

Thomas Martin Vicars, Jr. BIOMASS AND REMOTE SENSING OF AQUATIC MACROPHYTES
IN THE PAMLICO RIVER ESTUARY. (Under the direction of Graham J. Davis)
Department of Biology, June 1976.

The purpose of this study was to determine what ecosystem functions are served by submersed aquatic plants (macrophytes) in the Pamlico River estuary of North Carolina.

Aerial photography was used successfully to map submersed plant beds. Coverage of macrophytes varied considerably during the growing season but maximum coverage was relatively stable between 1974 and 1975, especially in upstream areas. Field studies in 1974 showed that the biomass of macrophytes ranged from 2.3 - 50 g/m² organic dry weight (ODW), and total biomass in August 1975 was 22 - 100 g/m² ODW, with highest values upstream and in deep water beds. Through the combined use of aerial photography and field studies total biomass estimates were made. These estimates were 104 MT (metric tons) ODW in August 1974 and 198 MT ODW in August 1975. High biomass was related to physiography of the littoral, stable salinity and reduced wind and wave stress. Studies of plant bed distribution patterns revealed that turbidity, fluctuating water levels and currents were important factors affecting colonization. Studies of floating macrophyte debris showed that most of the aquatic plant biomass was lost to detritus between August and November. Comparatively little plant material left the area of the estuary where it was produced in the floating stage. Inorganic nutrients in aquatic macrophytes, especially phosphorus, were relatively high. Vallisneria americana Michx., the dominant species, contained 2250 μ g-at/g ODW nitrogen and 235 μ g-at/g ODW phosphorus. These values are well above those reported to be limiting for the species.

QH
541.5
E8
V5x

BIOMASS AND REMOTE SENSING
OF AQUATIC MACROPHYTES
IN THE PAMLICO RIVER ESTUARY

A Thesis
Presented to
the Faculty of the Department of Biology

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts in Biology

by
Thomas Martin Vicars, Jr.

June 1976

558964

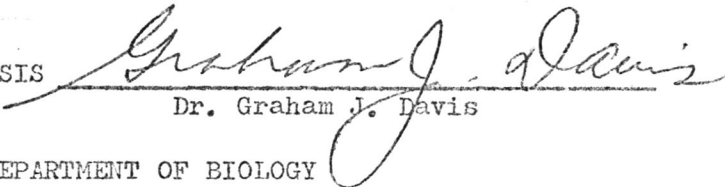
BIOMASS AND REMOTE SENSING
OF AQUATIC MACROPHYTES
IN THE PAMLICO RIVER ESTUARY

by

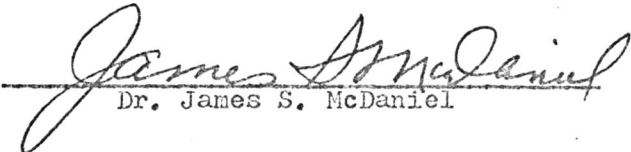
Thomas M. Vicars Jr.

APPROVED BY:

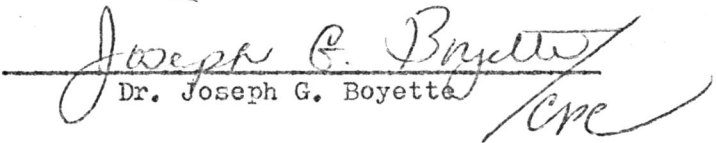
SUPERVISOR OF THESIS


Dr. Graham J. Davis

CHAIRMAN OF THE DEPARTMENT OF BIOLOGY


Dr. James S. McDaniel

DEAN OF THE GRADUATE SCHOOL


Dr. Joseph G. Boyette

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Dr. Graham J. Davis, my thesis supervisor, who guided me through this project and made my thesis possible. I would also like to thank the other members of my thesis committee, Drs. Mark Brinson, Charles O'Rear, Richard Stephenson, and Clifford Knight, for their constructive suggestions.

Craig Zamuda, Pete Kornegay, Kurt Getsinger, Dave Davis, Chuck Durham and David Bradley graciously donated equipment or their time to the completion of the field work. Their help is deeply appreciated.

This research was supported in part by the Water Resources Research Institute of The University of North Carolina and the United States Department of Interior (Project No. A - 077 - NC).

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES.	iv
LIST OF FIGURES	vi
INTRODUCTION.	1
<u>Study Area</u>	4
MATERIALS AND METHODS	11
<u>Field Studies - 1974</u>	11
<u>Field Studies - 1975</u>	15
<u>Aerial Photography</u>	17
<u>Floating Plant Study</u>	19
<u>Nutrient Analysis.</u>	20
RESULTS AND DISCUSSION.	22
<u>Aerial Photography</u>	22
<u>Physical Data.</u>	28
<u>Biomass Studies.</u>	32
<u>Diversity.</u>	40
<u>Total Estuarine Biomass.</u>	44
<u>Weight Relationships of Macrophytes.</u>	46
<u>Patterns of Submersed Plant Bed Distribution</u>	48
<u>Floating Plant Studies</u>	62
<u>Nutrients in Aquatic Macrophytes</u>	68
<u>Filamentous Algae.</u>	83
SUMMARY	91
LITERATURE CITED.	95
APPENDIX	99

LIST OF TABLES

	<u>Page</u>
1. Aerial photography obtained during flights over the Pamlico River estuary.	18
2. Accuracy and precision tests of panchromatic photography . . .	24
3. Summary of plant bed areas (ha) from four flights over the littoral of the Pamlico River estuary.	26
4. Annual means of hydrographic data from the Pamlico River estuary study area July 1974 through June 1975	29
5. Summary of transect data for aquatic macrophytes in the Pamlico River estuary during 1974	33
6. Species composition of aquatic macrophytes in the Pamlico River estuary in August 1974	37
7. Biomass and species composition of aquatic macrophytes in the Pamlico River estuary in August 1975	38
8. Diversity indices of aquatic macrophytes in the Pamlico River estuary in August 1974	41
9. Diversity indices of aquatic macrophytes in the Pamlico River estuary in August 1975	42
10. Estimated total biomass of rooted aquatic macrophytes in the Pamlico River estuary obtained with aerial photography and ground truth methods	45
11. Weight relationships of aquatic macrophytes in the Pamlico River estuary.	47
12. Index of clumping for <u>Vallisneria americana</u> within different bed types in Blount's Bay.	52
13. Seasonal and spatial distribution of floating macrophyte debris in the Pamlico River estuary during 1974 - 1975	65
14. Storm-induced changes in the concentration and distribution of floating macrophyte debris in Blount's Bay.	67
15. Nitrogen content of aquatic macrophytes in the Pamlico River estuary in August 1975	69

	<u>Page</u>
16. Phosphorus content of aquatic macrophytes in the Pamlico River estuary in August 1975	70
17. Biomass and nutrients in aquatic macrophytes in the Pamlico River estuary, August 1975	84
18. Biomass of <u>Compsopogon coeruleus</u> in the Pamlico River estuary during August 1974	85
19. Biomass estimates of nuisance algae in the Pamlico River estuary.	86
20. Standing crop and inorganic nutrient concentrations of <u>Cladophora glomerata</u> and <u>Vallisneria americana</u> during a bloom at km 21 S on the Pamlico River estuary, August 1975	88
21. Comparison of maximum submersed plant biomass in 1974 and 1975 as measured by two different methods	102
22. Sampling intensity needed for detecting year to year biomass changes with 95% confidence.	104

LIST OF FIGURES

	<u>Page</u>
1. The northern and central coastal regions of North Carolina .	6
2. The Pamlico River estuary.	8
3. Locations of transects in the Pamlico River estuary used in the 1974 biomass studies.	13
4. Upper - Mean water temperature in the littoral of the Pam- lico River estuary during 1974-75. Middle - Mean Secchi depth in the littoral of the Pamlico River estuary during 1974-75. Lower - Salinity in the littoral of the Pamlico River estuary during 1974-75	31
5. Aerial photograph depicting the two photographic images designated as "shallow" and "deep" bed types (indicated by arrows).	51
6. Aerial photograph taken from 1333 m altitude at km 14 S (23 October 1974).	55
7. Aerial photograph taken from 666 m altitude at km 29 N (10 September 1975).	57
8. Aerial photograph of "halo" circular beds from 666 m altitude in Blount's Bay (km 13 S)	60
9. Upper - Mean seasonal catch of floating material and total macrophyte biomass on the north shore of the Pamlico River estuary, August 1974. Lower - Mean seasonal catch of floating material and total macrophyte biomass on the south shore of the Pamlico River estuary, August 1974. . . .	64
10. Nitrogen:phosphorus ratios for <u>Vallisneria americana</u> in the Pamlico River estuary.	74
11. Upper - Biomass of <u>Vallisneria americana</u> in the Pamlico River estuary, August 1975. Middle - Nitrogen content of <u>Vallisneria americana</u> in the Pamlico River estuary, August 1975. Lower - Phosphorus content of <u>Vallisneria americana</u> in the Pamlico River estuary, August 1975.	76
12. Upper - Biomass of <u>Potamogeton perfoliatus</u> in the Pamlico River estuary in August 1975. Middle - Nitrogen content of <u>Potamogeton perfoliatus</u> in the Pamlico River estuary in August 1975. Lower - Phosphorus content of <u>Potamogeton</u> <u>perfoliatus</u> in the Pamlico River estuary in August 1975. . .	79

Page

13. Upper - Biomass of Najas guadalupensis in the Pamlico River estuary, August 1975. Middle - Nitrogen content of Najas guadalupensis in the Pamlico River estuary, August 1975. Lower - Phosphorus content of Najas guadalupensis in the Pamlico River estuary, August 1975 82

INTRODUCTION

In understanding an ecosystem one must know the diversity and relative importance of food sources as well as the distribution of inorganic nutrients in living and non-living components. This research was designed to study these parameters for the submersed aquatic plants (macrophytes) of the Pamlico River estuary.

Perhaps the most important function of aquatic plants is their role as a food source. Plant biomass lost through senescence, leaf breakage or uprooting can be digested and utilized by microorganisms which are, in turn, eaten by other organisms in the detrital food web. Food from macrophytes may also move through higher trophic energy levels by direct feeding on the plants by waterfowl, fish and invertebrates. In both waterfowl feeding and grazing by fish, cellulose, an important ecosystem food, is returned mainly undigested to the detrital system.

The aquatic plant component of an ecosystem also serves as a source and sink for inorganic nutrient elements, taking up nutrients during the growing season and recycling them during the annual die-back.

Plant beds also shelter smaller fish and invertebrates reducing predation in addition to shading the sediment and providing a diversity of microhabitats. The plant's physical structure functions as a substrate for epiphytes and invertebrate populations.

The objective of this study was to determine what, if any, ecosystem functions are served by aquatic macrophytes in the Pamlico River estuary. Specific objectives were to:

- (1) estimate the maximum seasonal biomass of submersed aquatic plants
- (2) study the distribution patterns of plant beds in the estuary and

some physical factors associated with these patterns

(3) study the distribution and biomass of nuisance filamentous algae

(4) determine the seasonal and spatial distribution of floating macrophyte debris resulting from senescence and death and,

(5) investigate the importance of aquatic plants as sources and sinks of inorganic nutrients.

An estimate of seasonal maximum (terminal) biomass might be a reliable measurement of the contribution of aquatic plants to the detrital food web. However it should be remembered that, in some cases, terminal biomass may be an underestimate of net primary productivity unless factors such as turnover rates, direct feeding losses and seasonal coverage fluctuations are considered. In earlier work on the Pamlico River estuary Reed (1976) found that most of the aquatic plant biomass enters the detrital decay system either as senescing leaves during the growing season or as uprooted plants, especially during fall storms at the end of the season. Notable exceptions are some grazing by waterfowl and fish. In isolated beds of Potamogeton perfoliatus var. bupleuroides (Fern.) Farw. (redheadgrass), leaves are stripped but midribs remain intact.

Harrison and Hobbie (1974) reported that the detrital pathway is apparently more important than direct feeding on phytoplankton by herbivores in the Pamlico River estuary. It has been suggested by Copeland and Hobbie (1972) that rooted aquatic macrophytes may form an important food source as detritus here, as compared to other estuaries, in that there are few marshes and these are not regularly flooded. In order to determine the magnitude of this source, terminal biomass estimates were made through the combined use of remote sensing (aerial photography) of submersed plant

beds and classical transect and quadrat techniques in the field (ground truth).

Remote sensing has only recently been applied to the analysis of estuarine or other coastal waters. The use of aerial photography for studying submersed plants has progressed from cameras suspended from a balloon (Edwards and Brown 1960) to sophisticated analytical techniques of color, as exemplified by Lukens (1968), and multispectral sensing (Gustafson and Adams 1973, Wezernak and Lyzenga 1975). In most cases, however, the methods have involved complicated analyses with expensive instrumentation which are just now beginning to be adapted to study of large areas. This study emphasizes unencumbered aerial photography as a tool for mapping submersed plant beds. This approach is relatively rapid, accurate and economically feasible. The resulting data helps develop the biomass estimates and provides information on the distribution patterns of submersed plant communities.

Localized but dense growths of filamentous algae in the estuary have caused some public concern by disrupting fishing and retarding recreational use. Compsopogon coeruleus (Balbis) Mont. and Cladophora glomerata (L.) Kutz. were the two most important species affecting public use of the estuary. Therefore studies of the distribution, biomass accumulation and nutrient composition of these species were undertaken to study the magnitude and possible causes of these nuisance growths.

Once the biomass of macrophytes and filamentous algae has been determined, it becomes important to know when and where this release of organic matter and nutrients to the detrital food web takes place. An important part of this research deals with the distribution and production of recently

shed plant biomass that floats in the estuary and soon becomes detritus. The emphasis is placed on seasonal changes in the abundance and distribution of floating plant debris. Through the special netting techniques it may be possible to estimate relative seasonal rates of debris production and locate the area and timing of detritus production from aquatic plant biomass.

Tissue analysis has been widely used as a measure of nutrient availability for aquatic plants (Gerloff 1975). This approach is based on the assumption that the concentration of an element in plant tissue varies over a wide range which is dependent on its concentration in the environment. Tissue analysis has been used also in an attempt to explain variations in plant distribution (Misra 1938) and as indicators of changes in water quality (Adams et al. 1973). In addition, inorganic nutrient levels are important in considering aquatic macrophytes for possible commercial uses (Boyd 1970). The tissue analysis approach was used here to determine possible correlations of tissue nutrients in aquatic plants with known water quality trends. Along with the biomass data the nutrient levels can help define the quantitative role played by macrophytes in the storage and release of nutrients.

Study Area

The Pamlico River estuary extends 60 km from its confluence with the Tar River at Washington, North Carolina (Figs. 1 and 2) to Pamlico Sound. The Tar River drains about 8000 km² of forests and farmland from the Piedmont through the Coastal Plain. The estuary has been classified as a natural, temperate, oligohaline system by Odum and Copeland (1974). Prominent characteristics of this system are a saltwater shock zone, seasonal programming of temperature, migrating fish populations and gradients of wave stress,

Fig. 1. The northern and central coastal regions of North Carolina.

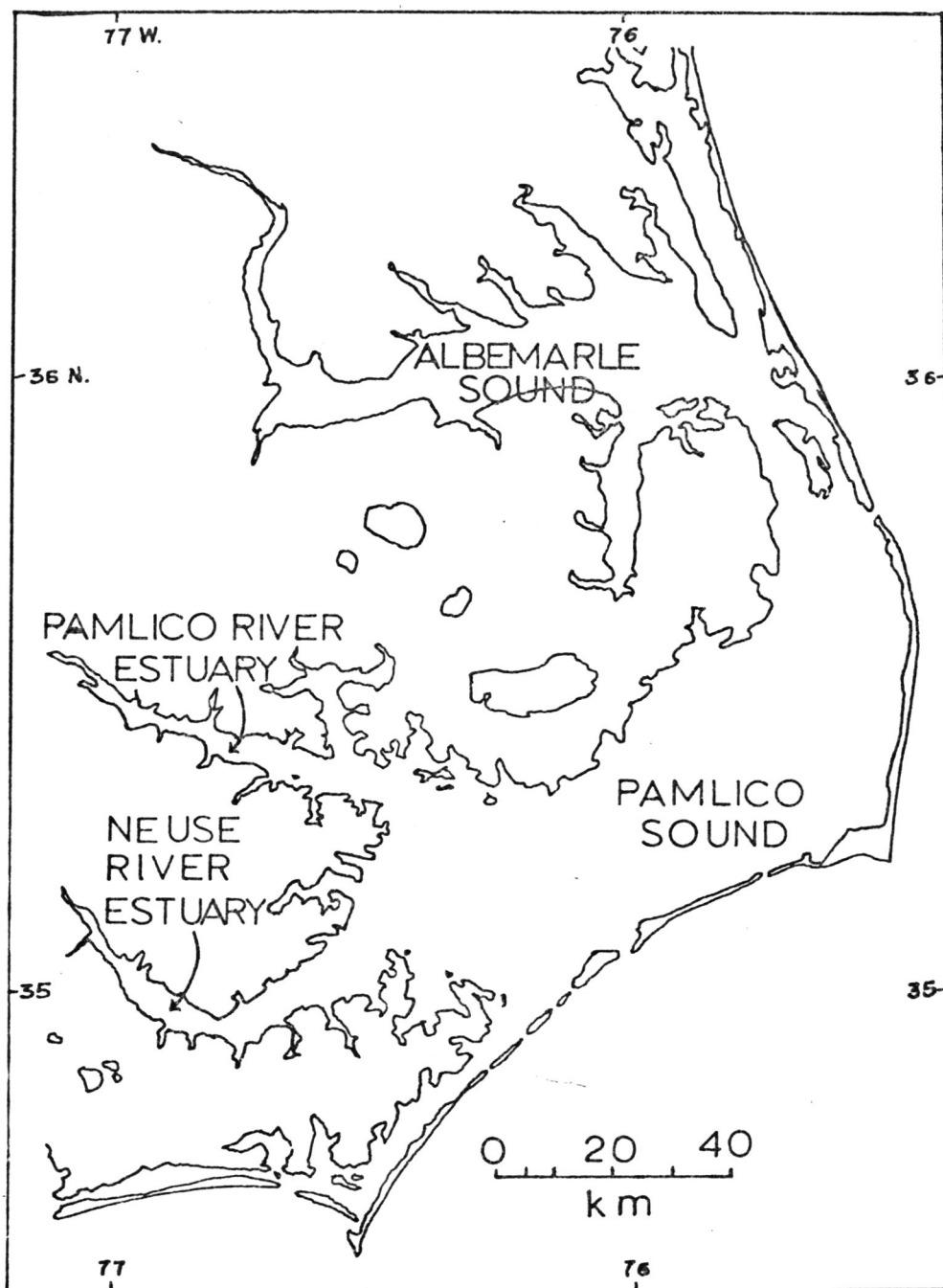
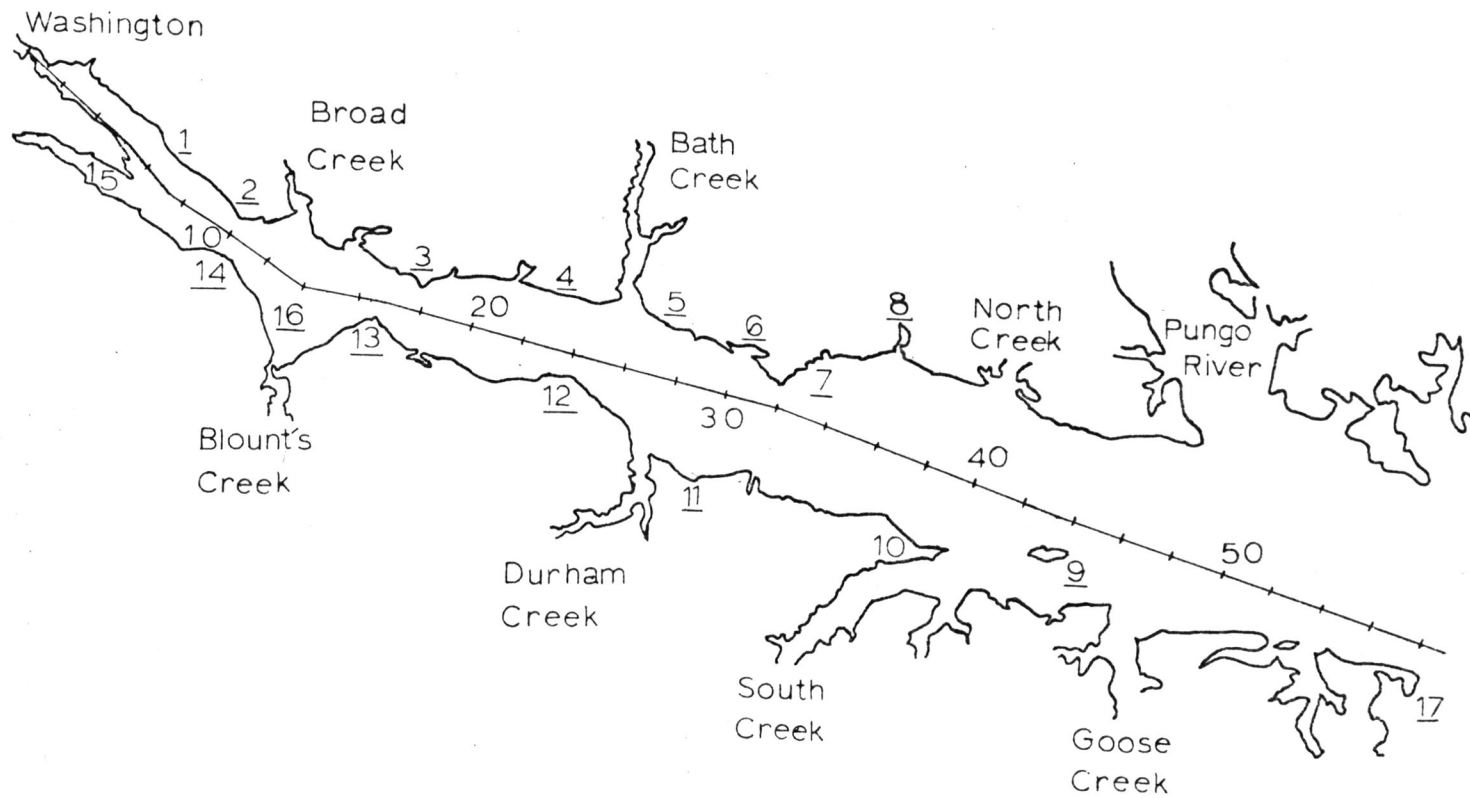


Fig. 2. The Pamlico River estuary. River km as shown begin at the Pamlico River estuary - Tar River confluence and generally follow channel markers. Locations: 1 - Austin Pt., 2 - Broad Creek Pt., 3 - Ragged Pt., 4 - Hawkins Ldg., 5 - Bayview, 6 - Mixon Creek, 7 - Gaylord Bay, 8 - St. Clair Creek, 9 - 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.



turbidity and nutrients.

Salinity is controlled by several factors, the most important being Tar River discharge and mixing by wind and resultant wave energy. However a well-defined salt wedge is not present at all times, especially during low river flow. Prevailing winds over the estuary are southwest during the summer and northeast during winter.

Turbidity in the estuary is influenced largely by discharge from the Tar River which is also the source of most of the estuary's nitrogen (Harrison and Hobbie 1974). Estuarine phosphorus levels are high and constitute an abnormal gradient in association with phosphate mining activities (Texasgulf, Inc.) on the south shore (Fig. 2, km 29 S).

Sediments in the littoral of the estuary are mainly coarse sands, with finer silty particles predominating in deeper portions. However in Blount's Bay (Fig. 2) the substrate is silty throughout. Settling of suspended matter from slowed river flow results in the deposition of a good portion of the Tar River's sediment load in this area.

Phytoplankton blooms, mainly of the dinoflagellate Peridinium triquetrum, occur in the upper and middle reaches of the estuary in the winter and appear to be associated with higher levels of nitrate in the water (Hobbie 1971). Phytoplankton growth in the upper estuary may be limited by turbidity; productivity has been estimated to be $40 - 80 \text{ g C/m}^2/\text{yr}$ (Crawford et al. 1974).

Previous research on the submersed aquatic plants in the estuary was by Harwood (1975) and Reed (1976). In studies of the distribution and seasonal dynamics of the macrophytes they found the major species was Vallisneria americana Michx. (wild celery). Smaller amounts of P. perfoliatus,

Ruppia maritima L. (widgeongrass), and Najas guadalupensis (Spreng.) Magnus (southern naiad) were present in particular areas. Two genera of Charophytes (Chara spp. and Nitella spp., muskgrasses) made up a minor portion of the plant biomass but are included in studies of the vascular plants here. Harwood and Reed found that the submersed plants were limited to the upper two-thirds of the estuary and exhibited the expected seasonal fluctuations in biomass characteristic of temperate regions.

Textual Note: Locations in the text are cited according to the following example: (km 29 S). This notation designates a point on the shoreline of the south shore of the estuary 29 km (by channel of river) downstream from the U. S. 17 highway bridge at Washington, North Carolina (See Fig. 2).

MATERIALS AND METHODS

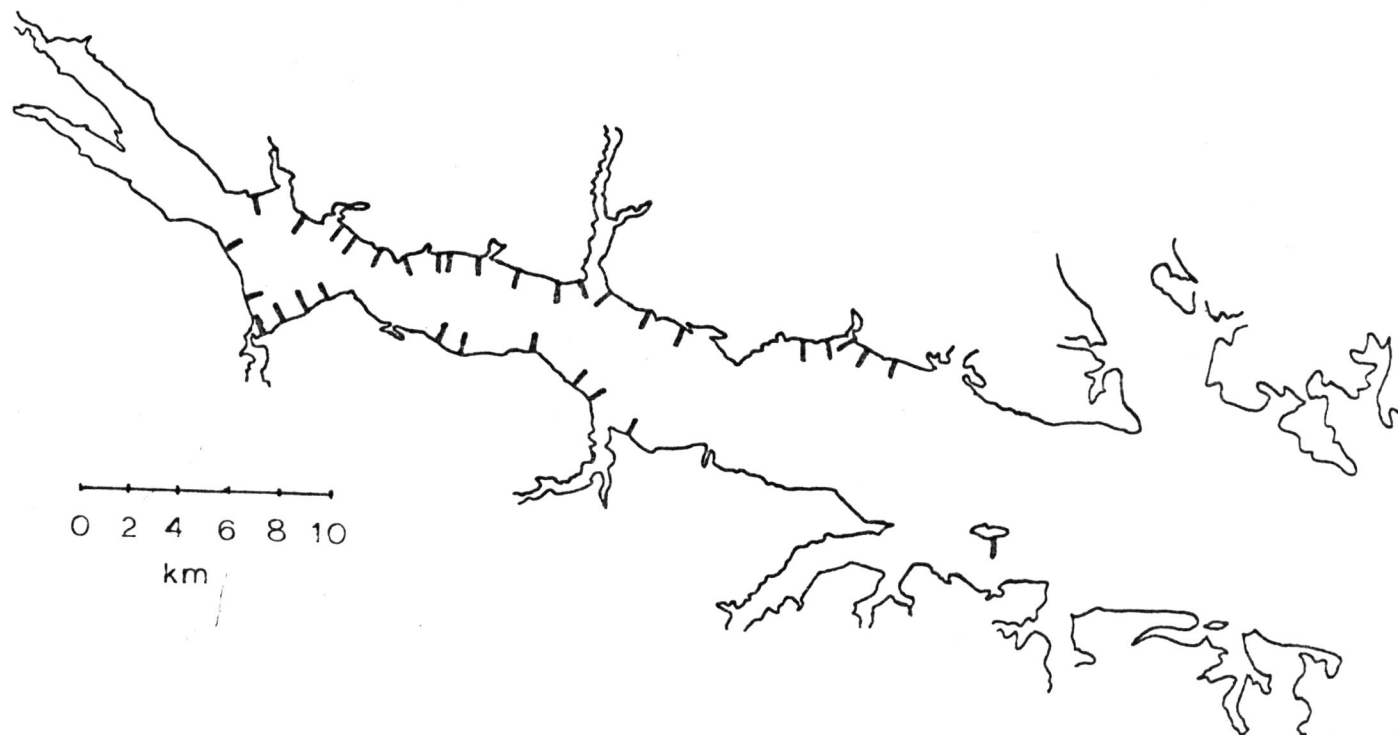
Field Studies - 1974

Field surveys were conducted during July and August of 1974 to provide ground truth on plant density and biomass. Preliminary aerial photography allowed comparison of plant distribution to the previous years' observations (Harwood 1975, Reed 1976) in order to stratify the study area. Plants were found as far downstream as Indian Island (km 43 - 44). The study area extended from Blount's Bay (km 10 - 16 S) to Texasgulf (km 30 S) on the south shore, including an extensive bed of Ruppia maritima L. on the leeward (south) side of Indian Island. On the north shore of the estuary the study area extended from Broad Creek Pt. (km 10 N) to the eastern limit of plant beds at North Creek (km 38 N).

For analytical purposes each shore of the estuary was divided into several strata that appeared to represent areas of homogenous salinity, shoreline configuration, and wave action. For example, Blount's Bay (Fig. 2) was divided into two strata, East and West, on the basis of shoreline orientation with respect to prevailing winds. Five random points on the shoreline of each of the eight major strata were chosen for line transects (Fig. 3) which ran perpendicular to the shoreline across the plant beds. Only one transect was studied at Indian Island. The numbers of each species of macrophytes rooted within a 0.1 m^2 quadrat frame placed every 2 m along the transect were recorded. Transects began at a random point less than 20 m from shore and ended at the deepest limit of plant growth.

To get biomass data weights of different species and size classes of plants counted in the field were determined. On the basis of aerial photographic images of the plant beds each stratum was subdivided for the col-

Fig. 3. Locations of transects in the Pamlico River estuary used in the 1974 biomass studies.



0 2 4 6 8 10
km

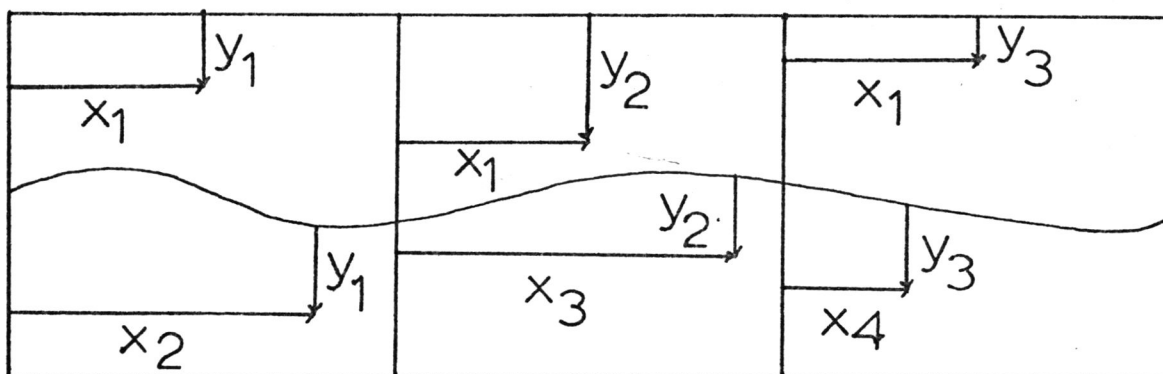
lection of 100 plants of each species recorded in the area characterized by a particular image type. The location for plant harvesting within each substratum was selected at random. Therefore plants (including roots and rhizomes) were harvested at 35 sites. The harvested material was washed thoroughly in the laboratory with a jet of water to remove adhering sand and loosely-bound epiphytes. Fresh weights were recorded on the 100 plant bundles after a 5 min spin in a domestic washing machine. Well mixed portions of fresh material (approximately 25 g) were then dried to constant weight at 80°C and weights recorded. Portions of the dry material were ashed at 500°C in a muffle furnace for 3 h and the decrease in weight was recorded as organic dry weight (henceforth referred to as ODW). Thus a factor for ODW/100 plants was derived for each species in each substratum and was used later to convert plant density (plants/m²) to biomass (ODW/m²).

Field studies included biomass sampling for nuisance filamentous algae as well as rooted vascular plants. The most important algal species in 1974 was Compsopogon coeruleus (Balbis) Mont. The biomass of C. coeruleus in July and August of 1974 was determined concurrently with aforementioned transects. Before the density of rooted macrophytes within the 0.1 m² quadrats was determined, all C. coeruleus within each quadrat was carefully removed by hand and "squeeze-dried" until water failed to drip. The volume of the collected alga was determined by water displacement in a graduated cylinder. Each month C. coeruleus samples were taken to the laboratory and the displacement measurements were calibrated by determining fresh, dry and organic dry weights as for the vascular macrophytes. Fresh weight was linearly correlated with water displacement giving the basis for biomass

estimates. Biomass of each stratum is reported as mean ODW (g/m^2); the total biomass calculations assumed that C. coeruleus was distributed throughout the total area of the plant beds as delimited with aerial photography. This assumption probably overestimated the areal distribution of the alga within the plant beds, but also omitted that portion of the biomass drifting in deeper water as well as that windrowed on the shore.

Field Studies - 1975

The ground truth data obtained in 1974 was density-dependent in that extrapolations were in terms of density with relatively little biomass harvested. In 1975 a direct harvesting method was employed without extrapolation in conjunction with a stratified systematic unaligned sampling model (Smartt and Grainger 1974). The strata used in 1974 studies were subdivided again according to photographic image into substrata of approximately equal areas. Sample sites were located with a rangefinder according to predetermined coordinates. The diagram below shows a major stratum divided into six substrata and the coordinates for one sample in each substratum. Multiple samples were obtained by replication of the coordinate choosing process.



All of the submersed plants rooted within 0.25 m^2 quadrats were dug up at locations in 54 substrata of the study area. Also in 1975 Chocowinity

Bay (km 3 - 6 S) and the region upstream from Broad Creek Pt. (km 10 N) were included in the study area so that results represented the entire estuarine community. The number of samples taken in each substratum was determined by allocation to achieve confidence intervals similar to the 1974 sampling in the same area. It is felt that the 1975 biomass data were more accurate than the 1974 data even though the 1975 data were consistently higher.

Fresh weight, dry weight and ODW for each rooted plant species in each substratum were determined by procedures established in 1974 studies and were carried out on randomly selected duplicate samples. During the August 1975 sampling, C. coeruleus that was found within the quadrats harvested for rooted macrophytes was also collected. Fresh weight, dry weight and ODW were determined directly for some samples with extrapolation from fresh weight for the rest.

The most important species of filamentous algae in the estuary in 1975 was Cladophora glomerata (L.) Kutz. Biomass measurements of this species on 20 August were simplified because of its limited distribution along a 2 km stretch on the south shore (km 20 - 22 S). Only insignificant quantities of C. glomerata were found outside the area of this "bloom." Scissors were used to harvest 21 random quadrats by cutting thick filaments from the surrounding submersed mat that sometimes approached a meter in thickness. Three transects perpendicular to the shoreline mat were located at random along the beach. Biomass was collected in five 0.25 m^2 quadrats spaced 1 m apart. Smaller quadrats were harvested in the shoreline mat than were used in the submersed mats (0.5 m^2) because of the tremendous amounts of C. glomerata and detached Vallisneria americana Michx. leaves

concentrated in this mat by a previous northeast wind storm. The harvested material was returned to the laboratory where fresh weight, dry weight and ODW were determined. In addition, the shoreline mat samples were separated into C. glomerata and V. americana leaves.

The area occupied by this bloom was estimated by measuring the distance from the shoreline to the deeper edge of the submersed mats with a rangefinder at 16 points 95 m apart throughout the length of the bloom. A map of the bloom was drawn to scale on graph paper and the total area determined by planimetry.

Aerial Photography

The aerial photography was accomplished within 2 wk after completion of the field surveys each month. A North Carolina Forest Service plane was contracted for several flights over the estuary (Table 1). The plane was equipped with a camera port in the bottom of the fuselage to which a padded frame was adapted for the use of 35 mm cameras. Flight lines followed the shoreline closely so that the plant beds were visible within the 35 mm format. In areas where the shoreline bent sharply the pilot looped the bend to prevent excessive tilt in the nearly vertical photographs. The flights on 15 June and 2 July 1974 were basically to check plant distribution and the feasibility of the adapted camera system.

Subsequently various film/filter combinations were checked, including tests at various altitudes, to determine an optimum system for water penetration. These are summarized in Table 1. Flights were always on clear, nearly cloudless days between 1 and 4 h after sunrise. Timing of flights was important in that well-planned flights considerably reduced effects of wind-induced wave action, sun glint and atmospheric haze, all of which

Table 1. Aerial photography obtained during flights over the Pamlico River estuary.

Date	Film	Filter	Altitude (m)
15 June 1974	Daylight Ektachrome	1A	600
2 July 1974	Daylight Ektachrome	1A	600
	Panchromatic	1A, P ^a	600
19 July 1974	Panchromatic	1A, P	666 ^b
	Kodachrome 7256 (16 mm)	1A	666
	Kodak SO - 224	Wratten 4	666
29 August 1974	Panchromatic	1A, P	666 ^b
	Panchromatic	1A, 85, 81A, 80C	666
23 October 1974	Panchromatic	1A, P	666 ^b , 1000, 1333
	Daylight Ektachrome	1A, P	666, 1000, 1333
10 September 1975	Panchromatic	1A, P	1000 ^b
	Panchromatic	1A, Wratten 25A	1000

^aP is a polarizing filter.

^bIndicates the photography used for areal measurements of plant beds

obscured visibility of the submersed plant beds.

The panchromatic film used for areal measurements was developed to prints (8 x 10) and plant bed areas determined by planimetry of uncontrolled mosaics (Avery 1968). Small plant beds were measured with a modified acreage grid. Stereoscopic pairing of the prints was not significantly better than careful alignment by eye with reference points on each photograph. Complete coverage of the study area required approximately 300 prints and stereoscopic viewing was deemed unnecessary for preparing the strip maps. Therefore only 20% overlap was necessary for the aerial photographs as compared with 60% overlap required for stereoscopic analysis. With the exception of the 16 mm Kodachrome all photography was with 35 mm Nikon and Nikkormat cameras, the best water penetration being attained when the film was slightly overexposed.

Floating Plant Study

Decay bag experiments (Zamuda 1976) showed that macrophyte leaves and uprooted plants would float for four or five days. Hence a surface netting technique would approximate an instantaneous rate of production of debris relative to an annual cycle. A 1 mm mesh net on a 1.0 m by 0.75 m frame was adapted to the bow of the 17 ft research boat. The frame could be raised at will and extended approximately 30 cm below the water surface when lowered into operating position.

The area studied was the same as for the 1974 biomass studies. Each major stratum was divided into three substrata for separate sampling: 1) within plant beds, 2) deeper water just beyond the plant beds and 3) mid-river. Of course, these areas could not be rigidly separated, but sampling areas were located far enough apart to insure that no overlap occurred.

The entire area was sampled monthly from July 1974 through February 1975 except in September and December. Netting times in each substratum ranged from 10 - 30 min with a constant speed throughout of about 5 knots. Netting times were varied to accommodate various sizes of the substrata.

Correlation of the fresh weight of macrophyte debris caught with netting time in both high ($y = 10.45x - 8.88$, $r = 0.93$) and low ($y = 1.54x - 22.92$, $r = 0.88$) floating biomass periods showed this method to be adequate when netting times were 10 - 30 min. Statistical tests showed that the correlation coefficients (r), but not the y - intercepts (-8.88 and -22.92), were significantly different from zero ($p < .05$). The correlation was most intense with netting times of 10 - 30 min.

The coarse particulate debris caught in the net was returned to the laboratory in river water in buckets, separated into species, washed, spun dry and weighed. Dry weights and ODW for floating debris samples were not determined. Results were expressed in grams of fresh weight caught per minute effort (g/min) and represent relative "concentrations" of macrophyte debris.

Nutrient Analysis

Tissue analysis was performed on every sample taken for dry weight and ODW in the biomass study of August 1975. No separation of vascular plant material into plant parts was made. Nutrient analysis data presented here is based on at least two samples for each species in each substratum. Analysis for nitrogen was on oven-dried samples with a Coleman Model 29 Nitrogen Analyzer. Phosphorus analyses were on portions of the same material used in the nitrogen analyses. Plant material that had been ashed for 3 h at 500°C in a muffle furnace was digested and filtered (Snell and

Biffen 1944) and total phosphorus was determined as orthophosphate in the filtrate by the ascorbic acid method (APHA 1971). All nitrogen and phosphorus concentrations are reported as microgram-atomic weights of the element per gram ODW ($\mu\text{g-at/g ODW}$). These units approximate the relative importance of nitrogen and phosphorus as nutrients for plant growth, and are not merely amounts of nutrient per gram of dry weight.

RESULTS AND DISCUSSION

Aerial Photography

Good water penetration and plant bed resolution was obtained with most of the film/filter combinations in Table 1. The 1A filter and the polarizer were invaluable in reducing haze and reflected light from the water surface. Without these aids resolution of the submersed beds was significantly reduced. The use of filtered color film in mapping the beds was rejected for two reasons: 1) prohibitive costs for development of color negatives to prints for accurate measurements, and 2) high sensitivity of color film to blue light, resulting in "fogging" of the transparencies by scattered light from the water. Use of the color film with the minus blue filter (Wratten 25A) was not tried, but it has been reported (Kelly 1971) to resolve submersed Zostera marina beds in turbid coastal waters. Superior resolution and contrast of deep water (1.5 - 2.0 m) beds was obtained in August 1975 with panchromatic film and the minus blue filter despite generally higher turbidity than on previous flights. The 16 mm Kodachrome movie film gave good penetration and excellent contrast but presented unique problems for mapping.

The Kodak SO-224 film was obtained from Eastman Kodak as an experimental film. It was developed for coastal water photography (Specht et al. 1973) and designed without a blue-sensitive emulsion layer. This film had been tested in tropical waters to depths of 100 ft with excellent results but in this study of turbid Pamlico waters, the results were no better than with regular Ektachrome. Resolution of submersed beds was diffuse especially in areas of low biomass. This film did, however, show excellent response to suspended matter in the water. Plumes from several creeks were shown

in black against the purple estuarine water lower in suspended matter.

The October 1974 flight included test photography at higher altitudes than were normally used for mapping. These experiments showed that good penetration and resolution were possible at higher altitudes with both panchromatic and color film. Some small circular beds ($8 - 10 \text{ m}^2$) were not resolved at 1333 m but area measurements of large plant beds at all altitudes showed no significant differences overall.

Table 2 presents results from analysis of the panchromatic photography for accuracy and precision. The scale of the photographs was calculated from measurements of ground features (usually piers) in seven locations throughout the estuary. Standard errors of the scale measurements were quite small considering that the photography was from a light plane subject to wind drafts. Maximum image displacement was also acceptable. Using the 35 mm format it may be expected that lens distortion is greater than in larger aerial cameras. However the plant beds were positioned near the center of the frame to reduce these effects. The overlap of adjacent photographs also allowed areal measurements to be made nearer the center of the photographs where image displacement was considerably reduced. Two successive passes were made over selected stretches (2 - 4 km) of the plant beds to determine the precision of the entire photogrammetric process. The data show that this simplified small format method can be adequately used to map submersed plant beds.

Using the panchromatic film (black/white), submersed plant beds were always accurately identified on the basis of tone and texture. Texture also provided for differentiation of two bed types: a granular mottled texture characterized shallow water beds with low growth profiles, and smooth

Table 2. Accuracy and precision tests of panchromatic photography.

Date	Scale	SE ^d	MID ^a	Planimetry ^b	Precision ^c
19 July 1974	1:1280	2.5	1.1	0.87	1.33
29 August 1974	1:1464	2.3	2.2	0.74	1.76
23 October 1974	1:1112	1.2	0.8	0.80	1.20
10 September 1975	1:4572	1.8	1.0	0.89	2.04

^a MID = maximum image displacement in mm that results from tilt in camera, lens distortion and parallax

^b 95% confidence interval of repeated measurements, expressed as a percent of the mean

^c The difference in measured plant bed area from two successive passes over a selected area, expressed as a percent of the mean

^d SE = standard error (here and throughout paper), expressed as a percent of the mean in this table

continuous textures defined deeper beds with leaves up to 1.5 m in length. The shallow clumped beds usually were lighter in tone, the image obviously being influenced by bottom characteristics in the shallow water. Plant bed types and gross growth patterns determined with aerial photography are discussed more fully later in this section.

Positive transparencies of several aerial photographs including both major bed types were made and subjected to optical density (O.D.) analysis with a Canalco microdensitometer. The mean O.D. of the deep continuous beds was 0.73 and that of the shallow clumped beds was 0.46 (The O.D. is based on a relative scale with the darkest spot on the photograph assuming an O.D. of 1.00). These two values were significantly different ($p < .05$). However, no correlation could be obtained between biomass and O.D., even after subtraction of effects caused by attenuation of light in the water column itself. This was accomplished with measurements of O.D. of a transparency showing no submersed beds at several points representing various water depths. It is felt that the combined effects of substrate differences, species composition and reflectance of different leaf forms and lengths mask any significant relationship between O.D. and biomass.

Submersed plant bed areas for each stratum and bed type are given in Table 3. Results for the three flights in 1974 indicate sizable changes in plant cover during the growing season. This was due primarily to extensive vegetative propagation by Vallisneria americana Michx. Significant increases in bed area in only one month (July 1974 to August 1974) were apparent for most of the strata. Turbidity may have obscured resolution of some deeper beds in Blount's Bay (km 10 - 16 S) and caused the slight decrease in area shown.

Table 3. Summary of plant bed areas (ha) from four flights over the littoral of the Pamlico River estuary.

Area	19 JUL 74	29 AUG 74	23 OCT 74	10 SEP 75
North Shore				
U.S. 17-Broad Creek Pt.	-	-	-	11.38 ^b
Broad Creek Pt.-Ragged Pt.				
Shallow	36.68	5.32	0	3.51
Deep	15.05	59.80	27.82	50.16
	(51.73)	(65.12)	(27.82)	(53.67)
Ragged Pt.-Hawkins Ldg.				
Shallow	13.67	18.77	0	13.75
Deep	18.24	23.88	38.75	33.82
	(31.91)	(42.65)	(38.75)	(47.57)
Hawkins Ldg.-Mixon Creek	22.60	21.75	10.48	25.02
Gaylord Bay-Mixon Creek	0.04	0.10	0	0
South Shore				
Chocowinity Bay-Hill's Pt.	-	-	-	20.34 ^b
Blount's Bay - West				
Shallow	18.18	19.60	0	22.93
Deep	18.29	31.06	38.43	27.23
	(36.47)	(50.66)	(38.43)	(50.16)
Blount's Bay - East				
Shallow	34.81	25.59	1.14	29.97
Deep	29.06	32.57	48.78	33.67
	(63.87)	(58.16)	(49.92)	(63.64)
Maul's Pt.-Core Pt.				
Shallow	29.94	58.20	0	30.68
Deep	60.76	51.33	73.74	64.41
	(90.70)	(109.53)	(73.74)	(95.09)
Core Pt.-Texasgulf				
Shallow	10.93	11.25	6.15	7.80
Deep	7.40	11.41	9.23	9.70
	(18.33)	(22.66)	(15.38)	(17.50)
Indian Island	3.18	0.97	0	0
North Shore Total	106.28	129.62	77.25	137.64
South Shore Total	212.55	241.98	177.47	246.73
River Total	318.83	372.60	254.72	284.37

Note: Parentheses give totals for shallow and deep beds in a stratum.

^b Due to high turbidity in these areas aerial photography was inadequate. These figures were calculated from ground surveys and estimates of cover.

A great decrease in area occurred in the Ruppia maritima L. beds off Indian Island (km 43 - 44) during the sampling period. These beds as well as the R. maritima beds in the Gaylord Bay-North Creek stratum (km 33 - 38 N) had disappeared by October of that year and failed to return in 1975. A similar situation was reported for Ruppia maritima var. obliqua in Florida (Phillips 1960) in which the species was shown to be sensitive to water temperatures above 30°C. It is possible that when the summer temperatures in the Pamlico River stabilized in August at 30°C or above vegetative growth was inhibited or thermal death of rhizomes occurred and the beds were eventually disrupted by turbulence or fluctuating water levels. That these beds failed to return in 1975 could be attributed to early destruction of the seed source in 1974 and loss of a major portion of the vegetative propagules. Salinity fluctuations are unlikely explanations because this species has been reported in borax lakes (Wetzel 1964) and in Texas estuaries up to 45 ‰ (Simmons 1957).

Between the August and October flights in 1974, there was a great decrease in plant bed area. In addition, throughout the season the measured area of the shallow bed types decreased while that of the deeper bed types increased. This is attributed to vegetative propagation of V. americana resulting in greater densities as well as increased leaf lengths. Both factors influenced the photographic image causing a greater proportion of the beds to exhibit the continuous texture image characteristic of deeper beds in October. The areal decrease of the bed types labelled as "shallow" should not be considered a loss of plant coverage but simply a conversion of image from shallow to deep characteristics. This image difference is important in that it determines the calibration material harvested in the

field and used for estimating biomass. By October the onset of cooler temperatures and fall storms caused a significant decrease in plant coverage.

The strata designated as Broad Creek Pt.-Ragged Pt. (especially downstream of Broad Creek at km 12 - 17 N), Hawkins Ldg.-Mixon Creek (km 23 - 31 N), Gaylord Bay-North Creek (km 33 - 38 N) and Core Pt.-Texasgulf (km 24 - 29 S) consisted predominantly of smaller circular beds of plants. These areas exhibited greater fluctuations in cover during the 1974 season as well as significant changes in comparable periods of 1974 and 1975. It is felt that these beds were less stable than those in areas such as Blount's Bay (km 10 - 16 S), Maul's Pt.-Core Pt. (km 16 - 24 S) and Ragged Pt.-Hawknis Ldg. (km 17 - 23 N) where extensive continuous stands of plants were common. Widespread production of winter buds of V. americana that remained buried in the substrate probably accounted for the relative stability of these continuous beds.

Physical Data

Hydrographic data taken at each of the 34 transect sites (0.5 m depth) from July 1974 to June 1975 are summarized by area in Table 4. Seasonal fluctuations of salinity (Goldberg refractometer and YSI Conductivity meter), water temperature and transparency (Secchi disc) are given in Fig. 4. Macrophytes were limited to the upper half of the estuary where salinities rarely exceed 15 ‰. Throughout the year this zone was subject to considerable freshwater inputs lowering the salinity to zero, as well as saltwater intrusions producing salinities up to 8 ‰ near Washington (km 0 - 3 N). These factors obviously limited the species able to exist in the estuary and resulted in lower diversity. Another interesting salinity

Table 4. Annual means of hydrographic data from the Pamlico River estuary study area July 1974 through June 1975.

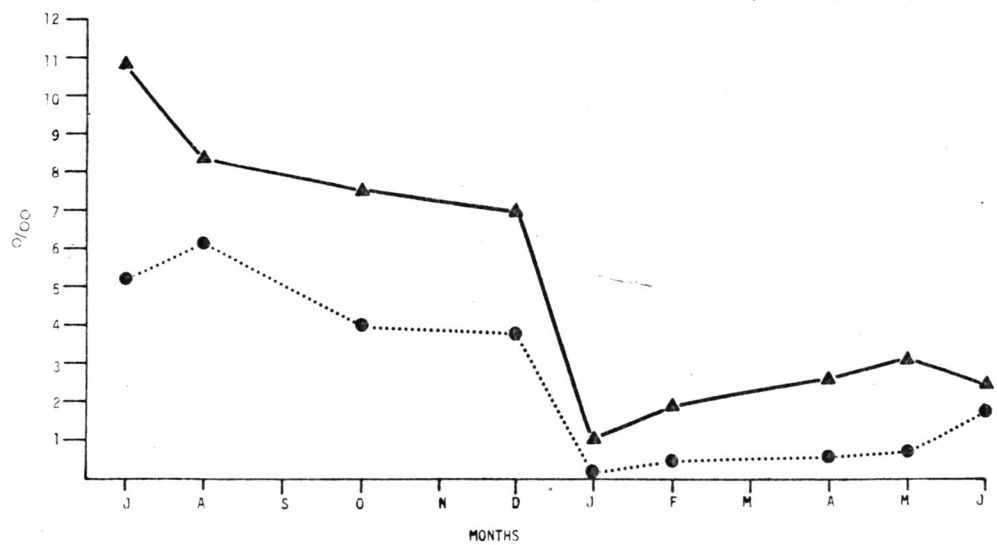
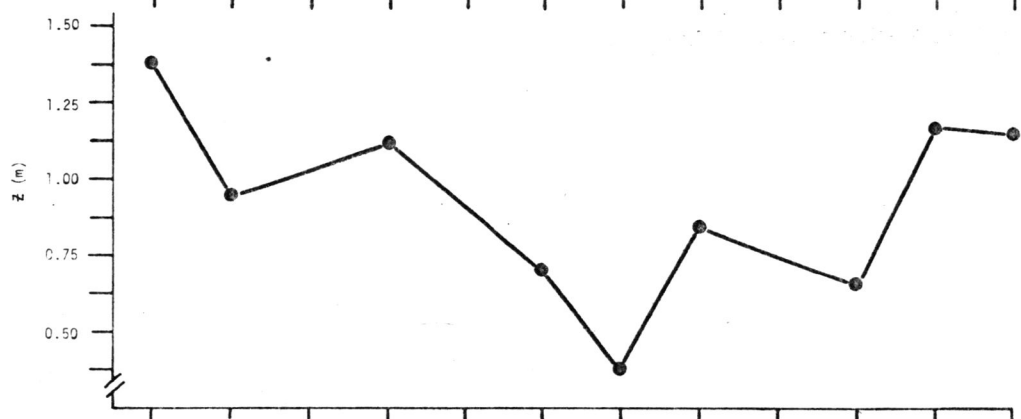
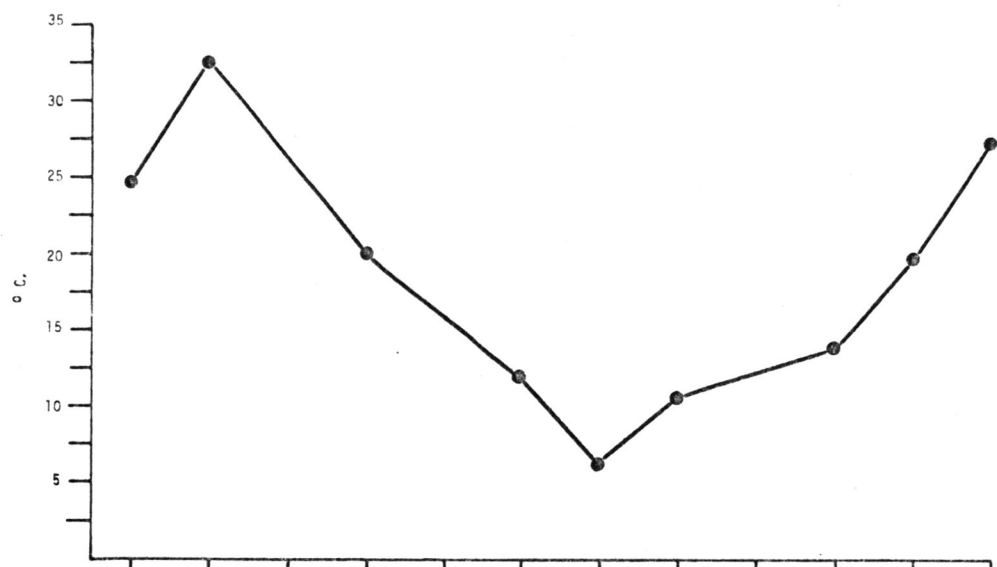
Area	Salinity		Temp.		Turbidity	
	mean	range	mean	range	mean	range
North Shore						
Broad Creek Pt.- Ragged Pt.	3.0	0-8.9	18.2	5.0-33.5	0.88	0.30-1.65
Ragged Pt.-Hawkins Ldg.	3.8	0-11.1	18.3	5.0-33.5	0.92	0.33-1.68
Hawkins Ldg.- Mixon Creek	5.3	0-12.8	18.5	6.0-34.0	1.05	0.33-1.83
Gaylord Bay-North Creek	7.6	2.2-13.9	18.5	6.0-33.5	1.03	0.51-1.96
South Shore						
Blount's Bay	1.3	0-6.1	18.7	5.0-34.0	0.83	0.35-1.68
Maul's Pt.-Core Pt.	2.9	0-8.3	18.3	5.0-34.0	1.03	0.33-1.83
Core Pt.-Texas- gulf	4.7	0-12.2	18.5	5.0-34.0	1.11	0.36-1.85
North Shore mean	4.9	0-13.9	18.4	5.0-34.0	0.97	0.30-1.96
South Shore mean	3.0	0-12.2	18.5	5.0-34.0	0.99	0.33-1.96
River mean	4.0	0-13.9	18.4	5.0-34.0	0.98	0.30-1.96

Salinity is in parts per thousand (‰).

Temperature is in °C.

Turbidity is Secchi disc depth in m.

Fig. 4. Upper - Mean water temperature in the littoral of the Pamlico River estuary during 1974-75. Middle - Mean Secchi depth in the littoral of the Pamlico River estuary during 1974-75. Lower - Salinity in the littoral of the Pamlico River estuary during 1974-75. (—▲— north shore, ---●--- south shore).



effect (Fig. 4) was the horizontal pattern of salinity difference that once exceeded 5 ‰ from shore to shore. This effect resulted from freshwater movement out of the Tar River along the south shore of the estuary.

Isolated stands of Potamogeton foliosus Raf. were found near Broad Creek Pt. (km 10 N) and Potamogeton pectinatus L. (Sago pondweed) was recorded near the mouth of Lee Creek (km 31 S) at Texasgulf and at Resthaven (km 35 N). However these species never lasted an entire growing season nor accumulated significant biomass, but disappeared abruptly. Lack of tolerance to salinity and turbidity fluctuations were probably important factors controlling the appearance and abundance of P. foliosus, but P. pectinatus often thrives in stressful environments (Hynes 1972).

The general trend in turbidity was toward increased clarity downstream. Turbidity was generally related to salinity (Fig. 4) which, in itself, was controlled primarily by Tar River discharge. Downstream from Blount's Bay water clarity was significantly greater during most sampling periods. However, high turbidities were recorded at all stations following periods of high discharge from the Tar River and other tributaries. Maximum Secchi disc readings for the estuary were near 2 m which corresponded to the maximum depth limits of submersed plant beds.

Biomass Studies

The summary of plant density data for 1974 appears in Table 5. Highest plant densities were found in Blount's Bay (km 10 - 16 S) and the Ragged Pt.-Hawkins Ldg. stratum (km 17 - 23 N). Lower densities were encountered further downstream where salinity tolerance limits of V. americana may have been approached. The shallow and deep bed types were not significantly different in density so the figures shown are weighted means for

Table 5. Summary of transect data for aquatic macrophytes in the Pamlico River estuary during 1974. All figures are weighted means for two to four substrata.

Area	N ^a	Density (plants/m ²)				ODW (g/m ²)			
		July	SE	August	SE	July	SE	August	SE
North Shore									
Broad Creek Pt.-									
Ragged Pt.	412	170.5	9.5	208.8	10.0				
Shallow	46					14.59	3.09	30.31	3.40
Deep	366					25.33	2.41	26.86	2.70
Ragged Pt.-									
Hawkins Ldg.	269	269.1	13.0	358.1	13.7				
Shallow	103					8.60	1.37	20.31	3.78
Deep	166					24.85	2.40	26.78	2.53
Hawkins Ldg.-									
Mixon Creek	186	166.1	13.0	171.4	20.4	63.70	7.82	10.59	2.01
Gaylord Bay-									
North Creek	77	79.7	16.4	133.1	31.0	2.33	0.86	2.96	1.08
South Shore									
Blount's Bay-									
West	158	295.1	9.2	349.2	11.6				
Shallow	59					26.24	3.45	23.25	3.59
Deep	99					30.48	2.99	41.31	4.35
Blount's Bay-									
East	161	281.0	8.3	342.8	9.5				
Shallow	76					25.81	3.19	29.08	2.82
Deep	85					30.04	3.36	35.23	3.66
Maul's Pt.-Core									
Pt.	460	162.9	6.9	225.2	8.7				
Shallow	150					8.23	3.01	11.15	3.37
Deep	310					22.30	2.27	50.00	4.25
Core Pt.-Texas-									
gulf	229	164.3	10.4	208.3	12.5				
Shallow	84					3.54	1.26	11.58	2.04
Deep	145					34.40	4.34	32.01	2.96
Indian Island	32	192.6	23.9	76.4	20.3	2.27	0.82	0.92	0.08
North Shore	944	208.3	12.1	268.5	16.9	41.50	3.58	24.95	3.11
South Shore	1040	224.9	8.7	289.2	9.9	25.50	2.86	37.37	2.56
River	1984	221.1	9.9	283.9	12.4	31.63	2.97	33.75	2.72

^a N is the number of quadrats examined in each area each month.

both bed types when present. Tests with random quadrats within specific bed types showed that the circular beds in deeper water in Blount's Bay had higher densities than adjacent continuous beds. Areas dominated by circular beds exhibited, in general, a greater percentage increase in density from July to August.

Biomass data for macrophytes during July and August 1974 also appear in Table 5. Mean biomass was calculated from transect density data (plants/m²) and the harvested material from each substratum (ODW/100 plants), yielding biomass in ODW/m². The biomass of deep beds was shown to be significantly higher ($p < .05$) than that of shallow beds in two strata: Blount's Bay-West (km 10 - 13 S) and Maul's Pt.-Core Pt. (km 16 - 24 S). In the extreme downstream strata on both shores biomass of plants was significantly reduced due to the absence of V. americana and the dominance of R. maritima, a much smaller plant, especially in these stressed areas.

Except in the Maul's Pt.-Core Pt. stratum (km 16 - 24 S) the biomass in the deep beds did not increase greatly from July to August in 1974. The deeper beds probably matured earlier with larger plants being the rule. Self-shading and similar phenomena could have then reduced productivity during this period. The larger increases in biomass were in the shallow beds with clumped dispersions of plants. Higher effective insolation probably resulted in greater increases in standing biomass. These changes took place even though the shallow areas were subject to wave stress which caused biomass losses through leaf breakage, etc.

In general greater biomass was recorded in Blount's Bay (km 10 - 16 S) and the Maul's Pt.-Core Pt. stratum (km 16 - 24 S). These areas are subject to higher turbidities from river discharge than for example, the

Ragged Pt.-Hawkins Ldg. area (km 17 - 23 N), but higher nutrient levels and generally smaller salinity fluctuations may have been conducive to greater productivity. The physiography of these areas was another factor influencing potential biomass accumulation.

The R. maritima beds adjacent to Indian Island (km 43 - 44) exhibited a significant decrease in biomass concomitant with a reduction in density, while R. maritima in the Gaylord Bay-North Creek stratum (km 33 - 38 N) showed little increase in biomass even though density had nearly doubled. R. maritima collected in Blount's Bay and near Ragged Pt. (km 17 N) increased in ODW/100 plants over the same period. This suggests that increased wave stress and/or salinity fluctuations were contributing factors to the decrease in biomass of R. maritima downstream. Other explanations are discussed above with regard to the decrease in plant coverage observed at the same time.

The other significant drop in biomass during the 1974 season was recorded in the Hawkins Ldg.-Mixon Creek stratum (km 23 - 31 N). The plants in this area were generally small beds with an unusually high proportion of Potamogeton perfoliatus var. bupleuroides (Fern.) Farw. The growth form of this species is much more resistant to water flow than the linear leaves of V. americana and the biomass losses in this stratum were largely due to the elimination of a significant amount of P. perfoliatus, presumably by wave action amplified by the seawalls common along the shore.

The decrease in biomass shown for the north shore between July and August of 1974 (due mainly to the loss of P. perfoliatus) was barely compensated for by the productivity on the south shore. Weighted mean biomass for the estuary did not significantly increase (31.63 to 33.75 g ODW/m²). Biomass values indicate the variability of plant beds in the estuary in

response to environmental stresses. Local changes in biomass occurred in response to local conditions of wave stress, turbidity, salinity and nutrients, with the net result being great variation in the observed productivity.

Species composition of each stratum in August 1974 appears in Table 6. V. americana was the dominant species by far, being found in over 90% of the quadrats containing plants in 34 transects. From Mixon Creek (km 31 N) westward on the north shore, P. perfoliatus was found in association with V. americana although its abundance was greatly reduced in deeper water. Najas guadalupensis (Spreng.) Magnus was limited to the upstream strata of generally low salinity conditions. Its increased importance on the south shore was a result of its abundance in certain sections of Blount's Bay (km 10 - 16 S). A small cove near Blount's Creek (km 13 S) was dominated exclusively by N. guadalupensis which was growing in a very silty substrate that was exceedingly permeable for at least 2 m into the sediment. Also in other areas N. guadalupensis was generally limited to protected areas with a silt substrate. East of Mixon Creek (km 31 N) on the north shore and Texasgulf (km 29 S) on the south shore R. maritima was the only species present, its importance decreasing westward. There seemed to be no stable communities of aquatic macrophytes in the Pamlico River estuary. Most of the minor species seem to be dispersed within the V. americana beds in response to local conditions of substrate, salinity, etc.

Biomass and species composition data for the 1975 sampling period are given in Table 7. The biomass was generally higher in 1975 although much of this difference could be attributed to sampling model changes. Addition of two strata upstream from Broad Creek Pt. (km 10 N) in 1975 showed that

Table 6. Species composition of aquatic macrophytes in the Pamlico River estuary in August 1974.

Area	Species ^b				
	VAL	POT	RUP	NAJ	CHA
North Shore					
Broad Creek Pt.-Ragged Pt.					
Shallow	40.0	53.1	0	5.7	1.2
Deep	92.6	6.6	0.4	0.2	0.2
Ragged Pt.-Hawkins Ldg.					
Shallow	69.5	29.1	1.4	0	0
Deep	94.6	1.8	3.3	0	0.3
Hawkins Ldg.-Mixon Creek	78.1	17.5	4.3	0	0.1
Gaylord Bay-North Creek	0	0	100.0	0	0
South Shore					
Blount's Bay-West					
Shallow	71.0	24.3	M	4.4	0.3
Deep	95.7	1.6	M	2.5	0.2
Blount's Bay-East					
Shallow	90.1	3.5	M	5.8	0.6
Deep	93.4	M	0	6.4	0.2
Maul's Pt.-Core Pt.					
Shallow	91.9	7.6	0.4	0	0.1
Deep	99.5	0.4	0.1	0	M
Core Pt.-Texasgulf					
Shallow	89.6	3.9	6.5	0	0
Deep	97.9	0.6	1.5	0	M
Indian Island	0	0	100.0	0	0
North Shore	86.2	10.7	1.4	0.4	0.2
South Shore	94.2	3.0	0.2	2.4	0.2
River	91.9	5.2	0.6	1.8	0.2

Note: Figures indicate percent of the total quadrats examined in the substratum that contained that species. "0" is indicated for areas where the species was not collected. "M" is shown for percentages less than 0.1.

^b Species symbols: VAL = Vallisneria americana, POT = Potamogeton perfoliatus, RUP = Ruppia maritima, NAJ = Najas guadalupensis, CHA = Chara spp. and Nitella spp.

Table 7. Biomass and species composition of aquatic macrophytes in the Pamlico River estuary in August 1975.

Area	N ^c	Total Biomass		Species Composition ^b				
		g ODW/m ²	SE	VAL	POT	RUP	NAJ	CHA
North Shore								
U.S 17-Broad Creek Pt.	10	66.33	4.39	47.1	6.2	0	41.1	5.6
Broad Creek Pt.-								
Ragged Pt.	17							
Shallow	5	30.78	2.07	20.0	69.0	0	9.1	1.9
Deep	12	22.31	1.36	89.0	10.0	0.5	0.5	0.1
Ragged Pt.-Haw-								
kins Ldg.	24							
Shallow	15	73.12	5.91	80.4	12.7	6.8	0.1	0
Deep	9	55.43	3.83	91.8	5.0	3.0	0.2	0
Hawkins Ldg.-								
Mixon Creek	15	46.67	6.25	100.0	0	0	0	0.1
Gaylord Bay-								
North Creek		0						
South Shore								
Chocowinity Bay-								
Hill's Pt.	9	65.78	5.31	40.1	6.1	0	52.7	1.1
Blount's Bay-								
West	21							
Shallow	15	63.92	7.74	91.4	4.3	0.1	3.4	0.9
Deep	6	41.48	3.62	94.3	3.6	0	1.1	1.0
Blount's Bay-								
East	24							
Shallow	15	35.84	5.13	98.6	0.1	0.1	1.3	0.1
Deep	9	30.43	3.28	100.0	0	0	0	0
Maul's Pt.-Core								
Pt	33							
Shallow	27	62.81	6.15	96.7	1.3	0	1.6	0.4
Deep	6	101.48	8.72	98.3	1.5	0.1	0.1	0.1
Core Pt.-Texas-								
gulf	11							
Shallow	3	30.18	3.56		0	0	0	0
Deep	8	39.67	2.95	99.5	0	0.5	0	0
Indian Island								
		0						
North Shore	66	53.57	3.71	78.2	7.5	2.3	10.8	1.2
South Shore	98	73.12	5.17	91.7	2.1	0.1	5.7	0.5
River	164	66.53	4.59	87.1	3.9	0.8	7.4	0.7

Note: Figures represent percent of total biomass.

^bSpecies symbols : see Table 6^cN = number of quadrats harvested

submersed macrophytes attained considerable biomass as far upstream as Runyon Creek (km 2 N) at Washington. N. guadalupensis was found to replace V. americana as dominant in these upstream areas. Despite high turbidity, N. guadalupensis grew to nuisance proportions in August 1975. Extensive mats of this species were formed along the north shore at Washington Park (km 3 N); these mats extended for 1 km downstream and for 20 m out from shore. The mats consisted of luxuriant growth of N. guadalupensis from the silty bottom to the water surface, even at 2 m depths. The mats were strictly limited to developed and populated areas on the shore and were not found in Chocowinity Bay, a less populated area of similar turbidity and salinity directly across the estuary from Washington Park. The rampant growth is suspected to have been the result of increased inorganic nutrient (probably nitrogen) input from the Tar River and upper estuary plus pollution from septic tank absorption fields in the populated area of Washington and Washington Park. N. guadalupensis collected in this area had the highest nitrogen content of any other area or species in the estuary.

High biomass was again recorded for the strata on the south shore, perhaps reflecting a degree of stability in these extensive submersed beds. Areas on the south shore of the estuary were more directly influenced by freshwater inputs (Fig. 4) and were also on the lee side of the estuary with respect to the prevailing southwest winds during the growing season.

The greatest difference in biomass between 1974 and 1975 was in the Maul's Pt.-Core Pt. stratum (km 16 - 24 S). V. americana plants with leaves over 2 m long was found in the deep beds here and this contributed to the 100 g ODW/m² biomass. A significant increase in biomass of the Hawkins Ldg.-Mixon Creek stratum (km 23 - 31 N) was noted along with an increase

in plant bed area (Table 3). P. perfoliatus lost in this area in 1974 did not return in 1975 and V. americana was the only angiosperm species collected here. Large increases in biomass for other strata on the north shore occurred, and suggest that conditions for growth were improved in the 1975 season.

It is interesting to note that although most of the areas showed similar biomasses during the two years (although slightly higher in 1975), the Maul's Pt.-Core Pt. stratum (km 16 - 24 S) and the Ragged Pt.-Hawkins Ldg. stratum (km 17 - 23 N) exhibited disproportionate increases in biomass. A major difference in biomass between 1974 and 1975 was also manifested in the shallow beds, while the deep beds remained about the same in most cases. This suggests that conditions for overwintering were favorable in 1974 and that a large proportion of vegetative propagules survived the winter and produced plants in 1975.

Diversity

Diversity indices of aquatic macrophytes for 1974 and 1975 are shown in Tables 8 and 9. Diversity was calculated from total collected biomass summed over a substratum, as used by Pielou (1966). Diversity of the macrophytes was associated with both downriver gradients and gradients associated with depth and distance from shore. In the 1974 season diversity decreased downriver. Some physical gradients involved here included increasing salinity, fetch and wave action. For most species salinity was likely the overriding factor affecting longitudinal distribution. Diversity was always lower in deep beds than in adjacent shallow beds where rooted plants would normally receive more light. V. americana was always dominant in mixed deep beds and seemed to be well-adapted to low light conditions as well as the coarse sandy substrate found throughout the littoral. The

Table 8. Diversity indices of aquatic macrophytes in the Pamlico River estuary in August 1974.

Area	Diversity ^a (natural bels)	No. of Species	Dominants ^b
North Shore			
Broad Creek Pt.-			
Ragged Pt.			
Shallow	2.834	4	POT, VAL
Deep	0.338	5	VAL
Ragged Pt.-Hawkins			
Ldg.			
Shallow	1.322	3	VAL, POT
Deep	0.149	4	VAL
Hawkins Ldg.-Mixon			
Creek	1.294	4	VAL, POT
Gaylord Bay-North			
Creek	0.0	1	RUP
South Shore			
Blount's Bay-West			
Shallow	1.471	5	VAL, POT
Deep	0.105	5	VAL
Blount's Bay-East			
Shallow	1.106	5	VAL
Deep	0.852	4	VAL, NAJ
Maul's Pt.-Core Pt.			
Shallow	0.331	4	VAL
Deep	0.0 ^c	4	VAL
Core Pt.-Texasgulf			
Shallow	0.407	3	VAL
Deep	0.059	4	VAL
Indian Island	0.0	1	RUP

^a Brillouin's Index modified for biomass (Pielou 1966)

$$H = \frac{1}{N} \ln \frac{N!}{(N_1! N_2! N_3! \dots N_S!)}$$

where N = total weight of all species, and N₁, N₂, N₃, ..., N_S = weight of each species

^b Lists dominant species having greater than 5 g ODW/m² in order of decreasing abundance. For species symbols see Table 6.

^c Areas where minor species were collected but comprised an insignificant portion of the biomass

Table 9. Diversity indices of aquatic macrophytes in the Pamlico River estuary in August 1975.

Area	Diversity ^a (natural bels)	No. of Species	Dominants ^b
North Shore			
U.S 17-Broad Creek Pt.	1.784	5	NAJ, VAL, POT
Broad Creek Pt.-Ragged Pt.			
Shallow	2.207	5	VAL, POT
Deep	1.156	3	VAL, POT
Ragged Pt.-Hawkins Ldg.			
Shallow	3.028	4	VAL, POT
Deep	2.605	4	VAL
Hawkins Ldg.-Mixon Creek	0.0 ^c	3	VAL
South Shore			
Chocowinity Bay- Hill's Pt.	0.862	4	NAJ, VAL
Blount's Bay-West			
Shallow	1.584	5	VAL
Deep	0.413	5	VAL
Blount's Bay-East			
Shallow	1.101	4	VAL
Deep	0.147	4	VAL, NAJ
Maul's Pt.-Core Pt.			
Shallow	0.112	4	VAL
Deep	0.098	5	VAL
Core Pt.-Texasgulf			
Shallow	0.0	1	VAL
Deep	0.0 ^c	4	VAL

^a Brillouin's Index modified for biomass (Pielou 1966). See Table 8.

^b Lists dominant species having greater than 5 g ODW/m² in order of decreasing abundance. For species symbols see Table 6.

^c Areas where minor species were collected but comprised an insignificant portion of the biomass

1975 data, which include the two additional upstream areas, show decreased diversity upstream where turbidity was highest. In the upstream strata (U.S. 17-Broad Creek Pt. and Chocowinity Bay-Hill's Pt.) influences of the turbid discharge of the Tar River were present for much longer periods of time than further downstream. The result was a decrease in abundance of species not tolerant of low light conditions in those strata. N. guadalupensis seemed to be well-adapted to these light conditions, perhaps to a greater degree than V. americana. Scattered N. guadalupensis was observed to grow in Blount's Bay (km 12 S) in 2.0 - 2.5 m depths where no other macrophytes grew. However N. guadalupensis is known to be limited to oligohaline areas and could well be dominant further downstream in this estuary were it not for higher salinities.

The only major difference in diversity over the two year study was found in some deep beds on the north shore: Broad Creek Pt.-Ragged Pt. (km 10 - 17 N) and Ragged Pt.-Hawkins Ldg. (km 17 - 23 N). A considerable increase in diversity was noted for these two areas in 1975. Low seasonal turbidity in 1975 perhaps resulted in growth of minor species in deep water.

The diversity of macrophytes in the Pamlico River estuary is low in comparison to the values reported for the same species in Currituck Sound and Back Bay during 1962 (Anon. 1965, Vol. I). Figures for diversity in the present study more closely approximate those found in a eutrophic lake dominated by Myriophyllum spicatum (Nichols and Mori 1971). However, in that study of Lake Wingra eutrophication was correlated with a decreased dominance of Vallisneria americana and Potamogeton spp. Lind and Cottam (1968) showed that the Vallisneria-Potamogeton community in University Bay, Wisconsin gave way to a nearly pure Myriophyllum exalbescens community

as eutrophication proceeded. It appears that the low diversity encountered in the Pamlico River estuary resulted from a combination of estuarine stresses (salinity, waves, light, etc.) with a dominance of a well-adapted species and relative exclusion of less tolerant species. Southwick and Pine (1975) showed large fluctuations in diversity (based on area and density) of Potamogeton perfoliatus, Ruppia maritima and Myriophyllum spicatum in the Rhode River, a subestuary of the Chesapeake Bay. These changes, although showing no apparent trend over several years, were believed to be related to the decline of environmental quality in that area.

Total Estuarine Biomass

The total biomass (metric tons) estimates of rooted aquatic macrophytes in the Pamlico River estuary are shown in Table 10. Estimates for the 1974 samplings showed an increase of nearly 20 MT ODW in total biomass for the entire estuary for only one month. However this increase was not statistically significant ($p < .05$). The large increase in 1975 resulted mostly from increases in biomass ($g\ ODW/m^2$) estimates. Total bed areas as measured with aerial photography were about the same for both years (Table 3), so the increase in estuarine biomass is believed to be affected somewhat by the sampling method. Biomass measurements in August 1974 were made at the first of the month while those in August 1975 were made near the end of the month. This could mean many tons difference when comparing the two August estimates. Percent of the total estuarine biomass is given in Table 10 to facilitate comparison.

Approximately 70% of the total estuarine biomass was along the south shore, predominantly in Blount's Bay (km 10 - 16 S), and between Maul's Pt. and Core Pt. (km 16 - 24 S). In August 1974 approximately equal percentages

Table 10. Estimated total biomass of rooted aquatic macrophytes in the Pamlico River estuary obtained with aerial photography and ground truth methods. All figures are in MT ODW.^a

Area	July 1974	SE	August 1974	SE	August 1975	SE
North Shore						
U.S. 17-Broad Creek Pt.	-		-		17.31(-)	2.7
Broad Creek Pt.-Ragged Pt.						
Shallow	5.35	1.1	1.61	0.2	1.08	0.2
Deep	3.81	0.4	16.06	1.3	11.12	0.8
Total	9.16(12.0)	1.5	17.67(17.0)	1.5	12.20(7.2)	1.0
Ragged Pt.-Hawkins Ldg.						
Shallow	1.18	0.3	3.81	0.4	9.86	0.8
Deep	4.53	0.6	6.40	1.1	16.83	0.5
Total	5.71(7.5)	0.9	10.21(9.9)	1.5	26.69(15.8)	1.3
Hawkins Ldg.-Mixon Creek	14.40(18.8)	1.6	2.30(2.2)	0.7	10.58(6.3)	1.3
Gaylord Bay-North Creek	0.00 ^b	0	0.00 ^b	0	0.00	0
South Shore						
Chocowinity Bay-Hill's Pt.	-		-		12.33(-)	2.6
Blount's Bay-West						
Shallow	4.77	0.6	4.56	0.6	13.87	1.0
Deep	5.58	0.7	12.83	1.3	10.89	0.7
Total	10.35(13.5)	1.3	17.39(16.8)	1.9	24.76(14.7)	1.7
Blount's Bay-East						
Shallow	8.98	0.7	7.44	0.7	10.86	1.0
Deep	8.73	0.4	11.47	0.8	5.13	0.4
Total	17.71(23.2)	1.1	18.91(18.3)	1.5	16.99(10.1)	1.3
Maul's Pt.-Core Pt.						
Shallow	2.46	0.4	6.49	0.4	16.71	1.3
Deep	13.55	1.0	25.67	1.3	55.71	2.1
Total	16.01(21.1)	1.4	32.16(31.0)	1.7	72.42(43.0)	3.4
Core Pt.-Texasgulf						
Shallow	0.39	0.1	1.30	0.1	2.35	0.3
Deep	2.55	0.3	3.65	0.5	2.47	0.3
Total	2.94(3.8)	0.4	4.95(4.8)	0.6	4.82(2.9)	0.6
Indian Island	0.07(0.1)	0	0.01(0)	0	0.00	0
North Shore	29.27(38.3)	4.0	30.19(29.1)	3.7	66.77(29.4)	6.3
South Shore	47.08(61.7)	4.1	73.42(70.9)	5.7	131.31(70.6)	9.0
River	76.35	8.1	103.61	9.4	198.08	15.3

^aFigures in parentheses indicate percent of total estuarine biomass. The two upstream strata added in 1975 are excluded to allow comparison.

^bPlants were found in this stratum in 1974 but the biomass was insignificant (1 kg ODW in July 1974 and 3 kg ODW in August 1974).

were found in these two strata. In 1975 a 10% increase in the Maul's Pt.-Core Pt. biomass coincided with a 10% decrease in the Blount's Bay biomass. Strata on the north shore comprised 30% of the total biomass and exhibited greater seasonal and year-to-year fluctuations. Considering each shore as a whole the two community areas produced surprisingly stable proportions of the total biomass.

The estimate for total biomass in 1975 was 198 (± 30.0 , $p < .05$) MT of organic material. This compares to just over 100 (± 18.4 , $p < .05$) MT in 1974. Comparison of data from both years for what are considered the most stable beds in the estuary showed that 50 - 60% of this difference could be due to changes in sampling models and times. Therefore 40 - 50% of the increase from 1974 to 1975 was probably due to a real change in biomass. Quadrats harvested in 1975 were always entirely within plant beds. Quadrats counted in 1974 were sometimes located on the edge of plant beds and often empty. Thus lower densities resulted in decreased biomass estimates in comparison to 1975 data. In addition when one considers that 2 wk were required to complete the field surveys each month and that a 25 MT difference in biomass was measured in July and August 1974, the difference between the two August estimates (1974 and 1975) is less significant.

Weight Relationships of Macrophytes

Weight relationships for the various species of macrophytes are given in Table 11. V. americana had the highest fresh weight/dry weight ratio of the angiosperm species. Comparatively small amounts of vascular tissue may account for this difference. The dry weight/ODW ratio for the angiosperm species were much more similar. The 1975 data include a correction which separates acid soluble plant ash from acid insoluble materials. The

Table 11. Weight relationships of aquatic macrophytes in the Pamlico River estuary.

Species	Dry Wt. as a % of FW ^a			ODW as a % of Dry Wt.					
	mean	SE	N	1974			1975		
				mean	SE	N	mean	SE	N
<u>V. americana</u>	6.6	1.2	127	74.9	1.0	52	79.3	1.2	75
<u>P. perfoliatus</u>	13.0	2.4	42	78.9	1.2	14	85.3	1.6	28
<u>N. guadalupensis</u>	10.5	2.3	43	78.0	1.7	18	78.2	1.6	25
<u>R. maritima</u>	12.5	2.3	31	71.6	1.4	10	81.9	1.3	21
<u>C. coeruleus</u>	5.6	1.1	26	70.1	0.8	19	76.4	1.4	7
<u>C. glomerata</u>	17.8	2.4	20	-	-	0	72.1	0.8	20
<u>Chara</u> spp. and <u>Nitella</u> spp.	9.3	1.2	35	80.2	1.0	15	82.6	1.1	20
Extraneous ^b	36.2	2.5	22	96.0	1.9	6	-	-	0

^aFW = fresh weight(or wet weight)

^bIncludes leaves of Pinus, Juncus, Taxodium, and Quercus collected in the study of floating macrophyte debris

acid insoluble fraction was thought to be silicon from abundant epiphytic diatoms plus some residual sand.

Patterns of Submersed Plant Bed Distribution

One of the distinct advantages of using aerial photography for the study of submersed plants is the ability to make an "instantaneous" appraisal of a large study area. Many features not readily seen in ground surveys are obvious in the photographs. Trends in plant bed growth patterns and an analysis of some physical factors associated with colonization and distribution in the estuary would be very difficult to study without this technique.

Plant beds in the estuary are found in the shallow littoral in less than 2 m of water. Light attenuation by high concentrations of suspended matter may limit the establishment of extensive beds in deeper water. Beds rarely grow within 5 - 8 m of the shoreline. Primary factors controlling colonization so close to shore are high wave energy and shallow fluctuating water levels. The width of the littoral varies greatly throughout the estuary. Beginning at Blount's Bay (km 10 S) on the south shore and eastward to Core Pt. (km 24 S), the littoral is generally broad and shallow. This physiography correlates well with the high macrophyte biomass; well over half of the total biomass in the estuary was found in this region.

On the north shore, a relatively steep gradient into deeper water associated with high marshes and bulkheading tends to predominate. Extensive plant beds associated with shallow water were found only in the Broad Creek Pt. (km 10 N) area and from Ragged Pt. to Hawkins Ldg. (km 17 - 23 N). Apparent effects of these shoreline configurations on plant bed development and stability are discussed later.

Three major plant bed types have been observed in the Pamlico River estuary. In the areas characterized by a relatively wide littoral two distinct photographic images appear. Plant beds in shallow water (generally up to about 90 cm) produced a lighter tone that was speckled or granular in texture. In deeper water beds produced a darker-toned image with smooth continuous texture (Fig. 5). Ground truth data showed these two bed types to differ somewhat in density, with the deeper beds having the greater density. Associated with this density difference is a rather sharp change in leaf length, especially in V. americana. Longer leaves which were nearer the water surface and greater plant density contributed to the production of the dark, smooth photographic image. The shallow beds were characterized by short, scattered plants existing in small vegetative clumps. Table 12 shows indices of clumping (David and Moore 1954) calculated from 20 random 0.1 m² quadrats counted within each of the three bed types. Both the deeper continuous beds and the circular beds (discussed below) showed a small degree of plant dispersion compared to the shallow clumped beds.

Harrison and Mann (1975) explained the variation in growth form of Zostera marina in Canada from short to tall with increasing depth as a function of wave action. A similar explanation is offered here for V. americana which exists in the tall form in deeper water or protected coves, and in the short form in shallow beds.

Circular plant beds were observed in several areas of the estuary. Near Ragged Pt. (km 17 N) pure stands of V. americana were about 5 m in diameter. Site surveys showed that these plant beds were associated with old cypress stumps in all cases. Occasionally the submersed stump was

Fig. 5. Aerial photograph depicting the two photographic images designated as "shallow" and "deep" bed types (indicated by arrows). This photograph was taken from 666 m altitude at km 19 S (29 August 1974).

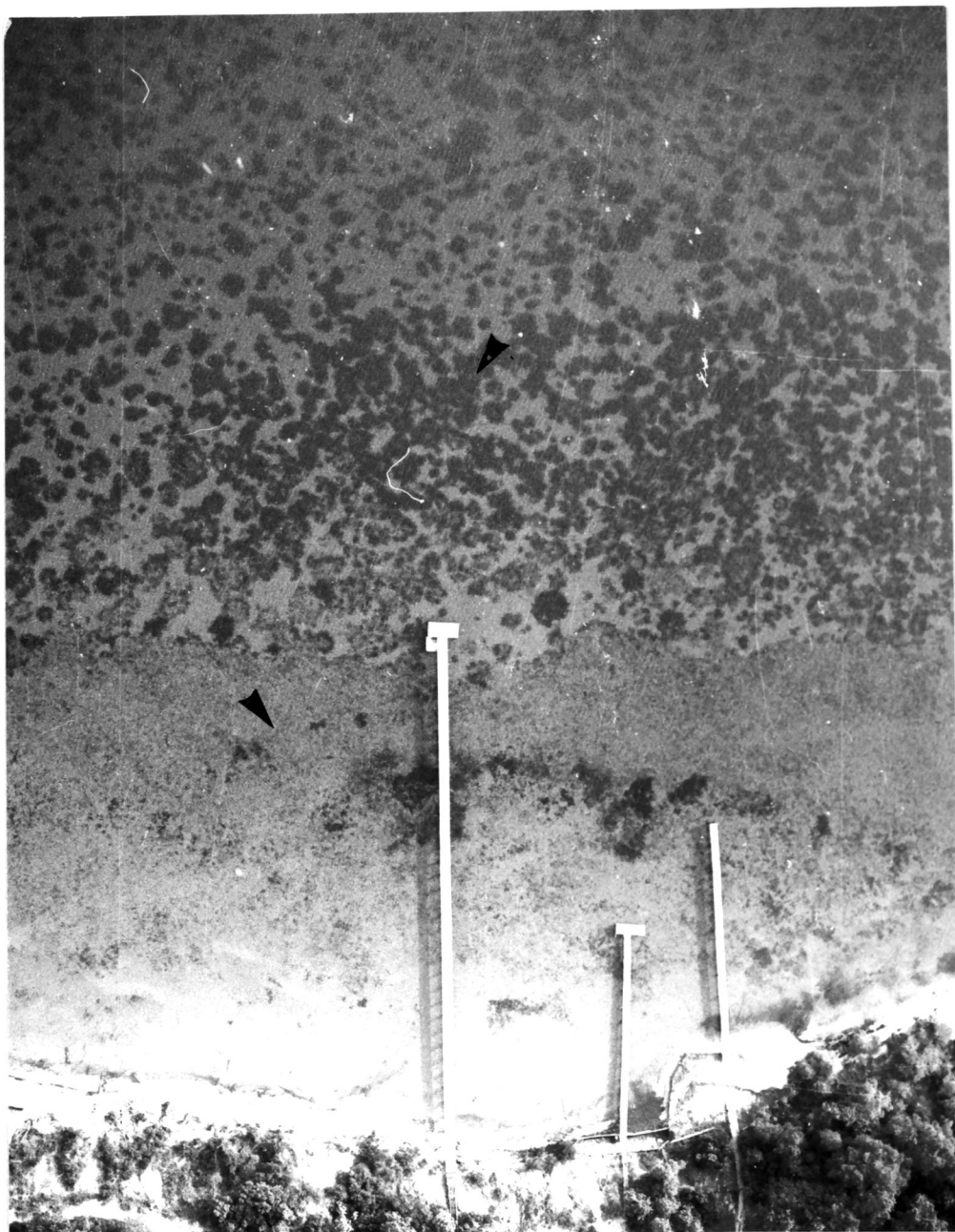


Table 12. Index of clumping for Vallisneria americana within different bed types in Blount's Bay.

Bed Type	Clumping Index ^a	Significance Level
Circular bed	0.367	NS
Continuous bed (deep)	0.398	NS
Clumped bed (shallow)	5.013	.05

^aCalculated as :

$$I_c = \frac{(\text{observed variance} - 1)}{(\text{observed mean})}$$

still present, and in others, a peaty layer consisting of decaying wood fragments was discovered beneath a few centimeters of sand. This marsh area on the north shore is subject to considerable wind and wave fetch across Blount's Bay and it is thought that wave action prevents colonization except in these pockets of organic soil left behind by the receding shoreline. Zieman (1972) found a similar pattern in Florida between beds of Thalassia testudinum and peat deposits of former mangrove trees.

Circular beds in the Pamlico River estuary were prominent also in deeper water beyond the continuous beds (Fig. 6). These beds increased considerably in size during the growing season. Most likely they start from clones of one or a few plants and develop rapidly by vegetative propagation throughout the season. Their circular shape results probably from changing current directions with winds as compared to teardrop-shaped beds often associated with flowing streams (Hynes 1972).

The plant beds in the Hawkins Ldg.-Mixon Creek stratum (km 23 - 31 N), especially along the populated shore of Bayview, North Carolina, existed in a band of exclusively circular beds approximately 50 m from shore (Fig. 7). This region is subject to considerable fetch resulting in a higher level of wave action which probably controls the formation of this bed type through changing water currents. The nearly continuous chain of seawalls and bulkheads in this area undoubtedly increases the intensity of wave action and its effectiveness in reducing substrate stability. These seawalls may be a major controlling factor in limiting distribution and biomass of plants in the vicinity. However colonization of plants on the ridged sandy substrate may help to stabilize the sediment in bulkheaded areas that would otherwise be washed away. The Archbell Pt. (km 25 N) shoreline is lined

Fig. 6. Aerial photograph taken from 1333 m altitude at km 14 S
(23 October 1974).

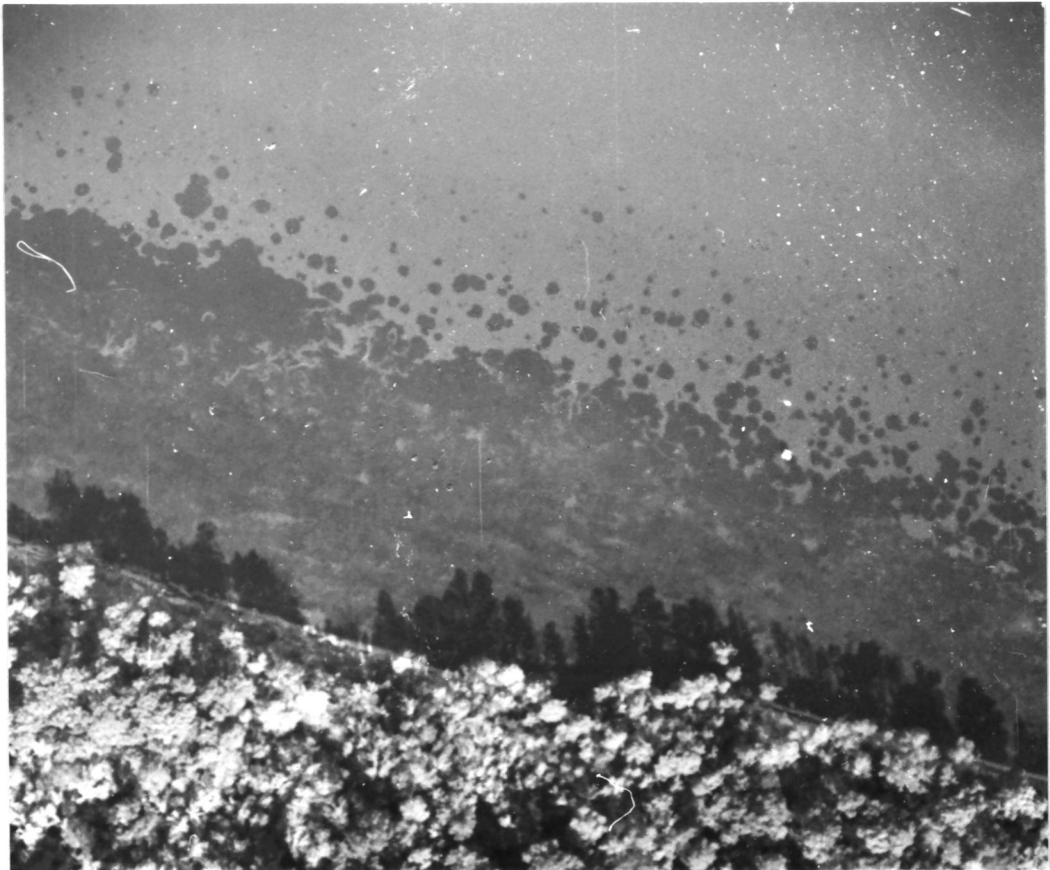


Fig. 7. Aerial photograph taken from 666 m altitude at km 29 N
(10 September 1975). Note the sand accumulation along
the continuous shoreline bulkheads.

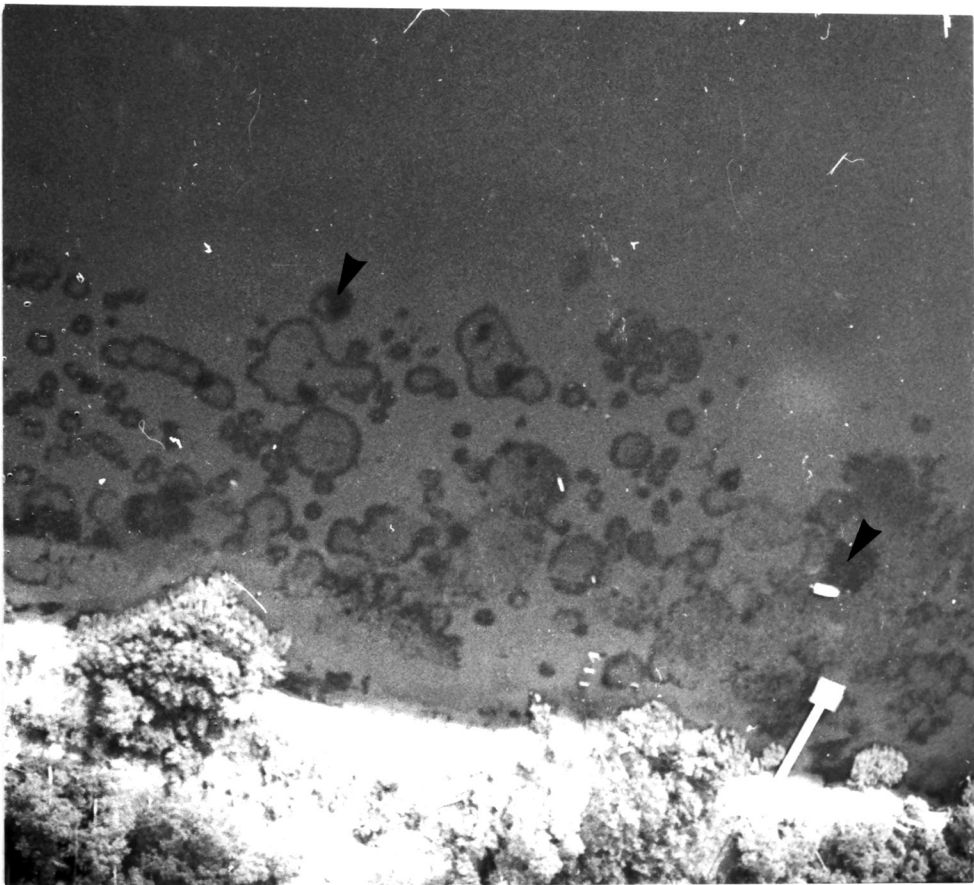


with a seawall bordering a large farm in addition to having a relatively narrow littoral. Here the V. americana was exclusively a short-leaved form with numerous broken leaves. The beds were limited to a narrow band in the deepest portions of the littoral.

The most interesting form of circular bed was discovered in a protected area on the eastern shore of Blount's Bay near Blount's Creek (km 13 S). These beds exhibited a "halo" photographic image with the rim of the beds producing the familiar dark continuous texture, and the central portions of the beds giving the granular texture common to shallow clumped beds. An aerial photograph of these plant beds is given in Fig. 8. The difference in image was due to a sharp differential in leaf length of V. americana, in which the outer plants had leaves up to 80 cm and the inner plants had leaves of 10 - 30 cm. One of these beds was observed frequently during the 1975 season, and its formation began in what later became the outer rim of tall plants. During late April and early May small vegetative clumps developed with long leaves; the clumps slowly coalesced in early June into a circular ring of plants with a bare center. During July and early August short plants appeared in the center of the bed but never developed leaves approaching the lengths found in the outer rim. The inner plants arose as vegetative extensions of more mature plants in the outer rim. In this protected, low flow area it is felt that the plants in the center were shaded by the taller plants and/or limited by the lack of available nutrients within these dense beds. Changing water currents probably influenced the developmental pattern of the outer rim.

In summary the three major bed types and combinations of types were associated with varying degrees of exposure to wave action. The most pro-

Fig. 8. Aerial photograph of "halo" circular beds from 666 m altitude in Blount's Bay (km 13 S). Arrows indicate beds of Potamogeton perfoliatus. Other beds are Vallisneria americana (19 July 1974).



tected areas had beds that contained long-leaved V. americana and produced the dark smooth photographic image. In more exposed areas with a wide littoral the shallow clumped beds were found in conjunction with the deeper continuous beds and circular beds with long-leaved plants. With the greatest degree of exposure the plants were limited to small circular patches with short-leaved plants in the deeper portions of the littoral. In some of the downstream areas where salinity was greater but the shoreline was somewhat protected, circular beds with short leaves were found, suggesting a complicating influence of salinity on the distribution and form of these plants.

Comparison of aerial photographs from 1974 and 1975 showed that the location of submersed plant beds was rather stable. Although biomass differed considerably between the two years, locations of the beds were very similar for the same period. The least stable plant beds were further downstream where fetch and turbulent wave action may have caused unstable substrate during the winter. During this period the winter buds of V. americana, actually modified rhizomes, are dormant in the sand. Spring growth from these buds is responsible for the year-to-year regrowth of V. americana. Unstable substrate could destroy the buds, thus reducing the probability of a plant bed being formed the next season.

An interesting trend can be seen in comparing bed area measurements in July, August and October of 1974 (Table 3). In those areas characterized by both shallow clumped and deep continuous beds, a definite increase in the deep bed area during the season was concomitant with a decrease on the area of the shallow clumped beds. These changes, however, did not represent a significant increase in the total plant bed area of the stratum, but merely an increase in the proportion of the total area occupied by the

deeper continuous beds. As the season progressed and the density of the beds increased, their resistance to wave action increased, resulting along with natural elongation in lowered leaf breakage and longer net leaf lengths. The end result was that the proportion of the plant beds producing the dark smooth photographic image increased. This is not to say that the deep beds were older or formed earlier in the season. No evidence of this has been found.

Floating Plant Studies

Figure 9 shows the distribution of the mean catch (g/min) of floating macrophyte debris for the entire study period (July 1974 to February 1975) along with the total biomass of rooted macrophytes in the same area. The data show, with one exception, that the abundance of floating debris was clearly related to the total biomass of plants in the same area. The anomalous occurrence of floating biomass near river km 15 S was due to considerable input of macrophyte debris from farther upstream, especially during high water, and from the west side of Blount's Bay. The data also indicate that there was very little movement of floating debris out of the portion of the estuary occupied by submersed plants. Although some could be transported underwater, the river current is normally too weak to expect much movement. Further evidence for low rates of transport of debris from the general area of production is given in Table 13 which shows the horizontal (shore to mid-river) distribution patterns of floating debris as well as the seasonal fluctuations for the study area. In July and August of 1974 when macrophytes were approaching maximum biomass, relatively little plant material was being lost to detritus. No real differences are evident in the horizontal distribution patterns. The values for August were

Fig. 9. Upper - Mean seasonal catch of floating material and total macrophyte biomass on the north shore of the Pamlico River estuary, August 1974. Lower - Mean seasonal catch of floating material and total macrophyte biomass on the south shore of the Pamlico River estuary, August 1974.

(—■— seasonal catch, ---●--- total macrophyte biomass).

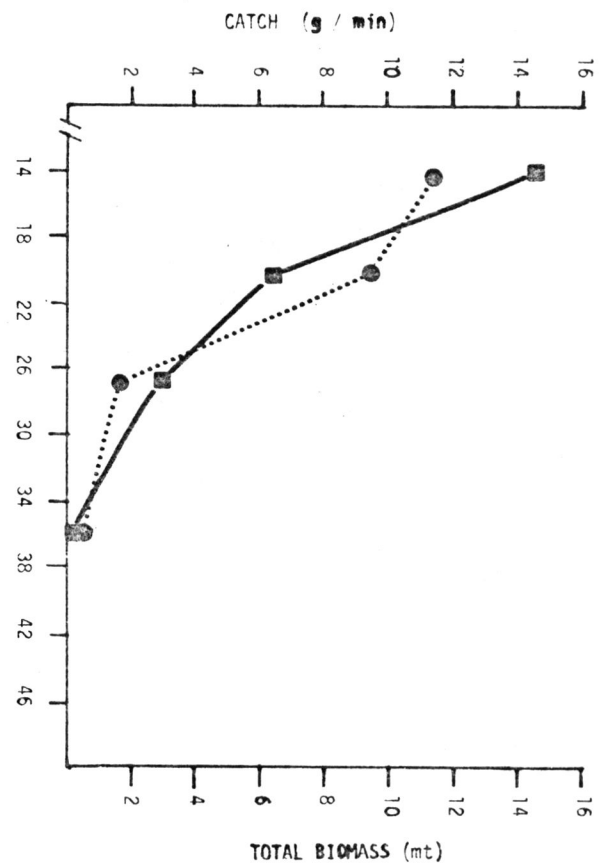
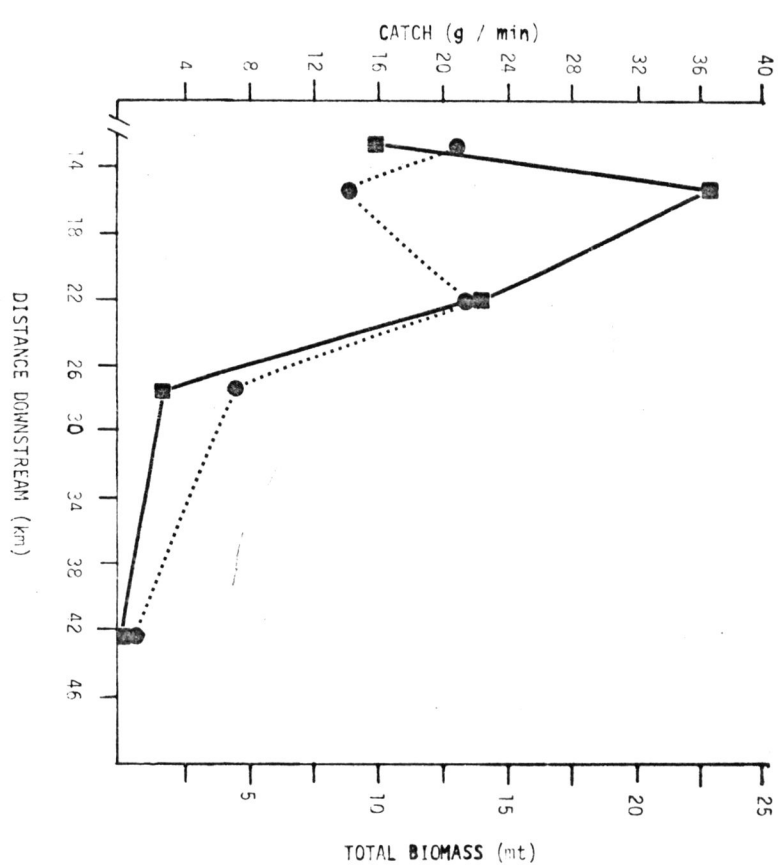


Table 13. Seasonal and spatial distribution of floating macrophyte debris in the Pamlico River estuary during 1974 - 1975.

Substratum	Catch (g/min)					
	July	August	October	November	January	February
Plant Beds	6.95	19.71	31.35	37.89	3.64	0.24
Beyond Beds	5.16	11.68	11.71	12.98	1.22	0.09
Mid-estuary	4.20	25.87	9.70	3.83	0.56	0.07
Mean for Estuary	5.44	22.08	19.88	16.81	1.81	0.13

artificially high due to storm activity about four days prior to the sampling period. Floating biomass increased greatly in the fall after maximum biomass was reached and the bulk of the rooted plants began to senesce. These factors, coupled with higher flows and more frequent storms, resulted in increases of debris concentrations within plant beds to about 5.7 times the original (July) level. However, the concentrations in the deeper portions of the estuary increased only slightly, or remained essentially unchanged. By January and February the concentrations of floating debris were very low and consisted mainly of residual basal stems and roots rather than senescent leaves. This tends to indicate that the bulk of the macrophyte standing biomass had been released by this time of year. During the winter months, leaves of Pinus, Taxodium, Quercus, and Juncus made up 1/3 to 1/2 of the floating debris in the estuary, indicating a significant increase in the input of allochthonous organic matter to the estuary. However the total amount was low compared to fall concentrations of macrophyte debris.

Therefore, seasonal patterns of floating macrophyte debris in the estuary reflected the increased losses of organic production that were expected as the annual die-back of the plants took place. This further substantiates the concept that floating debris concentrations can be used to show relative rates of debris production in submersed plant beds.

The effects of a strong storm from 7 - 9 October 1974 on the generation of floating debris in Blount's Bay (km 10 - 16 S) are shown in Table 14. A total net increase in catch of 42.5 g/min can be seen, although the deeper portions of the bay had a large net decrease. The discrepancy is explained by the production of large amounts of debris within the plant

Table 14. Storm-induced changes in the concentration and distribution of floating macrophyte debris in Blount's Bay.

Area	Catch (g/min)		Net Change
	6 October 1974	10 October 1974	
East Side			
Plant Beds	12.86	62.99	+ 50.13
Beyond Beds	5.84	11.99	+ 6.15
West Side			
Plant Beds	17.66	83.29	+ 65.63
Beyond Beds	65.05	10.46	- 54.59
Middle of Bay	29.37	4.50	- 24.87
Total Change			+ 42.45

beds in Blount's Bay. From these data it is clear that increased wave action from the storm resulted in the production of large amounts of additional macrophyte material in the bay, even though there seemed to be a sizable export or sinking of debris from the deeper sections.

Nutrients in Aquatic Macrophytes

The nitrogen contents of aquatic macrophytes in the Pamlico River estuary for August 1975 are shown in Table 15. Nitrogen values for samples within a substratum agreed closely. The standard error of measurements averaged 3.1% of the mean and was never greater than 5.8% of the mean.

Comparison of species collected from the same area indicates that P. perfoliatus generally has a lower concentration of nitrogen than V. americana which, in turn, has a lower concentration than N. guadalupensis. High ambient levels of inorganic nitrogen were probably associated with the rampant growth of N. guadalupensis upstream in the vicinity of Washington Park (km 3 N), a densely populated area with residential septic tanks. R. maritima and the muskgrasses (Chara spp. and Nitella spp.) seemed to have similar mean nitrogen levels in tissue which were somewhat lower than the tissue concentrations in V. americana.

Table 16 shows the phosphorus content of the plant material analyzed for nitrogen. Standard errors for substrata values averaged 5.3% of the mean and were never greater than 8.6% of the mean. P. perfoliatus had the highest mean phosphorus concentration and V. americana the lowest. In general the phosphorus content of the macrophytes in this estuary was ten times that found in the same or similar species from other areas. Adams, et al. (1973) tested many species of submergent and emergent macrophytes from various watersheds in Pennsylvania for phosphorus. In that study Vallisneria americana was found to be highly variable in phosphorus con-

Table 15. Nitrogen content of aquatic macrophytes in the Pamlico River estuary in August 1975. All values are in $\mu\text{g-at N/g ODW}$.

Area	Species ^a						
	VAL	POT	NAJ	RUP	CHA	COM	CLA
North Shore							
U.S. 17-Broad Creek Pt.	2560	1750	3130		1940	2510	
Broad Creek Pt.-Ragged Pt.							
Shallow	2330	2140	3330				
Deep	2380	2140					2250
Ragged Pt.-Hawkins Ldg.							
Shallow	2040	1450		1770			
Deep	2160	2180		2270			
Hawkins Ldg.-Mixon Creek	2440						
South Shore							
Chocowinity Bay-Hill's Pt.	2290	1880	2810				
Blount's Bay-West							
Shallow	1930	1810	2950			2380	
Deep	2010	1910	2950		2360	2520	
Blount's Bay-East							
Shallow	1780	1930					
Deep	2420		3030				
Maul's Pt.-Core Pt.							
Shallow	2020	1450	1900		1460		1910
Deep	2010			2190	2470		
Core Pt.-Texasgulf							
Shallow	2710						
Deep	2690					2550	
Mean for River	2250	1860	2870	2080	2060	2490	2080

^aSpecies Symbols: VAL = Vallisneria americana, POT = Potamogeton perfoliatus, NAJ = Najas guadalupensis, RUP = Ruppia maritima, CHA = Chara spp. and Nitella spp., COM = Compsopogon coeruleus, CLA = Cladophora glomerata

Table 16. Phosphorus content of aquatic macrophytes in the Pamlico River estuary in August 1975. All values are in $\mu\text{g-at P/g ODW}$.

Area	Species ^a						
	VAL	POT	NAJ	RUP	CHA	COM	CLA
North Shore							
U.S. 17-Broad Creek Pt.	251	254	238		227	91	
Broad Creek Pt.-Ragged Pt.							
Shallow	256	263	266				
Deep	250	326					117
Ragged Pt.-Hawkins Ldg.							
Shallow	218	352		191			
Deep	258	391		308			
Hawkins Ldg.-Mixon Creek	270						
South Shore							
Chocowinity Bay-Hill's Pt.	225	271	264				
Blount's Bay-West							
Shallow	202	267	380			183	
Deep	217	275	305		298	166	
Blount's Bay-East							
Shallow	189	315					
Deep	232		319				
Maul's Pt.-Core Pt.							
Shallow	230	312	296		265		132
Deep	224			350	298		
Core Pt.-Texasgulf							
Shallow	267						
Deep	242					187	
Mean for River	235	303	295	283	272	157	124

^aSpecies Symbols: See Table 15.

tent between locations, but plants from seven locations ranged from 10 - 25 $\mu\text{g-at/g ODW}$. Getsinger (1976) found Vallisneria americana in the Currituck Sound area of North Carolina to contain 65 $\mu\text{g-at/g ODW}$ in shoots and 53 $\mu\text{g-at/g ODW}$ in roots. The analysis reported here and those by Getsinger were performed in the same laboratory at East Carolina University. Similarly, two species of Potamogeton tested by Adams et al. that are similar in growth form and taxonomic position to a species found in the Pamlico River estuary (P. perfoliatus) contained 14 - 20 $\mu\text{g-at/g ODW}$ phosphorus. However in this estuary the mean concentration of phosphorus in P. perfoliatus was 300 $\mu\text{g-at/g ODW}$. Potamogeton perfoliatus var. bupleuroides stems from the Currituck Sound area were found by Getsinger to contain 58 $\mu\text{g-at/g ODW}$ phosphorus. Thus it is evident that high ambient levels of phosphorus in the sediments and waters of the Pamlico River estuary have resulted in exceedingly high phosphorus accumulation in the submersed plants. Comparative analyses of plant for nitrogen and phosphorus support, to say the least, the contention that the plants are not phosphorus-limited and probably not nitrogen-limited, even though nitrogen is less abundant than phosphorus.

Since submersed macrophytes are not woody and do not contain vast amounts of food reserves, their organic carbon content has a very limited range when expressed in terms of ODW rather than dry weight. The values for the carbon content of the ODW for submersed angiosperms varies around 43 to 48% with the mean about 46.5% (Westlake 1965). A 45% carbon content in the ODW was assumed for calculating elemental ratios.

As would be expected from the phosphorus data, the plants collected had low carbon:phosphorus and nitrogen:phosphorus ratios. Values for

carbon:phosphorus ranged from 123:1 upstream (km 4 N) to 53:1 near Texas-gulf (km 30 S), with the mean value at 65:1. Nitrogen :phosphorus ratios for V. americana ranged from 13.1:1 (km 4 N) to 7.6:1 (km 21 N) with a mean value of 10:1 (Fig. 10).

Some of the data presented thus far becomes more meaningful when the component nutrient values for each of the substrata are analyzed graphically with respect to one another. Biomass (g/m^2 ODW), nitrogen ($\mu\text{g-at/g ODW}$) and phosphorus ($\mu\text{g-at/g ODW}$) for V. americana are plotted in Fig. 11 as functions of distance downstream. The peaks in biomass on the south shore correspond to Blount's Bay (km 10 - 16 S) and the Maul's Pt.-Core Pt. stratum (km 16 - 24 S). The peak in biomass on the north shore corresponds to the Ragged Pt.-Hawkins Ldg. stratum (km 17 - 23 N).

No consistent pattern can be seen in nitrogen concentrations of V. americana. Locally higher plant nitrogen was found on the south shore just beyond the entrance of Blount's Creek (km 14 S), and in substrata influenced by Durham Creek (km 25 S and km 28 S). Nitrogen on the north shore was more variable presumably due to the influence of several creeks including Bath Creek (km 23 - 24 N). In the upper river a gradual decrease in nitrogen content is seen from Washington to Blount's Bay. This trend was interpreted as a direct influence of discharge by the Tar River.

Phosphorus concentrations in V. americana exhibited no obvious trends, the levels in the water and sediments presumably well above those required by the plant. Fig. 10 shows nitrogen:phosphorus ratios for V. americana and the data show again the influence of local tributaries on increasing nitrogen in these submersed plants, most notably Blount's Creek (km 13 S) and Durham Creek (km 25 S) on the south shore, and Broad Creek (km 10 N)

Fig. 10. Nitrogen:phosphorus ratios for Vallisneria americana in the Pamlico River estuary, August 1975. (—▲— north shore,●..... south shore).

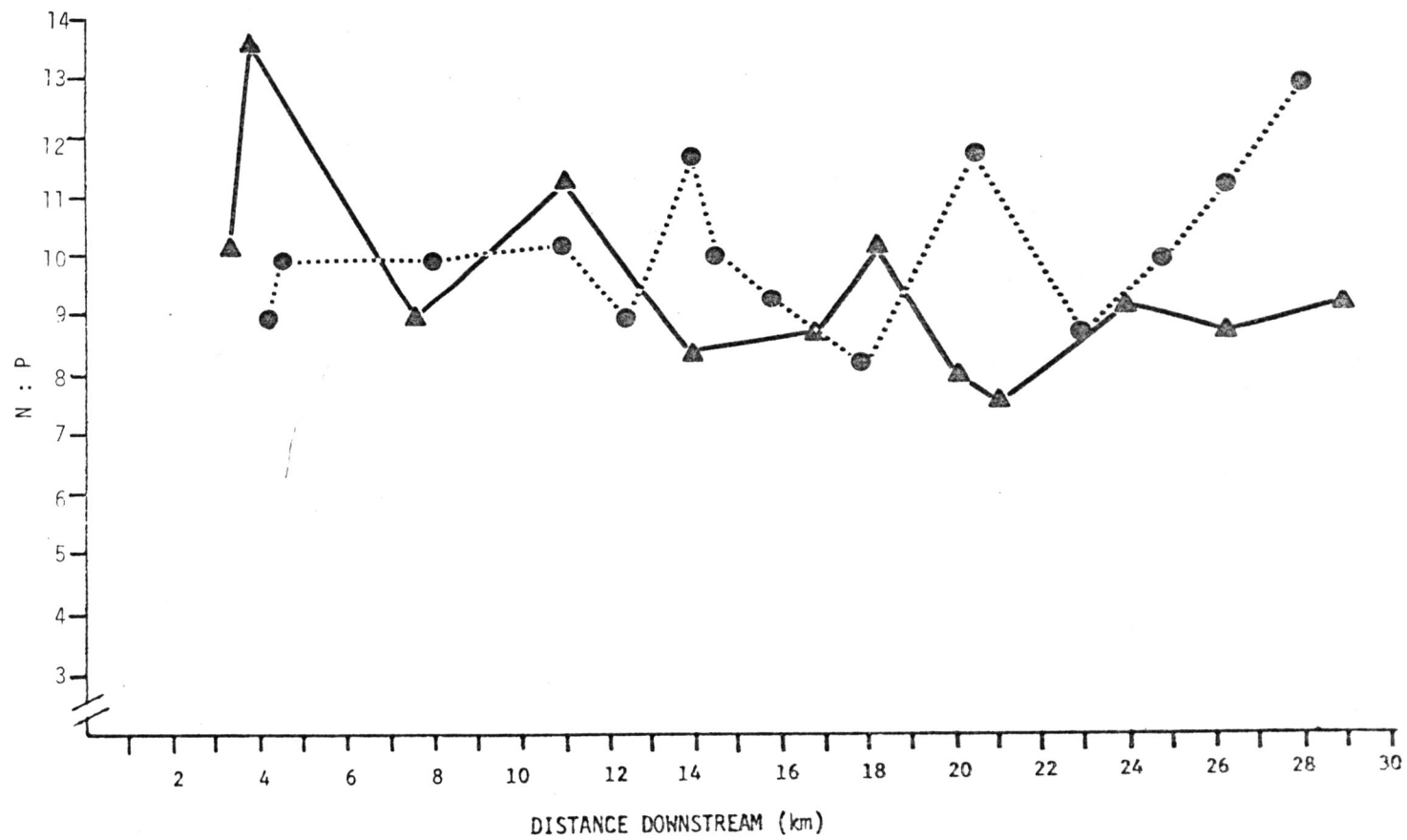
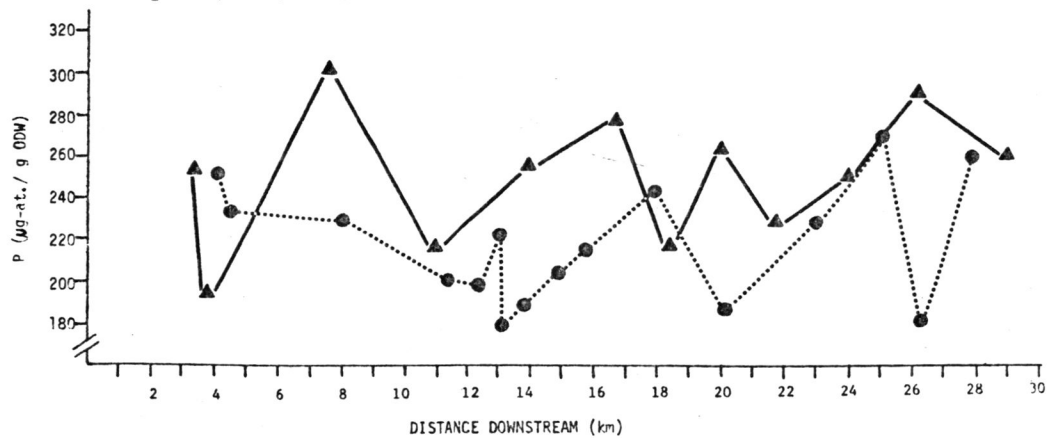
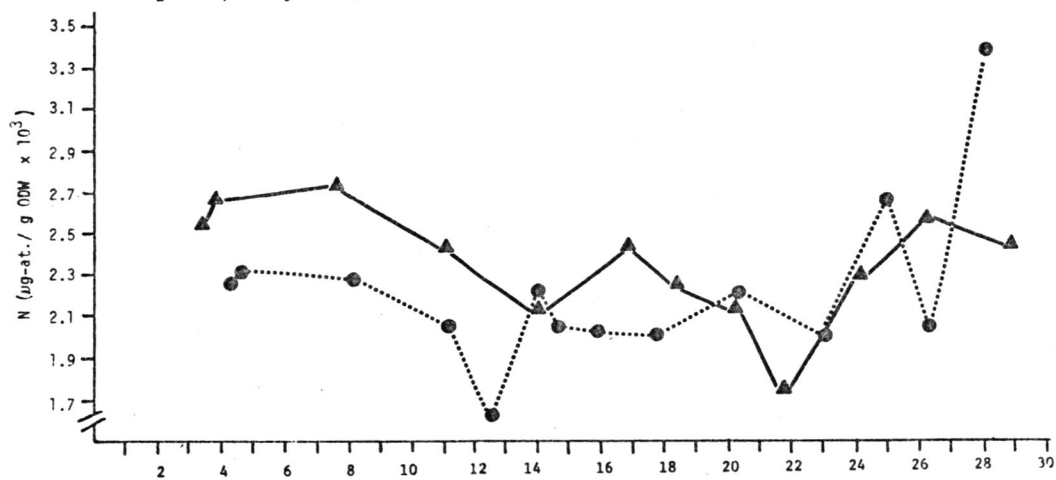
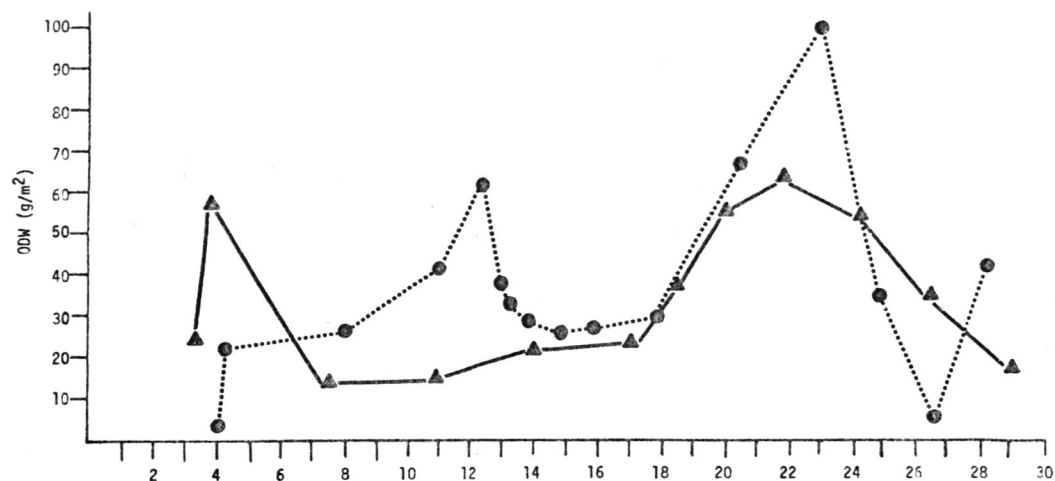


Fig. 11. Upper - Biomass of Vallisneria americana in the Pamlico River estuary, August 1975. Middle - Nitrogen content of Vallisneria americana in the Pamlico River estuary, August 1975. Lower - Phosphorus content of Vallisneria americana in the Pamlico River estuary, August 1975. (—▲— north shore,●..... south shore).



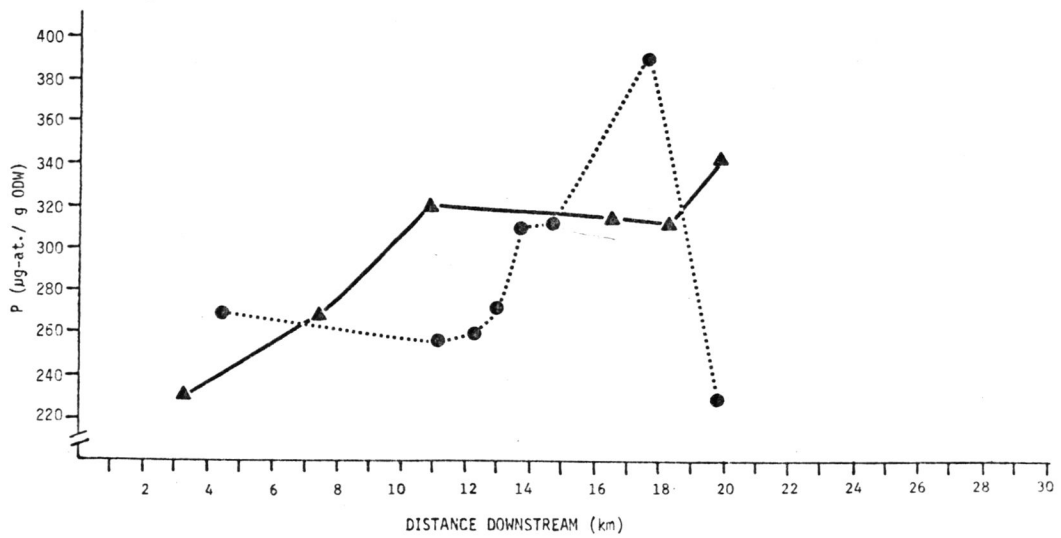
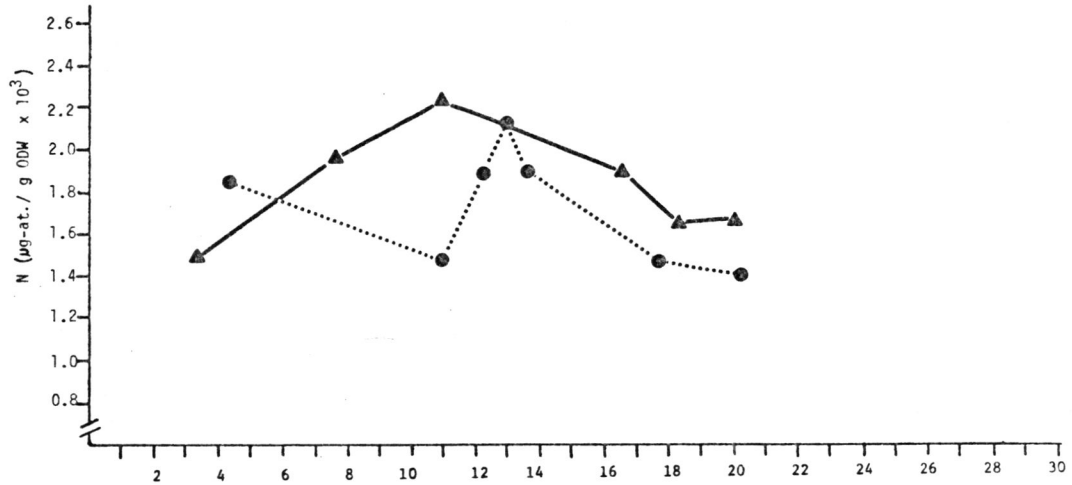
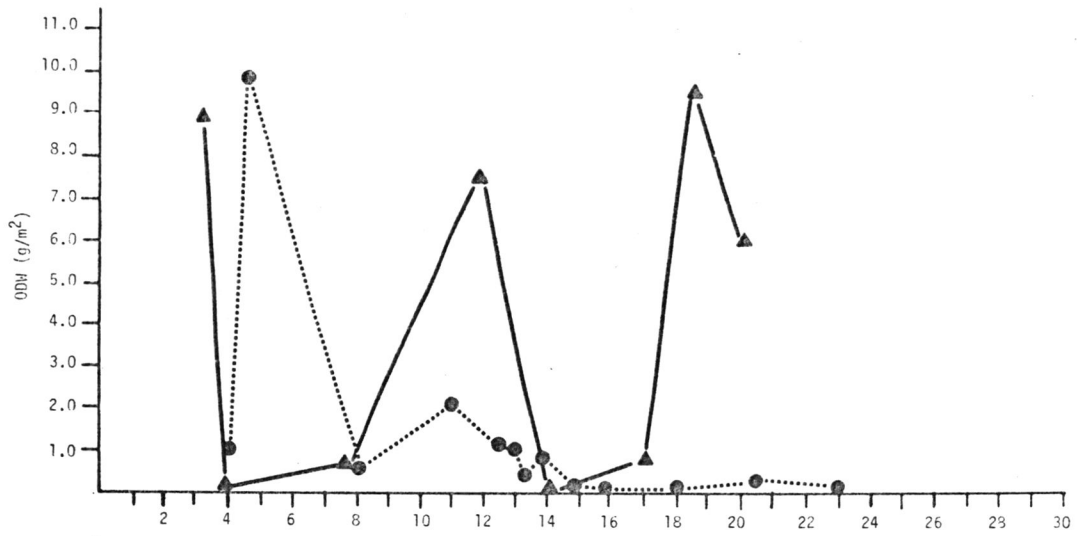
and Bath Creek (km 23 N) on the north shore. A high nitrogen:phosphorus ratio was also found at Sparrow Bay (km 20 - 22 S) which was the site of a Cladophora glomerata (L.) Kutz. bloom in August 1975.

Gerloff and Kromboltz (1966) reported that the critical concentration of nitrogen for Vallisneria americana (the tissue concentration just adequate for maximum growth) is 1.3% of the dry weight, or 1170 $\mu\text{g-at/g ODW}$. They also reported the critical concentration of phosphorus as 0.13% of the dry weight, or 52 $\mu\text{g-at/g ODW}$. In the Pamlico River estuary, V. americana contains about 1.4 - 3 times the critical concentration of nitrogen and five times the critical phosphorus concentration. Therefore the major species of rooted macrophytes does not appear to be nutrient-limited.

Biomass and nutrient curves for P. perfoliatus are given in Fig. 12. The biomass of P. perfoliatus was sporadic along the north shore and the peaks represent individual substrata where samples were taken within thick stands of the species. Nitrogen in P. perfoliatus was generally higher in the middle stretches of the river occupied by submersed beds. The nitrogen content of the species has been correlated with the nitrogen content of the substrate (Misra 1938), so the nitrogen curve may be related to differences in substrate although no data was collected on this.

Phosphorus in P. perfoliatus was significantly ($p < .05$) correlated with distance downstream on the north shore ($y = 229.1 + 5.5x$; y = phosphorus concentration in $\mu\text{g-at/g ODW}$ and x = distance in km; $r = 0.90$). A similar trend was seen for the south shore with the exception of samples taken from Sparrow Bay (km 20 - 22 S). According to Wetzel (1975), the major source of phosphorus for most aquatic plants is the water. The study of Potamogeton pectinatus (Jones and Cullimore 1973) supports this idea

Fig. 12. Upper - Biomass of Potamogeton perfoliatus in the Pamlico River estuary in August 1975. Middle - Nitrogen content of Potamogeton perfoliatus in the Pamlico River estuary in August 1975. Lower - Phosphorus content of Potamogeton perfoliatus in the Pamlico River estuary in August 1975. (—▲— north shore,●..... south shore).

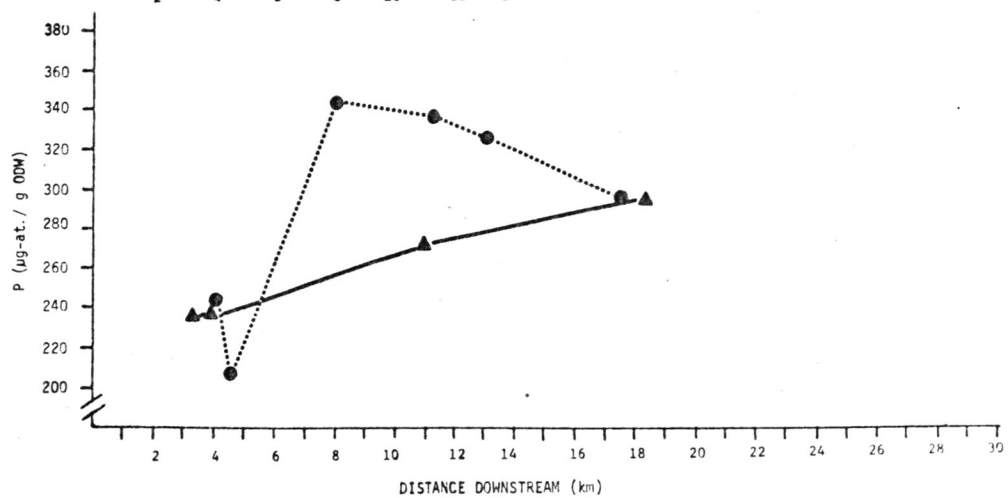
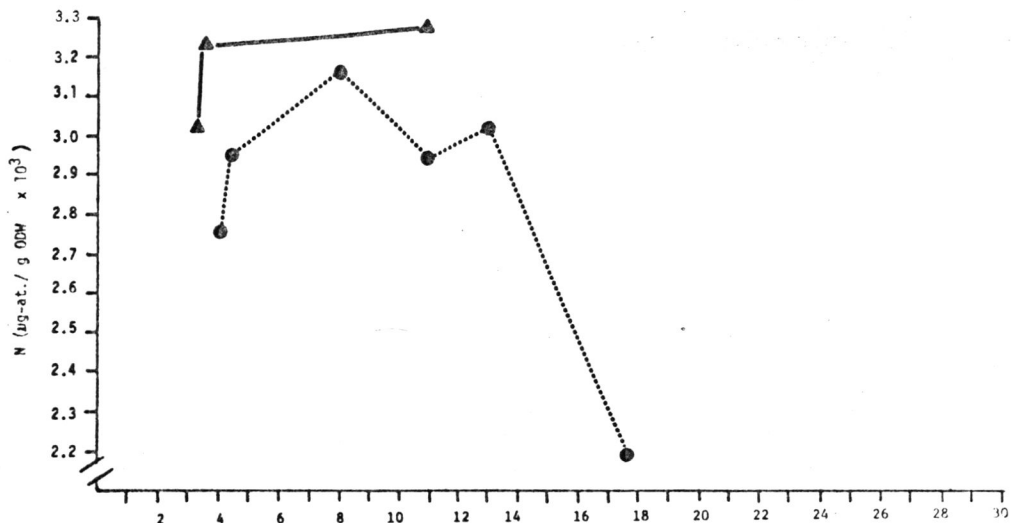
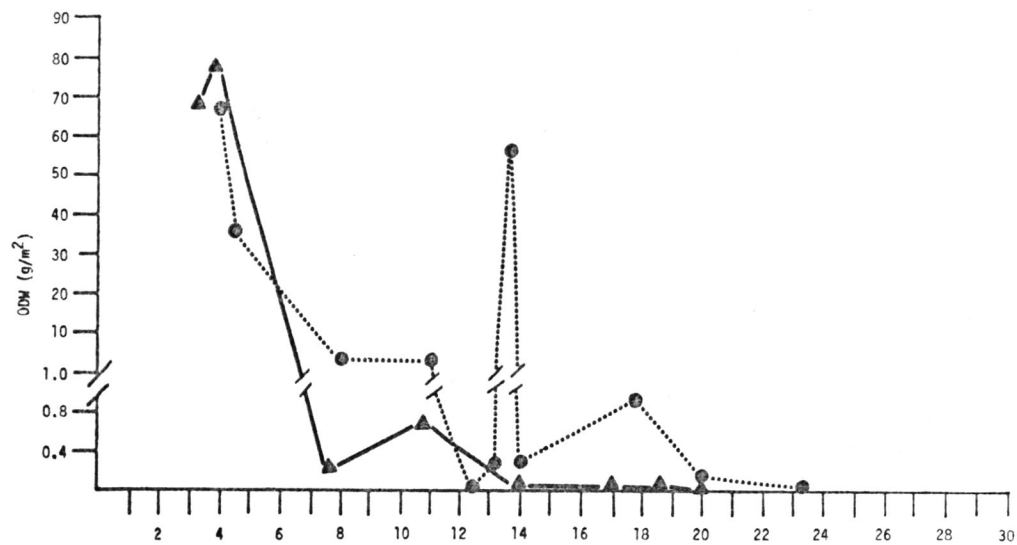


and indicates that phosphate in the sediments may not be so readily available, even though it may be present in high concentrations. However, there is evidence for phosphate absorption by roots of aquatic plants (McRoy and Barsdate 1970). In the Pamlico River estuary water further downstream near the lower limit of macrophyte colonization has been shown by Hobbie (1970) to have higher phosphorus concentrations than upriver areas. This same trend in phosphorus in P. perfoliatus indicates that this species is responsive to phosphate levels in the water. The low phosphorus levels in P. perfoliatus at Sparrow Bay (km 20 - 22 S) may have been the results of greatly reduced flow rate and "competition" for nutrients within the dense V. americana and C. glomerata mats in the area.

Similar curves for N. guadalupensis are given in Fig. 13. Although relatively few samples of this species were analyzed the nutrient data show two important features. N. guadalupensis had the highest nitrogen content of any macrophyte in the estuary and samples downstream (km 18 S) had greatly reduced concentrations. The magnitude of nitrogen accumulation in this species indicates a link between high nitrogen in the water during July 1975, and the rampant growth of N. guadalupensis at Washington Park. This growth is indicated on the biomass curve in Fig. 13 at km 3 - 5 on both shores. Trends in phosphorus content of N. guadalupensis were similar to those noted for P. perfoliatus. From its response to known trends in water quality in the estuary, namely, decrease in nitrogen downstream and increase in phosphorus downstream, N. guadalupensis is likely to be a good indicator of nutrients in the water column.

Estimates for the storage of nitrogen, phosphorus and organic biomass by the terminal crop (peak biomass) of rooted macrophytes in 1975 appear

Fig. 13. Upper - Biomass of Najas guadalupensis in the Pamlico River estuary, August 1975. Middle - Nitrogen content of Najas guadalupensis in the Pamlico River estuary, August 1975. Lower - Phosphorus content of Najas guadalupensis in the Pamlico River estuary, August 1975. ( north shore,  south shore).



in Table 17. Highest values for nutrients/m² were recorded for the two strata upstream from Blount's Bay (km 0 - 10 N and km 0 - 10 S) and the Maul's Pt.-Core Pt. stratum (km 16 - 24 S). These figures reflect the relatively high biomass present in those areas. Total peak biomass for the estuary reached nearly 200 MT ODW and the terminal crop contained 3.7 MT nitrogen and 1.4 MT phosphorus. The 3.7 MT nitrogen contained in macrophytes is less than 5% of the total nitrogen present in the waters of the estuary as reported for the summer of 1973 (Harrison and Hobbie 1974). However the storage data indicate that macrophytes are a significant producer component and a major source/sink of nutrients in the upper estuary.

Filamentous Algae

Measurable quantities of Compsopogon coeruleus (Balbis) Mont. were collected in almost every stratum during the summer of 1974, with the exception of the extreme downstream areas (Table 18). Only August biomass data is shown here although a limited amount of data was gathered in July. Biomass along the south shore was much higher than that along the north shore. Blount's Bay (km 10 - 16 S) and the Maul's Pt.-Core Pt. stratum (km 16 - 24 S) had both the highest totals and the highest biomass per unit area. In every case where the alga was found except the Core Pt.-Texasgulf stratum (km 24 - 29 S), mean biomass of C. coeruleus was much higher than that of all other macrophytes combined.

The August figure of 272 MT ODW of C. coeruleus (Table 19) was thought to be near the seasonal maximum since the species subsequently disappeared rapidly. Significant amounts of the alga could not be found one month after the August sampling date. Although the July estimate of only 40 MT is based on limited data, the several-fold increase during one month ill-

Table 17. Biomass and nutrients in aquatic macrophytes in the Pamlico River estuary, August 1975.

Area	ODW (g/m ²)	N (g/m ²)	P (g/m ²)	ODW (MT)	N (kg)	P (kg)
North Shore						
U.S. 17-Broad Creek Pt.	66.3	3.46	0.77	17.30	266.0	63.1
Broad Creek Pt.- Ragged Pt.	23.1	0.50	0.18	12.20	265.7	95.9
Ragged Pt.-Hawkins Ldg.	62.0	0.46	0.46	26.69	453.5	204.7
Hawkins Ldg.-Mixon Creek	46.7	0.77	0.38	10.58	167.5	87.4
South Shore						
Chocowinity Bay- Hill's Pt.	65.8	1.78	0.48	12.33	326.6	88.1
Blount's Bay-West	54.0	0.81	0.34	24.76	383.0	162.4
Blount's Bay-East	34.2	0.73	0.25	16.99	294.3	115.7
Maul's Pt.-Core Pt.	92.6	1.81	0.67	72.42	1352.3	505.8
Core Pt.-Texasgulf	35.0	0.70	0.32	4.82	91.5	40.7
North Shore	53.6	1.28	0.43	66.77	1152.7	451.1
South Shore	73.1	1.47	0.52	131.32	2447.7	912.7
River	66.5	1.40	0.49	198.09	3660.4	1363.8

Table 18. Biomass of Compsopogon coeruleus in the Pamlico River estuary during August 1974.

Area	ODW (g/m^2)	Total Biomass (MT)
North Shore		
Broad Creek Pt.-Ragged Pt.	44.1	28.7
Ragged Pt.-Hawkins Ldg.	18.8	3.5
Hawkins Ldg.-Mixon Creek	13.4	2.9
Gaylord Bay-North Creek	0	0
South Shore		
Blount's Bay	105.6	114.9
Maul's Pt.-Core Pt.	113.1	121.6
Core Pt.-Texasgulf	3.4	0.8
Indian Island	0	0

Table 19. Biomass estimates of nuisance algae in the Pamlico River estuary.

Species	ODW (MT)		
	July 1974	August 1974	August 1975
<u>Compsopogon coeruleus</u>	40	272	0.75
<u>Cladophora glomerata</u> ^a	-	-	10.90

^a Cladophora glomerata was found in 1974 only in small amounts scattered in the estuary.

ustrates the tremendous growth rate of this species. Significant amounts of C. coeruleus sampled during 1975 occurred only along the west side of Blount's Bay (km 12 S) and on the north shore above Broad Creek Pt. (km 10 N) near Washington.

Northeast wind storms probably accounted for the dense accumulations of C. coeruleus in 1974 in Blount's Bay and near Sparrow Bay (km 20 - 22 S). The extensive littoral area (more than 400 m from shore to 2 m water depths in some places), coupled with high summer temperatures and generally lower turbidity, provided prime conditions for proliferation of C. coeruleus at these sites. Growth to bloom proportions may have been associated with increased nitrogen (especially nitrate) levels in the water upstream, or from pulses of increased nitrate concentrations associated with periods of high river flow. Detailed seasonal studies of littoral inorganic nutrients are needed to test this hypothesis.

Some C. coeruleus was found in the estuary (as well as in creeks) during the winter. At any rate the data shown here indicates that little original "seed" material need be present for explosive growths of C. coeruleus to occur.

Biomass and nutrient data for the C. glomerata bloom in Sparrow Bay (km 20 - 22 S) during August 1975 are given in Table 20. The alga appeared very suddenly and a northeast wind storm was probably responsible for accumulation of the alga into extensive mats in the bay. Biomass per unit area of the submersed mats of C. glomerata equaled that of the rooted macrophytes, while the shoreline mats had a biomass of over seven times that of V. americana in the area. The entire bloom area covered 17 ha and contained 10.9 MT ODW, 291.2 kg nitrogen and 46.5 kg phosphorus. The

Table 20. Standing crop and inorganic nutrient concentrations of Cladophora glomerata and Vallisneria americana during a bloom at km 21 S on the Pamlico River estuary, August 1975.

Source	ODW ₂ (g/m ²)	SE	N ^a	P ^a	Area (ha)	Total ODW (kg)	Total N (kg-at)	Total P (kg-at)
Submersed								
<u>C. glomerata</u>	40.2	4.1	1906	132	15.5	6231	11.9	0.8
Rooted								
<u>V. americana</u>	41.4	2.8	2197					
Shoreline Mat								
<u>C. glomerata</u>	254.4	102.8						
<u>V. americana</u>	27.6	14.7	2574	287				
Totals:								
Shoreline Mat	282.0	58.7	1970 ^b	147	1.6	4512	8.9	0.7
Bloom					17.1	10643	20.8	1.5

^a Nitrogen and phosphorus concentrations are in $\mu\text{g-at/g ODW}$.

^b Estimates are based on nutrient concentrations of submersed C. glomerata

nitrogen:phosphorus ratios of the C. glomerata and V. americana were 14:1 and 10:1 respectively. High photosynthetic rates by the C. glomerata were evident because the submersed mats rose as oxygen accumulated during the day within the mats. It is interesting to note that the location of the C. glomerata bloom in 1975 is the same area where the highest mean biomass of C. coeruleus was measured in 1974. The 1975 bloom persisted for about 8 wk and dissipated more slowly than the C. coeruleus in 1974.

Reasons for the sudden bloom conditions remain obscure, although it could again be explained by the alga's reaction to increased nitrogen levels during restricted high flow periods. The only significant amounts of C. glomerata observed before this bloom were in Bath Creek (km 26 N). A severe northeast storm like the one that occurred for several days before the 1975 bloom appeared could account for transport of C. glomerata from its source in Bath Creek to Sparrow Bay where the bloom appeared. Here again, shallow water and warm temperatures favored maximum photosynthesis. A period of extensive rains occurred in the watershed during July and resulted in high estuarine flow. Runoff in the region could have been the key to bloom conditions in Sparrow Bay. Water samples taken in conjunction with a study of organic carbon flux in the estuary showed that the water in the immediate vicinity of the bloom contained 65.5 $\mu\text{g-at/l}$ of total soluble (filtered) nitrogen, while the water in Blount's Bay (upstream) and near Durham Creek (downstream) contained only about 50 $\mu\text{g-at/l}$ total soluble nitrogen. This difference prevailed in spite of the heavy macrophyte biomass. All of these values were significantly higher than the 11.6 - 34.5 $\mu\text{g-at/l}$ range for total filtered nitrogen reported by Harrison and Hobbie (1974) for the estuary on 8 September 1972. Thus, it appears that the water near the

C. glomerata bloom was higher than usual in nitrogen. It is not known whether this nitrogen was inorganic nitrogen from runoff or organic nitrogen secreted by C. glomerata and other macrophytes.

SUMMARY

Aerial photography was used successfully to map submersed plant beds. Coverage of macrophytes increased from 319 ha in July 1974 to 372 ha in August and then dropped to 255 ha by October. In September 1975 coverage was 284 ha. Significant areal changes occurred during the growing season but maximum coverage was relatively stable from year to year, especially in upstream areas. Used in conjunction with field studies the aerial photography made possible estimates of macrophyte biomass that should be more accurate than classical transect studies.

Field studies in 1974 showed that density of plants in the estuary ranged from 80 - 360 plants/m². Biomass values ranged from 2.3 - 50 g/m² organic dry weight (ODW), with the highest biomass occurring in the upstream areas and in deep water beds. Greatest differences in July and August biomass occurred in shallow areas protected from intense wave action.

Total biomass in August 1975 ranged from 22 - 100 g ODW/m² with average values around 65 g ODW/m². Recorded biomass was generally higher in 1975 although much of the difference could be attributed to sampling changes between the two years.

Hydrographic data showed that salinity fluctuated as much as 13 parts per thousand (‰) during a year, and water temperature ranged from 5 - 34 °C. Secchi disc transparency values ranged from 0.3 - 2.0 m. Fluctuations of these factors probably contributed to the low diversity (0 - 3.0 natural belts, Brillouin's Index) encountered in the submersed plant community. Dominance by Vallisneria americana Michx. with relative exclusion of other species was obvious.

Total estuarine biomass estimates were 76, 104 and 198 MT ODW for

July 1974, August 1974 and August 1975, respectively. High total biomass of various areas within the estuary seemed to be related to physiography of the littoral, lower turbidity, more stable salinity and reduced wind and wave stress. Biomass in 1975 was significantly higher than that in 1974 but only part of this increase could be attributed to a real change in biomass.

Study of submersed plant bed patterns in the estuary revealed several factors that may affect colonization. High turbidity likely limited beds to areas less than 2 m in depth, and fluctuating water levels probably prevented colonization very close to the shoreline in less than 40 cm of water. Wind-generated wave action appeared to be important in formation of circular beds and, in extreme cases, greatly reduced colonization and biomass, especially in areas adjacent to seawalls and bulkheads.

Studies of floating macrophyte debris revealed that most of the living plant biomass was lost to detritus between August and November. Catch values for this period were from 20 - 40 g fresh weight/min while catches before and after this time were less than 7 g fresh weight/min, even in the area of the plant beds. Comparatively little macrophyte debris left the area of the estuary colonized by plants, at least while it was in the floating stage. Storms correlated with production and transport of significant amounts of plant debris.

Inorganic nutrients in aquatic macrophytes, especially phosphorus, were relatively high. V. americana contained 2250 μ g-at/g ODW nitrogen and 235 μ g-at/g ODW phosphorus. These values are well above those reported to be limiting for the species. Comparison of species collected from the same area indicated that Najas guadalupensis (Spreng.) Magnus had higher

concentrations of nitrogen ($2870 \mu\text{g-at/g ODW}$) than V. americana ($2250 \mu\text{g-at/g ODW}$), which, in turn, had higher concentrations of nitrogen than Potamogeton perfoliatus var. bupleuroides (Fern.) Farw. ($1860 \mu\text{g-at/g ODW}$). P. perfoliatus had the highest mean phosphorus concentration ($303 \mu\text{g-at/g ODW}$) and V. americana the lowest ($235 \mu\text{g-at/g ODW}$). High tissue nitrogen in N. guadalupensis upstream may have been related to inputs from the Tar River and septic tank drainage, while phosphorus in P. perfoliatus seemed to follow a gradient of increasing phosphorus in the water downstream.

Calculation of the storage capacity of macrophytes indicated that the maximum, or terminal, crop of plants in 1975 contained 66.5 g ODW/m^2 , 1.4 g/m^2 nitrogen and 0.5 g/m^2 phosphorus. Considering the entire ecosystem the macrophyte community contained 198 MT ODW, 3.7 MT nitrogen and 1.4 MT phosphorus. Even though these values were a small portion of the total nitrogen in the estuary they indicated that aquatic plants were a significant producer component and source/sink of inorganic nutrients in the upper estuary.

Nuisance filamentous algae were prominent in the estuary during both years, though more so in 1974. The August 1974 biomass of Comosopogon coeruleus (Balbis) Mont. was estimated to be 272 MT ODW or over twice that of all other macrophytes combined. In 1975 Cladophora glomerata (L.) Kutz. was the dominant nuisance algae with a biomass of 11 MT ODW. Bloom conditions of these species may have arisen from optimum growth conditions in a clear warm littoral as well as high nitrogen levels in the water.

Submersed plant beds in the Pamlico River estuary responded to a large number of environmental factors that manifested changes in biomass, diversity and tissue nutrients which resulted in great spatial variation in those par-

ameters throughout the estuary. Although no significant trends were found during the two year study period, the appearance of filamentous algae in nuisance proportions indicates changing environmental quality and allows speculation of more widespread changes in the estuary.

The work reported here leaves much to be done. Further studies should involve the fluxes of nitrogen and phosphorus into and out of macrophytes (from water and substrate). The relationship of inorganic nutrients and wind tides to filamentous algal blooms needs investigation. Algal blooms are a significant indication of eutrophication tendencies in the Pamlico River estuary as well as being the most important macrophytes affecting human use of the estuary.

LITERATURE CITED

- Adams, F. S., H. Cole and L. B. Massie. 1973. "Element Constitution of Selected Aquatic Vascular Plants from Pennsylvania: Submersed and Floating Leaved Species and Rooted Emergent Species," Environmental Pollution 5:117-147.
- American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater, 13th ed., 874 pp.
- Anon. 1965. Back Bay-Currituck Sound Data Report, Vol I. Introduction and Vegetational Studies, U. S. Fish and Wildlife Service, Virginia Commission of Game and Inland Fisheries and N. C. Wildlife Resources Commission. Mimeo Report.
- Avery, T. E. 1968. Interpretation of Aerial Photographs, Minneapolis, Minnesota: Burgess Publishing Co., 324 pp.
- Boyd, C. E. 1970. "Vascular Aquatic Plants for Mineral Nutrient Removal from Polluted Waters," Economic Botany 24:95-103.
- Copeland, B. J. and J. E. Hobbie. 1972. Phosphorus and Eutrophication in the Pamlico River Estuary, N. C. 1966-1969, A Summary, Water Resources Research Institute, University of North Carolina, Report No. 65, 86 pp.
- Crawford, C. C., J. E. Hobbie and K. L. Webb. 1974. "The Utilization of Dissolved Free Amino Acids by Estuarine Microorganisms," Ecology 55:551-563.
- David, F. N. and P. G. Moore. 1954. "Notes on Contagious Distribution in Plant Populations," Annals of Botany London 18:47-53.
- Edwards, R. W. and M. W. Brown. 1960. "Aerial Photographic Method for Studying Distribution of Aquatic Macrophytes in Shallow Waters," Journal of Ecology 48:161-163.
- Gerloff, G. C. 1975. Nutritional Ecology of Nuisance Aquatic Plants. National Environmental Research Center, Office of Research and Development, U. S. Environmental Protection Agency, Corvallis, Oregon, 78 pp.
- Gerloff, G. C. and P. H. Kromboltz. 1966. "Tissue Analysis as a Measure of Nutrient Availability for the Growth of Angiosperm Aquatic Plants," Limnology and Oceanography 11:529-537.
- Getsinger, K. 1976. Changes in a Myriophyllum spicatum L. Community Following 2,4-D Treatment, M. A. thesis (in preparation), East Carolina University.

- Gustafson, T. D. and M. S. Adams. 1973. Remote Sensing of Aquatic Macrophytes, Environmental Studies Institute, University of Wisconsin, Report No. 24, 26 pp.
- Harrison, W. G. and J. E. Hobbie. 1974. Nitrogen Budget of a North Carolina Estuary, Water Resources Research Institute, University of North Carolina, Report No. 86, 172 pp.
- Harrison, P. G. and K. H. Mann. 1975. "Chemical Changes During the Seasonal Cycle of Growth and Decay in Eelgrass (*Zostera marina*)," Journal of Fisheries Research Board of Canada 32:615-621.
- Harwood, J. E. 1975. Aerial Multispectral Sensing of Aquatic Macrophytes in the Pamlico River Estuary, N. C. M. A. thesis, East Carolina University, 79 pp.
- Hobbie, J. E. 1970. Phosphorus Concentrations in the Pamlico River Estuary of North Carolina, Water Resources Research Institute, University of North Carolina, Report No. 33, 47 pp.
- Hobbie, J. E. 1971. Phytoplankton Species and Populations of the Pamlico River Estuary of North Carolina, Water Resources Research Institute, University of North Carolina, Report No. 56, 147 pp.
- Hynes, H. B. N. 1964. The Ecology of Running Waters, Toronto: University of Toronto Press, 555 pp.
- Jones, G. and D. R. Cullimore. 1973. "Influence of Macro-Nutrients on the Relative Growth of Water Plants in the Qu'Appelle Lakes," Environmental Pollution 4:283-290.
- Kelly, M. G. 1971. Studies of Benthic Cover in Near-Shore Temperate Waters Using Aerial Photography, New York Ocean Science Laboratory, Technical Report No. 0007, 43 pp.
- Lind, C. T. and G. Cottam. 1968. "The Submerged Aquatics of University Bay: A Study in Eutrophication," American Midland Naturalist 81: 353-369.
- Lukens, J. E. 1968. "Color Aerial Photography for Aquatic Vegetation Surveys," in Proceedings of the Fifth Symposium on Remote Sensing of Environment, Ann Arbor: University of Michigan, pp. 441-446.
- McRoy, C. P. and R. J. Barsdate. 1970. "Phosphate Absorption in Eelgrass," Limnology and Oceanography 15:6-13.
- Misra, R. D. 1938. "The Distribution of Aquatic Plants in the English Lakes," Journal of Ecology 26:411-452.

- Nichols, S. A. and S. Mori. 1971. "The Littoral Macrophyte Vegetation of Lake Wingra: An Example of a Myriophyllum spicatum Invasion in a Southern Wisconsin Lake," Wisconsin Academy of Science, Arts and Letters, 59:107-119.
- Odum, H. T. and B. J. Copeland. 1974. "A Functional Classification of the Coastal Systems of the United States," in Coastal Ecological Systems of the United States, H. T. Odum, B. J. Copeland and E. A. McMahan eds., Vol. I, Part I, Washington, D. C.: The Conservation Foundation, pp. 4-84.
- Phillips, R. C. 1960. Observations on the Ecology and Distribution of the Florida Seagrasses, Florida State Board of Conservation, Marine Laboratory, St. Petersburg, Florida, 72 pp.
- Pielou, E. C. 1966. "The Measurement of Diversity in Different Types of Biological Collections," Journal of Theoretical Biology 13:131-144.
- Reed, S. 1976. Seasonal Dynamics of the Aquatic Macrophytes of the Pamlico River Estuary, M.A. thesis (in preparation), East Carolina University.
- Simmons, E. G. 1957. "An Ecological Survey of the Upper Laguna Madre of Texas," Publications of the Institute of Marine Science of the University of Texas, 4:156-200.
- Smartt, P. F. M. and J. E. A. Grainger. 1974. "Sampling for Vegetation Survey: Some Aspects of the Behaviour of Unrestricted, Restricted, Stratified Techniques," Journal of Biogeography 1:193-206.
- Snell, F. D. and F. M. Biffen. 1944. Commercial Methods of Analysis, New York: McGraw-Hill, Inc., pp. 189-191.
- Southwick, C. H. and F. W. Pine. 1975. "Abundance of Submerged Vascular Vegetation in the Rhode River from 1966 to 1973," Chesapeake Science 16(1):147-151.
- Specht, M. R., D. Needler and N. L. Fritz. 1973. "New Color Film for Water-Penetration Photography," Photogrammetric Engineering 39: 359-369.
- Westlake, D. F. 1965. "Some Basic Data for Investigations of the Productivity of Aquatic Macrophytes," Memor. Inst. Ital. Idrobiol. 18 (suppl.):229-248.
- Wetzel, R. G. 1964. "Primary Productivity of Aquatic Macrophytes," Verh. Internat. Verein. Limnol. 15:426-436.

- Wetzel, R. G. 1975. Limnology, Philadelphia: W. B. Saunders Co., 743 pp.
- Wezernak, C. T. and D. R. Lyzenga. 1975. Analysis of Cladophora Distribution in Lake Ontario Using Remote Sensing, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 19 pp.
- Zamuda, C. D. 1976. Growth and Decomposition of Vallisneria americana in an Estuary, M. A. thesis (in preparation), East Carolina University.
- Zieman, J. C. 1972. "Origin of Circular Beds of Thalassia (Spermatophyta: Hydrocharitaceae) in South Biscayne Bay, Florida, and Their Relationship to Mangrove Hammocks," Bulletin of Marine Science 22(3): 559-574.

APPENDIX

The great variation in density, biomass and diversity of the submersed plants in the Pamlico River estuary presented many problems for accurate sampling. Two sampling models were employed to minimize variation due to the sampling methods alone. However the use of two methods confused comparison of biomass between the two years of the study.

The purpose of this appendix is to evaluate the sampling procedures used in the 1974 and 1975 field studies in terms of deriving an optimum method for obtaining total biomass estimates as well as the best method for comparing year to year changes in selected areas. With the information gained in the present study, future work on submersed plants in the estuary could be considerably reduced, yet accomplish the same end product.

In sampling submersed plants for biomass three sampling problems should be evaluated beforehand: optimum quadrat size, number of samples and a specific sampling model.

The present study employed two quadrat sizes: 0.1 m^2 was used in 1974 and 0.25 m^2 was used in 1975. Only after the 1974 work was completed was a quantitative test done to determine optimum quadrat size. As suggested by Greig-Smith (1964), nested quadrats of varying sizes were used. Plant density was determined in nested quadrats of .01, .05, .10, .25, .35 and $.50 \text{ m}^2$, with nine replications in a continuous uniform plant bed. Plots of density, variance and mean square against quadrat size were made. This data indicated that a quadrat of 0.25 m^2 yielded low variance and stable density with respect to other sizes. The mean square data also showed that the plants were clumped in aggregations of about $.08 \text{ m}^2$ due to vegetative propagation. Therefore use of a 0.1 m^2 quadrat, as was done in 1974, led to higher variance and somewhat

inflated density values. A matched pair test showed that within the same plant bed, the 0.1 m^2 quadrat gave higher density values than the 0.25 m^2 quadrat. This relationship was significant beyond the .001 level. However the 0.25 m^2 quadrat was not significantly different from the larger quadrat sizes (0.35 and 0.50 m^2).

The two sampling models used in this study were employed in different years and utilized different quadrat sizes. These factors led to confusion in year to year comparison of plant biomass in the same area. Since no direct comparison of methods at the same time was made, evaluation of each method with regard to biomass estimates also becomes more difficult. The precision, or repeatability, of each sampling method is also an important consideration for determining methods for future studies.

In 1974 a transect was replicated three times at the same place in the Blount's Bay-West stratum (km 10 - 13 S). One-way analysis of variance tests showed no significant differences in plant density between replications ($F_{(.05)} = .01$). In addition a transect in the Hawkins Ldg.-Mixon Creek stratum (km 23 - 31 N) was also replicated and the three replications tested for differences in biomass (by species) with a matched pair analysis. All replications were shown to be significantly different ($p < .05$) in total biomass of all species, and the biomass of three species: Vallisneria americana Michx., Potamogeton perfoliatus var. bupleuroides (Fern.) Farw., and Ruppia maritima L. Only two groups of minor species were not different: Najas guadalupensis (Spreng.) Magnus and Chara spp. and Nitella spp. Therefore the precision of the random transect, fixed station method used in 1974 was to some extent dependent on the location in the river and the distribution pattern of plants.

Precision tests of the 1975 sampling model were made in two substrata: a shallow clumped substratum in the Maul's Pt.-Core Pt. stratum (km 16 - 24 S) and a deep continuous bed in the Ragged Pt.-Hawkins Ldg. stratum (km 17 - 23 N). Three replications accomplished in each of these substrata were not significantly different ($p < .05$) in total biomass or biomass of any species. From these data it appears that the stratified systematic unaligned model used in 1975 was more precise than the transect method and performed well with lower variation under clumped and non-clumped plant distributions.

Table 21 is a comparison of maximum biomass estimates for 1974 and 1975 as measured by the two sampling methods. Standard errors averaged 8% of the mean in 1974 and 7% of the mean in 1975, and with few exceptions were less than 10% of the mean. Strata with the highest standard error:mean ratio in 1974 were shallow clumped beds and areas downstream that were characterized by clumped circular beds. This variation was reduced somewhat in 1975. For example, in the Hawkins Ldg.-Mixon Creek stratum the standard error was reduced from 18.9% of the mean in 1974 to 13.3% of the mean in 1975.

The number of samples required to obtain these variability levels is also an important criterion in the evaluation of methods. The reduction in the standard error:mean ratio of the Hawkins Ldg.-Mixon Creek stratum mentioned above was accomplished with 15 quadrats instead of 186 examined in 1974. In addition all 1974 calculations omitted three or more consecutive quadrats that contained no plants in an attempt to reduce variation of measurement. Considering the river as a whole the same level of variability was obtained

Table 21. Comparison of maximum submersed plant biomass in 1974 and 1975 as measured by two different methods.

Area	August 1974			August 1975		
	ODW (g/m ²)	SE	N	ODW (g/m ²)	SE	N
North Shore						
U.S. 17-Broad Creek Pt.	-	-	-	66.3	4.4	10
Broad Creek Pt.-Ragged Pt.						
Shallow	30.3	3.4	46	30.8	2.1	5
Deep	26.9	2.7	366	22.3	1.4	12
Ragged Pt.-Hawkins Ldg.						
Shallow	20.3	3.8	103	73.1	5.9	15
Deep	26.3	2.5	166	55.4	3.8	9
Hawkins Ldg.-Mixon Creek	10.6	2.0	186	46.7	6.2	15
Gaylord Bay-North Creek	3.0	1.1	77	-	-	-
South Shore						
Chocowinity Bay-Hill's Pt.	-	-	-	65.8	5.3	9
Blount's Bay-West						
Shallow	23.2	3.6	59	63.9	7.7	15
Deep	41.3	4.4	99	41.5	3.6	6
Blount's Bay-East						
Shallow	29.1	2.8	76	35.8	5.1	15
Deep	35.2	3.7	85	30.4	3.3	9
Maul's Pt.-Core Pt.						
Shallow	11.2	3.4	150	62.8	6.2	27
Deep	50.0	4.2	310	101.5	8.7	6
Core Pt.-Texasgulf						
Shallow	11.6	2.0	84	30.2	3.6	3
Deep	32.0	3.0	145	39.7	3.0	8
Indian Island	0.9	0.1	32	-	-	-
North Shore	25.0	3.1	944	53.6	3.7	66
South Shore	37.4	2.6	1040	73.1	5.2	98
River	33.8	2.7	1984	66.5	4.6	164

in 1975 with a 90% reduction in the number of quadrats examined. However the differences should not be interpreted to be only the result of the sampling models themselves. Tests showed that even with the transect sampling method a great reduction in sample number was possible without a significant change in biomass estimates. Alternate quadrats were eliminated from the 1974 data and biomass was calculated by strata. No significant differences ($p < .05$) prevailed in any stratum. Random elimination of transects within strata in 1974 showed that equivalent biomass estimates could have been obtained with only four transects in each stratum, and only three transects in some strata (Ragged Pt.-Hawkins Ldg., Hawkins Ldg.-Mixon Creek, and Gaylord Bay-North Creek). These tests were conducted after alternate stations had been eliminated from the data. Therefore it appears that a considerable reduction in sample size is possible with the transect method without a significant change in biomass estimates. However this still does not resolve any absolute differences between the two sampling methods.

The most important criterion in determining sampling intensity for year to year comparison of biomass in a selected area is the level of difference in biomass between years one wishes to detect. Milner and Hughes (1968) give a formula for determining the number of samples required for specified levels of accuracy:

$$N = n \left[\frac{t s}{D \bar{x}} \right]^2$$

where n is the number of trial samples, s is the standard error of the trial samples, D is the required level of accuracy (expressed as a decimal), $\bar{x}$ is the mean of the trial samples and t is from statistical tables (for the number of trial samples). Using the number of samples taken in the present study in 1975 it is possible to determine the number of samples needed for detec-

Table 22. Sampling intensity needed for detecting year to year biomass changes with 95% confidence.

Area	N ^a	Detectable Difference (%)			
		10	20	30	50
North Shore					
U.S 17-Broad Creek Pt.	10	22	6	3	1
Broad Creek Pt.-Ragged Pt.					
Shallow	5	16	4	2	1
Deep	12	23	6	3	1
Ragged Pt.-Hawkins Ldg.					
Shallow	15	45	12	5	2
Deep	9	22	6	3	1
Hawkins Ldg.-Mixon Creek	15	121	31	14	5
South Shore					
Chocowinity Bay-Hill's Pt.	9	30	8	4	2
Blount's Bay-West					
Shallow	15	100	25	12	4
Deep	6	27	7	3	2
Blount's Bay-East					
Shallow	15	139	35	16	6
Deep	9	55	14	7	3
Maul's Pt.-Core Pt.					
Shallow	27	111	28	13	5
Deep	6	27	7	3	2
Core Pt.-Texasgulf	11	69	18	8	3
North Shore	66	126	32	14	6
South Shore	98	198	50	22	9
River	164	304	76	34	13

^aN is the number of quadrats harvested in each area for the present study.

ting a specific level of change in year to year biomass. Table 22 shows the number of samples in each stratum that are required to show the given level of change. It is assumed that the samples are taken according to the sampling model used in 1975 in the present study. The data in Table 22 shows that with the sampling employed in the present study, it was possible in most strata to detect a 20% difference in yearly biomass. On the north shore in the Hawkins Ldg.-Mixon Creek stratum a 30% difference was possible. The same is true for shallow beds in both Blount's Bay strata and the Core Pt.-Texasgulf area. An increase in the number of samples allocated to these highly variable areas would achieve a uniform level of confidence for estimates in all areas of the estuary. This should be a goal of sampling in the future.

Future work on the Pamlico River estuary should take into consideration the environment and characteristics of the area selected for study before selecting a level of accuracy. The level of accuracy may even change with different locations. For example in the Hawkins Ldg.-Mixon Creek stratum (km 23 - 31 N) greater wave stress and salinity fluctuations would dictate a greater natural variability in year to year plant biomass than sheltered low salinity areas such as Blount's Bay. Therefore if the biomass changes are being attributed to some other factor, eutrophication, for example, a wider range of biomass must be considered normal in the downstream stratum.

The discussion heretofore has been based mostly on quantitative evidence derived from evaluation and comparison of the two sampling methods used in this study. However future work along these lines should also be based on some qualitative observations about the sampling that may aid in experimental design.

Classical random transect, fixed station studies, such as the one used

in the 1974 studies here, are excellent methods of determining effects of light and depth, wave action and distance from shore on the density and biomass of submersed plants. However several problems arise when this technique is applied to the estimation of total biomass, either in the river as a whole or on a selected area basis. Transect techniques are subject to large variation that arises from the random or aggregated nature of plant distribution within beds, and even the distribution of beds within the littoral. Clumped beds result in falsely low biomass values due to many empty quadrats, and high variability for the same reason. Continuous beds result in somewhat high biomass values since barren, or low biomass areas in a bed occur at random points and not at selected intervals. Transect techniques also require a great number of samples and a good deal of time for obtaining adequate repeatability and confidence intervals. For these reasons the classical transect methods are not well suited for biomass studies of a large study area such as the Pamlico River estuary.

A stratified systematic unaligned model, as was used in 1975 here, seems to perform well under continuous or aggregated plant distributions. Greatly reduced sample sizes are required, thus facilitating direct harvesting of biomass. Direct harvesting is certainly preferred over a technique which involves density measurements (with their own inherent errors), that are calibrated with relatively little plant biomass harvested. It is felt, therefore, that future work should employ a sampling procedure similar to that used in the 1975 studies presented here. Adjustment of sample size according to Table 22 will yield precise, confident biomass estimates for all areas of the river.

It is probably not necessary to sample the entire estuary in order to

obtain a total biomass estimate with reasonable confidence. Intensive sampling in selected areas will yield excellent estimates for those regions that could be extrapolated without much concern to other areas of the estuary. This type of study should include an area upstream from Broad Creek Pt. and Hill's Pt., on either shore. Biomass is typically uniform and high in these regions. A study of submersed plants as indicators of eutrophication or nutrient enrichment from the Tar River should also center around this area.

A second area for selected study should be Blount's Bay, probably the west side. This area is somewhat sheltered and is typified by medium biomass that could be extrapolated to plant beds from Broad Creek Pt. to Hawkins Ldg. on the north shore. Plant beds between Maul's Pt. and Core Pt. on the south shore should be studied due to the high biomass present and the abundance of macroalgae that accumulate in the area. Some sampling should also be done in the area of Bayview, North Carolina on the north shore. This region is stressed by wind and wave action. Biomass is highly variable here due to these factors and the bulkheaded shoreline. A sample site in this region would also give indications as to the effects of salinity fluctuation on plant biomass and diversity.

In a study such as described above, it would be advisable to obtain enough samples in each area to detect a 10% difference in yearly biomass. Since few stations are used an accurate representation of biomass at those stations is especially important. If the entire estuary is surveyed, sampling should attempt to resolve a 20% difference in biomass upstream from Core Pt. on the south shore and Bath Creek on the north shore. A detectable difference of 30% in the downstream areas would be reasonable since the biomass is low and scattered and an excessive number of samples would be required for 20%

precision. In addition, as mentioned above, the downstream strata should be expected to have a wider range of yearly biomass fluctuation.

In summary, some specific suggestions are given for future biomass studies of the submersed plants in the Pamlico River estuary:

- 1) use a stratified systematic unaligned sampling model, or similar one to the one used in the 1975 studies presented here
- 2) use a 0.25 m^2 quadrat
- 3) use Table 22 as a guideline to the number of samples needed in each area studied
- 4) attempt to achieve 10% accuracy in studies concentrating on selected areas as indicators of total biomass, but use only 20% or 30% accuracy if the entire estuary is sampled
- 5) choose areas that will be representative of other regions in the estuary. Suggestions are given in the preceding paragraphs.

The following citations were referenced in the Appendix but were not included in the Literature Cited section:

- Greig-Smith, P. 1964. Quantitative Plant Ecology, Washington, D. C.: Butterworth's, 2nd ed., 256 pp.
- Milner, C. and R. Ellyn Hughes. 1968. Methods for the Measurement of the Primary Production of Grassland, IBP Handbook No. 6, Blackwell Scientific Publications, 2nd printing, 70 pp.