declined progressively in November in Currituck Sound-Back Bay (Sincock, 1965). Buoyancy, leaf shape, and the relatively shallow root system were suggested as factors associated with *Vallisneria*, being easily uprooted by water turbulence, carp action, or waterfowl. *Vallisneria*, the dominant macrophyte in the Pamlico River estuary, reached its peak during September and declined to minimal biomass by December when water temperatures were 7 - 8°C. It was not easily uprooted in the Pamlico River until fall senescence began.

Between August and November in Back Bay, *Ruppia* decreased significantly. In the Pamlico River, *Ruppia* was more abundant during cooler periods with two relatively low peaks, one in October and one in April (Fig. 9).

Anderson (1969) found that _Ruppia maritima_ disappeared in the sections of the Patuxent River, MD following a thermal discharge from a power plant into the river. He also found _Potamogeton perfoliatus_ var. _bupleuroides_ to be more tolerant of elevated temperatures (up to 35°C) and even replaced _Ruppia_ in thermal stress locations. These findings have particular relevance to the Pamlico River if a decision is made to locate a thermal electric generating facility on the estuary. More study is needed on the temperature tolerances of the other species.

These previously described estuaries are all in the same general region, therefore, water temperatures are practically identical. Species present in each estuary are varied so some factor other than temperature must be responsible. Changing water temperature is the primary physical factor related to seasonal changes in biomass, although there are obvious seasonal differences in irradiance. The effects of temperature and light are difficult to differentiate in the field.

Turbidity

The mean Secchi disc transparency depth for the Pamlico River was 1.2 m during 1973 and 1974. The monthly mean transparency depths reached a maximum in July of 1.6 m and a minimum in April of 0.9 m following spring rains. Transparency depths in the oligohaline area averaged 1.1 m for the year compared to 1.3 m in the mesohaline area.

Tributaries, especially the Tar River, were the most important sources of turbidity in the estuary. Following rainfall events the effects of the river's suspended sediment load were evident, especially in Stratum A where transparency values were generally lower than in the other two strata (Fig. 9). This upstream stratum had clearer water during the fall sampling periods. Fetch and resulting waves are also important in effecting the river's turbidity. As the waves move into shallower water, they stir up the sediment as their energy dissipates. The wider the reach of open water, the longer the waves from a given wind speed and hence, lower transparency values. This wind induced turbidity is more localized than turbidity from the Tar River inputs which can reduce transparency down the estuarine gradient. When the wind is blowing across the river, the side washed by the waves will have lower values than the protected side.

Steenis (1970) pointed out that macrophyte communities in the Potomac have been almost completely destroyed by increased sediments and by nutrients creating algal blooms. He also mentioned that in the upper Chesapeake Bay, heavy rains have caused very turbid waters which caused a dieback of macrophytes. Either muddy water or eutrophic condition will prevent or reduce the light penetration needed for growth by the macrophytes.

Dillon (1968) stated that Bogue Sound was turbid in warm weather and clear in cold weather. Perhaps phytoplankton density was a major factor affecting turbidity there. He did not relate turbidity to macrophyte growth patterns. The Pamlico River had early summer and fall periods of low turbidity.

The turbidity of the Currituck Sound-Back Bay area as reported by Bourn (1932) reduced light to 5% of incident at 1 m depth. This 5% transmission figure is near the compensation point for most macrophytes or bottom of the photic zone (Peltier and Welch, 1969), and few will be found at lower transmission percentages. Percentage transmission measurements were not taken on the Pamlico, but plant growth exceeded 1 m depth in all strata. Turbidity and water depth determine the percentage of the incident radiation reaching the bottom. When other physical factors are the same, a macrophyte species will grow best in an area with turbidity ranges to which it is best adapted.

Bourn also stated that the only sections of the sound that were clear and transparent were those with well established plant growth. This is due to reduced water movement in macrophyte beds with sedimentation of finer particles. This role of macrophytes in reduction of turbidity was also observed in the Pamlico River, but its effects were not widespread.

Depth

The effects of turbidity and depth are closely related and are two important factors effecting plant presence, biomass, and distribution in an area. The deeper the water, the larger the water column which light has to pass through and the smaller the quantity reaching the bottom. Light quality also changes with increasing depth. Plant presence is determined by a number of factors including the light requirements of each species.

Plant growth in the Pamlico River estuary begins at a depth of 0.3 m and extends out to a depth of 2 - 2.5 m. Harwood (1975) recorded plant growth between 0.1 and 1.6 m in the Pamlico River estuary. During the early season, transparency depths in 1973-74 were reduced below 1 m depth in all strata which may have inhibited the growth of macrophytes at depths greater than 2 m. The shallow littoral is subject to the wind tides which can push the water out of the estuary with water level dropping 0.5 m or more (Debbie Landy, personal communication). Any macrophytes which have colonized these shallow areas would be desiccated or subjected to increased wave stress.

The 2 m depth appears to be near the compensation point for macrophytes in the Pamlico River. A few scattered clumps of Najas were found at depths of 2.5 m in Blount's Bay (14 km S).

No clear zonation of species with depth was shown for the river as a whole. Potamogeton generally grew in shallower water in the 0.5 to 1.3 m range. It was usually found in large, thick clumps especially in the lower mesohaline portions of the estuary. Maximum biomass of Vallisneria was around 1 m, but it grew well throughout the 0.3 to 2 m macrophyte growth range. The other species present had highest biomass around 1 m as well. Maximum density for Najas was reported by Harwood (1975) at 1.3 m with all other species having maximum values at 0.6 m.

Bourn (1932) found pure or mixed stands of Najas, Ruppia, and Vallisneria in shallow water of 0.6 m or less. Between 0.6 and 1.2 m, stands of all species blended together. At depths greater than 1.2 m, Potamogeton pectinatus was growing alone. Very little zonation of plants was observed.

From extensive data, Sincock (1965) summarized depth-frequency relationships for submersed macrophytes in Currituck Sound-Back Bay, as shown in Table 8. Najas was the most depth tolerant species in the Currituck Sound-Back Bay area with traces down to 1.9 m. Most species fell below 10% frequency at depths greater than 1.8 m. Najas was the most depth tolerant species (2.5 m) in the Pamlico River also. All species declined in standing crop with increasing depth past 1.4 m. The study points to light penetration as the controlling factor since the decline occurred on all soils in all geographical areas.

In Bogue Sound, both density and biomass peaked at 1 m (Dillon, 1968). The vascular plant biomass peaked at 1 m while the algal biomass peaked at 1.3 m and a lower

Table 8. Relationships between depth (m) and frequency of submersed macrophytes in Currituck Sound-Back Bay. (Sincock, 1965)

Species	Depth (m)	
	Highest Frequency	Reduced Beyond
Vallisneria americana	1.0-1.2	1.7-1.8
Potamogeton pectinatus	0.6-0.7	1.0
P. perfoliatus var. *bupleuroides*	0.6-0.7	0.8-1.5
Najas guadalupensis	1.2-1.3	1.3-1.9
Ruppia maritima	0.6-0.7	1.1-1.2

peak at 0.66 m. Vascular plants, primarily *Zostera marina*, had the greatest importance value at all depths.

SUMMARY AND CONCLUSIONS

Species Distribution

1. Benthic aquatic macrophytes were generally restricted to the shallow, sandy littoral of the upper oligo-mesohaline regions of the estuary.

2. Species distribution was affected by the salinity gradient. In the oligohaline zone macrophyte communities consisted of *Vallisneria americana*, *Potamogeton perfoliatus* var. *bupleuroides*, *Najas guadalupensis*, and the muskgrasses *Chara* sp. and *Nitella* sp. Mesohaline zone species included *V. americana*, *P. perfoliatus* var. *bupleuroides*, and *Ruppia maritima*. *Ruppia maritima* was also found in sheltered low energy environments of the polyhaline zone.

3. Two species of filamentous algae appeared during the survey in nuisance proportions. *Compsopogon coeruleus*, a red alga, was found in early summer with the green alga, *Cladophora* sp., which appeared later. Their distribution was primarily controlled by wind direction.

4. Plant growth began at a depth of 0.3 m and extended out to 2 - 2.5 m in some areas. Greatest biomass was at depths of around 1 m.

5. The turbidity of this estuarine ecosystem restricts macrophytes from growing at depths greater than 2 m.

6. Wind, wave energy, and shoreline features are probably the most important factors preventing establishment of

macrophyte communities in the lower one third of the estuary.

Seasonality

1. Macrophyte growth begins in April with maximum biomass of all species in September and October.

2. Water temperatures closely paralleled air temperatures, ranging from 5° to 30°C. Maximum water temperature was measured in August with a minimum for the two years in December.

3. From May through September, *Vallisneria americana* was the dominant macrophyte. *Potamogeton perfoliatus* var. bupleuroides was dominant from October thru February, although its biomass was declining. During March and April, *Ruppia maritima* was dominant but its biomass levels were low throughout the year.

4. Variations in physical factors, especially temperature, control the seasonal dynamics of the benthic aquatic macrophytes of the Pamlico River estuary.

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