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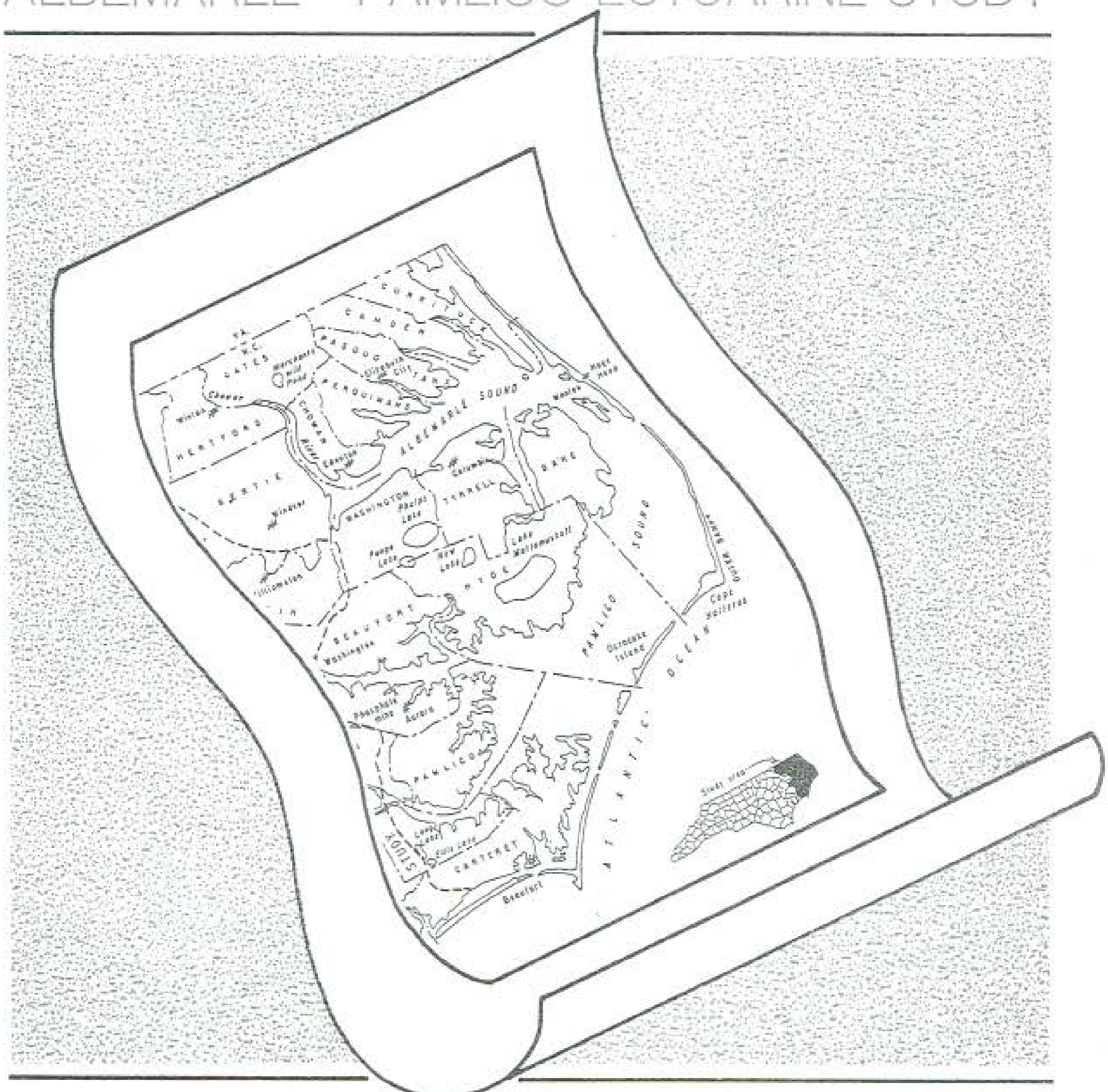
A SURVEY OF SUBMERSED AQUATIC VEGETATION OF THE CURRITUCK SOUND AND THE WESTERN ALBEMARLE-PAMLICO ESTUARINE SYSTEM

ALBEMARLE - PAMLICO ESTUARINE STUDY



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ALBEMARLE-PAMLICO

A SURVEY OF SUBMERSED AQUATIC VEGETATION OF THE CURRITUCK SOUND AND THE WESTERN ALBEMARLE-PAMLICO ESTUARINE SYSTEM

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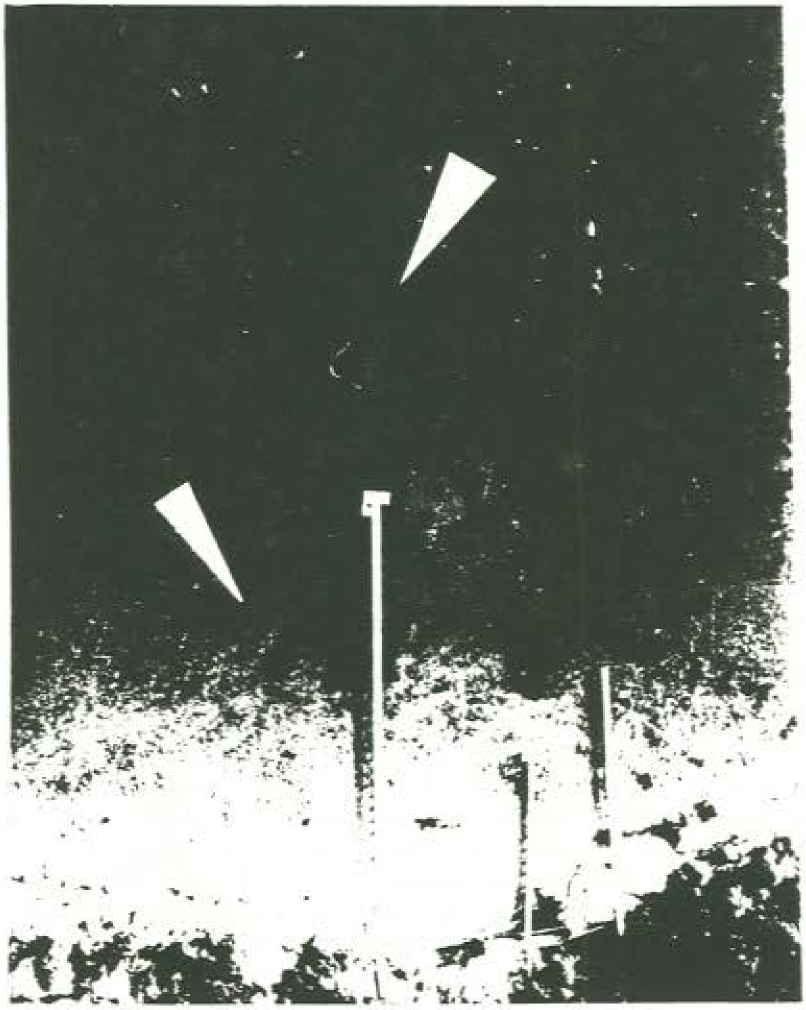

FRONTPIECE
(Explanation on facing page.)

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FRONTPIECE

Aerial photograph showing density and distribution of submersed aquatic vegetation in the Pamlico River during its former abundance in the mid-1970s. Shallow (<90 cm depth) and deep beds are indicated by arrows. Shallow beds are granual or speckled on photographic images, and were characterized by short, scattered plants in small clumps. The deeper circular and continuous beds are darker-toned with smooth continuous texture, and contain longer leaves of _Vallisneria americana_ Michx. (wildcelery), the dominant species in coverage and biomass at the time. Photograph was take at 666 m altitude at km 19 S on 29 August 1974. From Davis and Brinson (1976).

ABSTRACT

Surveys of SAV in the Pamlico River system were conducted in 1985, 1987, and 1988 to determine the species present and to estimate their abundance. In 1985 only widgeongrass was found in the river while in 1987 a small amount of wildcelery was found. By 1988 significant stands of wildcelery covered some areas in the middle reach. Wildcelery was stressed both years as indicated by small plants with narrow leaves and frequent fragmentation of leaves. Salinity and heavy epiphytic growth were among the stress factors observed. Traces of Sago pondweed and redhead grass appeared in 1988. Wildcelery transplanted into the Pamlico River system in 1987 and 1988 died at all but one site in 1988 where the species grew naturally.

Wildcelery was common in a portion of the narrow southern littoral in the upper reach of the Neuse River estuary in 1987 and 1988 while there were traces of widgeongrass on both sides of the estuary. Plant biomass in the Currituck Sound decreased from 1973 to 1978 and from 1978 to 1988 due to the decrease of Eurasian watermilfoil. In 1987 and 1988 Eurasian watermilfoil and widgeongrass were common in Kitty Hawk Bay while in 1988 diverse SAV communities were found in the Perquimans and Little Rivers. The Pasquotank River was essentially barren.

Except for man-made marsh creeks on South Creek, which also had Eurasian watermilfoil, the smaller tributaries of the Pamlico Sound typically are populated from December through May by horned pondweed which gives way to widgeongrass which usually forms monospecific stands through the summer. For reasons unknown, widgeongrass sometimes disappears in the tributaries and in the Pamlico River in August and September.

The Pamlico River and Currituck Sound are two areas of special concern relative to SAV populations. Compared with the Currituck Sound and all but one site in the Neuse River, wildcelery plants in the Pamlico River are in poor condition even though biomass and cover increased significantly in some areas from 1987 to 1988. In addition to epiphytic growth, often heavy, water transparency appears to have decreased drastically in the river since the mid-seventies, but it was about the same as for the Neuse River in the spring of 1988 and greater than for Currituck Sound. It seems unlikely that SAV in the Pamlico River would recover to conditions in the mid-seventies. Although widgeongrass biomass and cover are increasing in the Currituck Sound, biomass and cover are still low. Significant increases in water transparency in the Currituck Sound could lead to regrowth of Eurasian watermilfoil in nuisance proportions.

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SUMMARY AND CONCLUSIONS

This report addresses the temporal and areal distribution of SAV (submersed aquatic vegetation) in lower Back Bay, the Currituck Sound, and the western Albemarle-Pamlico estuarine system. The distribution and biomass of SAV in the system are an expression of conditions associated with system morphology such as fetch, depth, salinity regimes, and sediment texture. Other factors such as suspended sediments, weather, climate, nutrient availability (as effecting epiphytic growth), and the inherent adaptations of the SAV present are also important. Probably other unquantified factors such as biotic controls, nutrient dynamics in the sediments, and allelopathy impact SAV distribution and biomass.

Pamlico River

The virtual disappearance of SAV in the Pamlico River around 1979 is attributed to unusual weather conditions which resulted in high turbulence and suspended sediment runoff in the spring of 1978. Wildcelery reappeared in 1987 and spread rapidly in the middle reach in 1988. However, wildcelery shows signs of growing under stressed conditions as compared with growth in the Currituck Sound and all but one site in the Neuse River. Developmental and morphological signs of stress on wildcelery in the Pamlico River include production of narrow leaves and fragmentation of mature leaves.

The general lack of success in transplanting wildcelery and other SAV in the river in 1987 and 1988 and the lack of natural regrowth of SAV in Blounts Bay also suggest that the Pamlico River is a highly stressed environment for SAV growth. Lush meadows of SAV grew in Blounts Bay in the mid-seventies.

The reasons for poor growth and especially lack of growth of SAV in the Pamlico River are not clear. In 1988 light penetration of the water in areas of current and previous SAV growth in the Pamlico River appeared to equal that in a wildcelery bed in the Neuse River and exceeded that in a SAV bed in Currituck Sound. Wildcelery was stressed directly by high salinity in the Pamlico River for most of the year.

Dense growths of epiphytes on leaves of wildcelery in the Pamlico River, often rampant, was in striking contrast to those collected from all but one site in the Neuse River and from the Currituck Sound. The primary epiphytic organism observed was a brackish water hydroid. Hydroid growth could have been an important factor leading to leaf fragmentation. The hydroid will grow in fresh water but grows best at $15^{o}/oo$. Salinities were high where wildcelery grew in the Pamlico River in 1988. Salinities in

Currituck Sound (Coinjock Bay) do not approach those of the Pamlico River levels and limited data suggest that salinities at the Neuse River collection site were lower than for the areas of interest in the Pamlico River.

Propagules of wildcelery apparently became widespread in some areas of the middle reach in 1988. If growth conditions in the river do not worsen, further spread of wildcelery should occur in 1989. The range of two other native species found in trace amounts in 1988 should also increase. However, depth distribution of SAV in the Pamlico River may not increase to that of the mid-seventies because the river appears to be more turbid now than then.

Neuse River

Small and generally healthy beds of wildcelery grow in a short stretch of the narrow southern littoral of the upper reach of the Neuse River estuary. Widgeongrass is present in trace amounts on both sides of the estuary.

Assuming similar environmental conditions, the potential for areal increase of wildcelery is highly limited by morphologic features of the Neuse River as compared with the Pamlico River. In the area of the Neuse River where salinity and fetch stresses would be minimal, the littoral is narrow, especially on the southern side. An abrupt increase in depth restricts the lateral extent of sandy sediments for SAV colonization.

Western Pamlico Sound

Generally only traces of widgeongrass were found in the embayments along the western shore of the Pamlico Sound. This paucity of SAV is in contrast to the vast lush beds of SAV in the littoral of the eastern Pamlico Sound (Ferguson et al. 1989). Perhaps fetch and exposure to northeasters adversely affect SAV growth along the western shore. The narrower littoral along the western shore also would restrict SAV bed development.

Back Bay

The open waters of lower Back Bay appear to be highly turbid and essentially barren. There is a diversity of SAV in most of the creeks and tributaries which could repopulate the bay should conditions improve.

Currituck Sound

Biomass on Currituck Sound transects were lower in 1988 than in 1978 even though weather-related stresses were high in 1978.

Eurasian watermilfoil declined over the period of the 1973, 1978, and 1988 surveys. Widgeongrass is increasing in the sound but is still at low biomass.

The transect studies may not represent SAV biomass well at this time because most of it appears to be concentrated in embayments and between marsh islands. If the water in the northern sound and in Back Bay were to clear to 1977 conditions, development of much more extensive SAV beds should develop, perhaps dominated again by Eurasian watermilfoil.

Kitty Hawk Bay

Often dense mixed and monospecific beds of widgeongrass were found in Kitty Hawk Bay in 1987 and 1988. If changes occur which lead to increased SAV in the Currituck Sound and Back Bay, widgeongrass may become a co-dominant with Eurasian watermilfoil as it is now in Kitty Hawk Bay.

Perquimans, Little, Pasquotank and North Rivers

SAV grew in most of the littoral of the Perquimans River in 1988. Stands were often dense and diverse with Eurasian watermilfoil being found only once. Perhaps this was the most ideal ecosystem surveyed because it represents an acceptable balance between ecosystem productivity and minimal disruption by human usage. The Little River also had high areal coverage and biomass of SAV in the littoral but Eurasian watermilfoil and perhaps leafy pondweed could interfere with water activities at places. In contrast with the Perquimans and Little Rivers, the Pasquotank River was essentially barren. The lack of SAV in the Pasquotank River may be related to an extremely hard and shell dominated littoral. The history of SAV in the Pasquotank River is unknown. North River was characterized by moderate to dense Eurasian watermilfoil in creeks and embayments but other species were also present.

Other tributaries, embayments, and creeks of the Pamlico Sound system

Chocowinity Bay, Blounts Creek, Bath Creek, Durham Creek, South Creek, Goose Creek (Pamlico River), the Pungo River, Pantego Creek, Pungo Creek, Slocum Creek, Clubfoot Creek, Adams Creek, and Bay River had little or no SAV. SAV was present in tributaries of some of these.

Except for locally dense Eurasian watermilfoil in tributaries of North and South Creeks of the Pamlico River system, horned pondweed and widgeongrass comprised practically all the SAV biomass found in tributaries in these studies. The presence of these species in the littoral of smaller creeks to around the 1.0-1.2 m depth contour is reliable, especially for the upper and middle reaches. Horned pondweed commences growth in the winter and tends to be replaced by widgeongrass in May and June. Consequently there tends to be SAV cover in these creeks through most of the year. However early die-back of widgeongrass around August in the creeks and the Pamlico River can occur. This die-back is probably related to unfavorable water temperatures and excessive epiphytic growth.

Horned pondweed is mainly restricted to silty-clay sediments while widgeongrass grows in either the silty-clay sediments of creeks or sandy sediments in the Pamlico and Neuse Rivers where protected from fetch. The restricted distribution of these two species may be related more to their relative lack of resistance to turbulence than to sediment affinities. Wildcelery is usually absent from silty-clay sediments of the creeks.

Dense Eurasian watermilfoil appears to be endemic in man-made marsh creeks in South Creek, a tributary of the lower Pamlico River. Morphologic features of the river and the nature of the species are suggested as reasons why Eurasian watermilfoil has not invaded the Pamlico River.

SAV community dynamics and stress

Short-term and long-term environmental changes make estuaries a stressful environment for SAV growth. Assuming presence, dispersal, and establishment of propagules, as is occurring now for wildcelery in the Pamlico River, SAV spreads to occupy habitat available within environmental constraints at the time. The environment includes the abiotic factors discussed as well as biotic factors such as epiphytes, pathogens, and competition from other SAV. A change in any one of these factors may limit growth or result in the elimination of a species from an area or system. This report has emphasized changes in stress factors most easily observed or deduced-- turbulence, turbidity, and epiphytic growth. These are used to explain many of the observations but many other factors may be involved. Almost all of these stresses are intrinsic to the system but some are exacerbated by human activities.

RECOMMENDATIONS

1. Our data suggest that suspended sediments in the Pamlico River may have increased drastically from 1974 to 1988. Baseline studies with intensive sampling of tributaries of the Albemarle-Pamlico system should be done to establish the suspended sediment loads over time. The Pamlico River has recently been declared nutrient sensitive by the Division of Environmental Management and additional measures will be taken to control nutrient and sediment loading of the river. It would be useful to monitor the Pamlico River before and after management of the river and watershed as nutrient sensitive.

   The relative contributions of the Albemarle Sound to suspended sediment turbidity of the Currituck Sound should be evaluated. In a large shallow system such as the Currituck Sound, some suspended sediments may be desirable. Shore to shore Eurasian watermilfoil is not considered desirable by most people. Intensive sampling for suspended sediments at strategic locations could be conducted by citizen monitoring groups. Frequent collections during spates would help in tracing problems.

2. Secchi depth as an indication of water turbidity correlates with low SAV biomass in Currituck Sound and suggests that depth distribution in the Pamlico River littoral will not achieve the high levels of the mid-seventies even if significant SAV beds develop there. Frequent monitoring of these tributaries for water clarity in association with studies of SAV biomass should be done to test these hypotheses. Submarine photometers calibrated to give photosynthetically active radiation reaching the plants should be used.

3. The causes of epiphytic growth on SAV in the Pamlico River and at Green Springs Beach on the Neuse River estuary should be determined. Growth studies of plant epiphytes such as diatom should focus on inorganic nutrients such as nitrogen and phosphorus while growth studies of epiphytic animals such as colonial hydroids should focus on food sources which are probably linked to inorganic nutrients and productivity in the water column. Organic enrichment with concomitant growth of bacteria and fungi may be important in animal growth. Differential growth responses to variations in salinity for all organisms should be a component of all studies.

4. Causes of the frequent late summer demise of widgeongrass in the western Albemarle-Pamlico system should be investigated. Field measurements of epiphytic growth could be combined with epiphyte-temperature studies in controlled environments to test the hypothesis proposed in this report.

5. Littoral sediments in the Pamlico River frequently appeared to be anaerobic in the summer of 1989. SAV growth should be studied in relation to interrelationships with anaerobic sediments.

6. If SAV does not reappear in Blounts Bay, special studies should be done there to determine if features of the sediments prevent plants from becoming established. Very rapid death of transplants in the bay suggests that growth here may be restricted by factors related to the sediment.

7. In the 1988 transplantation experiments at Crystal Beach in the Pamlico River, there was a suggestion that the biomass production in wildcelery could be nutrient-limited. Experiments using individual nutrients and smaller plots with more replications could answer this question. Depth-light penetration relationships should be investigated.

8. The absence of SAV in the Pasquotank River as compared with the lush growth of SAV in the Perquimans and Little Rivers should be investigated. Also the ecosystem system productivities in these rivers should be compared, especially with regard to fish, shellfish, and waterfowl. Are there differences between these rivers and, if so, are they related to SAV? If there are no differences, concern over the lack of SAV in the Pasquotank River would be lessened but still puzzling. Similarly, the relationships of SAV to ecosystem productivity in primary nursery areas should be investigated.

9. If SAV recovers in the Pamlico River and SAV does not increase greatly in the Neuse River, comparative ecosystem productivity studies should be made for these estuaries.

10. SAV should be monitored on a regular basis and surveys of winter vegetation should be included. We have shown that a single visit usually does not give a true picture of SAV due to seasonal and annual variations.

Financial constraints will control survey frequency. Three persons with a small seaworthy boat with two on the boat each day should be able to survey the Currituck Sound and the western Albemarle-Pamlico system using all the methods used in this study in about 2 months. The results of current and past SAV surveys should be digitized for analysis and reference using a LRIS-compatible system such as the PC ARC/INFO Geographic Information System. The raking procedure developed in this research is recommended as a rapid semiquantitative survey method in which species presence can be determined and comparative biomasses estimated. Biomass estimates are more reliable with soft (silty) substrates than for hard (sandy) substrates. Practically all of the SAV in the smaller tributaries is in soft sediments. Raking should be calibrated with biomass studies to make the procedure more reliable.

The Pamlico and Neuse River estuaries were surveyed mainly to determine species presence. Rapid surveys using underwater viewers are probably the most cost-effective. If areal coverage and biomass of SAV continues to increase in the Pamlico River these surveys should be supplemented with transect studies and/or remote sensing. Since there is an increasing data base for transect studies for the Currituck Sound and South Creek tributaries, these studies should be continued using the same protocols. Remote sensing of SAV in the Currituck Sound is desirable.

Citizen groups could be asked to study seasonal and yearly SAV dynamics in specific areas. About all that is needed is a square frame, a line marked in meters, and a staff marked in tenths of meters. Transects can be run by wading. Conscientious citizen groups, after an hour or two of supervised work, could gather valid valuable data in such studies. The only known study of wildcelery made during the crash of SAV in the Pamlico River in 1979 was made when one of us (Davis) waded out into the river at Jakes Bay with the aforementioned equipment in tow!

INTRODUCTION

Contents and Objectives

The research covered in this report began in 1985 and has been supported by several grants. General surveys of submersed aquatic vegetation (SAV) of the Pamlico River were initiated in the summer of 1985 under grants from the Water Resources Research Institute of the University of North Carolina and the Division of Environmental Management of the North Carolina Department of Natural Resources and Community Development. These surveys were in response to concern of members of the Pamlico-Tar River Foundation and others over the apparent demise of the SAV in the Pamlico River beginning around 1978-1980.

In the summer of 1987 the Pamlico River was surveyed again along with several other areas in the Albemarle-Pamlico estuarine system under a grant from Texasgulf Chemicals Co. In the spring and summer of 1988 the surveys were expanded to include most of the rivers and tributaries in the Albemarle-Pamlico estuarine system under the grant from the Albemarle-Pamlico Estuarine Study. The 1988 studies included, in addition to the general surveys, a number of more structured transect surveys in which plant density and cover were determined along randomized lines (transects) run across SAV where similar studies were previously made.

Attempts were made to transplant SAV into the Pamlico River during the summer of 1987 and the spring and summer of 1988. Also in the spring and summer of 1988 the growth potential of one important species was studied both experimentally and by comparing natural growth in three estuaries.

The most commonly accepted common name is used for each species mentioned in this report. Scientific names are given in Appendix A, information on identification of SAV are given in Appendix B, and autecological aspects of four of the more important submersed species are discussed in Appendix C.

The objectives of this study and the management utility as outlined by managers, in the Request for Proposals were:

1. Documentation of present and historical patterns in location, abundance, and composition of SAV beds. <u>Management Utility</u>: Precise knowledge of locations of vegetative habitats would be invaluable in existing regulatory programs in evaluation of proposed development projects and mitigation efforts. Furthermore, this effort

would provide a baseline for trend analysis intended to identify threatened habitat types and to enable management program design. This analysis could also apply to proliferation of less desirable species such as Eurasian watermilfoil. Characterization of trends allows the identification of high priority areas and species management efforts so that evaluative studies and management assessments are applied most efficiently.

2. To examine the current suitability of the Pamlico River for SAV growth and evaluate the potential for reestablishment of historic SAV beds here.
Management Utility: The dramatic recent declines in SAV in the Pamlico River probably have serious implications for fish and waterfowl abundance in this area.

3. To develop a protocol for monitoring critical areas for SAV on a 5-10 year return period as suggested in the Request for Proposals or more often if managers, researchers, or local residents detect changes in trends.
Management Utility: The disappearance of SAV in the Pamlico River was evaluated after the fact. Early detection of similar problems would greatly increase the likelihood that causal relationships could be established and that effective management strategies could be developed.

Ecosystem Functions of SAV

Environmental interactions of SAV can be categorized as physical, biological, and chemical. Roots and rhizomes may help stabilize the sediment while shoots slow movement of the water causing accelerated sedimentation of finer suspended sediments, thus reducing turbidity (Davis and Brinson 1980, Kemp et al. 1983). Slower water movement can also result in higher concentrations of particulate food in the bed (Peterson et al. 1984). The plants may, by damping the effects of moderate wave energy, help to retard sediment migration.

Greatly expanded surfaces associated with shoot and root systems may serve as sites of physical attachment of algae, bacteria, fungi, invertebrates, and other organisms. SAV modify the environment as it affects gradients of physical factors such as light and temperature. These gradients lead to differing microenvironments which set conditions for specific types of communities in the plant stand. As summarized by Orth et al. (1984), fish and invertebrates are usually much more concentrated in vegetated as compared with non-vegetated areas.

Biological and chemical relationships of SAV to the ecosystem are complex and closely coupled. SAV produces food which may be utilized by bacteria, fungi, and invertebrates in the food web or eaten by higher animals such as waterfowl. Particulate and dissolved organic matter also move into the water from living plants.

Oxygen is produced and carbon dioxide is used in photosynthesis by SAV while carbon dioxide is produced and oxygen is used in respiration. A depletion of carbon dioxide in the water during photosynthesis will cause a rise in pH while addition of carbon dioxide (as at night) causes a decrease in pH. Dissolved oxygen produced in photosynthesis diffuses into the sediment from SAV roots (Wium-Anderson and Anderson 1972). This can result in the formation of iron complexes in the sediment to which phosphorus is sorbed, thus decreasing the levels of an essential nutrient for both SAV and other organisms (Jaynes and Carpenter 1986). The same process can also protect the plant from toxic sulfide in the sediment by oxidizing H_2S to innocuous forms of sulfur.

Inorganic nutrient dynamics are complex and vary greatly with conditions. Normally roots are the primary site of uptake of nitrogen and phosphorus (Nichols and Keeney 1976, Cardignan and Kalff 1979). These nutrients are released into the environment mainly through decay. Low levels of inorganic nutrients may be secreted directly into the water by living plants (Twilley et al. 1985a). Under some conditions potassium, taken by shoots from the water column, moves into the sediment from the roots (Barko et al. 1988). It is postulated that under nitrogen-limiting conditions, potassium is exchanged for ammonium ions in the sediment.

Nutrient enrichment of overlying waters through massive die-off and decay of SAV can contribute to growth of undesirable algae. Following the killing of SAV with herbicide in Kitty Hawk Bay in early summer, a bluegreen algal bloom occurred in the bay (Getsinger et al. 1982). Similar phenomena have occurred elsewhere. Furthermore, SAV may prevent the development of undesirable algal blooms through shading, removal of inorganic nutrients from the water column during the growth phase and, in some cases, production and release of inhibitory substances. Eurasian watermilfoil has been shown to produce phenolic compounds which are toxic to algae (Planas et al. 1981).

Responses of SAV to Environmental Factors

The amount of light reaching SAV leaves is of prime importance since it is the energy source for photosynthesis and hence food production. Light attenuation in water can be increased by abiotic factors such as suspended sediment and by biotic factors such as phytoplankton. Likewise the light reaching chloroplasts in leaves may be reduced by sediment adhering to the leaves and by epiphytes such diatoms and hydroid colonies on the leaves. In extreme conditions created by hurricanes and dredge spoils, SAV may become smothered by sediments. SAV propagules could be covered so deeply that they would not germinate (Rybicki and Carter 1986).

Turbid water caused by heavy suspended sediment loads can greatly reduce SAV biomass. While high suspended sediment turbidity during a single season or a year may or may not result in long-term changes in the persistence of SAV, prolonged increases in suspended sediment turbidity are almost certain to result in lasting deterioration of SAV beds.

Responses of SAV attributed at least in part to short-term and to long-term increases in turbidity have been documented for the Currituck Sound system. Biomass of Eurasian watermilfoil at a Coinjock Bay study site (Figure 1) was drastically reduced in the summer of 1978 as compared with the summer of 1977 (Davis and Carey 1981). In the spring of 1978 (early growing season) the water was very turbid. This high turbidity was associated with unusual weather conditions. During March and especially April, wind duration and force from the northeast was strong, even for this area with a long history for wintertime northeasters. Such winds roil the silty semisolid sediments common to Coinjock Bay and the northern sound. Rainfall in March 1978 was the highest for the 78 years recorded for this month. This contributed to the suspended sediment turbidity through land runoff. By June 1979 Eurasian watermilfoil biomass in Coinjock Bay approximated that of June 1977. Recovery had occurred in only one year.

In July 1978 Eurasian watermilfoil biomass in Currituck Sound was approximately one half that found by Kearson (1976) in 1973. Data from informal surveys in 1977 suggested that there had been a large decrease in Eurasian watermilfoil biomass between 1977 and 1978. Except for waxing and waning in Coinjock Bay, Eurasian watermilfoil has not been a serious problem in the Currituck Sound system as it was from around 1966 to 1977 (L. C. Barrow, personal communication, 1988). Hence, in Currituck Sound, the weather perturbations in 1978 appear to have contributed to long-term changes in SAV in the sound and to a lesser extent in Coinjock Bay.

Bourn (1932) observed that SAV in northern Currituck Sound and Back Bay, Virginia began to decrease in 1918, vast areas were almost denuded by 1926, and plants in the deeper areas disappeared completely. Around 1918 the locks of the Albemarle and Chesapeake Canal, which connects the Norfolk harbor at the mouth of the Chesapeake Bay with Currituck Sound by way of the North Landing River, were open. Bourn concluded that increased turbidity associated with the opening of the locks was the principal cause of the demise of the SAV. An even more

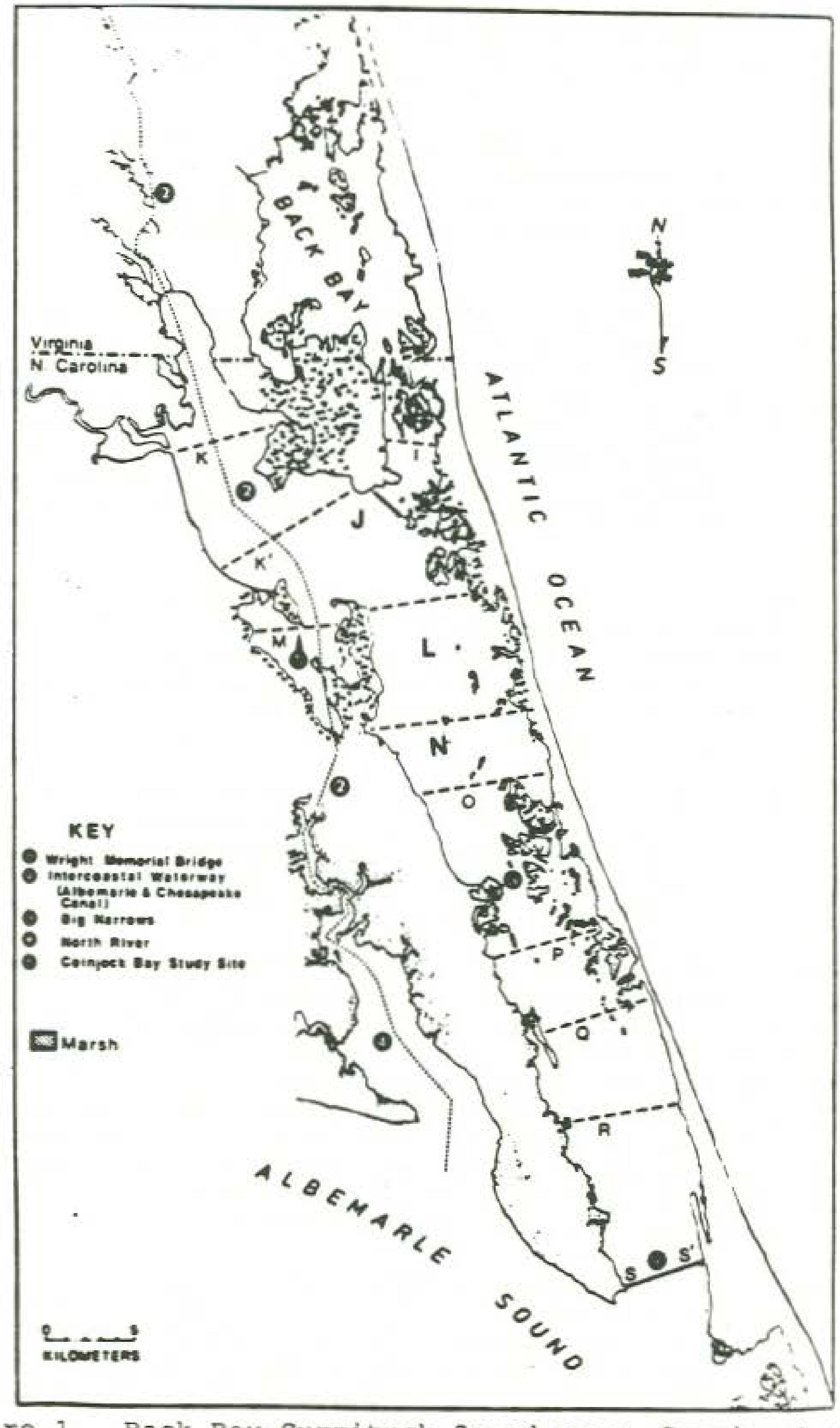

Figure 1. Back Bay-Currituck Sound area. Currituck Sound transects indicated.

important contribution to the turbidity was probably the extensive dredging in the canal and the North Landing River between 1914 and 1919 (Sincock 1966).

Complete recovery of SAV in Currituck Sound did not occur until 1951 (memorandum by Bourn cited in Sincock 1966). This is an example of long-term increases in turbidity in Currituck Sound associated with long-term repression of SAV growth.

A moderate increase in inorganic nutrients in the water such as nitrogen and phosphorus should have no direct adverse effects on SAV. If anything they would lead to increased growth, if previously limiting. Indirect effects of excess nutrients in lakes has been through increased algal growth which may be in the form of microscopic phytoplankton in the water with a concomitant increase in turbidity (Jupp and Spence 1977). Increases in filamentous algal growth may also smother and shade SAV (Phillips al. 1978).

Twilley et al. (1985b) demonstrated experimentally the adverse effects of phytoplankton in the water column and especially epiphytes on widgeongrass and redhead grass under Chesapeake Bay conditions. However, high biomasses of filamentous algae in and on SAV in the Pamlico River in 1974 did not appear to depress growth of SAV (Davis and Brinson 1976).

In some cases fish and other animals can adversely affect SAV by roiling silty sediments causing an increase in turbidity. The feeding activities of carp in Lake Mattamuskeet, North Carolina, increased turbidity so greatly that SAV did not become established until the fish were removed (Cahoon 1953).

As reviewed by Davis and Brinson (1980), many other factors, both physical and biological, may influence the distribution and abundance of various species of SAV in a lake, stream or an estuary. They include fluctuating water levels, turbulence (as associated with currents, and prevalence, force, and direction of winds), ice, the structural, physiological, and phenological nature of the species, nutrient availability and uptake, sediment characteristics, grazing pressures, and hydrostatic pressure. Of these, perhaps ice and hydrostatic pressure are least likely to limit growth in the Albemarle-Pamlico estuarine system.

Salinity is a potential stress for most species in this system. This is treated in Appendix C. Except for the extreme southern extent of the Albemarle-Pamlico system and near ocean inlets, astronomic tides have a small amplitude (Giese et al. 1985) and probably have no measurable impact on SAV outside these areas.

The Study Area

The Albemarle-Pamlico estuarine system is a shallow inland sea bordered on the east by barrier islands with small, shallow inlets and on the west by the North Carolina mainland (Figure 2). The system includes a number of tributaries, the largest of which are the Pamlico River and the Neuse River estuaries.

Because the tidal amplitude is quite low (< 6 cm, Giese et al. 1985) wind-driven water level fluctuations tend to swamp the tidal signal. In the long term the net flow is from the sounds to the ocean. Surface salinities in the open Pamlico Sound range from approximately 14 $^{o}/oo$ to 20 $^{o}/oo$ and diminish in the subestuaries, especially during periods of high runoff (Williams et al. 1973). Salinities in the Albemarle Sound system range from near fresh water to a few parts per thousand (Williams et al. 1973, Bowden and Hobbie 1977).

Pamlico and Neuse River estuaries

The Pamlico River estuary, a drowned river valley, is a subestuary of the Pamlico Sound (Figure 3). The Pamlico River extends some 60 km inland from the Sound where it joins its main tributary, the Tar River, at Washington. The estuary has a watershed of about 8000 km^2 which is mostly forest and farmland with a mainly rural population. Depth in the nearly flat central region between shorelines gradually increases downstream from 2 to 7 m. There is generally a narrow sandy littoral with a thick silt-clay bottom in open water (Matson et al. 1983). The Tar River, with headwaters along in the Piedmont, flows southeastward.

Salinity, with extremes varying between ~ 1 $^{o}/oo$ to 18 $^{o}/oo$ down the estuary and seasonally, is controlled mainly by the degree of freshwater runoff from the Tar River. This shallow estuary is usually well mixed by wind, but salinity stratification may be pronounced with high river flow and low wind stress (Davis et al. 1978).

The estuary is turbid with a gradient normally decreasing downstream as the suspended sediment load of the Tar River settles out. Secchi disc transparency extremes range from 0.2 to 2.0 m (Davis and Brinson 1976, Davis et al. 1978, this study) and tend to be inversely related to suspended sediment concentration.

The Neuse River estuary is very similar to the Pamlico River (Williams et al. 1973, Hobbie and Smith 1975, Matson et al. 1983). Average annual salinity at the mouth of the Neuse River is about 2 $^{o}/oo$ to 4 $^{o}/oo$ higher than at the mouth of the Pamlico River. The population density in the Neuse River watershed is greater than for the Pamlico River watershed.

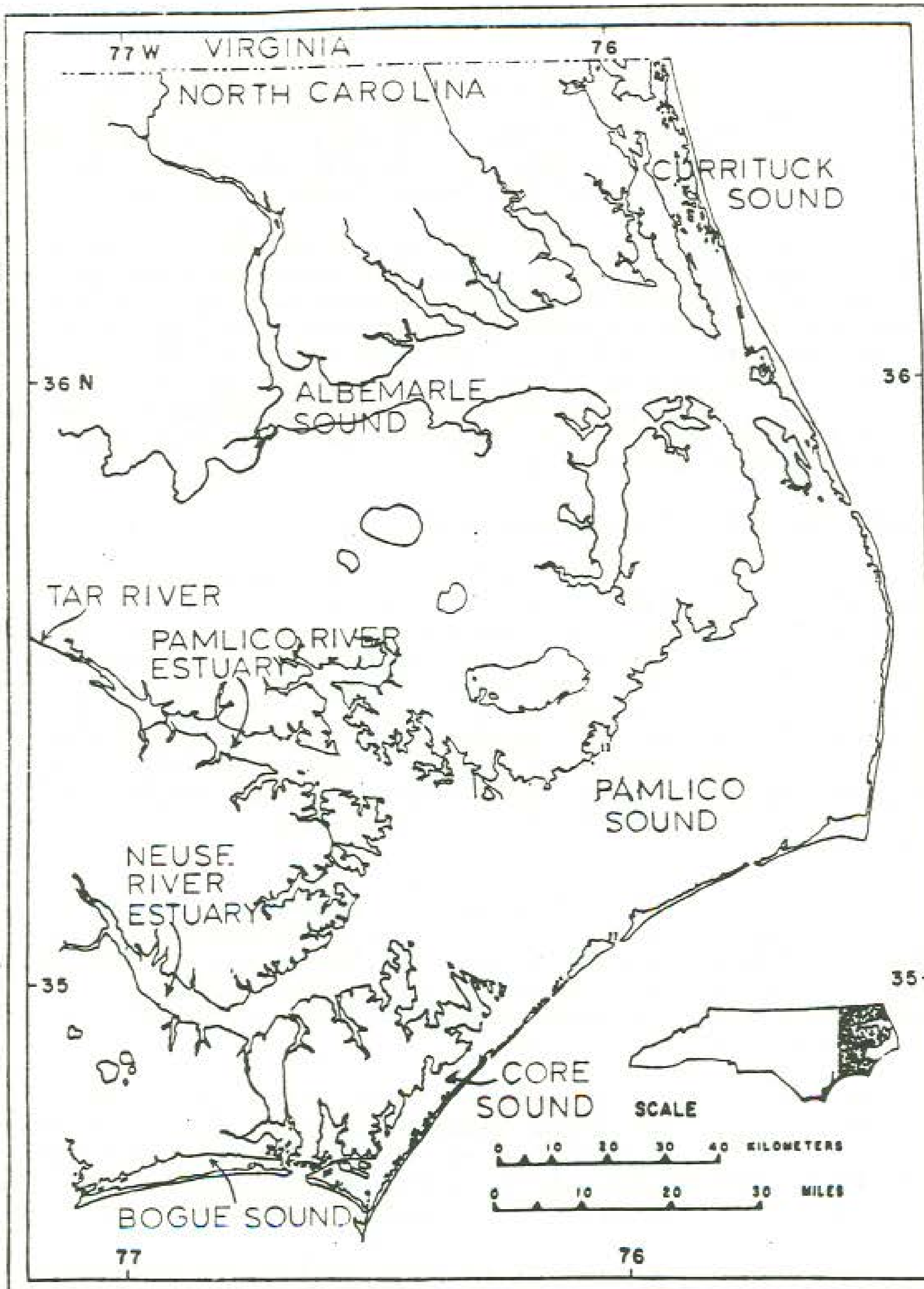

Figure 2. The northern and central coastal regions of North Carolina. Inset shows relation of the area to the rest of the state. Adapted from Williams et al. (1973).

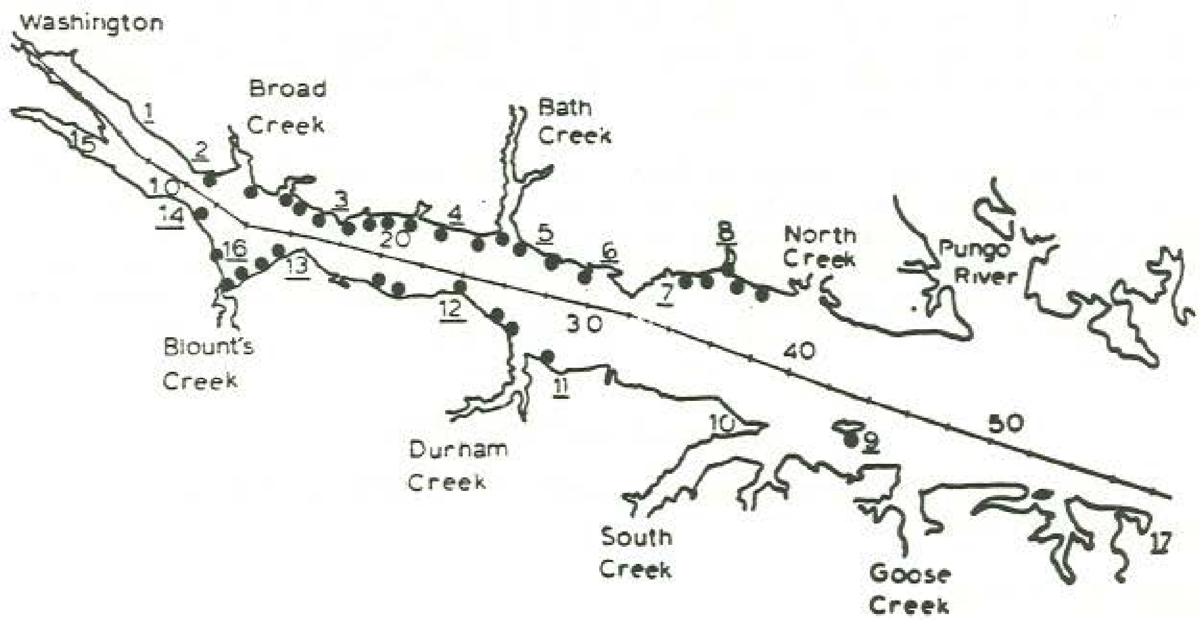

Figure 3. The Pamlico River estuary. Dots indicate survey sites. River km as shown begin at the Pamlico River-Tar River confluence and generally follow channel markers. Locations: 1-Austin Pt., 2-Broad Creek Pt., 3-Ragged Pt., 4-Hawkins Ldg., 5-Bayview, 6-Mixon Ck., 7-Gaylord Bay, 8-St. Clair Ck., 9-Indian Island, 10-Hickory Pt., 11-Texasgulf Chemicals Inc., 12-Core Pt., 13-Mauls Pt., 14-Hills Pt., 15-Chocowinity Bay, 16-Blounts Bay, 17-Pamlico Pt.

Currituck Sound-Back Bay

Currituck Sound is a northern arm of the Albemarle-Pamlico Sound system and is separated from the Atlantic Ocean by a narrow spit which is the northern extension of the barrier island system of the North Carolina coast (Figures 1 and 2). The sound is connected to Back Bay on the northeast by shallows between marsh islands. There are numerous marsh islands along the eastern shore and in the middle reach. The Currituck Sound system has ~ 40,000 ha of open water while the open water of Back Bay covers ~ 9,000 ha. The entire system is shallow with a mean depth of 1.6 m; over 80% of the area less than 2.1 m deep (Crowell et al. 1967). The record is incomplete, but it appears that since the New Currituck Inlet closed around 1830, the salinity has normally varied from less than one to a few parts per thousand (Sincock 1966).

No hydrologic studies have been reported, but the system is likely wind-driven with water levels rising and falling on the short-term as water is exchanged with the Albemarle Sound. Numerous creeks and farm ditches enter along the western shore and three rivers arising in or near the Great Dismal Swamp drain into the northwestern part of the sound.

SAV in the Study Area

The only known research reported on SAV in the study area is summarized below.

Pamlico River

The SAV on the Pamlico River estuary (Figure 3) was studied extensively from 1973 through 1975 (Davis and Brinson 1976). Extensive beds of SAV were found down to around 1.5 m depth in most areas of the upper half of the river. Total biomass for the river in August 1975 was estimated to be around 200 Mg moisture-free mass. (Unless otherwise specified, masses represent organic matter only. This convention partly eliminates the often high and variable contribution due to epiphytes and calcareous deposits.) Percent composition at this time was: wildcelery, 87.1%; bushy pondweed, 7.4%; redhead grass, 3.9%; widgeongrass, 0.8%; and charophytes 0.7%.

Durham Creek (Pamlico River tributary)

The lower reach of Durham Creek was surveyed at random stations in June 1973 (Davis and Brinson 1976). Plant samples were taken with modified oyster tongs. Species found with percent frequencies of occurrence for 90 samples (in parentheses) were: Bushy pondweed (34%); charophytes (26%); leafy pondweed (23%); wildcelery (12%); widgeongrass (12%); and redhead grass (2%). Although the frequency of wildcelery was comparatively low, this species composed 83% of the biomass. Fontinalis sp., an aquatic moss, was found in one sample.

South Creek (Pamlico River tributary)

Thirty random samples were taken in the upper reach of South Creek with modified oyster tongs in June 1973. The survey of South Creek yielded empty quadrats. However, small stands of widgeongrass were noted along the eastern shore near the mouth and SAV was common in some of the South Creek tributaries.

South Creek tributaries

Jacks and Jacobs Creeks of the South Creek system (Figure 4) were surveyed for SAV eight times from September 1981 to February 1983 (Davis et al. 1985b). The rooted SAVs present were horned pondweed and widgeongrass. Biomass was generally low with higher biomasses in the upper reach. Widgeongrass was present primarily during the warm season, while horned pondweed was present primarily during the cool season. Both species were present in June.

Jacobs and Drinkwater Creeks and Project Areas (PA) I and II (man-initiated systems) were surveyed for SAV in June, August, and October 1984 (Bradshaw and Davis 1985). PA I and II are bordered mainly by marshland and are on either side of the mouth of Drinkwater Creek. PA I was opened to South Creek in 1982 and PA II was opened to South Creek in 1983.

Except for PA I, which also had Eurasian watermilfoil, widgeongrass was the only SAV found in this area. Widgeongrass was found only in June on two of ten transects in PA II. Widgeongrass was well established in the upper reaches of Jacobs and Drinkwater Creeks in June, was not found in August, and was found again in October but with lower percent cover. Percent coverage by Eurasian watermilfoil in PA I was greater than 50% each month while percent coverage by widgeongrass decreased from 90% in June to 28% in August to 0% in October.

Currituck Sound region

As reviewed by Davis and Brinson (1983) SAV in the Currituck Sound region has been studied sporadically since 1909. Changes in suspended sediment turbidity were implicated to result in changes in SAV in Currituck Sound (see p. 3, Responses of SAV to Environmental Factors).

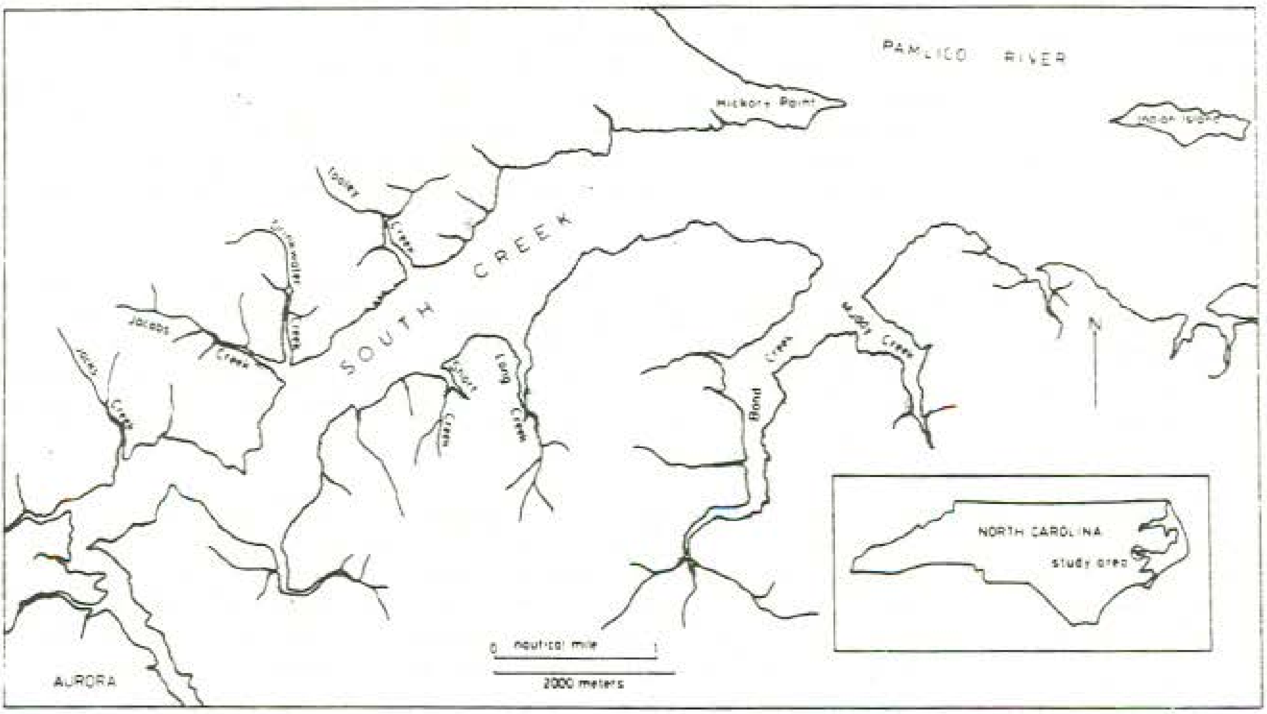

Figure 4. The middle and lower reaches of South Creek and its tributaries. PA I is on the point between Jacobs and Drinkwater Creeks while PA II is on South Creek just east of Drinkwater Creek. From West (1985).

McAtee (1919) surveyed the SAV in the northern sound in 1909 and found Sago pondweed to be dominant, bushy pondweed and wildcelery abundant, redhead grass common, widgeongrass scattered and leafy pondweed scarce. Subsequent observations by Bourn (1932) and others suggest that Sago pondweed remained dominant until the 1950's. From 1958 to 1964 quantitative studies showed bushy pondweed to be dominant and wildcelery to be generally subdominant (Sincock 1966). As compared with McAtee's (1919) report, charophytes were reported in the latter study. By 1966, Eurasian watermilfoil had spread throughout much of the Currituck Sound system including Coinjock Bay and severely impacted the system (Davis and Steenis 1973). In 1973 Eurasian watermilfoil was dominant in the system and bushy pondweed was a strong subdominant (Kearson 1976). In 1978 Eurasian watermilfoil was dominant and Sago pondweed was subdominant (Davis and Carey 1981). Bushy pondweed was found only in trace amounts and only 46% of the Eurasian watermilfoil biomass of 1973 was remaining in 1978.

<u>Kitty Hawk Bay</u>

By 1966 Kitty Hawk Bay was infested with Eurasian watermilfoil (Crowell et al. 1967). In study plots in the eastern bay in July 1974 Eurasian watermilfoil biomass was 242.9 g m^{-2}, similar to the peak summer Eurasian watermilfoil biomass in Coinjock Bay study plots in the summer of 1977 of 227.5 g m^{-2} (Getsinger et al. 1982). These masses are in the middle range of those reported for Eurasian watermilfoil infestations elsewhere (Grace and Wetzel 1978). Eurasian watermilfoil comprised 95% of the total SAV biomass in the Kitty Hawk Bay study. Other species found were bushy pondweed, widgeongrass, and Sago pondweed.

<u>Back Bay</u>

SAV dynamics in Back Bay appear to follow that of Currituck Sound but losses of SAV, when they occur, appear to be more devastating in Back Bay. From November 1962 to November 1964 there was a 97% reduction in SAV in Back Bay while the biomass in Currituck Sound remained about the same (Sincock 1966). Increased turbidity due to dredging in the bay was suggested as a contributing cause of the decline.

About the time that SAV biomass decreased in Currituck Sound (1978), SAV biomass in Back Bay (mainly Eurasian watermilfoil) began to decrease in lower Back Bay. By 1987 it was limited to a few creeks of Back Bay (Harold Grunstead, personal communication 1987). Mr. Grunstead has operated a fishing camp in the area for many years.

Transplanting of SAV

There is a long history of transplanting SAV in establishment of waterfowl habitat. In an Herculean effort, Bourn (1932) transplanted thousands of plants and propagules to the Back Bay-Currituck Sound area from 1926 to 1930 in an attempt to reestablish the vast lush SAV which once grew there. In addition to whole plants, he collected and planted rhizomes, winter buds, and tubers. Plants and propagules grew only where bulkheads were placed to prevent direct inflow of sound water. Establishment and growth in these sheltered areas were generally good no matter what the source of plant material.

Carter and Rybicki (1985) were successful in transplanting plugs, sprigs, and tubers of wildcelery into the freshwater tidal portion of the Potomac River in areas where suspended sediment turbidity was not excessive. They used exclosures to prevent grazing. Turtles were thought to be the primary grazers. Grazing in the Pamlico River appears to be minimal. We have observed some "leaf-nipping" of redhead grass by juvenile fish in the Pamlico River and there has been uprooting of wildcelery by mullet (Hallet Buck, personal communication 1985).

Seagrass transplanting techniques have been discussed generally by Phillips and Lewis (1983) and for the Morehead City, North Carolina area, by Fonseca et al. (1985). Strong tidal currents are often a problem in transplanting seagrasses.

METHODS

General Surveys

Pamlico River

The Pamlico River was surveyed twice in 1985, once in 1987 and twice in 1988 by visiting the 33 transect sites established in the 1974 biomass studies by Davis and Brinson (1976) (Figure 3). In 1985 and 1987 the transects were checked by raking (and/or) wading. In 1988 underwater viewers were used from a boat. These surveys were conducted by making one pass down the transect with two viewers. (The viewers were made from PVC pipe with a Plexiglass window giving a viewing area of 10 cm diameter. Lateral movement of the viewers increased the viewed area by perhaps 1.5- to 2-fold). Species found on the transects were noted and the sizes of the plant clumps were estimated.

In August 1979 a transect was run across the littoral west of Broad Creek (Figure 3; km 11 N) in a study of the Pamlico River clam float of 1979 (Davis et al. 1981). Three 0.1 m^2 quadrat samples were taken at 11 sites and the number of plants in the quadrats counted and the mean density calculated.

Two biomass studies of the widgeongrass stand on the southern side of Indian Island were made in 1985. On 20 June, 10 random transects were run through the bed perpendicular to the shore and presence of widgeongrass was determined by checking every 0.5 m along the transects. On 26 June, 20 random samples were taken in the vegetated areas with a 0.1 m^2 quadrat frame and dry weights determined as described below for the Currituck Sound section. The survey was repeated on 19 August by determining presence at 0.1 m intervals and by collecting 10, 0.1 m^2 samples in the vegetated areas. In these and subsequent transect surveys made in the Pamlico River system, sampling intensity along transects was determined by apparent biomass. Biomass for the vegetated areas was calculated as g dry weight per square meter and this was extrapolated to the entire bed, inclusive of bare patches inside the beds.

Neuse River estuary

The upper reach of the Neuse River estuary was surveyed on 7 August 1987 from the U.S. 17 bridge to McCotter Point on the northern shore and from the U.S. 17 bridge to Johnson Point on the southern shore, a linear distance of 8 km down the estuary. This was a systematic survey with raking every 500-700 m of shoreline. On 28 April 1988, 10 random sampling sites were visited on the northern shore from Sandy Point to McCotter Point while 15 random sampling points were visited on the southern shore from Union Point to Johnson Point, a linear distance of 7.5 km down the estuary. Raking at each site, as described below, was at the 0.5, 1.0, and 1.5 m depths. On 11 May 1988, three embayments in the estuary were visited from the marsh islands west of Daymark 48A down to the U.S. 17 bridge, a linear distance of 5 km down the estuary.

Tributaries and embayments

In the summer of 1985, most of the tributaries of the Pamlico River system were surveyed for SAV, including the Pungo River tributaries and those of the Goose Creek system. These rapid surveys were conducted by raking and making observations of plant stands from a boat. Beginning in the spring of 1987, these surveys were systematized with observations on SAV recorded for the upper, middle and lower reaches of each tributary as well as observations on embayments of the tributaries which often had SAV. An estimate of relative density of each species of SAV was made at each site visited by using three rakings of ~ 3 m length at the slowest boat speed. The sampling device was a 0.4 m wide garden rake with 15 tines and an extended handle. Each species was noted and ranked for relative density as follows:

Relative Density	Plant Material on Rakes
Trace	Up to 1/3 rake total.
Sparse	1/3 rake total to full rake.
Moderate	Full rake total to two full rakes.
Dense	Two full rakes total to 3 full rakes.
Very dense	Three full rakes total or two full rakes with "dip." ("dip"= ~ 1 m distance)

In a few cases, judgment was needed to assign relative density. For example, three full rakes with dip of two species of approximately equal biomass were classed as very dense for each species.

Transect Studies

Back Bay

Transects in the middle and lower reach of Back Bay, Virginia (Figure 3) used in the Back Bay-Currituck Sound Studies from 1958 to 1964 (Sincock 1966) were rerun on 26 and 27

September 1987 and on 28 June 1988. Following the protocol established for the earlier studies, sampling was conducted approximately every 500 yards along the transects. Location of sampling sites was determined by running time and sampling was by the raking method.

The transects run were:

Transect	Location	Number of Stations	Years Surveyed
E	Back Bay and Sand Bay; Whitehurst Pt. to Barbers Hill Landing	15	1988
F	Back Bay and Sand Bay; Pellitory Pt. to Green Pt. passing south Little Cedar Is.	17	1987 1988
G	Back Bay and Sand Bay; East Point of Egg. Is. to Horse Is. Ck.	10	1987 1988
G_1	Buzzard Bay; Public Landing to Slover Landing	8	1987 1988

There were a total of eight transects in the Back Bay-Currituck Sound Studies.

Currituck Sound

From 26 July 1988 to 29 July 1988 the 12 Currituck Sound transects run in July 1978 (Figure 1) were rerun using the same methods as in 1978 (Davis and Carey 1981). Two samples were dug by hand from a $0.25\ m^2$ quadrat frame every 500 yards along each transect. Intervals between sampling stations were determined by running time. All plants within the frame were placed in fine mesh bags, washed in ambient water, and washed again with a hose at the shore station. Plants were then sorted according to species, put into mesh bags and spun 7-8 minutes to no runoff in a domestic clothes washer. Subsamples were dried in an oven at 85 C and weighed. Subsamples of the dried plant material were then ashed at 550 C. These data were extrapolated to calculate organic (ash free) dry weight for all plants as $g\ m^{-2}$.

Tributaries of the Pamlico River

Three natural tributaries and two man-initiated tributaries on the western side of the middle reach of South Creek, which is a tributary of the Pamlico River (Figure 3 km 40 S, Figure 4), were surveyed by a transect method using an underwater viewer to determine plant cover and estimate relative density. In addition, the lower embayment of Nevil Creek (Figure 3 km 18.5 S) was studied by this method. Some of the features of these study areas as well as the dates of the studies are outlined:

Date (1988)	Tributary	Length (km)	Width (range) (m)	Depth (range) (m)
28 June 88	Jacks Creek	1.0	9-84	0.8-1.2
17 June 88	Jacobs Creek	1.0	11-50	0.6-1.0
23 June 88	Drinkwater Creek	0.9	8-91	0.7-1.1
22 June 88	PA I	0.3	7-12	0.1-0.7
16 June 88	PA II	0.5	17-32	0.8-1.5
30 May - 1 June 88	Nevil Creek (lower embayment)	0.8	27-205	0.8-2.1

Length is the distance along the length of the study area, width is the distance covered by transects across the stream, and depth is taken at the midpoint of the transects.

Except for Nevil Creek, which was not subdivided, each stream was divided into an upper reach and lower reach and five transect points were randomized in each reach. Boat running time was used to randomize transects in all streams except PA I which was too shallow to operate a boat. Randomization for PA I was by length measurement and a random numbers table. For PA II and Jacks, Jacobs, and Drinkwater Creeks, the study area began where navigation of a 15-foot boat was no longer possible and extended to the mouth. The entire lengths of PA I and the lower embayment of Nevil Creek were used as the study areas.

At each transect point a measuring line was extended across the stream channel and the SAV was observed along the line with an underwater viewer except for PA I where a viewer was not needed. For each transect, the width of the channel, depth at the midpoint of the channel, and information on plant beds were recorded. Along each transect, cover and the density of each species was classified as "dense," "moderate," or "sparse" based on the following criteria: 1) Dense. SAV formed a continuous bed. Substratum was barely visible between the plants if at all. 2) Moderate. SAV were not in a continuous bed and channel substratum was readily visible between individual plants. The plants covered at least 25% of the substratum. 3) Sparse. Plants were scattered, covering less than 25% of the substratum.

Transplant Experiments

1987 studies

Six littoral sites in the Pamlico River system were selected for these studies. Sites were selected to compare growth of transplants in soft sediments (silty) and hard sediments (sandy) in areas where either SAV was found in 1973-1975 (Davis and Brinson 1976) or widgeongrass was present in 1987. Water depths at the sites ranged from ~ 0.7 to 1.0 m. The sites and planting dates are given in Table 1.

All transplants used in 1987 were from the Currituck Sound system. Since wildcelery was the most abundant species during 1973-1975, it was featured in the studies. Other SAV transplanted were Sago pondweed and bushy pondweed. Transplants were dug by hand, placed in ambient water in laundry tubs, transported to the research site and maintained in shade until planted, usually within one or two days.

A single species was planted by hand in each plot with 5 rows of five plants each on 0.5 m centers. This gave a plot 2 m x 2 m or 4 m^2. A metal bar frame with a movable crossbar was used to align the transplants in the plot. The plots were separated by a 1-m wide corridor. The transplants were checked three times through 2 October 1987 to determine their presence and condition. Usually the perimeter plants were viewed with an underwater viewer and one or two plants were carefully dug, checked for condition, and replanted.

Early disappearance of transplants in Blounts Bay followed a storm, suggesting that they may have been uprooted. In one series of plantings, the transplants were anchored by tying them to coat hanger wire cut into a "V" and pushed into the sediment.

On 6 July wildcelery was dug in Currituck Sound to clean an area of plants. The cleared area was replanted as a control to determine potentially harmful effects of the transplanting process. This plot was last checked on 21 August 1987.

1988 studies

Four of the six study sites used in 1987 were used in 1988 and two sites were added. One site was added at Crystal Beach at the mouth of Nevil Creek. On 27 January 1988 much of the water was blown out of the Pamlico River by strong winds with a western component. Widgeongrass was noted in the exposed littoral at the Crystal Beach site covering perhaps 2% of an area extending ~ 150 m to a sandbar just east of the mouth of Nevil Creek. The largest clumps were ~ 1 m^2. This protected area appeared to be a study site with promise for plant establishment.

Table 1. Protocol for the 1987 transplant experiments in the Pamlico River. See Figure 3 for locations.

Site	River km	Dates	Plots planted
Blounts Bay I (soft bottom)	13 South	7 July	1 wildcelery
		9 July	1 Sago pondweed
		12 July	1 bushy pondweed
		16 July	2 wildcelery (anchored)
Blounts Bay II (hard bottom)	13.5 South	7 July	1 wildcelery
		9 July	1 Sago pondweed
		12 July	1 bushy pondweed
		16 July	2 wildcelery (anchored)
Nevil Creek (soft bottom)	18.5 South	7 July	1 wildcelery
		9 July	1 Sago pondweed
		11 July	1 bushy pondweed
		16 July	2 wildcelery (anchored)
Archbell Point (hard bottom)	25 North	7 July	2 wildcelery
		9 July	1 Sago pondweed
		11 July	1 bushy pondweed
		19 July	3 wildcelery (anchored)
Huddles Cut (soft bottom)	30 South	18 July	2 Sago pondweed (one anchored)
		19 July	2 Sago pondweed (one anchored)
South Creek (hard bottom)	37 (North littoral of creek)	7 July	1 wildcelery
		9 July	1 Sago pondweed
		11 July	1 bushy pondweed
		14 July	2 wildcelery (anchored)

The second site added was inside a silted unused boat basin protected by sea walls at Archbell Point. This gave a protected environment with soft sediment for a study site. The basin is owned by Texasgulf Chemicals and permission to use it was kindly given by Mr. Bill Schimming, Environmental Manager.

Only wildcelery was used in the 1988 studies. A significant difference between the 1987 and 1988 studies is that the 1988 studies were begun at a time (8 April 1988) when both dormant and germinating tubers could be transplanted. Also fertilization pellets were used in 1988 plots. One tablet was placed in the sediment at 3-5 cm depth and 3-5 cm from each transplant in the experimental plots. The 5 g, 10 g, 21 g Osmocote pellets were 20-10-5 (N-P-K) while the 7.5 g pellet was 16-8-12. The pellets were provided through the courtesy of Sierra Chemical Co., 1001 Yosemite Dr., Milpitas, CA 95035. Transplants were checked three times through 22 August as for 1987. Additional details for the protocol are given in Table 2.

Where sufficient growth of transplants occurred, the beds within a plot were diagramed on graph paper and percent cover in the plot was determined by counting squares. Five 0.1 m^2 square quadrat frame plant samples were dug by hand from each plot except for plots with sparse cover where it was convenient to remove all plant material. These plants were then processed as described on p. 17 (Currituck Sound) and g $plot^{-1}$ was calculated. Harvest was over the period of 17-20 August 1988.

Wildcelery Growth Potential

Sediment-ambient water studies

Two experiments were conducted during the spring and summer of 1988. Wildcelery was planted in sediment in plastic containers placed in laundry tubs except for one treatment in each experiment in which the plants were anchored to the bottom in ambient water by tying them to modified wire coat hangers. The laundry tubs were filled with ambient water to ~ 15 cm of the top (~ 60 L) and maintained in shade in a wooded area at the Crystal Beach research site. This water volume was maintained by dipping out water following rain. Initial and final wet weight biomasses were determined as for the Pamlico River above.

In the first experiment from 3 May to 8 August 1988, sediments were taken from the Blounts Bay site (hard sediment, 13.5 km S) in the Pamlico River and water was taken from the Crystal Beach site. In the Neuse River sediment, water, and wildcelery were taken from the collection station at Black Beacon Point. Each of 6 plastic containers were filled with ~ 2 L of Pamlico River sediment and six plants were planted in each.

Table 2. Protocol for the 1988 wildcelery transplant experiments in the Pamlico River. See Figure 3 for locations.

Site	River km	Dates	Plots planted	Source of plants
Blounts Bay (soft bottom)	13 km S	5 May	One each of control, 5, 10 and 21 g fertilizer pellets	Neuse River
		26 May	2 controls	Neuse River
Blounts Bay (hard bottom)	13.5 km S	5.6 May	One each of control, 5, 10, and 21 g fertilizer pellets	Neuse River
		26 May	2 controls	Neuse River
Crystal Beach (hard bottom)	18.5 km S	See Table 1 for protocol.		
Archbell Point (hard bottom)	25 km N	3 May	One each of control, 5, 10 and 21 g fertilizer pellets	Neuse River
		25 May	2 controls	Neuse River
		13 July	2 controls	Currituck Sound
Boat basin (soft bottom)	25 km N	8 April	2 dormant tubers 2 germinating tubers	Currituck Sound
		23 April	2 controls	Neuse River
		4 May	One each of control, 5, 10 and 21 g fertilizer pellets	Neuse River
		13 July	2 controls	Currituck Sound
South Creek (hard bottom)	37 km N	23 April	2 controls	Neuse River
		8 May	One each of control, 5, 10 and 21 g fertilizer pellets	Neuse River
		25 May	2 controls	Neuse River
		13 July	2 controls	Currituck Sound

Three of these containers were placed in a laundry tub (~ 60 L water) with Pamlico River water and three were placed in a tub with Neuse River water. This gave a total of 18 plants per treatment. This process was repeated using Neuse River sediment. Finally 9 plants were anchored in the bottom of a laundry tub with Pamlico River water only.

In the second experiment, from 12 July to 10 August 1988, the same protocol was used except that three plants were planted in each container (~ 1 L of sediment). Currituck Sound sediment and water were used, and both Pamlico River sediment and water were collected from the Blounts Bay site. In addition to calculating the percent of original plant wet weight remaining at the end of the experiments, the mean length and width of the longest leaf of the remaining plants and number of stolons per plant were determined.

Comparisons of natural growth of wildcelery

In all but one wildcelery stand observed in the Neuse River and in all wildcelery stands in Currituck Sound, growth was more lush than at the Crystal Beach site in the Pamlico River. To compare wildcelery growth at these sites, plants were harvested in August 1988 from a lush Neuse River stand, a stand in the Currituck Sound system (Coinjock Bay), and at Crystal Beach. Plants at Crystal Beach were harvested separately from sparse, moderate, and dense stands classified on the scale used for Transect Studies (p. 16). For each site the length and width of the longest leaf of each plant was measured and the number of stolons were counted. These measurements were also made on wildcelery collected on the transects on 31 July and 1 August 1987, on two groups of plants collected at Crystal Beach on 17 May 1989, and on two groups of plants collected from the Neuse River on 20 May 1989.

Physical Data

In 1987, physical data were taken 6 to 8 times at the primary transplant sites in the Pamlico River from 7 July to 2 August while in 1988 physical data were taken weekly at each of the transplant sites from 5 May to 22 August. In addition physical data were taken in the littoral at Black Beacon Point on the Neuse River and the littoral at Crystal Beach on the Pamlico River from 20 April to 7 May 1988. Data gathered in the littoral at Waterlily on Currituck Sound by Ms. Neda Moore and Mr. L.C. Barrow daily from 23 August 1987 to 15 August 1988 was kindly made available to us. Finally Secchi depths were taken at Crystal Beach from 2 to 25 May 1989.

Surface salinity and water temperature were measured by a Model 33 YSI SCT meter and turbidity (1987 only) by a Hach Model

16800 Turbidimeter. On a few occasions in 1987 water temperature was measured with a laboratory thermometer. Secchi depth and water depth were also determined. Normally when the Secchi disc was visible on bottom, Secchi depth was nearby where the water was deeper.

Comparison of Methods

The bewildering array of methods used in the present study as well as previous studies conducted by ourselves and others raises legitimate questions about comparisons among studies. One perspective is whether the sampling error associated with a given method results in variation that could exceed the expected variation among methods. For the kinds of comparisons made in this report, differences that were worthy of mention were usually so great that the more qualitative approaches would have been sufficient to illustrate real changes in SAV density and cover. In the Pamlico River, for example, SAVs have fluctuated from lush, vigorously growing beds to complete absence. Any differences attributable to sampling error would not affect the conclusions and interpretations in this report.

RESULTS

General Surveys

Pamlico River

The sites visited in the Pamlico River surveys of 1985-1988 are shown in Figure 3 and the data for occurrence and clump sizes of widgeongrass are summarized in Table 3. The data suggest that widgeongrass became more widespread in the river from 1985 to 1988. During the study period the western-most site where widgeongrass was found in the northern littoral was at km 16 and the eastern-most site where widgeongrass was found in the northern littoral was at km 38. Seventy-one percent of the sites in this stretch had widgeongrass at some time during the study. During the same period, the western-most site where widgeongrass was found in the southern littoral was at km 20 and the eastern-most site where widgeongrass was found in the southern littoral was at Indian Island (km 43). Eighty-eight percent of the sites in this stretch had widgeongrass at some time during the study. In informal surveys in 1988, widgeongrass was noted to be scattered throughout the area from Nevil Creek (km 18.5 S) to around Core Point (km 24 S).

Although widgeongrass was widespread in the littoral during the study period, the only sites found in the river with stands more dense than scattered clumps were along the eastern shore of the embayment at the mouth of St. Clair Creek (km 37 N) in June 1985 and on the southern side of Indian Island (km 43 S).

We first found wildcelery in the Pamlico River in the 1987 survey. Thirteen plants in two groups were found at km 15 N, two plants at km 20 S, and a small bed of perhaps 40-50 plants just east of the community pier at Camp Leach Estates (km 20 N). An analysis of some of these plants is given in a later section. A few clumps of wildcelery were noted just east of the pier at Billy K's Campground (km 20.5 S) during the summer of 1987 (Billy Kinnion, personal communication 1988).

In the summer of 1988 wildcelery was found on transects only at Camp Leach Estates and in Sparrow Bay just west of Billy K's Campground. However, wildcelery was frequently found along the southern shore from km 19 to km 22 in informal surveys. Some of the plant clumps covered several square meters. Furthermore, in 1988 the stand at the Camp Leach Estates had extended east from the pier by around 100 m. The western-most known wildcelery stand in the Pamlico River in 1988 was at Summer Haven (km 9 N) where a few clumps were found (Keith Hackney, personal communication 1988). Clumps of redhead grass were found on

Table 3. Occurrence and clump sizes of widgeongrass at sites in the Pamlico River as determined by surveys in 1985, 1987, and 1988.

Dates	Percent sites present	No. sites in clump size range (m^2)			
		trace-0.1	0.1-0.5	0.5-1.0	>1.0
24, 25 June 1985	9	--	--	1	2
10 August 1985	21	4	1	2	--
30, 31 July, 1 August 1987	30	6	2	--	2
20-22 June 1988	48	10	4	1	1
20 August 1988	27	--	3	4	2

occasions in the vegetated area along the southern shore (km 18.5 to km 22) and at Camp Leach Estates. A few clumps of Sago pondweed were found near the pier at Billy K's Campground.

Neuse River estuary

Survey, 7 August 1987. A trace of widgeongrass was found in an embayment just east of the mouth of the Trent River (Daymark 29). Wildcelery was dense to very dense along the southern littoral from the fertilizer plant at James City (Daymark 28) to 3 km west of Johnson Point. From there it became sparse and no plants were found at Johnson Point. Wildcelery was usually in a narrow band 20-30 m wide along a narrow littoral to a depth of 1.0-1.2 m. The plants were healthy as indicated by length of the leaves, around 0.7-0.8 m. No plants were found on the northern shore. Two crabbers said that SAV in the area had been breaking up and rafting since around the middle of July.

Survey, 28 April 1988. Traces of wildcelery were found on 8 of the 11 transects west of Johnson Point along the southern littoral, and traces of widgeongrass were found on 5 of the 11 transects. No plants were found east of Johnson Point. Since a dense to very dense wildcelery bed developed later in the season at the collection site at Black Beacon Point (Daymark 27), we assume that the SAV in the southern littoral developed to much the same as in 1987. Only traces of widgeongrass were found on 4 of the 10 transects in the northern littoral.

Survey, 11 May 1988. Traces of a charophyte and a trace of horned pondweed were found in one embayment at the three embayments visited west of the U.S. 17 bridge.

In summary, the only significant biomass found in the Neuse River was wildcelery along the southern littoral from Daymark 28 east to around 3 km from Johnson Point. Traces of widgeongrass were found in the area on both sides of the river.

Tributaries and Embayments

The data for these surveys are given in Appendix E. Included are the surveys of the Back Bay tributaries and embayments and the Currituck Sound marsh islands in the middle reach and the northern Currituck Sound.

The Pamlico Sound system

Except for locally dense Eurasian watermilfoil in a tributary of North Creek and some tributaries of South Creek, horned pondweed and widgeongrass comprised practically all of the SAV biomass found in tributaries in these studies. Horned pondweed begins to grow in the winter (Davis et al. 1985b) and tends to be replaced by widgeongrass beginning in May and June.

Typically, SAV was densest in the upper reach of the creeks with density gradually decreasing down the creeks. SAV may be locally dense in shallow embayments anywhere in the system. Usually one could expect to find SAV within the 1 to 1.2 m depth contours in the upper and middle reaches of small creeks and in embayments. Plants often are not found in the lower reaches of creeks at any depth.

Species found in the Pamlico River tributary system, other than horned pondweed and widgeongrass, were: (1) traces of bladderwort, charophytes, and bushy pondweed in tributaries of the upper reach of the river; (2) a dense stand of leafy pondweed in the upper reach of Durham Creek; (3) traces and locally dense Eurasian watermilfoil in some lower reach tributaries.

SAV biomass in the upper reach tributaries was low or none was present as was the case for the larger tributaries in the Pamlico River system. These sites include Chocowinity Bay, Blounts Creek, Bath Creek, Durham Creek, South Creek, and Goose Creek. SAV biomass was usually high, at least at times, for the smaller tributaries of some of these tributaries.

Species growing in the Pungo River system, other than horned pondweed and widgeongrass, were traces of Eurasian watermilfoil and a trace of leafy pondweed in Upper Dowry Creek and a small patch of leafy pondweed associated with alligatorweed in Pantego Creek. This was the only time alligatorweed was found in the water in the Pamlico Sound system.

Other than around the mouth of tributaries, no SAV was found in the Pungo River. Tributaries of the northern Pungo River along the east-west arm were usually barren or had low densities of SAV. This includes Pungo and Pantego Creeks, the two largest tributaries of the river. Dense beds were often found at other places, especially in the tributaries of Slade and Fortescue Creeks.

Brice Creek, a tributary of the Trent River near where it joins the Neuse River, had the greatest number of SAV species found in the tributaries of the Pamlico Sound system. In addition to horned pondweed, it had a charophyte, leafy pondweed, and wildcelery. A charophyte was found in the Trent River and a trace of eelgrass was found in a tributary in the lower reach of the Neuse River.

SAV was usually present in the Neuse River tributaries, often in high biomass. Clubfoot and Adams Creeks, where no SAV was found, are two notable exceptions.

A trace of eelgrass was found in the Bay River system. Tributaries of this system tended to have little or no SAV.

Some traces of eelgrass were found in tributaries and embayments along the western Pamlico Sound but no horned pondweed was found here. No SAV or only traces of widgeongrass was the norm for this area, especially to the north.

The Albemarle Sound system

The Perquimans River, beginning at Hertford, was the closest thing to an aquatic botanist's paradise encountered in these studies. Species found were bushy pondweed, redhead grass, wildcelery, a charophyte, and Eurasian watermilfoil. Eurasian watermilfoil was found only once. At least some SAV was found in each embayment visited. Grassy Point, in the upper part of the lower reach, is still well named.

Horned pondweed, bushy pondweed, Sago pondweed, leafy pondweed, redhead grass, wildcelery, and Eurasian watermilfoil were found in Little River. Leafy pondweed predominated along the eastern littoral in the middle reach and this graded into dense Eurasian watermilfoil beds to the mouth. The beds were often large and dense. Eurasian watermilfoil beds, also often large and dense, dominated the western littoral.

Only a trace of widgeongrass was found in the Pasquotank River. This was at Miles Point in the lower reach.

Bushy pondweed, widgeongrass, wildcelery, two species of charophytes, and Eurasian watermilfoil were found in North River. Dense beds of bushy pondweed, widgeongrass, and Eurasian watermilfoil, separately or mixed, grew in the middle and lower reaches. The upper reach was not visited.

Except for a trace of redhead grass at Point Harbor, widgeongrass and Eurasian watermilfoil were the only species found in the Point Harbor-Kitty Hawk Bay-Roanoke Island area. Eurasian watermilfoil was very dense at Point Harbor and moderate to very dense widgeongrass dominated Jean Guite Creek.

Widgeongrass and Eurasian watermilfoil were abundant and usually dense, sometimes in mixed stands, in the shallower areas in Kitty Hawk Bay. Some widgeongrass and a trace of Eurasian watermilfoil were found in Buzzard Bay.

Transect Studies

Back Bay

The Back Bay transects were essentially barren. In 1987 one widgeongrass shoot was found on Transect E while in 1988 traces of widgeongrass, wildcelery and Eurasian watermilfoil were found at the two eastern-most stations on Transect F (Figure 1 shows transect locations). Secchi depths along the transects in 1987 were 0.3 ± 0.1 m (mean $\pm$ SD; n=37) while Secchi depths along the transects in 1988 were 0.4 ± 0.1 m (n=31). Secchi depths taken in SAV beds in 1987 were 0.3 ± 0.0 m (n=3) while the same measurements in 1988 were 0.5 ± 0.1 m (n=13).

Currituck Sound

The data for the Currituck Sound transects are summarized in Tables 4 and 5. No plants were found in North Landing River (Transects K and K')and in the lower reach south of the marsh islands (Transects R and S). Eurasian watermilfoil had the highest biomass while the biomass for Sago pondweed, widgeongrass, and wildcelery were similar and lower than for Eurasian watermilfoil. Other species were present essentially in trace amounts.

Plant frequency was greater at 0.6-1.1 m depths than all other depths combined (Table 5). Widgeongrass and Eurasian watermilfoil both were found at 19 stations; however, widgeongrass had a greater depth range for maximum biomass and maximum depth, respectively (0.6-2.2 m, 2.3 m), than did Eurasian watermilfoil (0.6-1.6, 1.7 m).

In addition to the transect surveys, the northern Currituck Sound and the marsh islands area of the middle reach were surveyed in October 1987 (Appendix E). As in 1988 (Table 5) SAV was usually found clustered around the 1.1 m contour. Eurasian watermilfoil was the dominant species. Beds of this species were more extensive in the northern sound, especially in the Coinjock Bay and Knotts Island Channel areas.

Tributaries of the Pamlico River

The results of the South Creek tributary transects are summarized in Table 6. Jacks, Jacobs, and Drinkwater Creeks, the three natural creeks studied, were similar in that widgeongrass cover was high throughout and tended to be dense in the upper reach as compared with the lower reach. Eurasian watermilfoil was present in low cover and density in the lower reaches of Jacobs and Drinkwater Creeks. In PA I and PA II widgeongrass

Table 4. SAV biomass on the Currituck Sound transects in July, 1988 (g m^{-2}) and mean for each species in 1973, 1978, and 1988.

Transect	Charo-phytes	Sago pondweed	Red-head grass	Widgeon-grass	Bushy pondweed	Wild-celery	Eurasian water-milfoil
I	0.0	0.0	0.0	5.0	0.6	2.7	2.3
J	1.1	4.6	Trace	1.0	0.3	7.6	Trace
K′	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L	0.4	1.0	0.1	4.1	1.1	4.5	3.8
M	0.0	0.0	0.2	2.9	0.1	2.4	25.5
N	0.0	1.3	0.0	0.6	0.2	0.0	Trace
O	0.0	7.0	0.0	0.2	Trace	0.0	Trace
P	Trace	0.0	0.0	1.7	0.1	0.0	30.0
Q	0.6	3.1	0.0	0.0	0.0	0.0	0.0
R	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean*							
1988	0.2	1.4	Trace	1.3	0.2	1.4	5.1
1978	0.8	15.8	0.1	0.3	Trace	0.6	13.3
1973	1.3	5.6	2.1	0.1	20.4	3.2	27.2

*1973 and 1978 data from Davis and Carey (1981).

Table 5. Plant frequency-depth relationships for the Currituck Sound transect stations in July 1988.

Depths (m)	No. of Sites	Species and percent frequency							
		Charophytes	Sago pondweed	Redhead grass	Widgeon grass	Bushy pondweed	Wildcelery	Eurasian watermilfoil	Any species
0.6, 0.7	3	67	33	0	67	0	100	33	100
0.8, 0.9	10	0	0	20	50	40	50	50	60
1.0, 1.1	15	20	26	13	47	20	47	27	67
1.2, 1.3	9	0	11	0	11	11	0	11	11
1.4, 1.5	10	10	0	0	10	20	0	40	40
1.6, 1.7	19	0	0	0	5	0	0	21	26
1.8, 1.9	8	0	0	0	0	0	0	0	0
2.0, 2.1	10	0	0	0	10	0	0	0	10
2.2, 2.3	19	0	0	0	5	0	0	0	5

Table 6. Percent SAV cover in South Creek tributaries in June 1988 according to species, density estimates, and reach.

Creek	Density	Widgeongrass		Eurasian watermilfoil	
		upper	lower	upper	lower
Jacks	Sparse	13.6	11.4	--	--
	Moderate	18.5	1.1	--	--
	Dense	49.4	15.2	--	--
	Total	81.5%	27.7%	--	--
Jacobs	Sparse	7.8	26.8	--	1.3
	Moderate	14.3	5.7	--	0.6
	Dense	67.5	6.4	--	--
	Total	89.6%	38.9%	--	1.9%
Drinkwater	Sparse	34.3	21.2	--	12.6
	Moderate	11.9	8.5	--	2.4
	Dense	53.7	3.1	--	--
	Total	100.0%	32.8%	--	15.0%
PA I	Sparse	12.2	--	7.3	28.9
	Moderate	36.6	6.7	56.1	17.8
	Dense	51.2	42.2	17.1	53.3
	Total	100.00%	48.9%	80.5%	100.0%
PA II	Sparse	4.7	18.6	82.2	18.6
	Moderate	--	5.3	--	22.1
	Dense	95.3	31.0	4.6	43.3
	Total	100.0%	54.9%	86.8%	84.0%

cover and density were higher throughout while Eurasian watermilfoil cover was high throughout with high density in the lower reach.

The only species found on the Nevil Creek transects was horned pondweed. Cover was 23.5% while density estimates were: (1) sparse, 17.6%; (2) moderate, 3.4%; (3) dense, 2.5%.

Transplant Experiments

1987 studies

Except for the final survey of the transplant plots on 2 October 1988, the only survey conducted after all plots were planted was on 26 and 27 July 1987. The protocol for the plantings is given in Table 1. These observations are summarized below with plants found noted:

Blounts Bay (km 13 S). One wildcelery plant and one bushy pondweed plant, both in poor condition.

Blounts Bay (km 13.5 S). Four wildcelery plants and one Sago pondweed plant, all in poor condition.

Nevil Creek (km 14 S). Two Sago pondweed plants and one bushy pondweed plant, all in poor condition.

Archbell Point (km 25 N). Twenty-seven of 80 (33.8%) perimeter wildcelery plants, 9 of 16 (56.2%) perimeter Sago pondweed plants, and 6 of 16 (37.5%) perimeter bushy pondweed plants were present. Three of 10 (30.0%) wildcelery plants inspected each had a stolon and the two Sago pondweed plants inspected showed some growth. No new growth was observed for bushy pondweed. All plants had heavy epiphytes.

Huddles Cut (km 30 S). The few remaining Sago pondweed plants found in the plots showed no growth and had heavy epiphytic growth.

South Creek (km 37, northern shore of creek. Seventeen of 48 (35.4%) perimeter wildcelery plants, no Sago pondweed plants, and three bushy pondweed plants were found in the plots.

Except for occasional production of stolons by wildcelery at the Archbell Point and South Creek sites, there was no suggestion that the transplants would become established and spread. These observations were confirmed when no transplants were found in any plots on 2 October 1987.

On 21 August, 8 of 16 wildcelery plants were found in the perimeter of the control plot in Coinjock Bay. There were no visible epiphytes, the plants were healthy, and leaves were up to 0.5 m in length.

1988 studies

The 1988 wildcelery transplant sites were surveyed on 5 July 1988. The protocol for the plantings is given in Table 2. These observations are summarized below with reference to plants found with an underwater viewer on the perimeter of each plot:

Blounts Bay (km 13 S). No plants.

Blounts Bay (km 13.5 S). Two plants in poor condition.

Crystal Beach (km 19 S). Plots 1-31 had been planted before the survey date. Thirty of these plots had one to 9 clumps of plants. The clumps were formed by growth and reproduction of the original plants. Some of the clumps had probably grown together. Epiphytes were sparse to heavy.

Archbell Point, River (km 25 N). Twenty-two of 96 (22.9%) plants were remaining, and 12 of these (54.6%) had one to four daughter plants. Sparse filamentous algae were observed on the plants.

Archbell Point, Boat Basin (km 25 N). Forty-three of 160 (26.9%) of the plants were remaining with 18 of these (41.9%) with one to four daughter plants. Heavy epiphytes were observed.

South Creek (km 37) north shore of creek. No plants found. All plots were overgrown with widgeongrass.

All plots were surveyed again on 3 and 4 August 1988. Since it was obvious that biomass was decreasing in all but the Crystal Beach plots, the plots were surveyed in their entirety. The results are summarized below:

Blounts Bay (km 13 S). No plants.

Blounts Bay (km 13.5 S). One plant.

Crystal Beach (km 19 S). Biomass appeared to be about the same as for that harvested. Sparse to heavy epiphytes were found.

Archbell Point, River (km 25 N). Two small clumps and 20 single plants in the 8 plots.

Archbell Point,Boat Basin (km 25 N). Three small clumps in one plot, two small clumps in one plot and one plant in a third plot. Sparse to heavy epiphytes were present.

South Creek km 37, northern shore of creek. No plants. Heavy epiphytes were on widgeongrass.

The final survey, except for the Crystal Beach site which was harvested earlier, was conducted on 22 August 1988. Wildcelery was found in only one plot in the Archbell Point boat basin. The total remaining biomass in this plot was only 2.5 g. The principal epiphytic organism, an hydroid, is considered in Appendix D.

Since the transplants were nearly gone at the Blounts Bay stations and none were found at the South Creek site on 5 July, it is unlikely that growth occurred at these sites. Plants were established and reproducing vegetatively at the Archbell Point sites at this time but the biomass was reduced drastically over the period between 5 July and 2 August. By 22 August wildcelery at Archbell Point had virtually disappeared. Only the stand at Crystal Beach remained.

Crystal Beach harvest

Percent cover and organic weight of wildcelery were determined for the plots at Crystal Beach on 17-20 August 1988 (Table 7). Wildcelery was present in all 33 plots except for one planted on 23 May and the two planted in July. There was extreme variability among the plots in percent cover and especially organic weight. Mean percent cover ($\pm$ SD) in the untreated plots planted on 21-23 May was 11.9$\pm$4.6% while the same measurement for the 21 g fertilizer pellet plots was 14.3$\pm$6.3%. Mean weight of wildcelery for the untreated plots planted on 21-23 May was 44.7$\pm$32.4 g plot^{-1}, while the mean weight for the 21 g fertilizer plots was 107.6$\pm$80.3 g plot^{-1}. Thus the mean percent cover for the untreated and 21 g fertilizer plots were similar, but the treated plots had 2.4 times greater biomass than the untreated plots. These data suggest that fertilization with 21 g pellets resulted in higher biomass and greater density in the areas colonized by wildcelery but these differences are not significant at the 0.05 level. Mean percent cover for all plots planted on 21-24 April was 11.7$\pm$5.4% while mean percent cover for all plots planted on 21-23 May was 11.5$\pm$6.6. Mean weight for all plots planted on 21-24 April was 60.8$\pm$57.9 g plot^{-1} while mean weight for all plots planted on 21-23 May was 60.1$\pm$52.6 g plot^{-1}. There are obviously no statistical differences between the two planting dates in cover and weight.

Table 7. Summary of wildcelery transplant experiments at Crystal Beach, 1988.

Plot	Planting dates	Percent cover	Organic wt. (g $plot^{-1}$)
1. Dormant tubers	14, 18 April	14	54.8
2. Dormant tubers		6	30.9
3. Germinating tubers		12	36.0
4. Germinating tubers		10	25.4
5. Control	21-24 April	6	8.7
6. Control		16	112.5
7. Control		17	81.9
8. 5g pellets		7	14.5
9. 5g pellets		8	19.2
10. 5g pellets		15	60.0
11. 10g pellets		10	43.2
12. 10g pellets		10	57.8
13. 10g pellets		13	43.5
14. 21g pellets		3	16.9
15. 21g pellets		22	217.6
16. 21g pellets		13	53.2
17. Control	21-23 May	13	66.9
18. Control		12	45.6
19. Control		19	23.4
20. Control		6	5.2
21. 5g pellets		8	27.3
22. 5g pellets		17	116.6
23. 5g pellets		7	85.0
24. 7g pellets		4	10.5
25. 7g pellets		6	12.9
26. 10g pellets		24	102.1
27. 10g pellets		8	47.9
28. 10g pellets		0	0.0
29. 21g pellets		16	132.6
30. 21g pellets		15	177.0
31. 21g pellets		17	48.1
32. Control	13 July	0	0.0
33. Control		0	0.0

Wildcelery Growth Potential

Sediment-ambient water studies

The results of these experiments are given in Table 8. Except for the wildcelery maintained without sediment, increase in wet weight was four-fold or greater in the first experiment, while there was no growth or a reduction in biomass in the second experiment. The lack of growth as well as death of plants in the second experiment is unexplained. Except for the treatment without sediment in the first experiment, leaf length and width were consistently greater in the first experiment. Differences appeared in the second experiment. Except for the treatment where most plants died, the number of stolons per plant was consistently greater than in the first experiment.

By harvest date, a green filamentous alga (probably Cladophora glomerata) was common on plants in tubs in the first experiment containing Pamlico River water and in the tub in the second experiment with Pamlico River water but no sediment. This suggests that propagules of the alga were present in the Pamlico River water only and/or that Pamlico River water only was a suitable medium for algal growth.

In the second experiment there was slight to heavy fragmentation of wildcelery leaves in all treatments except for Currituck Sound sediment with Pamlico River water. Fragmentation is a phenomenon in which a portion of the leaf blade separates more or less at a right angle to the length, leaving a straight smooth edge as if cut with a razor. Fragmentation appears to be analogous to abscission in which leaves separate from nodes following the formation of an abscission layer. No leaves were fragmented in the first experiment.

Comparisons of natural growth of wildcelery

Mean leaf lengths and widths of wildcelery plants collected in this study are given in Table 9. A more detailed analysis of the appearance and morphological characteristics of the plants collected from the Pamlico and Neuse Rivers in May 1989 is given in Table 10. Except for the two plants found on the southern shore, all plants observed in the Pamlico River in 1987 were uniformly small, appearing as miniature plants. The mean leaf widths of all groups of wildcelery collected in the Pamlico River were less than those of wildcelery from Currituck Sound and the Neuse River. The generally shorter leaf lengths of the plants from the Pamlico River and Green Springs Beach than for other collections was due in part to fragmented leaves. The majority of the leaves of the plants collected from Crystal Beach in 1988 were fragmented.

Table 8. Percent of plants surviving and original wet weight remaining, mean leaf length and width (longest leaf of each plant), and mean number of stolons of wildcelery plants under differing sediment-water regimens. Eighteen plants were used per treatment in the first experiment (3 May-8 Aug) and nine plants were used per treatment in the second experiment (12 July-10 August).

Treatment: Sediment	Treatment: Water	Percent of orig. plants surviving	Percent of orig. wet weight	Longest leaf $\bar{x}$ (cm ± SD): Length	Longest leaf $\bar{x}$ (cm ± SD): Width	Stolons per plant
First experiment:						
Pamlico R.*	Neuse R.	100	400	39± 4	0.6±0.1	0.9
Pamlico R.*	Pamlico R.	100	460	69±12	0.7±0.1	0.7
Neuse R.*	Pamlico R.	100	440	57± 7	0.7±0.1	0.7
Neuse R.*	Neuse R.	100	400	58± 8	0.6±0.1	0.7
---	Pamlico R.	100	110	26± 7	0.4±0.1	0.6
Second experiment:						
Pamlico R.	Currituck S.	22	2	13± 4	0.4±0.0	0.0
Pamlico R.	Pamlico R.	78	50	33±10	0.5±0.1	1.4
Currituck S.	Pamlico R.	100	100	36±10	0.5±0.1	1.7
Currituck S.	Currituck S.	100	93	36±13	0.5±0.1	1.3
---	Pamlico R.	89	50	30±10	0.5±0.1	1.9

*Flowers and fruits produced.

Table 9. Mean leaf length and width (longest leaf) of wildcelery during 1987-1989.

Site	Date	No. Plants	Longest leaf $\bar{x}$ (cm ± SD) Length	Width
Pamlico River Transects*	31 July, 1 Aug 1987	7	6 ± 1	0.2 ± 0.0
Crystal Beach				
Sparse stand	1 Aug 1988	56	10 ± 2	0.4 ± 0.1
Moderate stand		37	14 ± 4	0.4 ± 0.1
Dense stand		52	15 ± 6	0.3 ± 0.1
Stressed stand	17 May 1989	20	7 ± 2	0.3 ± 0.1
Less stressed stand		20	18 ± 4	0.3 ± 0.1
Currituck Sound (Coinjock Bay)	23 Aug 1988	82	44 ± 4	0.5 ± 0.1
Neuse River				
Black Beacon Point	24 Aug 1988	100	40 ±15	0.6 ± 0.1
	20 May 1989	20	17 ± 4	0.6 ± 0.1
Green Springs Beach	20 May 1989	20	12 ± 2	0.5 ± 0.1

*Plants with five or more leaves measured.

Table 10. An analysis of wildcelery plants collected in the Pamlico and Neuse Rivers in May 1989. Twenty plants in each group.

	Pamlico River at Crystal Beach		Neuse River	
	Stressed	Less Stressed	Green Springs Beach	Black Beacon Point
Date	17 May	17 May	20 May	20 May
No. leaves ($\bar{x} \pm$ SD)	6.0 ± 1.4	6.4 ± 1.2	7.3 ± 1.0	8.8 ± 0.6
Longest leaf (cm)				
Length	7 ± 2	18 ± 4	12 ± 2	17 ± 4
Width	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
Leaves				
Fragmented (%)	30.58	16.41	15.0	0.00
Frayed (%)	28.92	0.03	15.0	0.01
Length of tuber stalk	3.9 ± 0.7 (n=16)	4.5 ± 1.1 (n=18)	4.9 ± 1.2	4.9 ± 1.3
No. plantlets ($\bar{x}$)	0.3	0.5*	1.0	1.0
No. Stolons ($\bar{x}$)	0.4	0.9	1.0	1.2
Total primary stolon length ($\bar{x}$ cm)	3.9 ± 2.8	6.9 ± 4.8*	9.9 ± 5.0	9.8 ± 5.1

*Five plants with broken stolons not counted.

Frayed leaves were observed in quantity for the first time in 1989 (Table 10). These leaves were broken but with a frayed margin where severed.

Practically all the plants at Crystal Beach in May 1989 are represented by the stressed group of plants (Table 10). Compared with the other groups collected in 1989, these plants had the fewest and shortest leaves and the greatest percent of fragmented and frayed leaves. These plants also had the fewest plantlets, number of stolons, and the shortest tuber stalk and stolon lengths. In addition, these stressed plants had a lower tuber weight ($\bar{x}$ 1.44 $\pm$ 0.81 mg, n=15) than did the less stressed plants ($\bar{x}$ = 2.37 $\pm$ 0.98 mg, n=15). (The tubers were air-dried overnight before weighing.)

Wildcelery was collected at Black Beacon Point (Daymark 27 S) in the Neuse River for the transplant experiments in 1987 and 1988. The wildcelery stand at Green Springs Beach (Daymark 28 S) was found in July 1988. The condition of the plants here appeared to be similar to those in the Pamlico River. This was the only such stand noted in the Neuse River. Except for the fragmented and frayed leaves of the plants at Green Springs Beach, the wildcelery here was similar to that at Black Beacon Point in May 1989.

Physical Data

Physical data collected from the transplant sites in the Pamlico River in 1987 and 1988 are given in Appendix F and Appendix G.

Data collected in the littoral at stations in the Neuse and Pamlico Rivers and Currituck Sound from 20 April to 7 May 1988 are summarized in order:

Black Beacon Point. Salinity, 0.5 ^{o}/oo maximum; Secchi depth, 0.7 $\pm$ 0.4 m (n=5).

Crystal Beach. Salinity, 4 $\pm$ 1.5 ^{o}/oo; Secchi depth 0.65 $\pm$ 0.4 m (n=4).

Waterlily. Secchi depth 0.4 $\pm$ 0.1 (n=18). Salinity not taken.

The Secchi depths taken at Crystal Beach in May 1989 are given in the discussion.

DISCUSSION

The Disappearance of SAV in the Pamlico River: When and Why?

In the mid-seventies SAV beds were obvious features in most areas of the littoral of the upper half of the Pamlico River (Davis and Brinson 1976). The beds extended from near Washington (km 3) to Durham Creek (km 27 S) on the southern shore and to North Creek (km 41 N) on the northern shore (Figure 3). Also a stand of widgeongrass was present on the southern side of Indian Island (km 41 S). Of the five major species of SAV in the river in 1975, only one, widgeongrass, remained in 1985. Around 99% of the SAV biomass present in 1975 had disappeared by 1985.

A transect run in August 1979 across the littoral at Jakes Bay (km 11 N) in the northwestern corner of Blounts Bay in a study associated with a Pamlico River clam float (Davis et al. 1981) supports the concept that the SAV in the area disappeared about that time. The only species found was wildcelery and it was in very low density (1.5 plants 0.1 m^{-2}) and in poor condition with most of the leaves fragmented down to around 10 cm of the base. There was silt and perhaps epiphytes on the leaves. Epiphytes were not mentioned in the field notes. Reed (1979) ran 9 transects in August 1973 and August 1974 from Jakes Bay east to km 29 in the Pamlico River to determine SAV species presence and biomass. Wildcelery and redhead grass were the only species found with significant biomass. The highest biomass for wildcelery for the study was found on the Jakes Bay transect in 1973 and the second highest biomass for redhead grass for the study was on the Jakes Bay transect in 1974. Obviously then, conditions in Jakes Bay were favorable for growth of SAV at that time.

While studying the relationship of dissolved oxygen to blue crab catch in Blounts Bay in 1982 (Harlan and Davis, unpublished), we surveyed the littoral of the bay for SAV. We found none.

These observations plus interviews with local commercial fishermen suggest that 1979 was probably the last year that wildcelery and other SAV were in the river (with the exception of widgeongrass). This is a reasonable answer to the question as to when all but one species and 99% of the SAV biomass disappeared from the Pamlico River. The question as to why is harder to answer.

Responses of SAV to environmental impacts are reviewed in the Introduction. Some of these will be considered in relation to their potential role in the loss of SAV in the Pamlico River.

Excess phytoplankton growth in the water may shade SAV resulting in a decrease in photosynthesis. Kuenzler et al. (1979) suggested that there probably was some increase in phytoplankton biomass in the river from the early seventies through the late seventies. However, phytoplankton density must be extremely high before it will seriously reduce light reaching SAV (Kemp et al. 1983). We know of no impact of phytoplankton on SAV in the Pamlico River. It could occur in a localized tributary with poor flushing and a persistent bloom or in the river under the same conditions. Blooms of Heterocapsa triquetra, mainly during winter-time, are characteristic of the river (Hobbie 1974). Blooms tend to occur during high tributary discharge in the winter) and SAV is not growing.

There is no evidence that abundance of filamentous algae was a critical factor in the changes which occurred in the Pamlico River. Very high biomasses of filamentous algae were present in the upper and middle reach of the Pamlico River in 1974. Biomass of filamentous algae within SAV beds was greater than the SAV biomass itself in 1974 or 1975 (Davis and Brinson 1976). However, SAV biomass in 1975 was higher than for 1974, suggesting no direct negative effect of the algae.

Epiphytic growth and suspended sediments which settled onto leaves could have been a factor in the loss of SAV in the river. As mentioned above, the decrepit wildcelery leaves found in Jakes Bay in 1979 were silted and possibly had epiphytes. However SAV is now returning to the river and the plants often have heavy epiphytic cover and/or silt.

Research in the Chesapeake Bay area (summarized in Kemp et al. 1983) indicates that low herbicide levels found in the water and their ephemeral nature should cause no adverse effects on SAV there. Herbicides in the Pamlico River are below the analytical detection limit (Jimmie Overton, personal communication 1985), so herbicide inhibition would be unexpected.

We do not believe that foraging and grazing by waterfowl contributed significantly to the SAV decline. Most waterfowl feeding occurs in late fall as senescence is occurring. Nonetheless, the observation above by Mr. Blaney McCoy on extensive feeding on SAV by swans in the Hills Point area is of interest. In the mid-seventies we noticed that in some areas juvenile fish nipped lower leaves of redhead grass while feeding. This at best caused some decrease in biomass where it occurred. Grazers (probably turtles) often disrupted transplant experiments with wildcelery in the upper Potomac River (Carter and Rybicki 1985) but we have seen no evidence of such grazing in the Pamlico River.

The 3-year period with the greatest known amount of land runoff for the months of April, May, and June as indicated by lowered surface salinity in Blounts Bay was 1978-1980 (concluded by reviewing data from Hobbie et al. 1972, Hobbie 1974, Davis and Brinson 1976, and Don Stanley, unpublished). The period of lower salinity coincides with the time of disappearance of SAV in the Pamlico River.

March, April, and May 1978 were also unusual months for weather for North Carolina (Davis and Carey 1981). What might have happened to the SAV in the Pamlico River as a result of the stormy spring of 1978? Highly turbid water, northeasters, and turbulence would stress wildcelery if it were growing. In 1975 wildcelery in the river began growing in March when the water temperature was ~10 to 14 C (Davis and Brinson 1976). The mean April temperature at two stations in Blounts Bay for 1976 through 1981 (excluding 1978) was 19.6 C while the mean for 1978 was 6.6 C. Temperature, then, must be considered another stress on the Pamlico River SAV during the early growing season of 1978.

In Currituck Sound in the spring of 1978, Secchi disc transparency was only 0.2 m for several months (Davis and Carey 1981) and a similar situation probably prevailed in the middle and upper reaches of the Pamlico River. Under such conditions, growth of submersed plants should be negligible due to light limitation of photosynthesis. Carter and Rybicki (1985) noted that 12 species of SAV returned to the upper tidal portion of the Potomac River in 1983 after being absent for decades. Mean Secchi depth for July-October, 1978-1981 was 0.5 m while that for the period in 1983 was 0.9 m. This is an interesting observation, but Secchi depths in the spring as growth begins are likely more important to SAV success.

Record high salinities occurred in the Pamlico River in 1981. During April, May, and June 1981 the mean salinity in Blounts Bay was 8.3 $^{o}/oo$ (Don Stanley, unpublished). If, as suggested, all SAV in the river except perhaps widgeongrass, disappeared during 1979-1980, potential regrowth of wildcelery and bushy pondweed may have been negated at these salinities. Both species can survive short periods at these salinity levels (Davis and Brinson 1976 and this study). However, these salinity levels in the spring are probably too high for new growth to occur. Even more damaging to overwintering belowground parts would be death of leaves after some new growth.

We suggest, then, that stresses described for 1978, followed by two more high turbidity years (1979, 1980) followed by a year of extreme salinity stress (1981) combined to virtually eliminate SAV in the Pamlico River. Other factors such as excessive sedimentation on plants and epiphytic growth could have contributed also.

The Reappearance of SAV in the Pamlico River: A Trend?

Wildcelery responses to stress

The contrast between the vast, lush SAV beds in the Pamlico River before their disappearance with the stunted conditions of wildcelery in 1987-89 during recovery leads us to consider the nature of stress phenomena that may be controlling SAV dynamics. We begin with the premise that both narrow or fragmented leaves in wildcelery are a manifestation of stress in the species. Although this phenomenon has not been reported for wildcelery, Phillips and Lewis (1983) found that the width of eelgrass leaves decreased as environmental stress on eelgrass increased, The width of leaves of the 1987 plants was uniformly 0.2 cm for the largest leaves and somewhat less for immature leaves. Radford et al. (1968) set the lower limit for the width of wildcelery leaves at 0.3 cm. The widest leaves found ($\bar{x}$ = 0.7 cm) were in the first sediment-water experiment.

Another sign of stress in wildcelery established in this study is the fragmentation of leaves. The majority of the leaves of wildcelery collected at Crystal Beach in 1988 were fragmented in contrast to those at Black Beacon Point in the Neuse River and in Coinjock Bay in Currituck Sound. Of 77 leaves found on 13 plants collected in 1987 in the Pamlico River in various stages of development, 31.2% were fragmented.

At least for the Crystal Beach site, there were signs of stress in wildcelery early in 1989 (Table 9). The plants were small and had a mean and rather uniform leaf width of 0.3 cm. Stress as demonstrated by loss of a portion of leaf blades was more pronounced than during 1987. Fragmented leaves comprised 30.6% of the total, while frayed leaves comprised 29.8% of the total. The frayed condition was found rarely in 1988. The cause of this condition is not understood. Because the frayed ends usually appear to be the remains of parallel leaf veins, perhaps the damage is due to grazers which ingest only leaf mesophyll and avoid eating the veins. Amphipods were active in fraying of leaves of wildcelery in decay bag experiments in the Pamlico River (Davis and Brinson 1976). Whether frayed leaves are an early season phenomenon in the Pamlico River is not known. Such leaves were not noted for wildcelery collected from the Neuse River and Currituck Sound for the transplant experiments in 1987 and 1988. However, frayed leaves were common in stressed plants collected at Green Springs Beach on the Neuse River in 1989 (Table 9).

Results of transplant experiments also suggest that wildcelery and other SAV were stressed in the Pamlico River in 1987 and 1988. Among the species transplanted in 1987, little early growth was seen for wildcelery and even less for Sago pondweed. Apparently no transplanted SAV survived the 1987 season. Except for the Crystal Beach site, none of the hundreds of wildcelery plants transplanted into the river in 1988 appeared to survive. Hence stresses in the system must have prevented growth and survival at the other sites.

Finally, the fact that plants with fragmented leaves have low biomass does not necessarily mean that net primary production is low. In 1975 growth dynamics of wildcelery in the Pamlico River were studied at two stations (km 10 N, km 29 N) which represented the extremes of densities of wildcelery in the river in 1974 (Davis and Brinson 1976). The upriver station had extensive continuous beds compared to the less dense scattered beds at the downriver station. Leaf productivity (g $plant^{-1}$ day^{-1}) was similar at the two stations through mid-July but was greater at the stressed downriver station through mid-August. This difference could have been related to allocation of carbon reserves toward fruit production at the upriver stations at that time; no female flowers and therefore no fruits were produced at the downriver station. Consequently, leaf per plant production at the two stations may have been the same although the quality differed. The two extremes represent very different qualities of habitat structure for aquatic organisms. The wildcelery plants upriver were large, having leaves up to 1.7 m long while the plants at the downriver station had short fragmented leaves. Because of the higher density of plants at the upstream station, primary productivity per unit area was greater in the less stressful environments. It is likely that stresses at the downstream site led to a lower cover developing during the growing season due to shorter stolons and/or less stolon production.

The primary source of the stress has not been revealed, however. During the early growing season at least, there was apparently no salinity stress at the downriver station. Greater turbulence would be expected in the shallow beds downstream because of greater fetch in that part of the estuary.

Environmental stress and SAV

Tubers are the propagules for reestablishment and continuity of wildcelery in the river. Tubers appeared to become progressively more widespread in the middle reach of the river during the 1987-89 recovery phase. Thus, reproductive potential does not appear to be limiting to the success of wildcelery in the Pamlico River. Presumably other factors will control the health, vigor, and perhaps even the survival of this key species.

Of the stresses discussed in the previous section, the amount of light reaching the photosynthetic cells in SAV leaves may be the most critical factor to consider in relation to complete recovery of SAV in the river. Thus, considering the current state of the river, epiphytic growth and, to a lesser extent, suspended sediment turbidity, are suggested as key factors which will control growth. The presence of tubers illustrates that the potential exists for recolonization.

There is some evidence that suspended sediment turbidity was much greater in the river in 1988 than it was in the mid-seventies. In making such comparisons one must compare segments of time when discharge from the tributaries, especially the Tar River, are similar. Discharge data have not been analyzed. However, if salinities are similar in the same river segments over the same time segment compared for different years, one might expect the average discharges for that time segment to be similar. The salinity and Secchi data compared are for May-August 1974 (Davis and Brinson 1976) and May-August 1988 (this study). The measurements were made in the littoral at three stations between km 18 and km 25 in both studies. Values for each station in 1974 represent single monthly measurements while values for the 1988 study are means of weekly measurements (Table 11). There is a striking difference in Secchi depths between the two years with somewhat similar salinity patterns, especially for May and June. This suggests that there was a greater supply of suspended sediments from tributaries. Because the Tar River is the major tributary, it is likely the source of much of the suspended sediment. However, as noted in the discussion of physical factors, wind direction and force can cause an increase of suspended sediments independent of the effects of tributary input. There is little evidence in the data, however, that wind was responsible for changes in the Secchi depths in 1988 (Appendix G). The only wind event large enough to cause resuspension of bottom sediment was a blowout of water from the middle reach on 18 July which had comparatively little effect on Secchi depths. The conclusion is that greater turbidity in 1988 was due primarily to sediment input from tributaries.

The potential impact of suspended sediments as a stress factor in SAV growth can be evaluated further by comparing recent Secchi depths in the Pamlico River during the growing season with those in the Neuse River and Currituck Sound. As described elsewhere, wildcelery growing in Currituck Sound and most places in the Neuse River during this study was relatively unstressed as compared with wildcelery growing in the Pamlico River.

Few data are available for the Neuse River. During the initial transplant studies in 1988, physical data were taken at the wildcelery collection site in the Neuse River (Black Beacon Point) and at the Crystal Beach site between 20 April and 7 May. The Secchi depth mean ($\pm$ SD) at Black Beacon Point was 0.7 $\pm$ 0.4

Table 11. Surface salinities and Secchi depths in the littoral of the middle reach of the Pamlico River, May-August 1974 and 1988.

Year	Month	Mean salinity ($^{o}/oo$)	Mean Secchi depth (m)
1974*	May	4.0	1.4
	June	6.0	1.6
	July	11.5	1.6
	August	5.0	0.9
1988**	May	4.5	0.7
	June	7.0	0.8
	July	8.5	0.75
	August	9.5	0.7

*Davis and Brinson (1976)
**This study (APPENDIX G)

m (n=5) and at Crystal Beach was 0.65 ± 0.4 m (n=4). The Secchi depth mean in a SAV bed at Waterlily on Currituck Sound for the period was 0.4 ± 0.1 m (n=18). Thus the Secchi depths for Crystal Beach and Black Beacon Point were similar while Secchi depths at Waterlily were lower. The data suggest then, that light penetration in SAV beds in the Pamlico River was as good as that in SAV beds in the Neuse River and better than that in beds in Currituck Sound.

Except for the stand of wildcelery at Green Springs Beach on the Neuse, epiphytes were absent or barely detectable on wildcelery in the Neuse River and Currituck Sound. Quite the contrary was true for wildcelery in the Pamlico River. Beginning with the plants first found in 1987, medium to heavy epiphytic growth was common on both natural plants and SAV transplants.

Epiphytes were not seen on wildcelery plants maintained under various sediment-water conditions from 3 May to 8 August 1988, the primary part of the growing season. The plants rooted in sediment produced flowers and fruits, grew well, and had no fragmented leaves (Table 8). Mean leaf lengths and widths were generally greater than for naturally growing plants (Table 9). The plants were probably light-saturated, were not exposed to turbulence, and grew in low salinities. Other factors such as growth in disturbed sediment did not appear to stress the plants. The poor condition of the wildcelery transplants at the end of the sediment-water experiment conducted from 12 July to 10 August cannot be explained. The greater stolon production by the viable plants in the second experiment suggests that, under the conditions of these experiments, accelerated stolon production may be a survival mechanism working in highly stressed plants. In a like manner, the only tubers produced in the experiments were produced by a stressed plant.

Clearly, epiphytes are often associated with stressed wildcelery and may be a primary cause of stress. Under conditions in the Pamlico River now, the primary effect of suspended sediment turbidity would be to limit the depth distribution of wildcelery. Further increases in epiphytic growth and turbidity could eliminate the generally stressed populations in the Pamlico River.

Widgeongrass has probably been in the Pamlico River at low biomass since the mid-seventies. Its presence at a given site is erratic if the two largest known stands, St. Clair Creek and Indian Island, are representative. All of the observations of the widgeongrass stands at St. Clair Creek and Indian Island are summarized in Table 12. Data on the bed at Indian Island for June and August 1985 are based on transect studies while all other information is based on field observations. Disappearance or drastic reduction of widgeongrass in the stands in late summer and fall with no recovery the following year is the most consistent pattern at St. Clair Creek and Indian Island. The lack of recovery of the stand at St. Clair Creek from 1986 to 1988 and the maintenance of the stand at Indian Island in the late summer of 1988 are variations of this trend. The status of widgeongrass in the river from 1975 to 1985 is largely unknown. Presumably widgeongrass dynamics at Indian Island were similar to that documented. We found a healthy stand of widgeongrass at Indian Island in the summer of 1982.

Water temperatures of around 30 C or higher tend to inhibit growth of widgeongrass (Setchell 1924, Phillips 1960, Joanen and Glasgow 1965, Anderson 1969). Summer temperatures in the Pamlico River are often 30 C or higher. However, there was a dense growth of widgeongrass at Indian Island on 31 July 1987 and in the following year when the mean water temperature at the nearby South Creek stations was 30.5 ± 2 C from 7 July to 26 July 1987. The stand at Indian Island, then, was not adversely impacted at these temperatures. Water temperatures in smaller tributaries tend to be higher than in South Creek and the river. For this same period in 1987, water temperature at the station in Nevil Creek was 34 ± 3 C with the upper extreme being 39 C. These temperatures could adversely impact the growth of widgeongrass and other SAV.

Table 12. Changes in widgeongrass communities at St. Clair Creek and Indian Island in the Pamlico River, 1974-1988. Data for 1974 and 1975 from Davis and Brinson (1976).

Date	Site	
	St. Clair Creek	Indian Island
July 1974	80 plants m^{-2}	193 plants m^{-2}
October 1974	no plants	no plants
August 1975	no plants	no plants
June 1985	20-30% cover, high density	63% cover, 109 g DW m^{-2}*
August 1985	3-5% cover, low density	3% cover, 1.2 g DW m^{-2}*
July 1986	no plants	no plants
July 1987	trace	dense growth near shore, largest individual beds around 1.5m X 7m, no plants beyond around 60m
June 1988	no plants	dense growth near shore, sparse growth 60m-134m
August 1988	no plants	similar to June 1988

*DW = dry weight

In summary, if the physical and biological conditions of the Pamlico River remain about the same, wildcelery will likely spread throughout much of the area previously covered in the middle reach, but probably in a stressed condition. If productivity of such stressed plants is as high as it was in 1975, significant amounts of food would be contributed to the littoral food web; however, much of its value as a waterfowl food and as cover for fish and shellfish would be lost due to low leaf area. Redhead grass and Sago pondweed could increase in importance but bushy pondweed, common in the upper reach in the mid-seventies, is yet to be seen again in the river. Widgeongrass appears to be spreading in the river but the biomass on a river-wide basis is still low.

Our inability to find SAV in Blounts Bay and to get transplants to grow there is surprising. As compared with Crystal Beach and Archbell Point, transplants don't even get started in Blounts Bay. The fact that some wildcelery was found in the river west of Blounts Bay at Summer Haven in 1988 suggests that this situation may change.

The Neuse River Estuary

Surveys to date indicate that the only significant SAV biomass in the Neuse River estuary is wildcelery in the narrow littoral of the upper reach on the southern shore from Daymark 28 to around Johnson Point. Higher salinities and greater wave action associated with an abrupt widening of the river and increased fetch east of Johnson Point may limit the eastern extent of wildcelery. Widgeongrass presence and biomass would not be limited by salinity in estuaries (see Appendix C) but could be limited by wave energy and turbulence. The two sites in the Pamlico River where the largest widgeongrass beds have been found, an embayment at Saint Clair Creek and the lee side of Indian Island, are sheltered habitats.

The paucity of SAV in the Neuse River estuary west of New Bern is not surprising. The same has been observed for the lower Tar River near Washington in informal surveys. Turbulence associated with high flow rates and suspended sediments could be factors in preventing SAV bed establishment in the narrow upper reaches of these estuaries.

The Neuse River surveys were limited temporally and areally. More detailed studies would be useful. Interviews with commercial fishermen and others with a long and intimate knowledge of the Neuse River estuary may be valuable. If SAV trends in the Pamlico River continue, perhaps comparisons with the Neuse River estuary could be made in the future.

Trends in SAV in Tributaries and Embayments

Kitty Hawk Bay

In 1974 the herbicide 2,4-D was applied in Kitty Hawk Bay to control an infestation of Eurasian watermilfoil (Getsinger et al. 1982), which was present in heavy biomass with only traces of other species. The Eurasian watermilfoil was eradicated in the study area and had become established in much lower biomass by 1978. Only traces of widgeongrass, wildcelery, and a charophyte were present then. The low biomass in 1978 coincided with a drastic decrease in Eurasian watermilfoil biomass in Coinjock Bay and apparently in the greater Currituck Sound (Davis and Carey 1981). In 1987 and 1988 we found dense to very dense stands of Eurasian watermilfoil and widgeongrass, both pure and mixed, in Kitty Hawk Bay. From 1987 to 1988, widgeongrass appeared to increase in biomass throughout the bay as compared with Eurasian watermilfoil. Hence over the 14-year period the SAV situation in Kitty Hawk Bay has improved to the extent that some Eurasian watermilfoil has been replaced by widgeongrass. Widgeongrass is an excellent waterfowl food (Martin and Uhler 1939) and does not cause as many problems for boat traffic as does Eurasian watermilfoil.

South Creek tributaries

Tributaries along the western shore of the middle of South Creek (Figure 4) have been visited sporadically since 1981. The greatest amount of data is for Jacobs Creek summarized for plant presence (Table 13). Horned pondweed grows in the tributaries in the winter with replacement by widgeongrass in late spring and summer. However horned pondweed has not been seen in Jacobs Creek since 1983. Warmer than normal water temperatures in the spring could lead to earlier disintegration of horned pondweed and more rapid growth of widgeongrass, although there are other possibilities. No SAV was found in September 1981 although horned pondweed and widgeongrass were relatively abundant in May 1981. Likewise no widgeongrass was found in August 1984, but there was only 13% cover in June 1984, mostly sparse. A trace of widgeongrass was found in the creek again in October 1984. Recovery of widgeongrass beds in the Pamlico River can take 2 years or more (Table 12).

If factors which led to the loss of 99% of the SAV biomass in the Pamlico River around 1978-1980 had any adverse impact on SAV in the South Creek tributaries, there is no evidence. Both Jacks and Jacobs had comparatively heavy biomass in May 1981 (Davis et al. 1985b). This may not be true for at least two other tributaries of the middle reach which connect directly to the Pamlico River.

Table 13. SAV presence in Jacobs Creek determined in three studies from May 1981 to June 1988.

Month	Year	Reach and species: Upper	Reach and species: Lower	Study
May	1981	horned pondweed widgeongrass	horned pondweed widgeongrass	Davis et al. (1985b)
Sep	1981	no plants	no plants	
Dec	1981	horned pondweed	horned pondweed	
Feb	1982	horned pondweed	horned pondweed	
Apr	1982	horned pondweed	horned pondweed	
Jun	1982	horned pondweed widgeongrass	horned pondweed widgeongrass	
Aug	1982	widgeongrass	widgeongrass	
Dec	1982	widgeongrass	widgeongrass	
Feb	1983	horned pondweed	horned pondweed	
Jun	1984	widgeongrass*		Bradshaw and Davis (1985)
Aug	1984	no plants*		
Oct	1984	widgeongrass*		
May	1987	widgeongrass	widgeongrass	This study
Jun	1988	widgeongrass	widgeongrass Eurasian watermilfoil	

*Reaches not differentiated.

Durham Creek

There were diverse SAV communities in the lower reach of Durham Creek in 1973 (Davis and Brinson 1976). Only once did we find SAV in the lower reach of Durham Creek in this study, and this was in embayments in essentially trace amounts. The loss of SAV in Durham Creek could have coincided with the loss of SAV from the Pamlico River.

Nevil Creek

We visited the lower reach of Nevil Creek in the summer of 1973 and found heavy SAV biomass throughout. In 1985 horned pondweed was found at the head of the lower reach and it had spread into the lower reach by 1987 (Appendix E). It was widespread in the lower reach in June 1988, but biomass was low. A small stand of widgeongrass was found in the lower reach in November 1988. From the amount of horned pondweed in windrows along the shore in the spring of 1989, horned pondweed in Nevil Creek appeared heavier than in 1988. Hence, SAV appears to be recovering in the creek, at least for horned pondweed. Conversations with local sports fishermen indicate that SAV disappeared in Nevil Creek about the time it did in the Pamlico River.

Eurasian watermilfoil in the Pamlico River system

The known history of Eurasian watermilfoil in the lower part of the Pamlico River system does not represent a trend. It tends to appear and disappear in all but man-made systems. In addition to PA I and PA II, Eurasian watermilfoil is present in man-made marsh creeks along Long Creek on the eastern side of the lower reach of South Creek (Figure 4). These creeks were opened to Long Creek in 1980 and Eurasian watermilfoil was present in high biomass in a year or two.

A large stand of Eurasian watermilfoil was found in Snode Creek of the Goose Creek system in the late seventies (Jack Donnelly, personal communication 1989) but we could not find it the following year. This observation prompted a search for Eurasian watermilfoil around this time in the lower Pamlico River system since its potential for rapid spread in the system was unknown.

Small beds of Eurasian watermilfoil were found in Campbell Creek of the Goose Creek system just south of Snode Creek. It was seen occasionally in roadside canals in the Goose Creek watershed. A crabber said that it had been dense in Oyster Creek on the southern side of the Pamlico River near the mouth. In our studies, sparse Eurasian watermilfoil was found in Dixon Creek of the Goose Creek system in 1985 and traces were found in James Creek in the Oyster Creek area in 1985 and 1987.

Eurasian watermilfoil was found in a roadside canal at the Pantego Creek bridge in Belhaven. Pantego Creek is a northern tributary of the Pungo River. A native said he had seen the plant in farm ponds since the mid-forties. Traces of Eurasian watermilfoil were found in 1987 and 1988 in Upper Dowry Creek on the northern Pungo River.

In 1985 Eurasian watermilfoil was moderate to dense in Frying Pan Creek at the mouth of North Creek but has not been found there since. This is the latest example of the normally fugacious nature of Eurasian watermilfoil in the Pamlico River system.

Our studies of PA II on South Creek illustrate how the development of a very dense SAV system with Eurasian watermilfoil can become an important part of the man-made system. PA II was excavated and opened to South Creek in 1983 and marsh plants were established on a gentle grade along both sides of the clay bottom watercourse. The system was established to simulate the upper reaches of other small creeks in the area (David Bradshaw, personal communication 1984). In June 1984 traces of widgeongrass were found on two of the ten transects in the upper and middle reaches, but no plants were found in August and October of 1984 (Bradshaw and Davis 1985). Sparse to dense horned pondweed and dense to very dense widgeongrass was concentrated in the shallow margins of the upper reach of PA II in May 1987. Horned pondweed was more dense in the upper portion. Within 3.5 months, the upper reach was covered by dense to very dense widgeongrass. Horned pondweed was not found. Dense widgeongrass and dense Eurasian watermilfoil occupied the middle reach. No horned pondweed was found in PA II in our transect survey in June 1988 (Table 6). In the upper reach, widgeongrass was dense and widespread while Eurasian watermilfoil was sparse and widespread. In the lower reach the density and cover of widgeongrass was lower, while density and cover of Eurasian watermilfoil was greater.

The development of SAV in PA I, another man-made stream, was even more rapid than for PA II. PA I was opened to South Creek in 1982, and by June 1984, 81% of the creek was covered by widgeongrass and Eurasian watermilfoil (Bradshaw and Davis 1985). Coverage by widgeongrass in PA I decreased in July and this species was not found in October. Coverage by Eurasian watermilfoil increased over the study period with 98% coverage in October. In June 1988 widgeongrass covered all of the upper reach at a high density and 54.9% of the lower reach with varying densities. Eurasian watermilfoil coverage of the upper reach was high at low densities and coverage of the lower reach was high with densities skewed toward the high side.

In May 1987 one sprig of Eurasian watermilfoil was found in Tooley Creek while Eurasian watermilfoil appears to have invaded the lower reaches of Drinkwater and Jacobs Creeks for the first time in 1988.

To date Eurasian watermilfoil appears to have become established in the Pamlico River system on a relatively long-term basis only in man-made water bodies. Stevenson and Confer (1978) theorized that Eurasian watermilfoil becomes epidemic in areas where natural systems are disturbed, especially by humans. Perhaps newly dug systems could be considered to be the ultimate representation of disturbed systems. The pattern of colonization in PA II seems to be invasion of the middle and upper reach by widgeongrass and horned pondweed as silty substrate accumulates followed by the seasonal dynamics of these species as established above. Eurasian watermilfoil later becomes established at the mouth where there is no competition and gradually moves into the upper reach at low biomass.

One possible explanation for reduced spread of Eurasian watermilfoil in creeks is the unfavorable conditions created by the wave-induced turbulence and sandy sediments near the mouths of creeks. Seasonal growth may be limited in the more favorable sediments up the creek through competition first with horned pondweed and then with widgeongrass. In Coinjock Bay in 1977 Eurasian watermilfoil approached the yearly peak biomass during the month of April. Horned pondweed should be present at this time in high biomass in the upper and middle reaches of most of the smaller creeks of the Pamlico and Neuse River systems. Future observations on Eurasian watermilfoil dynamics in Jacobs and Drinkwater Creeks may help to clarify the situation.

Sediment, turbulence and depth in the Pamlico River proper may prevent Eurasian watermilfoil from becoming widespread as it was in Currituck Sound (Davis and Carey 1981). Currituck Sound is very shallow and SAV should grow in most of the sound if turbidity or other factors are not limiting. The sediment is mostly silty and therefore favorable for Eurasian watermilfoil growth (see Appendix C). One factor in Currituck Sound which might not be favorable for Eurasian watermilfoil growth is the large surface area of the sound and therefore a potential for turbulence due to wind fetch. The explosive initial growth of Eurasian watermilfoil in Currituck Sound quickly damped the fetch effect through formation of a side to side, top to bottom, barrier to turbulence.

Six samples of littoral sediments down the Pamlico River ranged from 87.3% sand (Blounts Bay) to 98.6% sand with a mean

(± SD) of 95.0 ± 4% sand. The deeper sediments are composed almost entirely of silt and clay (Matson et al. 1983). Because Eurasian watermilfoil usually grows poorly on sandy sediments and since initial growth in the deeper waters with a suitable sediment would likely be light-limited, Eurasian watermilfoil may not become established in the Pamlico River. Wave turbulence in the littoral could also limit growth in the river.

Short-term changes

Except for the Kitty Hawk Bay area, there are few data in this study for considering short-term changes in SAV in tributaries other than for the Pamlico River system. Data in Appendix E suggest trends toward increasing SAV in Blounts Creek, Nevil Creek, Duck Creek and Durham Creek. Creeks which were checked only late in the season and found to have no SAV could have had horned pondweed which naturally breaks up early, or widgeongrass which tends to die back at times in late summer in both the Pamlico River and its tributaries.

Back Bay

The main body of lower Back Bay appears to be essentially void of SAV. The improvement in Secchi depths over 1987-1988 does not necessarily represent a trend since Secchi depths can vary with runoff and wind direction and force. If conditions change in the bay, there is a diversity of SAV in some of the creeks and embayments in the lower part of the bay which could serve as propagules to repopulate the open waters.

Currituck Sound

Compared with 1978, 1988 biomass of Eurasian watermilfoil and Sago pondweed on the transects was lower, biomass of widgeongrass and wildcelery was higher but remained small, and biomass of the other species was found in essentially trace amounts for both years (Table 4). Bushy pondweed, a strong subdominant to Eurasian watermilfoil in 1973, had almost disappeared by 1978 and showed few little signs of recovery in 1988. The trend of Eurasian watermilfoil biomass over the three studies is strongly downward.

The only species with a greater depth distribution in 1988 (2.2-2.3 m) compared with 1978 (1.8-1.9 m) was widgeongrass (Table 14). In 1988 the maximum depth range for wildcelery was 1.0-1.1 while in 1978 the maximum depth range for this species was 3.0-3.1 m.

As for other studies of SAV in the western Albemarle-Pamlico system, Secchi depths as measurements of relative turbidity give the primary data base available for comparing growing conditions.

Table 14. Approximate depth ranges for peak frequencies and maximum depths (m) for SAV in Back Bay-Currituck Sound and the Currituck Sound.

	Back Bay-Currituck Sound 1959/60*	Currituck Sound 1978**	1988***
Charophytes			
range	0.5-0.8	0.6-1.9	0.6-1.1
max. depth	1.8	1.9	1.5
Sago pondweed			
range	0.9-1.2	0.6-1.9	1.0-1.1
max. depth	1.8	1.9	1.3
Redhead grass			
range	0.8-1.3	0.8-1.5	0.8-1.1
max. depth	1.8	1.7	1.1
Widgeongrass			
range	0.6-1.9	0.6-1.9	0.6-1.1
max. depth	1.8	1.9	2.3
Bushy pondweed			
range	0.9-1.5	0.8-1.3	0.8-1.1
max. depth	3.2	2.1	1.5
Wildcelery			
range	0.8-1.2	0.6-1.9	0.6-1.1
max. depth	2.6	3.1	1.1
Eurasian watermilfoil			
range	---	0.6-2.1	0.8-1.7
max. depth	---	2.3	1.7

* Sincock (1966).
** Davis and Carey (1981).
*** This study.

Means of available Secchi depths for Currituck Sound for March-July of 1977, 1978, and 1988 are given in Table 15.

Although no transects were run, it was obvious to us in our studies and to others that 1977 was another good year for Eurasian watermilfoil in the northern Currituck Sound. The trend in Secchi depths from March to July tends to support these observations. In our Coinjock Bay study plots in 1977, initial growth was rapid and Eurasian watermilfoil shoots had reached the surface (~ 1.2-1.4 m depth) by 12 April. Presumably similar growth was occurring throughout the system around this time. As Eurasian watermilfoil reaches the surface and grows out over the surface, it presents an ever increasing barrier to wave action and turbulence. There is little roiling of the water to resuspend sediment and suspended sediments fall out rapidly in the quiescent water. These phenomena were probably the principal causes of the comparatively high and steadily increasing Secchi depths in the northern sound in 1977. We know of no other Secchi depths in the system as great as those reported for July 1977 in the northern sound.

Considering the prolonged period of high turbidity in the sound in 1978, the relatively high SAV biomass is surprising. Several factors are of interest in this regard. First, the biomass carryover of Eurasian watermilfoil in the Coinjock Bay study site from 1977 to 1978 was significant. The 1978 season began with a biomass of around 36 g m^{-2}. On the negative side, growth of Eurasian watermilfoil did not begin in Coinjock Bay until around 1 June when the Secchi depth reached 0.6 m. These observations are in agreement with those of Steenis et al. (1972) and others that Eurasian watermilfoil growth is more susceptible to turbidity than most other species.

On the other hand, of the SAV in the Chesapeake Bay area in the turbulent years of the 1960s and early 1970s, wildcelery was the most tolerant of turbidity (Steenis et al. 1972). Sago pondweed often grows well under highly turbid and polluted conditions such as those that occur at raw sewage outfalls (Ozimek 1978). Bourn (1932) found that under the highly turbid and odoriferous conditions in Currituck Sound in 1926, Sago pondweed invariably occupied the deeper parts. He also observed that single Sago pondweed shoots from tubers grow to the surface at around 1 m depth and then branch and fan out. This growth pattern could be adaptive to growth and establishment in highly turbid waters.

Both the high carryover of Eurasian watermilfoil in Coinjock Bay to 1978 and the rapid growth associated with clearing of the water beginning in June help to explain why there was higher biomass in 1978. Presumably the lower watermilfoil biomass in 1988 is associated with continuing high turbidities in the sound

Table 15. Mean Secchi depths (m) in the northern Currituck Sound for March-July 1977, 1978, and 1988.

Year	Reach	Month				
		March	April	May	June	July
1977*	upper	0.6	0.7	1.0	1.2	1.5
	lower	0.6	0.4	0.6	0.7	0.8
1978*	upper	0.2	0.2	0.2	0.4	0.6
	lower	0.2	0.2	0.2	0.3	0.5
1988**	upper	0.5	0.5	0.4	0.6	0.6

*Davis and Carey (1981)
**Meda Moore and L.C. Barrow, mean of daily readings in the littoral at Waterlily (unpublished data).

from 1978 to 1988. Now thick beds of Eurasian watermilfoil are found primarily in embayments, narrows, and in marsh island creeks. The vast beds in the deeper and open waters did not reappear. We believe that this is due to continuing rather high turbidities from 1978 to 1988. An increase in turbidity following a decrease in biomass in the northern sound (Table 15) supports this interpretation.

We hypothesized that the appearance of Eurasian watermilfoil in Currituck Sound in the mid-sixties was due to lowered turbidity associated mainly with the Ash Wednesday northeaster on 7 March 1962 (Sincock 1966). The barrier islands were breached by the sea briefly and salinities in the sound increased dramatically and remained above normal through August 1963, the last month of Sincock's study. Secchi depths during the spring and early summer in the northern sound were: 1961, 0.6 m; 1962, 0.9 m; and 1963, 0.8 m. These data do not give a true picture of water clarity in 1963 since the Secchi disc was seen on the bottom 11 of 12 times in 1963 but only 3 of 12 times in 1961 and 1962.

Eurasian watermilfoil was first seen in the northern sound in 1964. We suggest that decreased turbidity was the principal factor leading to the drastic long-lasting change in the SAV of the Currituck Sound-Back Bay system. If this is true, we must hypothesize that decreases in turbidity in the open sound for a few years in the early growing season to levels where Secchi depths would be ~ 0.8-1.0 m could lead again to dense Eurasian watermilfoil beds throughout much of the northern sound. This trend is occurring now in places such as Coinjock Bay, Kitty Hawk Bay, and Point Harbor.

Widgeongrass is becoming more widespread in Currituck Sound as indicated by both transect data and depth analysis. The number of transects in which it was found in more than trace amounts in the three studies were: 1973, 2; 1978, 4; and 1988, 7. In 1978 it was found in the depth range of 0.6-1.8 m and in 1988 the depth range was 0.6-2.3 m.

The reason for the demise of bushy pondweed in Currituck Sound is unknown. It was the dominant species before Eurasian watermilfoil came in (Sincock 1966) and was a strong subdominant in 1973 (Kearson 1976). Perhaps the changes in the sound in 1978 had an adverse effect on bushy pondweed.

Transplant Experiments

Since there was good growth in the control plot in Coinjock Bay and there was early growth and development of wildcelery at several sites in the Pamlico River, and since wildcelery became established at one Pamlico River site, the general lack of plant establishment in the river was probably not due to transplant techniques. Adverse factors could have included high turbidity, epiphytes, high salinities, and turbulence. At times all of these factors probably stressed the transplants. More experiments with more replications are needed to determine if biomass production in wildcelery is nutrient-limited in the Pamlico River.

The first sediment-ambient water experiment showed that wildcelery plants such as those found in low stress areas in the mid-seventies can be produced in Pamlico River water and sediment. Favorable conditions for growth here included low turbidity, turbulence, and salinity, and low epiphyte load during the early and middle growth period.

Physical Data

Data collected in monitoring physical factors are referred to where appropriate in discussion of various aspects of the study. However, the relationship of changing conditions to Secchi depths may provide additional insight. Here we discuss data taken daily at Crystal Beach at the mouth of Nevil Creek on the Pamlico River from 2 May to 25 May 1989. The data provide detail on some of the short-term stresses on SAV in the subestuaries in the Albemarle-Pamlico system. This study was initiated to determine the effects of heavy rains in the watershed on suspended sediment dynamics in the river as indicated by Secchi depth measurements. Heavy rains in the watershed were reported about the time the study began.

For the 5 days after 2 May, the mean (± SD) Secchi depth was 0.45 ± 0.0 m. On 7 May the Secchi depth decreased to 0.35 m from 0.50 m on 6 May. The river was rising and strong currents were flowing into Nevil Creek. This decrease in Secchi depth by 0.15 m signaled the arrival of the suspended sediment load from upriver, presumably the Tar River.

From 7 to 14 May the Secchi depth mean (± SD) was 0.35 ± 0.0 m with a gradual increase to 0.40 m on 13 May and 14 May. On 15 and 16 May the Secchi depths were 0.55 m and 0.45 m respectively. The effects of the suspended sediment load seen for the previous 8-day period had disappeared.

At 1140 on 17 May the Secchi depth had dropped to 0.3 m. On this day there was a blowout of water from the river due to strong sustained winds with a western component. At the time, both the river and Nevil Creek were filling rapidly. The decrease in Secchi depth was probably due to roiling of normally deep silty-clay sediments (Matson et al. 1983) which moved in with the water. By 1656 on the same day, depths in the river and creek were about normal and the Secchi depth had increased to 0.4 m. Thus, the turbid water noted in the morning had been replaced in the afternoon by less turbid water from downriver.

At 1615 on the next day (18 May) there were strong northeastern winds and the water was rising and flowing up Nevil Creek with heavy spray going over the bulkhead along the creek. The Secchi depth at this time was 0.25 m. By 1919 the winds had decreased to a moderate breeze (no white caps) and the Secchi depth had increased to 0.4 m. At 1301 on 19 May there was a brisk wind from the northeast and the water in the river and creek remained high with a strong flow up the creek. The Secchi depth was 0.35 m.

On 20 May the Secchi depth was 0.65 m and from 20 May to 25 May the mean (± SD) Secchi depth was 0.6±0.0 m. The three brief thunder storms which occurred over the period had no effect on Secchi depths.

Over the 24-day period of the study, then, there was in order:

1. Decreasing Secchi depth due to increasing sediment influx to the river.

2. A brief recovery period followed by a decrease in Secchi depth due to a blowout of the river with an increase in Secchi depth with a shift in wind and water on the same day.

3. A decrease in Secchi depth on the next day due to strong winds from the northeast followed by an increase in Secchi depth as winds abated on the same day.

4. Stable Secchi depths through three brief thunder storms.

Overall the Secchi depths found during the study period were abnormally low for the season and are an expression of abnormal weather.

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GLOSSARY

Abbreviations		Approximate U.S. equivalent
km	- kilometer	0.62 mile
m	- meter	39.37 inches
cm	- centimeter	0.39 inch
mm	- millimeter	0.04 inch
km^2	- square kilometer	0.3861 square mile
ha	- hectare	2.47 acres
m^2	- square meter	10.76 square feet
Mg	- megagrams or metric ton	1.1 tons
g	- gram	0.353 ounces
g OW m^{-2}	(grams organic weight per m^2)	
mg	- milligram	0.015 grain
L	- liter	1.057 quarts
^oC	- degrees Celsius	
$^o/oo$	- parts per thousand. A measure of salts in water as a measure of salinity. Seawater is around 35-37 $^o/oo$ (parts by weight in 1 L of solution).	

Terms:

Autecology - Ecology dealing with individual organisms or individual kinds of organisms.

Bloom - "Excessive" growth in water, usually of phytoplankton.

Bluegreen algae - Primitive phytoplankton or filamentous algae with bluegreen pigments.

Biomass - The amount of living material. Usually expressed in g OW m^{-2}.

Community - A group of plant and animal populations occupying and functioning in a given area.

Density - The population size related to some unit of space (i.e. number of plants m^{-2}).

Ecosystem - Composed of a community and all interactions which occur including those with the nonliving environment. Demarcation of an ecosystem such as "the Pamlico River ecosystem" is somewhat arbitrary.

Estuary - A semienclosed coastal body of water measurably diluted by land runoff and (or) has astronomic tides.

Epiphytes - (epi = on, phyte = plant). Organisms which grow on plants, or in the strictest sense, plants which grow on plants.

Filamentous algae - Growth in the form of cell filaments, usually in macroscopic clusters.

Frequency - The number of times a species is represented in a group of samples if only by one plant in a sample. Expressed in percent of total samples which have the species.

Inorganic nutrients - Principally inorganic ions such as nitrate, ammonium and phosphate which are utilized along with food produced in photosynthesis in production of cell material and plant structures.

Littoral - The shallow margin of a water body in which SAV may grow.

Phenology - Refers to changes in plant growth and differentiation over time.

Photosynthesis - The conversion of light energy into chemical energy in cells in the presence of chlorophyll.

Physical factors - Abiotic aspects of an ecosystem such as wind, temperature, and salinity.

Phytoplankton - Microscopic photosynthetic plants in the water, usually single cells.

Population - A group of individual organisms (red oak trees, sheep, geese, wildcelery) of the same kind (grove, herd, flock, stand).

Quadrat frame - A square frame from 0.1 to 1.0 m^2. All plants falling within the frame are dug or counted or both.

Respiration - The biochemical oxidation of food with production of energy transfer compounds in the cell such as adenosine triphosphate. In this sense breathing is a minor part of the respiratory process in animals.

SAV - Submersed aquatic vegetation. Includes rooted vascular plants and charophytes.

Scientific name - Composed of two italicized words. The first word is the generic name and the first letter of this word is capitalized. The second word is the specific epithet. The name of the author of the scientific name (usually abbreviated) follows. Thus:

Vallisneria	americana	Michx.
(generic name)	(specific epithet)	(author)

This is the scientific name or the name of the species for wildcelery. The generic name was in honor of an Italian botanist while the species was named by André Michaux. When sp. is used in place of the specific epithet, the species is unknown. The use of spp. indicates there are two or more unknown species.

Secchi disc - The Secchi disc used in these studies was 20 cm in diameter with the quadrants painted alternately black and white. The iron disc (or weighed in the case of plastic discs) is attached in the middle to a chain which is marked at 0.1 m intervals. The disc is lowered into the water and the mean depth at which it disappears and reappears as lowered in the water and raised is the Secchi depth. Secchi depths are used as relative measures of the turbidity of natural waters-- the shallower the Secchi depth, the more turbid the water. The Secchi disc was named for Dr. Secchi, the Italian oceanographer who first used it.

Sediment - The hydrosoil.

Species - A group of closely related individuals which interbreed but don't breed with other groups.

Turbidity - Refers to the qualities of natural waters which decrease their transparency due to suspended substances. Suspended sediments (silt and clay) and phytoplankton (to a minor extent usually) contribute to the turbidity of waters in the Albemarle-Pamlico estuarine system.

Appendix A. Species List

Division	Scientific Name	Common Name
Chlorophyco-phyta	*Cladophora glomerata* (L.) Kutz	---
	Enteromorpha clathrata (Roth) J. Agardh	---
	Enteromorpha spp.	---
Rhodophyco-phyta	*Compsopogon coeruleus* (Balbis) Mont.	---
Charophyta	*Chara* spp.	charophytes
	Nitella spp.	charophytes
Anthophyta	*Zostera marina* L.	eelgrass
	Potamogeton pectinatus L.	Sago pondweed
	Potamogeton foliosus Raf.	leafy pondweed
	Potamogeton perfoliatus var. *bupleuroides* (Fern.) Farw.	redhead grass
	Ruppia maritima L.	widgeongrass
	Zannichellia palustris L.	horned pondweed
	Najas guadalupensis (Spreng.) Magnus	bushy pondweed
	Vallisneria americana Michx.	wildcelery
	Alternantheria philoxeroides (Mart.) Griseb.	alligatorweed
	Nuphar luteum (L.) Sibth and Smith	spatterdock
	Myriophyllum spicatum L.	Eurasian watermilfoil
	Utricularia sp.	bladderwort

Appendix B. Identification and value as a waterfowl food for the more common submersed species found in this study (Sources used: Martin and Uhler 1939, Hotchkiss 1967, Radford et al. 1968, Beal 1977, Anderson and Low 1976, Carter et al. 1983).

Charophytes

The charophytes are algae and so have no roots, stems, leaves (or nodes) or flowers as do the other species treated here. However, it is convenient to use some of these terms to describe some analogous structures.

Identification. Rooted in the sediment. Upright green flexible stems with whorled arrangement of leaves arising from special nodes. Vary in size from 3 cm to 1.25 m tall. Members of the genus *Chara* usually have a musky odor, especially when bruised as by crushing with the fingers. Charophytes are illustrated in Fig. 5.

Value as a waterfowl food. Good to excellent.

Sago Pondweed

Identification. Threadlike leaves with narrow sheathed bases forming bushy clusters on flexible stems. Fruits in spikes. Vegetative Sago pondweed resembles vegetative widgeongrass. The sheathing base of the leaves have a long, tapering flimsy tip while the tip of the sheathing base of widgeongrass leaves is inconspicuous and rounded. Pull the base away from the stem to see this. Rhizomes (horizontal underground stems) of Sago pondweed are long and straight and often have tubers while rhizomes of widgeongrass are short and zip-zagged and without tubers. Tubers are smooth and pea-like. Sago pondweed is illustrated in Fig. 6.

Value as waterfowl food. Excellent. Through the 1930's at least, this was probably the most important waterfowl food plant on the North American continent.

Redhead grass

Identification. Leaves are perfoliate and vary from oval and flat to lance shaped and puckered. The blades of perfoliate leaves attach directly to the stems; there is no petiole. Flexible stems. Fruits in spikes. Rhizomes with dormant buds at tips which overwinter. Redhead grass is illustrated in Fig. 7.

Value as waterfowl food. Good, ranking among the more valuable pondweeds.

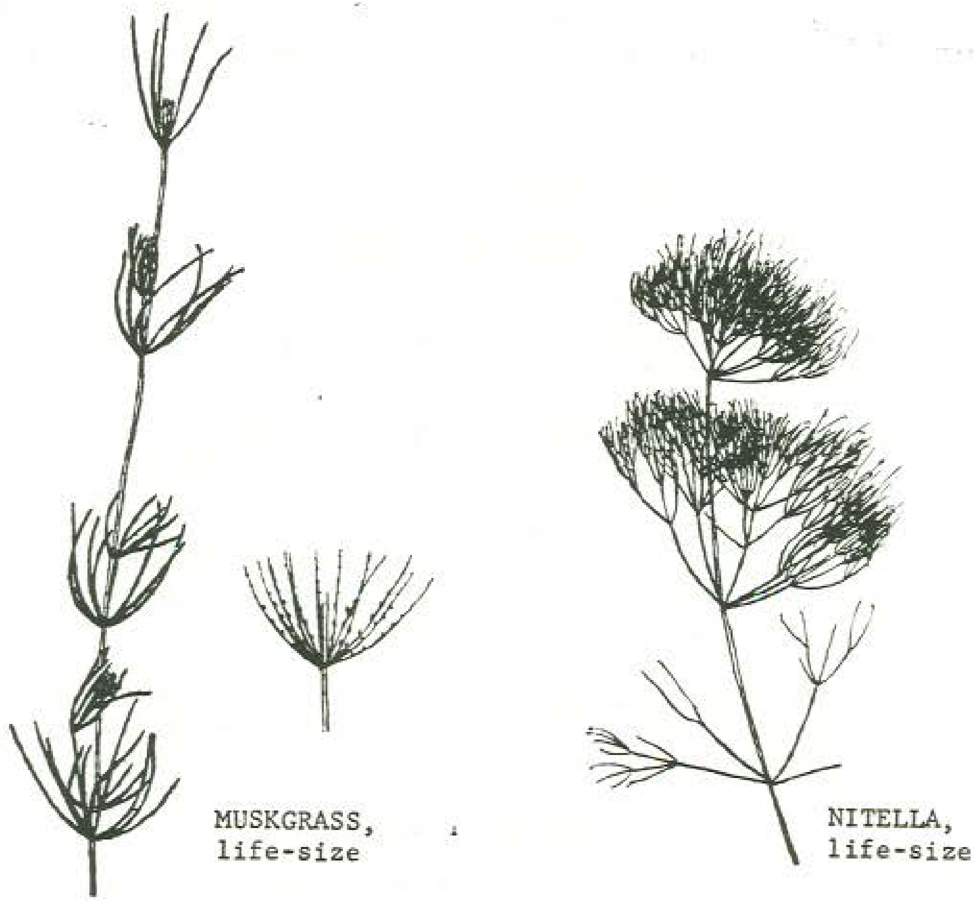


Fig. 5. Charophytes. From Hotchkiss (1967).

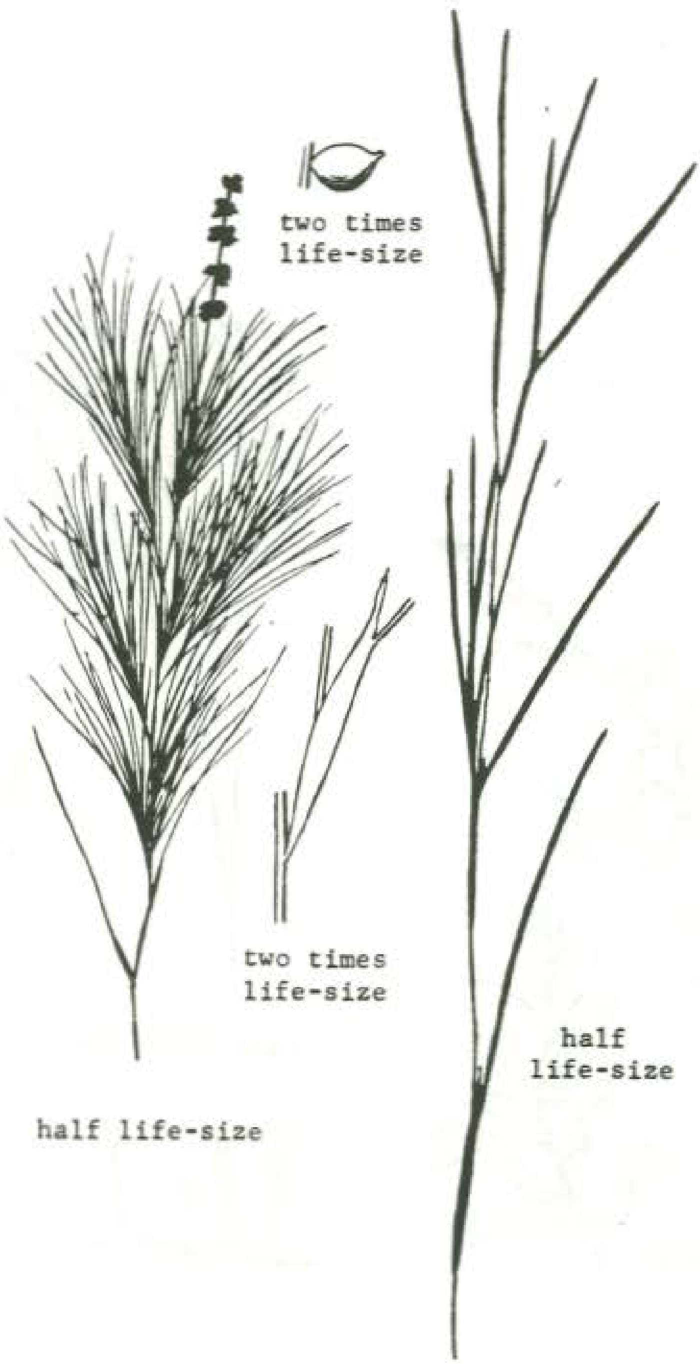


Fig. 6. Sago pondweed. From Hotchkiss (1967).

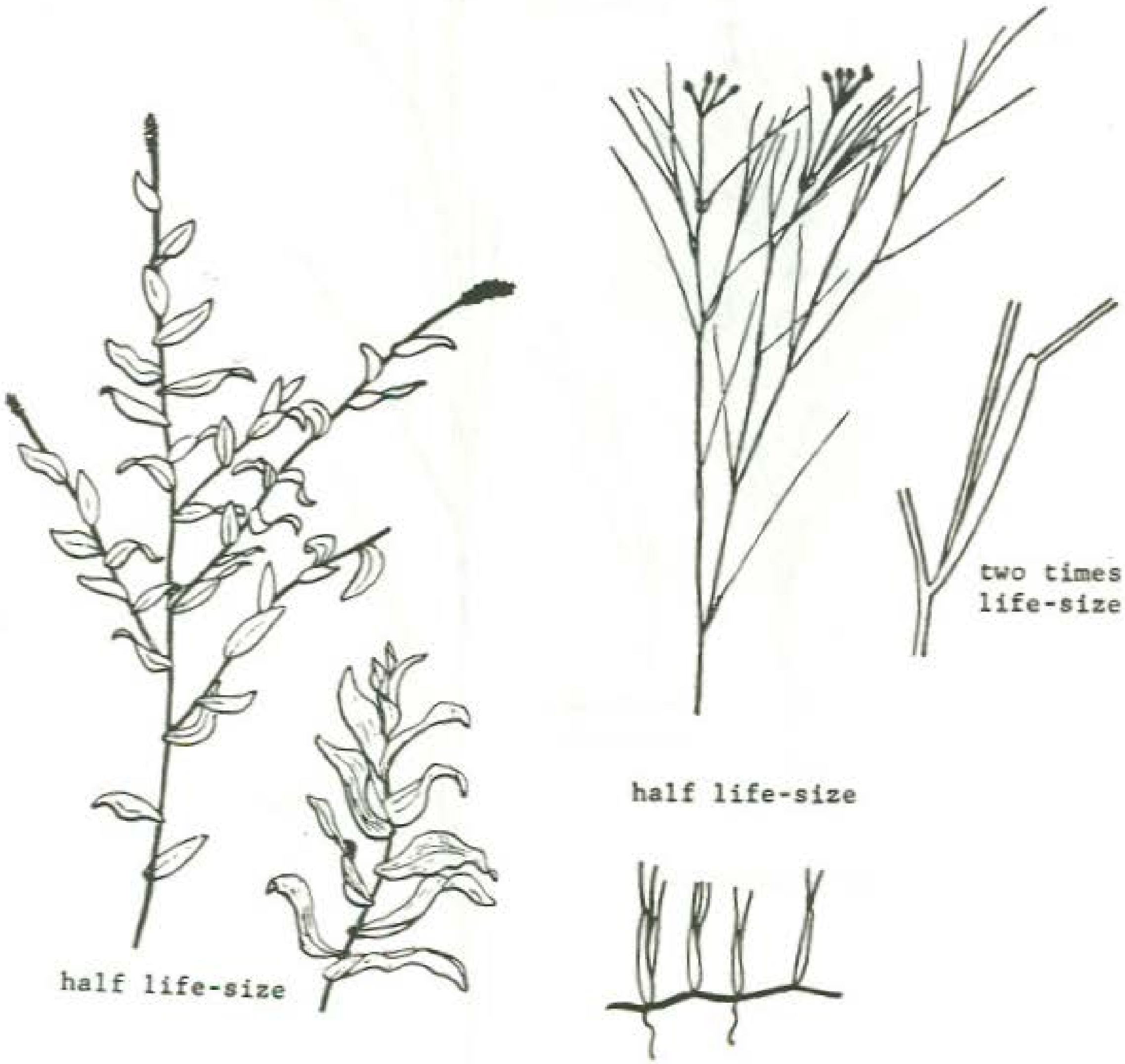


Fig. 7. Redhead grass (left) and widgeongrass (right). From Hotchkiss (1967).

Widgeongrass

Identification. As described in the comparison with Sago pondweed above, the tip of the sheath of the threadlike leaves of widgeongrass is inconspicuous and rounded while the rhizomes are short and zig-zagged and without tubers. Flexible stems. When in fruit, widgeongrass is easily identifiable. Flowers originate from nodes, send up stalks (peduncles) near the tip of which smaller stalks (podogyns) are attached. Each podogyn bears a fruit at its tip. Widgeongrass is illustrated in Fig. 7.

Value as waterfowl food. Excellent.

Horned Pondweed

Identification. In the vegetative condition horned pondweed might be confused with widgeongrass and some of the potamogetons. However, the threadlike leaves appear as paired on the flexible stems while widgeongrass and potamogetons have alternate leaves except on occasions near the tips of stems where they may appear as paired. Slender rhizomes. Hornlike fruits are usually found in the axils of leaves making horned pondweed easy to identify. Horned pondweed is illustrated in Fig. 8.

Value as waterfowl food. Fair to good.

Bushy Pondweed

Identification. Small, narrow, paired leaves with minute spines along the margins. Flexible stems. Small female and male flowers in axils of leaves and on separate plants. Fruits small and pointed. Bushy pondweed is illustrated in Fig. 8.

Value as a waterfowl food. Excellent.

Wildcelery

Identification. Individual plants form tufts with translucent ribbonlike leaves coming up from the sediment. Vegetative reproduction is by slender stolons (horizontal stems on the surface of the sediment) which produce a new plant at a node and the process is repeated. Small subglobose tubers, which overwinter, are produced at the tips of stems which grow down into the sediment as do peanut fruit stalks. Female and male flowers on separate plants. Long cylindrical fruit pods on long stalks which coil and take pods under water following fertilization. Wildcelery is illustrated in Fig. 9.

Value as a waterfowl food. Excellent; was second only to the pondweeds as a food in the Atlantic flyway.

Figure 8. Horned pondweed (lower left) and bushy pondweed (upper right). From Hotchkiss (1967).

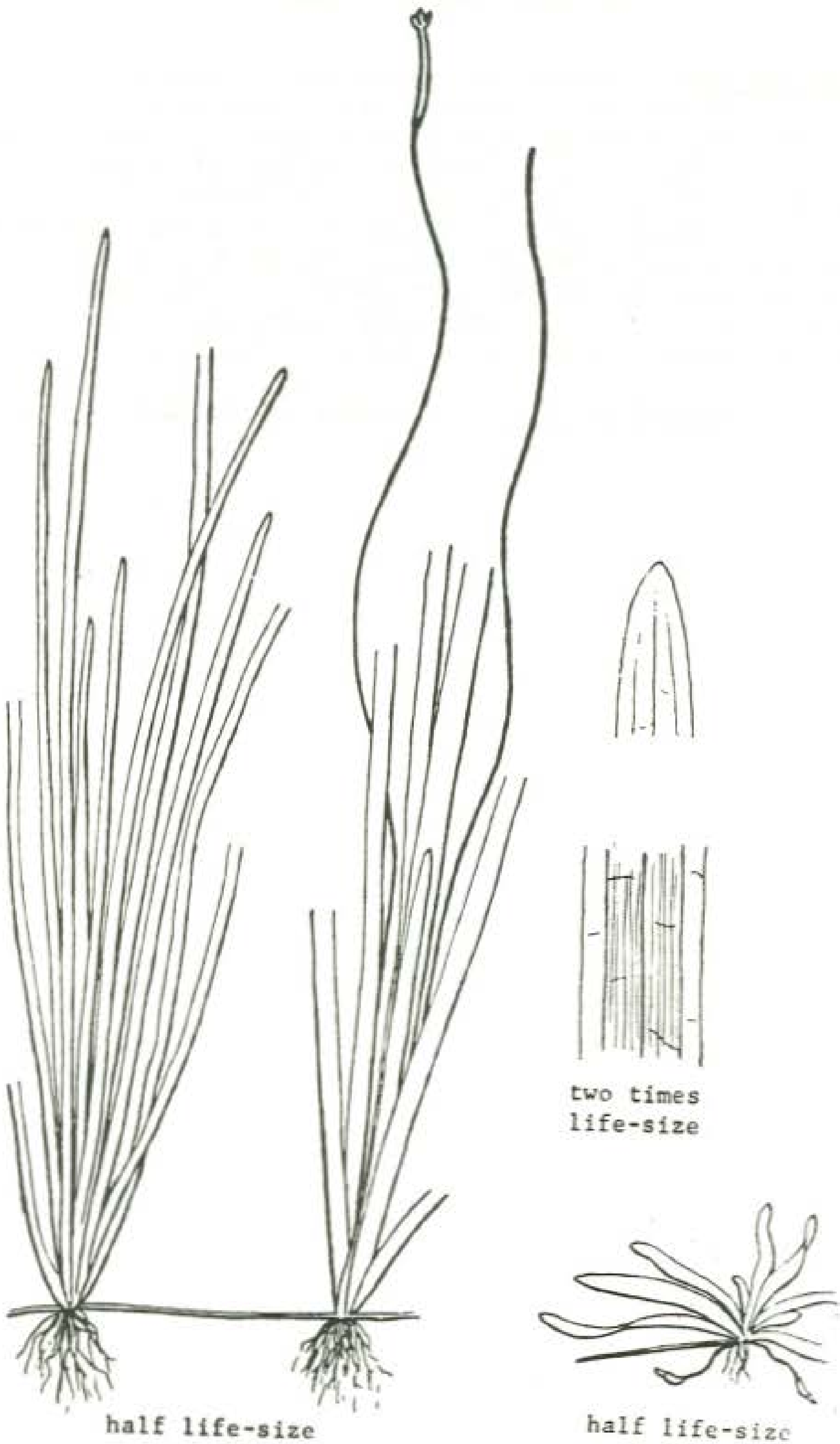


Fig. 9. Wildcelery. From Hotchkiss (1967).

Eurasian Watermilfoil

Identification. Leaves are whorled on the stem and feather-like with 14 to 24 pairs of threadlike divisions. They have been compared to weathered water soaked feathers. Flexible stems. Vegetative reproduction is by fragmentation of stem tips which float, sink and root in the sediment. Renewed growth in the spring is from "crowns" of matted roots, rhizomes and broken stems. Fruits are produced on spikes which break the water surface. Seeds can easily be germinated in the laboratory but no seedlings have been found in the area (personal observations). Eurasian watermilfoil is illustrated in Fig. 10.

Value as a waterfowl food. Generally slight to fair; locally good.

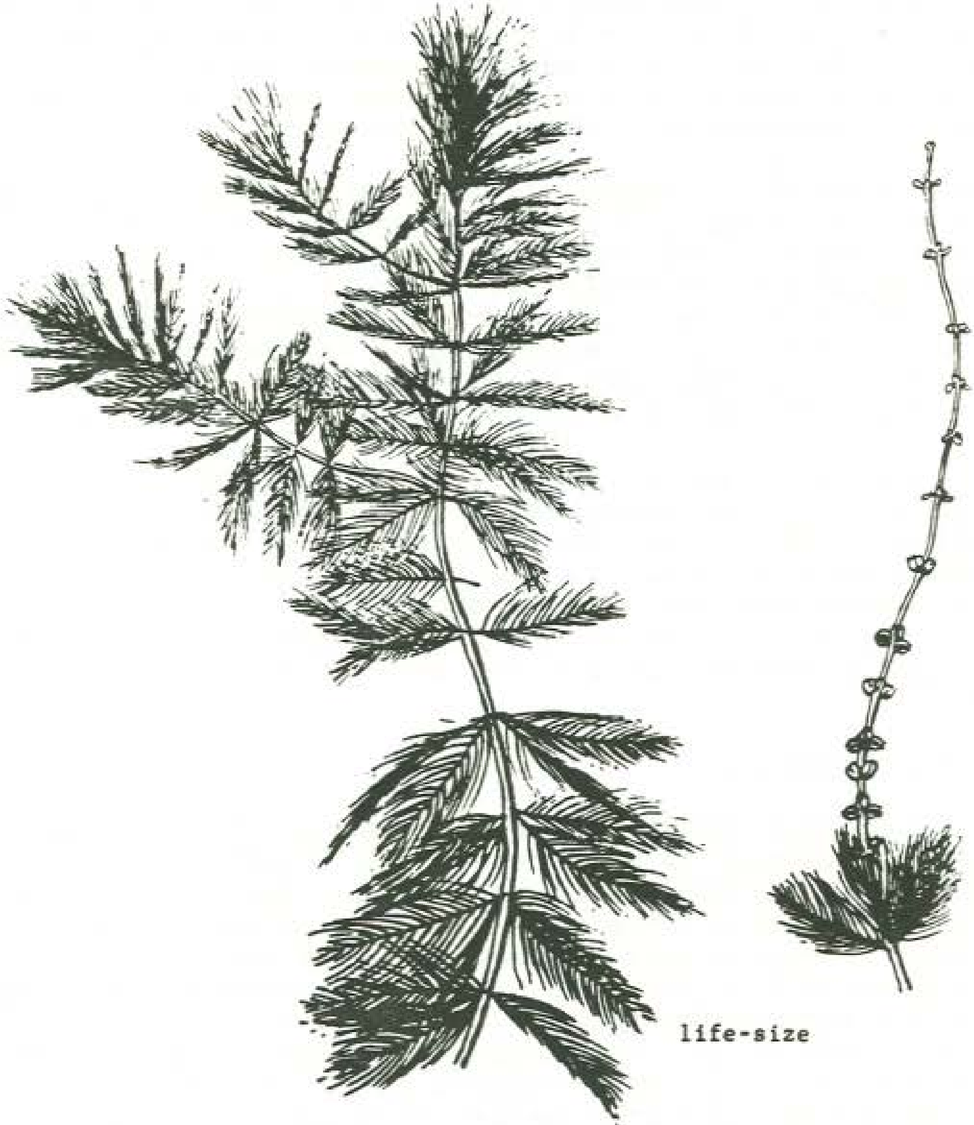


Fig. 10. Eurasian watermilfoil. From Hotchkiss (1967).

Appendix C. Autecological aspects of four important submersed species in the Albemarle-Pamlico estuarine system.

Wildcelery

Reproduction

We have not seen seedlings of wildcelery. Tubers are probably the primary over-wintering propagules if not the only ones. Perhaps the miniature plants found in the Pamlico River in the summer of 1987 were from seeds; however, as more plants are produced along a stolon, one might expect the plants to become more normal in appearance. This did not occur.

Plant growth from tubers as observed in this study began in late March to early April for the Pamlico and Neuse Rivers and the Currituck Sound. The mean tuber depth was around 7 cm or less in the sediment for tubers of the plants collected in the Pamlico and Neuse Rivers in the spring of 1989. This is determined by adding 2 cm to the mean lengths of tuber stalks (Table 10). One to 2 cm of the leaf bases were without chlorophyll, indicating that this portion of the plant was in the sediment.

This is in contrast to wildcelery tuber depth in Potomac River estuary and a tributary (Rybicki and Carter 1986). In sandy sediments 45% of the tubers were at 0-10 cm depth while 55% of the tubers were at 10-20 cm depth. In silty clay sediments 23% of the tubers were at 0-10 cm depth, 51% of the tubers were at 10-20 cm depth, and 26% of the tubers were at 20-30 cm depth. The tubers collected in the Pamlico and Neuse Rivers were in sandy sediments.

Growth characteristics

Soon after the original plant (mother plant) becomes established, it begins to produce stolons which grow along (or just beneath) the surface of the sediment. New plants (daughter plants) are produced at intervals along the stolon. The distance between daughter plants and the mother plant and each other can vary. For example the distance between the mother and daughter plants for the stressed plants at Crystal Beach in May 1989 was 4.0 ± 1.0 cm (n=5) while the distance between the mother and daughter plants for the less stressed plants there was 7.2 ± 1.3 cm (n=8). When the stolons senesce and disappear, the daughter plants become mother plants.

This pattern can affect the nature of the wildcelery stand, at least in the early part of the season. Assuming equal rates of production and growth of stolons, areal coverage should increase more rapidly where stolon length is greater while density should increase more rapidly where stolon length is less. These growth patterns could lead to self competition or more effective dominance over other species.

Wildcelery leaves grow up from a rosette in the sediment. Thus it is not surprising that Eurasian watermilfoil, which overtops wildcelery, tends to out compete wildcelery (Steenis et al. 1972, Titus and Adams 1979). Both hydrilla (Haller and Sutton 1975) and Sago pondweed also overtop wildcelery (Bourn 1932). A single shoot grows up from a Sago pondweed tuber from a depth of at least 1 m and then can produce branches which fan out over the surface.

Sediment affinities

A preponderance of observers associate wildcelery with sandy sediments (Martin and Uhler 1939, Lind and Cottam 1969, Carter et al. 1983, and this study) but wildcelery will grow on silty clay (Rybicki and Carter 1986). Perhaps the reason wildcelery is not found in the small creeks associated with our study area is related to the near anoxic conditions sometimes associated with the silty clay sediments found there (Bradshaw et al. 1985).

Salinity ranges

In the laboratory Bourn (1932, 1934) found the growth limit of wildcelery to be 7 ^{o}/oo while Haller et al. (1974) found the growth limit to be 3 ^{o}/oo with survival at 10 ^{o}/oo. The upper salinity range for wildcelery in the Chesapeake Bay region according to Steenis (1970) is 3 ^{o}/oo-5 ^{o}/oo while Anderson (1972) reported wildcelery for fresh water only.

The salinity range for growth or survival of wildcelery in the Albemarle-Pamlico estuarine system is wide. Traces were found in the middle reach of Brice Creek, a tributary of the Trent River which is a tributary of the upper reach of the Neuse River estuary. Wildcelery was common in the Perquimans River near Hertford. Both of these locations would be expected to have fresh water much of the time.

In 1974 the eastern-most bed of wildcelery in the Pamlico River was at km 29 N (Davis and Brinson 1976). From April to June 1974, salinities in this sector of the river gradually increased from 4.5 ^{o}/oo to 6.5 ^{o}/oo, peaked at 11.5 ^{o}/oo in July and dropped to 5.5 ^{o}/oo in August. Presumably growth was occurring in April-June and the plants obviously survived the high salinity pulse in July.

Wildcelery grew at Crystal Beach in the Pamlico River in the spring and summer of 1988 both naturally and in transplant plots. Mean monthly salinities (n=4) in the littoral at Crystal Beach were: May, 3 ± 0.5 °/oo; June, 6.5 ± 1.1 °/oo; July, 8 ± 2.1 °/oo; and August, 9 ± 0.5 °/oo. Perhaps the wildcelery was merely surviving after around 18 July. On 18 July the salinity was 10 °/oo as compared with 6.5 °/oo on 11 July. Salinity may have been the most important stress on the stressed wildcelery at Crystal Beach in 1988.

Death in place of wildcelery in the late summer of 1988 due to high salinity may have resulted in an unusual observation during a water blow out at Crystal Beach on 1 February 1989. Perhaps 10-12 small clumps of dead wildcelery (to ~ 0.2 m^2) were found, always associated with widgeongrass rhizomes and stunted shoots. No stolons were found but the wildcelery appeared suspended in time as normal stressed, albeit dead, plants. Perhaps death from salinity prevented normal abscission of leaves with the plants anchored by the thick mat of widgeongrass rhizomes in which they grew. Except for this, we have never seen wildcelery plants in the area in the winter, living or dead.

Horned Pondweed

Reproduction

Radford et al. (1968) described horned pondweed as a perennial but our observations in Jacks and Jacobs Creeks (Davis et al. 1985b) suggest that annual regrowth of horned pondweed here is from seeds. We found no biomass carryover and seedlings were present early in the season. Carter et al. (1983) state that new plants are found in the Potomac River estuary in late September and October. Practically no germination occurred in fresh seeds of horned pondweed collected in Europe (van Vierssen 1982a). Cold treatment led to germination. We may have a different race here. However, if seed germination occurred in Jacks and Jacobs Creeks before December it escaped us.

Growth characteristics

The slender rhizomes look much like the stems and the branching shoot system may be 1 m or more in length. Horned pondweed is a creek plant of the Pamlico and Neuse River systems. We have not found it rooted in open areas in either river. This is apparently due to little resistance to turbulence; it is lightly anchored. In both the Albemarle-Pamlico system and the Chesapeake Bay area (Stevenson and Confer 1978) horned pondweed is never found in high energy areas. These authors state that horned pondweed grows at shallower depths in the Chesapeake Bay area than does any other SAV. In the Albemarle-Pamlico system widgeongrass appears to grow at any depth where horned pondweed is found.

Sediment affinities

Martin and Uhler (1939) state that horned pondweed grows in good soil-- presumably loamy sediments. In the Chesapeake Bay area it grows in clay to sandy sediments (Anderson and Confer 1978). In the Albemarle-Pamlico system horned pondweed grows primarily in the silt-clay sediments characteristic of the smaller creeks and the upper reaches of larger creeks; thus the presence of horned pondweed here may be determined more by low turbulence than by sediment type.

Salinity ranges

According the Steenis (1970) horned pondweed is found in the Chesapeake Bay area at maximum salinities of 20 ^{o}/oo-25 ^{o}/oo while Anderson (1972) states that the species is found at 0 ^{o}/oo-5 ^{o}/oo. In laboratory experiments in the Netherlands (van Vierssen 1982a), horned pondweed grew best at 0 ^{o}/oo, grew poorly at ~ 13 ^{o}/oo and did not grow at ~ 18 ^{o}/oo. In nature in northern Europe this species does not grow at summer salinities above ~ 7 ^{o}/oo (van Vierssen 1982b). In addition horned pondweed there begins growing in May and begins to break up in October. It does well under turbulent conditions. Horned pondweed grew in Jacks and Jacobs Creeks at 15 ^{o}/oo-17 ^{o}/oo (Davis et al. 1985a, Davis et al. 1985b). Autecological studies at one site of horned pondweed from North Carolina, the Potomac River and northern Europe would be of interest.

Widgeongrass

Reproduction

Widgeongrass overwinters in the Pamlico River in the form of root-rhizome masses and stunted plants (this study) but probably did not overwinter in Jacks and Jacobs Creeks in 1982 and 1983 (Davis et al. 1985b). Thus renewed growth of widgeongrass in the spring in the Albemarle-Pamlico system is apparently from biomass carryover and seed germination with dispersal primarily if not entirely by seeds. In the Netherlands widgeongrass died during the winter with seed germination in April (Verhoeven and van Vierssen 1978).

Growth characteristics

Widgeongrass is anchored in tangled mats of roots and slender zig-zag rhizomes. In the Albemarle-Pamlico system shoots vary from a winter form of ~ 0.1 m or less in length to 1 m or more in length in the growing season. Plants are normally found up creeks or in sheltered areas in the western Albemarle-Pamlico system. In the lower Chesapeake Bay widgeongrass normally grew in areas sheltered from fetch or in mixed stands with eelgrass (Orth and Moore 1988). In such stands widgeongrass was in nearshore areas buffered by seaward stands of eelgrass.

Sediment affinities

According to Martin and Uhler (1939), widgeongrass grows on either fertile soils or sandy bottoms. In the Albemarle-Pamlico system it grows well on silt-clay sediments (up creeks) and in sandy sediments (i.e. Indian Island). As discussed above, the presence of and, to some extent, biomass of widgeongrass in the Albemarle-Pamlico system may be limited by excessive turbulence. This was also suggested for horned pondweed. This species appears to be more susceptible to stress from turbulence than widgeongrass since it has not been found rooted in the Pamlico and Neuse Rivers.

Salinity ranges

In the laboratory Bourn (1935) found that widgeongrass growth peaked at 3.5 ^{o}/oo but some growth occurred through 70 ^{o}/oo. Also in the laboratory, McMillan and Mosley (1967) observed that widgeongrass stopped growing at 70 ^{o}/oo but survived at 74 ^{o}/oo. Hence widgeongrass can grow in fresh water through salinities about twice that of full sea water.

Eurasian watermilfoil

Reproduction

Regrowth by Eurasian watermilfoil in the spring is normally from a mass of roots, rhizomes, and broken stems (crowns). As the season progresses, dispersal is from fragmented floating plants and small lateral stems which develop adventitious roots, abscise, float, and eventually settle to the bottom where a new plant may develop (Madsen et al. 1988).

Seeds in fruits collected from Currituck Sound sediment germinated readily in the laboratory (Davis et al. 1973) but we have yet to see seedlings in nature in North Carolina. *In situ* experiments should help answer the question of germination of Eurasian watermilfoil seeds in nature.

Growth characteristics

Growth of Eurasian watermilfoil can be very rapid in the spring with growth to the surface and over-topping of other species by mid-April (Davis and Carey 1981). Lower leaves senesce and abscise, leaving a heavy photosynthetic canopy trailing near the water surface. In the deeper waters of the Currituck Sound in the summer of 1977, Eurasian watermilfoil reached around 3 m in length.

Eurasian watermilfoil is more susceptible to turbulence and turbidity than most other SAV in the area (Steenis et al. 1972; Davis and Carey 1981). Based on the growth form, turbulence should become a factor in breaking up plants as they reach the surfac while turbidity would inhibit growth before overtopping. When a large thick bed becomes established in the spring as for the nearly shore to shore community in the northern Currituck Sound from the mid-sixties to the mid-seventies, neither turbulence nor turbidity are likely to have much impact. The beds dampened the effects of wind and sedimentation was accelerated.

Sediment affinities

In studies in a New Jersey lake, Patten (1956) found that Eurasian watermilfoil grew best in fine organic ooze and most poorly in sand. Barko and Smart (1986) found diminished growth in sediments with more than 75% sand. Most of the substrate in the Currituck Sound and Back Bay is overlain by silty clay of varying depths (Sincock 1966).

Salinity ranges

The growth limit of Eurasian watermilfoil in the laboratory was at 10 ^{o}/oo with survival at 13 ^{o}/oo (Haller et al. 1974). Steenis (1970) found the upper salinity tolerance level in the Chesapeake Bay region to be 12 ^{o}/oo-13 ^{o}/oo while Anderson (1972) reported Eurasian watermilfoil at 0 ^{o}/oo-20 ^{o}/oo in the area. In 1985 Eurasian watermilfoil was found in Frying Pan Creek (at the mouth of North Creek on the Pamlico River) at salinities estimated on the basis of data of Don Stanley (unpublished) to range from around 8 ^{o}/oo-14 ^{o}/oo.

Appendix D. An epiphytic colonial hydroid in the Albemarle-Pamlico estuarine system.

In April 1926 Bourn (1932) found some Sago pondweed in Back Bay and Currituck Sound to be covered with Cordylophora caspia, a colonial hydroid. By 1 June the hydroid had covered all Sago pondweed as well as pilings, stakes, set-nets, shells, and boat bottoms. Other SAV was little affected since they had made little growth by that time. Death of the hydroids occurred in early June leaving a decaying mat of gelatinous material called slur by natives. (Slur is from obsolete English dialect for thin mud.) Slur is at first slippery to the touch but gradually becomes like sandpaper following death. Large amounts of sediment and organisms collect in it.

Bourn did not know how long slur had been observed in the region, but about 1922 the water became more brackish, slur appeared, and SAV began to die. Bourn suggested that since the hydroid is strictly a plankton feeder and thus a competitor of fish it might impact fish production. Jewett (1929) quoted evidence that fish catch in the Currituck Sound decreased from 2 million pounds in 1920 to 15% of this amount in 1927. Most of the fish caught in 1927 were bottom feeders.

Bourn concluded that the hydroid growth observed in 1926 suffocated portions of Sago pondweed and suggested that the twining branches of the hydroid injured stems mechanically. He attributed the greatest damage to the gelatinous material left after death of the hydroid. Bacteria and diatoms grew profusely in this medium while larvae, rotifers, worms, protozoans, and fungi were usually very abundant. Bourn and Jenkins (1928) found one organism (Rhizoctonia solani Kühn, a fungus) in such a community on Sago pondweed to be parasitic on Sago pondweed.

This hydroid grows better in brackish water with maximum growth at 15 $^{o}/oo$ (Pennak 1978). Mean salinity at 26 stations in Back Bay and the Currituck Sound in the spring and summer of 1926, the year of Bourn's observations, was ~ 2.5 $^{o}/oo$ (Bourn 1932). This approximates the salinity in northern Currituck Sound now (Pete Kornegay, personal communication 1989). We did not see the hydroid in our studies of Currituck Sound and Back Bay.

We first noticed a colonial hydroid on SAV in the Pamlico River at Billy K's Campground in Sparrow Bay (km 20.5 S) in October 1973. The hydroid covered most of the wildcelery plants in the sparse stand present then. However neither hydroids nor heavy loads of filamentous algae appeared to depress SAV productivity in the Pamlico River from 1973 to 1975 (Davis and Brinson 1976).

The most obvious epiphytic growth on SAV in the Pamlico River in 1987 and 1988 was a colonial hydroid. Francis Belcik identified colonial hydroids on wildcelery transplants and boat bottom scrapings taken in July 1987. As described by Bourn (1932) for the Currituck Sound, the material is at first gelatinous becoming gritty and often spongy. There is little doubt that the colonial hydroid found in the Pamlico River is *Cordylophora caspia*, the same species reported for the Currituck Sound. Attempts were made to collect the hydroid for identification in the spring of 1989 but we were unsuccessful. Apparently high land runoff during this period created conditions unfavorable for growth.

Appendix E. Tributary and embayment surveys, 1985-1988.

Pamlico River Tributaries

1. Kennedy Creek

9 May 1988. No plants.

2. Runyon Creek

9 May 1988. Upper reach: Moderate horned pondweed, trace bladderwort. Middle reach: Moderate horned pondweed, trace charophyte. Lower reach: Moderate horned pondweed, trace bushy pondweed.

3. Rodman Creek

9 May 1988. No plants.

4. Crawford Creek

9 May 1988. No plants.

5. Chocowinity Creek

9 May 1988. No plants.

6. Chocowinity Bay

9 May 1988. No plants.

7. Broad Creek

14 May 1988. Upper reach: Trace horned pondweed.

8. Blounts Creek

9 May 1985. A few floating mats of horned pondweed in a small shallow area in the upper part of the middle reach, trace bushy pondweed and trace horned pondweed.

24 August 1985. Trace horned pondweed near area visited in May.

6 August 1987. Very dense charophyte (~ 2 m^2) in area visited previously.

14 May 1988. Sparse horned pondweed in same area. Middle reach: Trace horned pondweed. Lower reach: Trace horned pondweed.

9. Nevil Creek

9 May 1985. Very dense horned pondweed in the narrows between middle and lower (wide) reach, trace bushy pondweed.

11 August 1985. No plants.

14 May 1987. Middle reach: Traces of charophyte widespread. Narrows: Very dense horned pondweed. Lower reach: Sparse horned pondweed in a band around 20 m x 50 m in the middle part near the western shore.

7 August 1987. No plants.

30 May 1988. Narrows: Very dense horned pondweed. Lower reach: Trace to very dense horned pondweed in much of the reach. See data in the text.

7 November 1988. Lower reach: Dense widgeongrass bed around 0.5-1 m x 5 m observed in the middle part along the eastern shore. Traces were found for around 30 m beyond the dense bed to north.

10. Upper Goose Creek

24 August 1985. No plants.

24 August 1987. No plants.

14 May 1988. Lower reach: Sparse horned pondweed.

11. Mallard Creek

14 May 1988. Lower reach: Trace widgeongrass.

12. Duck Creek

24 August 1985. No plants.

24 August 1987. Upper reach: Trace to very dense widgeongrass at Hawkins Landing bridge.

14 May 1988. Upper reach: Very dense horned pondweed.

13. Bath Creek

14 May 1988. Middle reach: Trace horned pondweed.

14. Back Creek (tributary of Bath Creek)

13 May 1985. Middle reach: Traces horned pondweed in two tributaries on the western side.

24 August 1987. No plants.

14 May 1988. Middle reach: Trace horned pondweed. Lower reach (small tributary at mouth on eastern side): Moderate horned pondweed.

14 May 1988. Northern tributary on western side of creek. Trace horned pondweed.

14 May 1988. Southern tributary on western side of creek. Upper reach: Trace horned pondweed. Middle reach: Moderate horned pondweed. Lower reach: Trace horned pondweed.

15. Durham Creek

24 June 1985. Middle reach: One small patch of widgeongrass (~ 12 m^2).

24 August 1985. Upper reach (Bonnerton Bridge): Trace widgeongrass.

6 August 1987. Upper reach (Bonnerton Bridge): Sparse to dense widgeongrass, sparse to dense leafy pondweed. Middle reach: Trace widgeongrass.

16 May 1988. Upper reach (Bonnerton Bridge): Sparse horned pondweed, sparse leafy pondweed, trace widgeongrass.

17 May 1988. Upper reach: Embayment 1. Dense horned pondweed, dense widgeongrass. Embayment 2. Dense widgeongrass. Middle reach: Embayment 1. Trace widgeongrass. Embayment 2. Sparse horned pondweed, sparse widgeongrass. Lower reach: Embayment 1. Trace horned pondweed, trace widgeongrass. Embayment 2. Sparse horned pondweed. Embayment 3. Trace horned pondweed.

6 August 1987. Porter Creek. Upper reach: Trace widgeongrass.

17 May 1988. Porter Creek. Upper reach: Trace widgeongrass. Middle reach: Trace widgeongrass. Lower reach: Sparse widgeongrass.

16. Mixon Creek

13 May 1985. Upper reach (eastern arm): Embayment: No plants.

24 August 1987. No plants.

17. Saint Clair Creek

10 August 1985. No plants.

24 August 1987. Upper reach: Moderate horned pondweed. Middle reach: Very dense horned pondweed, dense widgeongrass. Lower reach: Trace widgeongrass.

18. North Creek

13 May 1985. Upper reach: Dense horned pondweed, trace widgeongrass. Middle reach (embayment): Very dense horned pondweed. Lower reach (Chambers Point to Frying Pan Creek): Moderate to very dense widgeongrass in band around 10 x 50 m.

24 August 1987. Upper reach: Trace widgeongrass.

16 May 1988. Upper reach: Dense horned pondweed. Middle reach: Trace horned pondweed.

10 August 1985. Frying Pan Creek. Moderate to dense widgeongrass, moderate to dense Eurasian watermilfoil. Higher SAV densities in upper reach throughout study.

20 August 1985. Frying Pan Creek. Widgeongrass appeared less dense while Eurasian watermilfoil appeared the same.

24 August 1987. Frying Pan Creek. Trace to dense widgeongrass.

16 May 1988. Frying Pan Creek. Trace to moderate horned pondweed, dense to very dense widgeongrass.

24 August 1987. Ross Creek. Upper reach: Moderate widgeongrass. Middle reach: Trace widgeongrass.

16 May 1988. Ross Creek. Upper reach: Very dense horned pondweed. Middle reach: Moderate horned pondweed. Lower reach: Very dense horned pondweed.

16 May 1988. Bailey Creek. Upper reach: Moderate horned pondweed, very dense widgeongrass. Middle reach: Dense horned pondweed. Lower reach: Dense horned pondweed.

24 August 1985. Little Ease Creek. Upper reach (both branches): Dense to very dense widgeongrass.

16 May 1988. Little Ease Creek. Upper reach (southern branch): Very dense widgeongrass. North branch (not visited)

appeared the same. Middle reach: Very dense widgeongrass grading downstream into very dense horned pondweed. Lower reach: Trace horned pondweed. This is the closest we noted horned pondweed to the Pamlico River.

19. South Creek. South Creek proper was not surveyed in detail.

8 May 1988. Dense widgeongrass to ~ 1 m between Long and Short Creeks.

12 May 1988. Aurora: Trace widgeongrass. Daymark 21: Moderate horned pondweed.

14 May 1987. Jacks Creek. Upper reach: Sparse horned pondweed and sparse widgeongrass.

26 August 1987. Jacks Creek. Upper reach: Very dense to trace of widgeongrass around the fork. Total coverage was around 100 m^2.

14 May 1987. Jacobs Creek. Upper reach: Very dense widgeongrass. Middle reach: Trace to moderate widgeongrass near shores.

26 August 1987. Whitehurst Creek. No plants.

5 May 1988. Whitehurst Creek. Upper reach. Dense horned pondweed and dense widgeongrass. Middle reach: Moderate horned pondweed and moderate widgeongrass.

26 August 1987. Little Creek. No plants.

5 May 1988. Little Creek. Upper reach: Moderate horned pondweed and moderate widgeongrass. Middle reach: Dense horned pondweed and dense widgeongrass. Lower reach: Dense horned pondweed and dense widgeongrass.

8 May 1988. Short Creek. Lower reach: Very dense horned pondweed.

14 May 1987. Drinkwater Creek. Upper reach: Sparse horned pondweed and dense widgeongrass.

30 August 1987. Drinkwater Creek. Upper reach: Dense to very dense widgeongrass. Middle reach: Dense widgeongrass. Lower reach: Trace widgeongrass.

14 May 1987. Tooley Creek. Upper reach (only western branch checked): Dense to very dense horned pondweed and dense to very dense widgeongrass, trace (one rooted sprig) Eurasian watermilfoil.

30 August 1987. Tooley Creek. Upper reach (both branches): Trace to moderate widgeongrass.

8 May 1988. Tooley Creek. Upper reach (only western branch checked): Very dense horned pondweed, trace widgeongrass.

14 May 1987. Project Area II. Upper reach: Sparse to dense horned pondweed, dense to very dense widgeongrass. Plants were concentrated in the shallow margins. Horned pondweed was more dense in the upper portion.

30 August 1987. Project Area II. Upper reach: Very dense widgeongrass. Middle reach: Dense widgeongrass and dense Eurasian watermilfoil.

Note: More detailed studies in 1988 of Jacks Creek, Jacobs Creek, Drinkwater Creek, and Project Area II are described in the text.

20. Bond Creek

26 August 1987. No plants.

12 May 1988. Lower portion up to Alligator Gut: Upper reach: Sparse horned pondweed. Middle reach: Dense horned pondweed. Lower reach: Moderate horned pondweed. Alligator Gut: Very dense horned pondweed. Upper reach: Sparse horned pondweed, trace widgeongrass. Middle reach: Moderate horned pondweed. Lower reach: Trace horned pondweed.

21. Muddy Creek

26 August 1987. No plants.

12 May 1988. Upper reach: Trace widgeongrass. Middle reach: Moderate horned pondweed, moderate widgeongrass. Lower reach: Moderate widgeongrass.

22. Davis Creek

12 May 1988. Upper reach: Moderate horned pondweed, moderate widgeongrass. Lower reach: Very dense widgeongrass.

23. Strawhorn Creek

20 August 1985. A few floating fragments of widgeongrass and Eurasian watermilfoil.

12 May 1988. Upper reach: Very dense horned pondweed. Middle reach: Very dense horned pondweed. Lower reach: Very

dense horned pondweed.

24. East Prong

20 August 1985. A few floating fragments of widgeongrass and Eurasian watermilfoil.

12 May 1988. Upper reach: Trace widgeongrass. Middle reach: Very dense horned pondweed, very dense widgeongrass.

25. Cypress Branch

12 May 1988. Upper reach: Very dense horned pondweed. Middle reach: Very dense horned pondweed, very dense widgeongrass. Lower reach: Very dense horned pondweed, very dense widgeongrass.

26. Oyster Creek

21 May 1985. No plants.

28 August 1987. Upper reach: Very dense to trace widgeongrass.

20 May 1988. Upper reach: Very dense horned pondweed. Lower reach (small creek on southern side east of crab plant): Trace horned pondweed.

27. Middle Prong

21 May 1985. Dense widgeongrass along marsh edge with dense horned pondweed grading in deeper water.

20 May 1988. Upper reach: Moderate to very dense horned pondweed. Middle reach: Moderate to very dense horned pondweed.

28. James Creek

21 May 1985. Moderate horned pondweed, moderate widgeongrass, trace Eurasian watermilfoil.

28 August 1987. Upper reach: Trace widgeongrass.

20 May 1988. Upper reach (northern branch): One area moderate horned pondweed, trace Eurasian watermilfoil. Another area very dense horned pondweed and very dense widgeongrass. Middle reach: Trace horned pondweed, moderate widgeongrass.

29. Clark Creek

28 August 1987. No plants.

Goose Creek (Pamlico River) Tributaries

1. Dixon Creek

21 May 1985. Dense horned pondweed, moderate widgeongrass, sparse Eurasian watermilfoil.

28 August 1987. Upper reach: Trace to moderate widgeongrass. Middle reach: Trace to moderate widgeongrass. Lower reach: Trace widgeongrass.

20 May 1988. Upper reach: Trace horned pondweed, very dense widgeongrass. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed, sparse widgeongrass.

2. Eastham Creek

20 May 1988. Middle reach: Dense widgeongrass in a small (~ 4 m^2) bed. Lower reach: Trace horned pondweed.

3. Upper Spring Creek

20 May 1988. Upper reach: Moderate horned pondweed, very dense widgeongrass. Middle reach: Very dense horned pondweed.

4. Campbell Creek

28 August 1987. Upper reach: Moderate to dense widgeongrass in small branch to north. Middle reach: Moderate to dense widgeongrass in largest branch to south.

20 May 1988. Upper reach: Very dense horned pondweed in bed (~ 160 m^2) at bridge. Middle reach: Trace horned pondweed, moderate widgeongrass.

5. Snode Creek

21 May 1985. Horned pondweed and widgeongrass in embayments.

28 August 1987. Upper reach: Moderate to very dense widgeongrass at bridge.

20 May 1988. Upper reach: Very dense horned pondweed, trace widgeongrass at bridge. Middle reach: Very dense horned pondweed, moderate widgeongrass clumped in horned pondweed beds. Lower reach: Sparse horned pondweed.

6. Lower Spring Creek

20 May 1988. Upper reach, western branch: Very dense horned pondweed, trace widgeongrass clumped in beds. Middle reach, northern branch from western branch: Trace horned pondweed, very dense widgeongrass.

Pungo River Tributaries

1. Lower Dowry Creek

23 August 1987. No plants.

5 June 1988. Upper reach: Trace horned pondweed, trace widgeongrass. Middle reach: Trace widgeongrass. Dense widgeongrass (~ 12 m^2) at mouth of small creek. Lower reach: Moderate widgeongrass.

2. Upper Dowry Creek

23 August 1987. Upper reach (western branch): Trace widgeongrass. Upper reach (eastern branch): Trace widgeongrass, trace Eurasian watermilfoil.

5 June 1988. Upper reach: Moderate widgeongrass, trace Eurasian watermilfoil. Middle reach: Sparse widgeongrass, trace Eurasian watermilfoil. Lower reach: Trace Eurasian watermilfoil, trace leafy pondweed.

3. Pungo River. North of U.S. 264

5 June 1988. No plants.

4. Tarklan Creek

23 August 1987. No plants.

5 June 1988. No plants.

5. Small creek north of Scranton Creek

5 June 1988. No plants.

6. Scranton Creek

23 August 1987. No plants.

5 June 1988. Upper reach: Dense widgeongrass at bridge ~ 24 m^2.

7. Smith Creek

23 August 1987. No plants.

5 June 1988. Upper reach: Trace horned pondweed.

8. Fishing Creek

23 August 1987. Upper reach: Trace widgeongrass.

5 June 1988. Upper reach: Dense to very dense widgeongrass. Middle reach: Sparse widgeongrass.

9. Slade Creek

23 August 1987. Upper reach: Sparse widgeongrass.

7 June 1988. Upper reach: Trace to very dense horned pondweed, trace to very dense widgeongrass.

28 May 1985. Jones Creek. Upper reach: Dense widgeongrass. Middle reach: Dense widgeongrass. Lower reach: Dense widgeongrass.

23 August 1987. Jones Creek. Upper reach: Sparse widgeongrass.

7 June 1988. Jones Creek. Upper reach: Very dense horned pondweed. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed.

23 August 1987. Jarvis Creek. Upper reach: Dense widgeongrass. Lower reach: Dense widgeongrass.

23 August 1987. Becky Creek. No plants.

7 June 1988. Becky Creek. Upper reach. Very dense horned pondweed. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed.

28 May 1985. Neal Creek. Upper reach and tributaries: Very dense widgeongrass.

5 June 1988. Neal Creek. Upper reach: Very dense widgeongrass. Middle reach: Dense horned pondweed, dense widgeongrass.

28 May 1985. Wood Creek. Upper reach: Very dense widgeongrass. Middle reach: Very dense widgeongrass. Lower reach: Very dense widgeongrass.

23 August 1987. Wood Creek. Upper reach: Moderate widgeongrass, eastern embayment.

7 June 1988. Wood Creek. Upper reach: Very dense horned pondweed, moderate widgeongrass. Middle reach: Very dense horned pondweed, moderate widgeongrass. Lower reach: Very dense horned pondweed, moderate widgeongrass.

7 June 1988. Spellman Creek. Upper reach: Very dense horned pondweed, moderate widgeongrass. Middle reach. Very dense horned pondweed, moderate widgeongrass. Lower reach: Very dense horned pondweed, moderate widgeongrass.

7 June 1988. Speer Creek. Upper reach: Very dense horned pondweed, moderate widgeongrass. Middle reach: Very dense horned pondweed, moderate widgeongrass. Lower reach: Very dense horned pondweed, moderate widgeongrass.

7 June 1988. Church Creek. Upper reach: Very dense horned pondweed, moderate widgeongrass. Middle reach: Very dense horned pondweed, moderate widgeongrass. Lower reach: Very dense horned pondweed, moderate widgeongrass.

8 June 1988. Allison Creek. Upper reach: Very dense horned pondweed.

10. Fortescue Creek

20 August 1985. No plants in creek.

8 June 1988. Upper reach: Very dense horned pondweed, sparse widgeongrass.

23 August 1987. Log Creek. No plants.

8 June 1988. Log Creek. Upper reach: Very dense horned pondweed. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed.

23 August 1987. Snell Creek. No plants.

8 June 1988. Snell Creek. Upper reach: Very dense horned pondweed. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed.

8 June 1988. Warner Creek. Upper reach: Dense horned pondweed and dense widgeongrass. Middle reach: Dense horned pondweed and dense widgeongrass. Lower reach: Very dense horned pondweed.

8 June 1988. Pasture Creek. <u>Upper reach</u>: Very dense horned pondweed. <u>Middle reach</u>: Very dense horned pondweed. <u>Lower reach</u>: Very dense horned pondweed.

8 June 1988. Island Creek. <u>Upper reach</u>: Very dense horned pondweed. <u>Middle reach</u>: Very dense horned pondweed. <u>Lower reach</u>: Very dense horned pondweed.

11. Abel Bay

8 June 1988. Eastern and western embayments. No plants.

8 June 1988. Box Creek. <u>Upper reach</u>: Trace widgeongrass. <u>Middle reach</u>: Trace widgeongrass. <u>Lower reach</u>: Trace widgeongrass.

8 June 1988. Bell Creek. <u>Upper reach</u>: Very dense horned pondweed. <u>Middle reach</u>: Very dense horned pondweed.

12. Willow Creek (eastern branch)

8 June 1988. Willow Creek. <u>Upper reach</u>: Very dense widgeongrass. <u>Middle reach</u>: Very dense horned pondweed, dense widgeongrass. <u>Lower reach</u>: Trace horned pondweed, trace widgeongrass.

13. Wright Creek

23 August 1987. <u>Upper reach</u>: Dense widgeongrass.

8 June 1988. Northern branch. <u>Upper reach</u>: Trace widgeongrass. Southern branch. <u>Upper reach</u>: Very dense horned pondweed. <u>Middle reach</u>: Very dense horned pondweed. <u>Lower reach</u>: Trace widgeongrass.

14. Satterthwaite Creek

23 August 1987. <u>Upper reach</u>: Very dense widgeongrass.

7 June 1988. <u>Upper reach</u>: Moderate widgeongrass. <u>Middle reach</u>: Trace horned pondweed. <u>Lower reach</u>: Southern branch near mouth. Trace horned pondweed, dense widgeongrass.

15. Jordan Creek

28 May 1985. <u>Upper reach</u>: Trace horned pondweed, sparse widgeongrass.

23 August 1987. <u>Upper reach</u>: Dense widgeongrass.

7 June 1988. Upper reach: Moderate horned pondweed. Middle reach: Trace horned pondweed. Alligator Gut: Very dense horned pondweed, moderate widgeongrass.

16. Pantego Creek

28 May 1985. Middle reach (first embayment on north to west of N.C. 92 bridge): Sparse widgeongrass.

23 August 1987. No plants.

7 June 1988. Middle reach: Dense patch of leafy pondweed (~ 1 m^2) next to small patch of alligatorweed along southern shore. Several small patches of alligatorweed (~ 1-2 m^2) were in the area.

17. Pungo Creek

28 May 1985. No plants.

23 August 1987. No plants.

7 June 1988. No plants.

Neuse River Tributaries

1. Brice Creek

11 May 1988. Upper reach (along side Country Road 1004): Very dense charophyte. Middle reach: Trace to dense horned pondweed, trace to sparse leafy pondweed, trace wildcelery, dense charophyte. Lower reach: Trace horned pondweed, trace leafy pondweed, moderate to very dense charophyte.

2. Trent River (mouth of Brice Creek to Union Point)

11 May 1988. Eastern side: Very dense horned pondweed along marsh to New Bern. Western side: Trace horned pondweed, very dense charophyte beginning ~ 3 m from shore.

3. Duck Creek

11 May 1988. Upper reach: Trace horned pondweed. Lower reach: Moderate horned pondweed.

4. Northwest Creek

11 May 1988. Upper reach: Very dense horned pondweed. Middle reach: Trace horned pondweed.

5. Upper Broad Creek

7 August 1987. Upper reach: Trace widgeongrass.

3 June 1988. Upper reach: Sparse to moderate horned pondweed, very dense widgeongrass. Middle reach: Very dense horned pondweed. Lower reach: Very dense horned pondweed in second branch to west from mouth.

6. Goose Creek

3 June 1988. Upper reach: Trace to very dense horned pondweed. Middle reach (two embayments). Very dense horned pondweed, trace widgeongrass. Lower reach: Trace horned pondweed, trace widgeongrass.

7. Lower Duck Creek

3 June 1988. Upper reach: Trace horned pondweed, very dense widgeongrass. Middle reach: Dense to very dense horned pondweed, moderate widgeongrass. Lower reach: Very dense horned pondweed, moderate widgeongrass.

8. Carraway Bay (on Neuse)

3 June 1988. Trace widgeongrass.

9. Beard Creek

3 June 1988. Upper reach. Near bridge: Moderate horned pondweed, trace widgeongrass. Embayment: Dense horned pondweed, dense widgeongrass. Middle reach: Very dense horned pondweed. Lower reach: Embayment A. Very dense horned pondweed, sparse widgeongrass. Embayment B. Moderate widgeongrass.

10. Slocum Creek

15 June 1988. Middle reach: Trace horned pondweed.

11. Hancock Creek

15 June 1988. Upper reach: Very dense widgeongrass. Middle reach: Very dense widgeongrass near marsh embayment. Lower reach (large embayment eastern side): Moderate widgeongrass.

12. Clubfoot Creek

15 June 1988. No plants.

13. Adams Creek

15 June 1988. No plants.

14. Dawson Creek

15 June 1988. Upper reach: Very dense horned pondweed in lower part along western bank. Middle reach: Small branch on eastern side. Very dense widgeongrass. Small embayment on eastern side. Very dense horned pondweed, sparse widgeongrass. Lower reach. Embayment on western side: Very dense widgeongrass.

15. Greens Creek

14 June 1988. Upper reach (eastern bank): Very dense widgeongrass. Middle reach: Moderate widgeongrass.

16. Kershaw Creek

14 June 1988. Upper reach: Trace widgeongrass.

Note: Trace to very dense dead horned pondweed in Greens and Kershaw Creeks.

17. Whittaker Creek

14 June 1988. Upper reach: Sparse widgeongrass. Lower reach: Very dense widgeongrass (spotty).

18. Pierce Creek

14 June 1988. Upper reach: Very dense widgeongrass. Middle reach (embayment western side): Sparse widgeongrass Lower reach: Trace horned pondweed.

19. Gum Thicket Creek

14 June 1988. Very dense widgeongrass.

20. Broad Creek

14 June 1988. Upper reach: Very dense widgeongrass. Middle reach: Embayment southern shore. Very dense horned pondweed. Embayment northern shore. Trace horned pondweed, very dense widgeongrass. Brown Creek. Very dense widgeongrass. Tar Creek. Sparse horned pondweed. Lower reach: (Pittman Creek). Trace horned pondweed, sparse widgeongrass. (Greens Creek). Moderate widgeongrass.

21. Swan Creek

14 June 1988. Upper reach: Trace widgeongrass. Lower reach: Trace widgeongrass.

22. Maw Bay

14 June 1988. Upper reach: Very dense widgeongrass.

23. Fishermans Bay

14 June 1988. Very dense widgeongrass, trace eelgrass.

Bay River Tributaries

1. Trent Creek

9 June 1988. No plants.

2. Chapel Creek

9 June 1988. No plants.

3. Mason Creek

9 June 1988. Upper reach: Very dense widgeongrass. Middle reach: Very dense widgeongrass.

5. Smith Creek

9 June 1988. Trace horned pondweed.

6. Ball Creek

9 June 1988. Upper reach. Trace horned pondweed. Middle reach: Trace horned pondweed.

7. Bonner Bay

9 June 1988. Riggs Creek. Lower reach: Trace horned pondweed.

9 June 1988. Spring Creek. Upper reach: Very dense horned pondweed along northern bank. Middle reach: Moderate horned pondweed, trace widgeongrass. Lower reach: Trace horned pondweed.

9 June 1988. Long Creek. Upper reach: Very dense horned pondweed. Middle reach: Moderate horned pondweed. Lower reach: Trace horned pondweed.

8. Bear Creek

9 June 1988. Lower reach: Trace horned pondweed.

9. Gale Creek

9 June 1988. Middle reach. Trace horned pondweed.

10. Rockhole Bay

9 June 1988. Embayment on western side: Very dense widgeongrass, sparse eelgrass. Small Creek: Very dense widgeongrass. Embayment on eastern side: Very dense widgeongrass, trace eelgrass. Embayment on eastern side near mouth of Bay: Trace widgeongrass.

Western Pamlico Sound Tributaries

1. Stumpy Point Bay

7 July 1988. Trace widgeongrass.

2. Sandy Bay.

7 July 1988. No plants.

3. Parched Corn Bay

7 July 1988. Trace widgeongrass.

4. Pains Bay

7 July 1988. Trace widgeongrass.

5. Pingleton Point

7 July 1988. No plants.

6. Far Creek

7 July 1988. No plants.

7. Wysocking Bay

7 July 1988. Embayment west of Daymark 7: Trace widgeongrass.

7 July 1988. Lone Tree Creek: Trace widgeongrass.

7 July 1988. Douglas Bay: Trace widgeongrass.

7 July 1988. Mount Pleasant Bay: No plants.

8. Hog Island. Embayments to west

8 July 1988. No plants.

9. North Bluff Point. Small embayment

8 July 1988. Dense widgeongrass.

10. East Bluff Bay

8 July 1988. No plants.

11. West Bluff Bay. Small embayment.

8 July 1988. Very dense widgeongrass.

12. Juniper Bay

8 July 1988. No plants.

13. Swanquarter Bay

8 July 1988. Upper reach: No plants.

8 July 1988. Oyster Creek. Upper reach: Trace widgeongrass. Lower reach. Embayment to north: Moderate widgeongrass.

8 July 1988. Caffee Bay. Upper reach: Trace widgeongrass. Middle reach: Trace widgeongrass. Lower reach: Moderate widgeongrass.

14. Judith Island

8 July 1988. Embayment west of Daymark 2: Moderate widgeongrass.

8 July 1988. Embayment at Judith Narrows: Very dense widgeongrass.

8 July 1988. Easternmost embayment on southern side of Island: Very dense widgeongrass, trace eelgrass.

15. Big Porpoise Bay
13 June 1988. Trace eelgrass.

16. Middle Bay

13 June 1988. Trace eelgrass.

17. Jones Bay

13 June 1988. Upper reach: Trace widgeongrass. Embayment to north: Very dense horned pondweed. Middle reach: Ditch Creek: Moderate horned pondweed, dense widgeongrass: Embayment near Maiden Point: Trace widgeongrass. Lower reach (embayment to south): Very dense widgeongrass.

Albemarle Sound Tributaries

1. Perquimans River

28 June 1988. Upper reach: Embayment near U.S. 17 bridge: Sparse bushy pondweed. Western side of Hertford Harbor along yellow waterlily beds: Trace charophyte. Between U.S. 17 and U.S. 17A bridges; Sparse bushy pondweed, trace charophyte. Racoon Creek: Very dense bushy pondweed. U.S. 17A bridge: Trace bushy pondweed, moderate wildcelery, trace charophyte. Embayment east of U.S. 17 A: Trace charophyte. Middle Reach. Eastern shore: Embayment A: Moderate bushy pondweed, trace wildcelery, moderate charophyte. Embayment B: Very dense bushy pondweed, trace charophyte. Embayment C: Moderate wildcelery. Embayment D: Trace bushy pondweed, sparse wildcelery, trace charophyte. Embayment E. Trace bushy pondweed, sparse wildcelery, trace charophyte, trace redhead grass. Sutton (creek mouth): Trace bushy pondweed, sparse wildcelery. Middle reach: Western shore: Embayment A: Trace charophyte. Embayment B: Trace bushy pondweed, sparse wildcelery. Embayment C. Moderate bushy pondweed, dense wildcelery. Lower reach. Eastern shore: Embayment A: Sparse bushy pondweed, moderate wildcelery, trace charophyte. Point north of Grassy Point: Dense bushy pondweed, dense redhead grass, sparse wildcelery. Daymark 8: Very dense bushy pondweed. Grassy Point: 1.8m. Very dense bushy pondweed, moderate redhead grass, trace wildcelery. 2.0m. Very dense bushy pondweed, trace wildcelery. Canaan Cove: 1.5 m. Very dense bushy pondweed, moderate wildcelery. 1.8 m. Moderate bushy pondweed, moderate wildcelery, very dense charophyte. Embayment B (between Canaan Cove and Piney Point): Very dense bushy pondweed. Piney Point (embayment): Very dense bushy pondweed, trace redhead grass. Muddy Creek (river littoral): Trace bushy pondweed, very dense redhead grass, sparse Eurasian watermilfoil. Lower reach. Western shore: Embayment A: Sparse wildcelery. Embayment B: Trace bushy pondweed, sparse wildcelery, trace charophyte. Embayment C: Trace bushy pondweed, trace wildcelery. Embayment D: Trace bushy pondweed, trace

wildcelery. Halsey Bay: Trace wildcelery, sparse redhead grass, trace charophyte. Embayment west of Blount Point: Trace bushy pondweed. Embayment E: Trace widgeongrass, moderate wildcelery. Harveys Point: Trace bushy pondweed, trace widgeongrass.

2. Little River

28 June 1988. Upper reach Trace horned pondweed, trace Sago pondweed. Middle Reach. Eastern shore. Embayment A. Northern end: Trace bushy pondweed, trace wildcelery, moderate leafy pondweed A. Southern end: Moderate bushy pondweed, very dense leafy pondweed, trace Eurasian watermilfoil. Embayment B. Long narrow embayment north of Nixontown: Trace bushy pondweed, trace leafy pondweed, very dense Eurasian watermilfoil. Embayment C. Moderate bushy pondweed, moderate wildcelery, trace redhead grass, trace leafy pondweed, trace Eurasian watermilfoil. Lower reach: Littoral: Dense Eurasian watermilfoil. Sunken boat: Very dense Eurasian watermilfoil. Mill Point: Trace bushy pondweed, sparse to very dense Eurasian watermilfoil. Very dense Eurasian watermilfoil into Albemarle Sound. Middle reach. Western shore: Embayment A. Trace bushy pondweed, very dense Eurasian watermilfoil. Mouth of Deep Creek: Trace horned pondweed, trace Sago pondweed. Embayment B: Trace bushy pondweed, very dense Eurasian watermilfoil. Lower reach. Embayment C: Very dense Eurasian watermilfoil. Embayment D: Very dense Eurasian watermilfoil. Embayment E: Trace bushy pondweed, trace wildcelery, very dense Eurasian watermilfoil. Embayment F: Very dense Eurasian watermilfoil. Stevenson Point: Trace wildcelery, dense leafy pondweed, very dense Eurasian watermilfoil.

3. Pasquotank River

29 June 1988. Lower reach. Miles Point: Trace widgeongrass.

4. North River

29 June 1988. Upper reach: Not visited. Middle reach: Deep Creek (mouth): Trace wildcelery. Deep Creek (middle reach): Trace wildcelery. Day Mark 152 (Buck Island): Very dense Eurasian watermilfoil. Backlanding Creek: Very dense Eurasian watermilfoil. Lower reach: Hunting Creek: Moderate bushy pondweed, moderate widgeongrass, moderate Eurasian watermilfoil, moderate charophytes (2 species). Broad Creek: Dense bushy pondweed, dense widgeongrass, dense Eurasian watermilfoil. Embayment (western): Trace widgeongrass. Camden Point: Very dense widgeongrass, trace Eurasian watermilfoil.

5. Point Harbor

29 June 1988. Trace widgeongrass, trace redhead grass, very dense Eurasian watermilfoil.

6. Jean Guite Creek

29 June 1988. Upper reach: Trace Eurasian watermilfoil. Middle reach: Very dense widgeongrass, trace Eurasian watermilfoil. Lower reach: Moderate widgeongrass, trace Eurasian watermilfoil.

7. Kitty Hawk Bay

24 September 1987. Embayment on northern side of Collington bridge: Western: Very dense widgeongrass. Eastern: Very dense widgeongrass. Area between eastern shore and Burnt Island: East to west: Shore to 0.7 m deep: Trace widgeongrass, very dense Eurasian watermilfoil. 0.7 m to 1.2 m deep: Very dense widgeongrass. 1.3 m to 0.7 m deep: Very dense widgeongrass, trace Eurasian watermilfoil. Western side of Burnt Island: To 1.5 m: Very dense widgeongrass, trace Eurasian watermilfoil. 1.5 m to 1.7 m: Trace widgeongrass. Eastern side of Bay beginning at the western end of marsh islands: Trace widgeongrass, dense to very dense Eurasian watermilfoil. Northeastern corner of Bay: Dense Eurasian watermilfoil. Northern shore of Bay: Very dense Eurasian watermilfoil.

29 June 1988. Northern side of Collington bridge: Dense widgeongrass, moderate Eurasian watermilfoil. Area between eastern shore and Burnt Island: Dense widgeongrass, very dense Eurasian watermilfoil. Channel between marsh islands: Dense widgeongrass, dense Eurasian watermilfoil Northern edge of marsh islands: Moderate widgeongrass. Northeastern corner of Bay: Dense widgeongrass, dense Eurasian watermilfoil. Northwestern side Bay (near mouth): Moderate widgeongrass.

8. Buzzard Bay

24 September 1987. Upper reach: Trace widgeongrass, trace Eurasian watermilfoil.

29 June 1988. Upper reach: Moderate widgeongrass. Lower reach: Trace widgeongrass.

9. Shallowbag Bay

24 September 1987. No plants.

29 June 1988. No plants.

10. Broad Creek

29 June 1988. Lower reach: Trace widgeongrass.

Northern Currituck Sound and Knotts Island Channel
8 October 1987

This was a rapid reconnaissance made with Dr. G.W. Thayer and Dr. R.L. Ferguson of the National Marine Fisheries Laboratory, Beaufort, N.C. primarily to assess the suitability of this area for mapping SAV beds by aerial photography. Surface salinity (average $\pm$ S.D) was taken at 6 sites (2.2 ± 0.2 $^{o}/oo$) and Secchi depth was taken at 8 sites (0.35 ± 0.1 m). Maximum depths of SAV beds were measured at 9 sites. Two of these were 1.5 m (at Bells Island) and 7 were at one m or less. Density determinations of SAV by raking were not made. The reference map used was "Map of Back Bay Virginia," by A.D.C., 6440 General Green Way, Alexandria, VA 22312. A summary of SAV observations made on the survey follows:

1. Coinjock Bay study site at Bells Island (Figure 3). Several hectares of Eurasian watermilfoil in the area to around 1.5 m deep. Wildcelery and bushy pondweed present.

2. East of Bells Island in vicinity of Bells Island Campground. Extensive beds of Eurasian watermilfoil and wildcelery with some redhead grass.

3. Eastern embayment at northern tip of Bells Island. Shoreline bed of wildcelery.

4. Bells Island neck, northern side. No plants.

5. Southwestern Makay Island. No plants.

6. Western shore of Makay Island west of Buck Island. Shoreline bed of wildcelery with some Eurasian watermilfoil.

7. Buck Island Bay between Buck Island and Mackay Island. Extensive Eurasian watermilfoil bed with some widgeongrass and wildcelery.

8. Sandy Cove. Thick shoreline wildcelery with some Eurasian watermilfoil.

9. Back Landing to ferry channel spoils. Wildcelery thinning into dense Eurasian watermilfoil.

10. Southern extreme of Knotts Island southeast of ferry landing. Wildcelery bed with widgeongrass and some bushy pondweed.

11. Mud Cove around Neck Point to Jack and Jill Island. Extensive Eurasian watermilfoil bed.

12. Knotts Island Channel and marsh islands to the Virginia-North Carolina line. Patches of Eurasian watermilfoil (usually thick) along the eastern shore of Knotts Island. Eurasian watermilfoil beds very common in the marsh island channels. Mixed wildcelery and Eurasian watermilfoil bed between Bucket Island, Gold Bush Point and Out Simon Island.

13. Northeastern extreme of Knotts Island Bay. Mixed widgeongrass and wildcelery in very shallow water.

14. North of Little Blubber Island. Widgeongrass bed with some charophyte.

15. Middle of Knotts Island Bay. Large Eurasian watermilfoil bed.

16. Near center of Knotts Island Bay. Large Eurasian watermilfoil bed.

17. Between Big Sheep Marsh and Little Sheep marsh Channels. Extensive Eurasian watermilfoil bed.

18. North and west of Swan Island and in cove of small island north of Swan Island. Extensive bed of widgeongrass and wildcelery.

19. Southern extreme of Back Landing at Swan Island. Dense widgeongrass with some wildcelery and widgeongrass.

20. South of Swan Island. Dense widgeongrass bed.

21. Near southeastern shore of Swan Island. Dense Eurasian watermilfoil mixed with wildcelery.

22. Nigger Bay. Dense charophyte bed in most of bay at 1.5 m.

23. Southwest and south of Johnsons Island. Large thin charophyte bed with some Sago pondweed.

24. Southeastern extreme of old Currituck Inlet. Widgeongrass with traces of wildcelery and Eurasian watermilfoil.

25. Northwest and south off Little Raymonds Island. Extensive area of thin and scattered wildcelery.

26. West and south of Monkey Island. Large Eurasian watermilfoil bed surrounded by a wildcelery bed.

27. Northeastern Ship Bay. Widgeongrass.

<u>Currituck Sound: Marsh Islands of the Middle Reach, 20 October 1987</u>

1. Thorofare Island: Trace bushy pondweed, trace widgeongrass, trace Eurasian watermilfoil.

2. Saunders Bay, <u>Upper reach</u>, northeastern corner: Trace bushy pondweed, trace to dense widgeongrass.

3. Wells Bay: Trace bushy pondweed.

4. Lone Oak Channel: Very dense widgeongrass, trace Eurasian watermilfoil.

5. Little Hog Island: Trace bushy pondweed, dense widgeongrass, trace Eurasian watermilfoil.

6. Beasley Bay. Hog Islands, east: Trace widgeongrass, trace Eurasian watermilfoil. West: Trace Eurasian watermilfoil. West: Trace widgeongrass, trace Sago pondweed, trace Eurasian watermilfoil.

7. Hog Islands, south of Steer island: No plants.

8. Indian Gap, east: Very dense Eurasian watermilfoil. West: Very dense Eurasian watermilfoil.

9. Greys Island. Northern end: Trace bushy pondweed, trace widgeongrass, trace Eurasian watermilfoil.

10. Southernmost eastern islands: Trace to dense widgeongrass, trace wildcelery, trace Eurasian watermilfoil.

12. Jews Quarter Island embayment, eastern side: Dense widgeongrass, dense Eurasian watermilfoil or dense widgeongrass and Eurasian watermilfoil mixed. Western side: Trace widgeongrass, trace Eurasian watermilfoil.

13. Little Narrows south of Narrows Island: Dense to very dense Eurasian watermilfoil.
Note: Many of the site locations are from a chart prepared by Gerald Bunch, Poplar Branch, N.C.

Back Bay (Southern Embayments)

1. Buzzards Bay

26 September 1987. No plants.

2. Buzzards Island Pond

26 September 1987. No plants.

3. Southwest Cove

26 September 1987. No plants.

4. Capsies Creek

26 September 1987. Upper reach: Very dense Eurasian watermilfoil. Lower reach (east of Buckle Island): Trace widgeongrass, trace wildcelery very dense Eurasian watermilfoil.

28 June 1988. Upper reach: Trace wildcelery, trace Sago pondweed, very dense Eurasian watermilfoil.

Note: These are summaries of special transects.

5. Horse Island Creek

26 September 1987. Middle reach: Moderate Eurasian watermilfoil. Lower reach: Dense widgeongrass, sparse wildcelery.

28 June 1988. Middle reach: Dense widgeongrass, trace Sago pondweed, trace wildcelery, trace charophyte, trace Eurasian watermilfoil. Lower reach: Trace widgeongrass, trace Sago pondweed, trace wildcelery, trace charophyte, trace Eurasian watermilfoil.

6. Bald Island Creek

26 September 1987. Lower reach (west of Little Bald Island): Dense to very dense charophyte to the south grading into dense to very dense widgeongrass to the north, trace bushy pondweed, trace Sago pondweed, sparse wildcelery, sparse Eurasian watermilfoil. East of Little Bald Island: Dense widgeongrass to south grading into dense Eurasian watermilfoil to north grading into moderate Eurasian watermilfoil.

28 June 1988. Lower reach (west of Little Bald Island) South: Moderate widgeongrass, trace Sago pondweed, trace charophyte, trace Eurasian watermilfoil. Mid: Trace bushy pondweed, very dense

widgeongrass, trace Sago pondweed, trace charophyte, trace Eurasian watermilfoil. North: Trace widgeongrass, moderate charophyte.

Note: Trace bushy pondweed, trace Sago pondweed, trace Eurasian watermilfoil were in an area from at the mouths of Horse Island and Ball Island Creeks north to around Wash Woods Boat Dock.

7. Green Point Cove

28 June 1988. Moderate widgeongrass, trace charophyte, trace Eurasian watermilfoil.

8. Tripps Cove

28 June 1988. Trace widgeongrass, trace charophyte, trace Eurasian watermilfoil.

9. False Cape Landing

28 June 1988. Trace bushy pondweed, moderate widgeongrass, trace Eurasian watermilfoil.

10. Cowpens Cove

27 September 1987. Trace widgeongrass, trace Sago pondweed, trace charophytes (2 species), trace Eurasian watermilfoil.

28 June 1988. Trace widgeongrass, trace charophyte.

11. Hammet Cove

27 September 1987. Trace widgeongrass, very dense charophyte, moderate Eurasian watermilfoil.

28 June 1988. Trace widgeongrass, trace wildcelery, trace charophyte, trace Eurasian watermilfoil.

12. Back Bay National Wildlife Refuge

27 September 1987. Masons Cove. Trace charophyte.

27 September 1987. Kitchen Cove. No plants.

Appendix F. Physical data for the transplant sites, 7 July 1987-2 August 1987.

Site	River km	Date	Temp. (°C)	Salinity (°/oo)	Depth (m)	Secchi (m)	Turbidity *(NTU)
Blounts Bay I	13 South	7 July	31	3.0	0.8	0.4	23.5
		9 July	38	2.5	1.0	0.4	16.5
		12 July	32	3.0	1.0	0.4	16.5
		15 July	26	4.0	1.1	0.5	18.0
		18 July	33	5.0	1.2	0.5	13.0
		19 July	32	4.0	1.0	0.4	19.0
		27 July	33	5.0	1.0	0.5	19.0
		2 August	26	5.5	1.0	0.5	10.5
Blounts Bay II	13.5 South	9 July	38	3.0	0.7	0.4	16.0
		12 July	32	3.0	0.6	0.5	17.5
		15 July	26	4.0	0.9	0.5	18.5
		18 July	31	4.5	0.8	0.5	14.0
		19 July	31	4.0	0.7	0.4	18.0
		27 July	33	4.5	0.6	0.5	17.0
		2 August	26	5.5	0.7	0.6	10.5
Nevil Creek	18 South	7 July	33	3.5	0.8	0.4	18.5
		9 July	39	3.5	0.7	0.4	16.5
		11 July	34	3.5	1.0	0.4	21.0
		14 July	32	4.0	0.8	0.4	27.0
		19 July	34	5.0	0.7	0.4	21.0
		27 July	30	5.0	0.9	0.4	22.5
		2 August	27	6.0	0.8	0.4	14.5
Archbell Point	25 North	7 July	30	5.0	0.9	0.8	17.0
		9 July	32	5.0	0.9	0.7	10.5
		11 July	30	5.0	0.8	0.5	12.0
		19 July	30	5.5	0.9	0.6	11.5
		27 July	30	7.5	0.9	1.0	7.0
		2 August	25	7.5	0.9	0.9	4.0
South Creek	37 (North littoral of creek)	7 July	30	7.0	0.7	0.7	9.5
		9 July	32	7.0	0.7	0.7	8.0
		11 July	32	5.0	0.6	0.7	7.5
		14 July	32	7.0	0.7	0.6	10.5
		19 July	27	8.0	0.6	0.8	9.0
		26 July	32	8.0	0.8	0.8	13.5
		2 August	25	9.0	0.9	0.7	7.0

*Nephelometric Turbidity Units.

Appendix G. Physical data for the transplant sites 9 May 1988-22 August 1988. Trailing plus (+) indicates that Secchi depth was greater than water depth.

Site	River km	Date	Temp (^{O}C)	Salinity ($^{O}/oo$)	Depth (m)	Secchi (m)
Blounts Bay I	13 South	9 May	22.0	2.0	1.0	0.6
		17 May	26.5	2.0	0.8	0.5
		23 May	27.5	3.0	0.8	0.4
		30 May	25.5	2.5	0.8	0.4
		6 June	23.0	4.0	0.7	0.5
		13 June	26.5	6.0	1.0	0.6
		20 June	29.5	7.5	1.0	0.7
		26 June	29.0	7.0	0.9	0.7
		5 July	28.5	7.0	0.5	0.5+
		11 July	32.0	6.5	0.9	0.5
		18 July	29.0	8.0	0.4	0.4+
		25 July	30.0	7.0	1.0	0.6
		1 August	31.0	9.0	0.9	0.6
		8 August	--	--	--	--
		15 August	31.5	8.5	0.8	0.3
		22 August	28.5	9.0	1.5	0.4
Blounts Bay II	13.5 South	9 May	22.0	2.5	0.8	0.6
		17 May	26.0	2.0	0.6	0.6
		23 May	29.0	3.0	0.6	0.4
		30 May	25.5	2.5	0.5	0.4
		6 June	29.0	4.0	0.4	0.5
		13 June	26.0	6.0	0.6	0.6
		20 June	29.5	5.5	0.6	0.9
		26 June	28.0	7.0	0.6	0.7
		5 July	28.5	5.5	0.8	0.6
		11 July	32.0	7.0	0.5	0.5+
		18 July	29.0	9.0	0.4	0.5
		25 July	29.0	6.5	0.6	0.6
		1 August	30.0	9.0	0.5	0.5
		8 August	--	--	--	--
		15 August	32.5	8.5	0.5	0.5
		22 August	27.5	9.0	0.8	0.8
Crystal Beach	19 South	9 May	22.0	3.0	0.9	0.6
		17 May	25.0	3.0	0.7	0.6
		23 May	31.0	3.0	0.4	0.5
		30 May	26.5	4.0	0.3	0.8

(Continued)

(Appendix G. Continued)

Site	River km	Date	Temp (°C)	Salinity (°/00)	Depth (m)	Secchi (m)
		6 June	25.0	5.5	0.2	0.9
		13 June	28.0	6.0	0.4	0.8
		20 June	29.0	6.5	0.4	1.0
		26 June	28.0	8.0	0.4	0.9
		5 July	28.5	5.5	1.0	0.4
		11 July	32.0	6.5	0.3	0.9
		18 July	35.0	10.0	0.1	0.7
		25 July	30.0	9.0	0.3	0.7
		1 August	31.0	8.5	0.4	0.6
		8 August	34.0	8.5	0.6	0.6
		15 August	29.0	9.5	0.3	0.5
		22 August	28.0	8.5	0.5	0.4
Archbell Point (river)	25 North	9 May	21.5	6.0	1.1	0.8
		17 May	26.5	4.5	0.8	0.6
		23 May	29.5	4.0	0.8	0.8
		30 May	29.5	6.5	0.7	0.8
		6 June	23.0	6.0	0.7	0.4
		13 June	26.0	7.0	0.9	0.9
		20 June	32.0	7.5	0.9	0.7
		26 June	28.0	8.5	0.8	0.9
		5 July	28.5	8.5	1.0	0.8
		11 July	32.0	7.5	0.7	0.7+
		18 July	31.0	8.0	0.5	0.5
		25 July	29.0	9.0	0.8	1.1
		1 August	33.0	8.0	0.8	0.9
		8 August	32.0	10.0	0.9	0.6
		15 August	--	11.0	1.2	0.7
		22 August	31.0	10.5	1.0	0.7
Archbell Point (boat basin)	25 North	9 May	22.0	5.5	0.5	0.9
		17 May	26.5	4.5	0.3	0.8
		23 May	30.0	4.4	0.4	0.8
		30 May	29.5	6.5	0.3	0.8
		6 June	22.5	6.0	0.4	0.4
		13 June	25.0	7.0	0.4	0.9
		20 June	32.0	7.5	0.5	0.7
		26 June	30.0	8.5	0.6	0.9
		5 July	28.0	10.0	0.6	0.6+
		11 July	32.0	7.5	0.3	0.7
		18 July	32.0	7.5	0.0	0.5
		25 July	29.5	9.0	0.4	1.1

(Continued)

(Appendix G. Concluded)

Site	River km	Date	Temp (^{o}C)	Salinity ($^{o}/oo$)	Depth (m)	Secchi (m)
		1 August	34.0	8.0	0.7	0.9
		8 August	32.0	10.0	0.5	0.6
		15 August	32.0	10.5	0.4	0.7
		22 August	31.0	10.5	0.7	0.7
South Creek	37 (North littoral of creek)	9 May	23.0	8.0	--	1.0
		17 May	23.0	8.0	0.7	0.7
		23 May	30.0	8.0	0.7	0.8
		30 May	22.5	9.0	0.6	0.9
		6 June	27.0	8.0	--	0.8
		13 June	25.0	9.0	0.8	0.8
		20 June	31.0	8.0	0.7	0.9
		26 June	27.0	11.5	0.8	0.7
		5 July	27.5	10.5	0.9	0.6
		11 July	32.0	10.0	0.7	0.6
		18 July	31.0	11.0	0.7	0.6
		25 July	29.0	12.5	0.7	0.5
		1 August	32.0	13.0	0.9	0.7
		8 August	32.5	13.0	0.9	0.5
		15 August	31.0	13.0	0.6	0.4
		22 August	29.5	13.5	1.0	0.5

Appendix H. Selected reference charts of the Pamlico-Albemarle system. Originals copyrighted 1987 by ADC of Alexandria, Inc. USED WITH PERMISSION.

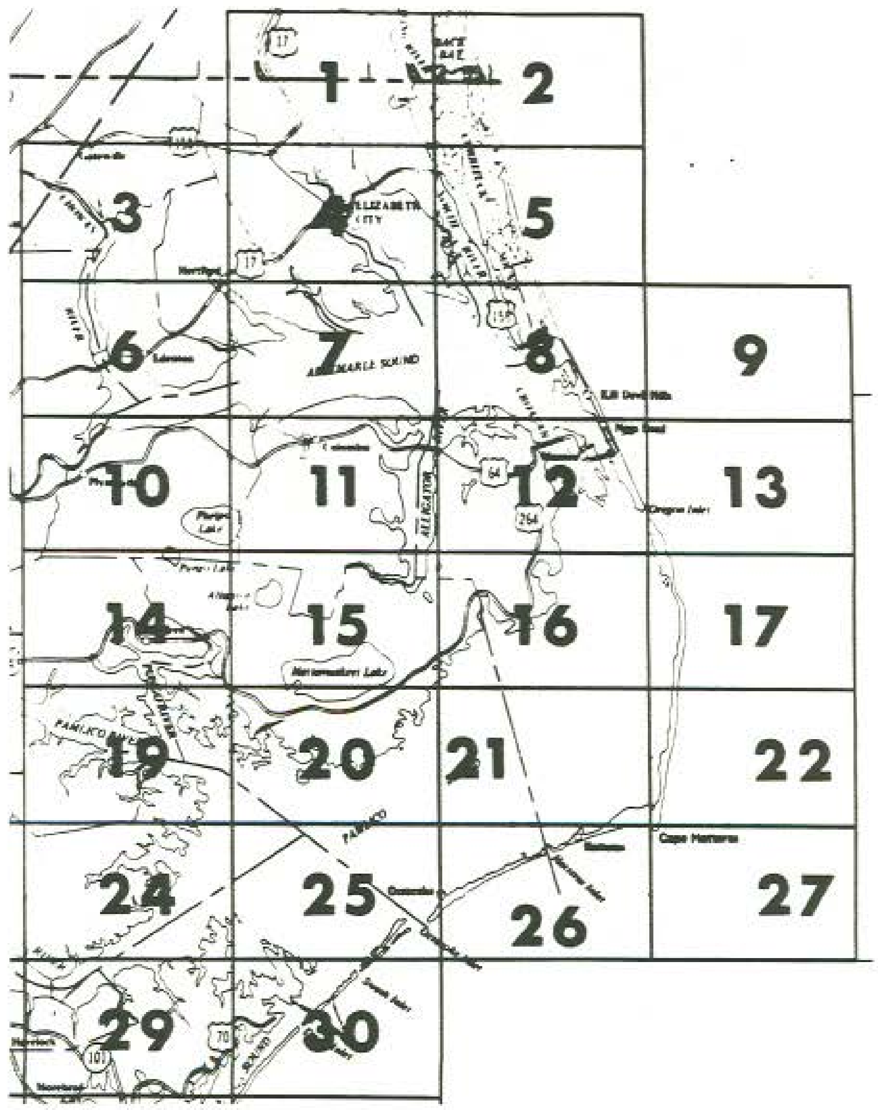
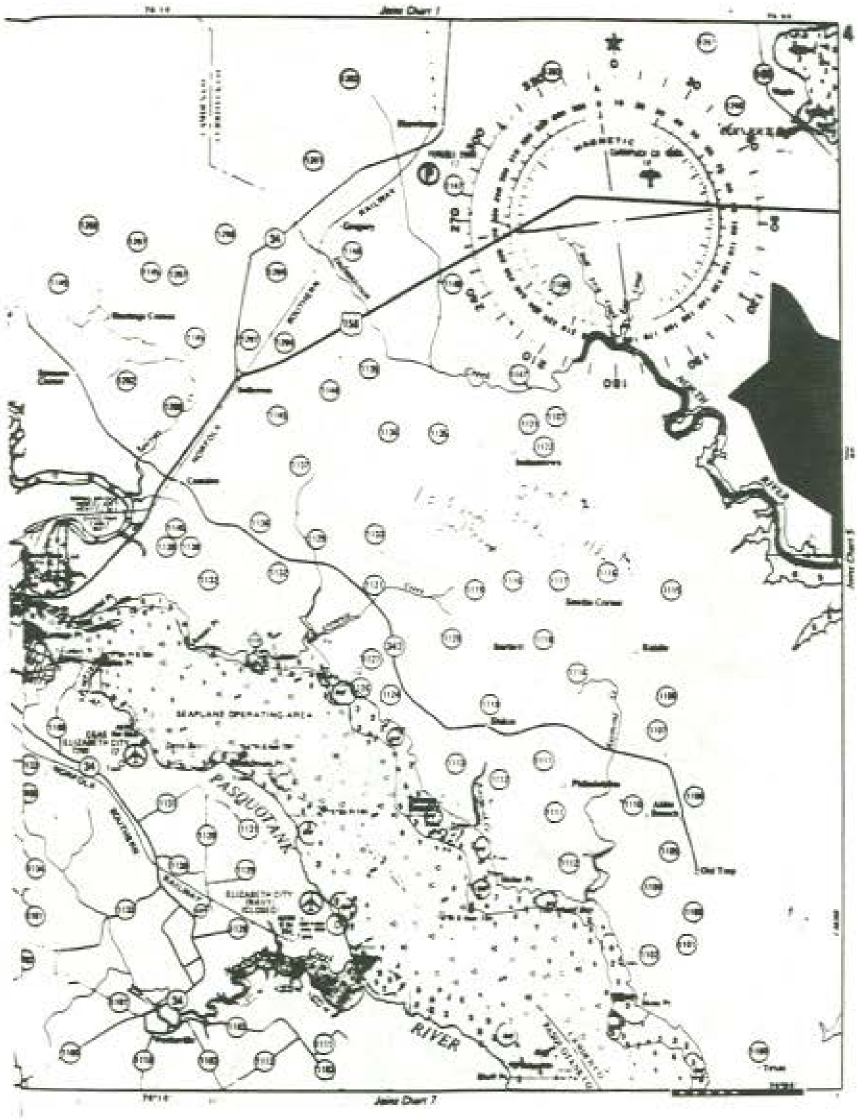


CHART INDEX

Not shown: Chart 18 (west of 19); Chart 23 (west of 24); and Chart 28 (west of 29).



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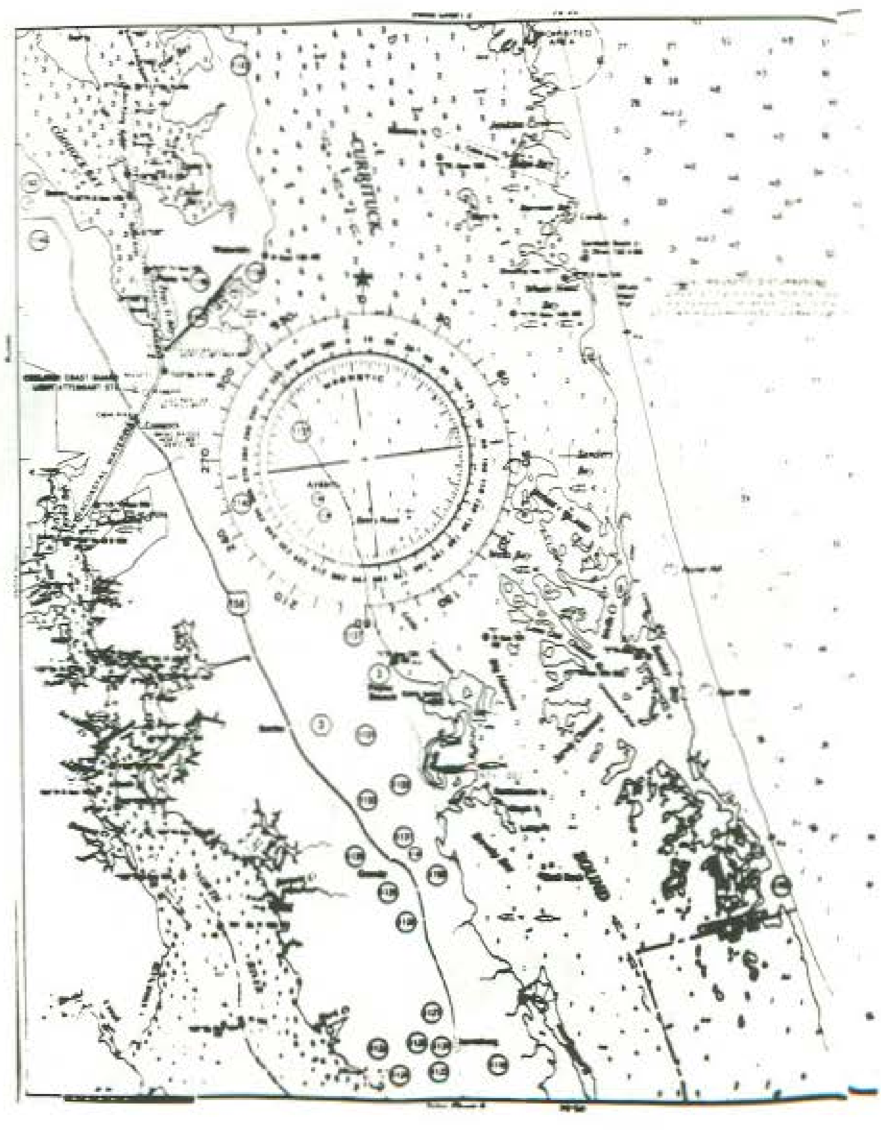

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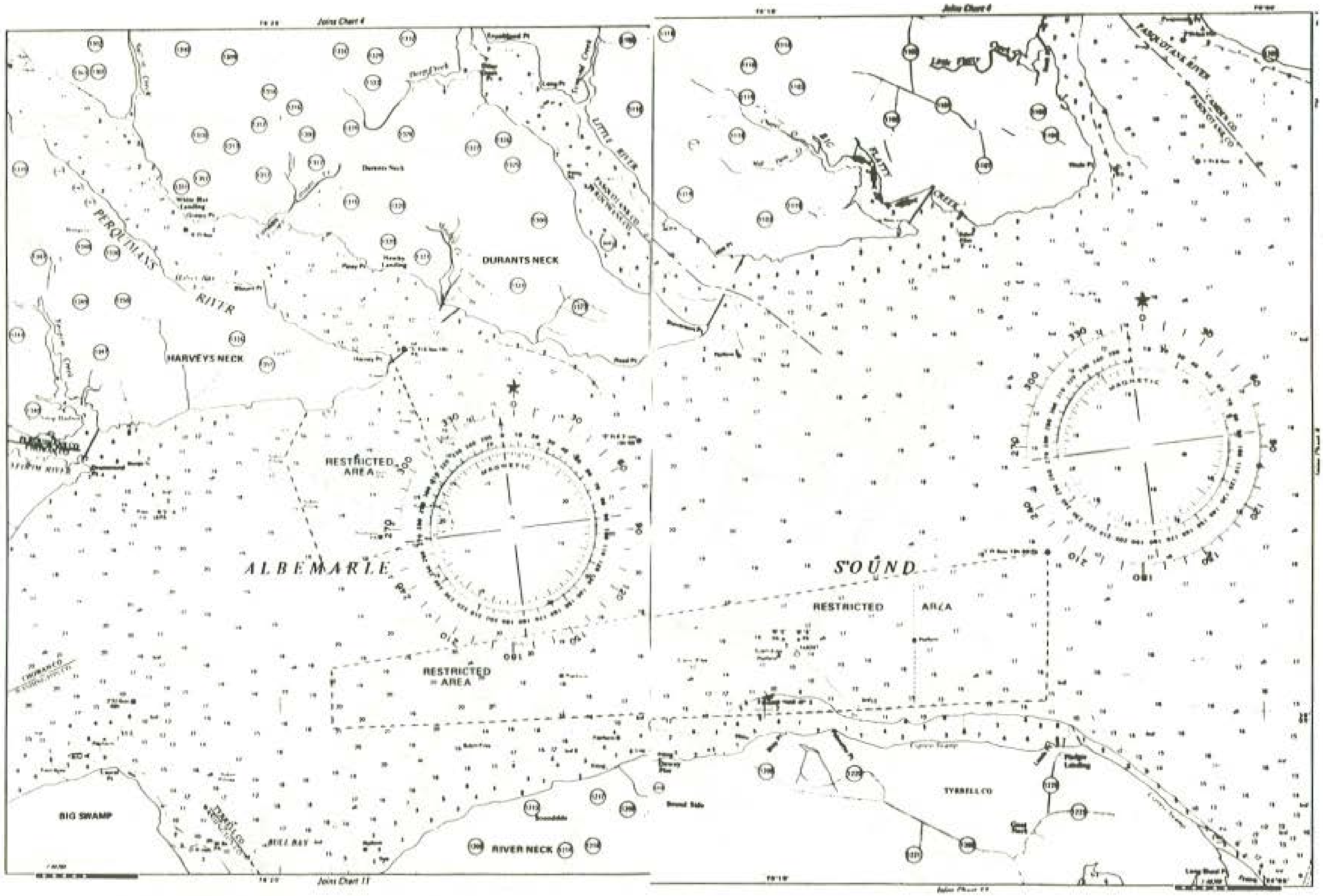

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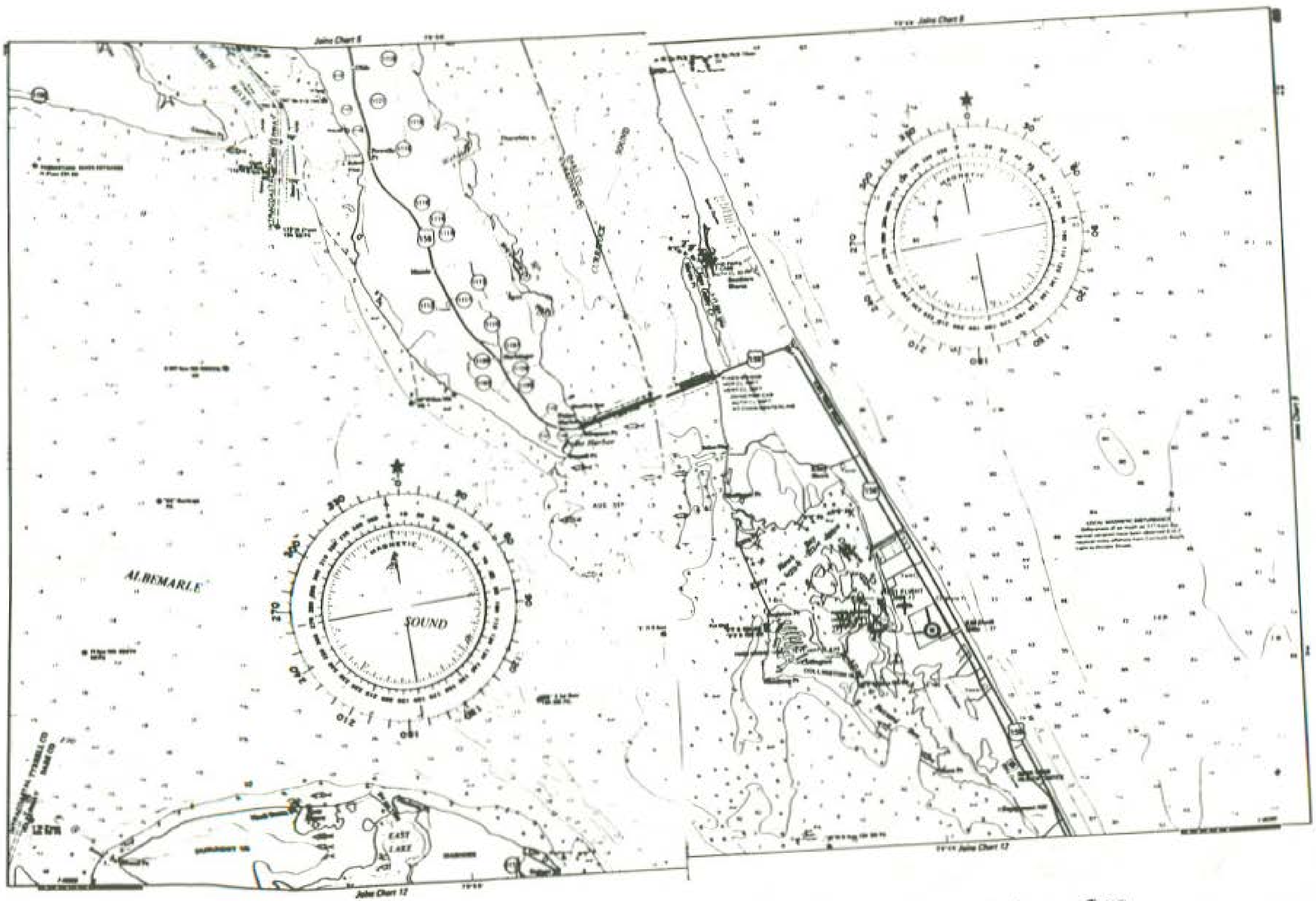

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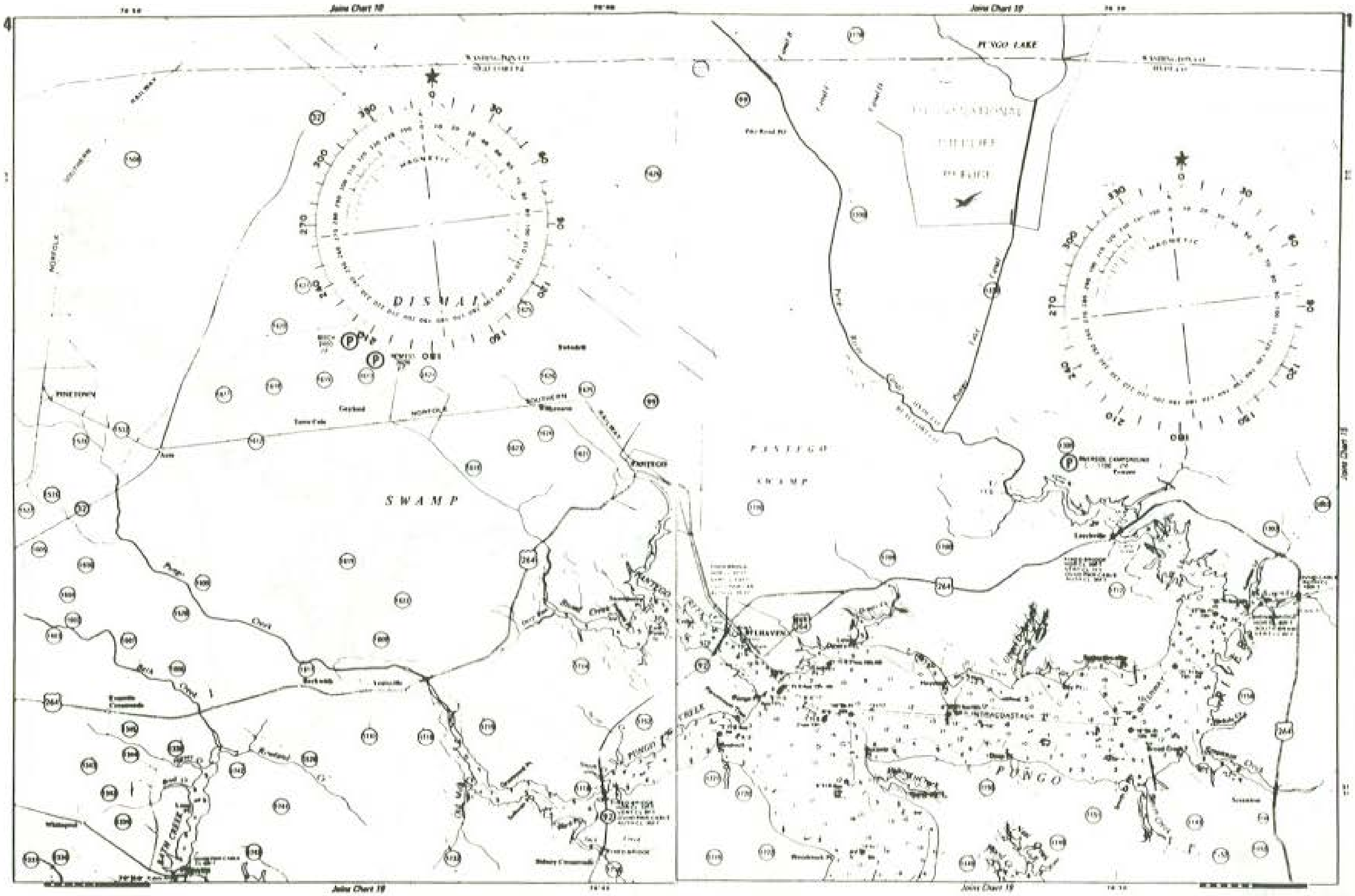

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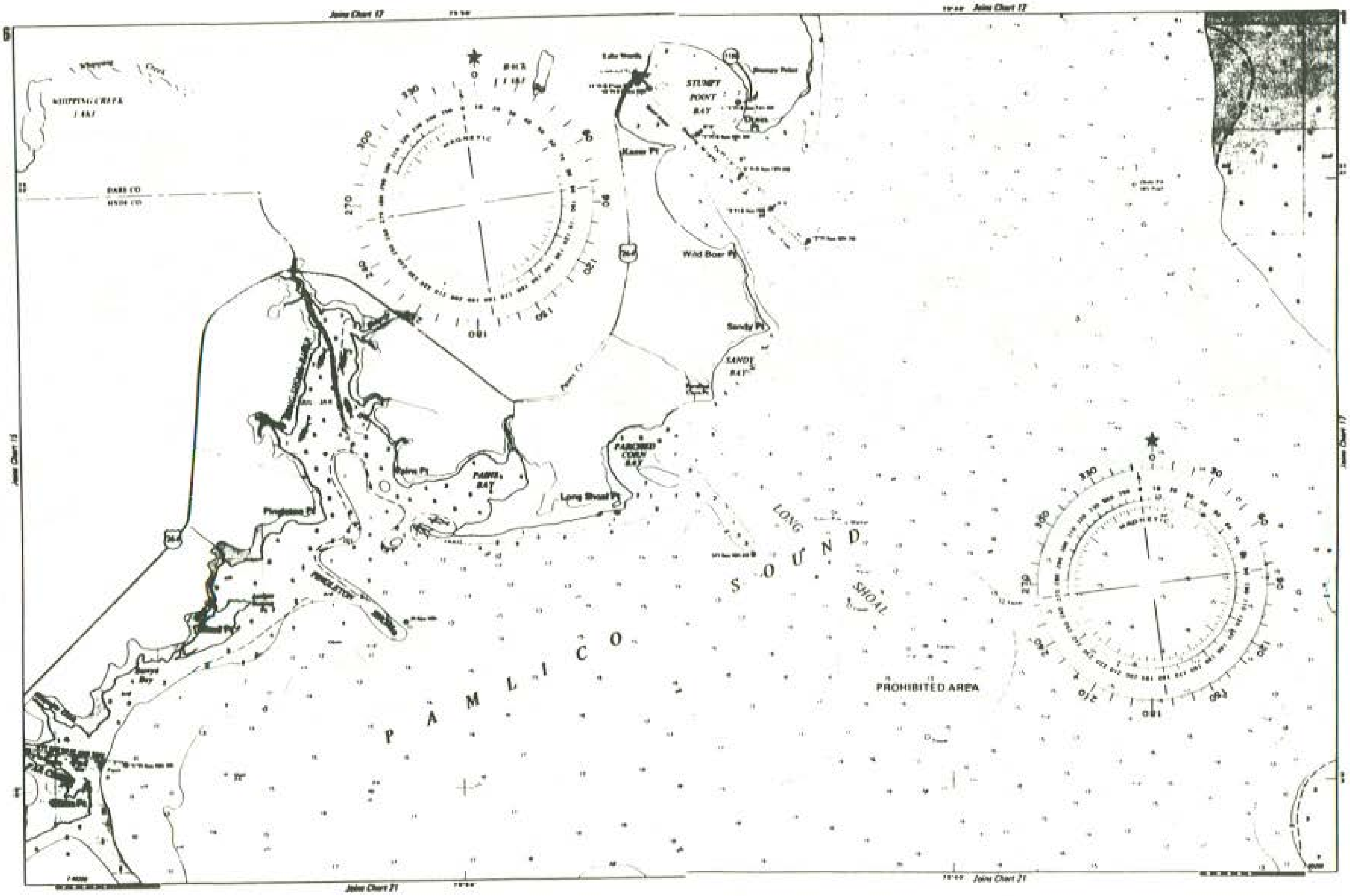

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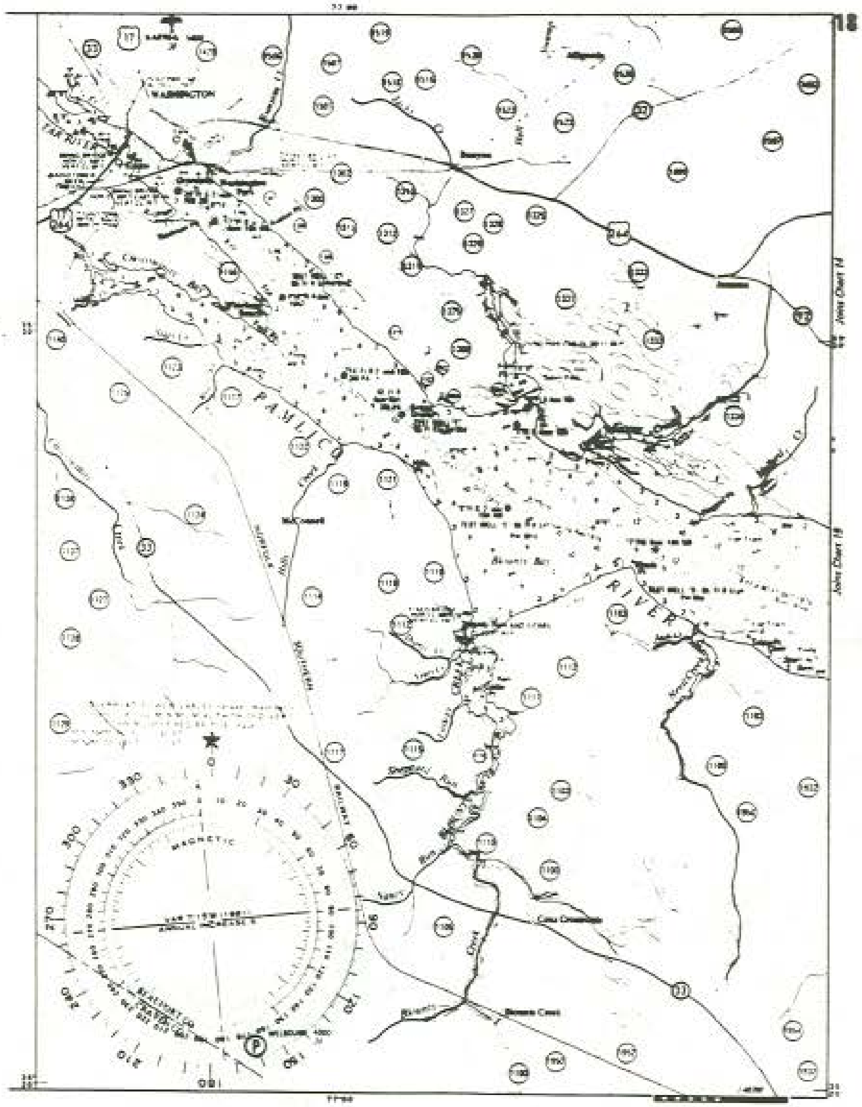

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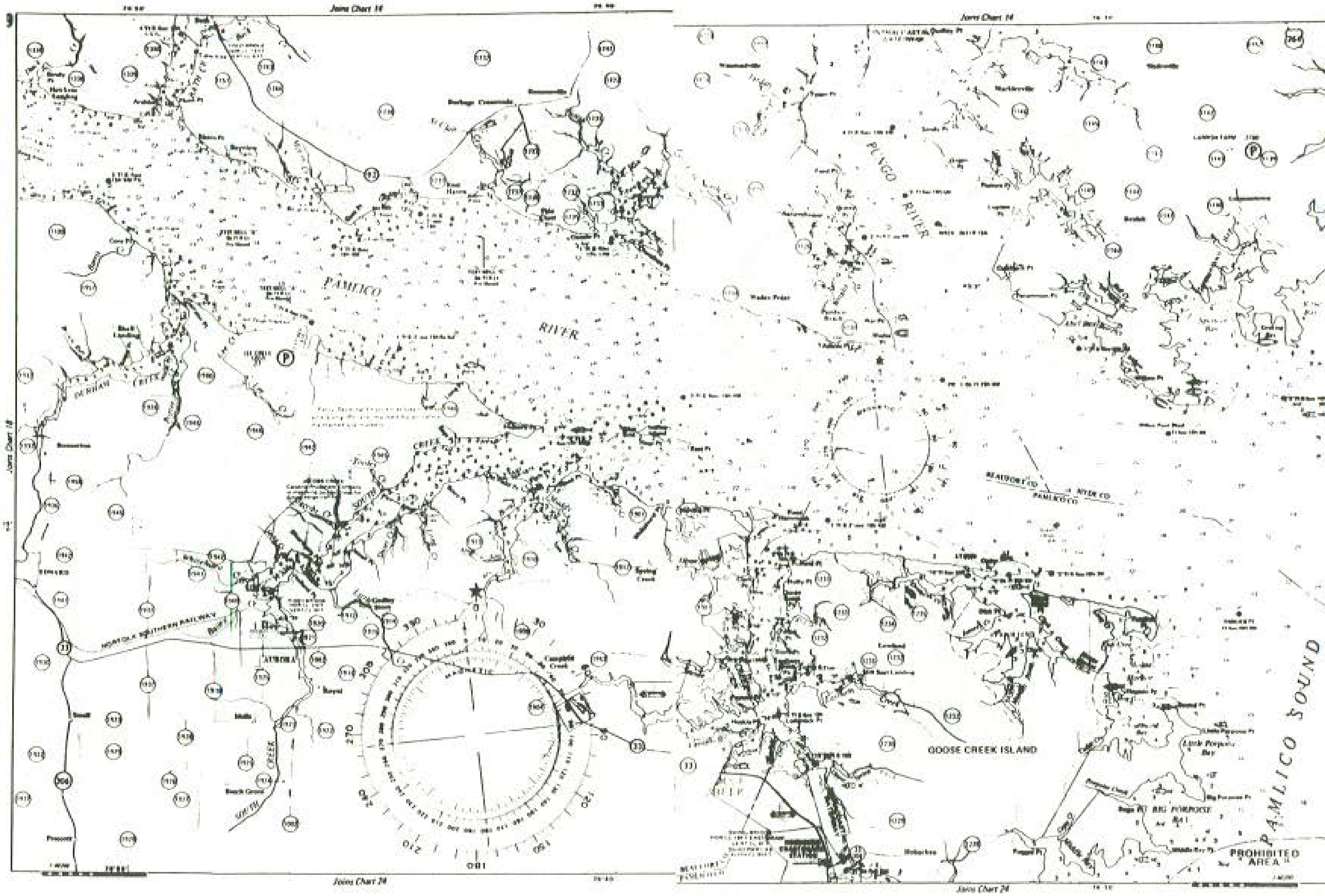

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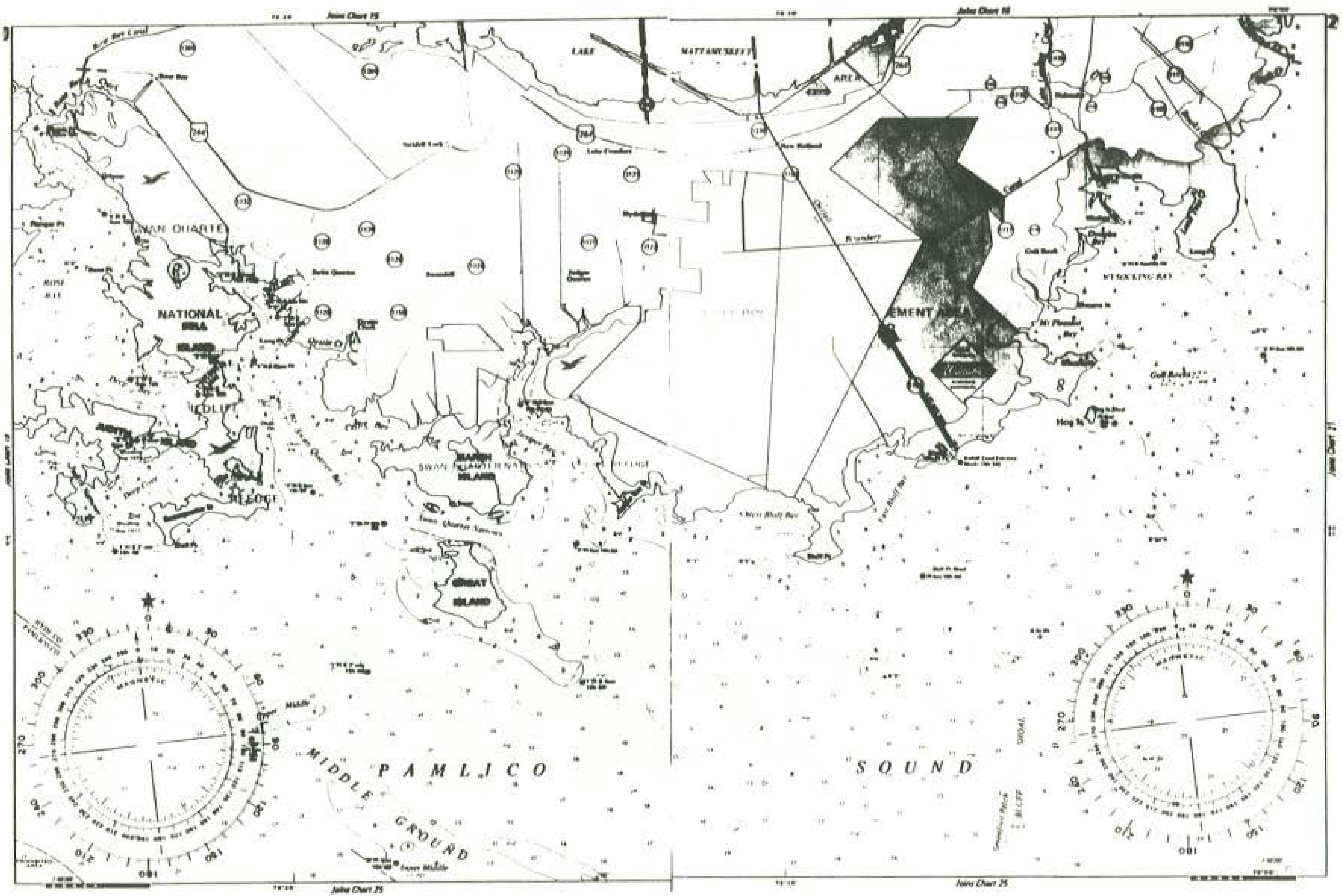

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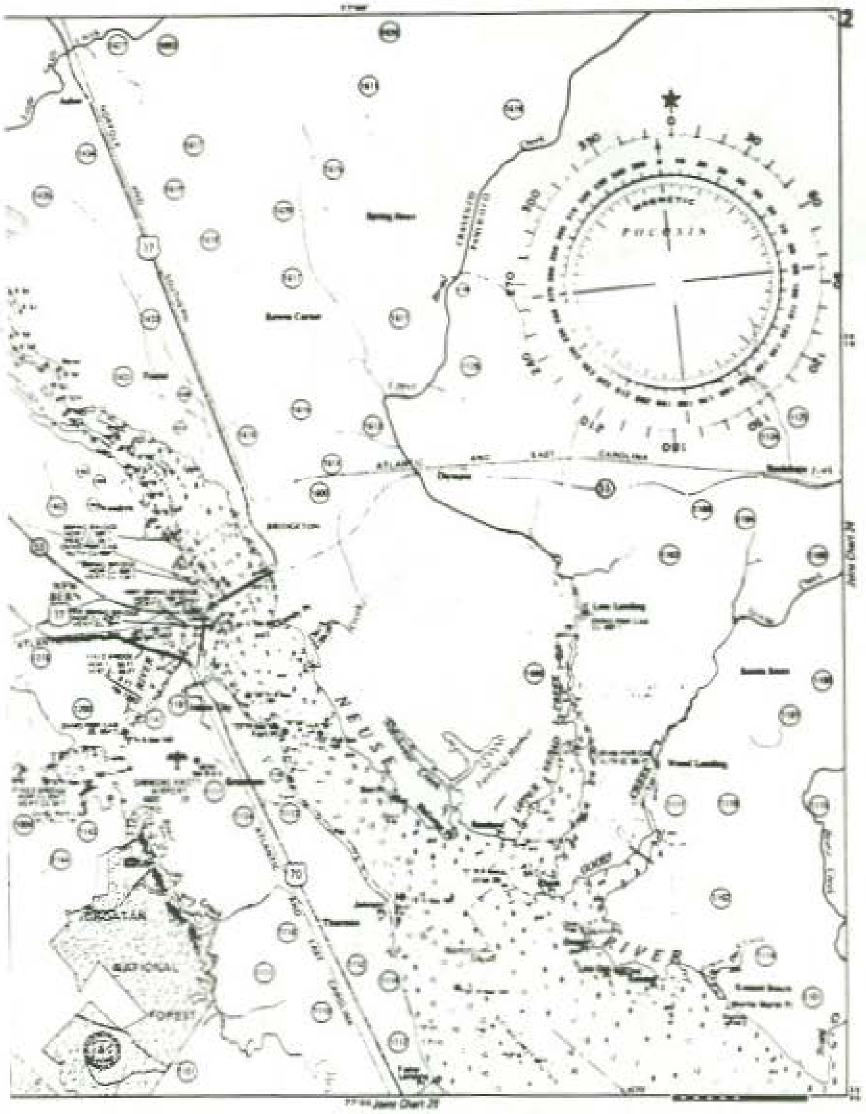

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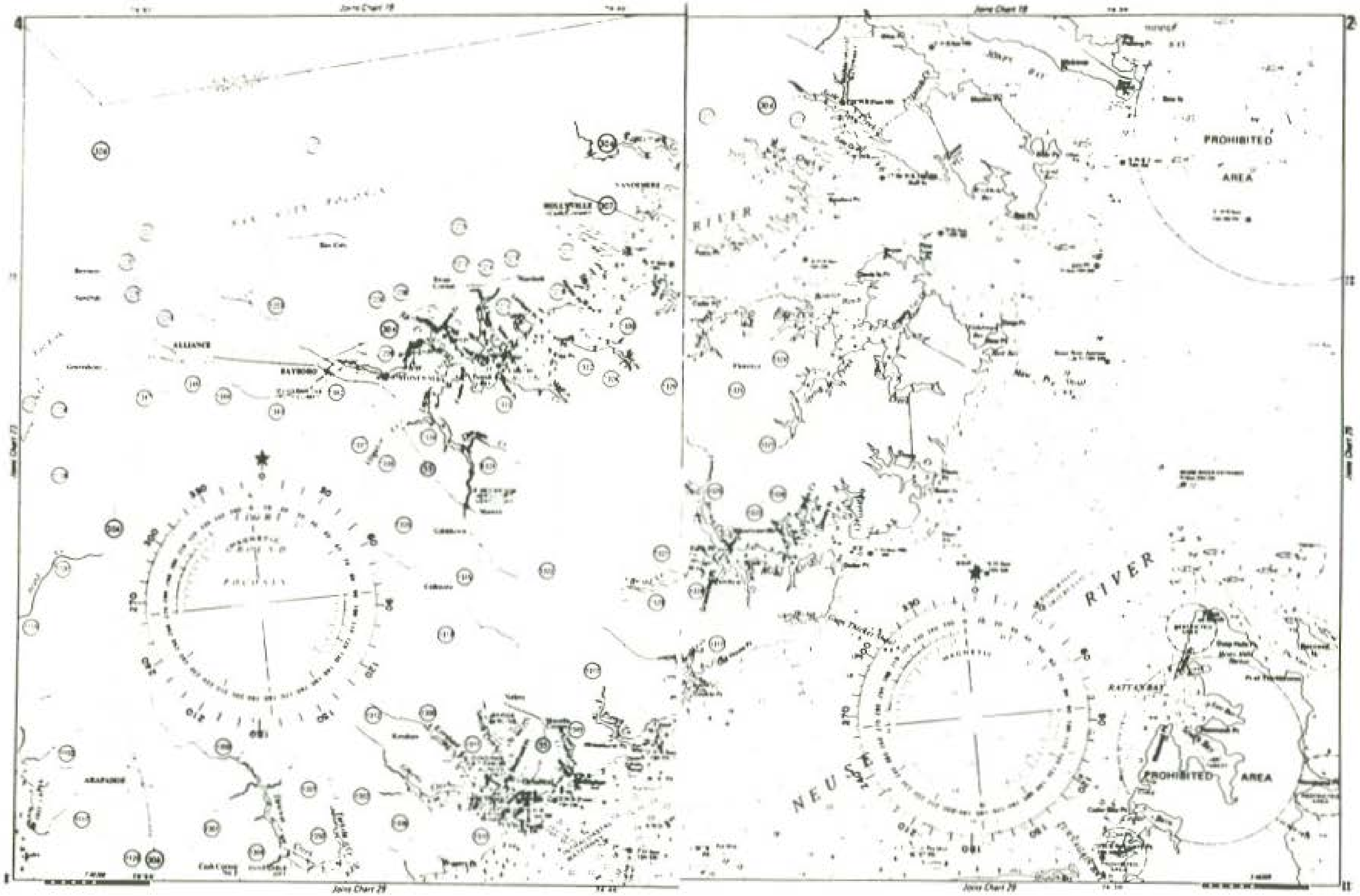
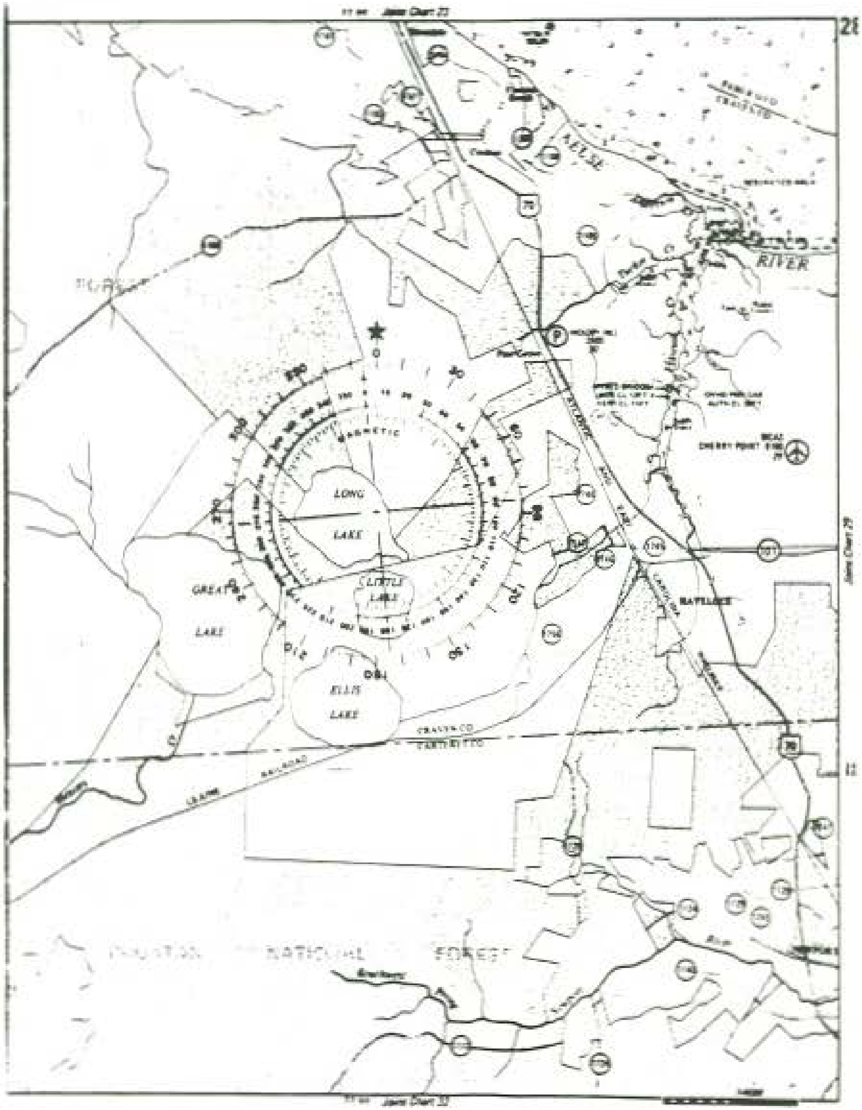

Joins Chart 19
Joins Chart 29
ALLIANCE
BAYBORO
ARAPAHOE
PROHIBITED
AREA
RIVER
NEUSE
RIVER
RATTAN BAY
PROHIBITED
AREA
MAGNETIC

CHART 24.



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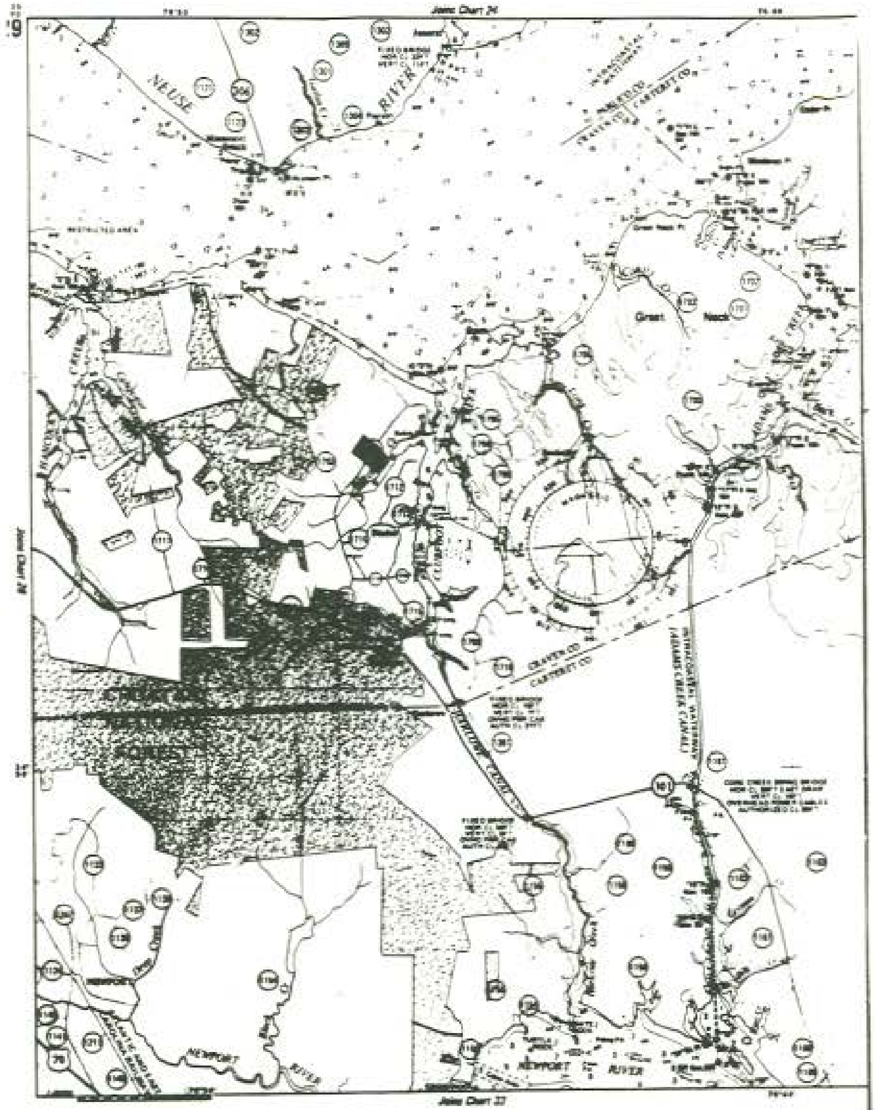

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