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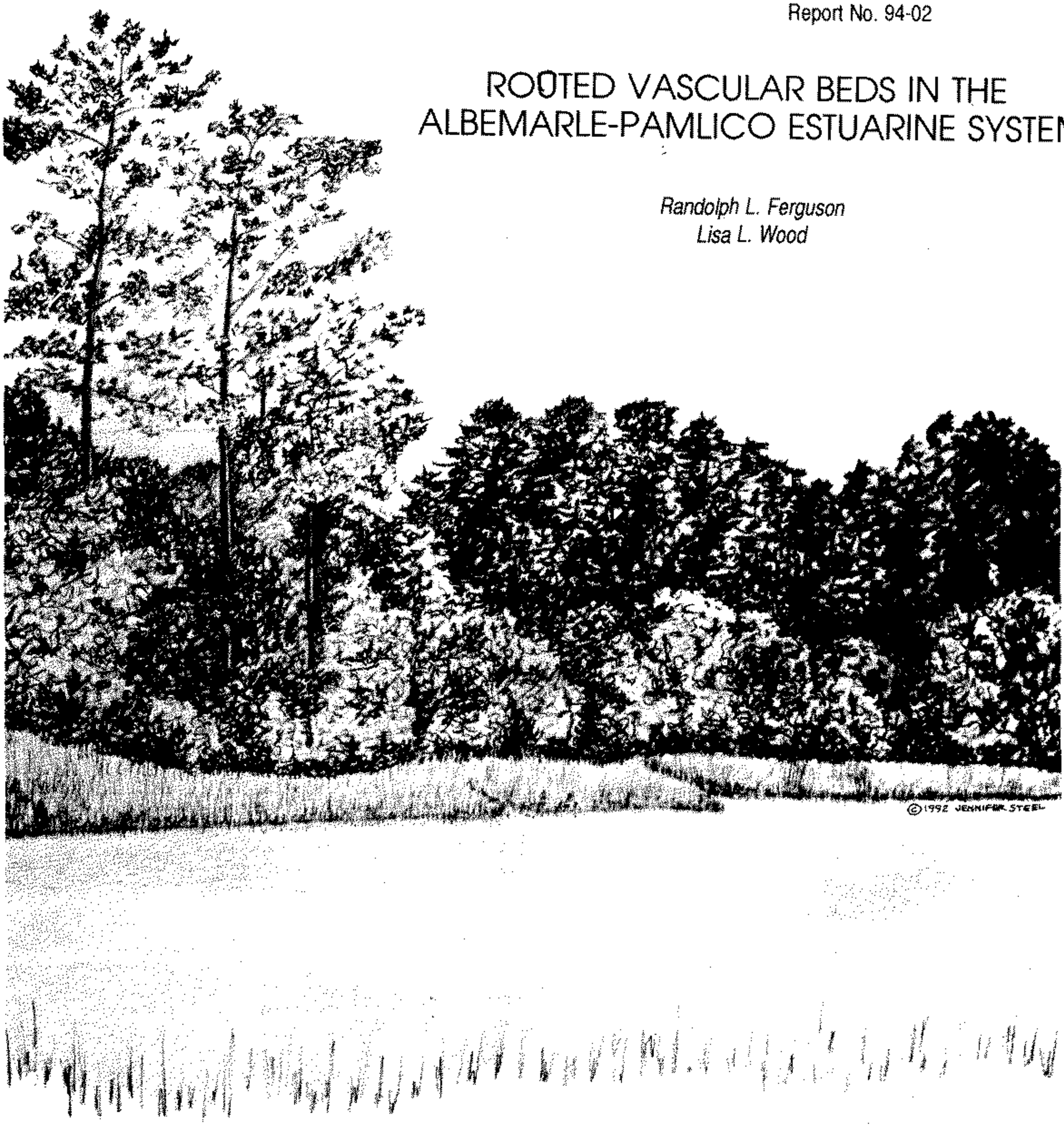
ROOTED VASCULAR BEDS IN THE ALBEMARLE-PAMLICO ESTUARINE SYSTEM

Randolph L. Ferguson
Lisa L. Wood



ALBEMARLE-PAMLICO ESTUARINE STUDY

NC Department of Environment, Health, and Natural Resources

Environmental Protection Agency National Estuary Program

ROOTED VASCULAR AQUATIC BEDS

IN THE

ALBEMARLE-PAMLICO ESTUARINE SYSTEM

By

Randolph L. Ferguson and Lisa L. Wood

National Marine Fisheries Service, NOAA
Beaufort Laboratory
Beaufort, NC 28516-9722

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Lisa L. Wood

National Marine Fisheries Service, NOAA
Beaufort Laboratory
Beaufort, NC 28516

ABSTRACT

Marine and estuarine aquatic beds are nurseries for estuarine-dependent commercially and recreationally exploited fish and shellfish. In the Albemarle-Pamlico Estuarine System of North Carolina, submersed rooted vascular beds (SRV) are extremely important, comprising an area approximately equal to that for salt marshes. These SRV provide nursery and feeding habitat for many fish, shellfish and wading birds. About 90% of commercial fishery landings in North Carolina are composed of estuarine-dependent species, many of which utilize these habitat types.

SRV occur in the sounds and estuaries of the Albemarle-Pamlico Estuarine System but not seaward of the Outer Banks. The geographic distribution of SRV in estuaries and sounds landward of the Outer Banks is associated with water depth, water clarity and salinity. SRV occurs at water depths of up to 2.4m. Although quite variable, water clarity in this system is typical of estuaries of the southeast coast of the US; freshwater and oceanic water are clearer than estuarine water. The distribution of SRV reflects this trend.

The distribution of species of SRV in The Albemarle-Pamlico Estuarine System is strongly associated with salinity. For our purposes, **high salinity** is ≥5.0 - ≤40‰. Two of the three species that occurred in **high salinity** waters are seagrasses which require **high salinity**: eelgrass (*Zostera marina*), a temperate species, and shoal grass (*Halodule wrightii*), a tropical species. The third is the euryhaline and panlatitudinal species, widgeon grass (*Ruppia maritima*). Eleven species of SRV occur in **low salinity**. For our purposes **low salinity** is <5‰. Six of these eleven species were observed in the present study: widgeon grass, wild celery (*Vallisneria americana*), Eurasian water milfoil (*Myriophyllum spicatum*), bushy pondweed (*Najas guadalupensis*), redhead grass (*Potamogeton perfoliatus*), and sago pondweed (*Potamogeton pectinatus*). Species of SRV that require **low salinity** were less abundant and wide spread than species which require or tolerate **high salinity**. A notable exception was in the **low salinity** Currituck Sound.

Nine subregions partition the Albemarle-Pamlico Estuarine System. The subregions are: **Currituck, Albemarle**, **Roanoke/Croatan**, **Pamlico River estuary**, **Neuse River estuary**, **western Pamlico Sound**, **eastern Pamlico Sound**, **Core**, and **Bogue**. This report focuses on the **Currituck, Albemarle**, **Roanoke/Croatan**, **Pamlico River estuary**, **Neuse River estuary**, **western Pamlico Sound**, and **Core** Subregions which were included in the funding agreement with EPA's National Estuary

Program (NEP) and NOAA, National Marine Fisheries Service, Beaufort Laboratory, Southeast Fisheries Science Center. Data from the **Bogue** and **eastern Pamlico Sound** Subregions, generated by research funded by NOAA's Coastal Ocean Program (COP), are included at the request of the Albemarle-Pamlico Estuarine Program Office.

The aquatic bed spatial data, interpreted from natural color metric quality aerial photography, have been digitized and are available through the North Carolina Center for Geographic Information and Analysis (NC-CGIA). The exception is the **Currituck** subregion for which base maps have recently (March 1994) been generated by NOAA, National Ocean Service (NOS). Base maps are required for registration of spatial habitat data to the external georeference system. Field inventories verified SRV signatures in the photographs and determined the geographic distribution of species of SRV relative to salinity, water clarity, and water depth. Charts, photographs, and digital data produced in this project form a baseline of location and abundance data of this critical fishery habitat for research and for environmental planning and impact evaluation.

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SUMMARY AND CONCLUSIONS

Submersed rooted vascular beds (SRV) constitute one of the most common estuarine habitats in North Carolina. The published estimate of area of SRV is 200,000 acres or about equal to that area for salt marshes (Field *et al.* 1988, Orth *et al.* 1990). In the contiguous 48 states, North Carolina is second only to Florida in acreage of SRV, and has over twice the acreage reported for Chesapeake Bay. SRV inhabit photic submerged land in low and high salinity water. **Low salinity** is <0.5‰ and **high salinity** is ≥5‰ (Klemas *et al.*, 1993).

SRV was frequently encountered in **high** and **low salinity** waters of subregions associated with the Outer Banks. SRV was most widespread and broadly distributed in the **high salinity** subregions (**eastern Pamlico Sound**, **Core**, and **Bogue**) but also was relatively abundant and widespread in a **low salinity** subregion (**Currituck**). SRV was limited in distribution and abundance in **high** or **low salinity** waters in subregions more closely associated with the mainland. This was true for a **high salinity** subregion (**western Pamlico Sound**), a **low salinity** subregion (**Albemarle**), and those subregions that contained both **low** and **high salinity** water (**Neuse River estuary**, **Pamlico River estuary**, and **Roanoke/Croatan**). The area of SRV habitat by subregion where data are now available is: **eastern Pamlico Sound** (*ca.* 90,000 acres), **Core** (19,938 acres), **Albemarle** (4,439 acres) **Croatan/Roanoke** (926 acres), **Neuse River estuary** (91 acres), **Pamlico River estuary** (378 acres) and **western Pamlico Sound** (83 acres). **Currituck** is being mapped at this time.

State and federal coastal habitat managers recognize the critical role of SRV and as a result of this study are in a stronger position to conserve and protect them in North Carolina. Needs are high, for example, for dredging projects to maintain the Atlantic Intracoastal Waterway and channels through inlets to the Atlantic Ocean and to maintain or create other waterways and access channels. Many of these needs potentially conflict with preservation of SRV. SRV are vulnerable to physical damage. *e.g.* excessive current speed (see Fonseca and Kenworthy 1987), mechanical clam harvest, trawling and boating. SRV also are subject to physiological stress from salinity fluctuation, light limitation, and nutrient overenrichment. Data provided in this inventory and the methods demonstrated here, when applied to monitor SRV habitat, can provide managers with information critical to evaluating the health of the Albemarle-Pamlico Estuarine System and feedback on the success of management strategies to enhance and maintain SRV.

Man's use of coastal resources in the estuaries and sounds of eastern North Carolina can be compatible with long-term maintenance of these resources. Preservation of SRV as a living coastal resource, however, requires spatial data of the location, species composition and extent of SRV, the goal of this research. With this information, managers can make informed decisions concerning development and use of coastal submerged lands and waterways.

The distribution of species of SRV in the Albemarle-Pamlico Estuarine System now can be described. SRV generally are restricted to low intertidal and subtidal bottoms between the 0 and 6 feet contour lines of NOAA nautical charts of the region. These depths are relative to the mean lower low water datum, MLLW. SRV were observed at ambient water depths up to 2.4m.

In the relatively clear **high salinity** waters of the **Bogue**, **Core** and **eastern Pamlico Sound** Subregions, eelgrass (*Zostera marina*), shoal grass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*) are abundant and widespread. North Carolina is the northern limit for shoal grass and the southern limit for eelgrass on the Atlantic coast of the U.S. (Thayer *et al.*, 1894; Ferguson *et al.*, 1993b). Shoal grass and eelgrass were collected in this study from Bogue Inlet to north of Oregon Inlet in southern parts of Roanoke and Croatan Sounds. Ambient salinities were 8 to 38‰ for shoal grass and eelgrass. For both species of seagrass, frequency of occurrence was highest at salinities $\geq$15‰. Widgeon grass occurs throughout the study area and was sampled at ambient salinities of 0 to 36‰. Frequency of occurrence of widgeon grass was highest at salinities in the interval of 15 to 28‰.

Aquatic beds of SRV are neither diverse in species nor widespread in spatial distribution in the predominantly mesohaline waters of the **Neuse River estuary**, **Pamlico River estuary**, **western Pamlico Sound**, and **Roanoke/Croatan** Subregions. SRV in these subregions may be limited due to physical and physiological stress. Extreme currents, long wind fetch, absence of protective shoals, variable salinity, reduced availability of light and nutrient overenrichment all are suspected stress factors. Occasionally widgeon grass but neither shoal grass nor eelgrass were observed in **western Pamlico Sound** or in the lower Neuse and Pamlico River estuaries despite the presence of mesohaline salinities favorable to all three species. Historically, eelgrass has been observed in western Pamlico Sound (G. Davis, personal communication). The frequency of occurrence of SRV in **low salinity** fresh water and oligohaline water of the Albemarle-Pamlico estuarine system generally is low with the notable exception of the **Currituck** subregion.

The historical case for loss and recovery of SRV is weak in North Carolina. Present levels of SRV in **low salinity** water, according to spatially unquantitative and anecdotal information, may be substantially less than historical levels (see Davis and Brinson 1976, 1983 and 1989). It is generally perceived that historically high abundances of SRV have been negatively affected by coastal development, increased commercial and recreational boat traffic and concurrent degradation of water quality. At a recent meeting of the Tar-Pamlico River Foundation Advisory Board (Oct., 1993) a resident suggested that an expansion of SRV has occurred in portions of the Pamlico River estuary, subsequent to our 1991 and 1992 photography. Such observations provide hope for the recovery of SRV in fresh, oligohaline and mesohaline waters, given ongoing improvements in land and water use management.

An historical case for loss, and partial recovery of SRV due to improved management practices is being made in Chesapeake Bay (Orth and Moore 1983, Orth *et al.* 1991). Historical losses have been documented, recovery is being monitored, and monitoring data are being integrated into water quality and aquatic bed restoration guidelines (Batuik *et al.* 1992 and Dennison *et al.* 1993).

Completion of the initial inventory in the Albemarle-Pamlico Estuarine System is a large but first step toward quantitative monitoring and effective management of SRV. Quantitative inventory and spatial change analysis monitoring of SRV, at least once every 5 years, combined with more traditional water quality monitoring could help assure effective management of these critical habitats.

RECOMMENDATIONS

- **MONITOR SRV IN THE ALBEMARLE-PAMLICO ESTUARINE SYSTEM EVERY FIVE YEARS WITH AERIAL PHOTOGRAPHY**

- **MAP SELECTED HABITAT LOCATIONS ANNUALLY WITH GPS AT SURFACE LEVEL**

- **PLACE THE DATA IN THE NORTH CAROLINA CORPORATE GEOGRAPHIC DATA BASE**

- **POSITION FIELD OBSERVATIONS AND SITE ASSESSMENTS WITH A GLOBAL POSITIONING SYSTEM TO LINK THEM TO THE SPATIAL RESOURCE DATA**

- **UPDATE SPATIAL DATA BY REFERENCE OF INTERPRETED SRV TO NOS CONTEMPORARY SHORELINE DATA AS THESE BECOME AVAILABLE**

- **APPLY THE GIS AND HARD COPY MAP PRODUCTION CAPABILITIES OF NC-CGIA TO IMPROVE IMPACT ASSESSMENT ACTIVITIES**

- **USE THE SPATIAL RESOURCE DATA TO: GUIDE RESEARCH, ERECT PREDICTIVE SPATIAL MODELS, AND EVALUATE MANAGEMENT PROGRAMS**

INTRODUCTION

The Habitat

Marine and Estuarine aquatic beds (Cowardin, 1979; Klemas *et al.*, 1993) are critical components of shallow coastal ecosystems worldwide (Ferguson *et al.*, 1980). Submersed rooted vascular beds, SRV (*e.g.* seagrasses), provide food and cover for a great variety of commercially and recreationally important fauna and their prey (Fonseca *et. al.*, 1992; Phillips, 1984; Thayer *et al.*, 1984; Zieman, 1982; Zieman and Zieman, 1989) along the margins of all continents except Antarctica (Larkum *et al.*, 1989). The leaf canopy calms the water, filters suspended matter and, together with an extensive roots and rhizomes, stabilize sediment (Thayer *et al.*, 1984). Macroalgal aquatic beds tend to be ephemeral, less abundant and limited in distribution relative to SRV in the Albemarle-Pamlico Estuarine System and are not quantified in this study.

SRV are phototrophic plants requiring light to conduct photosynthesis. The depth limit for SRV is a function of the penetration of light sufficient for net photosynthesis by these autotrophic rooted plants (Kenworthy and Haunert, 1991). In the generally turbid waters of eastern North Carolina this depth limit is approximately 6 ft mean lower low water, MLLW, (Ferguson *et al.*, 1989).

Thirteen species of SRV (Table 1) have been reported for the Albemarle-Pamlico Estuarine System (Beal, 1977; Davis and Brinson, 1990; Ferguson *et al.*, 1989). The reader is referred to Hurley

Table 1. SRV species list and salinity range. (Salinity range from Beal, 1977; Davis and Brinson, 1990; Orth *et al.*, 1992; and Ferguson *et al.*, 1993).

Taxonomic Name	Common Name	Salinity Range
		----- ‰ ----
Zostera marina	eelgrass	10 - >36
Halodule wrightii	shoal grass	8 - >36
Rupia maritima	widgeon grass	0 - 36
Vallisneria americana	wild celery	0 - 10
Myriophyllum spicatum	eurasian water milfoil	0 - 10
Najas guadalupensis	bushy pondweed	0 - 10
Potamogeton perfoliatus	redhead grass	0 - 20
Potamogeton pectinatus	sago pondweed	0 - 9
Potamogeton foliosus	leafy pondweed	0 - ?
Zannichellia palustris	horned pondweed	0 - 20
Alternantheria philoxeroides	alligatorweed	0 - ?
Nuphar luteum	spatterdock	0 - ?
Ultricularia sp.	bladderwort	0 - ?

(1990) for photographs and general ecological information on these species. Species of SRV thrive in fresh and oceanic water which has been classified according to salinity by Cowardin *et al.* (1979). Two species, eelgrass (*Zostera marina*) and shoal grass (*Halodule wrightii*) are true seagrasses, requiring salinities ≥5.0 to survive. One species, widgeon grass (*Ruppia maritima*), is euryhaline. The remaining ten species are most frequent at salinities ≤5.0‰ (*ibid*; Batuik *et al.*, 1992).

SRV support many species of fish and shellfish and are major fishery habitats of the shallow sounds behind the barrier islands of eastern North Carolina (Epperly and Ross, 1986; Thayer *et al.*, 1984). Here, fish and shellfish including gray trout, red drum, spotted seatrout, mullet, spot, pinfish, pigfish, gag grouper, silver perch, summer and southern flounder, pink and brown shrimp, blue crabs, hard shell clams and bay scallops utilize beds of SRV as nurseries. Beds of SRV also are frequented by adult spot, spotted seatrout, summer and southern flounder, pink and brown shrimp, hard shell clams and blue crab, and are the primary habitat of the bay scallop. Birds feeding in SRV beds include egrets, herons, sandpipers, terns, gulls, swan, geese, ducks, and osprey.

The acronym SRV is relatively new but the concept is well established in the literature. SRV is intended to replace the broadly accepted and widely used acronym SAV, submerged aquatic vegetation. The change from SAV to SRV is not trivial. As a necessary step in establishment of a national data base for inventory and change analysis of wetlands, submerged lands and adjacent uplands, NOAA's Coastal Ocean Program, CoastWatch Change Analysis Project (C-CAP) established a land cover classification system which meets the needs of the project and is compatible with related systems in other agencies (Dobson *et al.*, In Press). New and more appropriate terminology was requested by participants of the nation wide C-CAP developmental workshops and was necessary to become consistent with the Classification System published by Klemas *et al.* (1993).

The C-CAP Classification is rooted in Cowardin, a well established and carefully conceived system for categorizing wetlands and deepwater habitats (Cowardin *et al.* 1979). The Cowardin system defines **Aquatic Bed**, as a class of landcover with a number of subclasses including **Algal**, **Rooted Vascular**, and **Floating Vascular**. Aquatic bed applies to both the subtidal and intertidal zones. C-CAP created a new classification to be as consistent as possible with the Cowardin Classification but which met specific program needs not met by earlier systems (Klemas *et al.*, 1993). The C-CAP Classification System includes a priority category for change analysis: Superclass, **Water and Submerged Land**; Class, **Marine/Estuarine Aquatic Bed**; and Subclass **Rooted Vascular** (Klemas *et al.*, 1993; Dobson *et al.*, In Press). Unfortunately the classification nomenclature does not lend itself to a memorable acronym. **Submersed Rooted Vascular**, **SRV**, on the other hand, is a memorable acronym. Use of the adjective submersed is intended to specifically differentiate SRV from floating rooted vascular beds, **FRV**.

The concept of SAV, submerged aquatic vegetation, although broadly applied, is, in fact, a regional concept, contrary to common English usage, and inconsistently defined. Hurley (1990), excludes from submerged aquatic vegetation, not only algae, nonvascular plants which together with vascular plants comprise vegetation, but also, intertidal plants because they do not grow completely underwater. In areas such as the west coast, seagrasses can occur in the intertidal zone. The difference between the words submersed and submerged also is important. In the context of plants, 'submersed' specifically means growing or adapted to grow under water. This meaning fits seagrasses and their freshwater and euryhaline analogues. Finally, adjoining the words submerged and aquatic is redundant. In another report, SAV is defined differently; "**19 taxa from 10 vascular macrophyte families and 3 taxa from 1 freshwater macrophytic algal family, the Characeae, but excludes all other algae, both benthic and planktonic, which occur in the Chesapeake Bay and tributaries**" (Orth and Nowak, 1990). This definition has explicit taxonomic and geographic limits.

The System

The Albemarle-Pamlico Estuarine System contains abundant photic shallow bottoms which potentially can support SRV (Fig. 1). The nine subregions which partition the Albemarle-Pamlico Estuarine System based on geomorphological considerations are: **Currituck** including Currituck Sound, adjacent embayments, and waters extending to the northern extreme of the study area, *i. e.*, Back Bay and Ships Bay in Virginia; **Albemarle** including Albemarle Sound

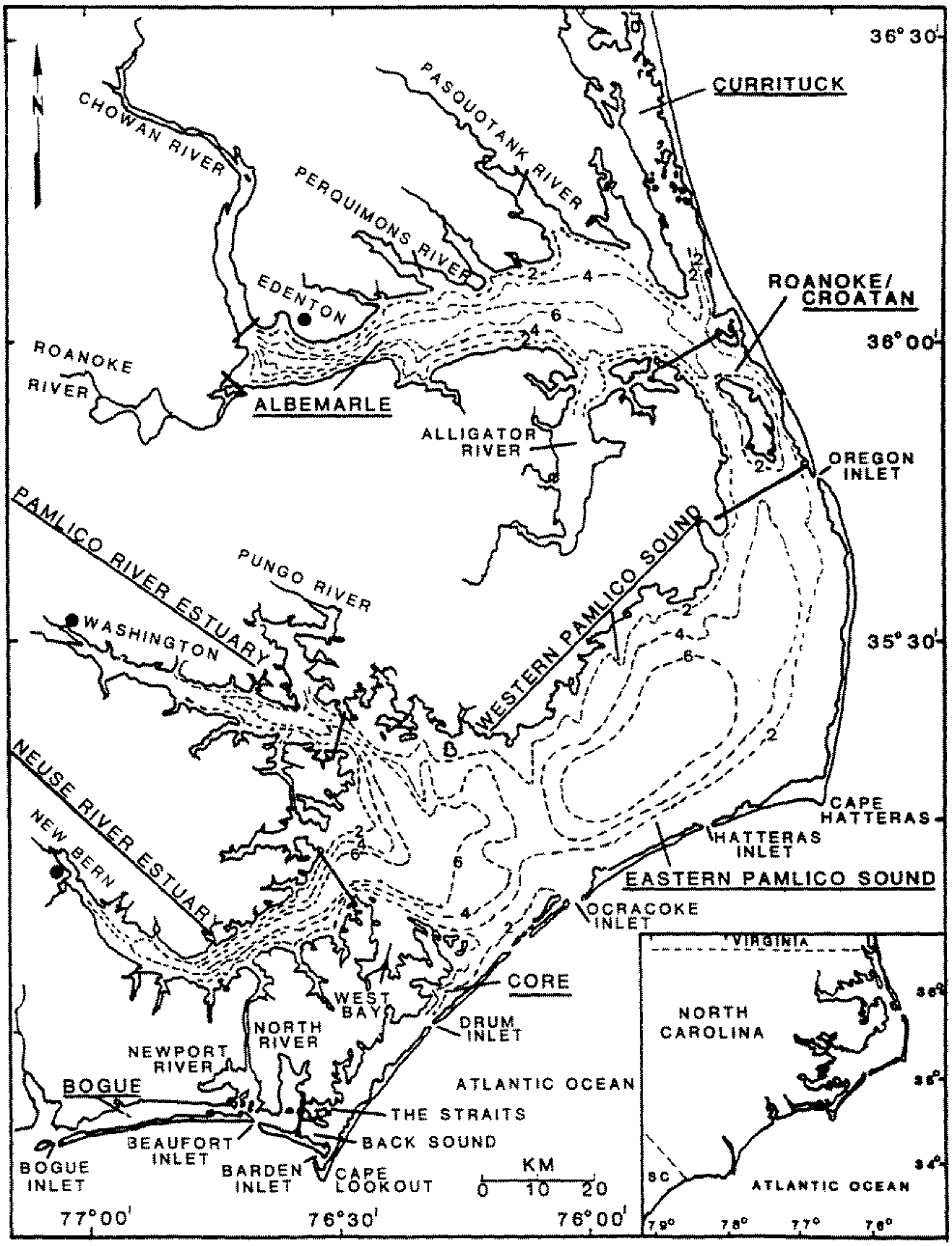


Figure 1. The Albemarle-Pamlico Estuarine System with the nine geomorphic subregions. Bathymetry, depth in meters, is modified from Wells (1989)

and the broadened regions of all rivers north and south of the sound, *e. g.*, Alligator, Perquimons, Pasquotank etc., from Edenton on the west through Kitty Hawk Bay on the east; **Roanoke/Croatan** including Roanoke Sound and Croatan Sound from Albemarle Sound on the north to Oregon Inlet on the south; **Pamlico River estuary** from Washington to Pamlico Sound including the widened section of the Pungo River; **Neuse River estuary** from New Bern to Pamlico Sound; **western Pamlico Sound** from Croatan Sound on the north, along the mainland shore, past the Pamlico River, and to the mouth of the Neuse River; **eastern Pamlico Sound** from Roanoke Sound on the North along the inland side of the Outer Banks to the mouth of the Neuse River and including West Bay; **Core** which is Core Sound from Pamlico Sound on the north to Cape Lookout on the south including The Straits and Back Sound on the north and south side of Harkers Island, respectively; and **Bogue** which includes Bogue Sound, Newport River and North River and extends from Bogue Inlet on the West to Back Sound on the east.

Low salinity and **high salinity** aquatic beds (Klemas *et al.*, 1993) have different species of SRV and occur in different subregions of the Albemarle-Pamlico Estuarine System. **Low salinity** or **high salinity** is less resolved but compatible with the salinity classification of Cowardin *et al.* (1979). **Low salinity** includes fresh (<0.5‰) and oligohaline water (≥0.5 - <5‰). **High salinity**, includes mesohaline (≥5.0 - 18‰), polyhaline (>18 - 30‰), and euhaline (>30 - 40‰) water. Salinity varies seasonally in the study area (Fig: 2a, b).

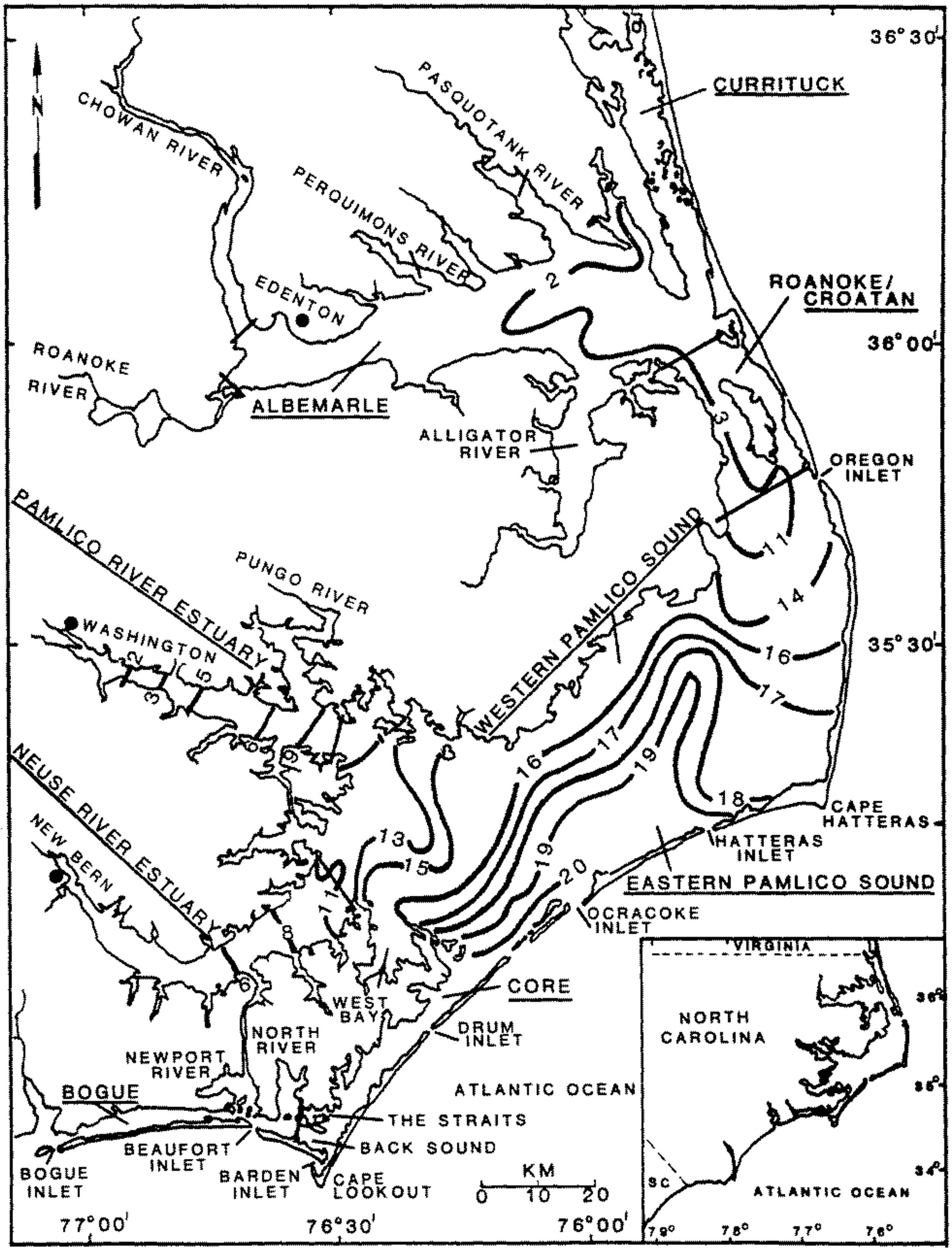


Figure 2a. Average surface salinity (parts per thousand) of Albemarle and Pamlico Sound area waters (from Giese et al. 1979) during the month of April - lowest salinity.

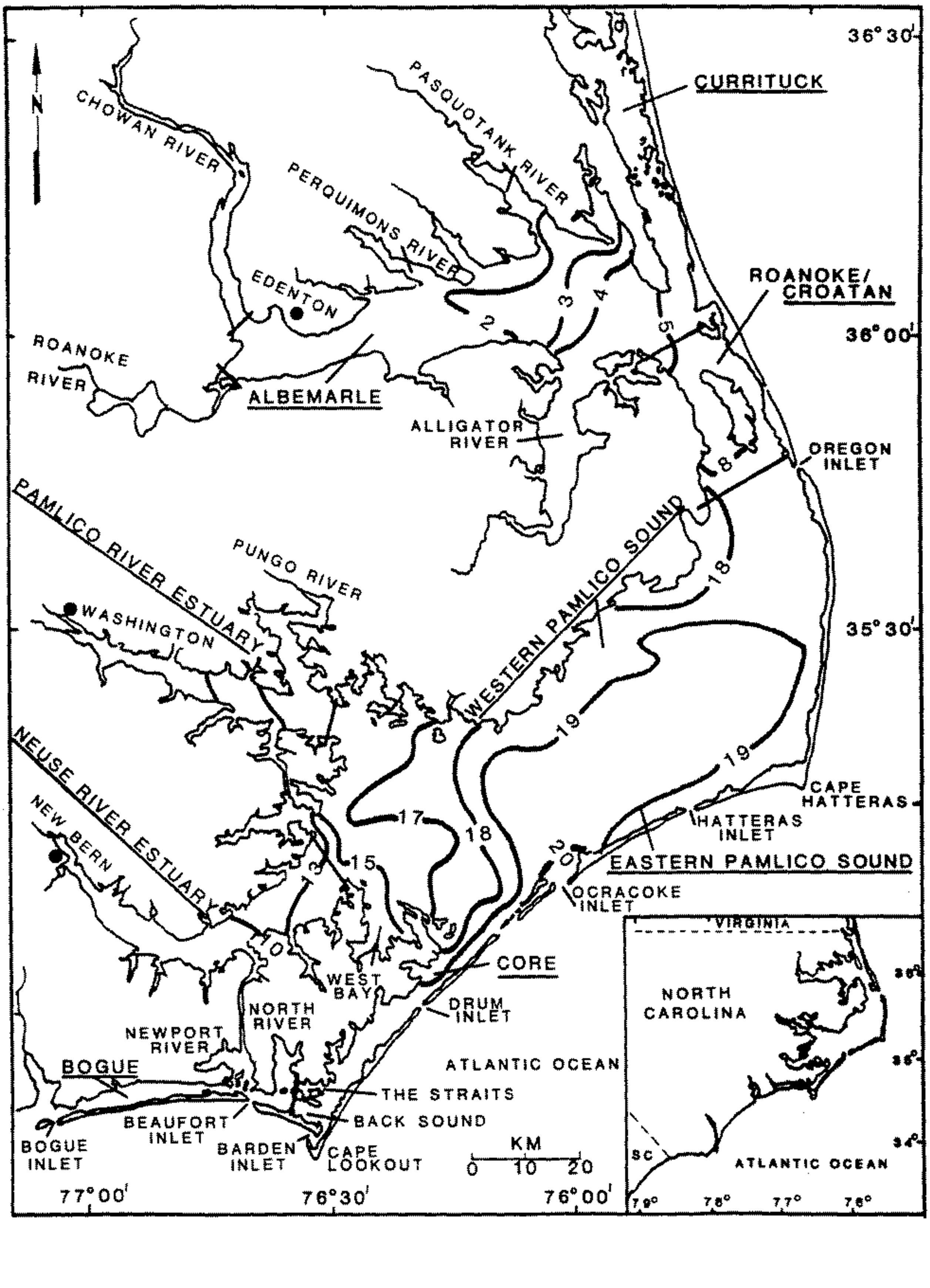


Figure 2b. Average surface salinity (parts per thousand) of Albemarle and Pamlico Sound area waters (from Giese et al. 1979) during the month of December - highest salinity.

The **Albemarle** and **Currituck** Subregions are exclusively **low salinity**. **Low salinity** water also occurs in the northern part of the **Roanoke/Croatan** Subregion and in the upper reaches of the **Neuse River estuary** and **Pamlico River estuary** Subregions. **High salinity** occurs in the lower parts of the **Neuse River estuary** and **Pamlico River estuary** Subregions, and in the southern section of the **Roanoke/Croatan** Subregion. The **western Pamlico Sound**, **eastern Pamlico Sound**, **Core**, and **Bogue** Subregions are exclusively **high salinity**. Highest salinities are associated with locations that have limited fresh water inputs (e.g., the **Bogue** and **Core** Subregions) or that exchange water with the Atlantic Ocean through Bogue Inlet, Beaufort Inlet, Barden Inlet, Drum Inlet, Ocracoke Inlet, Hatteras Inlet, or Oregon Inlet (*i.e.* the **Bogue**, **Core** and **eastern Pamlico Sound** Subregions). SRV do not occur on the oceanic side of the barrier islands in North Carolina.

The Problem

It has long been suspected that a crucial factor in the reported decline of fisheries in coastal regions is decreasing quantity and quality of habitat (*e.g.* Fonseca *et al.*, 1992; Dobson *et al.*, In Press). For many marine fishery species, SRV are nurseries or feeding areas and are of great importance. Change in the location and extent of SRV will directly affect these species. Change in SRV also may be an integrative index of pollution, sedimentation, and other factors that determine habitat quality and abundance. Urban development and farming, for example, disturbs soil and can increase erosion, surface runoff, turbidity and sedimentation. Both activities can release excess water, soil, fertilizer, and pesticides into estuarine water. Hence, changes in land cover and land use are linked to changes in salinity and clarity of estuarine waters which impact the quantity and quality of SRV.

SRV, habitat critical to many commercially and recreationally exploited fish and shellfish, are being destroyed by erosion, dredge and fill operations, impoundments, toxic pollutants, eutrophication, and excessive turbidity and sedimentation (Ferguson *et al.*, 1980). Since SRV loss can exceed natural rates of recovery, habitat losses and decline of fisheries can occur, as, for example, happened in Chesapeake Bay (Orth and Moore, 1983). Loss of SRV could contribute to and be associated with a collapse of estuarine dependent fisheries in North Carolina. Documentation of the loss or gain in aquatic beds is needed now to effectively manage marine fisheries (Thomas and Ferguson, 1990; Thomas *et al.*, 1991) and to monitor environmental quality of coastal waters (Dennison *et al.* 1993). The location and extent of seagrasses and species of SRV that are tolerant of lower salinity waters may be a crucial indicator of water quality and overall health of coastal ecosystems (Dennison *et al.*, 1993). **Change (increase or decrease in areal extent, movement, consolidation, fragmentation, or qualitative change) in SRV may be a sensitive indicator of change in water quality and potential for precipitous change in fisheries productivity.** Changes in SRV can be rapid and pervasive. Hence, effective management requires monitoring at least twice per decade (Dobson *et al.*, In Press).

The Approach

The method of choice for comprehensive inventory and monitoring of SRV in the Albemarle-Pamlico estuarine system is aerial photography supported with field surveys (Ferguson and Wood, 1990; Orth *et al.*, 1990; Ferguson *et al.*, 1992, 1993a). Previous studies on the distribution and abundance of SRV in the Currituck Sound and in the western Albemarle-Pamlico estuarine system were reviewed and supplemented by Davis and Brinson (1989). These studies were spot checks and transect surveys or transplant experiments, and provide spatially and quantitatively limited historical perspective. Published observations date back to the 1970's for Pamlico River (see Davis and Brinson, 1976) and sporadic observations date back to the early 1900's for Currituck Sound (see Davis and Brinson, 1983).

Accurate and current planimetric base maps of coastal land features, at a minimum scale of 1:24,000, are essential for georeferencing (establishment of geographic location) and scaling polygons of SRV interpreted from aerial photographs. It is important to use the most accurate and current base map available for the study area. The accuracy of the base map used for local horizontal control places a limit on the accuracy of the inventory data.

Two base maps broadly available are NOAA, National Ocean Service (NOS) shoreline maps and USGS 7.5' topographic maps. When available and current, NOAA shoreline and coastal data should be used. NOAA data depict the delineation of the mean high water line, the limit of emergent vegetation (apparent shoreline) and/or cultural shoreline, and in some areas, e.g., North Carolina, the approximate mean lower low water (MLLW) line. NOAA/NOS shorelines are a data source both for NOAA nautical charts and USGS topographic maps. NOAA shoreline data are not currently available for the entire Albemarle-Pamlico Estuarine System. The area was photographed in 1988 through 1991, as a result of this study, and the shoreline data are being generated by NOAA/NOS.

For the present study, USGS 7.5′ topographic maps were the only base maps available for the Albemarle-Pamlico Estuarine System at a scale of 1:24,000. These maps delineate the high tide line and cultural features. For the study area, however, these maps are out of date and temporal changes in shorelines cause problems in the application of local horizontal control to compile the habitat polygons (Ferguson and Wood, 1990). This reduces the positional and scaling accuracy of habitat data. Updates of the 7.5′ topographic maps include cultural changes but not natural changes in shoreline. Coverage of the study area is comprehensive, except for the majority of Currituck Sound, but the available maps generally depict shorelines from photographs taken in the 1940′s. In some coastal areas, 1:24,000 scale orthophotoquads have been published as an alternative to the topographic maps. Orthophotoquads at a scale of 1:24,000 are unsatisfactory for compilation from aerial photographs in remote areas because these orthophotoquads do not have delineated shorelines which may be needed when the preferred cultural features are insufficient for the purpose of registration of the photograph to the map base.

Funding History

Aerial photography of SRV was initiated by the NOAA/NMFS Beaufort Laboratory and contracted to NOS, Photogrammetry Branch, for Bogue Sound and southern Core Sound in that 1985. Funding was obtained through the Albemarle-Pamlico Program, NEP, in 1988, to photograph Core Sound and eastern Pamlico Sound from Cape Lookout to Oregon Inlet and to generate an inventory of SRV in southern Core Sound from the 1985 photography (Ferguson *et al.*, 1989a, 1989b). Funding from NOAA, Coastal Ocean Program was obtained to continue interpretation and mapping of the 1988 photography and to develop methods for detection of change and accuracy assessment in SRV. Subsequent funding to photograph and inventory the remainder of the Albemarle-Pamlico Estuarine System was obtained in 1990 and 1991 through the Albemarle-Pamlico Estuarine Program Office.

PURPOSE AND OBJECTIVES

This study delineates and quantifies the location and extent of SRV in the Albemarle-Pamlico Estuarine system based on conventional color aerial photography. Sampling in the field was performed to assure accurate interpretation of the photographs and to provide subregional and ecological information on the distribution of species of SRV. The specific objectives were to:

1) Acquire aerial photography at a scale of 1:20,000 for the **Neuse River estuary**, **Pamlico River estuary** and for **Albemarle**, **Currituck**, **Roanoke/Croatan** and **western Pamlico Sound** Subregions of the Albemarle-Pamlico Estuarine System.

2) Interpret the photographs after visiting the locations of questionable signatures for SRV and register the interpreted data on overlays of stable base 7.5' USGS topographic maps.

3) Submit the spatial SRV data to NC-CGIA for digitization and mensuration.

4) Conduct SRV field sampling to verify photographic signatures and to provide subregional and ecological information on the distribution of species of SRV in the study area.

5) Be responsive to state and federal habitat managers requesting information and data pertinent to decisions on water use management and conservation of living resources including SRV.

All of these objectives have been met. The single exception is for the **Currituck** subregion where USGS 7.5' topographic maps have not been published. Registration of the spatial photographic data to the external georeference system began in April 1994 with delivery of NOAA/NOS shoreline data. At the request of the Albemarle-Pamlico Program Office, field data for **Bogue**, spatial data for **eastern Pamlico Sound** and SRV change data for **Core** (1985 to 1988), funded by NOAA, C-CAP, are included in this report.

PRODUCTS

- This narrative report
- Aerial photographic imagery at a scale of 1:20,000 or 1:24,000 covering the Albemarle Pamlico study area
- Supplemental aerial photographic imagery which extends coverage or is a basis for change detection in SRV
- Three published charts of SRV from Cape Lookout to Ocracoke Inlet available from the Beaufort Laboratory
- Digitized spatial SRV data of the study area resident in the North Carolina Corporate Geographic Database (CGDB).
- Published articles: Dobson *et al.*, In Press; Ferguson and Wood, 1990; Ferguson, Pawlak and Wood, 1993; Ferguson, Wood and Graham, 1992 and 1993; Orth, Ferguson and Haddad, 1991; Klemas *et al.*, 1993

PROCEDURES

Aerial photography of SRV at a scale of 1:20,000 was subcontracted to NOAA/NOS, Photogrammetry Branch, in 1990 and 1991. The subcontract, including reflights, was completed in 1992. This photography and photography acquired outside of the current contract, but also designed for delineation of SRV (1985 and 1992 of Bogue and Core Sounds, and 1988 of Core and eastern Pamlico Sounds) are described in Table 2.

All methods and procedures were intended to be as consistent as possible with C-CAP; the methods for C-CAP were developed and improved by this work (Ferguson and Wood, 1990; Ferguson *et al.*, 1993). The text below is from the SRV section of the C-CAP Guidance for Regional Implementation (Dobson *et al.*, In Press) and included here for the convenience of the reader.

Film

The preferred film recommended by C-CAP is Aerocolor 2445 color negative film. A haze filter is used to minimize the degrading effect of haze on photographic images. The 1985 photography was conducted with Aerocolor 2448 color positive film and the 1988 photography was conducted with both Aerochrome 2448 color positive film and Aerochrome 2443 color infrared film (Ferguson *et al.*, 1989a). All subsequent photography was obtained with Aerocolor 2445 color negative film. In our experience in North Carolina with tandem cameras, Aerochrome 2443 infrared

Table 2. NOAA, National Ocean Service, Photogrammetry Branch and National Marine Fisheries Service, Beaufort Laboratory photographic archives of SRV habitat in the Albemarle-Pamlico study area.

SUBREGION YEAR	SCALE	NEGATIVES[1] TRUE COLOR	NEGATIVES[1] FALSE COLOR IR	PRINTS[1] TRUE COLOR TRANS-PARENCY	PRINTS[1] TRUE COLOR PAPER	PRINTS[1] FALSE COLOR IR TRANS-PARENCY	PRINTS[1] FALSE COLOR IR PAPER
Albemarle							
1990	1:20,000	326		155			
1991	1:20,000	41		12			
1992	1:12,000	48		45			
Currituck							
1990	1:20,000	397		156			
Pamlico River estuary							
1991	1:20,000	234		112			
1992	1:20,000	38		21			
1992	1:12,000	24		19			
Neuse River estuary							
1991	1:20,000	84		42			
Roanoke/Croatan							
1990	1:20,000	96		96	29		
	1:50,000	11		11			
eastern Pamlico Sound							
1988	1:24,000	288	218	108	107		76
	1:50,000	70		23	23		
1990	1:20,000	12		12			
	1:50,000	11		11			
western Pamlico Sound							
1991	1:20,000	17		12			
1992	1:20,000	39		17			
Core							
1985	1:12,000	31	41	29		30	
	1:20,000	41	40	40		39	
1988	1:24,000	96	68	51	51	26	8
	1:50,000	73	56	21	21	17	5
1992	1:20,000	130		111			
Bogue							
1985	1:12,000	160	133	79		97	
1992	1:20,000	81		57			

[1] NOS archives the negatives, Beaufort Laboratory archives the prints.

film, was much less effective than true color film at recording benthic features in shallow, moderately turbid water. True color film gives more information than black and white or infrared film, which is critical for initial mapping attempts in unfamiliar areas. Color negative film also appears to be better than color positive or black and white film for identification of habitat under moderately turbid or hazy conditions (Ferguson *et al*. 1993). Color transparencies are dimensionally stable and are more amenable than paper prints to illumination of dark areas of the photograph for viewing and interpreting under magnification. Paper prints are not as dimensionally stable as transparencies (*i.e.*, are subject to stretching and shrinking) but are more resistant than transparencies to damage from handling.

Metric Photography and Photographic Scale

Metric quality aerial photographs (≤3° of tilt off-nadir) are acquired with the protocol employed by NOAA/NOS, Photogrammetry Branch (1980) to produce the highest quality photographic data possible. The need for rectification of photography is minimized by control of aircraft altitude and orientation relative to the vertical during photography and the low relief of coastal land in eastern North Carolina. Photography is acquired at a scale, in this case 1:20,000, most appropriate to the areal extent of habitat, local water conditions, type of habitat being studied and resolution requirements. Photographic scale is a compromise among resolution of signatures, coverage of habitat, inclusion of land features sufficient for horizontal control, and cost. For extensive areas of high and variable turbidity such as eastern North Carolina, 1:24,000 or 1:20,000 scale photographs is adequate when the turbidity is low.

Flightlines, Reconnaissance Flights, and Photographic Overlap

Flightlines are planned with reference to aeronautical and nautical charts to include all areas known to have or which potentially could have SRV. Reconnaissance flights provide valuable perspective on SRV distribution if timed to optimize visualization of shallow bottoms. The efficiency of photographic missions can be optimized by minimizing the number of flightlines and by contingency planning. Some airspace is restricted for military or other use, for example, and is indicated on aeronautical charts. Nautical Charts provide bathymetric data useful for designating potential habitat areas when combined with local knowledge of the depth of vegetated bottoms. Unfortunately, in remote waters such as eastern North Carolina, bathymetric data are not updated with regularity. Most of the bathymetric soundings for the Albemarle-Pamlico estuarine system were collected in the late 1800's (NOAA/NOS unpublished index of bathymetric data).

Ideally, each aerial photograph records cultural and shoreline features required to register the image to the base map, about 1/3 of the exposure. This permits correction of photographic scale and orientation to the external reference system. At a scale of 1:24,000 (1" = 2,000'), a standard 9 x 9" aerial photograph has a coverage of 18,000′ by 18,000′. Large areas (relative to coverage of a single photograph) of open water require parallel flightlines and bridging of the large scale photography to control points with smaller scale photography (*e.g.* 1:48,000), construction of towers, *etc.*, to supplement horizontal control features, or kinematic GPS positioning of photographic centers.

Overlap of photographs includes endlap of adjacent photographs along a flightpath and sidelap of photographs along parallel flightpaths. Sixty percent endlap allows stereoscopic interpretation; facilitates monoscopic interpretation from the most central region of the photographs; and compensates for loss of coverage due to sun glint in the photographs. Sun glint is the image of the sun reflected off the surface of the water. Sidelap of 30% ensures contiguous coverage of parallel flightlines and produces a block of aerial photographs which may be subjected to photogrammetric bundle adjustment for rectification and geopositioning if necessary.

Environmental Considerations

Knowledge of the study area that is important to a successful project includes: species of SRV, morphology and phenology of these plants, depth range and location of known habitat; locations with water depth potentially suitable for habitat, types and locations of benthic features that may confuse photointerpretation of SRV, seasonality of turbidity, weather, and haze; daily patterns in wind speed and direction, and progression of sun angle through the day.

Primary and secondary seasonal windows and the day and time of conducting photography are selected to optimize the visibility of aquatic beds in the photography. Surface waters in different locations and at different times of the year will be more or less sensitive to turbidity from local runoff, plankton blooms and local resuspension of sediment, and surface waves. Seasonal and daily trends for haze, cloud cover and wind direction, duration and velocity, should be included in planning for photography. The decisions of when to have the aircraft arrive at the study area (within the seasonal window), and when to collect photography are based on NOAA/NOS tide tables, local knowledge of factors affecting water clarity and depth, observation of recent weather patterns (precipitation and wind direction and speed), and water clarity. The final decision to fly and photograph includes advice from the field observer and observations from the air.

Primary and secondary photographic windows should be one or two months in duration to assure the occurrence of optimal conditions for photography. In North Carolina, staging of the plane and flight crews to the study area several times for periods of several days was required to complete missions involving more than one day of actual photography. For single day missions it may be possible to conduct the mission from the plane's home base.

Phenology

The best time of year to acquire photography is during the season of maximum biomass or flowering of dominant species, considering the phenologic overlap for the entire community. This is April and May, for eelgrass and shoal grass in eastern North Carolina, and September for widgeon grass and most of the **low salinity** species of SRV.

Clouds and Haze

It is best to have no clouds and minimal haze. Thin broken clouds or thin overcast above the plane may be acceptable when these are determined by visualization from the air neither to cast shadows nor adversely affect illumination of the study area. Haze reduces illumination and clarity of the image of benthic features being recorded in the photograph. Planning includes reference to the *Aerial Photographers Clear Day Map,* U.S. Department of Commerce, Environmental Data Service.

Turbidity

Aerial photography is conducted when turbidity is low. Care should be exercised in areas adjacent to sources of suspended sediment and nutrients. Photography is avoided during seasonal phytoplankton blooms or immediately following heavy rains or persistent strong winds. Potential days for photography are those during the photographic window for which high water clarity is expected, based on local experience, recent weather patterns, and surface level observation.

Tides

Aerial photography is conducted within ±2 hours of the lowest tide as predicted by the NOAA/NOS tide tables although factors affecting water depth and water clarity are considered simultaneously. In general, extreme low tide, which may be -0.5 to -1.0m is preferred, if compatible with other constraints.

Wind and Surface Waves

No wind and waves is best. Low wind (< 10 mph) may be acceptable. The direction, persistence and fetch (the distance that wind can blow unobstructed over water) and recent wind events should be taken into account. Waves breaking over shallows and associated turbidity, white caps in open water, lines of bubbles, and/or floating debris should not be visible from the air or in the photographs.

Sun Angle

Sun angle affects the illumination of benthic features, sun glint (the reflection of the image of the sun off the surface of water) and shadows from tall shoreline features in the photographs. A sun angle of 20-25° is optimal to record benthic features (Keller, 1978). A sun angle of 15 to 30° is recommended by C-CAP and maximizes the potential duration of daily photography considering both the illumination of submerged features and sun glint. Sun angles above 15° illuminate shallow bottoms sufficiently for photographic purposes. Sun glint increases with sun angle and precludes visualization of benthic features. As sun angle increases, the glint also moves toward the center of the photograph. Loss of coverage due to sun glint at sun angles of up to about 30° is compensated (to assure monoscopic coverage, at a minimum) by the endlap of 60%. Eighty percent endlap improves coverage when high sun angles cannot be avoided. Photography at sun angles above 30° is not recommended by C-CAP. Sun glint is minimized when the sun and land are on the same side of the plane. Shadows from tall objects on shore such as trees, however, can preclude visualization of benthic features when the land and sun are on the same side of the plane.

Photointerpretation of SRV Habitat

SRV can be interpreted from metric quality aerial photographs exposed as outlined above. SRV species identification is not possible from aerial photography in North Carolina but may be possible in tropical areas (Dobson *et al.*, In Press). The accurate identification of SRV in aerial photographs requires visual evaluation of the fundamental elements of image interpretation (tone, color, contrast, texture, shadow etc.). It also requires extensive experience at ground level in the study area. The photographic images of SRV and other benthic features vary in ways which cannot readily be modeled, described or communicated. Training for photointerpretation includes: literature research, discussions with local ecologists and biologists, site visits, overflights in a small plane, and examination of historical aerial photographs of the area. Training for photointerpretation is ongoing throughout the life of the project.

SRV are observed best using stereo pairs of photographs and high quality stereoscopic instruments. We use a Wild, AVIOPRET®, APT2, stereoscope. Polygons are traced on overlays fixed to each photograph. To be delineated as SRV, recognizable and verified signatures of SRV must be present in the photographs. SRV (and other benthic features) in a given area will present a variety of signatures depending upon species present, bottom sediment, depth, season, and haze. Shadows from clouds or trees, turbid water, white caps, or sun glint may obscure SRV signatures in the photograph.

The designation of a given area as SRV is a function of minimum detection unit, minimum mapping unit, and its proximity to other SRV. Assuming a photographic scale of 1:24,000, high quality optics, high resolution film and ideal conditions (*e.g.*, dense clusters of large vigorous shoots growing on light-colored sediment in shallow, clear, calm water), SRV is expected to have a minimum detection unit of approximately 1 m^2. All detected SRV signatures which appear to be in a continuum with adjacent SRV in an area which exceeds 0.03 hectare are mapped as a single polygon. **The C-CAP minimum mapping unit of 0.03 hectare is the smallest area of SRV required to be mapped as habitat.** At the map scale of 1:24,000, the minimum mapping unit of 0.03 hectare is a diameter of about 0.8 mm on the map and a diameter of about 20 m on the ground.

Therefore, isolated groups of SRV with a diameter of less than 20 may be detected but not mapped. **The presence of verified SRV signature in the photograph defines SRV habitat to be mapped if: 1) the total area of signature exceeds 0.03 hectare, 2) no discontinuities such as dredged or natural channels lacking SRV partition the distribution into spatial units less than 0.03 hectare, and 3) areas between SRV do not exceed the minimum mapping unit.** In certain cases it may be possible and desirable to map SRV which is smaller than the minimum mapping unit. In any case the minimum mapping unit for a project should be specified.

Unfortunately, not all areas of SRV which are, in fact, larger than the minimum mapping unit can be mapped. This is likely to be true when photographic conditions are less than ideal. Due to the constraint of the minimum mapping unit and the possibility of suboptimal photography, delineations of SRV habitat will tend to be conservative. The degree of underestimation depends upon the atmospheric and hydrographic conditions at the time of photography, the experience of the photointerpreter, the nature of the subject area and the quality and amount of surface level data.

Optimizing conditions for photography will minimize underestimation of SRV, particularly in areas that are intrinsically more difficult to interpret. Where habitat edges are clearly distinct in superior quality photography, they may also be detected in inferior quality photography (*e.g.* high biomass of SRV along a clear water channel with a steep bank of light-colored sediment). In other cases where the edges are not clearly distinct in superior quality photography they are likely to remain undetected in inferior photography (*e.g.* low biomass of SRV growing on a shallow depth gradient of deep, turbid water over dark-colored sediment). The deep-water edge of habitat often will be difficult to delineate. This edge may also be at high risk for loss due to degradation in water quality that limits the illumination of the bottom with photosynthetically active radiation (Kenworthy and Haunert, 1991).

Unrecognized SRV signatures due to poor photographic conditions cannot be mapped as habitat unless the area is rephotographed or additional sources of data are incorporated into the data base. When photointerpretation is difficult or not possible, the preferred option is to rephotograph the area under better conditions. Although desirable, this may not be possible. Even under the best photographic conditions, delineation of all or part of some habitat polygons may require additional effort in regard to surface level verification or direct inclusion of surface level data. Polygon borders derived from surface level data are so designated in the lineage data base for "truth in labeling". Suitable surface level positioning techniques include differentially corrected GPS or more traditional survey positioning techniques that can be demonstrated to provide positional accuracy within national map accuracy standards.

Within an SRV polygon, the extent of coverage of the bottom by shoots of SRV and the pattern of distribution of the shoots or bed form (*e.g.*, circular, doughnut-shaped, irregular patches and or continuous cover of SRV) reflects the interaction of biotic, physical, and anthropogenic factors (Fonseca and Kenworthy, 1987). In some locations disturbances such as scarring by the propellers of boats are visible in the photographs. Coverage, bed form, and scarring of SRV within habitat polygons can be visualized in aerial photographs but was not done in this study. Coverage indices and bed form identification are affected by factors such as water depth and brightness of bottom sediments. The degree of contrast between shoots and exposed sediment and clarity of the photographic image determines the minimum detection unit of features within aquatic beds. Comparison of habitats with different depths, water clarity or substrate brightness, therefore, is problematic and requires consistent photographic conditions and field verification.

Field Surveys

Stations are visited to become familiar with the study area, determine the regional occurrence of species of SRV and collect ancillary data. Ancillary data recorded are: time of day, salinity (temperature compensated refractometer), water clarity (Secchi disc), water depth, latitude and longitude, and descriptions of benthic sediment, algae, animals or animal shells, rocks, *etc.* Stations may be selected by randomly placing a rectangular matrix of dots over a nautical chart. The density of dots is controlled to provide the desired number of stations according to the resources and scale of the project. A range of 1.5 to 2.5 nautical miles from station to station was used in the present study. Great care is taken to allow all locations which could potentially have SRV an equal chance to be sampled in the surface level survey. SRV are limited to water depths less than about 6ft MLLW for Chesapeake Bay. A similar depth limit was assumed for eastern North Carolina. To confirm that depth in North Carolina, potential habitat areas are sampled to water depths of 10 feet MLLW as depicted on NOAA nautical charts (Ferguson and Wood, 1990). Stations with a water depth of ≥2.0m required SCUBA, and due to time and resource costs were sampled less frequently than shallower water depths in this study. Bathymetry and reference coordinates in NOAA nautical charts of the study area facilitate selection and positioning of stations. Navigation to stations was with LORAN C. LORAN C was calibrated daily to latitude and longitude by reference to navigational aids in the study area and both time delays and latitude and longitude were recorded at the stations. This technology has limited accuracy, ≥100 m to an external georeference system. Toward the end of the project, and **after completing all of the surveys reported here, LORAN C was replaced with a Global Positioning System (GPS).** A single GPS position fix is taken to be differentially corrected (post-processing) to a circular error probable (CEP) of <5m.

Subregions of the study area were sampled as follows: **Albemarle** (Aug. and Sept., 1990), **Currituck** (Sept. 1990),

Roanoke/Croatan (March, 1988 and Aug., 1990), **Pamlico River estuary** (Sept. 1991), **Neuse River estuary** (Sept. and Oct., 1991), **western Pamlico Sound** (Sept. and Oct., 1991), **eastern Pamlico Sound**, (March, 1988), **Core** (March and April, 1988 and May, 1989), and **Bogue** (April and May, 1989) (Fig. 3).

Upon arrival on station coordinates, the water depth was determined; if water depth was not too deep for sampling (*i.e.*, the station was not a designated SCUBA station and the depth did not exceed 2m, or the depth of a designated SCUBA station did not exceed 4m), the area was examined for SRV. If SRV was not present an area with a depth suitable for sampling with a radius of up to 0.2 nautical miles was searched for SRV, visually or by raking from the boat. With narrow areas of suitable depth, *e.g.* along a shore, the area searched paralleled the shoreline. If SRV was present the station position and SRV and ancillary observations were completed and recorded. If no SRV could be located, this along with ancillary observations and location were recorded. If the water was too deep for sampling, the nearest shore, if not too distant, was approached to discover a location with a depth suitable for sampling. If this action was successful observations were conducted at the alternative location, if not, the station was abandoned. If the station could not be reached by water the station was approached by land or abandoned.

Frequency of occurrence for SRV was determined for each subregion of the study area. Confidence intervals (95%) for the

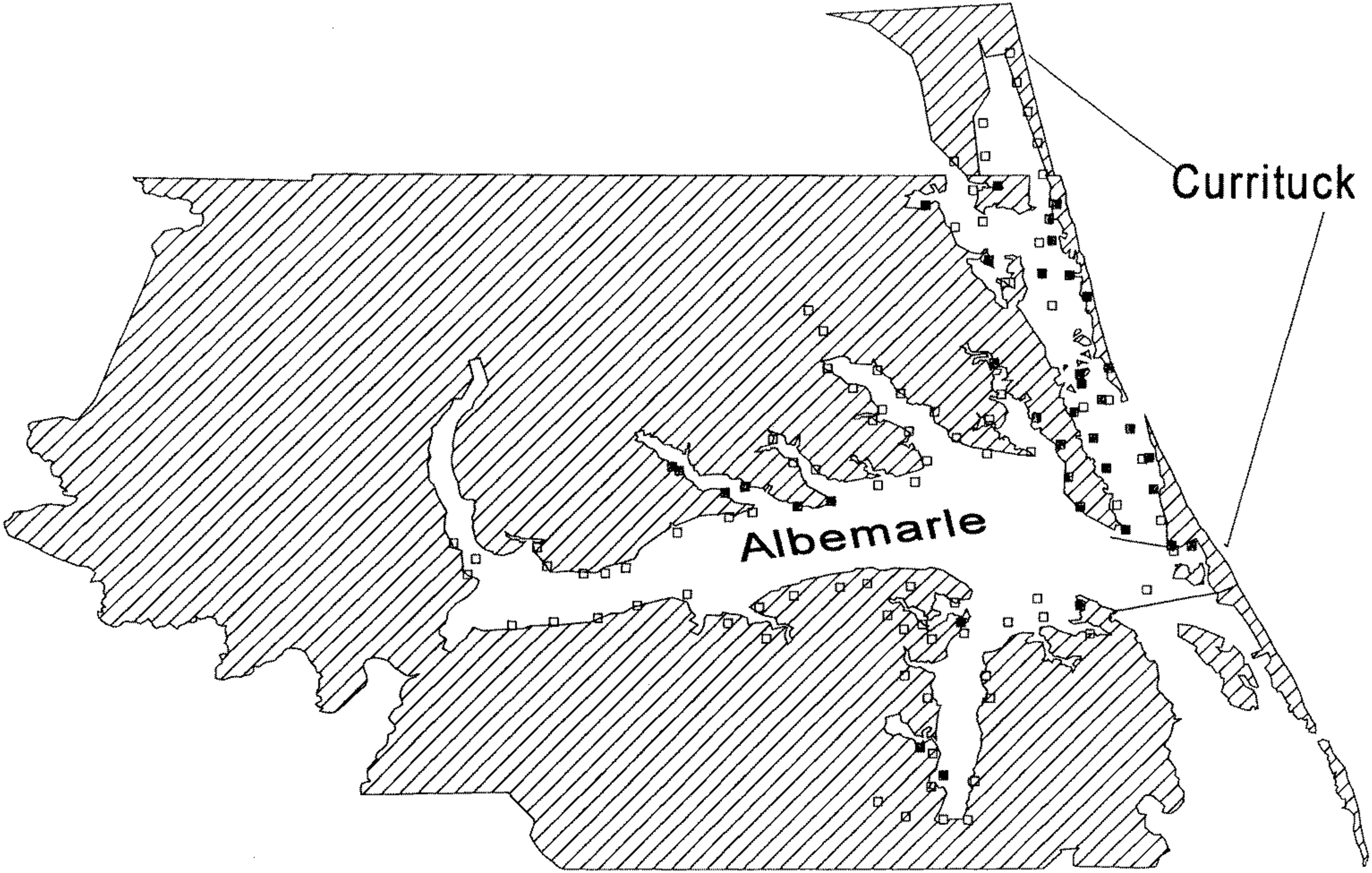


Figure 3A. Approximate location of stations sampled in the systematic grid survey, northern subregions. Appearance of some stations over land is due to their being within an unmapped bay or waterway or due to inaccurary in the LORAN C data. Symbols represent presence (closed) or absence (open) of SRV.

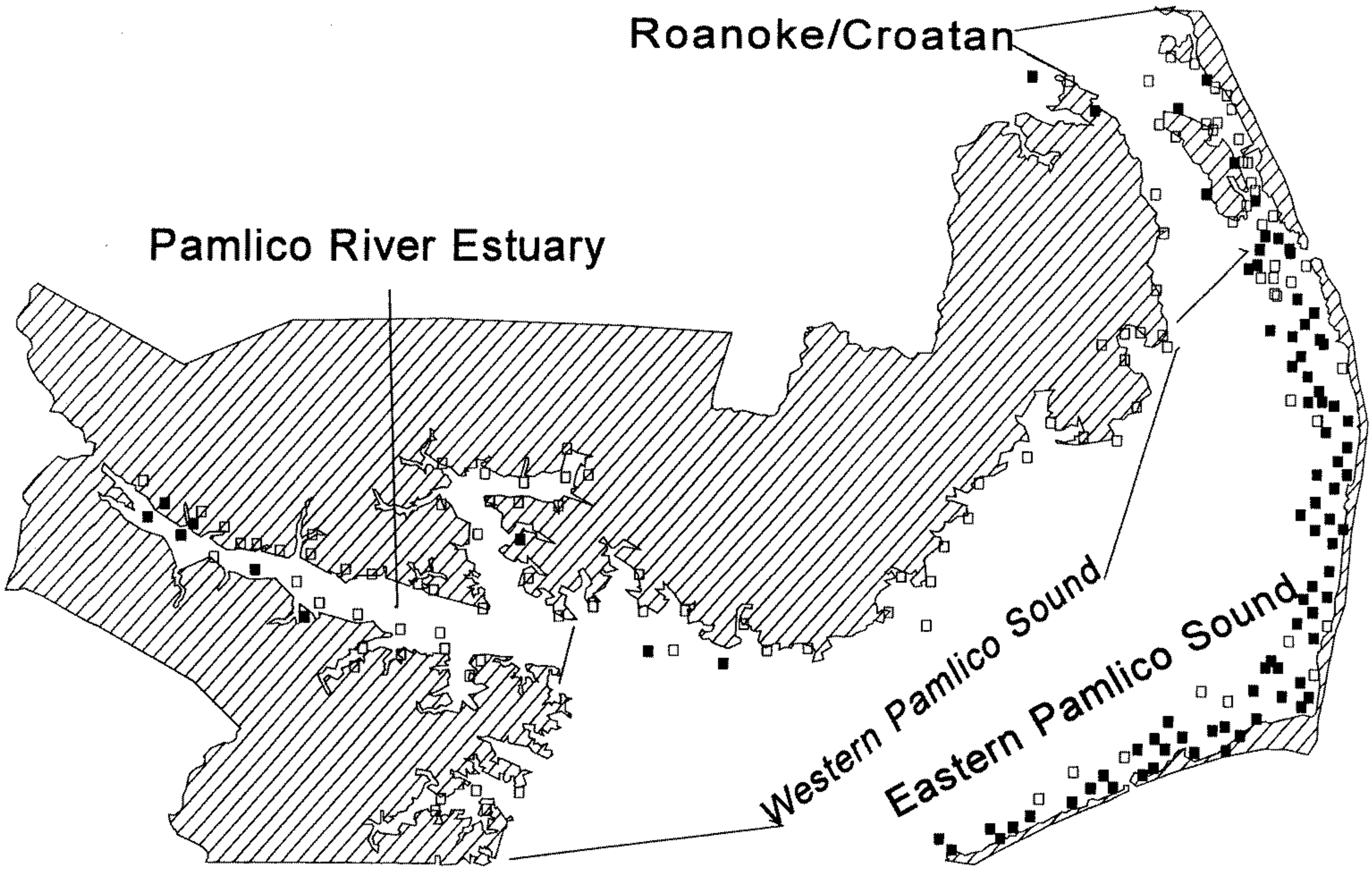


Figure 3B. Approximate location of stations sampled in the systematic grid survey, central subregions. Appearance of some stations over land is due to their being within an unmapped bay or waterway or due to inaccuracy in the LORAN C data. Symbols represent presence (closed) or absence (open) of SRV.

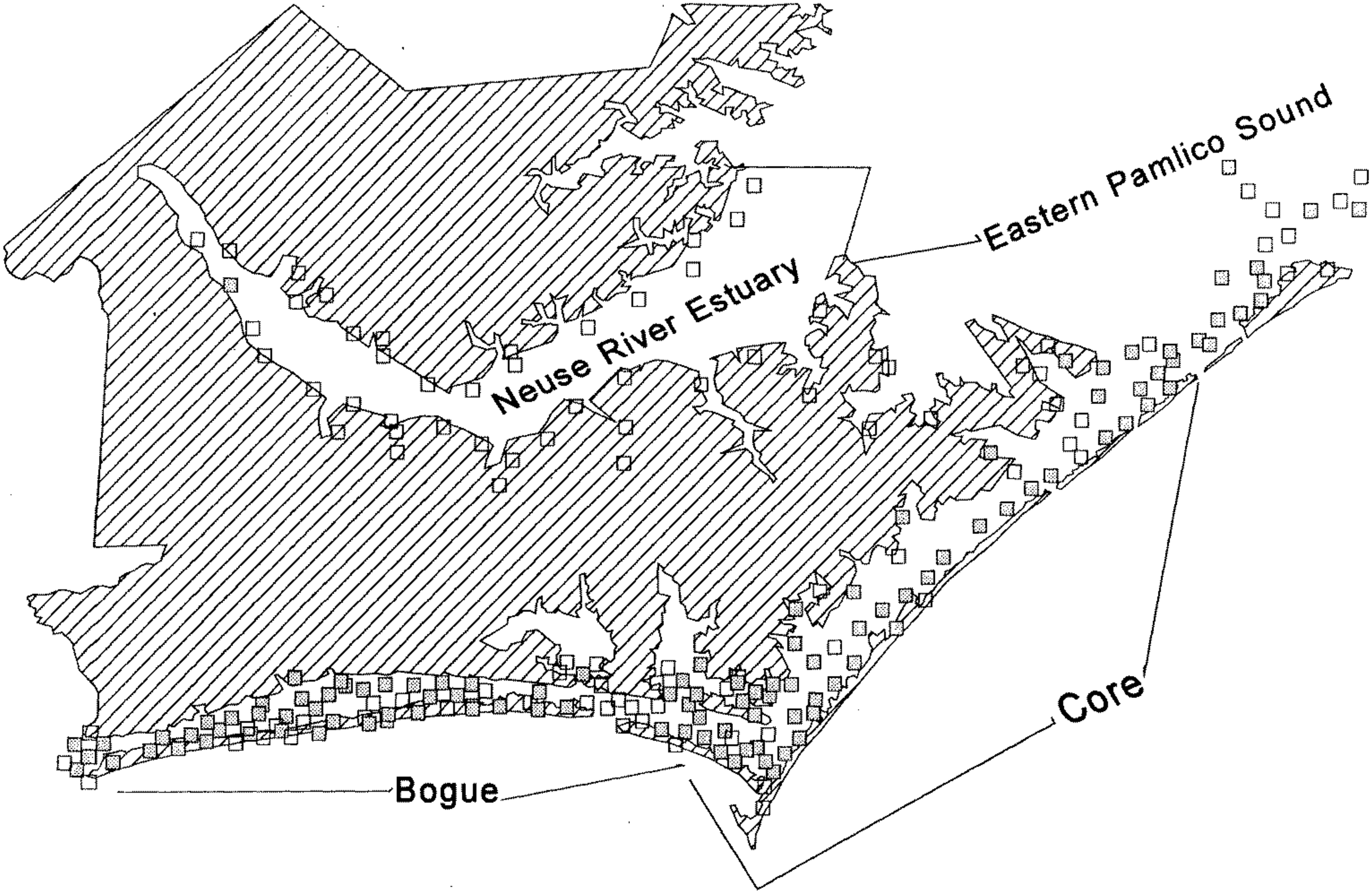


Figure 3C. Approximate location of stations sampled in the systematic grid survey, southern subregions. Appearance of some stations over land is due to their being within an unmapped bay or waterway or due to inaccuracy in the LORAN C data. Symbols represent presence (closed) or absence (open) of SRV.

frequency data were calculated for the binomial data according to formulations and tables in Rohlf and Sokal (1981).

Signature Verification and Supplemental Spatial Data

Locations selected from the photographs are observed within one year of the photographic mission. The purpose of this survey was to resolve uncertainties in the photographs and, if necessary, collect surface level data for inclusion in the spatial data base. Surface level data intended to augment photointerpreted data require differentially corrected GPS positioning (Circular Error Probable, CEP, <5m) or by positioning with equipment of similar accuracy. **No spatial data referenced with surface level positioning to an external georeference system is included in this study.** In cases where imagery was sufficient to detect but not to delineate the verified SRV signature, points were included in the spatial data. The point data types are flagged and qualified in the data attribute files.

Base Maps and Registration of Habitat Polygons

USGS 7.5′ topographic maps are the base maps for this study. This limits the positional and scaling accuracy of aquatic bed data especially in areas where cultural features, preferred for registration of the photographs, are rare or absent.

Transfer of Polygons to the Map Coordinate Projection System

Polygons of aquatic beds interpreted from aerial photographs are mapped into the standard map projection coordinate system of the base map. The approach employed is to optically scale the polygons and photographic image with a zoom transfer scope to fit planimetric horizontal control in the base map. This is a well established and reliable method when stable base media (mylar, not paper overlays and maps) are used throughout the process. Habitat delineations drawn at the photographic scale through stereo or monoscopic viewing under magnification are transferred using camera lucida principles from the photographic overlay directly onto an overlay of the planimetric base map generated by NC-CGIA. The overlay, unique to each 7.5′ map base includes label, neat lines and internal tick marks to assure proper registration of the interpreted polygons to the coordinate system.

Digitization of Habitat Polygons

Habitat polygons, after transfer to the planimetric base map, were digitized by NC-CGIA, approved by Beaufort Laboratory and incorporated into the North Carolina Corporate Geographic Data Base. Digitization was accomplished using a digitizing tablet in point mode using standard procedures. Compilations were checked for clear delineation and cartographic acceptability of line work, existence of and consistency in feature attributes, and adequacy of horizontal control points. Compilations were checked along neat lines to confirm edge line match and label match for polygons extending over adjoining maps. Any inconsistencies were resolved by the author of the map.

Compilations were affixed to a digitizing table for georeferencing and data entry. The accuracy of the reference points, the four corners of the neat line and no less than four internal tick marks on the overlays, were checked to assure that control points are within ±0.02". This translates to ±40 feet or ±12.2 m from its stated location. If tolerance was exceeded on any one point, new control points are selected, digitized and re-evaluated until all points tested within tolerance. Information regarding the georeferencing error for each control point was recorded on a documentation form. In addition the technician recorded other information about the overlay manuscript such as scale, size, media type, source map information, and author.

Polygons are digitized with the cartographic style and accuracy that is represented on the source manuscript. A technician performs digitizing and data processing to map completion, including edge line matching, initial check plots, review, edits, and final check plots. All line work and labeling are reviewed using check plots produced at the source map scale. Each arc is checked for acceptance on a light table with the source map and the final check plot overlaid on the source map. Digitized line work should conceal original line work with exceptions for difference in line thickness, differences in media, and in subtle differences of horizontal control on the source map and in digital files. Unacceptable data is flagged, edited, and reviewed prior to acceptance into the digital database. A data layer specification form is completed for formal documentation at the conclusion of all digitizing.

RESULTS AND DISCUSSION

Field Sampling

Overview. Five hundred fifty-four stations were visited and observed for SRV, salinity, Secchi depth, and water depth between March, 1988, and October, 1991 (Fig. 3, Table 3). Two hundred forty-one stations, or 43.5% contained at least one species of SRV. The subregions varied in terms of the species and frequency of occurrence of SRV, salinity, and Secchi depth but not water depth. Water depth for the stations in the different subregions was similar with a mean of 0.9 to 1.1m except for the **Core** and **Bogue** Subregions where water depth averaged 0.7m. The field data are a geographically extensive data set collected over a period of 3½ years without replication. Subregional sampling was during season, period of weather, and tide stage favorable for sampling SRV. Sampling was tide coordinated to the extent that certain stations could not be approached at low tide and others could not be effectively sampled without SCUBA at high tide. As a result the majority of stations in subregions with substantial lunar tides, *e.g.*, up to about 1m in **Core** and **Bogue**, were sampled during mid to low tide. Sampling was conducted predominantly in spring (**high salinity** subregions) and early fall (**low salinity** subregions) to assure that above ground structures and optimize the chance for observing flowers of SRV. Due to variable rainfall and evapotranspiration, the seasonal sampling would tend to favor somewhat higher than average salinities for the

Table 3. The number of stations visited, the number of stations having SRV of any species and of a particular species, and the number of observations, the data intervals and the means for salinity, Secchi depth and depth of the water, grouped by subregion, in the Albemarle-Pamlico estuarine system in 1988 through 1991.

SUBREGION	STATIONS[1]				SALINITY[2]				Secchi DEPTH[2]				WATER DEPTH[2]			
(YEAR)	TOTAL	WITH SRV	WITH SPEC: SPEC CODE	WITH SPEC: N	N	MIN	MAX	AVE	N	MIN	MAX	AVE	N	MIN	MAX	AVE
						- - ppt - -				- - meters - -				- - meters -		
ALBEMARLE (1990)	89	17	WG	7	84	0	2	1	84	0.2	2.0	0.7	85	0.4	2.4	1.1
			WC	12												
			EM	8												
			BP	7												
			RG	4												
CURRITUCK (1990)	41	21	WG	13	36	0	3	2	36	0.1	0.6	0.3	37	0.5	1.8	1.1
			WC	10												
			EM	11												
			BP	5												
			SP	3												
ROANOKE/ CROATAN (1988)	39	10	WG	8	33	1	14	6	32	0.2	1.2	0.7	38	0.4	2.7	1.0
			EM	2												
			SG	2												
NEUSE RIVER (1991)	40	1	WC	1	39	0	18	8	36	0.4	1.3	0.7	36	0.5	2.5	1.1
PAMLICO RIVER (1991)	44	7	WG	1	8	2	14	9	43	0.5	1.0	0.6	43	0.6	1.3	0.9
			WC	6												

Table 3. (continued)

SUBREGION (YEAR)	STATIONS[1]				SALINITY[2]				Secchi DEPTH[2]				WATER DEPTH[2]			
	TOT	WITH SRV	WITH SPEC: SPEC CODE	WITH SPEC: N	N	MIN	MAX	AVE	N	MIN	MAX	AVE	N	MIN	MAX	AVE
						- - ppt - -				- - meters - -				- - meters -		
PAMLICO SOUND																
WESTERN (1991)	31	2	WG	2	21	8	22	17	29	0.4	1.4	0.9	31	0.5	1.5	1.0
EASTERN (1988)	121	83	WG	45	112	4	30	18	57[A]	0.5	3.6	1.1	111	0.0	3.0	1.0
			SG	53												
			EG	65												
CORE (1988)	82	57	WG	17	81	15	38	30	32[A]	0.3	2.0	1.0	82	0.1	1.7	0.7
			SG	36												
			EG	53												
BOGUE (1989)	67	43	WG	2	65	28	37	33	42[A]	0.2	1.9	0.9	64	0.1	2.1	0.7
			SG	37												
			EG	35												

[1] The total number of stations occupied (TOT), the number of stations having submersed rooted vascular plants (WITH SRV), and stations having a particular species: Widgeon grass (WG), wild celery (WC), Eurasian water milfoil (EM), bushy pond weed (BP), sago pond weed (SP), redhead grass (RG), shoal grass (SG), and eelgrass (EG) and the number of stations having the species (N).

[2] The number of stations at which the dependent variable was measured (N) and the minimum (MIN), the maximum (MAX), and the mean (AVE) values for those measurements.

[A] The number of stations measured for Secchi depth is low because for many of the stations in eastern Pamlico, Core, and Bogue Sounds the water was sufficiently clear for the Secchi disk to be visible on the bottom, water of sufficient depth was not in the vicinity of the station, and a Secchi depth measurement could not be made.

Albemarle, **Currituck**, **Pamlico River estuary**, **Neuse River estuary**, and **western Pamlico Sound** data. The data would tend to favor somewhat lower salinities than average for **eastern Pamlico sound** which was sampled in the spring (See Fig. 2a, b). Although salinity, Secchi depth, and water depth vary over time at each location, the geographically extensive nature of the data set provides a basis for characterization of subregional trends.

The occurrence of SRV in the study area was related to water depth, Secchi depth, and salinity (Table 3). The maximum water depth for presence of SRV of any species was 2.4m (Fig. 4a). SRV appeared to occur with the highest frequency at shallow 0.3 to 0.7m or at deeper, 1.9 to 2.4m water depths (Fig. 4b). There is no obvious explanation for this observation. The frequency distribution of water depths sampled was not uniform and shallowest depths, <0.4m, and deepest depths, >1.5m, were relatively rare in the data (Fig. 4a). The distribution of water depth in the data may be biased low in the shallowest and deepest water depths due to practical limitations. Access to the shallowest potential stations was often restricted by extensive unnavigable shallows in extremely remote areas. Some stations were deeper than depicted on nautical charts. In these and some other cases, positions were changed in the field to accommodate sampling. Five (18.5%) of the 27 stations lacking water depth data contained SRV.

The maximum Secchi depth recorded was 3.6m (Fig. 5a) and the distribution of the data was not uniform. The mode was 0.6m and

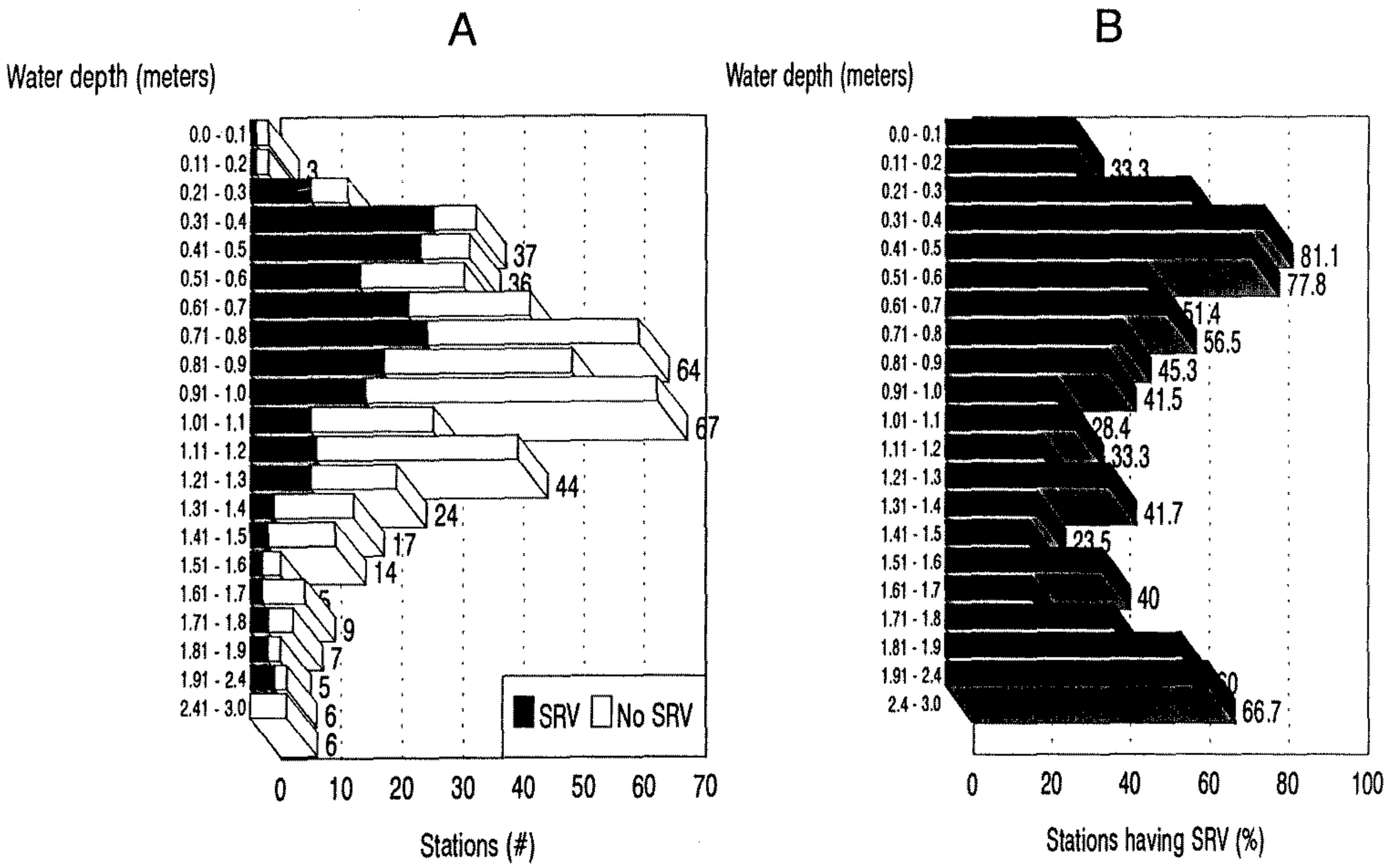


Figure 4. Occurrence of SRV with water depth: (A) number of stations having or lacking SRV, (B) ratio of stations having SRV.

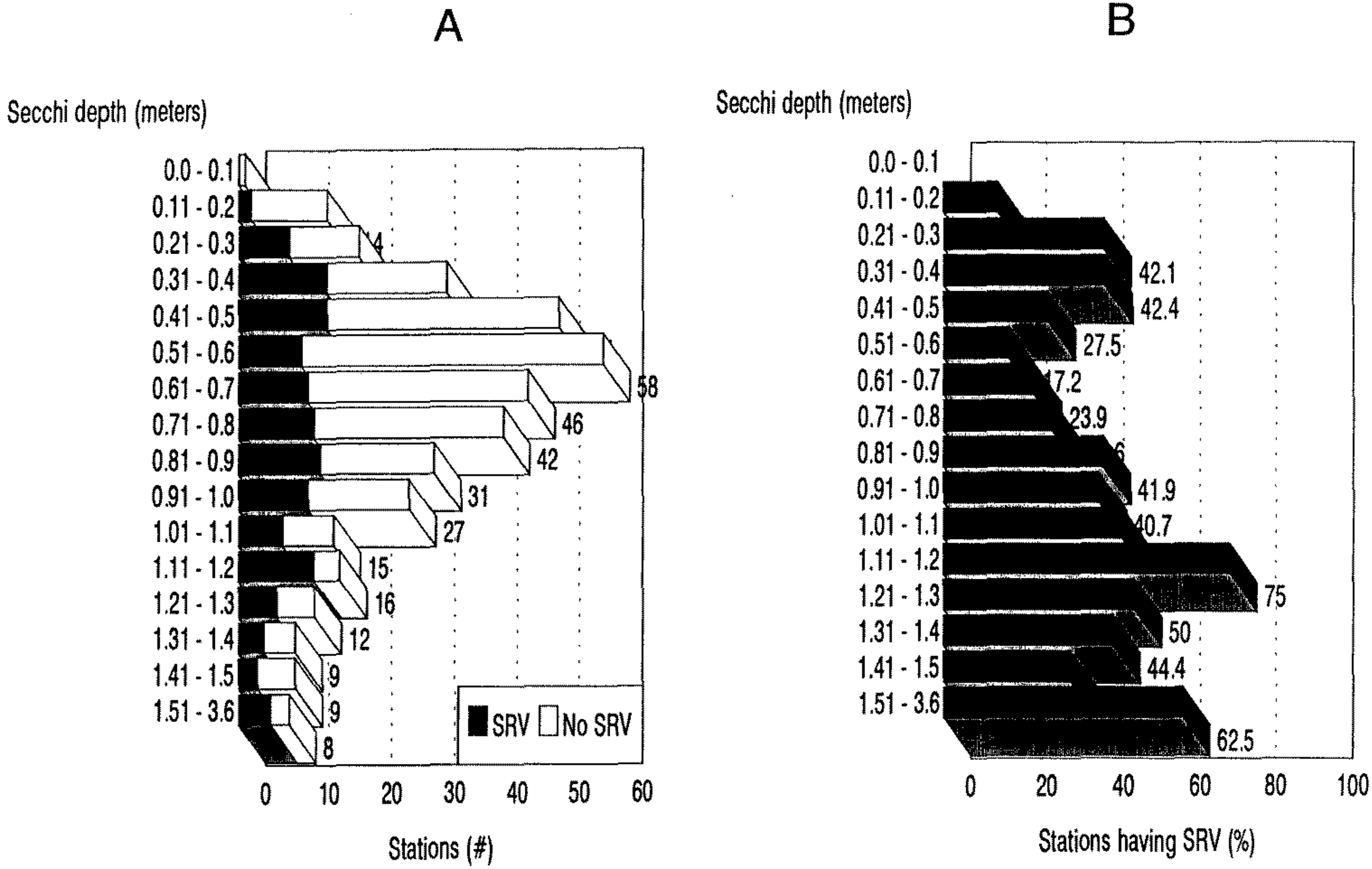


Figure 5. Occurrence of SRV with Secchi depth: (A) number of stations having or lacking SRV, (B) ratio of stations having SRV.

most data were in the interval of 0.4 to 1.0m. Relatively few stations had a Secchi depth of <0.2m or >1.3m. The frequency of occurrence of SRV generally increased with increasing Secchi depth but there were three local maxima in the frequency distribution: 0.21 to 0.4m, 1.11 to 1.2m and 1.51 to 3.6m (Fig. 5b). The lowest frequencies for SRV were in the Secchi depth intervals of 0.11 to 0.2m and 0.51 to 0.6m. Of the 163 stations lacking Secchi depth data, 109 (66.9%) had SRV.

Salinity ranged from 0 to 38‰ (Fig. 6a). The most frequent salinities sampled were 0‰ and 2‰. The frequency of occurrence of SRV increased over the interval of 0 to 5‰, was variable and low from 6 to 12‰, and was variable and high above 13‰ (Fig. 6b). Of the 75 stations lacking salinity data, 12 (16%) had SRV.

The salinity and Secchi depth data covaried, to some extent, but the relationship was not monotonic. In general, the **high salinity** waters of the **Bogue** and **Core** Subregions had Secchi depths that were relatively deep and variable and rarely as shallow as the shallowest Secchi depth values frequently observed at **low salinity** in the **Albemarle** and **Currituck** Subregions (Fig. 7d).

Among the **low salinity** stations (Fig. 7a) Secchi depth varied inversely with salinity. In the fresh and oligohaline salinity range, lower salinity water tended to be clearer than higher salinity water. Relatively deep Secchi depths were recorded at a number of freshwater and very low salinity stations but only in the **Albemarle** Subregion. No Secchi depths deeper than 1.4m

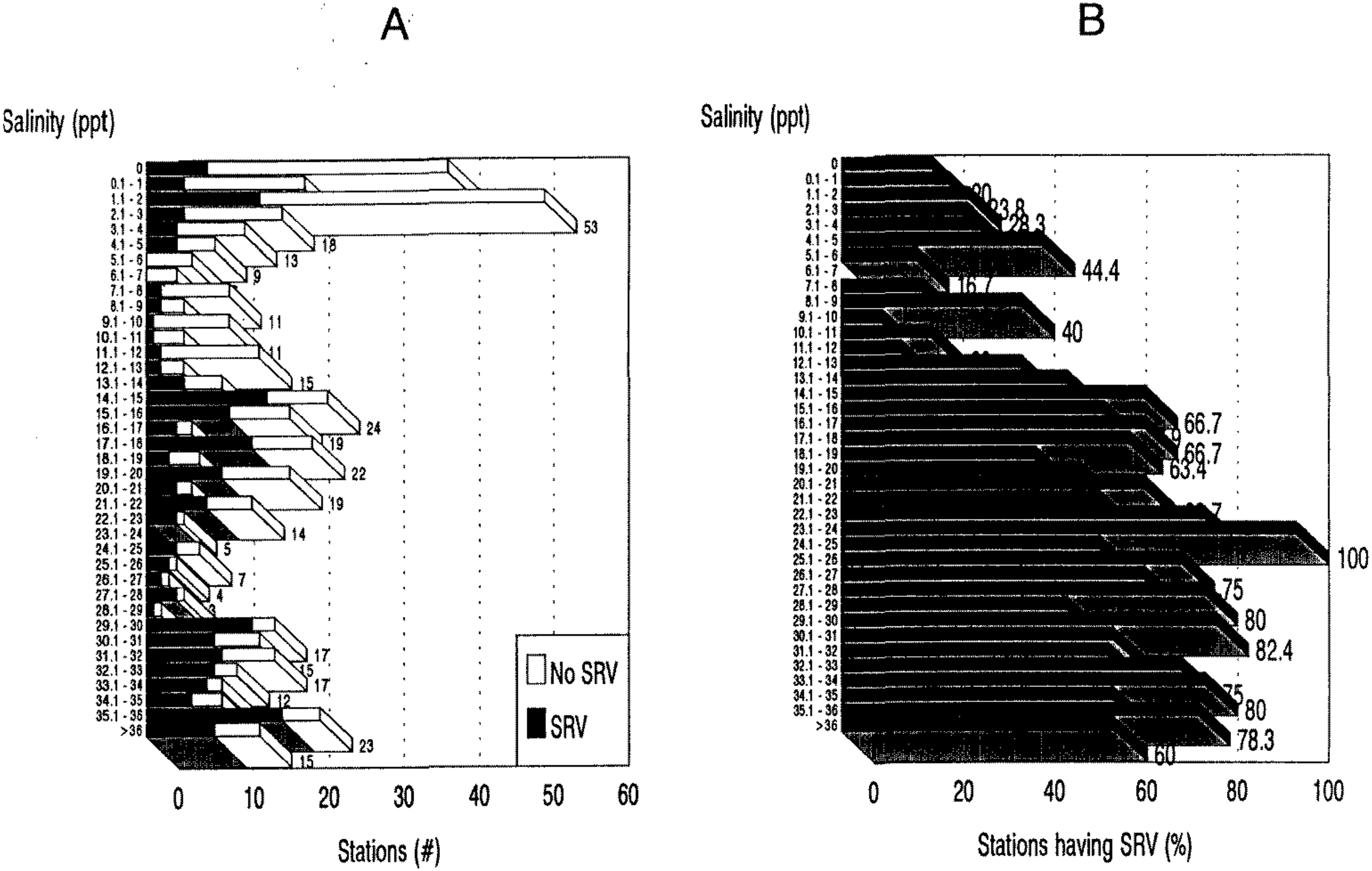
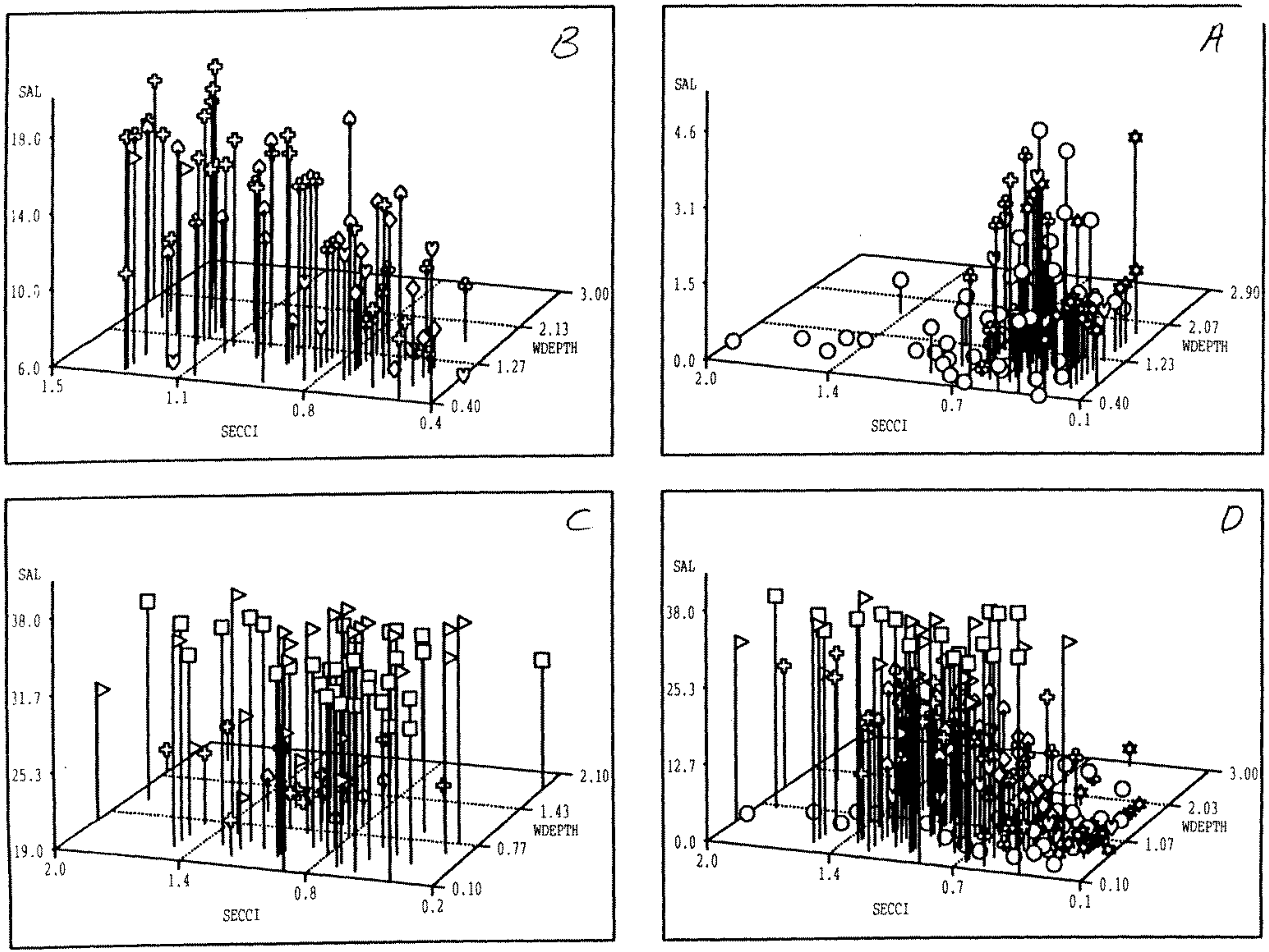


Figure 6. Occurrence of SRV with salinity: (A) stations having or lacking SRV, (B) ratio of stations having SRV.

FIGURE 7. Secchi depth, water depth and salinity for those stations at which all three measurements were recorded. The subregions are: o = **Albemarle**, star = **Currituck**, ♥ = **Roanoke/Croatan**, ♣ = **Neuse River estuary**, ♦ = **Pamlico River estuary**, ♠ = **western Pamlico Sound**, † = **eastern Pamlico Sound**, flag = **Core** and square = **Bogue**. a) 0 to <5.0‰, b) 5.0 to 18‰, c) >18‰, and d) All salinities.


B
SAL
18.0
14.0
10.0
6.0
1.5
1.1
0.8
0.4
SECCI
3.00
2.13
WDEPTH
1.27
0.40
A
SAL
4.6
3.1
1.5
0.0
2.0
1.4
0.7
0.1
SECCI
2.90
2.07
WDEPTH
1.23
0.40
C
SAL
38.0
31.7
25.3
19.0
2.0
1.4
0.8
0.2
SECCI
2.10
1.43
WDEPTH
0.77
0.10
D
SAL
38.0
25.3
12.7
0.0
2.0
1.4
0.7
0.1
SECCI
3.00
2.03
WDEPTH
1.07
0.10

occurred with salinities above 1.0‰. In the salinity range of 2 to 5‰, Secchi depth did not exceed 1.0m. Both the **Albemarle** and **Currituck** Subregions were consistently low in salinity but only the **Currituck** Subregion had consistently shallow Secchi depths (Fig. 7a). Shallow Secchi depth data indicate limited subsurface illumination and, therefore, limited photosynthesis and survival potential of SRV. Although both bodies of water support a large number of low salinity-tolerant species, these species occur more frequently in the **Currituck** than in the **Albemarle** Subregion (Table 3).

In the mesohaline salinity range, Secchi depth tended to vary positively with salinity (Fig. 7b). The Secchi depth interval for the data was narrower than for either the **low salinity** or the polyhaline and euhaline stations. The maximum Secchi depth was shallowest and the minimum Secchi depth was greatest for the mesohaline stations. In the **Roanoke/Croatan** Subregion, which lies between the **low salinity** waters of Albemarle Sound and the **high salinity** waters of Pamlico Sound, water was oligohaline or mesohaline and had shallow Secchi depths (Fig. 7a, b). The **Neuse River estuary** and **Pamlico River estuary** Subregions had variable salinity and Secchi depth (Fig. 7a, b); the salinity ranged from fresh water at upstream stations, near New Bern (Neuse River) and Washington (Pamlico River), to mesohaline at stations near the mouths of these Rivers. There was no trend between salinity and Secchi depth with polyhaline and euhaline salinity (Fig. 7c).

The exclusively **high salinity** subregions include: **western Pamlico Sound**, **eastern Pamlico Sound**, **Core** and **Bogue** (Fig. 7c). All four of these subregions had mean Secchi depths ≥0.9m which is deeper than the five lower salinity subregions, all of which had mean Secchi depths ≤0.7m, (Table 3). Mean salinities of the **western** and the **eastern Pamlico Sound** Subregions were similar (17 and 18‰, respectively). The latter subregion included a single **low salinity** station (4‰) and a higher maximum salinity, 30‰, compared to a minimum of 8‰ and a maximum of 22‰ for **western Pamlico Sound**. The minimum, mean and maximum Secchi depths all were deeper in the **eastern** than in the **western Pamlico Sound** Subregion. The **western Pamlico Sound** Subregion also had a low diversity (1 species) and frequency of occurrence of SRV (6.5%, 2 of 31 stations). The **eastern Pamlico Sound**, **Core, and Bogue** Subregions had mean salinities in the polyhaline range, wide ranging but relatively high mean Secchi depths and a high frequency of occurrence of SRV (67.8%, 183 of 270 stations). Very importantly, a high percentage of the stations in these three subregions, 51.5% compared to 8.5% of the stations in the more turbid lower salinity subregions of the study area, had water depths at the stations that were too shallow to obtain a Secchi depth reading. In these high salinity waters the Secchi disc frequently was visible on the bottom. This indicates that substantial illumination was available to SRV.

Distribution of species of SRV. **Low salinity** species (wild celery, Eurasian water milfoil, bushy pondweed, redhead grass and sago pondweed) occurred in the **Albemarle** and **Currituck** Subregions

(Table 3). Only wild celery was observed in the **Neuse River estuary** Subregion. The euryhaline species widgeon grass was observed in all subregions of the study area except **Neuse River estuary** where it has been reported to occur (Davis and Brinson, 1990). Its absence from the Neuse River in this data set may be an artifact of the small number of stations sampled, 40, but deserves further study.

Eelgrass, shoal grass, and widgeon grass were very abundant in the **high salinity** waters of the **eastern Pamlico Sound**, **Core**, and **Bogue** Subregions (Table 3). The two seagrass species, shoal grass and eelgrass, were observed at two stations each in the **high salinity** waters in the southern extreme of the **Roanoke/Croatan** Subregion but were not observed in the **western Pamlico Sound** Subregion. The absence of seagrasses in **western Pamlico Sound** and the low frequency of occurrence there of widgeon grass is associated with reduced subsurface illumination (shallow Secchi depth) but not markedly reduced salinity relative to the **eastern Pamlico Sound**.

The frequency of occurrence of widgeon grass relative to shoal grass and eelgrass decreased markedly in the geographic gradient from the **eastern Pamlico Sound** through the **Core** and to the **Bogue** Subregions (Table 3). This geographic trend is associated with increases in the minimum salinity (4, 15, and 28‰, respectively) and the mean salinity (18, 30, and 33‰, respectively).

The occurrences of the 8 species of SRV were strongly associated with salinity (Fig. 8) Three types of distributions of

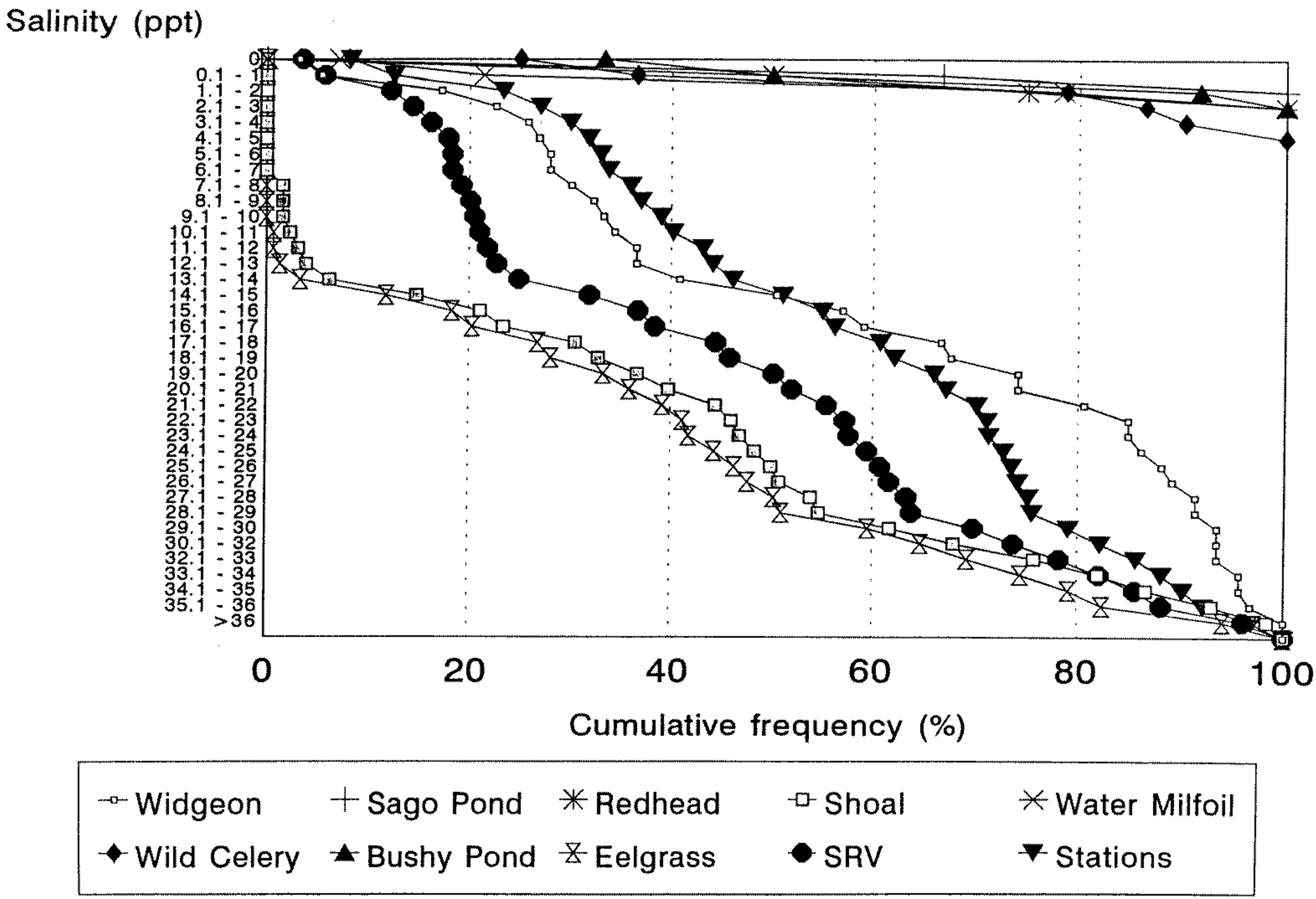


Figure 8. Cumlative frequency distributions for stations and species of SRV with salinity.

species are: **low salinity**, euryhaline, and **high salinity**. The steepness of slope indicates the frequency of occurrence of the species in a given interval of salinity. The cumulative frequency for all stations without regard to SRV is provided for reference. The frequency of occurrence of the five low salinity species increased rapidly from minimum salinities of 0 or 1‰ to maximum salinities of 2 to 5‰, dependent upon species. As a group, the five low salinity species were most frequent at salinities <3‰. This is due in part to the large number of stations having salinities in that range.

The cumulative frequency plots of all stations and of those stations having any species of SRV were approximately parallel over much of the observed interval of salinity but showed important differences (Fig. 8). The cumulative frequency plot for stations having SRV increased more gradually than the plot of all stations in the salinity interval of 3 to 14‰. The slope was steeper for stations with SRV, than the slope for all stations in the salinity intervals of 14 to 15‰ and 29 to >36‰. Considering all species, therefore, the salinity range of 3 to 14‰ was the least favorable for SRV and the salinity ranges of 0 to 3‰, 14 to 15‰, and 29 to 36‰ were the most favorable for SRV.

The most frequently observed species of SRV were widgeon grass (95 stations), shoal grass (128 stations) and eelgrass (153 stations) (Table 4). The euryhaline widgeon grass

Table 4. The occurrence of species of SRV according to salinity, Secchi depth, and water depth in the Albemarle-Pamlico estuarine system in 1988 through 1991.

SPECIES OF SRV	N[1]	SALINITY[2]				Secchi DEPTH[2]				WATER DEPTH[2]			
		N	MIN	MAX	AVE	N	MIN	MAX	AVE	N	MIN	MAX	AVE
			- - - ppt - -				- - - meters - - -				- - meters - - -		
WIDGEON GRASS	95	87	0	36	15	54	0.2	1.8	0.7	95	0.2	2.3	0.8
WILD CELERY	29	26	0	5	2	28	0.2	2.0	0.6	28	0.4	2.4	0.9
EURASIAN WATER MILFOIL	21	14	0	5	2	14	0.2	1.4	0.6	17	0.5	2.4	1.1
BUSHY PONDWEED	12	12	0	2	1	12	0.2	2.0	0.7	12	0.5	1.7	1.0
SAGO PONDWEED	3	3	1	3	2	3	0.2	0.4	0.3	3	0.6	0.9	0.8
REDHEAD GRASS	4	4	1	2	1	4	0.4	1.4	0.9	4	0.4	1.7	1.2
SHOAL GRASS	128	128	8	38	25	60	0.4	2.0	1.0	128	0.1	2.1	0.8
EELGRASS	153	153	11	38	26	72	0.3	2.0	1.0	153	0.1	2.5	0.8

[1] The number of stations from a total of 554 throughout the study area at which a species of SRV was observed.

[2] The number of stations at which measurements were taken (N), the minimum (MIN), the maximum (MAX), and the mean (AVE) value for the variables. Note that the number of observations for Secchi depth is lowest because for many stations the Secchi disk was visible on the bottom and a measurement could not be made. Thus for approximately 40% of the stations Secchi depth exceeded water depth. This situation was most frequent in the higher salinity waters inhabited by Widgeon grass, shoal grass and eel grass.

was found in the salinity range 0 to 36‰ (Fig. 8). The slope of the cumulative frequency plot for this species was steepest at salinities <4‰, steep in the interval 14 to 23‰, and moderate at the intervals from 4 to <14‰ and from >23 to 36‰. Comparison of the relative steepness of slopes of the widgeon grass plot and the all stations plot indicates that the salinity interval of 14 to 23‰ was the most favorable and that the salinity interval from 30 to >36‰ was the least favorable for widgeon grass.

The cumulative frequency distributions for shoal grass and eelgrass are similar (Fig. 8). The distribution of shoal grass extends to a slightly lower salinity, 8‰, compared to 11‰ for eelgrass in these data. In field sampling for signature verification, data not included in this Figure 8, we observed eelgrass at ambient salinity as low as 8‰ in Croatan Sound. As salinity increases above 8‰ the cumulative frequency for shoal grass equals or slightly exceeds that for eelgrass.

It is noteworthy in Figure 8 that the distributions of widgeon grass, shoal grass and eelgrass overlap at salinities above 11‰. For these three species, widgeon grass has absolute dominance in **low salinity** water, the three species are co-dominant through most of the mesohaline salinity interval, and shoal grass and eelgrass establish a two species co-dominance as salinity increases through polyhaline and euhaline salinities. This change in species dominance as salinity increases also occurs among the **eastern Pamlico Sound**, **Core** and **Bogue** Subregions.

Wild celery, Eurasian water milfoil, bushy pondweed, redhead grass, and sago pondweed were encountered relatively infrequently and only at stations with **low salinity**. This contrasts with the broader salinity distributions reported previously for these species (see Table 1). For three of these species, sago pondweed, redhead grass and bushy pondweed, the salinity, Secchi depth, and water depth data were very limited due to the small number of stations having these species (Table 3). Sago pondweed was found at three stations. Salinity, Secchi depth and water depth data were confined to relatively narrow intervals for stations with sago pondweed: salinity 1 to 3‰, Secchi depth 0.2 to 0.4m, and water depth 0.6 to 0.9m. Redhead grass was observed at four stations with salinities which ranged from 1 to 2‰. Redhead grass was associated with deeper Secchi depths (clearer water) and a wider interval of water depths than sago pondweed. Bushy pondweed occurred at 12 stations within a narrow salinity interval, 0 to 2‰, but having fairly wide ranges of Secchi depth and water depth.

Both wild celery, present at 29 stations, and Eurasian water milfoil, present at 21 stations, were associated with ambient salinities from 0 to 5‰ and a mean salinity of 2‰ (Table 4). Wild celery was collected most often at an ambient salinity of 2‰, the most frequently encountered salinity, but was collected with the highest frequency at an ambient salinity of 5‰ (Fig. 9). Eurasian water milfoil was most frequently observed and had the highest frequency of occurrence at 2‰ (Fig. 10). Widgeon grass occurred most frequently in the salinity interval of 14 to 28‰ but there was

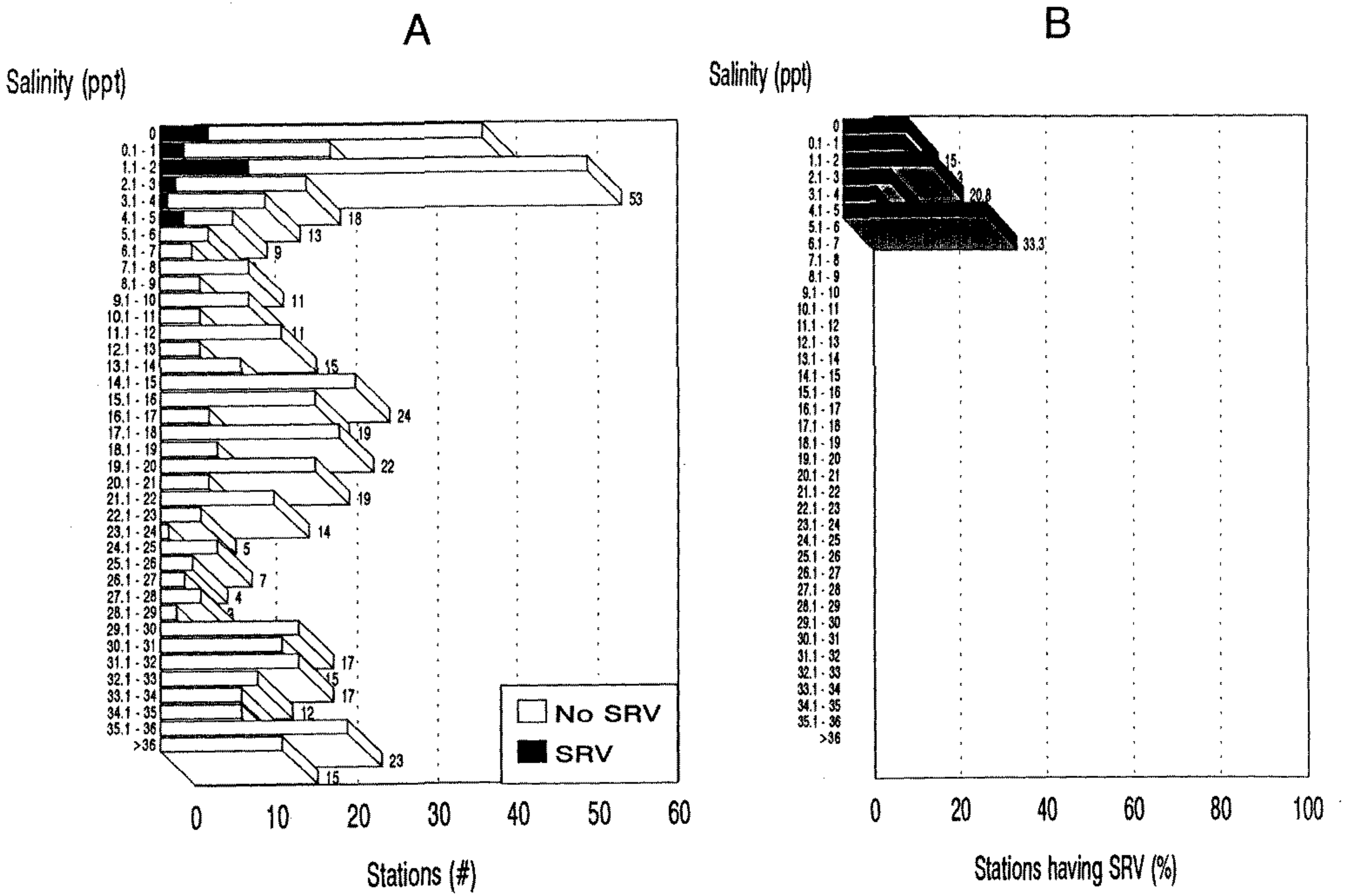


Figure 9. Occurrence of wild celery with salinity: (A) stations with or without wild celery, (B) ratio of stations with wild celery.

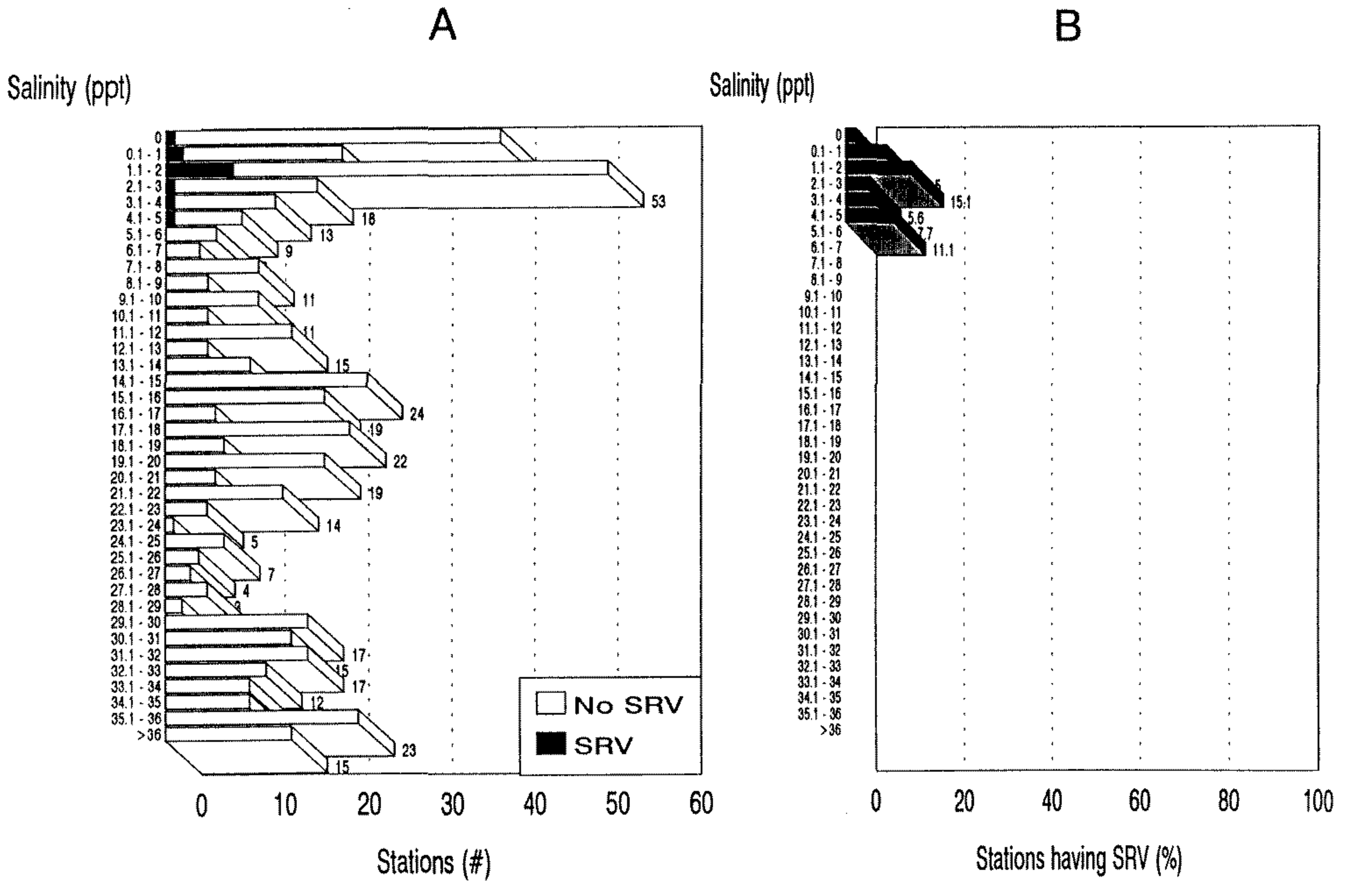


Figure 10. Occurrence of Eurasian water milfoil with salinity: (A) stations with or without Eurasian water milfoil, (B) ratio of stations with Eurasian water milfoil.

a local maximum frequency in the salinity interval of 2 to 8‰ (Fig. 11). Frequency of occurrence for this species with salinity was: over all, 17.9%; at ≤28‰, 24%; and at >28‰, 6.6%. Shoal grass (Fig. 12), and eelgrass (Fig. 13) had similar occurrences and cumulative frequency distributions plotted as a function of salinity. Both species were absent at **low salinity**, and progressively were, occasionally present (frequency ≤20%), to frequent (frequency >20%) as salinity increased through mesohaline salinities. Frequencies of occurrence remained high for both species throughout the polyhaline salinity interval. The frequency of occurrence of shoal grass (Fig. 12), but not of eelgrass (Fig. 13), decreased at eusaline salinities above 35‰. Shoal grass and eelgrass also had remarkable similarities in their distributions relative to Secchi depth and water depth. The intervals and means for salinity, Secchi depth, and water depth all were similar (Table 4) indicating little or no difference in the distribution of these two species which often co-occur in NC (Ferguson *et al.*, 1989a).

Distribution of SRV by subregion. The frequency of occurrence of SRV at stations within the subregions ranged from 2.5 to 69.5% and was related to mean salinity for the subregion (Fig. 14). Subregions are arranged in the figure from least frequent to most frequent occurrence of SRV and also are ranked according to mean salinity from 1, lowest, to 9, highest salinity. The three Subregions **Neuse River estuary**, **Pamlico River estuary**, and **western Pamlico Sound** have the lowest frequency of SRV and intermediate

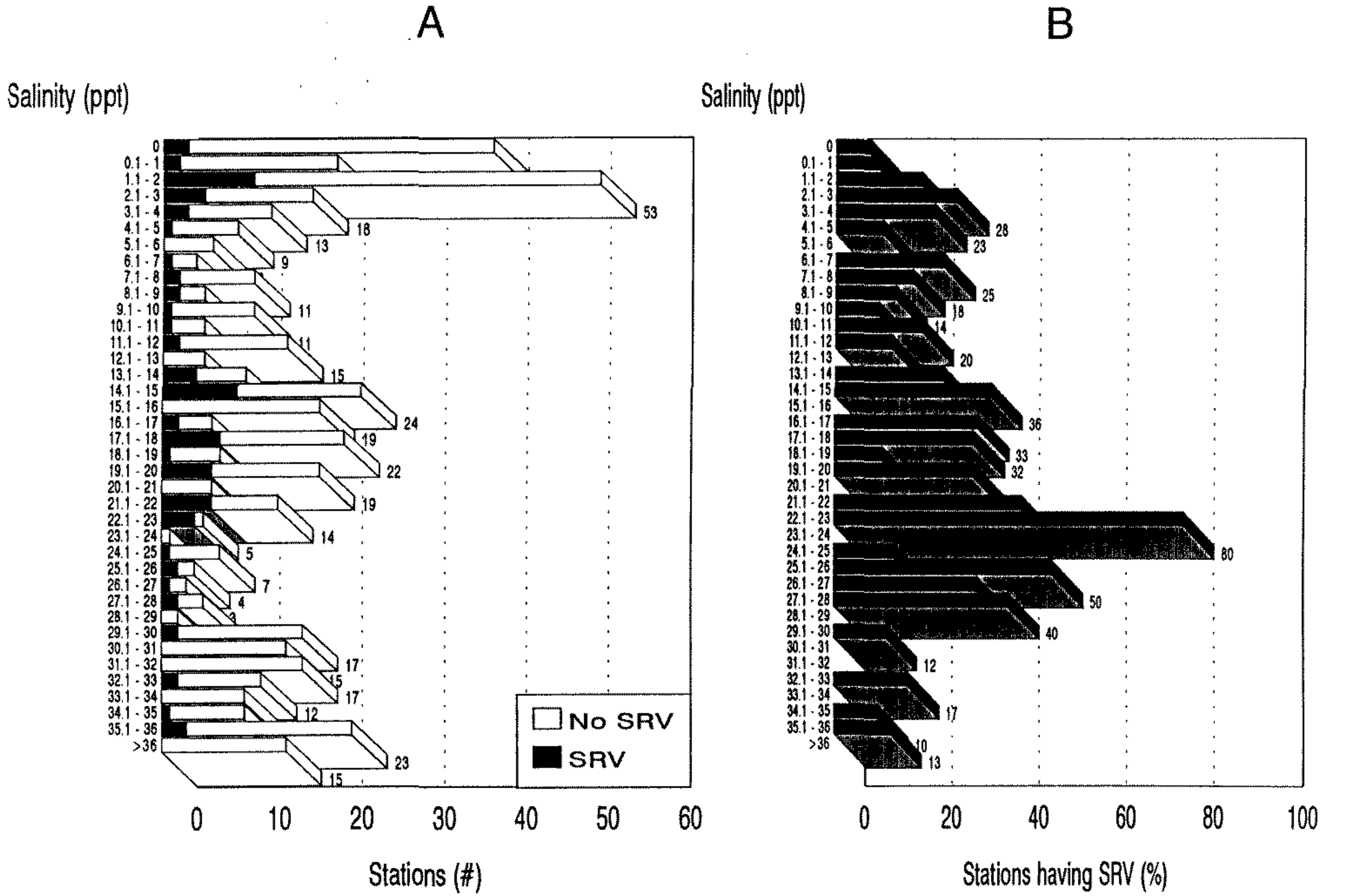


Figure 11. Occurrence of widgeon grass with salinity: (A) stations with or without widgeon grass, (B) ratio of stations with widgeon grass.

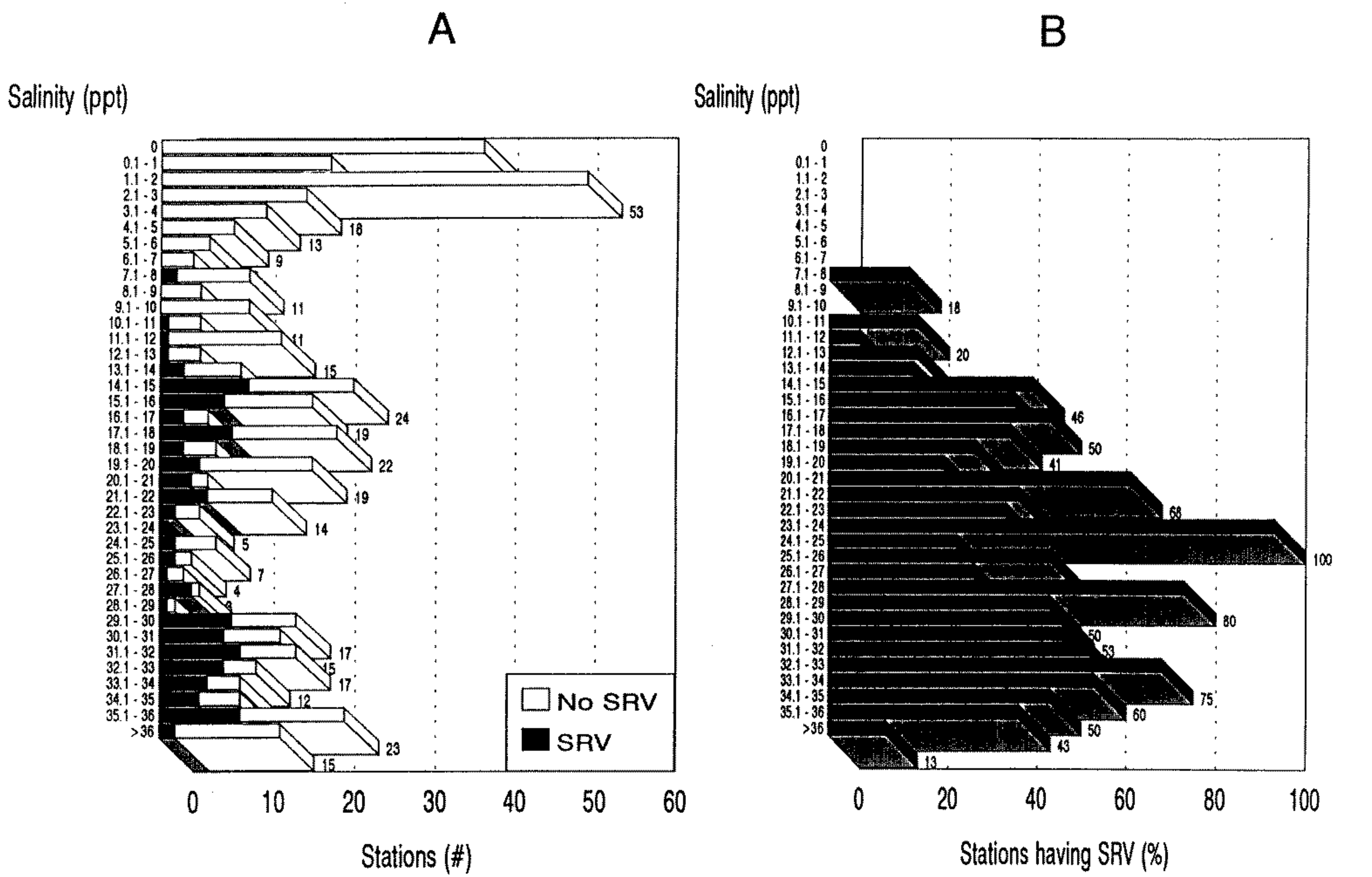


Figure 12. Occurrence of shoal grass with salinity: (A) stations with or without shoal grass, (B) ratio of stations with shoal grass.

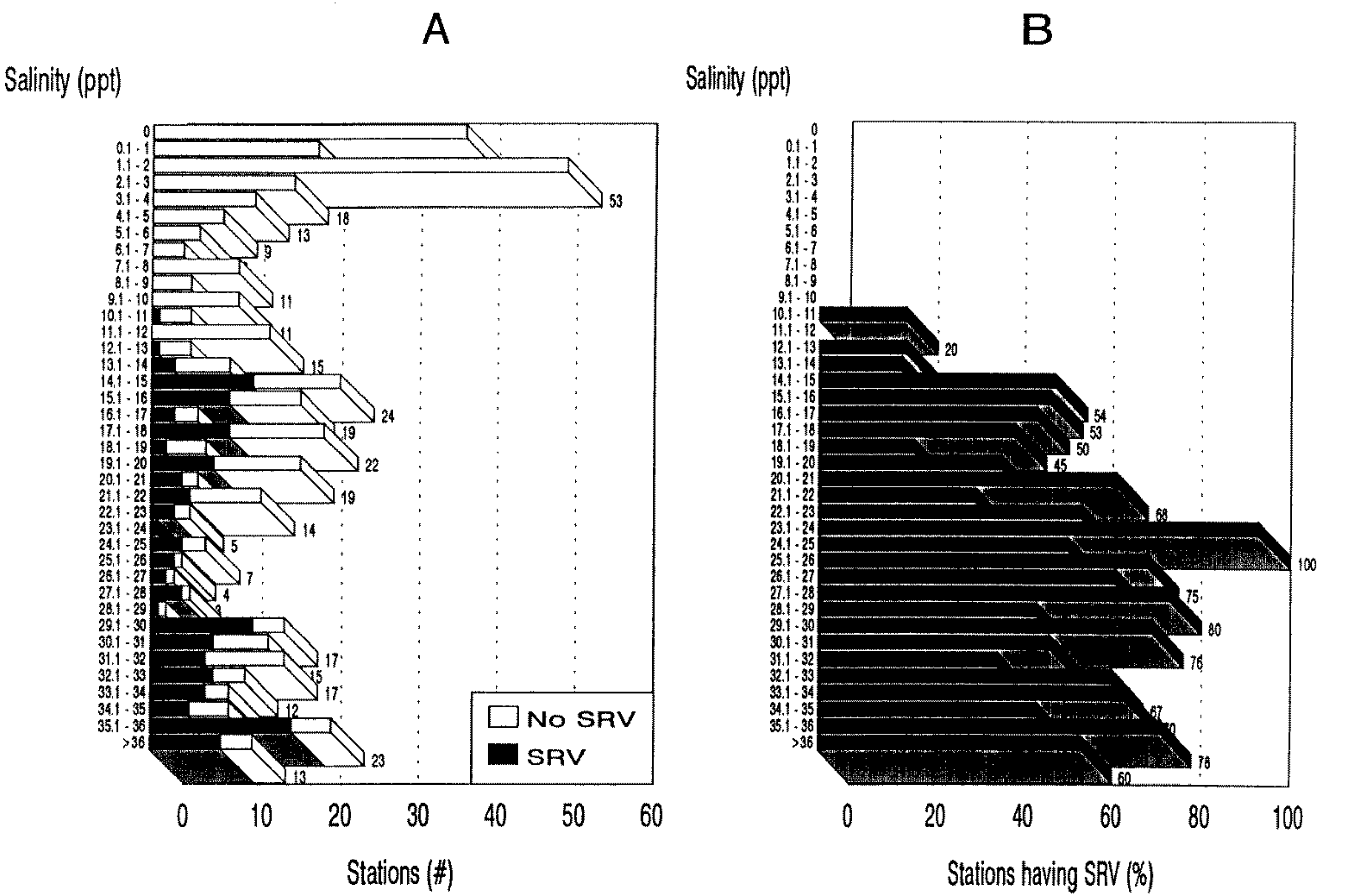


Figure 13. Occurrence of eelgrass with salinity: (A) stations with or without eelgrass, (B) ratio of stations with eelgrass.

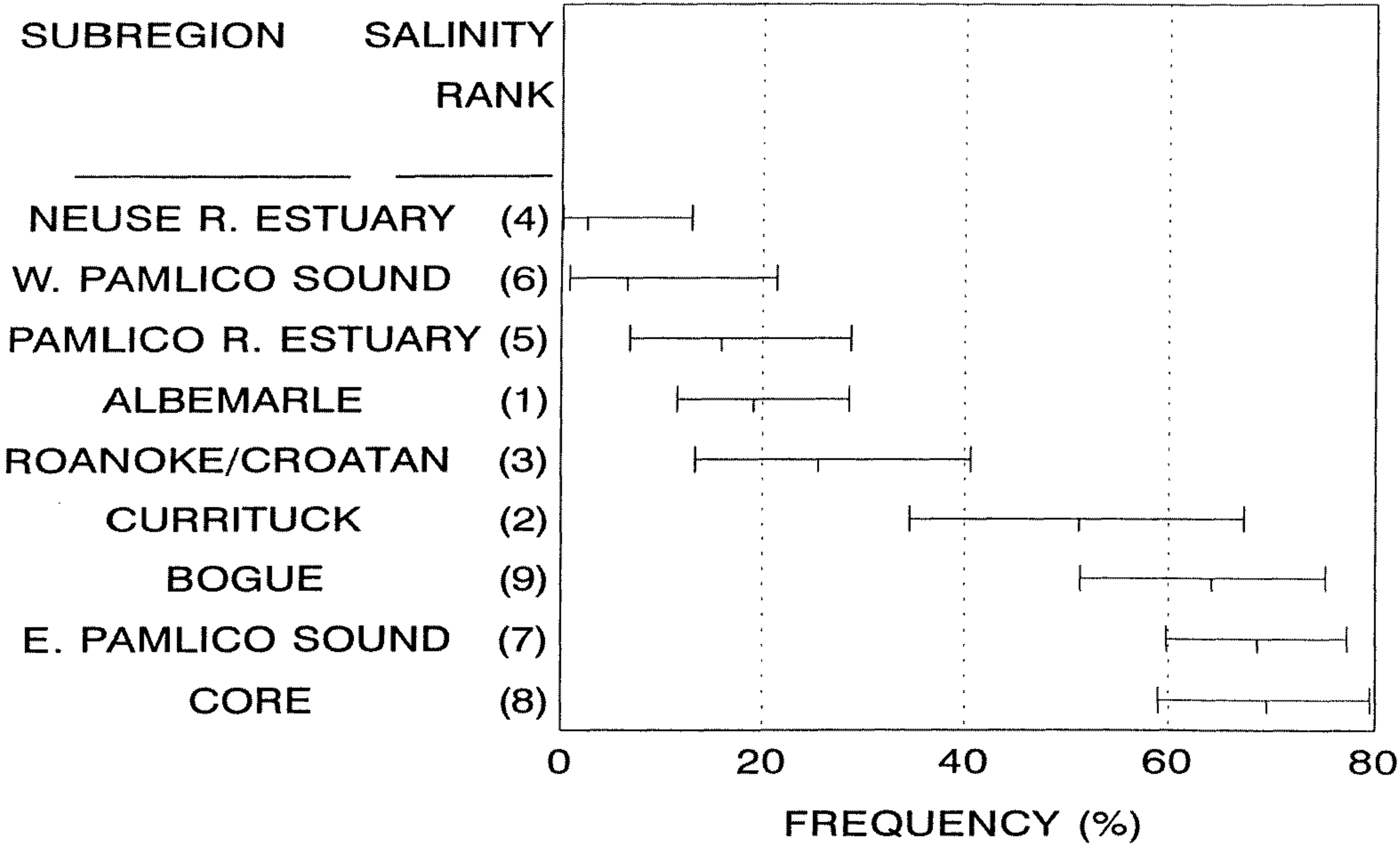


Figure 14. Frequency of the occurrence of SRV by Subregion, with 95% confidence intervals, and ranking of Subregions from lowest, 1, to highest, 9, mean salinity.

mean salinities (8‰, 9‰, and 17‰, respectively). The **Albemarle**, **Roanoke/Croatan**, and **Currituck** Subregions have intermediate frequencies of SRV and the lowest mean salinities (1‰, 2‰, and 6‰, respectively). The **eastern Pamlico Sound**, **Core**, and **Bogue** Subregions have the highest frequency of SRV and the highest mean salinities (18‰, 30‰ and 33‰ respectively). An absence of overlap between the 95% confidence intervals of frequency of SRV between subregions is a measure of statistical significance. The four subregions with the lowest frequencies of SRV, **Neuse River estuary**, **western Pamlico Sound**, **Pamlico River estuary**, and **Albemarle**, are not significantly different from each other. The four Subregions with the highest frequency of SRV, **Currituck**, **Bogue**, **eastern Pamlico Sound**, and **Core**, are not significantly different from each other but are significantly different from the four subregions with the lowest frequencies for occurrence of SRV. The **Roanoke/Croatan**, with an intermediate frequency for SRV is significantly higher than the **Neuse River estuary**, and significantly lower than the **Bogue**, the **eastern Pamlico Sound**, and the **Core** Subregions.

In the **Albemarle** Subregion, SRV was diverse in species present but not widespread in areal distribution. Seventeen of the 89 stations, 19.1% (95% CI, confidence interval, 11.5 to 28.6%), contained SRV (Fig 14). Five of the six species tolerant of **low salinity** (widgeon grass, wild celery, Eurasian water milfoil, bushy pondweed, redhead grass) were present at from four to 12 stations, respectively (Table 3). The most frequently encountered species was wild celery. Salinity averaged 1‰ and had a narrow interval of

0 to 2‰. Secchi depth was shallow, with a mean of 0.7m, and variable having a range of 1.8m, but most of the stations and most of the stations having SRV were relatively turbid having Secchi depth readings from 0.3 to 0.6m (Fig. 15a). Three of the seven stations, 42.9%, of the stations with the clearest water also had SRV compared to 14.8% of stations with shallower Secchi depths but the frequency data for clear water stations are based on a small sample size and were not statistically different from the turbid water stations. SRV was widely spread at water depths from 0.4 to 2.4m (Fig. 15b).

In the **Roanoke/Croatan**, **Neuse River estuary**, **Pamlico River estuary** and **western Pamlico Sound** Subregions, shallow Secchi depths (low water clarity), are associated with reduced frequencies of SRV and/or limitation of SRV to relatively shallow water compared to the **Albemarle Subregion**. In the **Currituck** Subregion, however, SRV was diverse and moderately widespread despite the shallowest mean Secchi depth for the study. Twenty-one of the 41 stations, or 51.2% (95% CI, 34.6 to 67.3%), contained SRV (Fig. 14). Five of the six species tolerant of **low salinity** water (widgeon grass, wild celery, Eurasian water milfoil, bushy pondweed, and sago pondweed) were present at from 3 to 13 of the stations, respectively (Table 3). The most frequently encountered species was widgeon grass. Secchi depth was very shallow with a mean of 0.3m. The observed interval for Secchi depth was small, 0.1 to 0.6m (Fig. 16a). Most

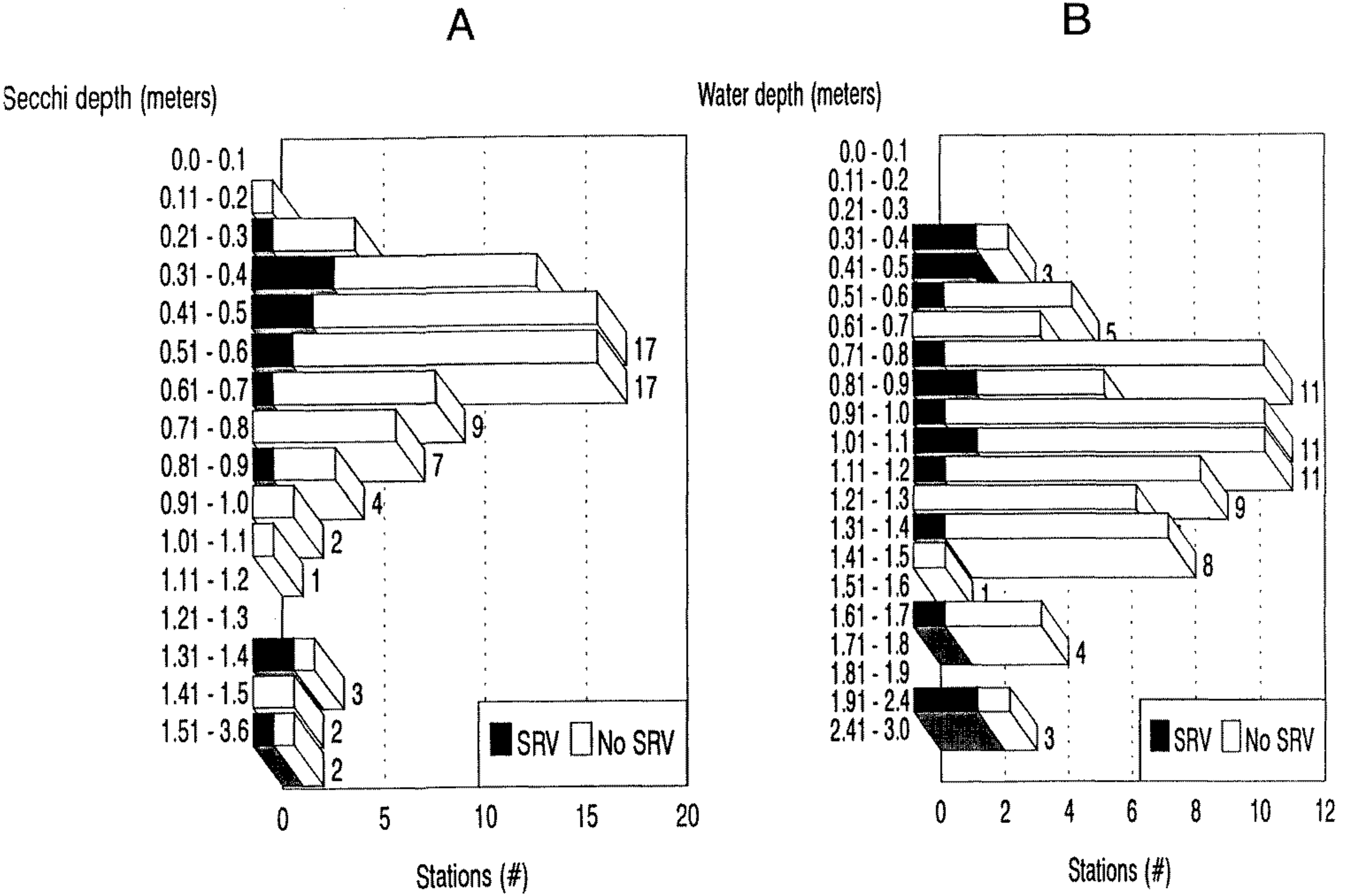


Figure 15. Number of stations having or lacking SRV in the Albemarle Subregion according to: (A) Secchi depth, (B) water depth.

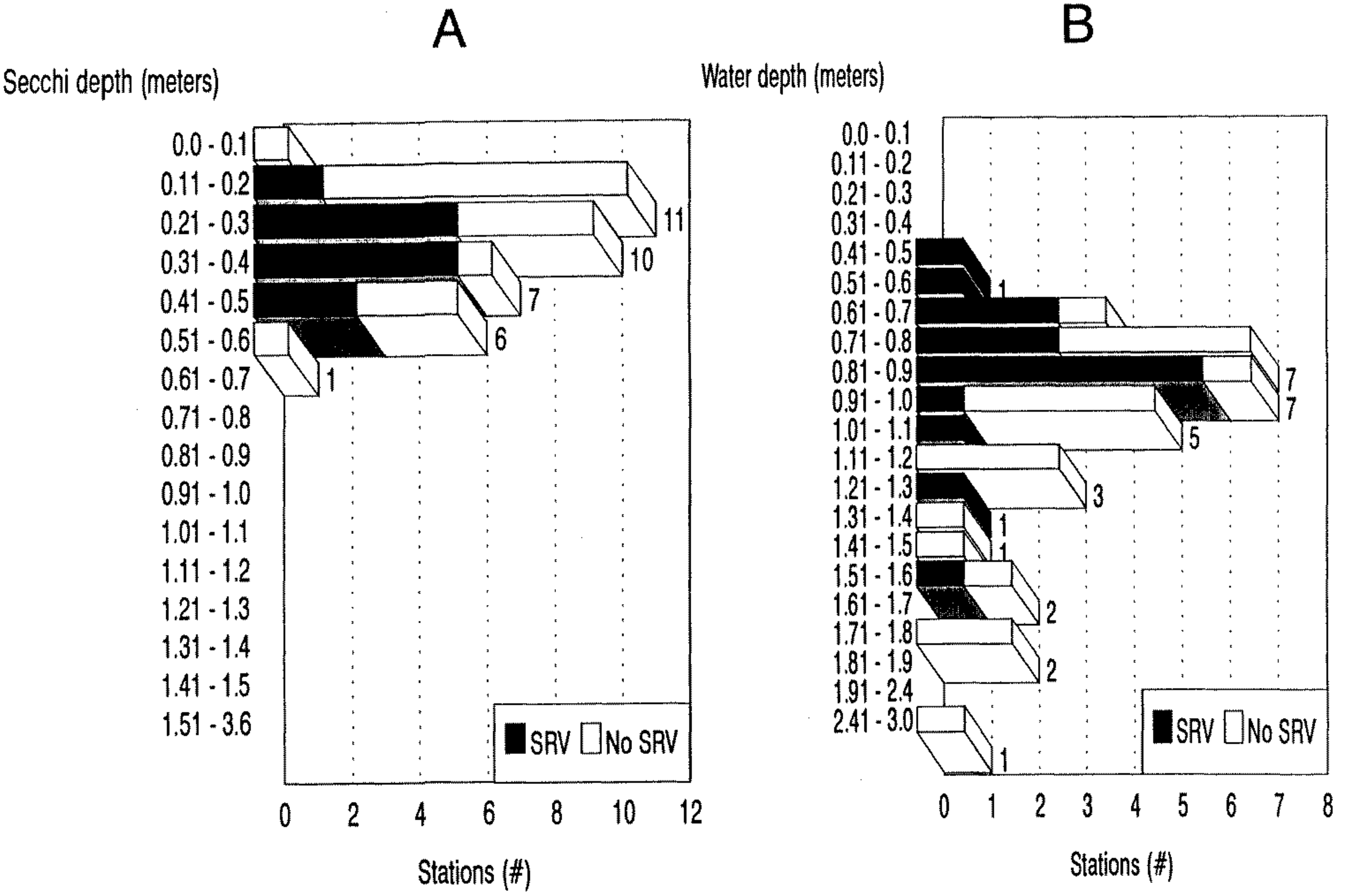


Figure 16. Number of stations having or lacking SRV in the Currituck Subregion according to: (A) Secchi depth, (B) water depth.

stations having SRV had water depth <1.0m and the maximum water depth was 1.6m (Fig. 16b). Salinity averaged 2‰ with a small interval of 0 to 3‰.

In the **Roanoke/Croatan** Subregion, SRV was not diverse in species and occurred less frequently than in the **Currituck** Subregion despite deeper Secchi depth readings. Of the 39 stations, 24.4% (95% CI, 13.3 to 40.6%), possessed SRV (Fig. 14). Widgeon grass, the only species tolerant of **low salinity** found in this subregion was frequently observed (8 of 39 stations). Shoal grass and eelgrass were observed at two of the **high salinity** stations in this subregion. The mean salinity of the subregion was 6‰ with an interval of 1 to 14‰. Secchi depth was shallow with a mean of 0.7m and an interval of 0.2 to 1.2m. SRV was observed at Secchi depths from 0.4 to 1.2m (Fig. 17a). The highest frequency of SRV was at water depths less than 0.7m and the maximum water depth for SRV here was a relatively shallow 1.3 m (Fig. 17b).

The **Neuse River estuary** Subregion had the lowest frequency of occurrence and diversity of SRV in the study area (Fig. 14). Only one station of the 40 stations occupied contained SRV, i.e. 2.5% (95% CI, 0.1 to 12.9%). The only species observed was wild celery. Salinity was negatively associated with distance upstream, averaged 8‰ and varied from 0‰ to 18‰. Secchi depth was shallow, the mean was 0.7m and Secchi depth interval was 0.4 to 1.3m. Most of the stations had Secchi depths between 0.5 and 0.8m (Fig. 18a). Water depths were sampled from 0.5 to 3.0 m but the single station having SRV was 0.8m deep (Fig. 18b).

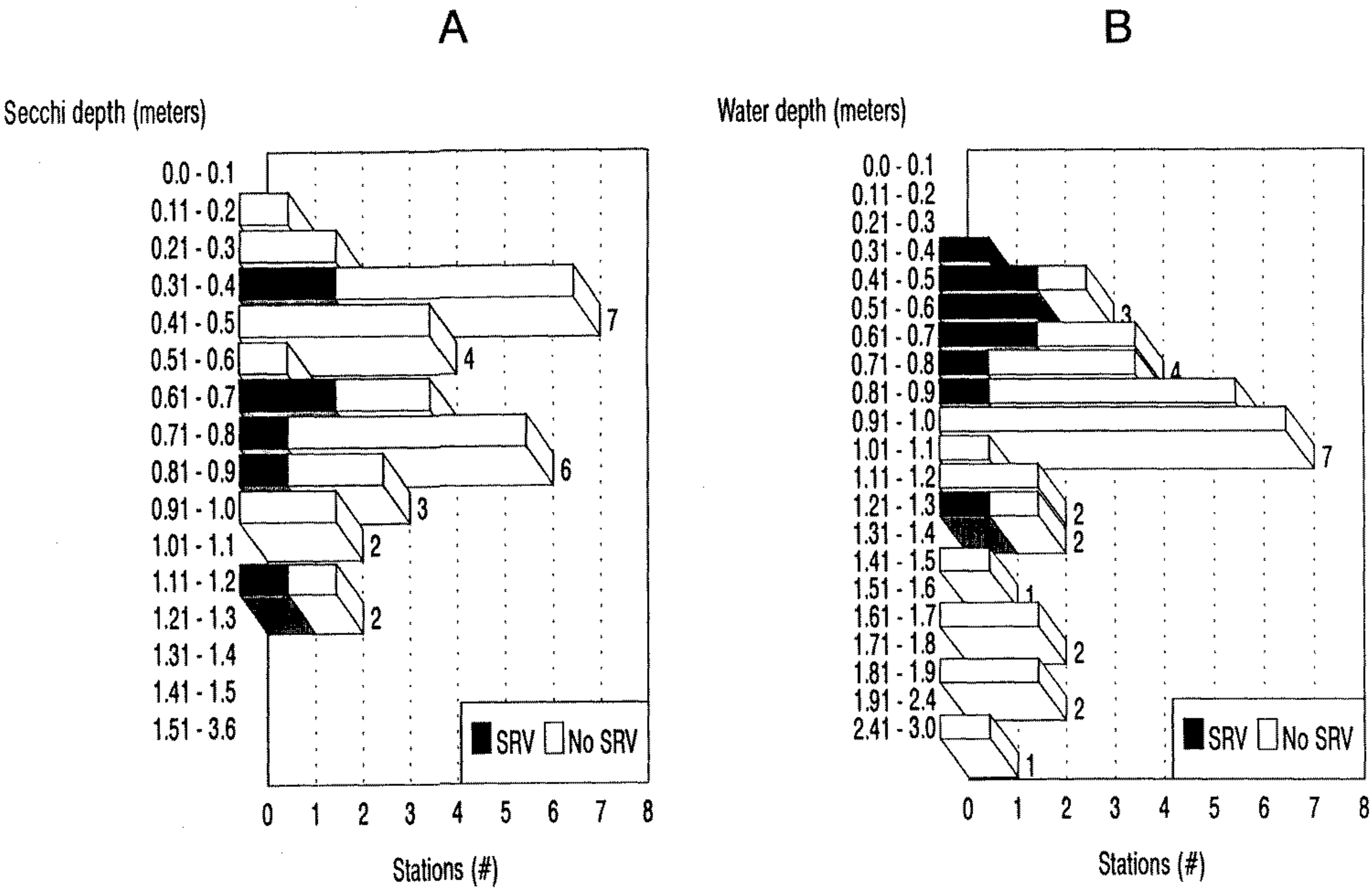


Figure 17. Number of stations having or lacking SRV in the Roanoke/Croatan Subregion according to: (A) Secchi depth, (B) Water depth.

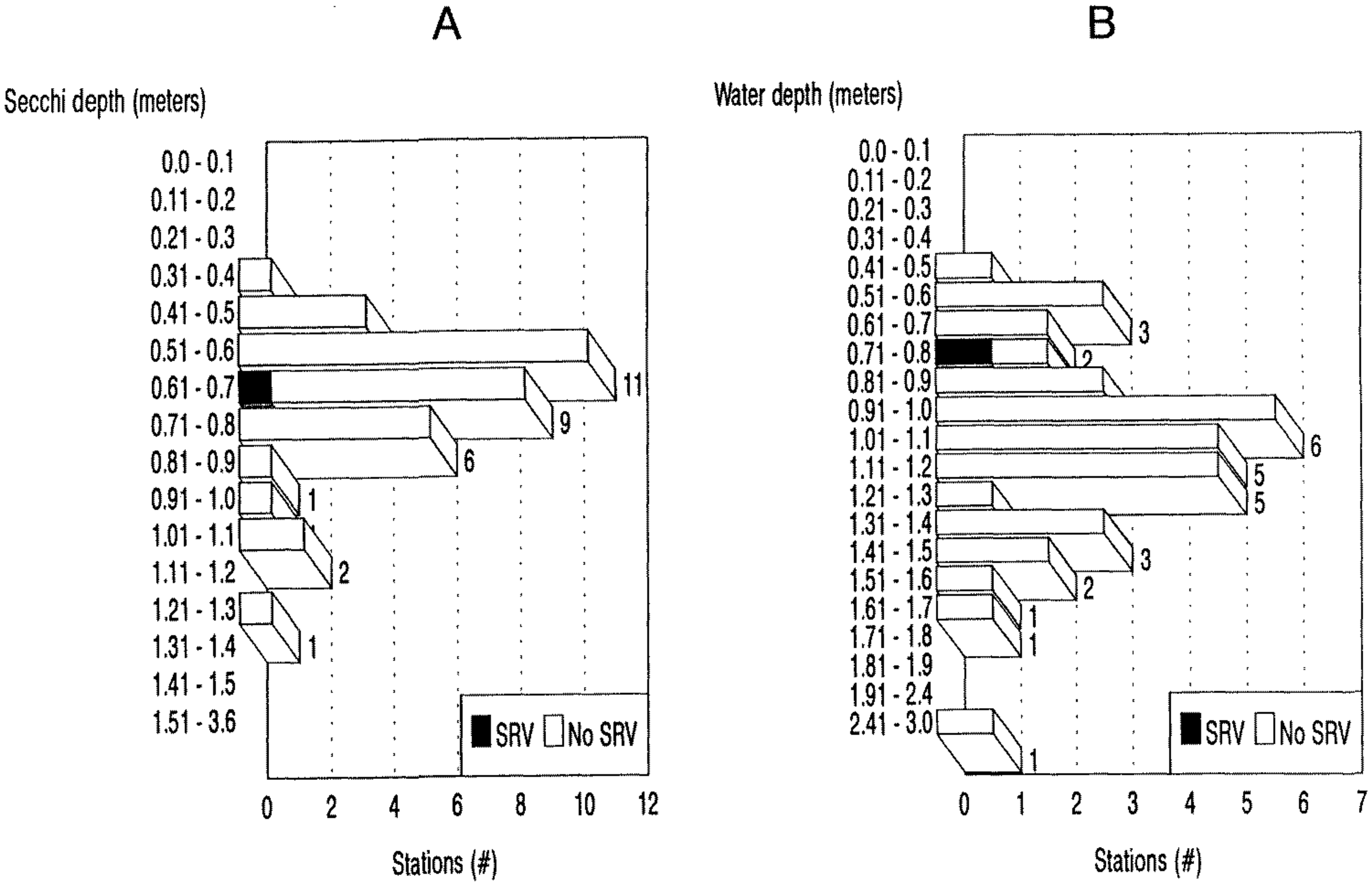


Figure 18. Number of stations having or lacking SRV in the Neuse River estuary according to: (A) Secchi depth, (B) water depth.

SRV was not widespread in the **Pamlico River estuary** Subregion and had a low diversity of species (Fig. 14, Table 3). Seven of the 44 stations, 15.9% (95% CI 0.1 to 12.9%) contained SRV. The two species observed were widgeon grass (1 station) and wild celery (6 stations). Salinity was negatively associated with distance upstream, averaged 9‰ and varied from 2 to 14‰. Unfortunately, salinity data were collected only at 8 of the 44 stations due to loss of the refractometer and water samples. Secchi depth was shallow, mean of 0.6m and had a small interval of observations from 0.5 to 1.0m. Most stations had Secchi depth readings of 0.5 to 0.7m; water depth sampled was 0.6 to 1.3 m and the depth interval positive for SRV was 0.8 to 1.2 m (Fig. 19a, b).

In the **western Pamlico Sound** Subregion SRV was not diverse and low in frequency of occurrence. Two of the 31 stations, 6.5% (95% CI 0.8 to 21.4%), contained SRV of the single species widgeon grass (Fig. 14). The mean salinity was 17‰ with an interval of 8 to 22‰. Secchi depth was somewhat deeper than the lower salinity bodies of water listed above. The mean Secchi depth was 0.9m and varied from 0.4 to 1.4m. Most of the stations had Secchi depth readings of 0.6 to 1.3m (Fig. 20a). Water depth of stations was 0.5 to 1.5m; maximum depth with SRV was 0.8m (Fig. 20b).

The **eastern Pamlico Sound** Subregion had ten times the frequency of occurrence of SRV observed in the **western Pamlico Sound** Subregion (Fig. 14). 68.6% (95% CI 59.8 to 77.3%) of the 121 stations sampled contained one or more of the three species of **high salinity** tolerant SRV. All three species were widespread and had

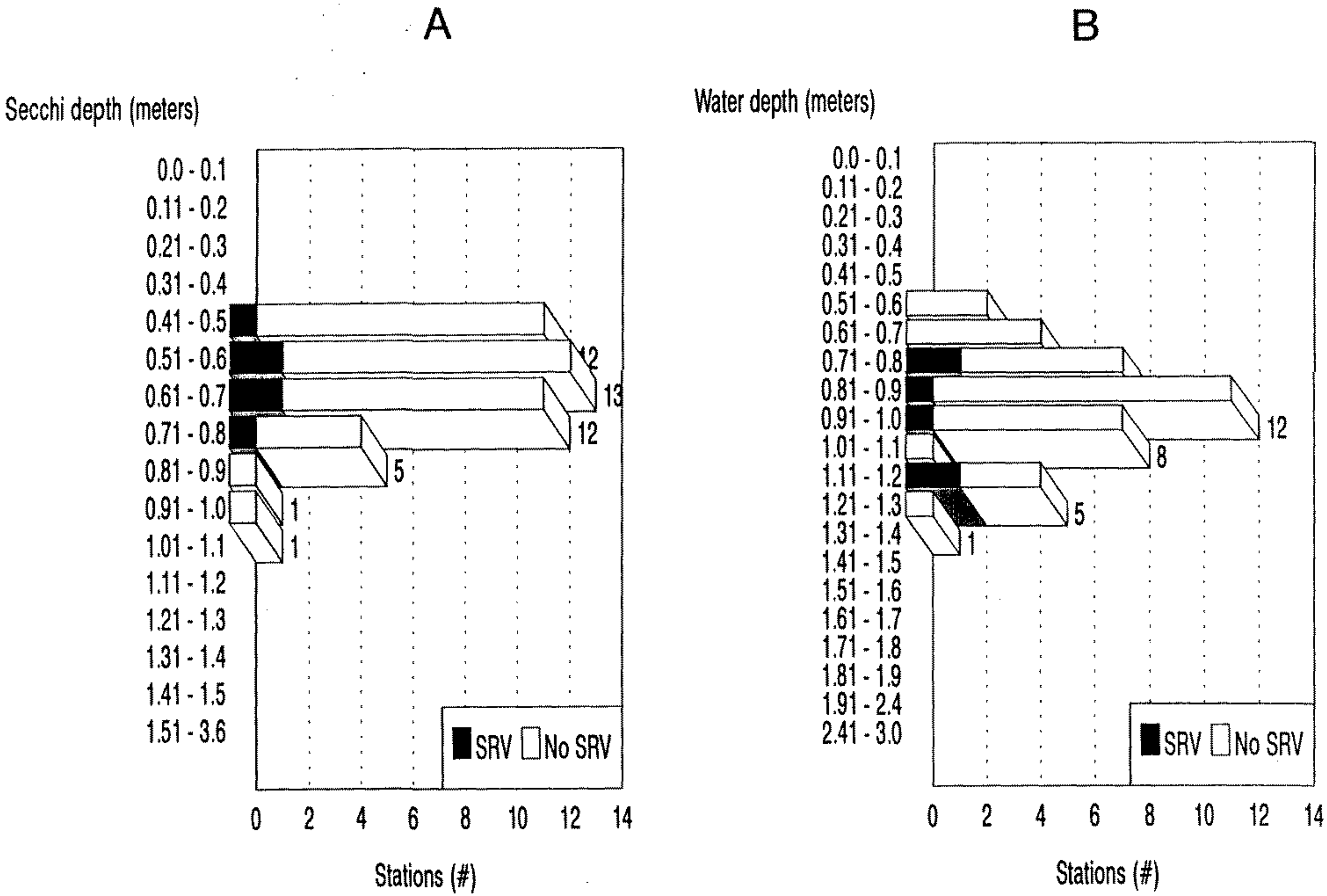


Figure 19. Number of stations having or lacking SRV in the Pamlico River estuary according to: (A) Secchi depth, (B) water depth.

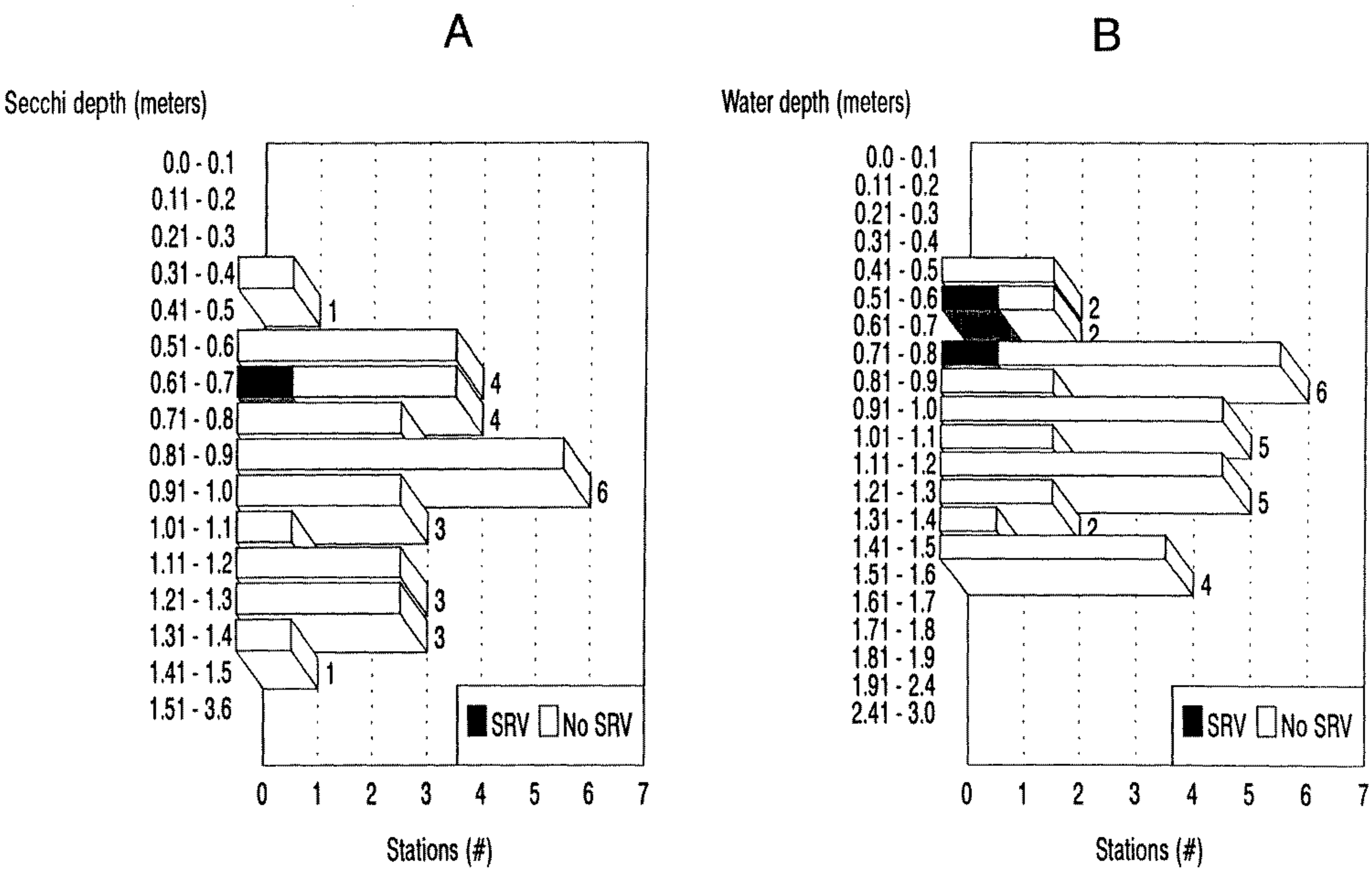


Figure 20. Number of stations having or lacking SRV in the western Pamlico Sound according to: (A) Secchi depth, (B) water depth.

high frequencies of occurrence: widgeon grass - 37.2%, shoal grass- 43.8%, and eelgrass - 53.7%. The salinity range of 26‰, interval of 4 to 30‰, was larger than that range 14 ‰, for **western Pamlico Sound**, but the mean salinities for the two Subregions, 18 and 17‰, respectively, were similar. The Secchi depth also had more deep values, deeper maximum values, 3.6 m (Fig 21a), and a deeper mean value, 1.1m, in the **eastern** than in the **western Pamlico Sound** Subregion (Table 3). Very importantly, 52.9% of the stations in **eastern Pamlico Sound**, and a substantial number of the stations sampled in the other **high salinity** subregions, **Core** and **Bogue**, were too shallow or too clear to obtain a Secchi depth reading; *i.e.* the Secchi disc was visible on the bottom. Of the stations lacking Secchi depth data within the **eastern Pamlico Sound**, 68.4% had SRV compared to 68.6% of all stations, indicating that SRV was frequently present throughout the subregion whether or not Secchi depth measurements were made. SRV occurred at water depths from 0.3 to 2.4m (Fig. 21b).

The **Core** Subregion had a high frequency of occurrence of SRV (Fig. 14). SRV was observed at 69.5% (95% CI 59.0 to 79.5%) of the 82 stations . All three species of **high salinity** tolerant SRV (widgeon grass, shoal grass and eelgrass) were observed. The frequency of eelgrass was highest - 64.6%, followed by shoal grass - 43.9%, and widgeon grass - 20.7%. The salinity interval was 15 to 38‰ and the mean salinity was 30‰. Mean Secchi depth was 1.0m but 61.0% of the stations were too shallow to obtain Secchi depth data. Most Secchi depth readings exceeded 0.8m (Fig. 22a).

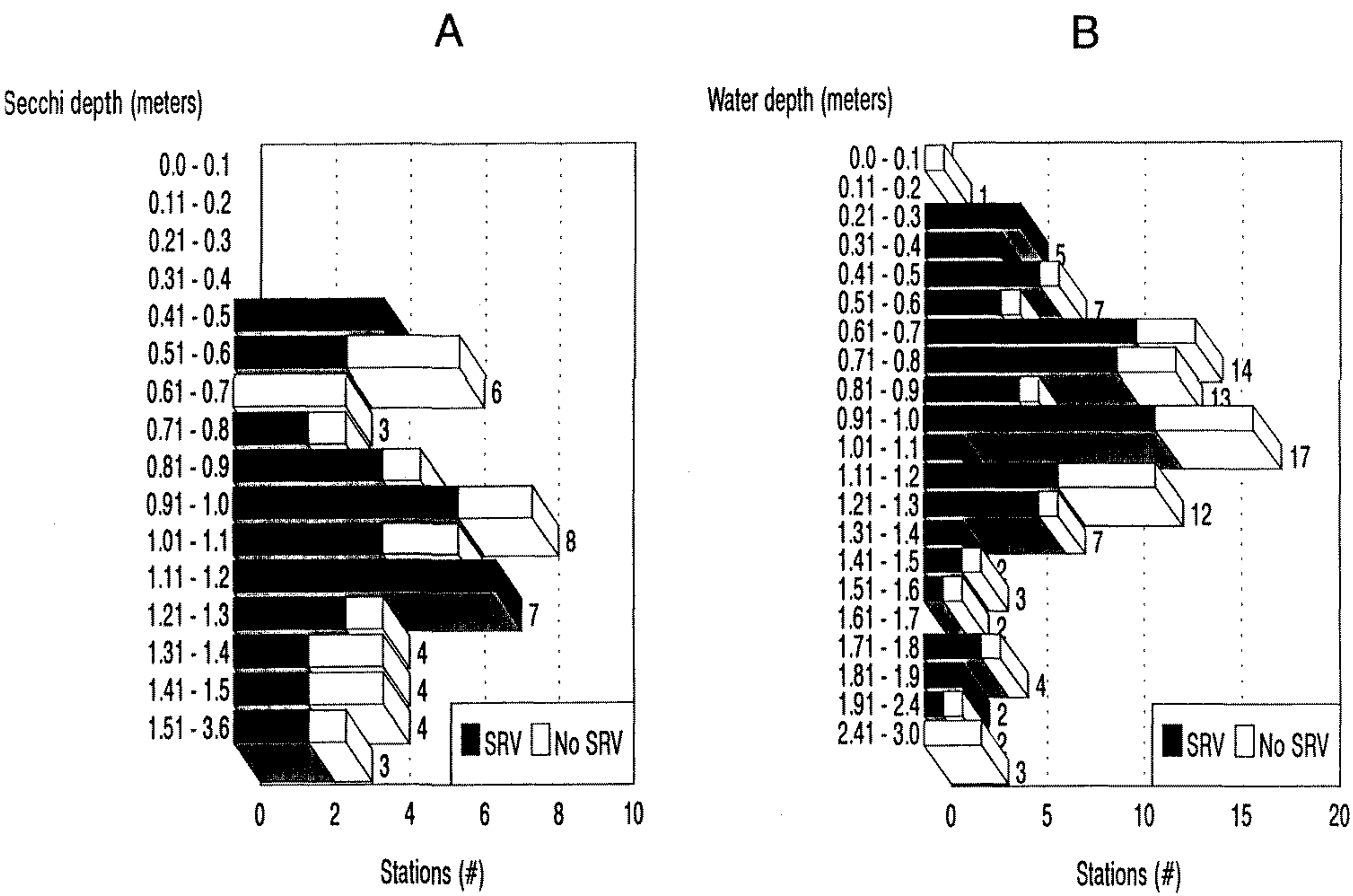


Figure 21. Number of stations having or lacking SRV in the eastern Pamlico Sound according to: (A) Secchi depth, (B) water depth.

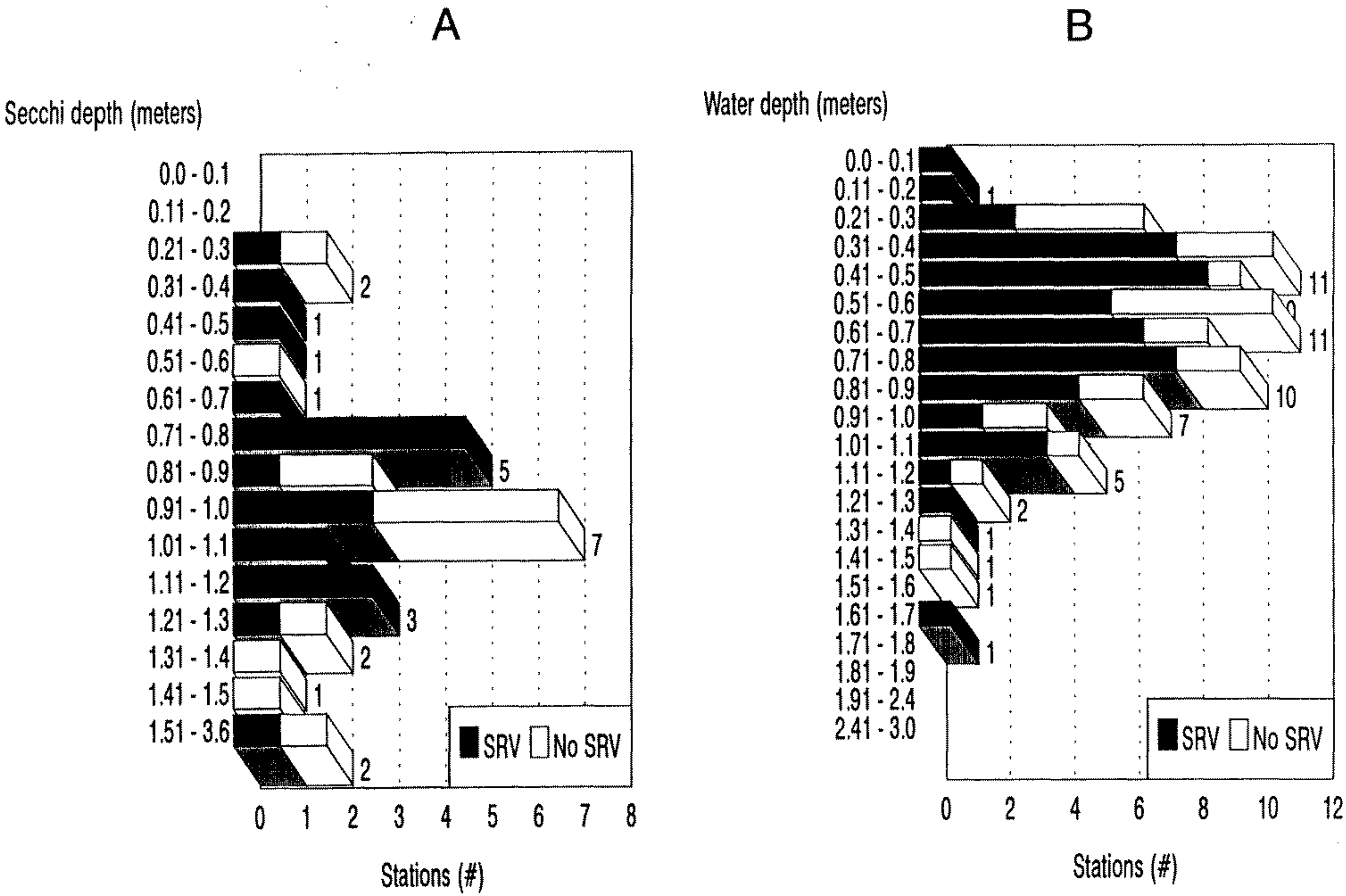


Figure 22. Number of stations having or lacking SRV in the Core Subregion according to: (A) Secchi depth, (B) water depth.

Stations too shallow and/or clear to obtain Secchi data had a frequency of occurrence of 74% compared to 69.5% for all stations within the subregion. SRV occurred over the entire interval of water depths sampled, 0.1 to 1.7m (Fig. 22b).

The **Bogue** Subregion had a high frequency of occurrence of SRV (Fig. 14), 64.5% of the 67 stations (95% CI 51.3 to 75.2%). All three species of **high salinity** tolerant SRV (widgeon grass, shoal grass and eelgrass) were observed. The frequencies of shoal grass - 55.2% and eelgrass - 52.2% were high but the frequency for widgeon grass - 3.0%, was low. The salinity interval was narrow, 28 to 37‰ and the mean 33‰ was the highest in the study area. Mean Secchi depth was 0.9m but 62.7% of the stations were too shallow to obtain Secchi depth data. The most frequently observed Secchi depth was 0.9m (Fig. 23a). SRV was found at stations with Secchi depth values of 0.4 to 1.9m. Of the stations too clear and/or too shallow to obtain Secchi data, 68% of the stations also had SRV compared to 64.5% for all stations in the subregion. Water depths of 0.4 or 0.5m were most often sampled and these stations frequently had SRV (Fig. 23b). The water depth range for SRV was 0.3 to 2.0m.

Aerial Photographic Inventory.

<u>Status.</u> The aerial photographic inventory of SRV has four distinct phases: 1) photography, 2) interpretation of photographs, 3) registration of photographic data to external geographic reference system, and 4) digitization. The inventory is

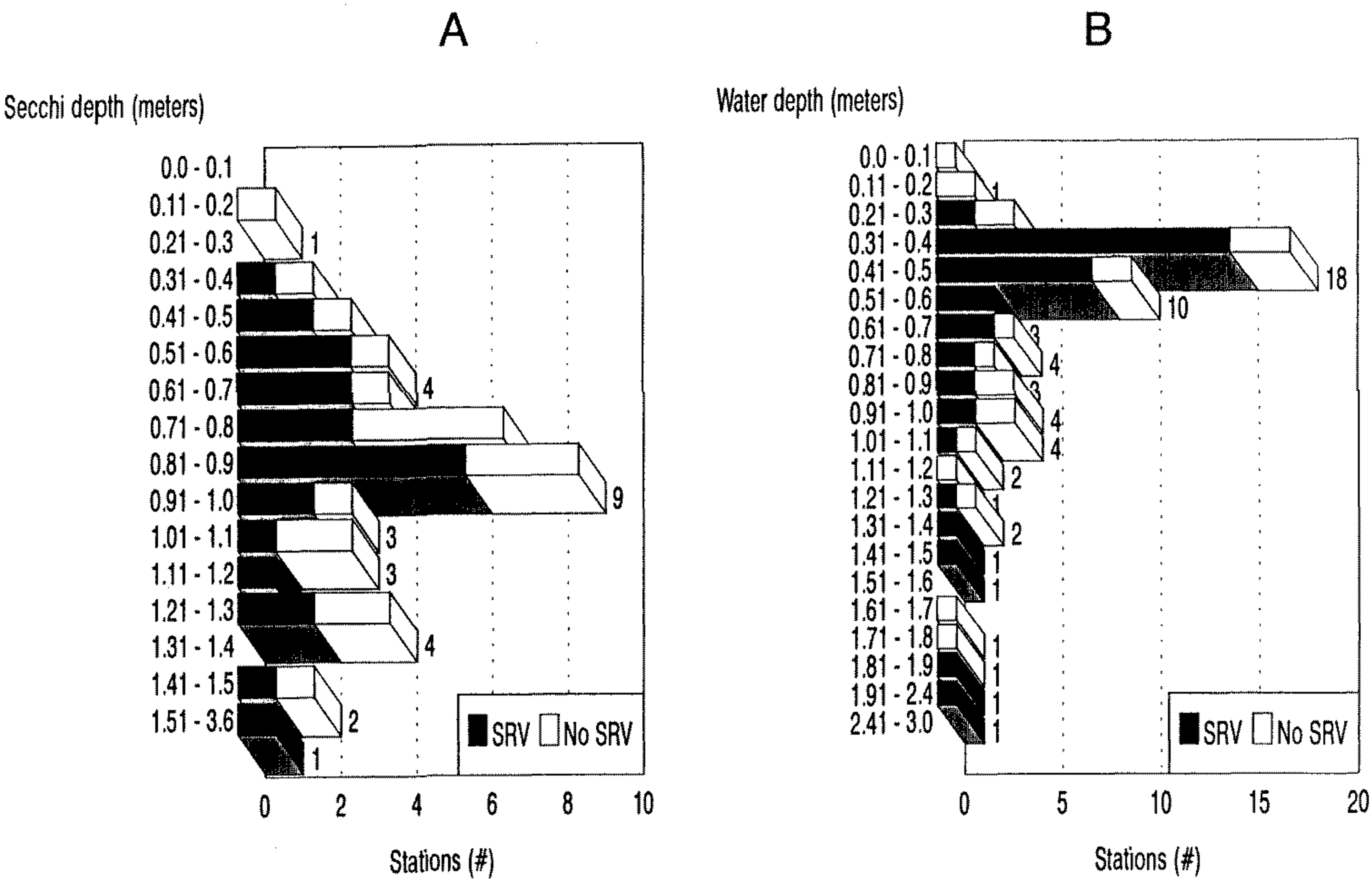


Figure 23. Number of stations having or lacking SRV in the Bogue Subregion according to: (A) Secchi depth, (B) water depth.

complete for six of the nine Subregions of the Albemarle-Pamlico Estuarine System and is complete for six of the seven Subregions funded by the Albemarle-Pamlico Estuarine Program. The completed subregions are: **Albemarle**, **Roanoke/Croatan**, **Neuse River estuary**, **Pamlico River estuary**, **western Pamlico Sound**, and **Core**. **Currituck**, **eastern Pamlico Sound**, and **Bogue** Subregions are incomplete. The photographic phase is complete for the entire study area. All nine subregions have been photographed. Interpretation is not complete for the **Currituck** region. Interpretation is complete for Ocracoke Island but not for most of the **eastern Pamlico** subregion or for the **Bogue** subregion. Registration of the photographic data for **Currituck** requires NOAA/NOS shoreline maps. As of 3/94 we have received and approved one prototype map and expect delivery of the final maps from Virginia to Duck, NC, in April, 1994, and from Duck to Avon, NC in May, 1994. SRV habitats for a small part of the **eastern Pamlico Sound** Subregion: Oregon Inlet, Long Bay, Point of Marsh, and North Bay map areas are digitized. Acreage for the Pea Island represents only those parts of polygons in the Oregon Inlet map which extend into the Pea Island map. SRV data for the **eastern Pamlico Sound** Subregion, from Oregon Inlet to Ocracoke Inlet, and for all of the **Bogue** Subregion will be registered on NOAA/NOS base maps as they become available. These data, as completed, will be transferred to NC-CGIA for digitization and mensuration.

SRV Acreage. The total area of SRV in the six completed subregions of the study area is 29,559.9 acres (Table 5). SRV

Table 5. Acreage of SRV determined from aerial photography in the Albemarle-Pamlico Estuarine System by water body and USGS 7.5' topographic map area.

SUBREGION	USGS 7.5' MAP BASE[1]	SRV
		(ACRES)
ALBEMARLE	MANNS HARBOR	74.30
	FORT LANDING	681.39
	WEEKSVILLE	54.82
	STEVENSON POINT	245.36
	NIXONTON	426.16
	YEOPIM RIVER	89.22
	KITTY HAWK	1,734.46
	HERTFORD	470.95
	HARVEY NECK	662.28
	SUBTOTAL	4,438.94
CURRITUCK[2]	NOT AVAILABLE	
ROANOKE/CROATAN	MANTEO	610.66
	ROANOKE ISLAND NE	29.96
	EAST LAKE	285.77
	SUBTOTAL	926.39
NEUSE RIVER	CHERRY POINT	1.45
	SOUTH RIVER	14.24
	BROAD CREEK	3.93
	ORIENTAL	1.10
	NEW BERN	70.04
	SUBTOTAL	90.76
PAMLICO RIVER	LOWLAND	7.88
	AURORA	0.27
	HACKNEY	43.60
	PAMLICO BEACH	4.72
	SOUTH CREEK	19.70
	BATH	24.79
	BLOUNTS BAY	271.15
	RANSOMVILLE	5.54
	SUBTOTAL	377.65

Table 5. Acreage of SRV in the Albemarle-Pamlico Estuarine System by water body and USGS 7.5 minute topographic map (Continued).

SUBREGION	USGS 7.5' MAP BASE[1]	SRV
WESTERN PAMLICO SOUND	SCRANTON	9.61
	MIDDLETON	3.93
	LITTLE FISHING POINT	0.16
	JONES BAY	9.25
	ENGELHARD NE	7.21
	WANCHESE	1.84
	LONG SHOAL POINT	0.55
	GREAT ISLAND	22.69
	PAMLICO POINT	27.71
	SUBTOTAL	82.95
EASTERN PAMLICO SOUND[3]	OREGON INLET	2,315.05
	LONG BAY	762.70
	POINT OF MARSH	24.72
	NORTH BAY	584.58
	PEA ISLAND	20.28
	SUBTOTAL	3,707.33
CORE	DAVIS	3,869.89
	CAPE LOOKOUT	84.99
	ATLANTIC	399.41
	WILLISTON	93.80
	HARKERS ISLAND	2,326.78
	WAINWRIGHT ISLAND	7,759.54
	STYRON BAY	1,206.11
	HORSEPEN POINT	4,195.37
	SUBTOTAL	19,935.89
BOGUE	NOT AVAILABLE	
	GRAND TOTAL	29,559.91

[1] Map bases not listed had no visible SRV in the aerial photographs.

[2] Data unavailable at this point due to lack of USGS 7.5' map bases.

[3] This listing does not include the vast majority of SRV in this subregion. Those which occur from Pea Island through Portsmouth Island have not been compiled on USGS 7.5' map bases. The data reported for Pea Island are for those sections of aquatic bed polygons which originated in the Oregon Inlet map base area and extended into the Pea Island map base area.

totaled 23,726.2 acres in **high salinity** water with 84% of that total from the **Core** Subregion. SRV totaled 5,833.7 acres in **low salinity** water with 76% of that total from the **Albemarle** Subregion. SRV are broadly distributed throughout shallow **high salinity** waters in the study area. The completion of the **Bogue** and **eastern Pamlico Sound** Subregions will greatly increase acreage estimates of SRV associated with **high salinity** water. A preliminary mensuration of SRV in **eastern Pamlico Sound**, from Oregon Inlet to Ocracoke Inlet, was completed at the request of the North Carolina Department of Administration. The mensuration was based on photointerpretation of 1:50,000 scale photographs registered to 1:100,000 scale base maps. The result was 89,454 acres of SRV. The **Bogue** Subregion also is known to have a substantial amount of SRV. Upon completion of the inventory the total area of **high salinity** SRV could exceed 115,000 acres.

The mapped acreage in **low salinity** is not large. SRV in the low salinity **Currituck** subregion will markedly increase the totals for **low salinity** water when these are mapped. In the **Albemarle** Subregion, the distribution of SRV was highly localized. Of the 24 USGS 7.5 topographic maps that include potential habitat areas in this subregion, only nine actually contained SRV. SRV areas for individual maps here varied from 54.8 to 1,734.5 acres for a total of 4,438.9 acres. In contrast, in the **Roanoke/Currituck** Subregion all three maps which comprise the subregion contained SRV habitat for a total of 926.4 acres. In the **Neuse River estuary**, 5 of the 9 map bases included some SRV but SRV was not abundant and totaled

90.8 acres. 77% of the SRV for the **Neuse River estuary** was present in the New Bern area map. In the **Pamlico River estuary**, 8 of 10 map bases contained SRV, and the total area of SRV was 377.6 acres. Of that total, 72% was found in the Blounts Bay area map.

Quality of the Photography

The 1990 flightlines included the **Currituck**, **Albemarle**, and **Roanoke/Croatan** Subregions. In general, the 1990 photography was adversely affected by white caps, turbidity, and sun glint. The overall quality of the photographic images and the SRV signatures were marginal. There was little contrast and sharpness, the result of heavy haze or fog, which caused overall graininess in the photographic images. Due to the windy conditions during photography, Perquimans River and the mouth of Alligator River were rephotographed in the fall of 1992 and 1991, respectively. SRV polygons interpreted from the 1990 photography are conservative, especially in those areas exposed to NE winds. In some locations SRV signature was visible in the photography but the spatial limits for that signature were indistinct. For those locations, if SRV was confirmed during field verification, points were drawn to indicate presence of SRV and these were qualified in the digital data base to indicate that SRV was present but with undetermined spatial extent. Such points appear in the spatial data base on the eastern and western shores of the **Roanoke/Croatan** Subregion and near Durant Island in the **Albemarle** Subregion.

The 1991 photography was significantly better than the 1990 photography. The 1991 flightlines covered the Subregions: **Pamlico River estuary**, **Neuse River estuary**, **western Pamlico Sound**, and **Albemarle**. Quality improvement was due to daily input from the photointerpreter to the flight crew during the mission, quality review of photography (photonegatives) during the mission, and rephotographing where necessary. Review of photonegatives and survey of the study area by boat revealed that SRV existed in many of the tributaries of Pungo, Pamlico, and Neuse River estuaries but that these could not be successfully photographed due to very dark colored water and sediments. The combination of dark colored water and a background of dark sediments resulted in gradients of color tones in the photographs that could not be interpreted as SRV signatures. Flightlines that covered those areas either were not flown or they were not reflown. There was some graininess present in the fall 1991 photography due to foggy conditions. The photointerpretations of the Neuse River agreed with the results of the field observations, both grid sampling and verification sampling. Due to sun glint and tree shadows along the shore, sections of the north and south shores of Pamlico River were rephotographed in 1992. A combination of 1991 and 1992 photography, therefore, was interpreted for Pamlico River. The difficulty of successfully capturing SRV in aerial photography of locations with dark colored water and hazy conditions made the photointerpretations of such areas conservative.

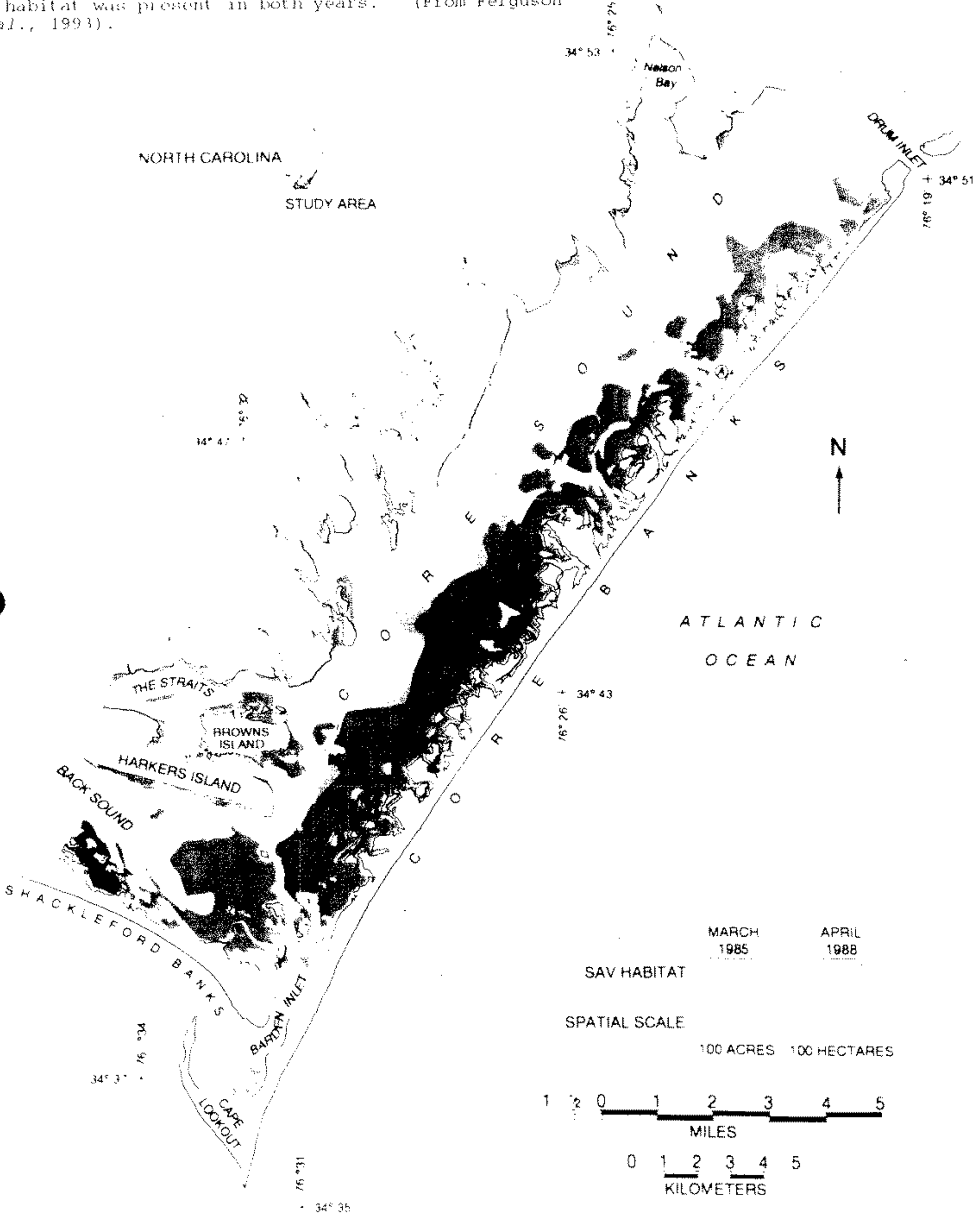
The 1992 flightlines covered the **Core** and **Bogue** Subregions, and parts of the following Subregions: **eastern Pamlico Sound** (West Bay), **western Pamlico Sound**, **Pamlico River estuary**, and **Albemarle** (Perquimans River) . As a result of choosing the best weather conditions to photograph the study area, the 1992 photography was superior to the 1991 photography. Calm, clear water conditions allowed the capture of distinct SRV signatures. In the 1992 photography, minimal white caps, turbidity, and sun glint optimized viewing of submerged features and the differentiation of SRV from non-SRV features. Although the quality of 1985 and 1988 photographs were good, the color tones and patterns which denote SRV were easiest to discern from non-SRV features in the 1992 photography of the **Core** and **Bogue** Subregions. Some of this improvement was due to switching from Aerochrome 2448 color positive to Aerocolor 2445 color negative film. The 1988 photography had an unnatural blue tone while the 1992 and 1985 photography depicts the submerged features in more natural color tones.

Change Detection and Assessment

The following text, included at the request of the Albemarle-Pamlico Program Office is taken with minor modifications from the publication by Ferguson, Wood and Graham, 1993. That publication assessed change between 1985 and 1988 in part of the **Core** Subregion. The publication differs from this report in an important way. The photographic data reported in the publication are georeferenced to NOAA/NOS shoreline data contemporary with the SRV data and not, as in the present report, to USGS 7.5′ topographic maps. As a result the positioning of the data reported in the publication is presumed to be more accurate than the data included in the present report. The decision to georeference photographic data to the USGS 7.5′ topographic maps was due to their nearly complete coverage of the study area. NOAA/NOS shoreline data still are available for only a small part of the study area. Shoreline photography was completed by NOS in 1991 and the resultant data will be the base map of choice as they become available over the next several years. The terminology of "Seagrass habitat" in the publication is equivalent with **high salinity** rooted vascular aquatic bed in Klemas (1993) and SRV in this present report.

> Seagrass habitat is a major resource in southern Core Sound, Back Sound, and The Straits, comprising *ca.* 35% of the subtidal land (Fig. 24). Total extent, location and size distribution of polygons of seagrass habitat was similar in 1985 and 1988. Total area of habitat changed less than 6% from 7030 hectares in 1985 to 6637 hectares in 1988. Polygons along the mainland and Harkers Island tended to be linear and close to shore. Large broad areas of seagrass habitat occurred in the subtidal shallows east of Browns Island, north of Shackleford Banks, and west of Core Banks. The total number of habitat polygons was similar in the two years, 151 in 1985 and 149 in 1988. Polygons tended to occur in the same approximate sizes, shapes and locations. Five percent of the polygons exceeded 48 hectares and 61 hectares in 1985 and 1988, respectively. The largest in 1985 was 4187 hectares but most were much smaller (mean of 1.6 hectares and median of 1.4 hectares). The largest in 1988 was 3189 hectares but most were much smaller (mean of 1.9 hectares and median of 1.6 hectares). The smallest unvegetated area mapped within seagrass habitat was 0.06 hectares.

FIGURE 24. Spatial distribution of SRV in southern Core Sound in 1985 and 1988. Head of The Hole (A), and Spoil deposition island (B). The dark areas are where the habitat was present in both years. (From Ferguson et al., 1993).



Locations of apparent gain or loss of habitat between the two years were re-examined to categorize these apparent changes: confirmed change with known cause, confirmed change with unknown cause, and unconfirmed change. Four locations of habitat loss were confirmed. Two of these were attributed to their causes. Mechanical harvest of clams, in North Carolina by a process called clam kicking, eroded bottom sediments with propeller wash to bring clams to the surface. This fishery (NC division of Marine Fisheries, 1988) eroded seagrass habitat near Head of the Hole, in Core Sound (A in Fig. 24), and left characteristic scars. These scars were visible in the photographs and were confirmed by site visit. In early 1988, a dredging operation (Wilmington District Corps of Engineers, 1987) buried seagrass habitat when uncontained spoil was deposited on a spoil island (B in Fig. 24). The northward expansion of the spoil island, shallowing of open water and burial of seagrass was observed by M. Fonseca (personal communication). Losses of seagrass habitat in Back Sound and in The Straits (Fig. 24) were confirmed by site visit, but these losses were due to unknown causes.

Some instances of apparent habitat increase between 1985 and 1988 remained unconfirmed because of limitations in the 1985 photographs and absence of surface level surveys in 1985. The presence of visual clues in photographs that were consistent with unvegetated bottom was sufficient to delineate with certainty, in most cases, edges of seagrass habitat. Unfortunately, photographic coverage in 1985 was not complete for parts of central Core Sound due to the limited foot print of the 1:20,000 scale photographs and apparent increases there could not be confirmed. In addition, benthic features were partially or totally obscured by turbidity in a few locations in 1985. In 1988, the photographic scale was reduced to 1:24,000 which improved coverage and photography was delayed until after the end of the season for mechanical harvest of clams (N.C. Division of Marine Fisheries, 1988), a major source of turbidity. Apparent increase in seagrass habitat which could not be confirmed was in Nelson Bay (Fig. 24). Local turbidity plumes from small creeks were visible in the 1985 photographs and these may have obscured habitat.

Application of the Data

The fifth objective of this research was to be responsive to state and federal habitat managers requesting information and data pertinent to decisions on water use management and conservation of living resources including SRV. This objective was met. As a result of the improved availability and cartographic quality of inventory and change data of SRV, available from NOAA/NMFS through NC-CGIA, planning and permitting activities in the Albemarle-Pamlico Estuarine System are being conducted with an improved resource information base. One example has been reported above (See "Results of the Inventory" Section, above). Two examples of the integration of spatial SRV aquatic bed data with dredging activities sponsored by the North Carolina Department of Transportation and by the US Army Corps of Engineers, Wilmington District follow.

The North Carolina Department of Transportation (DOT) sought a permit to obtain sediment from Pamlico Sound to reinforce State Highway 12 on the Outer Banks near Buxton, NC. One consideration was the possible direct impact on SRV, known to be abundant on the Pamlico Sound side of the Outer Banks. SRV data, based on 1988 photography, was supplied by us to NC-CGIA and combined by them in a GIS with differentially corrected GPS positions of the proposed borrow area. The GPS data were collected by DOT in the vicinity of Canadian Hole, NC. The combination of the 1988 photographic and 1993 GPS data in the GIS demonstrated the absence of historical and contemporary SRV within the proposed borrow area (Fig. 25). The

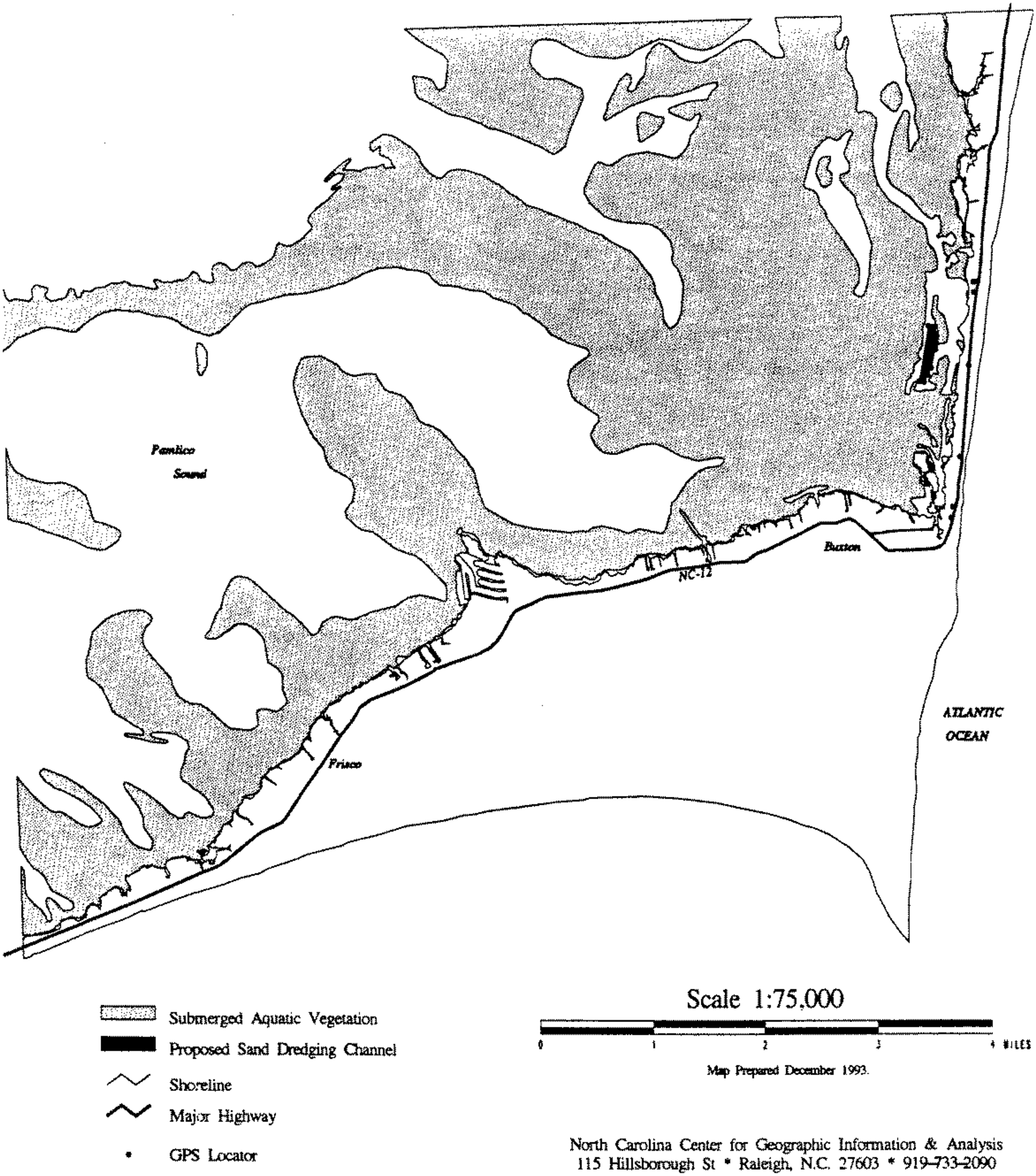


Figure 25. Potential sand borrowing area mapped with GPS by the North Carolina Department of Transportation and its proximity to photographically mapped SRV habitat. Data overlay accomplished in a GIS by the North Carolina Center for Geographic Information and Analysis.

field observations also confirmed the absence of SRV in 1993 in the proposed borrow area. Removal of the sediment from the borrow area, therefore, would involve no direct loss of SRV. The permit was approved and has been implemented.

The US Army Corps of Engineers (COE) may propose to dredge a navigation channel from Core Sound to the Atlantic Ocean through Drum Inlet. SRV are known to occur near Drum Inlet. To improve their planning process, COE requested historical SRV data from us. The preliminary map created by COE demonstrates the position of one possible channel and its avoidance of mapped SRV (Fig. 26). Note the highly mobile shoreline at the inlet.

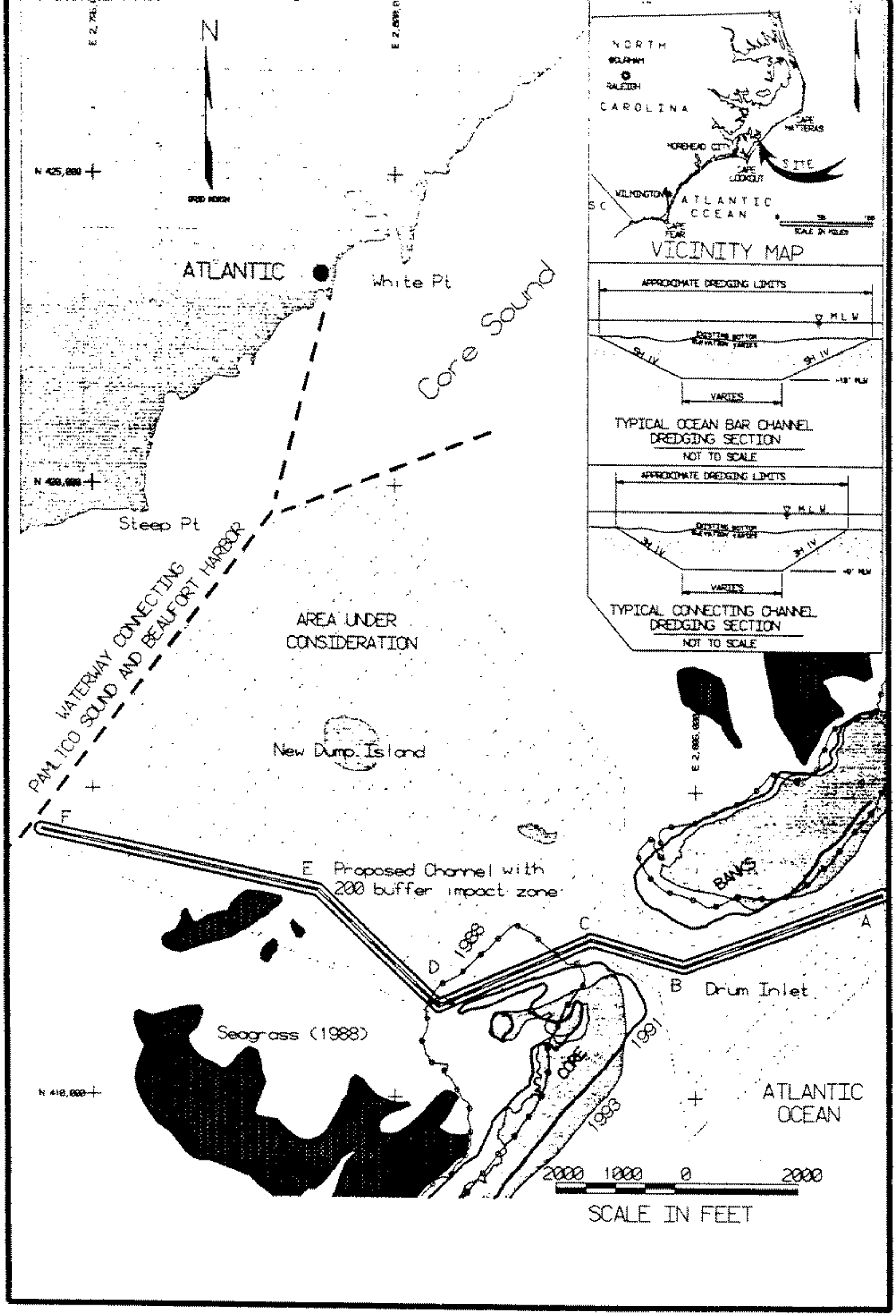


Figure 26. Proximity of mapped SRV habitat to U. S. Army Corps of Engineers preliminary proposed dredging at Drum Inlet, North Carolina

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APPENDIX

SUMMARY OF AQUATIC BED DATA AT NC-CGIA

NCCGIA Data Layer Summary

AQUATIC BED/ROOTED VASCULAR

Data Layer Description:	Polygon data (and 8 point features) depicting areas of Aquatic Beds of Rooted Vascular Plants predominantly submersed rooted vasculars (SRV) but including some floating rooted vasculars (FRV). The nomenclature and definitions for all data described here are consistent with V.V. Klemas, J.E. Dobson, R.L. Ferguson, and K.D. Haddad. 1993. A Coastal Land Cover Classification System for the NOAA CoastWatch Change Analysis Project. Journal of Coastal research 9(3):862-872.
Source Agency:	National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Beaufort Laboratory, Southeast Fisheries Science Center, Beaufort, North Carolina.
Source Agency Contact:	Dr. Randolph L. Ferguson
Source Agency Phone:	(919) 728-8743 or (919) 240-2876
NCCGIA Staff:	Michael D. Rink, Ken Shaffer, Zsolt Nagy
Project:	APES/272
Geographic Extent:	Albemarle/Pamlico Estuarine Study area plus the area from Bogue Inlet south to the border with South Carolina
Final Digitization Date:	November 9, 1993 (for coverage 1, see comments section for additional coverages)
Revision Date(s):	None (for coverage 1, see comments section for additional coverages)
Library Name:	/statsp
Coordinate System:	N.C. State Plane
Source Media:	USGS 7.5' topographic or NOAA, NOS Shoreline base maps (1:24,000-scale); NOAA, NOS; Photogrammetry Branch-Photography (1:12,000 to 1:50,000 but predominantly 1:20,000 or 1:24,000) (see comments section)
Source Map Dates:	See comments
Archive Tape:	TBD

Data Use Restrictions:	Users are advised to refer to publications listed in the comments section or communicate with Source Agency Contact prior to use of this data. **CAUTION**: the area within the Manns Harbor and Wanchese 24 k quads contain 8 points of SRV habitat location. They indicate photointerpreted presence of SRV habitat but not the spatial extent of that habitat. (See Comments Section for coordinates).
Extension Tables:	None
Approximate File Size:	675,000 bytes

NC.24.SRV.PAT Polygon Attribute Table - Item Definitions and Description

ITEM NAME	INTERNAL WIDTH	OUTPUT WIDTH	ITEM TYPE	DECIMAL PLACES	ALTERNATE NAME	DESCRIPTION
AREA	4	12	F	3		Total area in coverage units
PERIMETER	4	12	F	3		Total perimeter in coverage units
NC.24.SRV#	4	5	B	-		Polygon internal identification number
NC.24.SRV-ID	4	5	B	-		Polygon user identification number
PHDATE	4	4	I	-		Date of photography
SRV#	4	5	B	-		SRV identification number
ACRES	4	12	F	3		Acres per polygon (This item must be recalculated whenever this data is altered)
METHOD	35	35	C	-		Data collection method by which SRVs were identified
TYPE	3	3	C	-		Type of rooted vascular (submersed or floating)

No arc attribute table exists for this coverage.

No point attribute table exists for this coverage.

Other Specifications

Coordinate Processing Specifications:

map units:	feet
precision:	single
fuzzy:	1.00
dangle:	10.0

Cartographic Specifications:

Look up table:	None
Annotation:	None
Cartosets:	None

Comments: PHOTOGRAPHY DATES, PHOTOGRAPHY AND BASE MAP SCALES AND RELEVANT PUBLICATIONS BY COVERAGE
Each of the subdivisions below relate to a unique Coverage in this data layer.

1.) The most comprehensive (as of April, 1994) coverage of aquatic bed data (/statsp/nc.srv), based on USGS 7.5'.topographic 1:24,000-scale maps (except Kitty Hawk - 7.5' USGS Orthophotoquad), contains SRV and FRV plant areas as depicted by Dr. Randolph L. Ferguson and Lisa L. Wood from 1985, 1988, 1990, 1991 and 1992 photography listed below. The vast majority of polygons are SRV. The few FRV polygons are restricted to East Lake (east of Alligator River and south of Albemarle Sound). Eight locations of SRV habitat are designated as point data. Points indicate the photointerpreted location but not the areal extent of SRV).

Coordinates in degrees, minutes, seconds for the 8 buffered points:

35	56	15.06	75	48	45.19
35	52	37.66	75	45	11.56
35	54	48.81	75	46	13.07
35	49	45.97	75	40	31.19
35	49	50.86	75	40	26.00
35	49	51.65	75	39	28.27
35	49	22.47	75	39	38.23
35	49	20.63	75	39	25.86

Each 7.5' map has the photography date in the attribute table. The inventory based on published 7.5' topographic maps is complete for the study. For coverage of the area of Currituck Sound for which 7.5' topographic maps were not available see No. 5 below. References include: Ferguson, R.L., J.A. Rivera, and L.L. Wood, 1990. Submerged Aquatic Vegetation in the Albemarle-Pamlico Estuarine System, Project No. 88-10; and Ferguson, R.L. and L.L. Wood, 1990. Mapping Submerged Aquatic Vegetation in North Carolina with Conventional Aerial Photography, (eds.) S.J. Kiraly, F.A. Cross and J.D. Buffington, Federal Coastal Wetland Mapping Programs, U.S. Fish and Wildlife Service Biological Report 90(18) 125-132.

1985 photography (1:20,000-scale), (1989 APES/NOAA) - Cape Lookout, Harkers Island, Horsepen Point, Davis, Styron Bay, Atlantic. 1990 photography (1:20,000-scale), (1991 APES/NOAA)-Elizabeth City, Shiloh, Nixonton, Weeksville, Wade Point, Camdem Point, Edenhouse, Edenton, Yeopim River, Harvey Neck, Stevenson Point, Albemarle Sound 1, Albemarle Sound 2, Kitty Hawk, Westover, Roper North, Leanards Point, Columbia West, Columbia East, Fort Landing, East Lake SE, Manns Harbor, Manteo, Roanoke Island NE, Frying Pan, Buffalo City, Wanchese, Oregon Inlet, Fairfield NE, Engelhard NW.

1991 photography (1:20,000-scale), (1993 APES/NOAA) - Englehard NE, Stumpy Point, Washington, Bunyan, Pantego, Belhaven, Ponzer, Engelhard E, Little Fishing Point, Pamlico Sound 2, Hackney, Blounts Bay, Bath, Ransomville, Pamlico Beach, Scranton, Swanquarter, Middleton, Middletown Anchorage, South Creek, Lowland, Pamlico Point, Great Island, Bluff Point, Pamlico 7, Vandemere, Jones Bay, Little Fishing Point, New Bern, Upper Broad Creek, Orient, Broad Creek, Havelock, Cherry Point, Merrimon, South River.

1992 photography (1:20,000-scale), (1993 APES/NOAA) - Blounts Bay, North Bay, Point of Marsh, Long Bay, Atlantic.

2.) Data on aquatic beds generated to meet a special request from NC Dept. of Administration related to possible exploratory drilling for natural gas by Mobile Oil Company (/stats/???). Aquatic bed data based on 1:100,000-scale USGS maps for Dare and Hyde Counties with areas of rooted vascular plants denoted from 1:50,000-scale photography by R.L. Ferguson and L.L. Wood. These data are considered preliminary due to the small scale of the photographs and map base, and will be superseded with more accurate data (see No. 5 below). Refer to the Albemarle/Pamlico Estuarine Study, Submerged Aquatic Vegetation in the Albemarle-Pamlico Estuarine System, Project No. 88-10, by R.L. Ferguson, J.A. Rivera, and L.L. Wood.

3.) From 1:24,000-scale 1981 NC DOT photography (listed below), there is a coverage (/statsp.cr.sav) of the Carteret County area depicting SAV data from the Carraway & Priddy SAV study, DEIP Report No. 20, R.J. Carraway and Loie J. Priddy, 1983 Mapping of Submerged Grass Beds in Core and Bogue Sounds, Carteret County, North Carolina, By Conventional Aerial Photography. Office of Coastal Management, Morehead City,NC, 86 p.
1981 Cape Lookout, Swansboro, Salter Path, Mansfield, Beaufort, Harkers Island, Horsepen Point, Davis, Stryon Bay, Wainwright Island, Portsmouth Island.

4.) Mapping of SRVs from Bogue Inlet to the border with South Carolina has not been initiated.

5.) Data registered to NOAA shoreline map bases (1:24,000-scale) and photography from 1:12,000 to 1:24,000-scale (/statsp/??). These data are in the process of being digitized or are awaiting transfer from interpreted photographs to map bases as the map bases become available. These data are more accurate and ultimately will supersede those described in Coverage 1 on (1:24,000-scale) 7.5' topographic or USGS Orthophotoquad map bases. The NOAA shoreline data are from photography (1988 through 1991) which is contemporary with the SRV photography and therefore more appropriate map base than the 7.5' map series which are most often based on photography from the 1940's. Orthophotoquads are more recent but as they do not delineate natural features such as shorelines, they are problematic map bases in remote areas with limited cultural features. NOAA shoreline data are being generated at this time for the entire coastline of North Carolina, as far inland as New Bern and Washington, for example, and will become available over the next few years. The area from Cape Lookout to Cape Hatteras is available now. The next group of shoreline data to be available from NOAA are from Oregon Inlet to the border with Virginia including all of Currituck Sound.