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Biogeochemical Studies of the Salt Marsh and a Barrier Island at Cape Romain National Wildlife Refuge, South Carolina

by

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Open-File Report 93-303

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1993

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EXECUTIVE SUMMARY

Product U.S. Geological Survey Open-File Report 93-303, 1993: Final Contract Report, "Biogeochemical Studies of the Salt Marsh and a Barrier Island at Cape Romain National Wildlife Refuge, South Carolina."

The U.S. Fish and Wildlife Service (FWS) is responsible for assessing the impact of atmospheric pollutants in wildlife refuges throughout the country. This report presents the study design, sampling methods, and chemical analysis procedures and results for cooperative biogeochemical studies between the FWS and the U.S. Geological Survey (USGS) at Cape Romain National Wildlife Refuge (CRNWR).

This report is divided into four chapters: (A) methods and results for the determination of baseline concentrations in *Spartina alterniflora* (smooth cordgrass) and associated sediments in the intertidal salt marsh; (B) methods and results for the determination of baseline element concentrations in soils and plants on Bull Island; (C) an integrated assessment of the biogeochemical studies at CRNWR, including stable sulfur isotope ratios, with respect to anthropogenic and natural sources of elements in vegetation, sediments, and soils; and (D) a data compilation of the raw chemical analysis results and a summary of quality control results obtained during the chemical analysis of the various samples.

These studies were initiated to help define baseline elemental concentrations in the predominant intertidal salt marsh plant species and associated sediments and barrier island plants and soils at CRNWR. In addition, spatial scales of chemical variability in plants and sediments are defined. A minor objective of the work was to examine seasonal variability in plant chemistry by sampling a subset of sites at two times during the year. Results of these studies are integrated into an assessment of the potential for the trace elements being derived from natural or anthropogenic sources.

Summary statistics and baseline 95 percent expected element concentration ranges are reported for *S. alterniflora* and associated sediments in the salt marsh and for *Tillandsia usneoides* (Spanish moss), *Pinus taeda* (loblolly pine), and surface soils on Bull Island. Element concentrations in plants and soils on Bull Island exhibited little spatial variability, whereas element concentrations in *S. alterniflora* and salt marsh sediments had significant spatial variability. The large spatial heterogeneity of element concentrations in the salt marsh media indicate that extensive sampling is required to reproducibly map or evaluate concentrations in these media.

All field sampling was completed before the destructive forces of Hurricane Hugo hit Cape Romain National Wildlife Refuge on September 21, 1989. Re-sampling is required to assess the effects of Hurricane Hugo and validate existing baseline element concentration ranges or establish new baseline ranges.

Although *S. alterniflora* is the dominant plant species in CRNWR and a major source of food in the estuarine detrital-based food chain, it may not be a good biomonitor for anthropogenic trace metals additions to this environment because of high turnover rates and relatively small metal uptake. In addition, sulfur concentrations in *S. alterniflora* and sediments were highly variable. Total sulfur concentration in these media is unlikely to be a useful monitor of anthropogenic sulfur additions owing to the great variability and the large oceanic input of sulfate.

The biogeochemistry of the vegetation, sediments, and soils at CRNWR indicate that this environment is not highly contaminated with anthropogenic additions of trace elements. Lead and nickel concentrations in Spanish moss and lead and copper concentrations in the salt marsh sediments may be symptomatic of anthropogenic additions of these elements.

Stable S isotope ratios of *S. alterniflora* and sediments indicate that dissimilatory sulfate reduction in the sediment is an important process controlling the isotopic signature of the *S. alterniflora*. Spanish moss and loblolly pine exhibited S isotope ratios that indicate seawater sulfate is not directly the predominant source of S for these two species. The isotopically light signatures of these plants compared to seawater S suggest an anthropogenic and/or a biogenic source of S. Although anthropogenic S emissions have been estimated to be a significantly greater source of S in the region than natural emissions, biogenic S flux is an important component of the salt marsh S cycle that is poorly understood and insufficient data are available to compare anthropogenic and natural sources of S at CRNWR. A better understanding of natural processes controlling the cycling of S and trace elements in the environments at CRNWR is required before the anthropogenic additions of elements can be accurately estimated.

Form of Product: USGS Open-File Report 93-303, Typed Report, 8½ x 11 inches, 137 pages, including 41 tables and 22 figures.

GEOGRAPHICAL NAMES

The nomenclature used throughout this report is consistent with the names used on the U.S. Geological Survey topographic map series and the U.S. Fish and Wildlife Service (FWS) Atlantic Coast Ecological Inventory map series. Bull Island and Bulls Bay are often referred to by the variants Bulls Island and Bull Bay, respectively. These variants are used and preferred by the local refuge.

ACKNOWLEDGEMENTS

This work was performed under Interagency Agreement #14-16-0006-87-928 between the USGS and the FWS with Wayne King (FWS) as contracting officer. We wish to express our appreciation to G. Garris, D. Browning, J. Loflin, L. Davis, the other members of the Cape Romain National Wildlife Refuge staff, W. Baldwin (III), and M.S. Gough for their assistance in the field work and to the members of the USGS Branch of Geochemistry for their assistance in chemical and mineralogical analysis.

CONVERSION FACTORS

Measurement values in the International (metric) System (meter/kilogram units) used in this report may be converted to the U.S. Customary System (inches/pounds units) by using the following factors:

To convert from	To	Multiply by
millimeter (mm)	inch (in)	0.03937
meter (m)	foot (ft)	3.281
	yard (yd)	1.094
kilometer (km)	mile (mi)	0.6214
hectare (ha)	acre	2.471
kilometer^2 (km^2)	mile^2 (mi^2)	0.3861
gram (g)	ounce avoirdupois (oz avdp)	0.03527
kilogram (kg)	pound avoirdupois (lb avdp)	2.205
liter (l)	quart (qt)	1.057

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Chapter A

Baseline Element Concentrations in *Spartina alterniflora* and Salt-Marsh Sediments at Cape Romain National Wildlife Refuge, South Carolina[1]

By Larry L. Jackson[2], Larry P. Gough, *and* R. C. Severson

ABSTRACT

Baseline 95 percent expected element concentration ranges were determined for *Spartina alterniflora* (smooth cordgrass) and sediments in the intertidal salt marsh ecosystem at Cape Romain National Wildlife Refuge for November 1987. Spatial and seasonal variability in element concentrations were examined for both sample media. Interelement relationships in *Spartina alterniflora* and in sediments were used to identify elements controlled by the same biogeochemical processes and to determine element enrichment in the sediments.

INTRODUCTION

This report describes biogeochemical studies in the intertidal salt marsh at Cape Romain National Wildlife Refuge. The primary objectives of this study were to determine baseline ranges and spatial variability in element concentrations in *Spartina alterniflora* Loisel. and the associated sediments. A minor objective was to examine temporal variability in these two media.

Cape Romain National Wildlife Refuge (CRNWR) is located about 32 km (20 mi) north of Charleston, South Carolina and extends northward about 35 km along the coast (Figure A1) to within about 30 km of Georgetown, South Carolina. The refuge contains approximately 13,800 ha (34,200 acres) of intertidal marsh, barrier islands, and small bays and about 12,100 ha of open water. Within this area, 11,200 ha of marsh, tidal creeks, and barrier islands are defined as wilderness in the National Wilderness Preservation System. CRNWR is also an integral part of the Carolinian-South Atlantic Biosphere Reserve (Hopkins-Murphy, 1989).

Inland and to the west of CRNWR is the Francis Marion National Forest, 81,000 ha of upland pine forests and bottomland tupelo and cypress swamps. To the south of CRNWR, closer

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[1] Chapter A of Jackson, L. L., editor, 1993, Biogeochemical studies of the salt marsh and a barrier island at Cape Romain National Wildlife Refuge, South Carolina: U.S. Geological Survey Open-File Report 93-303, 137 p.

[2] All authors at USGS, Box 25046, MS 973, DFC, Denver, CO 80225.

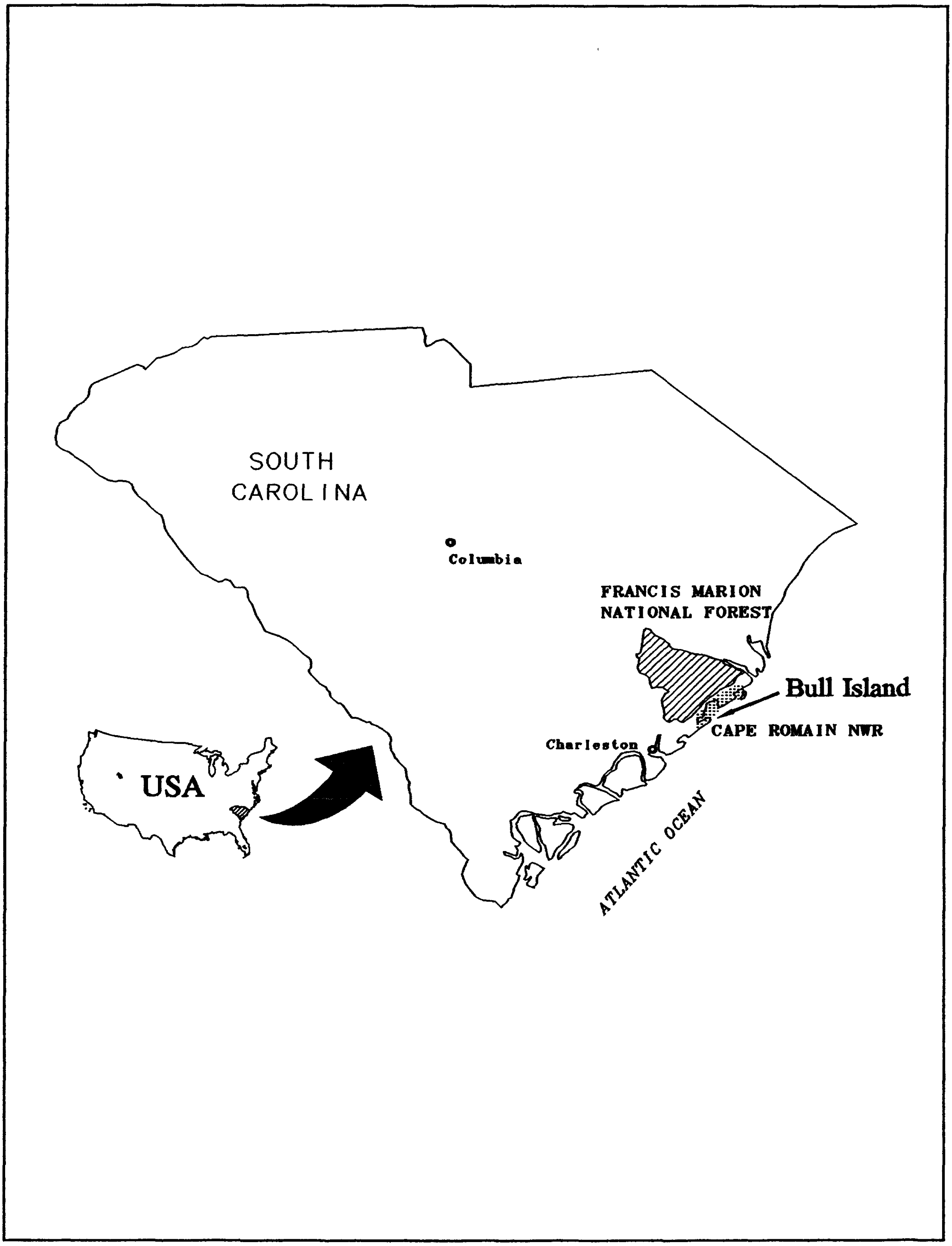

Figure A1. Location map for Cape Romain National Wildlife Refuge and Francis Marion National Forest, South Carolina.

to Charleston, is a narrow coastal zone of salt marsh protected by a series of transgressive barrier islands. Just to the north of CRNWR, two distributaries of the Santee River enter the Atlantic Ocean. Historically the Santee River had the fourth largest discharge on the East coast, draining about 40,000 km^2 of mostly Piedmont Province and a small amount of Atlantic Coastal Plain (Neiheisel and Weaver, 1967). The marshes and barrier islands of CRNWR were formed as part of the Holocene cuspate delta complex of the Santee River (Brown, 1977). In addition to the marshes, mud flats, and sand bars at the mouths of the distributaries, the shoreline components of the delta included Cape Romain as a cuspate foreland and Raccoon Key as an eroding beach-barrier complex. The extensive salt marshes of CRNWR developed in the protected areas behind these barrier islands and to the south behind Bull Island, currently the largest barrier island in CRNWR with about 1,800 ha, more than half of which is salt marsh. As is evidenced from the shape of many of the geomorphic features of the area, the littoral drift is southward along the coast.

During the early 1900's the Santee River had an average discharge of 525 m^3/sec. In 1942, the Santee-Cooper River diversion project was completed and the Santee River discharge was dramatically decreased with a minimum required flow of 14 m^3/sec, except during flooding. The remainder of the flow and a significant portion of the sediment load were diverted to Charleston harbor (Stephen and others, 1975, 1976; Kjerfve, 1976). After the diversion, the average discharge was 62 m^3/sec with salinity of 35 parts per thousand (ppt) in a salt wedge estuarine system at the mouths of the distributaries. Construction of the hydroelectric dams on the Santee River in the early 1900's began the retrogressive phase of the river's delta area and completion of the diversion project accelerated it (Stephen and others, 1976). In 1985 the rediversion of a large part of the Santee River's historic discharge back to the original river system was completed. Prior to the rediversion, it was estimated that the increased flow in the Santee River should result in an average discharge of 419 m^3/sec, increased sediment load, and restoration of the original freshwater regime with a salinity of about 1 ppt at the mouth of the distributaries (Kjerfve, 1976). Whereas the Santee River has been the fluvial source for much of the CRNWR sediment and the immature coarse beach sands of the northern barrier islands (Brown, 1977), the decrease in sediment load has undoubtedly had an impact on the eroding ancient deltaic complex. The nature of the impact on CRNWR of the rediversion is yet to be determined.

The CRNWR is composed of a number of complex ecosystems--the most extensive being salt marsh and to a lesser extent maritime forested barrier islands (Dames and Moore, 1985; Newman and Hart, 1982; Sandifer and others, 1980). The salt marsh is classified after the system of Cowardin and others (1979) as euhaline, estuarine, regularly flooded, persistent, emergent wetland with smooth cordgrass, *S. alterniflora*, as the dominant plant species. *S. alterniflora* is ubiquitous in salt marshes throughout the Atlantic and Gulf coasts from Newfoundland to Texas and usually grows in extensive monotypic stands where tidal submergence is the greatest. The plants grow to about 40 cm, including their inflorescence, in areas of high marsh or salt pans and up to a height of 2.5 m in low marsh areas (Duncan and Duncan, 1987). Flowering occurs between March and October depending on the location.

CRNWR is dominated by extensive areas of *S. alterniflora* linked by an intricate network of tidal creeks with a large tidal range. As one progresses southward along the coast from North Carolina to Georgia the tidal range changes dramatically from a microtidal to mesotidal system with the mean high tide at the mouth of the Santee River of 1.37 m (Stephens and others, 1976) and 1.6 m with average spring tides of 1.9 m and the highest tides exceeding 2 m at Charleston (Kana and others, 1984).

The climate in the region is reasonably mild with temperatures ranging from an average of 10°C in December to 27°C in July with winds predominately from the north in the winter and from the south and southwest in the summer (Brown, 1977).

STUDY DESIGN

The intertidal salt-marsh biogeochemical study at CRNWR was composed of three parts: (1) an orientation field study in October 1987 was used to familiarize us with the CRNWR ecosystems and to obtain preliminary data on the concentration and spatial variability of elements in the marsh plants and sediments; (2) the primary field study, a gridded field sampling of the emergent wetland within the wilderness area, was conducted in November 1987; and (3) a follow-up sampling of a few selected sites was completed in June 1988 to examine seasonal variability in elements in *S. alterniflora* and sediments.

Orientation Field Study--Fall, 1987

On October 7-9, 1987, an orientation study was conducted at CRNWR. This preliminary study focused on collecting a small number of samples to examine the spatial variability of elements in intertidal marsh *S. alterniflora* and associated surface sediments. This data was used as a guide in designing a subsequent, more detailed grid sampling study. A simple barbell sampling design (Severson, 1979) was used to establish eight study sites (Figure A2). The barbell design had major axes of about 26, 8, and 2 km. Four sites each were located in the northern and southern sections of the refuge. Replicate samples were collected 30 m apart and 3 m apart at four randomly located sites for each distance increment. Additionally, four samples were split in the laboratory, making a total of 20 samples each of *S. alterniflora* and sediment. These samples were analyzed for major, minor, and trace elements.

Primary Field Study--Fall, 1987

The primary field study sample collection was performed November 9-20, 1987. The objective was to determine the spatial variance and baseline values for elements in *S. alterniflora* and associated sediments in the intertidal marsh within the CRNWR Wilderness Area.

The CRNWR intertidal marsh area was divided into square cells with an area of 2.6 km^2 (1 mi^2) (Figure A3). The cells were established using a grid with an orientation point that was arbitrarily selected as latitude 33° 00' 00" N and longitude 79° 32' 30" with grid lines parallel to true north. The cells were identified by numbers 1-17 from south-to-north and by alpha characters A-S from west-to-east. The orientation point was the southwest corner of cell 10H. For field number encoding, those cells to the northeast of the orientation point were considered in the "north" section of the refuge, whereas those points to the southwest were in the "south" section.

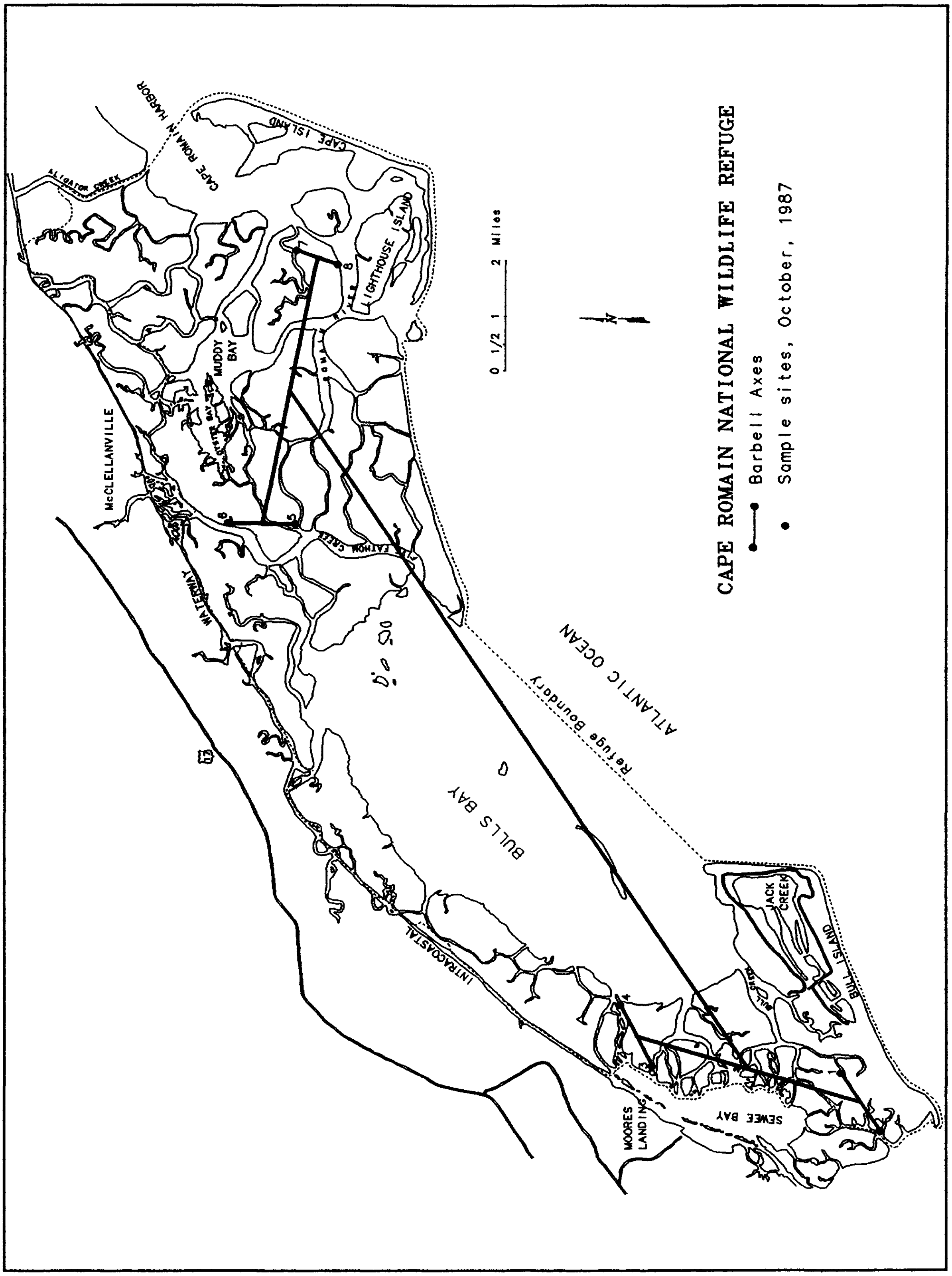

Figure A2. Location map for orientation study sample sites at Cape Romain NWR, October 1987.

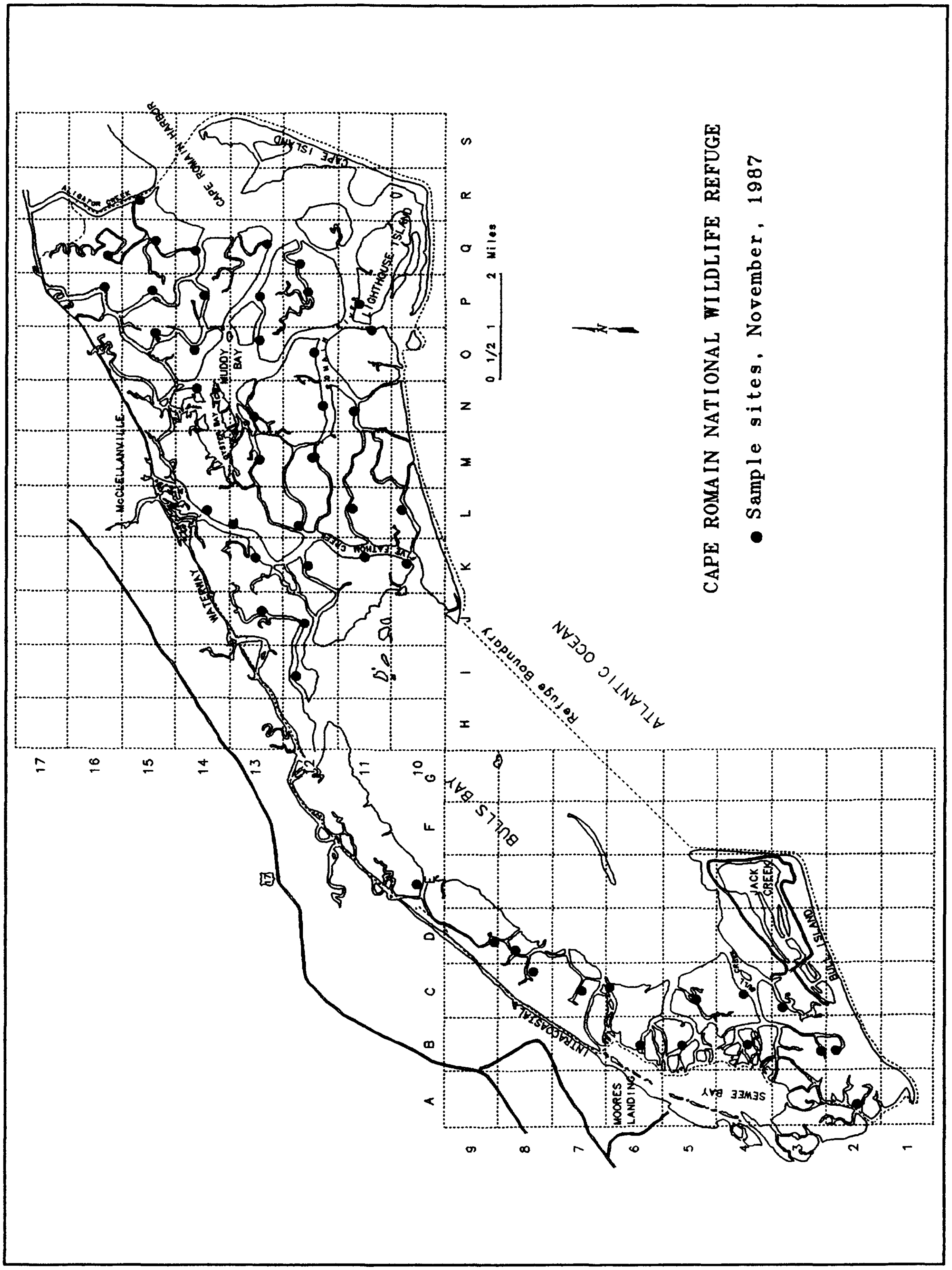

Figure A3. Location map for intertidal salt-marsh grid sample sites at Cape Romain NWR, November 1987.

Intertidal marsh grid cells were considered for sampling if they met the following criteria: (1) at least one half of the cell was in the CRNWR Wilderness Area; (2) at least one half of the cell possessed representative monotypic stands of *S. alterniflora*, mud flats, or open water; (3) the cell had a sample site that was not adjoined by the occasional forested island, or the sample site was at least 0.4 km from forested land; and (4) the cell had a sample site that was accessible. Fifty-four potentially suitable cells were identified from topographic maps (15 in the south section and 39 in the north section); of those, 12 of the potential cells were considered marginally suitable.

An unbalanced, hierarchical, analysis-of-variance (ANOVA) design was used for sample collection so that spatial variability within and among grid cells could be examined (Severson and Tidball, 1979). Within-cell replicate samples were collected at distances of 3 m apart or 30 m apart. Approximately one third of the cells were replicated at each of these distances. Additionally, about one third of the samples were split and analyzed in replicate. The within-cell replicate sites were chosen as every third cell sampled. These cells were considered randomly chosen because the sequence of cells sampled was dictated by the pattern and size of tidal creeks and the tidal fluctuations. In order to provide some comparisons of plant and sediment chemistry over time, seven of the eight sample locations sampled in the orientation study were included in the grid cell collection. Because one of the original orientation study sample sites was not accessible owing to the tidal conditions prevalent during the fall primary sampling trip, a nearby site was chosen as a replacement (11P).

Follow-up Field Study--Spring 1988

A follow-up field study was conducted from May 31 through June 2, 1988 (referred to as the June 1988 collection in the Tables). Eight intertidal-marsh sites were resampled for *S. alterniflora* and associated sediments using the barbell sample design and the different levels of sample replication outlined above for the original orientation field trip. Seven of these sites were identically sampled during the October and November 1987 collection trips. The eighth site was (13Q) sampled only in November 1987.

Surface water samples from the tidal creeks were also sampled at the eight intertidal-marsh sites using the barbell sample design. The primary objective of water collection at these sites was to examine potential differences in salinity and its influence on stable sulfur isotope ratios.

STUDY METHODS

Sample Collection

<u>Intertidal-Marsh Sample Collection</u> Sampling sites were chosen as the nearest accessible point to the center of each grid cell. However, the original sample sites from the orientation survey were resampled even though they may not have been near the center of the cell. Sample points were located about 10 m towards the center of the *S. alterniflora* stand from the tidal levee. Stands of short- to intermediate-form *S. alterniflora* (< 1 m) were sampled where possible. At each location a hoop of 1 m^2 area was positioned randomly in the stand. The number of

individual plants within about one quarter of this area was estimated, and the number of inflorescent stems and the average plant height without inflorescence were recorded. The sediment sample also was collected within the hoop. A 50-cm core section was extracted at each site with a peat-coring tool and a visual description of oxidized and reduced zones was recorded.

S. alterniflora culms (including the flowering stem above the uppermost leaves but without the inflorescent portion) and leaves were collected from 15-20 plants (approximately 50-80 g) and composited at each site in each of the three field trips. Only the material above the sediment encrusted tide mark (i.e., above about 20 cm) was collected. The plants sampled were within about 5 m of the sediment collection point. In June 1988, two composite samples at each site were collected; one sample, which included the senescent flower stem, and one sample, which included only the uppermost leaves and culms without the flower stem. The samples were stored in Hubco cloth bags.

Surface sediments (0-5 cm) were collected at 3 points within a 1 m^2 area using a plastic coring tip. Samples were composited and stored in plastic "whirl-pak" bags. The majority of any standing water in the sample bag was poured off in the field. Two-to-three hundred grams of water-saturated material were retained.

The latitude and longitude of each sample point were determined using a LORAN-C receiver (Spotlink Model SL-1000, Pathcor Div., Technology Projects, Ltd., Tempe, AZ). Locations were recorded to the nearest 0.01 minute. The LORAN-C receiver was calibrated daily at the shore end of the mainland refuge pier at Moores Landing. The reference latitude and longitude used for this point were 32° 56' 40" N and 79° 39' 46" W as measured from the 7½' USGS topographical map.

Surface-water samples from the main tidal creeks adjacent to the sediment and *S. alterniflora* sampling locations were collected at eight locations in June 1988. The grab samples were collected in pre-acid washed polyethylene bottles.

Sample Preparation[3]

Prior to preparation and analysis, samples were arranged in randomized suites with a maximum of 40 samples segregated by sample type. Analytical results and coding information are permanently archived in the USGS Rock Analysis Storage System (RASS).

All plant material was washed three times in deionized water by submerging in large beakers and manually agitating. The washed plant samples were then dried at 40°C for approximately 24 hr. The dried plant material was ground in a Wiley mill to pass a 2 mm screen. Sediment samples were air-dried at ambient temperature under forced air for 48 hours or more and then disaggregated in a ceramic mortar to pass a 10-mesh (2 mm) sieve. The sediment material passing through the sieve was further ground to pass a 100 mesh (0.15 mm) sieve using an agate shatter box. The >10-mesh material was discarded.

Sample duplicates were submitted to the laboratory within the randomized suites of samples. The duplicates were obtained by splitting the ground plant or sediment material in a Jones riffle splitter and were given unique field and laboratory identification numbers.

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[3] Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

Sample Analysis

All plant samples were ashed in Vicor crucibles at 450-500°C over an 18 hour period. One hundred milligrams of the ash were digested with mixed acids. After complete digestion of the plant ash, 40 major, minor, and trace elements (see Chapter D, Table D3) were determined by inductively coupled plasma atomic emission spectroscopy (ICP) (Lichte and others, 1987; Arbogast, 1990). Total sulfur was determined directly on 250 mg of the ground plant material by combustion at 1370°C in an oxygen atmosphere with infrared detection of evolved SO_2 (Jackson and others, 1985).

All sediment samples were analyzed by ICP for the same suite of elements as the plants. Two hundred milligrams of ground material were digested completely with mixed acids. Total sulfur was determined in the sediments by the same procedure used for the plants. Total carbon was determined by combustion of 0.25 to 1 g of ground material at 1370°C in an oxygen atmosphere with infrared detection of evolved CO_2 (Jackson and others, 1987). Carbonate carbon was determined by coulometric titration of acid-evolved CO_2 (Engleman and others, 1985). Organic carbon was determined by the difference of total and carbonate carbon (Jackson and Roof, 1992).

All raw chemical analysis results as reported by the laboratory are presented in Chapter D of this report. The lower detection limits for trace elements are typically on the order of a few μg/g (see Table D3). The detection limit for elements in plant materials determined by ICP is twice as great as those for sediments owing to the use of the smaller sample size. The precision for most determinations is on the order of 5-10 percent relative standard deviation or better. ICP results are reported to a maximum of two significant figures. All other analyses are reported to a maximum of three significant figures.

The field study quality control results also are summarized in Chapter D. Based on these results, data for Co and La in *S. alterniflora* and Ba in sediments should be viewed with caution. However, it should be noted that potential errors or biases in results for these particular elements do not significantly influence any conclusions drawn in this report.

The pH of water samples was determined in the field at the site of collection using an Orion model SA250 portable pH meter with a Ross electrode. Samples were filtered through 0.4 μm polycarbonate membrane filters (Nuclepore) in the field within a few hours of collection. Filtered water samples were analyzed in the laboratory for chloride and sulfate by ion chromatography (Smee and others, 1978).

Particle-size determinations and silt and clay mineralogy were performed on subsamples from 5-cm diameter core slices 2.5-5 cm thick (depending on depth) that had been disaggregated, dried, and pretreated with HCl, HNO_3, and H_2O_2 to decompose organic matter in order to do other analyses (Martin and Rice, 1981). The influence of this pretreatment on the size fractionation and clay and silt mineralogy is not clearly understood. At the very least, carbonates and sulfides were destroyed. The expanding clays, such as montmorillonite, were probably altered or destroyed to a greater degree than kaolinite. The particle size analysis (Starkey and others, 1984) was performed by wet sieving about 3 g of sample with a 230-mesh (62 micron) stainless steel sieve to separate the sand-sized fraction from the silt- and clay-sized fractions. The material not passing through the sieve was dried and weighed as the sand-sized fraction. The material less than 62 micron was centrifuged at 600 rpm for 7.5 minutes, which left the clay-sized fraction in suspension. A small portion of the suspension was vacuum filtered and transferred to a glass slide for X-ray diffraction analysis (XRD) of the well-oriented clays (Pollastro, 1982). The mounted clay specimen was analyzed from 2°-32° by XRD four times: once unaltered, once glycolated, once after heating to 400°C, and once after heating to 550°C. The remainder of the clay suspension was decanted, dried, and weighed. The silt-sized fraction remaining was dried and weighed and selected samples were analyzed by XRD. Bulk and silt-sized sediment fractions were analyzed by XRD from 4°-60° in packed powder mounts. Bulk mineralogical determinations were done on the disaggregated and dried sediment only. No organic matter decomposition pretreatment was used on the bulk mineralogical specimens.

DATA ANALYSIS

Data analysis has been performed using a variety of public domain and commercial software on an IBM-compatible personal computer. The unbalanced, hierarchical analysis of variance was done using programs in the USGS Statpac library (Grundy and Miesch, 1988).

All sediment data have been analyzed on a dry-weight basis (i.e. air-dried). For plants, S concentrations and ash yield are on a dry-weight basis (at 40°C) and all other element concentrations are on an ash-weight basis. All data, unless otherwise specified, have been logarithmically (base 10) transformed prior to statistical analysis. Where appropriate, qualified data, which are those results below the analytical detection limit, have been replaced with 0.7 times the detection limit prior to statistical analysis. Elements with more than 33 percent qualified values have been excluded from any statistical analyses. In general, limited replacement of qualified values has little influence on robust statistical techniques such as ANOVA. However, appropriate caution should be used in interpreting correlation-based techniques where we have used replacement of qualified values.

The geometric means for elemental concentrations were determined as weighted averages of the transformed data owing to the unbalanced nature of the sample design. The hierarchical ANOVA levels were used for weighting so that the lowest level, laboratory replicates, was averaged first and then each succeeding level upward through the hierarchical chain was averaged sequentially. Pooled geometric deviations were determined as the square root of the total variance determined in the unbalanced, hierarchical ANOVA. Geometric means and deviations were calculated for several elements which required replacement of some of the qualified values. This introduces a bias to these results, but it is important in order to allow comparisons to be made between different data sets to guide future research.

Chemical baselines have been defined in various ways. Usually a baseline refers to a specific set of conditions and point in time (i.e. when the samples were collected) and not to historical or pre-industrial conditions. One definition of a baseline is the expected 95 percent range, which is the mean plus or minus two standard deviations. For lognormally-distributed data (Tidball and Ebens, 1976) the expected 95% range is:

(geometric mean/geometric deviation^2) to (geometric mean X geometric deviation^2)

We have defined baseline ranges for selected elements in *S. alterniflora* and sediments for the November 1987 collection period using the formula presented above.

The combination of the November and June sampling designs and analytical data for the eight sample locations was truly a crossed-hierarchical ANOVA design, which incorporated both temporal and spatial aspects. However, these data have only been analyzed one season at a time by ANOVA. Inter-seasonal comparisons have been made by parametric analysis of the logarithmically-transformed data as paired sets. Analytical splits were averaged prior to doing the paired-t test.

Spatial trends in element concentrations in *S. alterniflora* and in sediments were calculated using an inverse distance-squared algorithm which incorporated up to ten nearest neighbors within a five cell radius. The log-transformed, hierarchically-averaged grid cell means were used to generate the contours. The contours plotted were based on approximately the 10th, 30th, 50th, 70th, and 90th percentiles of the 51 grid cell means.

Calculation of the variance-mean-ratio and the estimated sampling density required for 80 and 95 percent confidence geochemical-element-concentration maps followed the methods of Miesch (1976).

RESULTS AND DISCUSSION

Physical characteristics of the *S. alterniflora* and salt-marsh sediments collected

S. alterniflora growth habits include short, intermediate, and tall ecophenic forms (Shea and others, 1975) that are apparently environmentally induced. The tall form (1-2 m) characteristically grows on the higher elevation, better drained tidal levee with the shorter form (about 0.5 m or less, although some researchers in other regions define the short form as up to 1 m) occurring behind the tidal levee in less drained marsh area. The intermediate height form tends to occur in marsh locations between the two elevation extremes. The difference in height has been attributed to a number of factors: tidal inundation, interstitial water salinity, nutrient availability and utilization, redox conditions of the root zone, sulfide toxicity, and subsurface drainage (Chalmers, 1982; Delaune and others, 1983; Howes and others, 1986; Koch and others, 1990; Mendelssohn and McKee, 1982).

The *S. alterniflora* samples that we collected were located about 10 m behind the tidal levee usually in short to intermediate form stands. The range in estimated height of a stand of *S. alterniflora* culms and leaves was 25-80 cm with an average height of 45 cm. The estimated plant density ranged from about 25 to 125 groups of culms per square meter (a group of culms was assumed to be stems from one plant). The average density was 60 groups of culms per square meter. Based on Spearman's non-parametric rank correlation coefficient using measurements at 67 locations, there was a weak inverse correlation between our rough measurements of *S. alterniflora* height and plant density ($r = -0.279$) that was significant at $p = 0.05$.

Visual examination of cores to a depth of 50 cm at all sample locations indicated that the sediments were relatively uniform throughout CRNWR at the type of location that we were sampling. The sediments at each location were predominantly silt with the surface oxidized zone ranging from a few millimeters to a few centimeters, with an average thickness of about 1 cm. Below the oxidized zone was usually a zone of grey silt with abundant fine roots down to about 20 cm. The lower portion of the core (below 20) cm was generally grey silt with varying amounts of coarse roots. No zones of peat formation were observed within the upper 50 cm of sediment that was sampled.

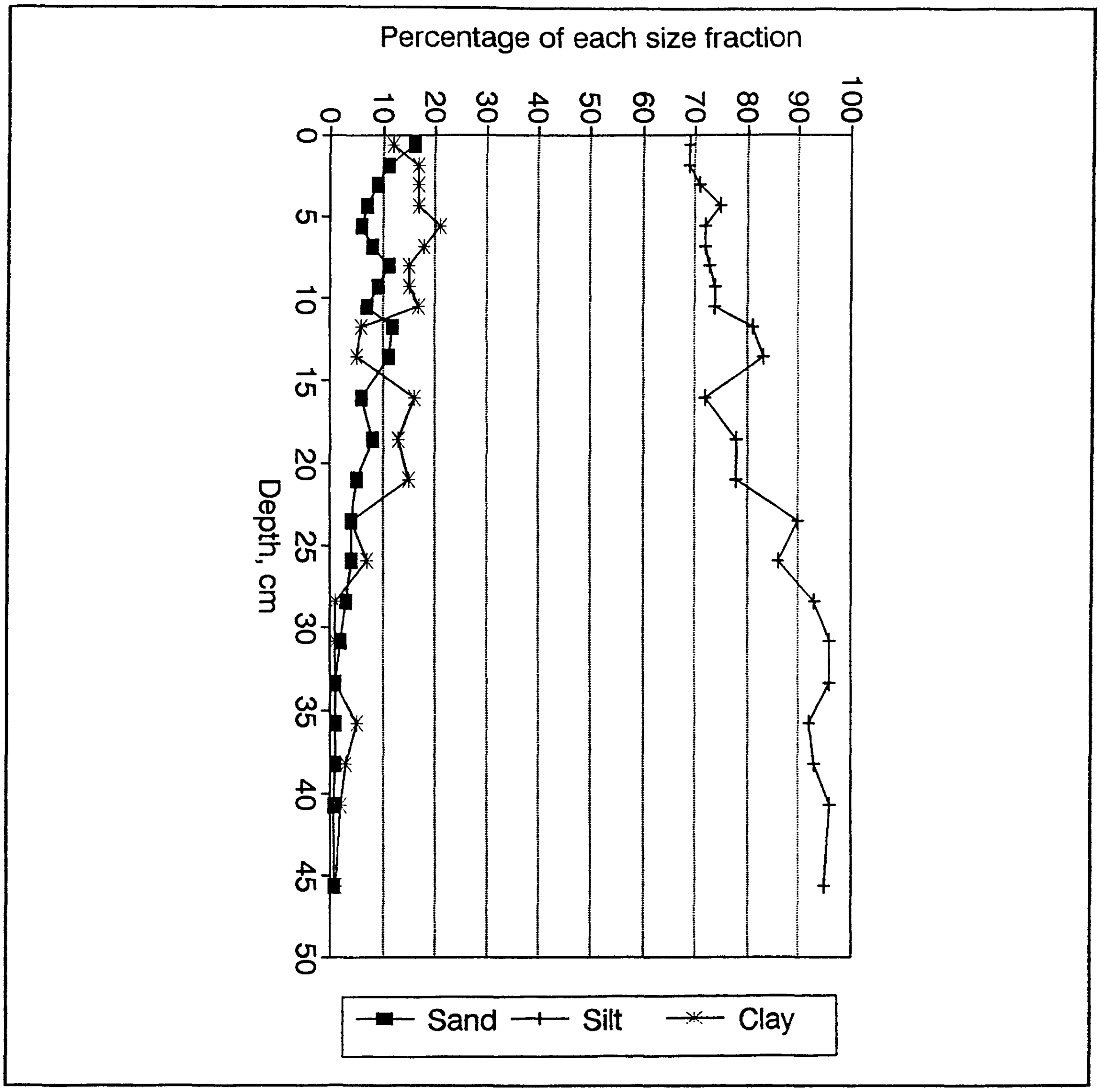

Figure A4. Percentage of sand-, silt-, and clay-sized material in salt-marsh sediment at grid location 12L.

One core at grid location 12L, near the intersection of Papas and Five Fathom Creeks in the northern portion of CRNWR, was analyzed for grain size and major mineralogical components. The weight percentage of material in sand-, silt-, and clay-sized fractions is shown in Figure A4. The sediments were predominately silt with the clay-sized fractions ranging from about 5-20 percent and the sand-sized fraction from about 5-15 percent from the surface down to a depth of about 20 cm. Below a depth of 20 cm, the silt-sized fraction increased and the sand- and clay-sized fractions were less than 5 percent. Qualitative X-ray diffraction analysis of the bulk sediment indicated that quartz, plagioclase, and kaolinite were the major crystalline mineral components of the sediment down to a depth of 20 cm. At about 20 cm and downward, pyrite was observed as a major mineralogical component in addition to the other three minerals. Quartz and plagioclase were the major components in the silt-sized fraction. The clay-sized fraction was composed of kaolinite with the addition of illite from about 25 cm downward.

Summary Statistics and Analysis of Variance

Orientation Field Study--Fall 1987 For *S. alterniflora* and sediments collected during the orientation study, the percentages of the total variance accounted for by each level in the ANOVA design and the observed range of element concentrations are shown in Tables A1 and A2. With the exception of sulfur, elements in *S. alterniflora* are presented on an ash-weight basis because we believe that this weight basis will minimize differences in element concentration trends between different growth forms or proportions of leaves and culms that were sampled from site to site. However, this weight basis will emphasize differences in sediment or salt-spray contamination that was not successfully removed by our plant washing procedure, although gross contamination was not obvious after washing.

For *S. alterniflora*, a large proportion of the total variance for several elements was at the 26 and 8 km ANOVA levels, although more than 50 percent of the total variance for most elements was at the 2 km and 30 m ANOVA levels. Generally, only a few percent of the total variance were attributable to the 3 m ANOVA level or to laboratory error. Similar results were obtained for the sediments, although generally, very little variance was attributable to the largest spatial level, at 26 km. These results indicate that differences in element concentrations in plants or sediments between the northern and southern portions of CRNWR are of the same magnitude as differences measured within smaller sampling units. In addition, they indicate that to accurately map spatial trends in element concentrations throughout the refuge, large numbers of samples collected at increments of tens of meters to at most 2 km are required. Based on these results, the practical aspects of sampling in CRNWR, the project objectives, and the budgetary constraints dictated a grid size of 1.6 km x 1.6 km for future sampling.

The analysis of the *S. alterniflora* ash by ICP indicated that the concentration of a large number of trace elements did not exceed the detection limit of the analytical technique. Concentrations of only a few trace elements (Ba, Cr, Cu, Li, Mn, Sr, and Zn), in addition to the major elements (Al, Ca, Fe, K, Mg, Na, P, and Ti), were consistently above the ICP detection limits. For the sediments, a larger number of elements were above the analytical detection limits.

Primary Field Study-November 1987 The ANOVA results and summary statistics, including our estimate of the 95 percent expected baseline concentration for elements in *S. alterniflora* and their associated sediments, based on the November 1987 collection are given in Tables A3 and A4. Generally, the greatest variance in the analytical results for *S. alterniflora* was found to be among grid cells with usually less than 20 percent of the total variance between north and south units of CRNWR.

Several elements had more than 25 percent of their total variance associated with the within-cell replicates at 3 and 30 meters. Calcium and Na, which make up more than 25 percent by weight of the plant ash, Mn, and ash yield had about 30 percent of their variance at the 3 meter within-cell replicate level. Potassium, Mg, Mn, and P, all essential plant nutrients, each

Table A1. ANOVA results and observed concentration range[1] for elements in *S. alterniflora*--October 1987.

	Percentage variance[2] at each ANOVA level							Observed range	
Element	26km	8km	2km	30m	3m	lab error	Ratio[3]	Minimum	Maximun
Ash%[1]	9	< 1	23	62*	5*	< 1	20/20	9.27	13.4
S%[1]	26	< 1	24	49*	1*	< 1	20/20	0.42	1.36
Al%	< 1	6	< 1	75	17*	2	20/20	0.15	0.98
Ca%	< 1	58	21	8	9	3	20/20	2.6	5.3
Fe%	< 1	< 1	< 1	91*	8*	< 1	20/20	0.17	0.85
K%	< 1	< 1	72*	< 1	21	7	20/20	5.3	7.7
Mg%	16	< 1	61*	18	5*	< 1	20/20	2.0	5.9
Na%	22*	< 1	27	39	< 1	12	20/20	20	29
P%	41	< 1	< 1	51*	6	2	20/20	0.82	1.8
Ti%	< 1	43	< 1	10	42*	5	19/20	0.01	0.05
Ag µg/g							0/20		< 4
As µg/g							0/20		< 20
Au µg/g							0/20		< 16
Ba µg/g	< 1	< 1	< 1	36	62*	2	20/20	9	32
Be µg/g							0/20		< 2
Bi µg/g							0/20		< 20
Cd µg/g							0/20		< 4
Ce µg/g							0/20		< 8
Co µg/g							4/20	< 2	4
Cr µg/g	< 1	< 1	< 1	97*	3*	1	20/20	4	62
Cu µg/g	26	18	< 1	50*	3	2	20/20	12	34
Eu µg/g							0/20		< 4
Ga µg/g							0/20		< 8
Ho µg/g							0/20		< 8
La µg/g							8/20	< 4	6
Li µg/g	< 1	24	4	52	9	11	20/20	4	14
Mn µg/g	44*	< 1	< 1	53*	2	1	20/20	150	480
Mo µg/g							1/20	< 4	6
Nb µg/g							0/20		< 8
Nd µg/g							0/20		< 8
Ni µg/g							3/20	< 4	36
Pb µg/g							0/20		< 8
Sc µg/g							0/20		< 4
Sn µg/g							0/20		< 20
Sr µg/g	< 1	47	36	8	7	1	20/20	360	760
Ta µg/g							0/20		< 80
Th µg/g							0/20		< 8
U µg/g							0/20		< 200
V µg/g							5/20	< 4	13
Y µg/g							0/20		< 4
Yb µg/g							0/20		< 2
Zn µg/g	45	10	< 1	38	7*	< 1	20/20	24	110

[1] Elements with ANOVA results and summary statistics calculated on a dry-weight basis (i.e., 40°C), all other elements on an ash-weight basis.

[2] * significant at 0.05 probability level.

[3] Ratio of samples with detectable concentrations to the total number of samples.

Table A2. ANOVA results and observed concentration range for elements in sediments--October 1987.

	Percentage of variance[1] at each ANOVA level							Observed range	
Element	26km	8km	2km	30m	3m	lab error	Ratio[2]	Minimum	Maximum
C total%	< 1	17	59*	13	10*	< 1	20/20	1.99	3.89
C org%	< 1	< 1	70*	21	9*	< 1	20/20	1.96	3.87
C crbnt%	< 1	38	6	50*	6*	< 1	20/20	0.02	0.36
S%	17	19	< 1	64*	1*	< 1	20/20	0.20	2.63
Al%	< 1	< 1	84*	11	4*	< 1	20/20	6.0	8.6
Ca%	< 1	52	20	23	4*	< 1	20/20	0.34	1.8
Fe%	< 1	< 1	56	37	7*	< 1	20/20	2.9	4.9
K%	< 1	< 1	< 1	99	< 1	< 1	20/20	0.76	1.2
Mg%	< 1	66	21	6	6*	< 1	20/20	0.60	0.99
Na%	< 1	57*	< 1	43*	< 1	< 1	20/20	1.3	2.8
P%	< 1	< 1	64	27	9	< 1	20/20	0.06	0.11
Ti%	< 1	7	< 1	86*	5	1	20/20	0.41	0.50
Ag µg/g							0/20		< 2
As µg/g	< 1	11	< 1	68	< 1	21	20/20	20	50
Au µg/g							0/20		< 8
Ba µg/g	< 1	< 1	50	50*	< 1	< 1	20/20	200	340
Be µg/g							20/20	2	2
Bi µg/g							0/20		< 10
Cd µg/g							0/20		< 2
Ce µg/g	< 1	< 1	69*	24	< 1	7	20/20	65	85
Co µg/g	< 1	< 1	63	14	23*	< 1	20/20	9	12
Cr µg/g	20	< 1	67*	4	9*	< 1	20/20	73	110
Cu µg/g	< 1	28	52*	17	1	3	20/20	14	23
Eu µg/g							0/20		< 2
Ga µg/g	< 1	< 1	89*	< 1	< 1	11	20/20	15	20
Ho µg/g							0/20		< 4
La µg/g	< 1	< 1	74*	20	3	4	20/20	33	43
Li µg/g	< 1	< 1	89*	6	5*	< 1	20/20	50	90
Mn µg/g	< 1	17	2	78*	2	1	20/20	280	360
Mo µg/g	< 1	6	< 1	83*	< 1	11	6/20	< 2	3
Nb µg/g	< 1	< 1	49	12	18	20	20/20	13	17
Nd µg/g	3	< 1	63*	18	< 1	16	20/20	30	40
Ni µg/g	< 1	< 1	81*	12	5	2	20/20	16	27
Pb µg/g	18*	< 1	< 1	68	11	3	20/20	18	28
Sc µg/g	< 1	< 1	87*	< 1	13*	< 1	20/20	10	15
Sn µg/g							0/20		< 10
Sr µg/g	< 1	34	31	31*	4*	< 1	20/20	78	190
Ta µg/g							0/20		< 40
Th µg/g	< 1	< 1	32	35*	< 1	33	20/20	10	14
U µg/g							0/20		< 100
V µg/g	< 1	< 1	64	32*	4*	< 1	20/20	84	130
Y µg/g	< 1	< 1	58	30	12	< 1	20/20	15	20
Yb µg/g							20/20	2	2
Zn µg/g	7	< 1	85*	< 1	7*	1	20/20	50	76

[1] * significant at 0.05 probability level.

[2] Ratio of samples with detectable concentrations to the total number of samples.

Table A3. ANOVA results and summary statistics[1] for *S. alterniflora* from November 1987 collection.

	Percentage Variance[2] at each ANOVA Level								Observed Range		Estimated Baseline Range	
	N-S unit	Grid cell	30 meters	3 meters	Lab error	Ratio[3]	Geometric Mean	Geometric Deviation	Minimum	Maximum	Minimum	Maximum
Ash%[1]	6	38	27	29 *	1	99/99	10.4	1.10	7.68	13.1	8.51	12.7
S%[1]	4	72 *	12	13 *	< 1	99/99	0.57	1.70	0.19	1.3	0.20	1.64
Al%	18 *	64 *	12 *	5 *	1	99/99	0.36	2.14	0.10	1.7	0.08	1.7
Ca%	< 1	58 *	7	33 *	2	99/99	3.8	1.20	2.5	5.5	2.7	5.5
Fe%	16 *	59 *	15 *	10 *	1	99/99	0.24	1.79	0.09	0.92	0.07	0.77
K%	< 1	2	77 *	19 *	2	99/99	5.2	1.24	3.0	8.2	3.4	7.9
Mg%	< 1	56 *	26 *	14 *	4	99/99	4.0	1.24	2.5	6.9	2.6	6.1
Na%	8 *	46 *	< 1	31 *	14	99/99	22	1.10	19	27	18	27
P%	6	48 *	33 *	11 *	1	99/99	1.0	1.40	0.45	2.0	0.51	2.0
Ti%	20 *	57 *	15 *	7 *	1	87/99	0.02	2.12	< 0.01	0.09	< 0.01	0.09
Ba µg/g	19 *	59 *	11 *	9 *	2	99/99	12	1.58	5	37	5	30
Ce µg/g						5/99			< 8	13		
Co µg/g						21/99			< 2	4		
Cr µg/g	18 *	59 *	14 *	3	6	99/99	7	1.59	3	21	3	17
Cu µg/g	7	30	< 1	9	54	99/99	9	1.80	2	30		
La µg/g						65/99			< 4	10		
Li µg/g	24 *	62 *	6	4	5	87/99	6	1.68	< 4	19	< 4	17
Mn µg/g	8	21	45 *	25 *	1	99/99	590	1.44	320	2000	290	1200
Mo µg/g						12/99			< 4	9		
Ni µg/g						10/99			< 4	9		
Pb µg/g						3/99			< 8	10		
Sr µg/g	< 1	57 *	8	33 *	2	99/99	570	1.21	340	920	390	840
V µg/g						58/99			< 4	28		
Zn µg/g	13 *	< 1	70 *	17 *	1	99/99	57	1.49	26	210	26	130

[1] Elements with ANOVA and summary statistics calculated on a dry-weight basis (i.e., at 40°C), all other elements on an ash-weight basis.

[2] * significant at 0.05 probability level.

[3] Ratio of samples with detectable concentrations to the total number of samples.

had more than 25 percent of their total variance associated with the 30 m within-cell ANOVA level. Only Cu had a large fraction of its variance associated with laboratory error.

For the sediments, only organic C, Co, Cu, and V had 20-30 percent of their total variance associated with differences between north and south units. The variance for the other elements at this ANOVA level was usually less than 15 percent. The majority of the variance for most elements was found among the grid cells and at the 30 m within-cell replicate levels. Laboratory error usually represented only a few percent up to about 20 percent of the total variance. Thus, there appears to be considerable variability in element concentrations in the sediments over relatively short distances of 10's to 100's of meters, perhaps owing to micro-topologically and sedimentation differences, whereas there is relatively little difference for most major and trace elements from the northern to southern extent of CRNWR.

Element-concentration means in *S. alterniflora* and in sediments were not estimated for the October 1987 sample collection. However, the observed concentration ranges do not generally differ dramatically between the two sampling periods, although the observed range for November frequently was larger.

The 95 percent expected baseline-concentration range was calculated for those elements that did not have a large proportion of their total variance associated with laboratory error and that had more than 67 percent of results above the analytical detection limit. The baseline range was estimated for only a few elements in which replacement of qualified values with 0.7 times

Table A4. ANOVA results and summary statistics for sediments from November 1987 collection.

	Percentage Variance[1] at each ANOVA Level								Observed Range		Estimated Baseline Range	
Element	N-S unit	Grid cell	30 meters	3 meters	Lab error	Ratio[2]	Geometric Mean	Geometric Deviation	Minimum	Maximun	Minimum	Maximun
C total %	27 *	31	31 *	10 *	< 1	99/99	3.39	1.37	1.1	6.14	1.80	6.40
C org %	28 *	28	34 *	10 *	< 1	99/99	3.31	1.39	1.04	6.14	1.71	6.42
C crbnt %	8	48 *	37 *	7 *	< 1	78/99	0.04	3.45	< 0.01	0.42	< 0.01	0.44
S%	< 1	65 *	30 *	5 *	< 1	99/99	0.84	2.69	0.08	4.55	0.12	6.09
Al%	13 *	72 *	12 *	< 1	2	99/99	7.7	1.12	5.6	9.4	6.2	9.5
Ca%	12 *	60 *	25 *	4 *	< 1	99/99	0.71	1.45	0.39	1.9	0.34	1.5
Fe%	12 *	75 *	7 *	2	4	99/99	4.1	1.20	2.3	6.1	2.8	5.9
K%	8	19	53 *	5	14	99/99	1.1	1.10	0.89	1.4	0.94	1.4
Mg%	< 1	83 *	11 *	< 1	6	99/99	0.87	1.13	0.66	1.1	0.68	1.1
Na%	< 1	73 *	17 *	8 *	2	99/99	2.4	1.15	1.6	2.9	1.8	3.2
P%	< 1	61 *	25 *	< 1	14	99/99	0.08	1.23	0.04	0.12	0.05	0.11
Ti%	1	< 1	96 *	< 1	3	99/99	0.49	1.15	0.23	0.56	0.37	0.65
As μg/g	9	47 *	38 *	< 1	6	98/99	22	1.55	< 10	50	< 10	54
Ba μg/g	< 1	58 *	35 *	1	6	99/99	140	2.30	24	370	26	740
Be μg/g	< 1	47 *	< 1	< 1	53	99/99	2	1.18	1	2		
Ce μg/g	6	61 *	15 *	< 1	18	99/99	75	1.09	58	95	62	90
Co μg/g	23 *	63 *	1	11 *	2	99/99	10	1.15	7	14	8	14
Cr μg/g	5	27	< 1	50 *	19	99/99	77	1.17	52	160	56	100
Cu μg/g	25 *	50 *	7	< 1	17	99/99	19	1.35	6	31	11	35
Ga μg/g	9	64 *	10	< 1	17	99/99	17	1.13	12	20	13	21
La μg/g	< 1	61 *	22 *	6	11	99/99	35	1.09	28	43	30	42
Li μg/g	1	88 *	7 *	2 *	1	99/99	70	1.17	44	95	52	95
Mn μg/g	8	22	48 *	20 *	2	99/99	340	1.24	210	700	220	530
Mo μg/g						33/99			< 2	8		
Nb μg/g	15 *	< 1	63 *	< 1	23	98/99	10	1.34	< 4	14	5	18
Nd μg/g	< 1	67 *	17 *	< 1	15	99/99	32	1.09	25	40	27	39
Ni μg/g	16 *	76 *	6 *	< 1	3	99/99	23	1.16	16	29	17	31
Pb μg/g	< 1	54 *	29 *	9 *	7	99/99	25	1.16	15	34	19	34
Sc μg/g	8	69 *	13 *	5 *	4	99/99	12	1.11	9	14	10	15
Sr μg/g	12 *	47 *	34 *	5 *	2	99/99	120	1.16	89	180	91	170
Th μg/g	< 1	52 *	10	20	18	99/99	11	1.12	8	15	9	14
V μg/g	22 *	65 *	10 *	< 1	3	99/99	110	1.15	76	150	85	150
Y μg/g	8	74 *	8	5	5	99/99	17	1.10	13	21	14	21
Yb μg/g	< 1	29 *	< 1	< 1	71	99/99	2	1.09	2	3	2	2
Zn μg/g	10 *	70 *	8	< 1	12	99/99	65	1.19	29	83	46	93

[1] * significant at 0.05 probability level.

[2] Ratio of samples with detectable concentrations to the total number of samples.

the detection limit was used. In these cases if the calculated lower limit of the range was less than the analytical detection limit, the analytical detection limit was substituted for the actual calculated lower limit of the baseline range (Tables A3 and A4).

The observed range in concentration frequently included higher values than the 95 percent expected baseline range. For most elements in *S. alterniflora* and in sediments, this higher value was owing to only one sample out of 99 which fell outside the upper limit of the calculated baseline range. This is not unexpected because our baseline range is only defined to include 95 percent of a log-normally distributed population.

Follow-up field study--June 1988 The ANOVA results and the observed concentration ranges are shown in Tables A5-A7 for elements in *S. alterniflora* and sediments at eight sites that were

Table A5. ANOVA results and observed concentration range[1] for elements in culms and leaves including the senescent flowering stalk of *S. alterniflora*--June 1988.

	Percentage variance[2] at each ANOVA level							Observed range	
Element	26km	8km	2km	30m	3m	lab error	Ratio[3]	Minimum	Maximun
Ash%[1]	< 1	22	< 1	56	20*	1	20/20	3.78	7.20
S%[1]	< 1	82*	< 1	13	2	3	20/20	0.19	0.35
Al%	41	< 1	49	4	5*	< 1	20/20	2.3	5.3
Ca%	< 1	76	1	19*	4*	< 1	20/20	2.7	6.2
Fe%	38*	< 1	54*	2	5*	< 1	20/20	1.5	2.8
K%	< 1	6	18	< 1	74*	2	20/20	1.5	2.1
Mg%	11	< 1	68	13	8*	< 1	20/20	4.1	5.7
Na%	< 1	70	15	6	6	2	20/20	6.7	14
P%	< 1	65	18	< 1	17*	< 1	20/20	0.76	2.6
Ti%	35	< 1	51	6	7*	1	20/20	0.14	0.29
Ba µg/g	49*	< 1	29	12	5	5	20/20	82	120
Ce µg/g	46*	< 1	42*	< 1	11*	1	20/20	26	52
Co µg/g	46*	< 1	48*	< 1	5	< 1	20/20	6	9
Cr µg/g	16	< 1	44*	< 1	< 1	40	20/20	31	67
Cu µg/g	< 1	75*	< 1	< 1	19	6	20/20	17	41
Ga µg/g	17*	< 1	58	7	10	9	16/20	< 8	13
La µg/g	48*	< 1	43*	< 1	8*	1	20/20	17	28
Li µg/g	39	< 1	52*	1	6	1	20/20	20	52
Mn µg/g	< 1	90*	6	1	2*	< 1	20/20	420	1600
Mo µg/g							0/20		< 4
Nd µg/g	39	< 1	40	< 1	11	11	20/20	13	23
Ni µg/g	51*	< 1	40	5	< 1	3	20/20	13	22
Pb µg/g	21	< 1	23	52*	3	< 1	20/20	21	36
Sc µg/g	29	< 1	64*	2	1	4	19/20	< 4	8
Sr µg/g	< 1	51	30	14	5	< 1	20/20	440	1000
V µg/g	42*	< 1	53*	< 1	5*	< 1	20/20	41	87
Y µg/g	44*	< 1	49*	< 1	7	< 1	20/20	7	14
Zn µg/g	< 1	< 1	94*	5*	< 1	1	20/20	97	200

[1] Elements with ANOVA results and summary statistics calculated on a dry-weight basis (i.e., 40°C), all other elements on an ash-weight basis.

[2] * significant at 0.05 probability level.

[3] Ratio of samples with detectable concentrations to the total number of samples.

resampled in May/June 1988. *S. alterniflora* leaves, culms, and a flowering stalk without the flower or seed head were collected in November 1987. During the follow-up field study May/June 1988, the flower stalk was in the latter stages of senescence or missing. Therefore, because the samples collected during November 1987 included the flowering stalk, in June 1988 the *S. alterniflora* samples were composited including the senescent flowering stalk. An additional *S. alterniflora* sample was collected at each site which was a composite of plants without the flowering stalk. There are some distinct chemical differences between these two types of *S. alterniflora* samples as seen in Tables A5 and A6.

Table A6. ANOVA results and observed concentration range[1] for elements in culms and leaves without the senescent flowering stalk of *S. alterniflora*--June 1988.

	Percentage variance[2] at each ANOVA level							Observed range	
Element	26km	8km	2km	30m	3m	lab error	Ratio[3]	Minimum	Maximun
Ash%[1]	< 1	65	< 1	31*	3	2	20/20	11.9	13.8
S%[1]	< 1	< 1	71	22*	7*	< 1	20/20	0.26	0.68
Al%	< 1	26	< 1	61*	13*	< 1	20/20	0.8	2.3
Ca%	2	< 1	72	< 1	24*	2	20/20	2.2	3.4
Fe%	< 1	26	< 1	58*	16*	< 1	20/20	0.48	1.3
K%	< 1	31	< 1	< 1	63*	6	20/20	7.9	9.8
Mg%	< 1	48	< 1	25	25*	2	20/20	1.8	2.9
Na%	< 1	39	25	29*	< 1	7	20/20	17	21
P%	< 1	58	19	12	7	4	20/20	1.2	2.0
Ti%	< 1	34	< 1	46	18*	2	20/20	0.04	0.12
Ba µg/g	3	23	< 1	63*	10*	< 1	20/20	18	43
Ce µg/g							11/20	< 8	15
Co µg/g	17	16	< 1	41	26	< 1	20/20	2	4
Cr µg/g	< 1	< 1	59	16	< 1	25	20/20	11	24
Cu µg/g	< 1	52	< 1	< 1	13	35	20/20	8	30
Ga µg/g							0/20		< 8
La µg/g	1	< 1	< 1	79*	7	12	20/20	6	11
Li µg/g	9	15	< 1	62*	8	6	20/20	12	25
Mn µg/g	26	28	16	12	17*	< 1	20/20	470	1100
Mo µg/g							6/20	< 4	5
Nd µg/g							4/20	< 8	10
Ni µg/g							14/20	< 4	8
Pb µg/g							3/20	< 8	11
Sc µg/g							0/20		< 4
Sr µg/g	8	< 1	61	< 1	30*	1	20/20	310	500
V µg/g	< 1	39	< 1	54*	7*	< 1	20/20	13	38
Y µg/g							0/20		< 4
Zn µg/g	< 1	< 1	94*	3	3*	< 1	20/20	58	94

[1] Elements with ANOVA results and summary statistics calculated on a dry-weight basis (i.e., 40°C), all other elements on an ash-weight basis.
[2] * significant at 0.05 probability level.
[3] Ratio of samples with detectable concentrations to the total number of samples.

There was not a great difference in the spatial distribution of the variance for the major elements. The greatest percentage of the variance was usually found at the intermediate distance ANOVA levels of 30 m to 8 km. However, for the composite sample including the flowering stalk 20-50 percent of the total variance for most trace elements occurred at the 26 km level, the distance increment that represents differences between the northern and southern extent of CRNWR. Although it was not obvious and would not necessarily be expected, there may havebeen a difference in the degree of senescence of the flowering stalk between the northern and southern extent of CRNWR.

Table A7. ANOVA results and observed concentration range for elements in sediments--June 1988.

	Percentage of variance[1] at each ANOVA level							Observed range	
Element	26km	8km	2km	30m	3m	lab error	Ratio[2]	Minimum	Maximum
C total%	35	< 1	62*	3*	< 1	< 1	20/20	2.16	6.08
C org%	33	< 1	63*	4*	< 1	< 1	20/20	2.16	6.08
C crbnt%							14/20	< 0.01	0.17
S%	< 1	< 1	86	8	6*	< 1	20/20	0.27	2.02
Al%	2	< 1	97	< 1	< 1	< 1	20/20	4.1	7.9
Ca%	< 1	39	8	50*	2	1	20/20	0.55	1.2
Fe%	< 1	< 1	97*	< 1	3*	< 1	20/20	2.0	4.5
K%	9	< 1	70*	6	< 1	14	20/20	1.0	1.2
Mg%	< 1	< 1	97*	2*	< 1	< 1	20/20	0.39	1.0
Na%	1	< 1	95*	2*	< 1	1	20/20	1.6	3.2
P%	2	< 1	94*	1	1	2	20/20	0.03	0.09
Ti%	< 1	< 1	94*	< 1	< 1	5	20/20	0.37	0.51
As µg/g	4	34	< 1	62	< 1	< 1	20/20	10	30
Ba µg/g	< 1	< 1	59	< 1	36*	5	20/20	44	330
Be µg/g	< 1	< 1	100	< 1	< 1	< 1	20/20	1	2
Ce µg/g	5	< 1	83*	7*	< 1	6	20/20	53	79
Co µg/g	9	< 1	87*	< 1	2	2	20/20	6	12
Cr µg/g	< 1	< 1	95*	3	1	1	20/20	37	110
Cu µg/g	12*	< 1	87*	< 1	< 1	< 1	20/20	6	21
Ga µg/g	5	< 1	92*	2	< 1	1	20/20	10	20
La µg/g	2	< 1	87*	5*	< 1	7	20/20	26	40
Li µg/g	< 1	< 1	99*	< 1	< 1	< 1	20/20	27	78
Mn µg/g	< 1	< 1	98*	< 1	< 1	1	20/20	220	370
Mo µg/g							13/20	< 2	4
Nb µg/g	< 1	< 1	97*	2*	< 1	2	18/20	< 4	11
Nd µg/g	3	< 1	72	17	< 1	8	20/20	24	36
Ni µg/g	6	< 1	94*	< 1	< 1	< 1	20/20	10	27
Pb µg/g	< 1	< 1	85*	5	2	7	20/20	15	26
Sc µg/g	2	< 1	95*	< 1	1	1	20/20	7	14
Sr µg/g	< 1	< 1	58	35*	< 1	6	20/20	110	150
Th µg/g	< 1	< 1	81*	6	< 1	14	20/20	8	13
V µg/g	5	< 1	94*	< 1	< 1	1	20/20	54	120
Y µg/g	7*	< 1	92*	< 1	< 1	< 1	20/20	10	19
Yb µg/g	4	< 1	72*	< 1	25	< 1	20/20	1	3
Zn µg/g	4	< 1	94*	< 1	< 1	< 1	20/20	27	75

[1] * significant at 0.05 probability level.

[2] Ratio of samples with detectable concentrations to the total number of samples.

The composite sample that included the flowering stalk had an ash content that was about a factor of two lower than the June composite sample without the stalk and the November 1987 collection. The observed range for the ash content was also slightly lower in November 1987 compared to the June 1988 composite without the flowering stalk. Other comparisons between the seasons are discussed below.

For the sediments (Table A7) most of the total variance, 80-100 percent for most elements, occurred at the 2 km ANOVA level. This was similar to previous results from October and November 1987, however it was even more pronounced than either of the two earlier collections. It helps confirm that there is no large chemical difference between the northern and southern extent of CRNWR and that most of the spatial variability in the concentration of elements in sediments is on a scale of 100's of meters.

Interelement relationships in *S. alterniflora* and in Sediments

Exploratory factor analysis was performed on a subset of the variables determined in the *S. alterniflora* and sediment samples from the November 1987 collection in order to reduce the dimensionality and examine the latent variables or factors inherent in the data. Our objective was to obtain a "simple structure" of easily interpretable factors that explained an acceptable amount of the total variance. Models with five factors that explained about 90 percent of the variance were derived for *S. alterniflora* and the sediments. The factor loadings are shown in Tables A8 and A9. Those elements that have high loadings on an individual factor are the elements that are most highly correlated with each other in multi-dimensional space.

For *S. alterniflora* the first factor was predominantly comprised of Al, Fe, Ba, Cr, and Li which may be associated owing to pedological or plant physiological processes controlling the micronutrient Fe and some trace elements. The second factor was comprised of ash and S which were inversely related to the nutrients P and Zn. The third factor is comprised of the divalent alkaline earth elements Ca, Mg, and Sr, and inversely related to Na. This factor may be important with respect to the pore water salinity and regulating osmotic pressure in the plant. Factors four and five were influenced primarily by one nutrient element each, Mn and K, respectively. Thus, the most variance in plant chemistry associated with an individual factor is attributable to trace elements with the remainder of the variance associated with factors that are probably attributable to plant physiological processes influenced by nutrient utilization and uptake processes and edaphic factors related to salinity and redox status.

A five factor model was also derived for the sediments with the first factor comprised largely of major rock forming elements, Al, Fe, and Mg and many of the minor and trace elements determined, P, Ce, Cr, Cu, La, Li, Ni, Pb, Sc, V, and Zn. Factor two was comprised of organic C, S, Na, and As, which were inversely related to P, Ba, La, and Pb. Factor 3 was comprised of alkaline earth elements and carbonate C. Factor 4 was composed of Fe and Mn, which undergo oxidation/reduction in the upper centimeters of the sediments and are frequently associated with oxyhydroxides in the oxic zone of sediments. Factor 5 was comprised of K and Ti. The association of elements in Factors 1, 3, and 5 is probably owing to the mineralogical makeup of the sediments and the nature of the major silicic minerals, the carbonates, and themore resistant minerals, respectively. Factor two is probably the factor most influenced by the biogeochemical cycling of C and S and factor 4 appears influenced by the oxidation/reduction and precipitation of Fe and Mn oxyhydroxides.

Table A8. Varimax rotated factor loadings for *S. alterniflora* from November 1987.

	Factor Loadings > 0.50				
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Ash		0.85			
S		0.88			
Al	0.93				
Ca			0.96		
Fe	0.97				
K					-0.92
Mg			0.71		
Na			-0.65		
P		-0.89			
Ba	0.95				
Cr	0.94				
Li	0.89				
Mn				0.92	
Sr			0.97		
Zn		-0.56			
Eigenvalue	5.0	3.2	2.9	1.2	1.1
% of total variance	33.5	21.5	19.5	8.0	7.6
Cumulative % variance	33.5	55.0	74.5	82.5	90.1

Spatial element concentration trends in *S. alterniflora* and sediments

The ANOVA results give some indication of the spatial trends in element concentrations for *S. alterniflora* and sediments. In general, they demonstrated that there are not large differences between northern and southern extents of CRNWR. Most of the variability is found at distance increments of 10's of meters up to a few kilometers. The ability to produce a stable or reproducible biogeochemical map is critically dependent upon the scale of spatial variability of an element concentration and the density of sampling. The map stability (V_m) and the minimum number of random samples (n_r) required for a grid cell of 2.6 km^2 are shown in Table A10. These data are based on the ANOVA results for the primary field collection in November. The variance-mean-ratio is an estimate of variance among grids to the variance within grids. Ratios greater than one usually indicate that relatively few samples are required within grids in order to produce reliable maps. Our estimates of the minimum sampling density show that reproducible biogeochemical maps representing the true element patterns could be produced for most elements in *S. alterniflora* and in the sediments with 2-3 samples at the 80 percent confidence level and 3-5 samples at the 95 percent confidence level. We averaged about 2 samples per grid cell in our sampling. Hence, biogeochemical maps produced from our data are deemed reliable only at the lower confidence level. Several elements would not be suitable for mapping: K, Mn, and Zn in *S. alterniflora*, and K, Ti, Cr, Nb, and Yb in sediments. In order to produce more stable maps for these elements, either a greater number of samples would have to be obtained within each grid or the grid size would have to be reduced.

Table A9. Varimax rotated factor loadings for sediments from November 1987.

	Factor Loadings > 0.50				
Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
C organic		-0.76			
C carbonate			0.91		
S		-0.97			
Al	0.95				
Ca			0.94		
Fe	0.64			0.55	
K					0.54
Mg	0.60		0.71		
Na		-0.76			
P	0.66	0.63			
Ti					0.90
As		-0.56			
Ba		0.90			
Ce	0.72				
Cr	0.76				
Cu	0.84				
La	0.64	0.64			
Li	0.90				
Mn				0.87	
Ni	0.95				
Pb	0.52	0.74			
Sc	0.96				
Sr			0.75		
V	0.94				
Zn	0.90				
Eigenvalue	9.6	5.5	3.9	1.8	1.4
% of total variance	38.6	21.9	15.5	7.4	5.5
Cumulative % variance	38.6	60.5	76.0	83.4	88.9

Figure A5 shows biogeochemical contour maps for several elements in *S. alterniflora*. The map for Al should be roughly representative of the spatial trends for the other elements that loaded highly on Factor 1 (Table A8). Sulfur and Zn were inversely loaded on Factor 2 and Na was loaded on Factor 3. Maps for these elements are also somewhat representative of other elements that loaded on the same factors. Maps for Al and S have confidence limits of about 80 percent and the map of Na is somewhat less. The map of Zn in *S. alterniflora* has a much lower confidence level because a large proportion of the total variance was within grids. Regardless of the confidence level of the map, it seems difficult at best to interpret these results on any physiographical or biogeochemical basis.

Figure A6 shows geochemical contour maps for six elements in the sediments. In this case, both Al and Zn were highly loaded on Factor 1 and organic C, Na, and S, which were inversely related to Pb, were loaded on Factor 2. The maps for Al, Na, and Zn have confidence

Table A10. Variance-mean-ratios and estimated sample density for 2.6 km^2 grid cells for *S. alterniflora* and sediments.

	S. alterniflora				Sediment		
Element	V_m	n_r-80%	n_r-95%	Element	V_m	n_r-80%	n_r-95%
				C total %	3.9	3	4
				C org %	3.5	3	4
Ash%[1]	2.4	3	6	C crbnt %	3.5	3	4
S%[1]	9.4	2	3	S%	5.0	3	4
Al%	12.9	2	3	Al%	16.9	2	3
Ca%	4.7	3	4	Ca%	6.7	2	3
Fe%	8.8	2	3	Fe%	22.8	2	3
K%	0.1	31	129	K%	1.1	4	10
Mg%	3.9	3	4	Mg%	15.2	2	3
Na%	4.9	3	5	Na%	8.1	2	3
P%	3.4	3	5	P%	5.1	3	4
Ti%	9.8	2	3	Ti%	< 0.1	51	219
As µg/g				As µg/g	3.6	3	4
Ba µg/g	10.7	2	3	Ba µg/g	4.0	3	4
Be µg/g				Be µg/g	5.4	3	5
Ce µg/g				Ce µg/g	7.8	3	4
Co µg/g				Co µg/g	23.6	2	3
Cr µg/g	10.3	2	3	Cr µg/g	1.8	4	8
Cu µg/g	3.3	3	7	Cu µg/g	13.0	2	3
Ga µg/g				Ga µg/g	10.6	2	3
La µg/g	14.3	2	3	La µg/g	5.1	3	4
Li µg/g	20.4	2	3	Li µg/g	25.8	2	3
Mn µg/g	1.1	4	9	Mn µg/g	1.2	4	9
Nb µg/g				Nb µg/g	0.5	6	19
Nd µg/g				Nd µg/g	7.3	3	4
Ni µg/g				Ni µg/g	34.7	2	3
Pb µg/g				Pb µg/g	3.6	3	5
Sc µg/g				Sc µg/g	10.4	2	3
Sr µg/g	4.5	3	4	Sr µg/g	3.9	3	4
Th µg/g				Th µg/g	4.1	3	5
V µg/g	13.1	2	3	V µg/g	19.8	2	3
Y µg/g				Y µg/g	15.5	2	3
Yb µg/g				Yb µg/g	2.5	4	9
Zn µg/g	0.4	7	22	Zn µg/g	15.1	2	3

[1] Elements in *S. alterniflora* calculated on a dry-weight basis (i.e., 40°C), all other elements on an ash-weight basis.

levels of about 80 percent and their variance-mean-ratios ranged from about 8 to 16. The maps for organic C, S, and Pb have somewhat lower confidence levels. Their variance-mean-ratios were about 3 to 5. Just as the element contour maps for *S. alterniflora* were difficult to interpret, these are equally so. There are insufficient differences in concentration or map resolution to clearly delineate spatial trends owing to potential element sources such as McClellanville or the Santee River as significantly influencing the sediment chemistry. Lead in sediments is slightly higher at the northern edge of CRNWR (Figure A6c). However, attributing this to a specific source such as particulates or sediment input from the Santee River is not warranted with these data, particularly when less than one percent of the total variance in the Pb concentrations was attributable to differences between the north and south sections of the refuge.

S. alterniflora-sediment elemental relationships

Frequently there is not a good correlation between the total concentration of elements in plants with that of soils because the total element concentration in soils is not representative of what is actually bioavailable. We did, however, find some weak to moderate correlations between element concentrations in *S. alterniflora* and sediments. Non-parametric Spearman's rank correlation coefficients that were significant ($p = 0.001$) are given in Table A11. Calcium, Fe, Ba, and Sr were not significant. Sulfur in *S. alterniflora* was positively correlated with S and negatively correlated with P, Ba, and Pb in the sediments. These correlations may indicate that higher sediment S concentrations represent higher sediment sulfide concentrations, which in turn, may have a phytotoxic effect on *S. alterniflora* and nutrient uptake such as P or NH_4^+ (Koch and Mendelssohn, 1989; Koch and others, 1990). Sediment sulfide concentrations also may be indicative of rhizosphere pH and the bioavailability of P, or there may be a competitive uptake of S or P species so that the halophyte may internally balance anions. Increased concentrations of Ba and Pb in the sediments may be indicative of lower porewater S concentrations owing to formation of insoluble sulfate and sulfide species. However, because the sample locations are regularly flooded and the sites are not a closed system, it is not obvious why S from seawater is not in such an excess that no correlations are obtained.

Several of the significant correlations found between elements in *S. alterniflora* and the sediments appear related to cycling of S and P. *S. alterniflora* serves as an important pathway for P movement from the sediment through the plant and ultimately to the estuarine waters (Reimold, 1972).

Broome and others (1975) measured a number of elements in *S. alterniflora* and associated sediments in North Carolina salt marshes and developed multiple regression models to explain *S. alterniflora* yield and height differences between short and tall forms. Only their model for yield included any sediment factors. They found that total concentrations of sediment Mn were negatively related and that total concentrations of P were positively related to *S. alterniflora* yield. However, contrary to what others have found (Howes and others, 1986), their study did not find a very strong relationship between yield and height of *S. alterniflora*. Delaune and Pezenshki (1988) looked at similar relationships and found that there were significant correlations between *S. alterniflora* plant productivity (as measured by biomass and height) and total concentrations of sediment Fe, K, Mg, Mn, P, and Zn, and sediment bulk density in Louisiana. We found somewhat different results in that there were some weak correlations between plant height and several elements that were highly loaded on Factor 1 of the sediment factor analysis model (Al, Fe, Li, Ni, V, and Zn) and insignificant correlations between plant height and sediment concentrations of K, Mn, and P. Correlations such as these suggest that sediment mineralogy, perhaps the concentration or type of clay minerals, may play a role in the

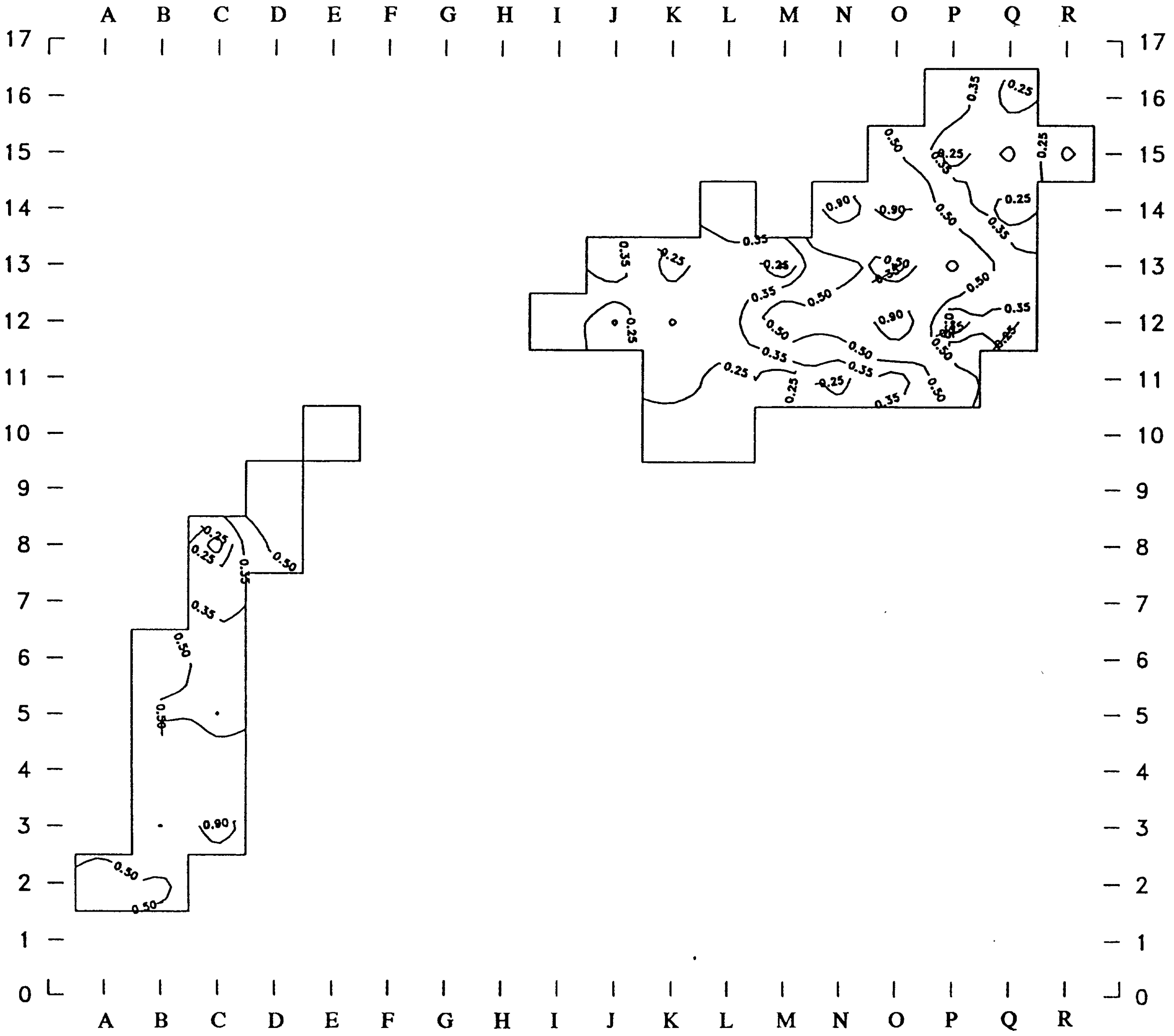

Figure A5a. Biogeochemical contour map for aluminum (ash-weight basis) in *S. alterniflora*.

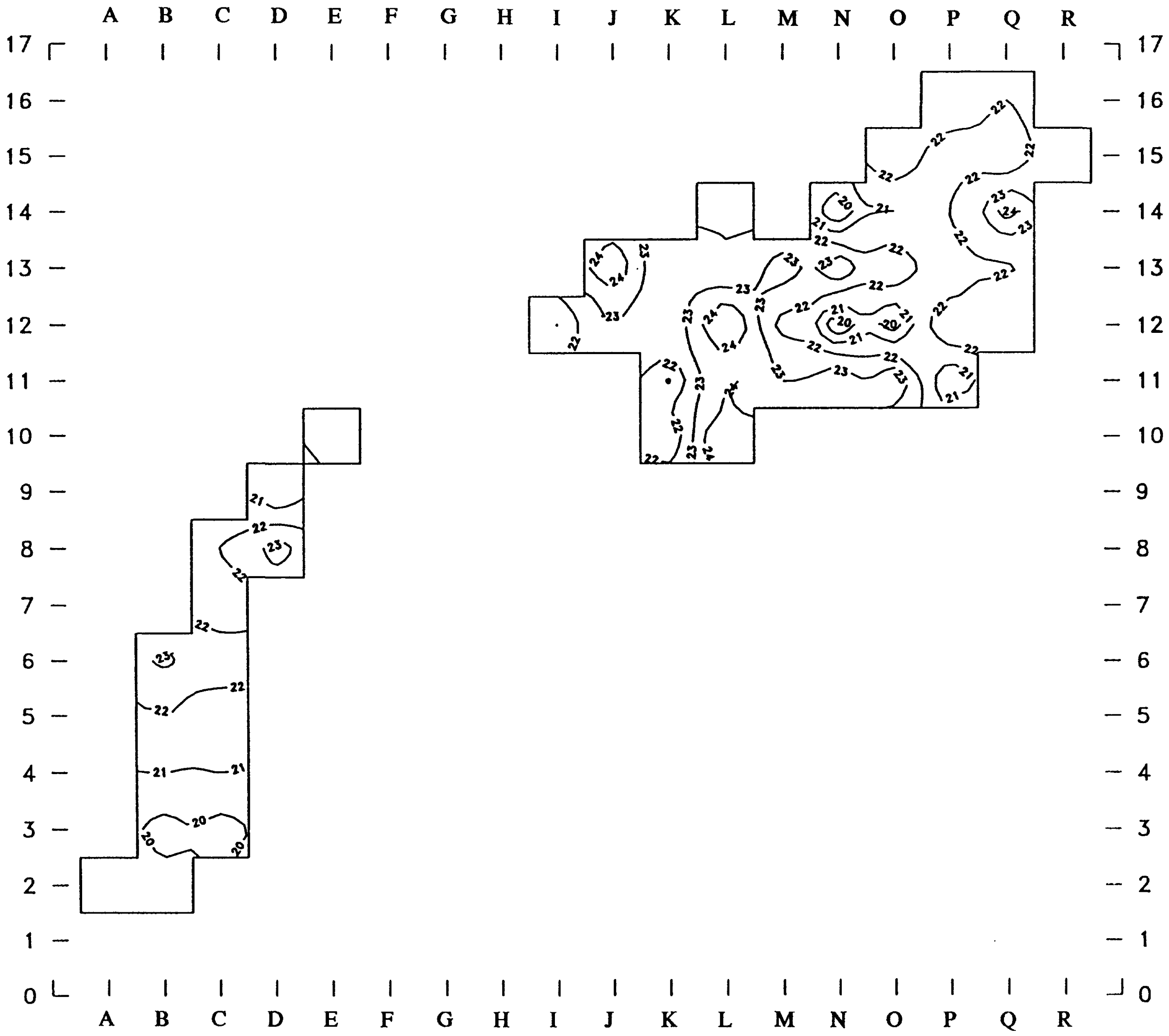

Figure A5b. Biogeochemical contour map for sodium (ash-weight basis) in *S. alterniflora*.

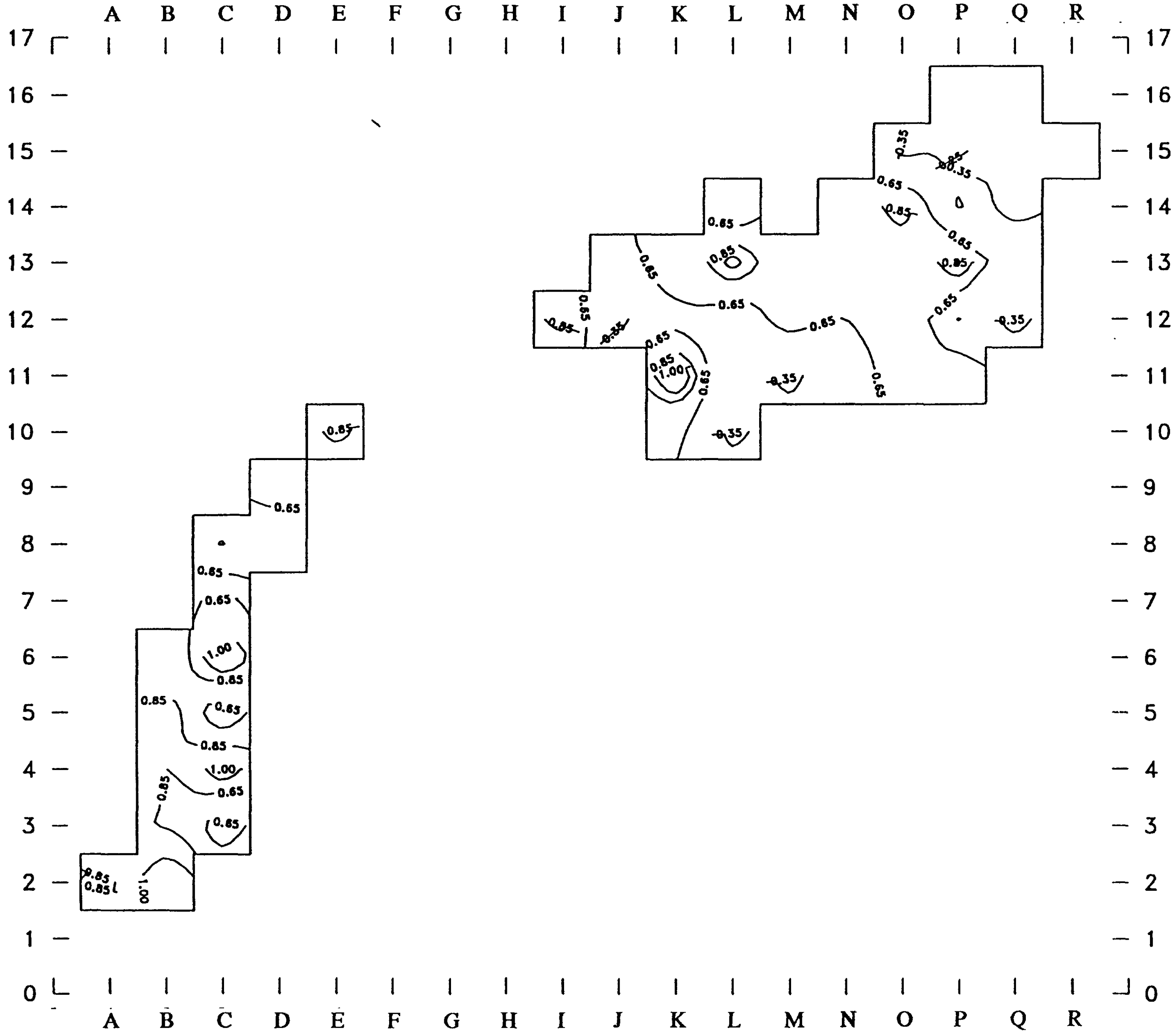

Figure A5c. Biogeochemical contour map for sulfur (dry-weight basis) in *S. alterniflora*.

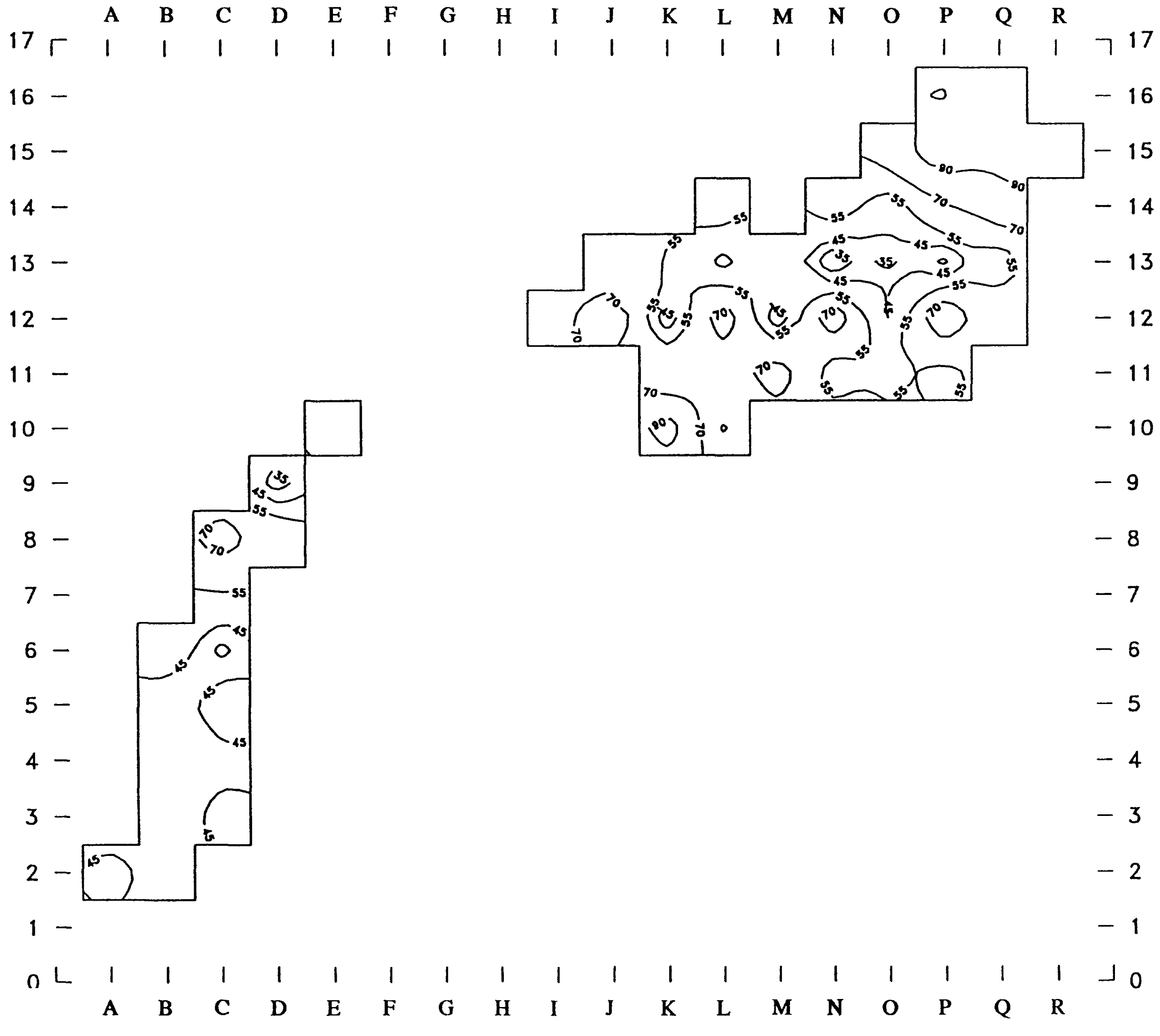

Figure A5d. Biogeochemical contour map for zinc in *S. alterniflora*.

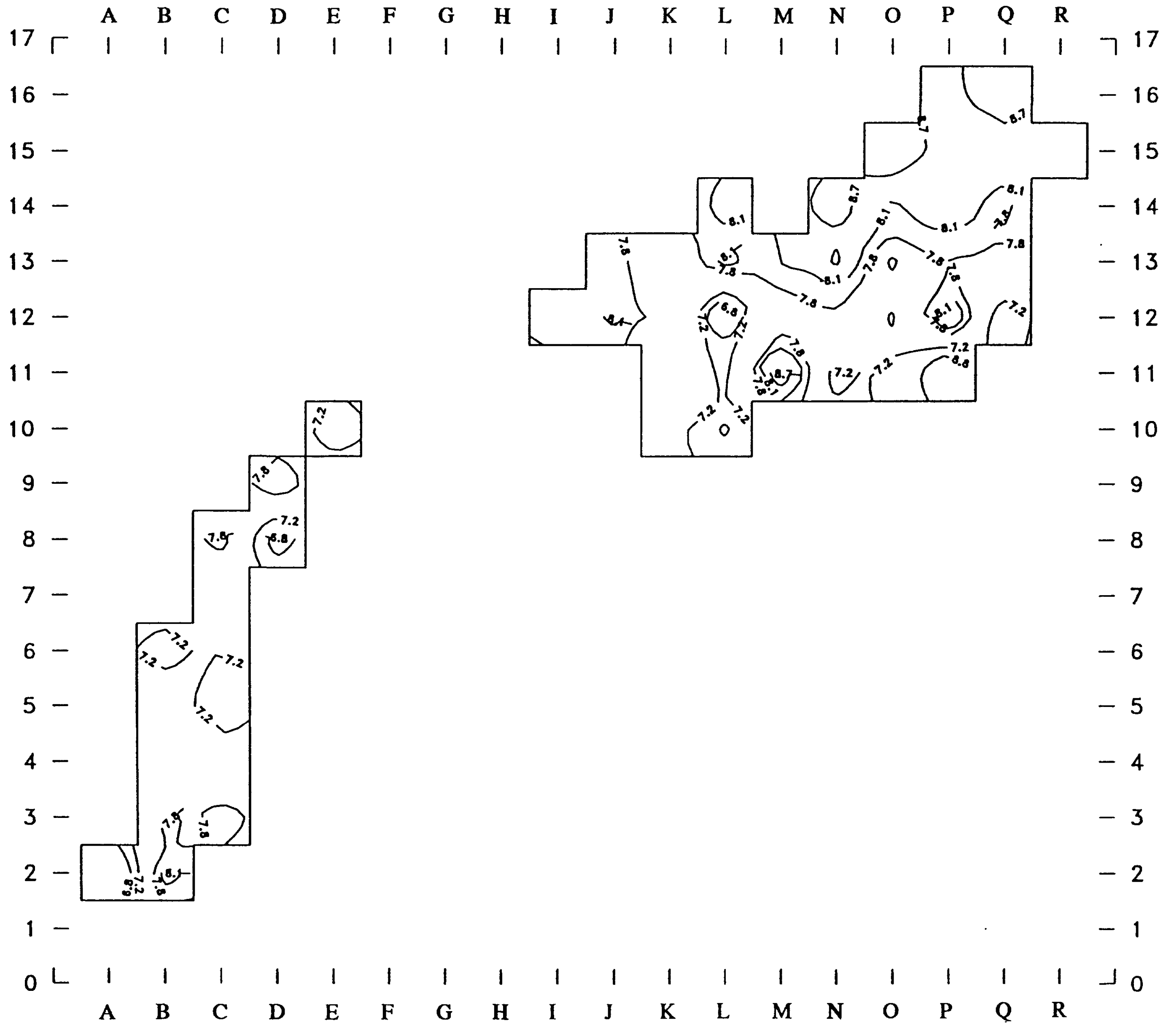

Figure A6a. Biogeochemical contour map for aluminum in sediment.

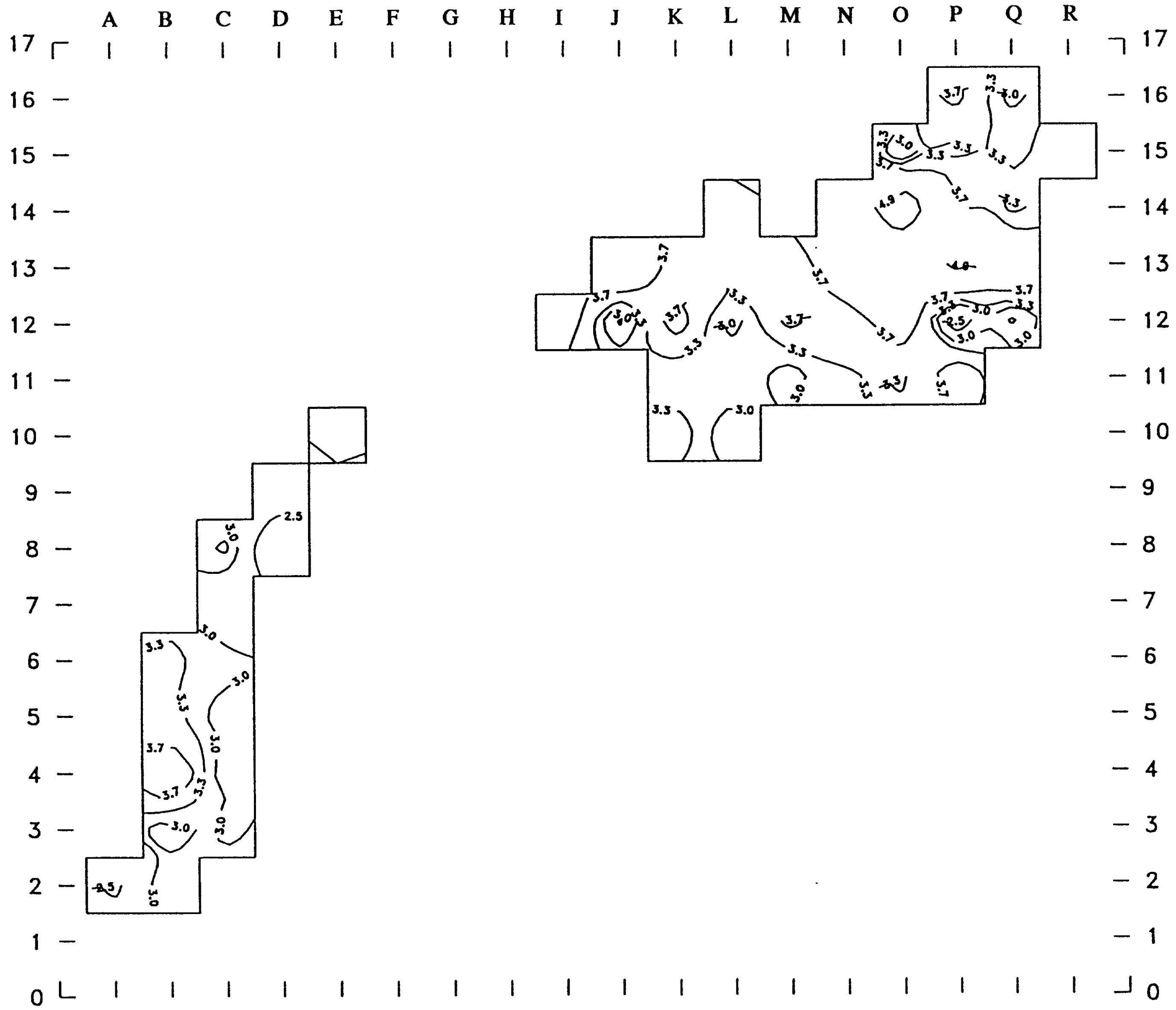

Figure A6b. Biogeochemical contour map for organic carbon in sediment.

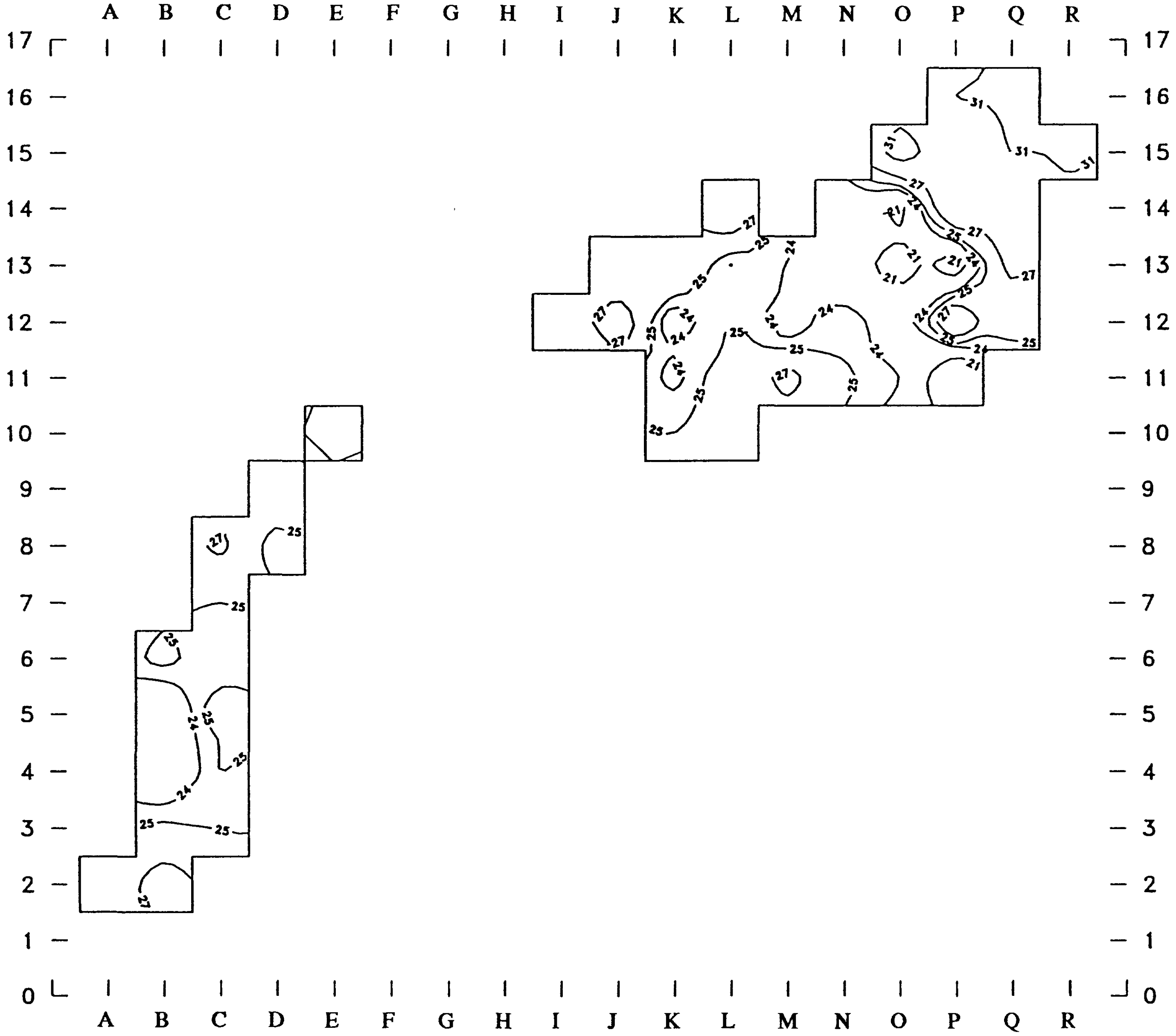

Figure A6c. Biogeochemical contour map for lead in sediment.

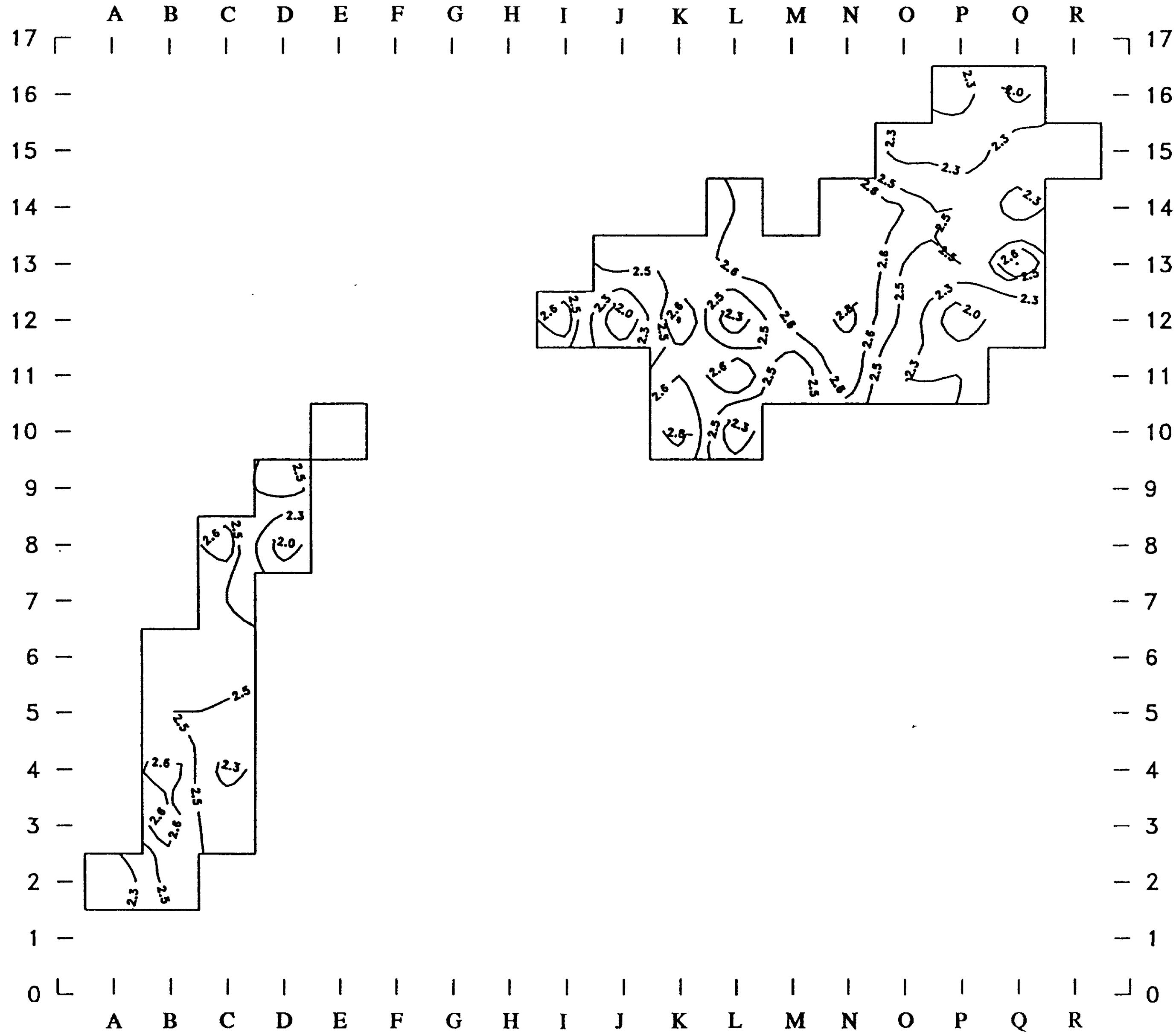

Figure A6d. Biogeochemical contour map for sodium in sediment.

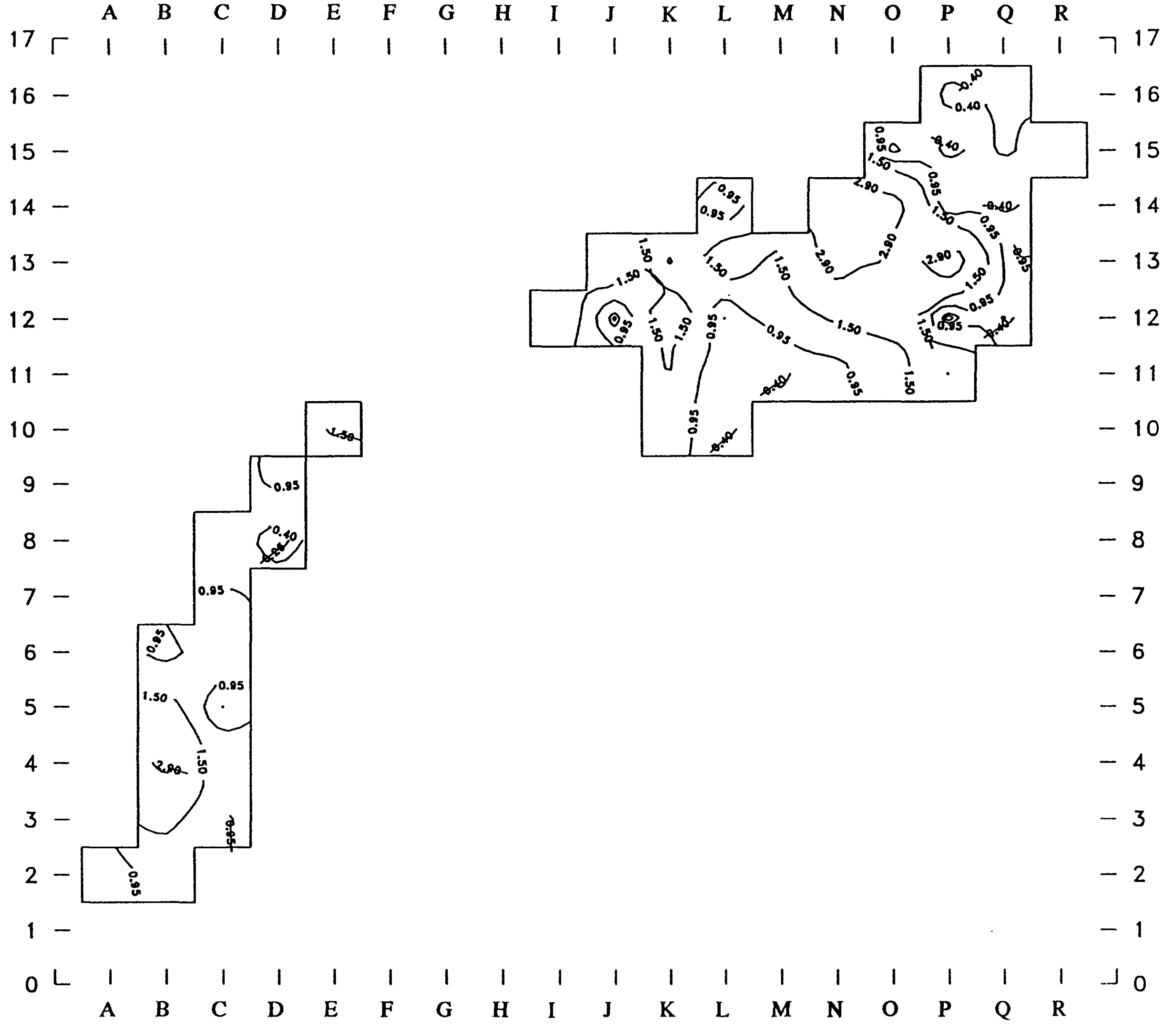

Figure A6e. Biogeochemical contour map for sulfur in sediment.

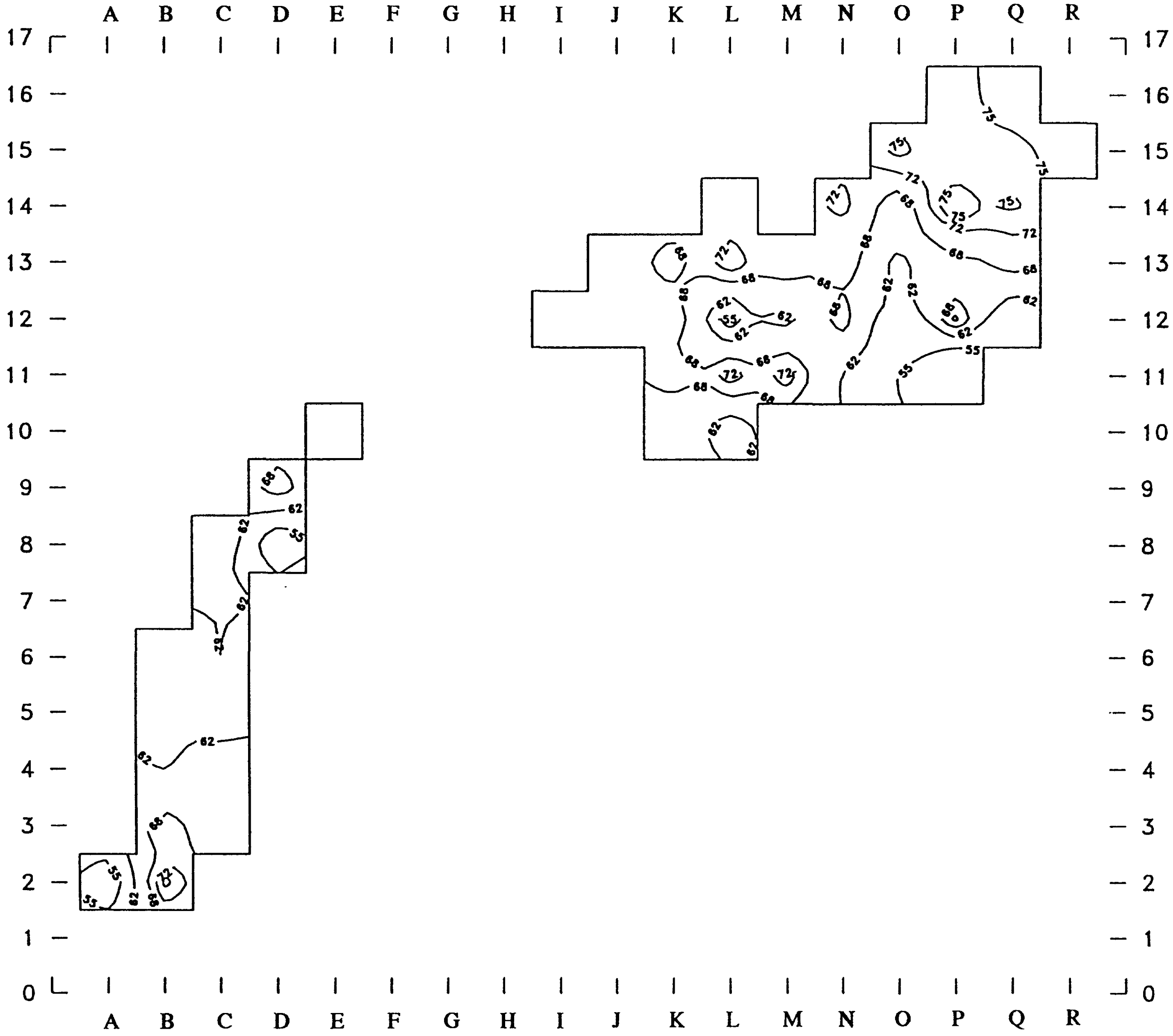

Figure A6f. Biogeochemical contour map for zinc in sediment.

Table A11. Spearman Rank Correlation Coefficients for elements in *S. alterniflora* and sediments from November 1987.

Sediment Variable	S. alterniflora variable												
	Density	Height	Ash	S	Al	K	Mg	Na	P	Cr	Li	Mn	Zn
C org						-0.41			-0.41				
C crbnt						0.47							
S			0.54	0.76	0.46		0.48		-0.77	0.42	0.49		-0.60
Al		0.42											
Ca													
Fe		0.42											
K													
Mg													
Na				0.43					-0.42				
P			-0.60	-0.66	-0.47				0.63	-0.43	-0.54		0.55
Ti	-0.43												
As													
Ba			-0.50	-0.70	-0.46		-0.45	0.41	0.74	-0.42	-0.47		0.52
Ce			-0.49	-0.43							-0.40		
Cr													
Cu													
La			-0.46	-0.50					0.51		-0.42		0.49
Li		0.41											
Mn												0.52	
Ni		0.44											
Pb			-0.55	-0.64	-0.42				0.63	-0.42	-0.48		0.64
Sc													
Sr													
V		0.40											
Zn		0.50											

S. alterniflora growth forms. However, it may be fortuitous that these intercorrelated elements in sediments seem related to plant height. Impeded drainage, with increased sediment porewater salinity and reduced aeration, and phosphorous availability have been proposed as possible controlling factors on *S. alterniflora* growth forms. It is likely that if impeded drainage has an influence on *S. alterniflora* culm height that it also has an influence on a site's sedimentalogy and, hence, the geochemical makeup of the sediments.

In addition, there was a weak inverse correlation between *S. alterniflora* culm stand density and Ti in the sediments. Although Ti concentrations in sediments may be indicative of increased concentrations of heavy or resistant detrital minerals in the sediments, this can not be interpreted as a causative agent for decreased *S. alterniflora* density, but again may be a sedimentalogical characteristic of a site with impeded drainage.

Seasonal element concentration trends

Parametric paired-t tests were made to compare the two types of *S. alterniflora* samples collected in June 1988. Based on the obvious large difference in ash content it is not surprising that most element concentrations in the two types of samples, with and without the senescent flowering stalk, were significantly different at a probability level of $p = 0.01$. When the elements determined by ICP were compared on an ash-weight basis, only Mn was not

Table A12. Paired t-test results for interseasonal comparisons of element concentrations in *S. alterniflora* and sediments.

	S. alterniflora leaves, culms, & flowering stalk[1]		*S. alterniflora* leaves & culms[2]			Sediments	
Element	t value[3]	average difference[4]	t value	average difference	Element	t value	average difference
Ash %[5]	17.4**	5.42	8.53**	-1.85	C total %	0.37	-0.07
S %[5]	11.2**	0.48	6.95**	0.31	C org %	0.62	-0.10
Al %	25.4**	-3.5	10.8**	-0.98	C crbnt %	2.41*	0.03
Ca %	2.70*	0.68	6.04**	1.3	S %	1.04	-0.05
Fe %	26.2**	-1.9	10.2**	-0.54	Al %	2.26*	0.34
K %	16.4**	3.2	10.4**	-4.0	Ca %	2.04	0.09
Mg %	1.77	-0.46	10.3**	2.0	Fe %	< 0.01	-0.01
Na %	13.6**	11	8.50**	3.3	K %	6.3**	0.08
P %	4.31**	-0.26	7.48**	-0.50	Mg %	1.43	0.04
Ti %	23.9**	-0.20	9.30**	-0.05	Na %	0.35	-0.03
Ba µg/g	43.5**	-86	11.2**	-16	P %	0.39	< 0.01
Cr µg/g	25.5**	-36	11.3**	-8	Ti %	4.34**	0.02
Cu µg/g	12.8**	-19	6.53**	-9	As µg/g	1.34	-2
Li µg/g	33.7**	-31	12.7**	-10	Ba µg/g	2.04	29
Mn µg/g	1.77	-110	3.30**	-210	Be µg/g	1.00	< 1
Sr µg/g	2.20*	93	7.51**	230	Ce µg/g	0.32	< 1
Zn µg/g	13.9**	-90	5.14**	-24	Co µg/g	1.24	< 1
					Cr µg/g	0.11	-1
					Cu µg/g	0.41	1
					Ga µg/g	2.79*	-1
					La µg/g	2.28*	-1
					Li µg/g	1.35	3
					Mn µg/g	1.65	17
					Nb µg/g	1.41	1
					Nd µg/g	0.36	< 1
					Ni µg/g	0.60	-1
					Pb µg/g	2.52*	2
					Sc µg/g	1.52	-1
					Sr µg/g	1.93	5
					Th µg/g	2.02	-1
					V µg/g	0.23	< 1
					Y µg/g	0.97	-1
					Yb µg/g	0.35	< 1
					Zn µg/g	1.17	3

[1] *S. alterniflora* flowering stalk collected in both November and June.

[2] *S. alterniflora* leaves and culms without senescent flowering stalk collected in June.

[3] t value degrees of freedom = 15; * = significant at p = 0.05, t = 2.13; ** = significant at p = 0.01, t = 2.95.

[4] Average difference (November-June value) for 16 pairs.

[5] Element concentrations in *S. alterniflora* on a dry-weight basis, all other elements on an dry-weight basis (i.e., at 40°C).

significantly different between the two sample types. When these same elements were compared on a dry-weight basis, Mn was significantly different, however, on this weight basis several intercorrelated elements (Al, Fe, Li, and V) were no longer significantly different between the two sample types.

Seasonal comparisons of element concentrations in *S. alterniflora* and sediments were made using a paired t-test for the sites that were sampled in both November and June (Table A12). The element concentrations in *S. alterniflora* collected in November and the samples of culms, leaves, and senescent flowering stalk collected in June had significant differences for most elements (except Mg and Mn on an ash-weight basis) at the 0.01 probability level. Significant differences were also found when comparing the November collection with the June collection of culms and leaves only. There were significant interseasonal differences regardless of whether the material collected in June included the senescent flowering stalk or not. However, the magnitude of the differences, in particular for the ash content, was dependent upon the type of material collected. All the elements in *S. alterniflora* listed in Table A12, except Mn, were statistically different at the 0.01 probability level for the two sample types collected in June. Although the ash content was greatly different in the two types of June samples, the interseasonal element concentration differences were still significantly different when the paired-t tests were made after converting all elements to a dry-weight basis. Most intraseasonal differences were still significantly different on the dry-weight basis except for Al, Fe, Li, and V, which were elements associated with Factor 1 of the factor analysis model. These differences are not surprising when taking into account the large seasonal differences that have been measured in above-ground and below-ground biomass (Dame and Kenny, 1986; Ellison and others, 1986; Gallagher and others, 1984; Schubauer and Hopkinson, 1984) and even leaf density (Giurgevich and Dunn, 1979).

For the sediments many elements did not exhibit a difference between the November and June sampling periods (Table A12). However, K and Ti were significantly different at the 0.01 probability level and Al, Ga, La, and Pb were significantly different at the 0.05 probability level. However, with the exception of Al, the average differences were about the same as the analytical error and are not considered to be true interseasonal differences in the sediments. The average difference for Al represents only about 3-10 percent relative difference between the collection periods and it is not obvious that this indicates that there were any true interseasonal differences in the sediments.

Trace element enrichment in sediments

The chemical composition of sediments varies greatly depending upon the proportions of the various size fractions, sand, silt, and clay, and on the mineralogical composition of each size fraction. The greatest concentration of trace elements is usually associated with the finer sediment fractions, in particular the clay minerals. In order to examine trace element enrichment in sediments or make comparisons between different localities a variety of normalization techniques have been used (Salomons and Forstner, 1984). The techniques most frequently used are based on: (1) the chemical analysis of a specific grain size fraction, (2) the partial chemical extraction of trace elements, (3) or normalization to a conservative element in the sediment. In the latter case, normalization to a conservative element, enrichment factors are typically calculated as the ratio of an element to Al and then compared with crustal abundance. Various other "conservative" elements have been used for normalizing such as Sc, Cs, Eu, Rb, and Sm as summarized by Salomons and Forstner (1984). Recently, Li has also been proposed as a suitable element for granulometric normalization (Loring, 1990).

Table A13 lists the geometric mean concentrations for elements in CRNWR sediments and for elements in average shale and continental crust. In addition, element to Al ratios are shown for these three materials. Salomons and Forstner (1984) suggest that for comparisons with sediments, average shale makes a better global standard than continental crust. However, our results indicate marine sediments are not well matched to the average shale which is composed of a large proportion of shales derived from terrestrial-freshwater sediments in addition to marine sediments. Concentrations of several major elements (S, Ca, K, Mg, and Na) differed by a factor of 2 or more in CRNWR sediments versus the average shale. Even greater differences occurred for some of these major elements compared to crustal abundance, although the Al concentration for all three materials was approximately equal. Average trace element concentrations for Co, Cr, Cu, Ni, V, and Zn, were lower in CRNWR sediments than in either the average shale or the crust. Arsenic and Pb were slightly elevated compared to shale. These increases in As and Pb may be owing to their incorporation in sulfide minerals, which are high in anoxic marine sediments (Forstner, 1977) or adsorbed on iron oxyhydroxides (Brannon and Patrick, 1987; Kersten and others, 1991).

Element to Al ratios in the sediments were calculated in two ways: (1) as the arithmetic average of the element ratio in all samples and (2) for those elements that covaried with Al as the slope of a linear regression model for the element concentration (non-log-transformed) versus Al concentration. In some cases the two methods give somewhat different results owing to the distribution of the data. However, because the sediment Al concentration was about the same as average shale and crust, the conclusions are about the same as those from the comparison of concentrations alone: As is enriched in the sediments compared to shale and Pb is equal to or slightly enriched compared to shale depending upon which mode of normalization is used. The other trace elements mentioned above are not enriched in the sediments compared to average shale.

Windom and others (1989) analyzed several hundred coastal marine and estuarine sediment samples from the southeastern United States and found that several trace elements (As, Co, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) covaried with Al. They used this extensive data set to generate linear regression equations for these elements in sediments from the Georgia/South Carolina coast and from the Florida coast in order to assess anthropogenic influences at other locations. Their regression model parameters along with coefficients of determination for selected elements with Al and organic C are shown in Table A14. Linear regression models for selected elements versus Al and coefficients of determination for elements versus Al, Li, and organic C for CRNWR sediments are also shown in Table A14. Regression models were calculated for several additional elements in CRNWR sediments that were not determined in the other coastal marine sediments.

Plots of elements in CRNWR sediments versus Al and two linear regression models are shown in Figure A7. In CRNWR sediments As and Mn did not covary with Al as was found by Windom and others (1989). Also, the linear models for CRNWR sediments frequently explained less of the variance than was found for the coastal marine sediments. In general, we

Table A13. Comparison of element concentrations and their ratio to Al in sediments versus average shales and crustal abundances.

	Elemental Abundances			Element/Al Ratios			
Element	Sediment GM[1]	Averages in Shales[2]	Averages in the crust[2]	Sediment Linear model[3]	Sediment Ave. ratio[4]	Shales	Crust
C total%	3.39		0.02		0.46		0.002
C org%	3.31				0.45		
C crbnt%	0.04				0.01		
S%	0.84	0.24	0.026		0.16	0.03	0.003
Al%	7.7	8.0	8.13		-	-	-
Ca%	0.71	2.21	3.63		0.10	0.28	0.45
Fe%	4.1	4.72	5.00	0.70	0.53	0.59	0.62
K%	1.1	2.66	2.59		0.15	0.33	0.32
Mg%	0.87	1.50	2.09		0.12	0.19	0.26
Na%	2.4	0.96	2.83		0.32	0.12	0.35
P%	0.08	0.07	0.105		0.01	0.0088	0.013
Ti%	0.49	0.46	0.44		0.06	0.058	0.054
As µg/g	22	13	1.8		3.1	1.6	0.22
Ba µg/g	140	580	425		25	72	52
Be µg/g	2	3	2.8		0.26	0.38	0.34
Ce µg/g	75	50	60	6.0	9.9	6.2	7.4
Co µg/g	10	19	25	1.4	1.4	2.4	3.1
Cr µg/g	77	90	100	8.1	10	11	12
Cu µg/g	19	45	55	4.7	2.6	5.6	6.8
Ga µg/g	17	19	15	2.3	2.2	2.4	1.8
La µg/g	35	24	30		4.7	3.0	3.7
Li µg/g	70	66	20	12	9.1	8.2	2.5
Mn µg/g	340	850	950		46	110	120
Nb µg/g	10	11	20		1.3	1.4	2.5
Nd µg/g	32	24	28		4.3	3.0	3.4
Ni µg/g	23	68	75	3.8	3.0	8.5	9.2
Pb µg/g	25	20	13	2.4	3.4	2.5	1.6
Sc µg/g	12	13	22	1.4	1.6	1.6	2.7
Sr µg/g	120	300	375		16	38	46
Th µg/g	11	12	7.2		1.5	1.5	0.88
V µg/g	110	130	135	17	14	16	17
Y µg/g	17	26	33		2.3	3.2	4.0
Yb µg/g	2	2.2	3.4		0.27	0.28	0.42
Zn µg/g	65	95	70	10	8.6	12	8.6

[1] GM = geometric mean from Table A4.

[2] Elemental abundance averages from Dietrich and others, 1982.

[3] Slope of the linear regression model in Table A14.

[4] Average of element/Al ratio for each sample, n = 83.

Table A14. Linear regression models[1] for elements versus Al for sediments and coefficients of determination for elements versus Li and organic C.

	Cape Romain NWR linear model coefficients					Georgia and South Carolina coastal marine sediments (Windom and others, 1989)			
element	slope	constant	r^2(M:Al)	r^2(M:Li)	r^2(M:C_{org})	slope	constant	r^2(M:Al)	r^2(M:C_{org})
Al	-	-	-	0.86	0.03				
As			0.05	0.16	0.26	7.5[2]	-0.7	0.77	0.13
Ce	6.0	30	0.50	0.23	0.04				
Co	1.4	-0.52	0.66	0.70	0.18	1.15	0.05	0.60	0.13
C org			0.03	0.10	-				
Cr	8.1	16	0.23	0.20	< 0.01	9.5[2]	4.0	0.81	0.31
Cu	4.7	-16	0.72	0.66	0.18	1.8	-1.4	0.64	0.39
Fe	0.70	-1.2	0.52	0.59	0.10	0.47	-0.08	0.91	0.45
Ga	2.3	-0.95	0.92	0.81	0.03				
Li	12	-21	0.86	-	0.32				
Mn			0.04	0.02	0.13	55	57	0.61	0.13
Ni	3.8	-6.1	0.93	0.90	0.10	4.4	-3	0.53	0.21
Pb	2.4	7.5	0.24	0.05	0.11	3.5	1.5	0.62	0.21
S			< 0.01	0.12	0.09				
Sc	1.4	1.3	0.90	0.74	< 0.01				
V	17	-22	0.95	0.81	0.05				
Zn	10	-11	0.69	0.61	0.03	12	-8	0.70	0.49

[1] Linear regression model is based on the equation $M = m(Al) + b$, where m equals the slope and b equals a constant with Al, C_{org}, Fe, and S concentrations in percent and all other elements in µg/g. Models for all elements in NWR sediments with slope and constants included were significant at $p = 0.001$ for $n = 83$. Models for coastal marine sediments were significant at $p = 0.05$ for $n = 264$.

[2] Linear regression model for Florida coastal marine sediments with $n = 73$.

found even weaker associations of the elements with organic C than was found for the coastal marine sediments. We also examined element versus Li ratios and found that generally Li was not a better normalizing element than Al.

For most of the elements, the CRNWR regression models produced parameters which were not greatly different from the coastal marine sediment models even though most of the element/Al associations were weaker than in the coastal marine sediments. However, as Windom and coworkers found, Cu did give a somewhat different model which appears to be dependent upon the specific location. Ni and Zn also gave models with a lower slope than those for the coastal marine sediments. Windom and others observed lower ratios for Zn in Savannah River sediments analyzed by Goldberg and others (1979). However, they attributed this to differences in analysis methods. Ratios for Pb and Zn to Al in a *S. alterniflora* salt marsh sediment core also fell in the range of CRNWR sediments (Goldberg and others, 1979).

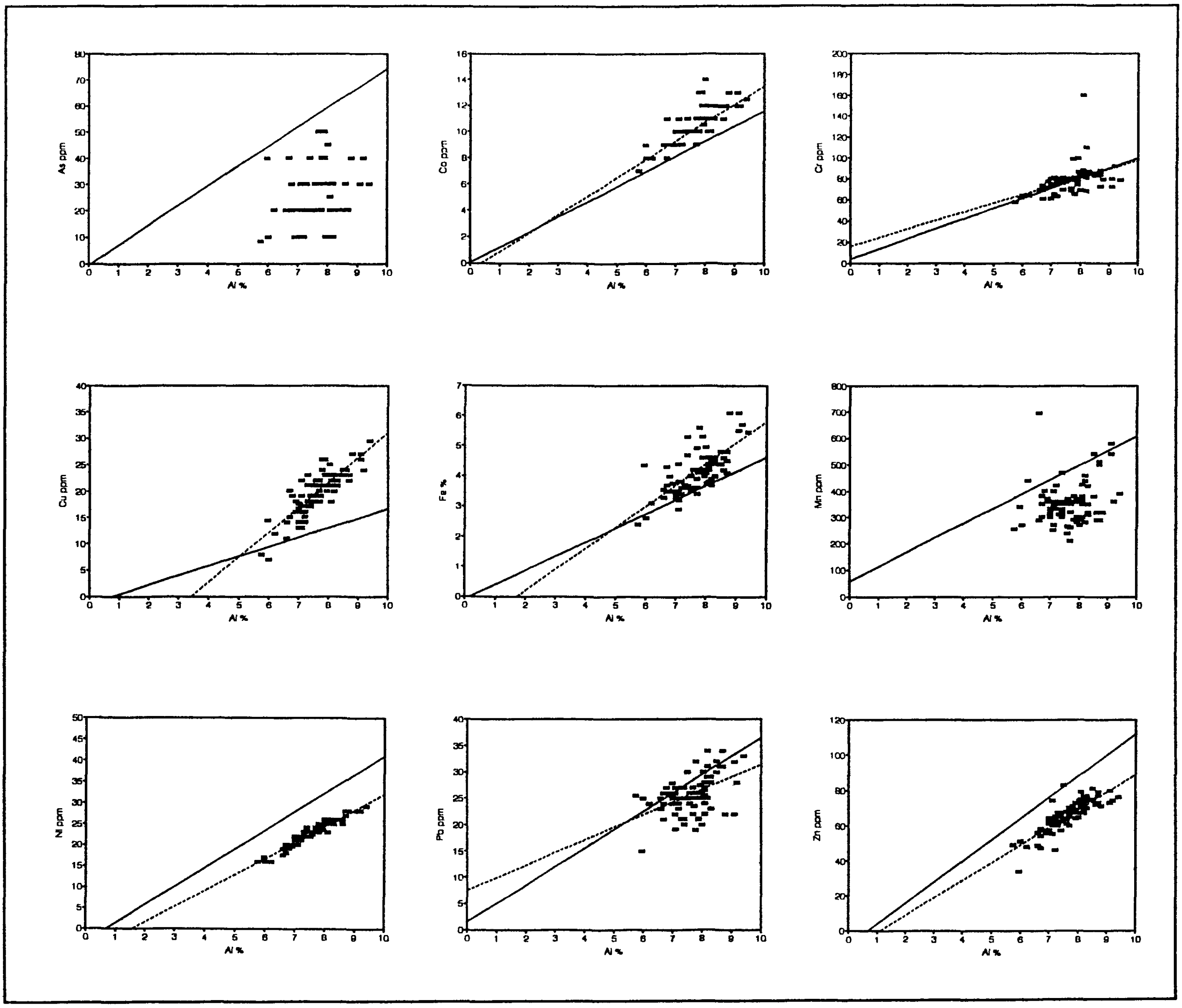

Figure A7. The concentration of As, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn versus Al in sediments. Dashed line represents linear regression model for CRNWR sediment data. No regressions were calculated for As and Mn versus Al. Solid line represents linear regression model for coastal marine sediments (Windom and others, 1989).

It should be noted that the majority of the coastal marine sediments had less than 2 percent Al, whereas CRNWR sediments had 6-9 percent Al. This may be in part owing to dilution of the coastal marine sediments by marine sands, that are primarily quartz. Also the distribution of silt and clay-sized minerals is likely different. In addition, the clay mineralogy is probably quite different with the coastal marine sediments having a much higher illite and montmorillonite content with a theoretical Al content of about 14 percent versus CRNWR sediments composed of primarily kaolinite with a theoretical Al content of about 21 percent. The illite and montmorillonite clays also have a higher cation exchange capacity than the kaolinite. Most of the coastal marine samples were collected from nearshore subtidal areas of southern-most coast of South Carolina and from the coast of Georgia. The coastal areas that are largely influenced by rivers draining the Piedmont Province such as the Santee, Savannah, and Altamaha Rivers compared to those areas with smaller rivers predominantly draining the Coastal Plain have much higher concentrations of kaolinite than montmorillonite or illite (Neiheisel and Weaver, 1967; Windom and others, 1971). Offshore sediments are high in montmorillonite and illite (Windom and others, 1971). Thus, the differences in the clay mineralogy and subtidal nature of the coastal marine sediments compared to CRNWR sediments makes comparisons of the models more complex and suggests that independent models should be produced for different sediment and clay assemblage regimes. However, in general, it appears that CRNWR sediments do not exhibit any anthropogenic contamination compared to the coastal marine sediments that Windom and others (1989) analyzed that they identified as being collected from sites relatively remote from contamination sources.

Surface water chemistry

Surface water samples were collected at eight locations in tidal creeks distributed throughout CRNWR. There were two primary objectives in collecting the water samples: (1) to determine if sulfate and chloride concentrations were significantly different from average seawater and (2) to determine if the average sulfur stable isotope ratio was significantly different from average seawater.

Seawater has an average salinity of 35 ppt with chloride and sulfate concentrations of 19.35 and 2.71 g/kg, respectively and a pH of approximately 8 (Stumm and Morgan, 1981). For eight sites we obtained average concentrations of 22 g/kg chloride and 2.6 g/kg sulfate with relative standard deviations of less than 2 percent; field pH's ranged from 7.43-7.82 (see Table D17). The influence of freshwater from the Santee River and other minor sources on the surface water chemistry of CRNWR is not known. However, we believe that based on our limited analyses and the large daily tidal changes that seawater has the major influence on the surface water chemistry of CRNWR, especially with regard to sulfur chemistry.

SUMMARY

Hierarchical ANOVA was used to examine scales of spatial variability in element concentrations in *S. alterniflora* and sediments. Generally, most elements in *S. alterniflora* exhibited the greatest amount of variance among different grid cells. Although in *S. alterniflora* there was not a large proportion of the total variance attributed to differences between northern and southern extents of the CRNWR, several elements did have 10-25 percent of their variance at this ANOVA level. For a number of elements there was a significant proportion of their total variance attributed to differences over relatively short distances (30 m). The broad scale heterogeneity indicates that there may be spatial trends in element concentration within the CRNWR and that it would be difficult to sample a small subset of the *S. alterniflora* population within the area studied that would be truly representative of the entire population.

Similar hierarchical ANOVA results were found for the sediments. However, there was frequently a larger proportion of the total variance attributed to differences at distances of 30 m than was obtained for the plants. These differences may be owing to significant microtopological and sedimentation differences between locations at distances of only 10's to 100's of meters. In general, there was not a large proportion of the total variance that was attributable to differences between northern and southern extents of the CRNWR for most major elements in the sediments. Although the mineralogical make up of the sediments is believed to be the same throughout the CRNWR, minor differences in the proportion of different minerals may have a significant influence on the element content, particularly for trace elements.

Biogeochemical contour maps for selected elements were developed; however, there were no obvious trends that could be readily explained with respect to either the sources of sediment input, potential pollution sources, or geomorphological characteristics of the CRNWR. Based upon our ANOVA results, estimates of the required sampling density to generate stable biogeochemical maps were obtained. In general, 3-5 samples would be required within grid cells of 2.6 km^2 for most elements in *S. alterniflora* and in sediments. However, it is not obvious that these maps would provide any interpretable trends, or that they would be meaningful for trends in any other type of sample locality other than the type of marsh area that we sampled. Wolaver and others (1988) have found significant differences in import and export of inorganic and organic suspended sediments between different elevational aspects of the marsh. In addition, the estimated sampling densities for maps of a given confidence level may be invalid for other types of sample localities.

Factor analysis models were developed for selected elements in *S. alterniflora* and sediments. They give some clues as to the inter-element relationships in these media and those elements that are likely to be controlled by the same biogeochemical processes. We found some moderate-to-weak relationships between sediment chemistry and plant chemistry and height. These relationships appear to be controlled by edaphic factors related to sediment mineralogy, salinity, and redox properties.

Interseasonal differences measured in *S. alterniflora* chemistry indicate that both the time of sampling and the nature of the plant parts sampled have a significant impact on the element concentrations obtained. Thus, minor differences in season of sampling or growth stage may produce significantly different baseline element concentration ranges. Thus, the comparability of future measurements with the baseline ranges that we have determined may be very sensitive to similarities in the season of sampling and the plant's growth stage, the nature of the plant sample collected, the height of the plants, and the type of growth locality.

Although our measurements indicated that there may be some interseasonal differences in the sediments at CRNWR, we believe that there are no true interseasonal differences, but that the differences observed represent artifacts of the analytical measurements or sediment inheterogeneity over short distances.

Comparisons of the sediment chemistry at CRNWR with average continental crust and average shale indicated that most elements in CRNWR sediments were at or below average abundances for either material. Arsenic and Pb were slightly elevated compared to average shale; however, this may be expected for an anoxic marine sediment where these elements may be incorporated as insoluble sulfides (Forstner, 1977) or adsorbed on iron oxyhydroxides (Brannon and Patrick, 1987; Kersten and others, 1991). Normalization of the As and Pb sediment concentrations by ratioing to Al also indicated that As was enriched compared to average shale, whereas Pb was only equal to or slightly enriched compared to average shale.

Linear regression models were developed for those elements which covaried with Al. These models were compared with similar models derived for subtidal coastal marine sediments of South Carolina and Georgia. Although there are some probable differences in the mineralogy and the bulk chemical characteristics of the coastal sediments and CRNWR sediments and there were some differences in the model results, the CRNWR sediments do not appear to have any more enrichment in the trace elements Cr, Ni, Pb, or Zn than already exists in the coastal marine sediments that were supposedly collected from relatively non-contaminated areas. Copper did appear to be elevated compared to the coastal marine sediments, but it may be that this is more a reflection of differences in the types of sediments used in the models than to a true Cu enrichment from an anthropogenic source in the CRNWR sediments. Before truly quantitative comparisons can be made with these models more research needs to be done on the chemistry and mineralogy of sources of sediments at CRNWR.

The major sources of any freshwater input into CRNWR would be from the Santee River, which had a dramatic increase in discharge after rediversion in 1985, rain, or upland pine forest surface runoff. Limited analyses of surface water indicated that the waters in CRNWR are primarily seawater with little or no freshwater dilution at the time of sampling in June 1988.

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Chapter B

Baseline Element Concentrations in Soils and Plants, Bull Island, Cape Romain National Wildlife Refuge, South Carolina[1]

By Larry P. Gough[2], R. C. Severson, *and* Larry L. Jackson

ABSTRACT

Baseline element concentrations are given for Spanish moss (*Tillandsia usneoides*), loblolly pine (*Pinus taeda*), and associated surface soils. Baseline and variability data for ash, Al, Ba, C, Ca, Cd, Ce, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Na, Nb, Nd, Ni, P, Pb, S, Sc, Sr, Th, Ti, V, Y, and Zn are reported; however, not all variables are reported for all media because, in some media, certain elements were below the analytical detection limit. Spatial variation in element concentration among and within 0.5 km grid cells are given for each of the sample media. In general, only a few elements in Spanish moss showed statistically significant landscape patterns, whereas several elements in loblolly pine and in soils exhibited differences among sampling grids. Significant differences in the concentration of three elements in Spanish moss and eight elements (including S) in loblolly pine were observed between two sampling dates (November and June); however, the absolute amount of these differences was small. Except for perhaps Ni and Pb concentrations in Spanish moss, element levels in all sample media exhibited ranges that indicate natural rather than anthropogenic additions of trace elements.

INTRODUCTION

This chapter focuses on the chemistry of plants and soils collected at Bull Island[3], South Carolina (Figure B1). Lands on this island and the adjacent bays, channels, sand bars, and salt marshes comprise the Cape Romain National Wildlife Refuge (CRNWR). The U.S. Fish and Wildlife Service (FWS), which manages the refuge, is responsible for assessing the effect of atmospheric pollutants in wildlife refuges throughout the United States. There is concern that

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[1] Chapter B of Jackson, L. L., editor, 1993, Biogeochemical studies of the salt marsh and a barrier island at Cape Romain National Wildlife Refuge, South Carolina: U.S. Geological Survey Open-File Report 93-303, 137 p.

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[3] The name "Bull Island" used throughout this report is consistent with the name used on the U.S. Geological Survey topographic map series. However, the original name was Bull's Island and the variant used by CRNWR is Bulls Island.

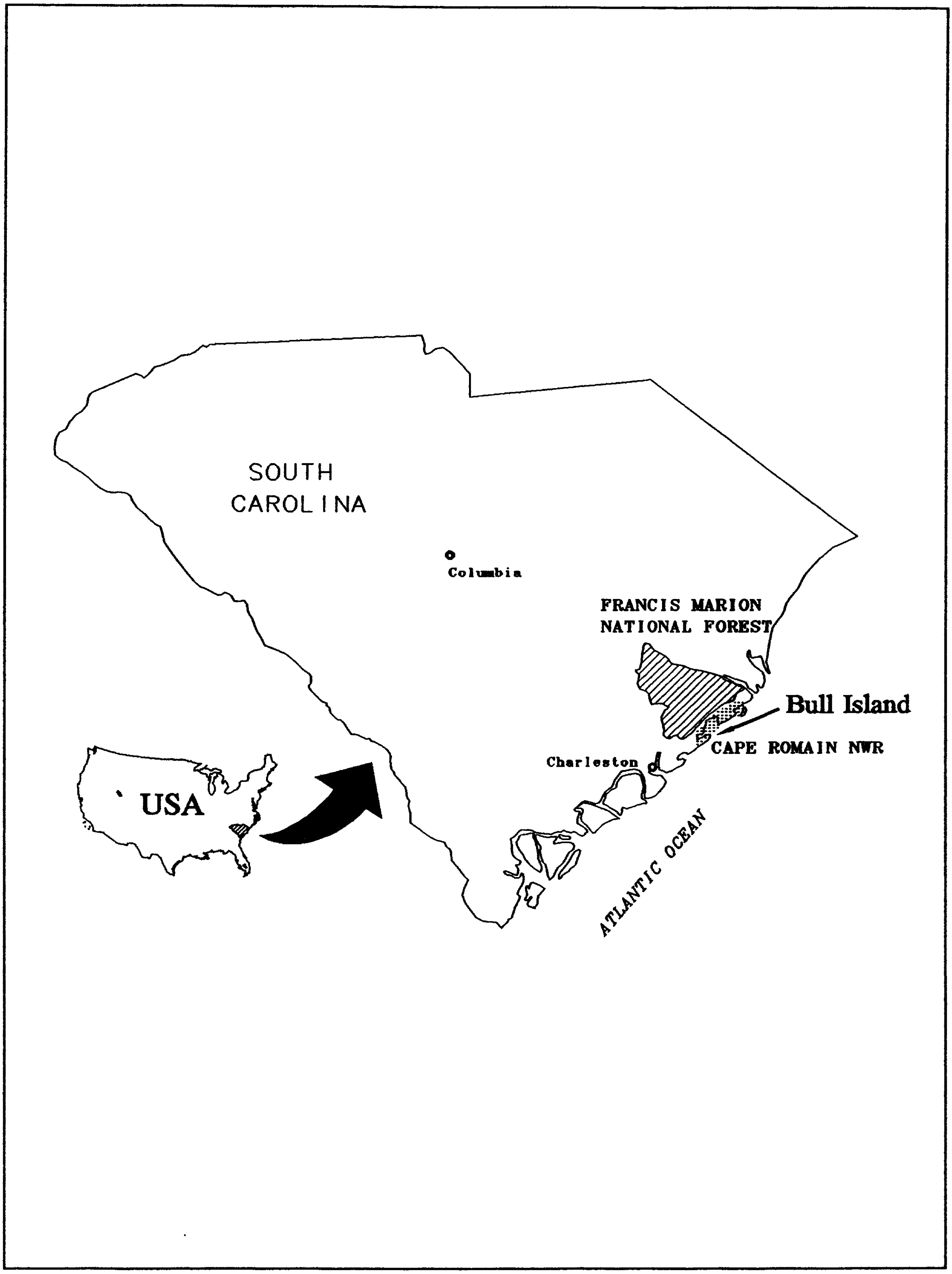

Figure B1. Location of the Bull Island, Cape Romain National Wildlife Refuge, South Carolina, study area.

the refuge lands might be subject to degradation from current and future air- and water-borne industrial emissions of trace elements.

Spanish moss (*Tillandsia usneoides* L.) occurs extensively throughout Bull Island and the adjacent mainland. Like many *Tillandsia* species, it is an epiphyte ("air plant") and does not possess roots, obtaining all of its nutrients from the atmosphere through dry and wet deposition. Its ecophysiology makes Spanish moss ideal as a biomonitor in air quality studies. Early work by Martinez and others (1971), Shacklette and Connor (1973), and Schrimpff (1981) and more recent work by Benzing (1989) and Schaug and others (1990) have demonstrated the utility of *Tillandsia* as an accumulator of environmentally important metals. Like other *Tillandsia* species, Spanish moss is also sensitive to the anthropogenic gases sulfur dioxide (SO_2) and ozone (O_3) (Benzing, 1989).

Loblolly pine (*Pinus taeda* L.) is an economically and ecologically important forest species in the southeastern United States. Its susceptibility to gaseous, particulate, and organic and inorganic air pollutants has been studied (Sheffield and others, 1985; Adams and others, 1988)). There is concern by FWS that the mature stands of loblolly pine on Bull Island could be adversely impacted by industrial emissions from the Charleston, South Carolina area (42 km to the southwest) (Zedaker and others, 1990). In this study we establish elemental concentration baseline data for Spanish moss, loblolly pine, and soil as an aid in assessing present and future air quality changes. These baselines will serve as a point of reference against which future change can be measured. In addition, spatial scales of variability were defined for plants. A minor objective of the study was to examine seasonal variability in soils and plants by sampling a subset of sites at two times during one year.

METHODS

Study Site Description

CRNWR is the largest of five barrier island/salt marsh wildlife refuges on the eastern United States coast and contains approximately 26,000 ha. Since 1975 most of this land has been designated as wilderness and is protected from significant air-quality deterioration by the Clean Air Act and its amendments. Bull Island, which is on the southeastern edge of CRNWR, is comprised of about 2,100 ha and areas of it are part of the wilderness. It supports a rich and diverse maritime forest flora (Stalter, 1977; Wetmore, 1989), whose composition changes from sand dune to broadleaved and coniferous-tree communities. Long-term management practices have enhanced the diversity of wildlife habitats and plant communities throughout the island (Stalter, 1977).

Bull Island is a barrier island composed of sand and built by the process of longshore drift that progresses generally north-to-south along the coast. Vegetation on the island has succeeded in stabilizing much of the sand for many decades; however, the island is constantly subjected to processes of erosion and deposition, which alter the shape, location, and area of its land mass.

In September, 1989, Hurricane Hugo, by far the most significant storm to hit this area in the 20th Century (Schuck-Kolben and Kaufman, 1992), came ashore about 20 km south of CRNWR. With sustained winds of 217 km/hr (135 mi/hr), Hugo created a peak tidal surge of 6.1 m (20 ft.) above sea level at Bulls Bay, which is adjacent to and just northwest of Bull

Island. Damage to Bull Island was extensive and assessments of short- and long-term effects on the vegetation, wildlife, and land mass are continuing to be evaluated. As chance would dictate, our study, conducted in November 1987 and June 1988 succeeded in establishing baseline geochemical information for the island immediately prior to the major disruptive influence of the hurricane.

Soil and Plant Sampling Site Identification

A grid with centers spaced at 0.5 km intervals (0.25 km^2) was oriented parallel to true north over Bull Island (Figure B2). The starting point for sampling within the grid was randomly selected. Samples were collected as near as possible to the intersection points of the grid lines for sites meeting the following criteria: (1) the site must be at least 0.25 km from the edge of the maritime forest as identified on the Bull Island quadrangle map; (2) the site must have loblolly pine of greater than 10 cm diameter at breast height with accessible limbs no higher than 15 m above the ground; (3) the sampled limbs should face west (toward the mainland and the anthropogenic sources of S); (4) Spanish moss should be present at the site; and (5) the site should not be within 0.25 km of any other site. An unbalanced, hierarchical, analysis-of-variance design was used so that spatial variability among and within grid points could be examined. Ten sites were randomly selected for among-tree replication at a site, and five of these ten sites were randomly selected for within-tree replication.

Soil and Plant Sampling

Field work was conducted over two time periods, November 1987 and June 1988. This was done so that possible temporal geochemical and biogeochemical changes could be assessed.

Weakly developed soil (Inceptisol) was prevalent on the coarse-to-fine size sand parent material of Bull Island. The soils consist of an accumulation (1 to 8 cm) of organic debris on the surface, and a grayish E horizon (7 to 10 cm) (A2 horizon, old terminology) overlying a light-brown B horizon. Samples of the E horizon were collected by first removing any plant debris from the surface and then extracting a channel sample to the base of the E horizon. At each site, the sample was composited from a single location near the base of the loblolly pine chosen for sampling. The samples were placed in Kraft paper soil collection bags and shipped to the laboratories of the U.S. Geological Survey in Denver, Colorado.

Loblolly pine was collected at each site and Spanish moss was collected where possible. Dominant or co-dominant branches from the lower, exposed crown of mature loblolly pine were removed with an extension pruner or a 12-gauge shotgun with steel shot. Where possible, west-facing branches were collected. Within-tree replicates were collected from east-facing branches in order to assess the potential differences in pine-needle chemistry with respect to onshore or offshore winds. Current year needles were composited from three to five sub-branches off of one major branch and placed in Hubco cloth bags. Clumps of Spanish moss were collected, where present, at sites from the accessible lower branches and trunks of the overtopped crown of live oak (*Quercus virginiana* Miller) or red bay (*Persea borbonia* (L.) Sprengel.) and placed in Hubco cloth bags.

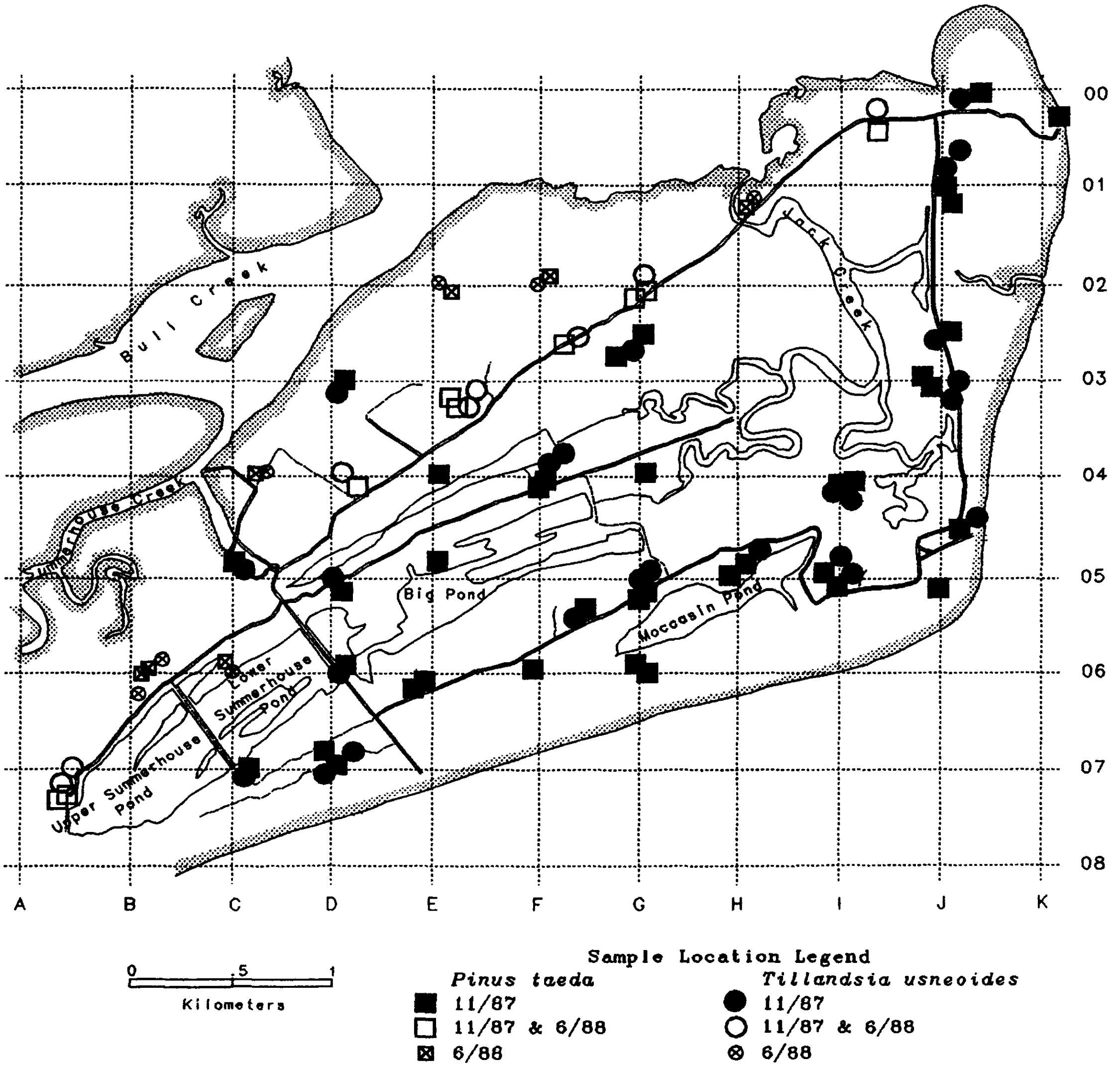

Figure B2. Diagram showing the unbalanced, hierarchical analysis-of-variance grid sampling design for surface soil, Spanish moss, and loblolly pine.

Sample Preparation and Analysis

Soil and plant samples were prepared as described in Chapter A. Soil and plant-ash samples were analyzed for 40 elements using inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Lichte and others, 1987). Preparation and analysis of reagent blanks, soil and plant reference materials (using both U.S. Geological Survey and National Institute for Standards and Technology reference materials), and sample replicates follow established USGS quality assurance and quality control (QA/QC) procedures (Arbogast, 1990). Analytical QC results are reported in Chapter D. Based on the quality control results presented in Chapter D, results for Co and La in botanical samples and Ba in soils should be viewed with caution. The elements Ag, As, Au, Be, Bi, Cd, Eu, Ga, Ho, Mo, Sn, Ta, U, and Yb were not detectable by ICP-AES in any soil samples; elements below detection limits by ICP-AES in all Spanish moss plant samples were Ag, As, Au, Be, Bi, Eu, Ga, Ho, La, Nb, Sc, Sn, Ta, Th, U, and Yb; and elements below detection limits by ICP-AES in all pine plant samples were Ag, As, Au, Be, Bi, Ce, Eu, Ho, Mo, Nd, Sc, Sn, Ta, Th, U, Y, and Yb.

Total S in both soil and dry plant material was determined by combustion-infrared photometry (Jackson and others, 1985). Total S in all soil samples was below the detection limit of 0.05%. Total carbon in soil also was determined by combustion-infrared photometry (Jackson and others, 1987). Carbonate carbon in soil was determined by coulometric titration of acid-evolved CO_2 (Engleman and others, 1985). Organic carbon was determined by difference between total and carbonate carbon. There was no detectable carbonate carbon in the Bull Island soils, so all carbon is reported as organic carbon.

Statistical Techniques

An unbalanced, hierarchical, analysis-of-variance (ANOVA) design was used to assess the variability of element concentrations in plants and soils. This statistical design allows the partitioning of the total measured natural variation into component parts. For loblolly pine, the first of four components (levels) is related to differences among the 0.5 km grid cells. The second component is related to variability between trees within a grid cell. The third component is related to variability of samples from the same tree. In addition, several samples were chosen at random and split into two parts; each part was analyzed independently. This duplicate analysis of samples is the fourth level of the design and represents a component that estimates all procedural errors including analytical variance. For Spanish moss, we did not test the third level above (variability of moss within a tree) and therefore a three-level design was used. For soil, we did not test the second or third levels (variability between and within sites within a grid) and therefore a two-level design was used.

A further precaution was taken to convert any systematic error that might occur in either sampling or analysis into apparent random error. This was accomplished by analyzing all samples (original and duplicate samples) in a randomized sequence. As a result, samples collected in the field to represent some geographic progression would not be analyzed in that same progression.

Statistical analyses require completely numeric data sets. Some elements were reported as being below the limit of determination of the analytical method (censored). Where more than

30 percent of the determinations were censored (detection ratio column, Tables B1-B3), summary statistics are presented, but the element is omitted from any further interpretation. When some, but less than 30 percent, of the reported values were censored, the censored values were replaced with arbitrary values equal to 70 percent of their determination limit. For the elements with censored distributions, the geometric means and deviations were estimated by the technique of Cohen (1959) for singly truncated distributions. Data were transformed to common logarithms before statistical analysis because distributions of trace element concentrations in plants and soils are commonly positively skewed. After logarithmic transformation, the frequency distributions of the data more closely resemble normal distributions.

Data reported for plant material on an ash-weight basis were converted to dry-weight equivalents and then transformed to logarithms prior to statistical analysis. Because ash-yield varied, the conversion from an ash-weight base to a dry-weight base produced variable lower limits of determination (LLD) values for elements with censoring. The mean and deviation estimation of Cohen (1959), however, could not handle variable LLD values. Variable LLD values were adjusted to a common value based on a procedure that produces the fewest overall changes in the data in order to make that adjustment.

In addition to comparison with the general literature values and the ANOVA results, possible anthropogenic additions to plant chemistry were evaluated using the enrichment factor (EF) calculations as presented by Wiersma and others (1992):

$$EF = \frac{[X]_{plant} / [Al]_{plant}}{[X]_{soil} / [Al]_{soil}}$$

where [X] and [Al] are the concentrations of the element of concern and aluminum, respectively, in the plant material and in the soil. This procedure normalizes the data with respect to a geochemical reference (in this case, Al concentrations). As a rule of thumb, Wiersma and others (1992) notes that enrichment factors greater than about 10 indicate element additions over reference levels that may be attributed to anthropogenic influences.

RESULTS AND DISCUSSION

Soil Chemistry and Spatial Trends

Summary statistics for elements in E-horizon soil samples are presented in Table B1. The summary statistics provide an overview of the element concentration in soils from all grid locations sampled. The observed range shows that, for about one-third of the elements, the samples with lowest and highest element concentrations differ by a factor of greater than five. Several elements (Al, Ba, Ca, Co, Cr, Fe, K, Mg, Na, Ni, Pb, Sc, Sr, V, Y, and Zn) are more uniform from sample to sample and differ by a factor of four or less. Three elements (Li, Nb, and Th) were detected in less than 70 percent of the samples. Because of the low detection ratio for these elements, only summary statistics of the data are given and no further interpretation is made.

ANOVA data (Table B1) show what proportion of the total variation is distributed between two levels, natural variability among grid cells and procedural errors. No elements

Table B1. Statistics for the concentration of elements in surface soil samples from Bull Island, South Carolina. Detection ratio is the number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed. Leaders (-.-) indicate not determined.

	Summary Statistics				Analysis of Variance		
						Percentage of variance:	
Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range	Total log 10 variance	Among Grids	Procedural error
Al, %	16:16	1.3	1.22	0.93 - 1.7	0.00774	88.4*	11.6
Ba, µg/g	16:16	220	1.31	150 - 310	0.01388	93.9*	6.1
C-organic, %	16:16	1.7	2.27	0.62 - 17	0.12111	93.2*	6.7
Ca, %	16:16	0.46	1.27	0.33 - 0.72	0.00961	97.0*	3.0
Ce, µg/g	16:16	18	2.14	5 - 72	0.09647	95.8*	4.2
Co, µg/g	13:16	1.1	1.43	< 1 - 2	0.02826	100.0*	0.0
Cr, µg/g	16:16	14	1.43	7 - 23	0.02165	89.9*	10.1
Cu, µg/g	12:16	1.3	2.00	< 0.5 - 3	0.05985	90.0*	10.0
Fe, %	16:16	0.52	1.52	0.24 - 0.97	0.03184	99.1*	0.9
K, %	16:16	0.51	1.35	0.33 - 0.84	0.01882	63.5	36.5
La, µg/g	16:16	9.1	2.07	3 - 36	0.08876	95.6*	4.4
Li, µg/g	5:16	-.-	-.-	< 2 - 3	-.-		
Mg, %	16:16	0.11	1.31	0.07 - 0.17	0.01395	98.1*	1.9
Mn, µg/g	16:16	150	1.82	66 - 390	0.06193	99.2*	0.8
Na, %	16:16	0.29	1.29	0.21 - 0.42	0.01243	96.4*	3.6
Nb, µg/g	7:16	-.-	-.-	< 2 - 7	-.-		
Nd, µg/g	14:16	8.7	2.04	< 4 - 32	0.08393	94.7*	5.3
Ni, µg/g	14:16	2.1	1.48	< 1 - 3	0.01753	65.8	34.2
P, %	15:16	0.0094	1.77	< 0.003 - 0.03	0.05519	87.1*	12.9
Pb, µg/g	16:16	9.2	1.27	6 - 16	0.01036	93.9*	6.1
Sc, µg/g	11:16	2.8	1.67	< 2 - 6	0.04697	93.4*	6.6
Sr, µg/g	16:16	83	1.16	62 - 100	0.00386	92.2*	7.8
Th, µg/g	7:16	-.-	-.-	< 4 - 14	-.-		
Ti, %	16:16	0.23	1.77	0.10 - 0.62	0.05538	99.5*	0.5
V, µg/g	16:16	16	1.41	9 - 30	0.02077	98.2*	1.8
Y, µg/g	13:16	3.4	1.79	< 2 - 8	0.05853	98.7*	1.3
Zn, µg/g	16:16	5.8	1.44	3 - 9	0.02375	88.6*	11.4

* Statistically significant at the 0.05 probability level.

exhibit excessive (>50 percent) procedural error. For all elements except K and Ni (Table B1), a large and statistically significant proportion of the natural geochemical variability exists among grid cells, even though the observed concentration range for many elements was narrow. Small procedural errors permit detection of very small changes in soil geochemistry--an important property of the data if anthropogenic additions of elements are to be observed.

The most appropriate way to characterize the geochemistry of these soils is to use the geometric mean and deviation presented in Table B1 to construct baseline ranges in element concentration for Bull Island. Preparation of maps showing aerial distribution of isopleths of element concentration is possible, but based on the ANOVA results, it would add little to the understanding of soil geochemistry of Bull Island for the majority of the elements of environmental interest. Most maps would contain only a single isopleth separating areas above and below the geometric mean concentration because the range in values for element concentration is so small. Possible exceptions are the elements C, Ce, La, Nd, and P that show large observed ranges relative to the other elements, however anthropogenic additions of these elements to soils are only of minor interest.

Other trace elements of environmental concern, such as As, Cd, and Mo were below detection levels in all of the samples, and, therefore, no interpretation of trends in the data were possible.

Plant Chemistry and Spatial Trends

Summary statistics for ash yield and the concentration of 25 elements in Spanish moss, and ash yield and 26 elements in loblolly pine are given in Tables B2 and B3. A few elements (Mo, Nd, and Y in Spanish moss; and Cd, Ga, Nb, and V in loblolly pine) were detected in less than 70 percent of the samples. Because of the low detection ratio for these elements, only the observed range of the data is given.

The observed range in element concentrations for Spanish moss seldom exceeded a factor of five; however, a factor of 10 (or greater) difference was observed for concentrations of Mn and Na. The observed concentration range for Na differed by a factor of 15 and had a geometric deviation (GD) of 2.00 (Table B2). The large differences in Na levels in Spanish moss probably reflect both the proximity of sampling sites to the ocean and the range in canopy density from site to site. Concentration ranges of Al, Li, Mn, Na, Ni, and Sr also exceeded a factor of ten in the loblolly pine samples. The observed concentration range for Na in pine differed by a factor of 80 and had a geometric deviation (GD) of 3.24 (Table B3), again reflecting ocean proximity and canopy density differences. Observed concentration ranges tended to be broader for samples of loblolly pine than for Spanish moss; however, nearly two-thirds of the elements exhibited ranges in concentration with factors of four or less. This small variability, coupled with the fairly uniform soil chemistry, suggests that anthropogenic additions of elements to Bull Island are of less importance than additions from the natural terrane.

The ANOVA for element concentrations in Spanish moss (Table B2) shows the distribution of the biogeochemical variability among grid cells, within grid cells, and the proportion of the total variation that is related to procedural error. The ANOVA for loblolly pine (Table B3) shows the distribution of the variability among grids, between trees, within trees, and procedural error. In loblolly pine, only the analyses for Ba show excessive (>50 percent)

Table B2. Statistics for the concentration of elements (dry-weight basis) and ash yield in Spanish moss samples from Bull Island, South Carolina. Detection ratio is the number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed. Leaders (-.-) indicate not determined.

	Summary Statistics				Analysis of Variance			
						Percentage variance:		
Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range	Total log10 variance	Among grids	Within grids	Procedural error
Ash, %	38:38	3.1	1.27	1.7 - 4.7	0.01073	52.8	46.7*	0.5
Al, %	38:38	0.034	1.40	0.019 - 0.078	0.02128	30.3	69.3*	0.4
Ba, μg/g	38:38	4.2	1.26	2.7 - 7.4	0.01024	19.8	79.8*	0.4
Ca, %	38:38	0.23	1.36	0.11 - 0.50	0.01802	54.0	45.6*	0.4
Cd, μg/g	24:38	-.-	-.-	< 0.10 - 0.19	-.-			
Ce, μg/g	34:38	0.41	1.49	< 0.23 - 1.2	0.03604	39.3	56.5*	4.2
Co, μg/g	38:38	0.25	1.24	0.16 - 0.41	0.00890	56.5	40.8*	2.7
Cr, μg/g	38:38	2.1	1.32	1.3 - 4.0	0.01475	23.2	59.4*	17.4
Cu, μg/g	38:38	4.7	1.69	2.2 - 16	0.05300	68.3*	31.5*	0.2
Fe, μg/g	38:38	270	1.33	160 - 530	0.01542	21.3	78.2*	0.5
K, %	38:38	0.48	1.34	0.20 - 0.89	0.01612	23.7	76.1*	0.2
Li, μg/g	38:38	0.26	1.29	0.15 - 0.66	0.03019	42.2	57.6*	0.2
Mg, %	38:38	0.23	1.28	0.14 - 0.35	0.01132	49.0	50.9*	0.1
Mn, μg/g	38:38	120	1.70	33 - 380	0.05400	44.0	55.9*	0.1
Mo, μg/g	6:38	-.-	-.-	< 0.07 - 0.19				-.-
Na, %	38:38	0.22	2.00	0.047 - 0.71	0.09217	63.3*	36.6*	0.1
Nd, μg/g	16:38	-.-	-.-	< 0.19 - 0.53				-.-
Ni, μg/g	38:38	1.2	1.21	0.81 - 1.7	0.00722	41.8	57.4*	0.8
P, %	38:38	0.049	1.43	0.018 - 0.098	0.02408	45.7	54.*+	0.1
Pb, μg/g	38:38	4.9	1.28	3.2 - 9.6	0.01141	15.3	81.5*	3.2
S, %	38:38	0.14	1.22	0.09 - 0.21	0.01047	0.0	98.9*	1.1
Sr, μg/g	38:38	15	1.29	8.8 - 23	0.01245	73.6*	26.3*	0.1
Ti, μg/g	38:38	26	1.39	14 - 57	0.02050	23.5	74.6*	1.9
V, μg/g	38:38	1.2	1.36	0.59 - 2.5	0.01818	3.4	96.0*	0.6
Y, μg/g	19:38	-.-	-.-	< 0.095 - 0.29	-.-			
Zn, μg/g	38:38	17	1.26	12 - 27	0.01705	0.0	99.9*	0.1

[*] Statistically significant at the 0.05 probability level.

Table B3. Statistics for the concentration of elements (dry-weight basis) and ash yield in loblolly pine needle samples from Bull Island, South Carolina. Detection ratio is the number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed. Leaders (-.-) indicate not determined.

	Summary Statistics				Analysis of Variance				
						Percentage of variance:			
Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range	Total log10 variance	Among grids	Between trees	Within trees	Procedural error
Ash, %	59:59	3.2	1.16	2.3 - 4.4	0.00451	68.6*	0.0	28.3*	3.1
Al, %	59:59	0.017	1.98	0.0019 - 0.042	0.08990	87.5*	3.2	9.1*	0.2
Ba, µg/g	59:59	0.30	1.51	0.099 - 0.78	0.04486	34.3*	0.0	0.0	65.7
Ca, %	59:59	0.21	1.28	0.11 - 0.34	0.01310	65.9*	0.0	32.0*	2.1
Cd, µg/g	7:59	-.-	-.-	< 0.093 - 0.189	-.-				
Co, µg/g	56:59	0.13	1.66	< 0.055 - 0.33	0.05043	89.0*	0.0	4.1	6.9
Cr, µg/g	59:59	0.26	1.29	0.13 - 0.41	0.01254	31.6*	19.0	19.3	30.1
Cu, µg/g	59:59	2.9	1.19	2.0 - 5.9	0.00637	65.6*	0.0	19.5	14.9
Fe, µg/g	59:59	49	1.39	26 - 100	0.02061	56.6*	21.7	20.4*	1.3
Ga, µg/g	9:59	-.-	-.-	< 0.19 - 0.45	-.-				
K, %	59:59	0.38	1.35	0.20 - 1.2	0.01843	25.6	56.4*	0.0	18.0
La, µg/g	44:59	0.12	1.26	< 0.099 - 0.21	0.01039	40.6*	13.7	11.5	34.2
Li, µg/g	42:59	0.20	2.00	< 0.11 - 1.1	0.09702	78.9*	14.9*	0.0	6.2
Mg, %	59:59	0.14	1.20	0.092 - 0.22	0.00655	42.8	34.3*	15.6	7.3
Mn, µg/g	59:59	190	1.73	57 - 670	0.07232	65.1*	0.0	34.0*	0.9
Na, %	59:59	0.048	3.24	0.0052 - 0.42	0.26562	68.0*	16.5	15.1*	0.4
Nb, µg/g	2:59	-.-	-.-	< 0.19 - 0.58	-.-				
Ni, µg/g	52:59	0.19	1.66	< 0.11 - 1.3	0.04998	77.3*	12.9	9.5*	0.3
P, %	59:59	0.15	1.22	0.096 - 0.25	0.00761	65.3*	6.2	25.0*	3.5
Pb, µg/g	29:59	0.25	1.45	< 0.20 - 0.59	0.03115	51.0*	0.0	37.0*	12.0
S, %	59:59	0.12	1.11	0.10 - 0.17	0.00211	13.3	41.0	11.3	34.4
Sr, µg/g	59:59	4.9	1.78	1.1 - 15	0.06384	76.1*	13.8	8.8*	1.3
Ti, µg/g	23:59	-.-	-.-	< 2 - 6	-.-				
V, µg/g	3:59	-.-	-.-	< 0.093 - 0.19	-.-				
Zn, µg/g	59:59	30	1.27	17 - 49	0.01345	1.8	0.0	93.4*	4.8

* Statistically significant at the 0.05 probability level.

procedural error. Results of analyses for Cr, La, and S in loblolly pine were also high (30.1, 34.2, and 34.4 percent, respectively) but were not considered excessively high.

Three elements (Cu, Na, and Sr) in Spanish moss (Table B2) and all but three elements (K, Mg, and S) in loblolly pine (Table B3) show a statistically significant proportion of natural element concentration variation between grid cells. Extreme concentrations in samples from one grid cell would be the only feature shown on maps of aerial distribution of isopleths for element concentrations for most elements. In addition, environmentally important elements which should be associated geochemically (Cd, Cu, Ni, and Zn for example), do not exhibit similar map patterns for either Spanish moss or loblolly pine. We conclude that the few anomalous values for environmentally important elements probably are not related to anthropogenic additions, but are spurious values. It would be statistically valid to prepare maps showing element distributions in loblolly pine and Spanish moss for many elements, but these maps would be of little practical value. For most elements, the maps would contain only a single isopleth separating areas above and below the geometric mean concentration because the range in values for element concentration is so small. Map patterns for elements that show a large observed range relative to the other elements (Ce, Cu, Mn, and Na in Spanish moss; Al, Li, Mn, Na, Ni, and Sr in loblolly pine) would show only one or two cells with high values, while the remaining area of Bull Island would contain a single isopleth separating values either above or below the geometric mean.

For many elements there is a considerable proportion of the total natural variability that is found among samples of Spanish moss collected from different trees within individual grids and for loblolly pine collected from branches with different aspects from the same tree. The biogeochemical variability for these elements between trees (Spanish moss) or within a single tree (loblolly pine) and from a single cell masks any biogeochemical differences between grid cells. Further, it is interesting to note that only Mn and Na in Spanish moss and Al, Li, Mn, Na, Ni, and Sr in loblolly pine show large (greater than about a factor of ten) differences in their observed concentration ranges (Tables B2 and B3). This means that, of the elements showing statistically significant differences between grid cells, only a very few showed relatively large overall concentration differences.

There are no clear patterns in the data that relate differences in the biogeochemistry of Spanish moss and loblolly pine from one grid cell to another to accumulations of trace elements related to anthropogenic sources. In general, concentrations of environmentally important elements showed no areal trends and were, in fact, very uniform and similar.

Temporal Trends

In June 1988 a follow-up field study was conducted and a subset of six of the November 1987 soil, Spanish moss, and loblolly pine sampling sites were revisited. The new collections of soil were taken as close to the original sites as possible; Spanish moss was collected from the same trees at the six sites with two between-tree replicates also collected; and loblolly pine was collected from six of the same trees with three between-tree replicates also collected. All samples were handled in the field, prepared for chemical analysis, and analyzed by the same methods as used for the November 1987 sampling. A paired *t*-test was used to determine differences in element concentration between the two sampling dates. Summary statistics for

Table B4. Elements and ash in soils and plants (dry-weight basis) from Bull Island, South Carolina which show significant ($p = 0.05$) differences in concentration at two different sampling periods (November 1987 and June 1988). The samples were collected from the exact same sites each season and significance of differences was determined using a paired *t*-test (n, number of sample pairs).

	November 1987		June 1988	
	Geometric mean	Geometric deviation	Geometric mean	Geometric deviation
		Soil (n = 4)		
Zn, μg/g	6.3	1.42	2.1	1.42
		Spanish Moss (n = 8)		
Cr, μg/g	2.0	1.27	1.5	1.45
Cu, μg/g	6.3	1.27	3.7	1.26
Ti, μg/g	23	1.37	14	1.52
		Loblolly Pine (n = 9)		
Ash, %	3.1	1.21	3.7	1.17
Ca, %	0.21	1.27	0.31	1.13
Co, μg/g	0.12	1.31	0.13	1.41
Cr, μg/g	0.25	1.38	0.44	1.25
Fe, μg/g	43	1.29	65	1.29
K, %	0.31	1.29	0.40	1.15
Li, μg/g	0.16	2.25	0.35	1.83
S, %	0.12	1.06	0.13	1.15
Sr, μg/g	4.1	1.46	5.8	1.39

only those elements showing statistically significant differences between sampling dates are given in Table B4. Rather than listing data for each sample pair for soil, Spanish moss, and loblolly pine, only the geometric means and deviations are presented for elements from the subsets of samples showing significant differences. Table B4 shows that concentrations of Zn (soil) and Cr, Cu, and Ti (Spanish moss) decreased by about half from November 1987 to June 1988. Loblolly pine elemental concentrations increased from November 1987 to June 1988 by about 10 to 20 percent (Ash, Co, S, K) to 50 percent or more (Fe, Ba, Cr, Li, and Sr). Although significant, the difference in the absolute amount of these elements was small and may represent only the vagaries of the sampling technique and of the inhomogeneity of the material collected. For example, a difference of 0.01 percent in the concentration of total S in pine between sampling dates may be statistically significant but hardly seems important. These temporal changes, however, should be considered when attempting to detect anthropogenic additions of elements. The range in geometric mean values can be used as an estimate of temporal variability so that temporal trends do not confound the detection of anthropogenic inputs.

Element-Concentration Baselines

The baseline ranges (Table B5) represent the normal, contemporary concentrations in samples of soil, Spanish moss, and loblolly pine. These baselines can be compared with new values from samples collected in the future to assess any changes in elemental composition, assuming that the newly collected samples are of the same soil horizon or plant part and that they are prepared and analyzed by methods comparable to those used in the present study. The baselines were calculated using the GM's and GD's in Tables B1, B2, and B3. The baselines are expressed as a concentration range (Tidball and Ebens, 1976) and are calculated as GM/GD^2 to $GM \times GD^2$. For those elements with significant variance components between grid cells (Tables B1, B2, and B3), preparation of maps showing areal distribution of isopleths of element concentrations would be an appropriate way to present the data; however, as explained above, it would add little to understanding areal geochemical trends.

Shacklette and Boerngen (1984) present perhaps the most appropriate baseline element concentration data with which to compare our soil values. Their data from the eastern half of the United States includes a mixture of many types of soils including sandy soils like ours. The upper baseline value (Table B5) for most trace elements in our soils is from one-third to less than one-tenth the upper baseline value reported by Shacklette and Boerngen (1984). Neodymium is the exception, where the upper baseline value from the present study is about five times the reported mean value for subsoil (Shacklette and Boerngen, 1984). We have no explanation for this large discrepancy. In general, the low trace element concentrations in soils from the present study are not surprising because these soils are developed on sand and contain small amounts of clay and, with a few exceptions, organic matter. These soils are probably low in easily weatherable minerals. Anthropogenic inputs of trace elements into these soils should be relatively easy to detect because of the low natural levels of trace elements. On the other hand, deposition of trace elements from the atmosphere may not be easily retained by soils low in organic matter or clays.

The use of Spanish moss collected *in situ* to monitor anthropogenic airborne additions of trace elements is well documented (Schaug and others, 1990). Baseline data for Spanish moss collected from throughout the southeastern United States (Shacklette and Connor, 1973) is provided for comparison with samples from the present study (Table B5). The upper baseline concentration value for Spanish moss from Bull Island ranges from about one-half to one-fifth the upper baseline concentration value given by Shacklette and Connor (1973). The exception is Pb, where Bull Island Spanish moss is over two-hundred times lower in concentration (many of the Shacklette and Connor sampling locations were close to roadways).

Normalized enrichment factor (EF) values are presented in Table B6 for Spanish moss and loblolly pine. Wiersma and others (1992) state that EF values greater than about 10 for the environmentally important, non-nutrient elements probably indicate enrichment over reference levels owing to external, non-physiological influences. Values greater than 10 for the nutrient elements simply indicate accumulation owing to physiological controls. Except for Fe, Table B6 shows that enrichment of nutrient elements has occurred. Of the environmentally important, non-nutrient elements only Ni and Pb in Spanish moss show enrichment. These values may indicate some anthropogenic influence; however, as noted above, absolute concentration values fall far below the baseline values presented by Shacklette and Connor (1973) (Table B5).

Table B5. Baseline ranges for the concentration of elements in surface soil, Spanish moss, and loblolly pine needle samples from Bull Island, South Carolina with comparison data from various sources. Leaders (—) indicate not determined.

Variable, unit of measure	Bull Island			Comparison Data		
				Shacklette[1,2]		FMNF[3]
	Surface soil	Spanish moss	Pine	Soil[1]	Spanish moss[2]	Pine[4]
Ash, %	—	1.9 - 5.0	2.4 - 4.3	—	2.2 - 9.8	2.3 - 3.8
Al, %	0.87 - 1.9	0.017 - 0.067	0.027 - 0.42	0.40 - 27	0.039 - 0.93	0.027 - 0.052
Ba, μg/g	130 -380	2.6 - 6.7	0.13 - 0.68	53 - 1600	4.8 - 140	2.4 - 11
C-org.%	0.33 - 8.8	—	—	—	—	—
Ca, %	0.29 - 0.72	0.12 - 0.43	0.13 - 0.34	0.036 - 3.2	0.19 - 1.1	0.25 - 0.64
Cd, μg/g	—	0.14 - 0.20	—	—	0.13 - 0.98	—
Ce, μg/g	3.9 - 82	0.19 - 0.91	—	18 - 220	—	—
Co, μg/g	0.54 - 2.2	0.16 - 0.38	0.047 - 0.36	0.89 - 39	0.13 - 1.5	0.082 - 0.27
Cr, μg/g	6.8 - 29	1.2 - 3.7	0.16 - 0.43	4.9 - 220	0.87 - 7.8	0.19 - 0.31
Cu, μg/g	0.35 - 5.2	1.6 - 13	2.0 - 4.1	1.7 - 100	1.7 - 28	1.2 - 2.3
Fe, %	0.23 - 1.2	0.015 - 0.048	0.0025 - 0.0095	0.17 - 12	0.021 - 0.26	0.0036 - 0.015
K, %	0.28 - 0.93	0.27 - 0.86	0.21 - 0.69	0.01 - 2.7	0.14 - 1.3	0.18 - 0.28
La, μg/g	2.1 - 39	—	0.076 - 0.19	7.4 - 110	0.044 - 9.2	0.13 - 0.23
Li, μg/g	—	0.16 - 0.43	0.050 - 0.80	3.6 - 79	0.43 - 2.3	<0.074 - 0.11
Mg, %	0.064 - 0.19	0.14 - 0.38	0.097 - 0.20	0.017 - 2.6	0.070 - 0.63	0.082 - 0.13
Mn, μg/g	45 -500	42 - 350	63 - 570	18 - 3800	16 - 740	25 - 880
Na, %	0.17 - 0.48	0.055 - 0.88	0.0046 - 0.50	0.012 - 5.2	0.0061 - 1.6	0.018 - 0.095
Nd, μg/g	2.1 - 36	—	—	4.0 - 9.0	1.6 - 7.5	—
Ni, μg/g	0.96 - 4.6	0.82 - 1.8	0.69 - 5.2	1.6 - 77	6.0 - 5.5	0.26 - 0.61
P, %	0.003 - 0.029	0.024 - 0.10	0.10 - 0.22	0.0023 - 0.17	0.018 - 0.10	0.053 - 0.098
Pb, μg/g	5.7 - 15	3.0 - 8.0	0.12 - 0.53	3.7 - 53	19 -1900	0.50 - 0.79
S, %	—	0.094 - 0.21	0.097 - 0.15	—	—	0.10 - 0.14
Sr, μg/g	62 -110	9.0 - 25	1.5 - 16	4.1 - 690	9.4 - 110	6.0 - 11
Ti, %	0.073 - 0.72	0.0014 - 0.0050	0.0002 - 0.0005	0.070 - 1.1	0.0029 - 0.042	<0.0002 - 0.0003
V, μg/g	8.0 - 32	0.65 - 2.2	—	6.8 - 270	1.4 - 13	—
Y, μg/g	1.1 - 11	—	—	5.2 - 78	0.38 - 3.8	—
Zn, μg/g	2.8 - 12	11 - 27	19 - 480	9.0 - 180	16 - 180	15 - 149

[1] Shacklette and Boerngen, 1984.
[2] Shacklette and Connor, 1973.
[3] Francis Marion National Forest, this study.

Table B6. Enrichment factors for concentrations of elements in Spanish moss and loblolly pine needles from two collections, November 1987 and June 1988. Values were calculated based on the formula presented under "Statistical Techniques". November 1987 values used geometric mean concentrations presented in Tables B1-B3. Only elements that showed significant temporal differences between collection dates are presented for June 1988; these calculations are based on the geometric mean concentrations presented in Table B4. Leaders (--) mean "not calculated" either because of the presence of censored values or because no significant temporal differences between collection dates was noted.

	November 1987		June 1988	
Macro-nutrients	Spanish moss	loblolly pine	Spanish moss	loblolly pine
Ca	19	35	--	43
K	36	57	--	51
Mg	84	103	--	--
Na	30	13	--	--
P	200	1225	--	--
S	107	183	--	153
Major micro-nutrients				
Mn	31	97	--	--
Fe	2	0.7	--	0.8
Cu	138	171	112	--
Zn	111	40	--	--
Environmentally important				
Ba	0.7	0.1	--	--
Ce	0.9	--	--	--
Co	9	9	--	6
Cr	6	1	2	1
La	--	1	--	--
Ni	22	7	--	--
Pb	20	2	--	--
Sr	7	4	--	5
Ti	--	--	0.2	--
V	3	--	--	--

Because of possible SO_2 contamination to the island, the Spanish moss total S values are of particular interest. Total S ranged from 0.09 to 0.21 percent with a geometric mean of 0.14 (Table B2). Although not reported by Shacklette and Connor (1973), Benzing (1989) reported S concentrations in Spanish moss from Big Thicket National Preserve, Texas, with a range of 0.13-0.25 percent S and a mean concentration of 0.18 percent S. Benzing (1991) also found about the same or somewhat higher S levels in other *Tillandsia* species collected near S

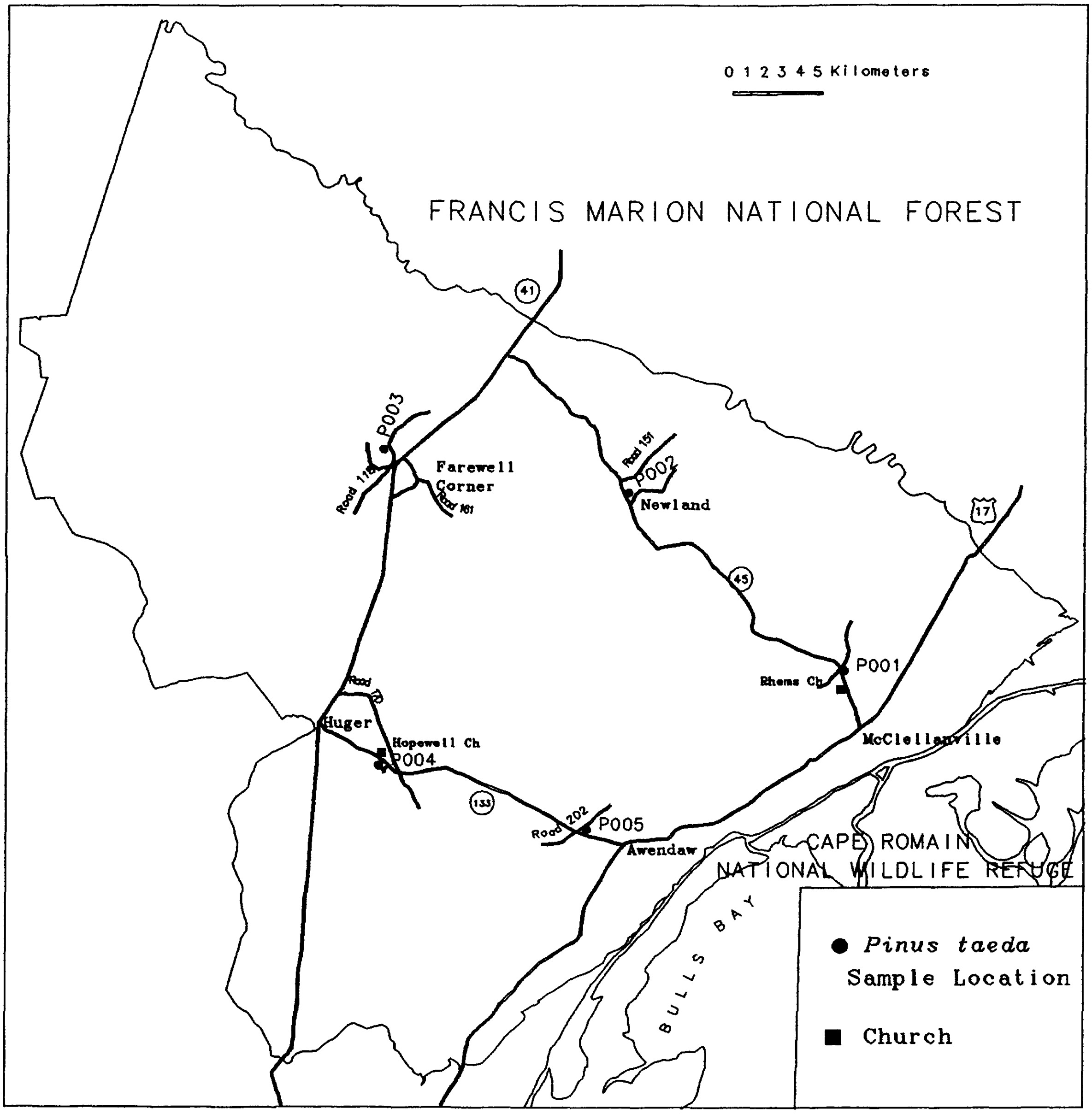

Figure B3. Location map for loblolly pine sample sites in Francis Marion National Forest.

contamination sources in south Florida. The Spanish moss concentration data are also quite comparable to the general literature for S levels in epiphytic lichens (Gough and others, 1988).

We know of no trace element data from the literature for loblolly pine that is comparable to Bull Island. In November 1987 we collected five samples of loblolly pine from the Francis Marion National Forest located inland from Bull Island (Figure B3). Baseline ranges in element concentrations in loblolly pine from Bull Island and from Francis Marion National Forest, for most elements, are similar (usually differing by less than a factor of two). The exceptions are Li, Na, Ni, and Zn, which are much higher in loblolly pine on Bull Island than in the Francis

Marion National Forest. Differences in Na and Li are probably owing to ocean influence, but we have no explanation for the differences in Ni and Zn.

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Chapter C

Assessment of Possible Anthropogenic Influences on the Biogeochemistry of the Salt Marsh and a Barrier Island at Cape Romain National Wildlife Refuge, South Carolina[1]

By **Larry L. Jackson[2], Larry P. Gough,** *and* **R. C. Severson**

ABSTRACT

Based on trace element concentrations in intertidal salt-marsh and barrier-island vegetation, sediments, and soils presented in the two previous chapters and sulfur stable isotope ratios in these same materials presented herein, this chapter provides an integrated assessment of possible anthropogenic influences on trace element concentrations at Cape Romain National Wildlife Refuge. Of the elements measured in the biogeochemical studies, concentrations of Pb and Cu in sediments and Pb and Ni in Spanish moss represent possible anthropogenic additions; however, additional research is required to distinguish between natural and anthropogenic sources of these elements. Stable sulfur isotope ratios of *Spartina alterniflora* and sediments indicate that dissimilatory sulfate reduction is an important biogeochemical process influencing the isotopic signature of these media. The isotopically light, compared to seawater, stable sulfur isotope ratio of the barrier island vegetation indicates that anthropogenic and/or biogenic emissions are a significant source of sulfur in this environment. Insufficient evidence exists to understand the relative importance of anthropogenic and biogenic sulfur emissions and their influence on local vegetation, although anthropogenic emissions have been estimated to be a significantly greater source of sulfur in the region than biogenic emissions.

INTRODUCTION

The intricate network of tidal creeks, salt marsh, and barrier islands at Cape Romain, South Carolina once harbored pirates; just as the hardwood swamps only a few kilometers inland hid Francis Marion, alias the "Swamp Fox", from the British during the Revolutionary War.

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[1] Chapter C of Jackson, L. L., editor, 1993, Biogeochemical studies of the salt marsh and a barrier island at Cape Romain National Wildlife Refuge, South Carolina: U.S. Geological Survey Open-File Report 93-303, 137 p.

[2] All authors at USGS, Box 25046, MS 973, DFC, Denver, CO 80225.

Today, about 13,800 ha of coastal salt marsh, barrier islands, and bays are protected as Cape Romain National Wildlife Refuge (CRNWR) and serve as a major migratory bird stopover and wintering area on the Atlantic seaboard. CRNWR, only 30 kilometers north of Charleston, is one of the largest and most important coastal marsh/barrier island refuges in the southeastern U.S. Numerous waterfowl, shorebirds, and migratory songbirds visit or reside at the refuge, as well as several Federally protected wildlife species with endangered or threatened status. Loggerhead turtles nest on some of the last remaining undeveloped beaches in the region. Bald eagles and brown pelicans also nest on the refuge, and the American alligator can frequently be seen basking in the sun in the brackish and freshwater marshes on the major barrier island. These biologically productive salt marshes serve as the spawning and nursery grounds for economically important marine life such as oysters, shrimp, and commercial and sport fish.

Cape Romain, unique among coastal wetlands because a large portion of it was set aside as a wilderness area in 1975, has been defined as a Prevention of Significant Air Quality Deterioration (PSD) Class 1 area under the Clean Air Act amendments of 1977. In such a PSD Class 1 area, industry that may emit pollutants, such as sulfur dioxide to the atmosphere, must undergo State and Federal permit review. Cape Romain is the first PSD Class 1 area where a permit to exceed the existing pollutant limits has been requested by industry.

Many PSD Class 1 areas are scenic national parks and wilderness areas where pollutant damage to ecosystems and effects on visibility are more readily apparent. Cape Romain, on the other hand, is a coastal marsh where little scientific research has been done on the effects of air quality on the vitality, significance, and integrity of biological, scenic, and recreational resources. These coastal wetlands, typical of salt-marsh ecosystems, can never be replaced. Today, we still do not understand the intricacies of their dynamic web of life.

Damage to a coastal ecosystem, like CRNWR, because of poor air quality may be subtle and chronic. Nature's effects may be as well. Although the continued erosion of the barrier islands that protect the marshlands is not so subtle, it certainly is a chronic problem. At other times, nature is devastating in its acute effect. On September 22, 1989 the eye of Hurricane Hugo hit the refuge with winds reaching a maximum speed of over 200 kilometers per hour (Schuck-Kolben and Kaufman, 1992). A 6-meter storm surge moved through Bulls Bay, the unprotected center of the refuge. A few kilometers to the north at McClellanville, which is protected by several kilometers of salt marsh and barrier island, the storm surged to a height of almost 5 meters. The exceptional maritime forest on Bull Island was reduced to kindling. Decades will be required for this forest to recover. But, despite the movement of tons of sand and sediment, life in the salt marsh will continue much as before--wildlife was lost, nesting sites were destroyed, but the marsh grasses continue to grow. The marsh grasses will continue to support through their detrital-based food web one of the most productive ecosystems on earth (Pomeroy and Wiegert, 1981; Teal, 1962).

We understand some of the physical processes that lead to the creation and loss of a salt marsh (Williams and others, 1990). Lack of sediment input, natural subsidence, and/or apparent sea level rise is causing the loss of as much as 100 km^2 per year of Louisiana coastal wetlands. East coast barrier islands, islands that protect the fragile wetlands from the forces of the sea, are themselves being eroded at a significant rate. Dramatic changes may occur as a result of a single storm such as Hurricane Hugo. Unfortunately, despite decades of research (see, for example, Pomeroy and Wiegert, 1981), there are still many areas of salt-marsh ecology and biogeochemistry that are poorly understood. Salt marshes are such a dynamic ecosystem with effects of sediment input and removal, the seasons, and the daily tidal cycles that it is difficult to create a unified picture of the biogeochemical processes and their controlling factors for the *Spartina* marshes of the East coast. This is difficult for even a small intertidal marsh area like CRNWR.

This chapter integrates the assessment of (1) the trace element concentrations measured in the salt marsh (Chapter A) and on Bull Island (Chapter B); and (2) stable sulfur isotope measurements of vegetation and sediments in this environment with respect to the potential for anthropogenic influence on these ecosystems. A summary of all raw data and quality control results are found in Chapter D of this report.

TRACE ELEMENTS IN ECOSYSTEMS AT CRNWR

Despite the prodigious amount of research on salt marshes, baseline ranges of trace element concentrations have not been determined in the past for either *Spartina alterniflora* Loisel. (smooth cordgrass) or marsh sediments. The same is true for barrier island plant species. To our knowledge, the baseline element concentration ranges presented in this report are the only extensive measurements available and they represent only a very small geographic area. This makes assessing the relationship of these measurements to measurements from other areas or to understanding the potential anthropogenic influences difficult. Comparisons must be qualitative at best. In addition, because of the spatial variability of trace elements in *S. alterniflora* and sediments that we found, it is questionable whether reasonable comparisons with other salt-marsh populations are possible without the extensive type of sampling that was done in this study.

Goldberg and others (1979) determined trace element concentrations for Co, Cr, Cu, Mn, Ni, Pb, V, and Zn in two cores of marsh sediments supporting *S. alterniflora* (unspecified height form) near the mouth of the Savannah River estuary. The ratio of Cr, Pb, and V to Al with depth was apparently uniform, whereas in cores from the river itself (further upriver) there was a decrease in the ratios with depth. The element profiles in the marsh core indicated that there had not been much change with time regarding element input. However, based on the element profiles in the river core, which showed a decrease with depth, they concluded that there had been anthropogenic additions of these elements in recent times (less than 30 years) in the river sediments. This is a pattern that is frequently found and has often been attributed to human induced contamination of the sediments (Forstner, 1977; Salomons and Forstner, 1984). More than half of the Savannah River drainage basin is within the Piedmont Province and should have relatively similar sediment mineralogical composition to that of the Santee River. It does, however, have a greater portion of its drainage basin in the Coastal Plain Province than the Santee River and, therefore, may have a significantly greater proportion of montmorillonite (Neiheisel and Weaver, 1967). The concentrations of all of the metals determined in the upper 5 cm of the Savannah River cores were within the range of values found at CRNWR and ratios of metal/Al were about equal or lower at CRNWR. This suggests that CRNWR sediments are not greatly contaminated with any of these metals compared to the Savannah River estuary.

Menon and Ghuman (1985) studied Zn in *S. alterniflora* and sediments at one site along the terminal course of the Altamaha River, Georgia. They found that the maximum Zn concentration in above-ground tissue occurred in July. In comparing above- and below-ground tissue, significantly greater Zn concentrations were measured in below-ground portions of the plant. Rhizomes had only slightly greater concentrations of Zn (about 2x) than the above-ground tissue, whereas living and dead roots had 10-30 times greater concentrations than either living or dead above-ground tissues. Based on import and export modelling, they determined that on an annual basis the S. *alterniflora* marsh system had a net increase in Zn concentration.

The marsh functioning as a living filter for metals has been noted by others (Giblin and others, 1980, 1983; Ragsdale and Thorhaug, 1980). Giblin and others (1980, 1983) studied the uptake of metals in natural and sewage-amended S. *alterniflora* marshes in the Great Sippewissett Marsh, Massachusetts. They found Cd, Cr, and Zn to be easily mobilized to biota from marsh sediments, whereas Pb accumulated in the sediments and was not easily translocated to the biota. Copper had intermediate behavior in that it was tied up mostly in the sediment, but some was bioavailable. A large seasonal variability was observed for metal concentrations in both natural and sewage-amended S. *alterniflora* marsh plots with an increased metal content of the dead litter for Cr, Cu, Pb, and Zn and a decrease for Cd. Because of Pb's immobility in the sediments, they attributed the increase in Pb in litter to adsorption from the air. They also found a greater retention of these metals in the S. *alterniflora* high-marsh area than the low marsh. In the later study, retention in the sediment with depth was more closely examined and they found that most added metals were retained in only the upper few centimeters of sediment and that the majority of Cd and Zn and almost half of the Cr, Cu, and Pb added directly to the sediments was lost from the marsh sediments. From the limited data available for comparison (from a natural marsh but of unspecified S. *alterniflora* height form) the mean concentrations of Cr, Cu, Fe, Pb, and Zn were from 3 to more than 25 times lower at CRNWR than at the Great Sippewissett Marsh in the 1980 study. In the second study (Giblin and others, 1983) much lower concentrations of Pb and Cr were measured in S. *alterniflora* tops. These lower values suggest that there is a great heterogeneity in the S. *alterniflora* population at the Massachusetts marsh site, or that there was a significant bias introduced as a result of different research methods. Unfortunately, there was too little information provided to evaluate the cause of the differences, but this clearly points out the inherent difficulties in comparing results from one study to another, or from one site to another.

Dunstan and others (1975) measured Cd, Cu, and Pb in S. *alterniflora* and sediments from six southeastern U.S. rivers including the Santee River. They apparently determined the metals in a composite of the entire S. *alterniflora* plant including roots and in a composite of the upper 40 cm of sediment. They concluded that the accumulation of these three metals in salt marsh sediments was the result of deposition of suspended sediments and that regionally the concentrations of the metals did not differ significantly except for higher concentrations of Cd and Cu in the Santee estuary. Although they found that Pb did not differ significantly between the rivers, it was at the high end of the range in the Santee estuary. We found comparable concentrations for Pb and slightly lower concentrations of Cu in the CRNWR sediments than was measured in the Santee estuary sediments. However, our measurements of Cu and Pb were several times lower in S. *alterniflora* at CRNWR. Once again, quantitative comparisons are difficult. Dunstan and coworkers (1975) composited sediment to a much greater depth than we did and their sampling was conducted more than 20 years earlier. They analyzed the entire S. *alterniflora* plant and we analyzed only the culms and leaves.

Gardner (1976) studied Cu, Mo, Pb, and Zn in sediments from the relatively pristine

North Inlet marshes near Georgetown and in the Dill Creek marshes in Charleston Harbor. He found greater concentrations, by factors of 1.5-3 of Cu, Pb, and Zn in the potentially contaminated Dill Creek sediments than in the North Inlet sediments. Only Mo was a factor of 2.5 times greater in the North Inlet sediments. The mean concentrations of Cu, Mo, and Zn that we measured at CRNWR were slightly lower after normalizing for Al content than at North Inlet. The Pb concentrations at CRNWR were about two times greater than at North Inlet but still lower than at Dill Creek in the Charleston Harbor.

Based on these limited number of comparisons and the evaluation of the CRNWR intertidal-marsh-sediment geochemistry in relation to southeastern coastal sediments (Windom and other, 1989) discussed in Chapter A, there does not appear to be any gross contamination of the trace elements determined. Lead and Cu concentrations may be elevated, but additional research is required to elucidate whether this is owing to sediment mineralogical differences in the CRNWR sediments, differences in the Santee River source material, or other factors.

Because of the spatial heterogeneity in trace element concentrations in *S. alterniflora* and in sediments and the temporal and tissue variability in *S. alterniflora* chemistry at CRNWR, it is extremely difficult to make quantitative comparisons with biogeochemical results from other areas. These difficulties are particularly enhanced by the elevation, tidal flooding, and drainage nature of the marsh site; differences in mineralogical composition of the sediments; and the growth form and stage of growth of *S. alterniflora*.

Trace element concentrations in Spanish moss and loblolly pine from the relatively small area of Bull Island exhibited much less spatial heterogeneity than elements in the salt-marsh ecosystem. Unfortunately, very little data is available for comparison with our results from Bull Island. Limited comparisons can be made with the intertidal salt-marsh sediments and the barrier island soils. First, the marsh sediments have on average about 6 times more Al, 2 times more organic C, and greater than 10 times more S than Bull Island soils. Secondly, in comparing the ratios of the metals Co, Cr, Cu, Ni, Pb, V, and Zn to Al in the sediments with the soils, the sediments had about two times larger ratios for Co, Cu, Ni, and Zn, about equal ratios for Cr and Ni, and about two times lower ratio for Pb than the Bull Island soils. The Pb concentration in Bull Island soils is also an apparent enrichment of about four times over the crustal abundance ratio of Pb to Al. Although the Pb/Al ratio is greater than the ratio of these elements in average crust, this is primarily owing to the low concentration of Al in the island's sandy soils. The actual concentration of Pb in the soils is less than crustal abundance. Thus, the reason for this apparent increased Pb concentration in Bull Island soils is unknown but may be related to anthropogenic additions. Church and Scudlark (1992) found that atmospheric deposition of Pb and Zn to coastal waters of the Middle Atlantic Bight dominated the total input of these metals compared to the net tidal flux of the Chesapeake, Delaware, and Hudson River estuaries. A similar relationship of inputs may be occurring at CRNWR, although the general industrialization and fossil-fuel based power production along the South Carolina coast is less than the industrialized northeastern U.S.

In general, as was found for the salt-marsh ecosystem, our data do not indicate that there is a large anthropogenic influence on the trace element biogeochemistry for the Spanish moss and loblolly pine species on Bull Island. Comparisons can be made with other plant species from other areas, including areas that are particularly remote. Several elements, including Cu and Pb, have been measured in moss, *Acrocladium auriculatum*, (Wiersma and others, 1990) and in lichens, *Nephroma antarcticum*, (Wiersma and others, 1992) from remote parts of southern Chile. The Cu and Pb concentrations in these two species, species which should be good collectors of atmospheric deposition, were lower than generally reported in the literature. Values for Cu and Pb in the moss were 4.6 μg/g and 0.8 μg/g, respectively, on a dry-weight basis. For Bull Island the mean values for Cu and Pb in Spanish moss were 4.7 μg/g and 4.9 μg/g, respectively, and in loblolly pine they were 2.9 μg/g Cu and 0.25 μg/g Pb. In the *S. alterniflora* the average concentrations of Cu and Pb were about 0.9 μg/g and < 0.8 μg/g. A possible indication of anthropogenic enrichment of Pb in Spanish moss is the six times larger Pb concentration at Bull Island than in the Chilean moss. However, it is not obvious that trace element concentrations can be reliably compared in different plant species. Lead concentrations in the Bull Island Spanish moss can be compared to Pb concentrations in Spanish moss collected from throughout the southeastern U.S. (Shacklette and Connor, 1973). In this case, the Pb concentrations were over two hundred times lower on Bull Island than the average value found by Shacklette and Connor. The preponderance of Shacklette and Connor's Spanish moss samples were collected from easily accessible sites along roadways in an era when gasoline was leaded. Thus, compared to a large but undoubtedly different population of Spanish moss, the Bull Island samples do not appear to exhibit an anthropogenic influence on their Pb burden.

Enrichment factors were calculated for elements in Spanish moss and loblolly pine (Chapter B; Gough and others, 1993):

$$EF = \frac{[X]_{plant} / [Al]_{plant}}{[X]_{soil} / [Al]_{soil}}$$

where [X] and [Al] are the concentrations of an individual element and aluminum, respectively, in the plant material and in the soil. Enrichment factors of about 20 were found for Ni and Pb in Spanish moss, which may indicate anthropogenic additions of these elements to the Bull Island ecosystem. Wiersma and others (1992) suggested that enrichment factors greater than 10 indicate element uptake by plants that may be attributed to anthropogenic sources. Much greater factors were obtained for macro- and micro-nutrients in both Spanish moss and loblolly pine. However, enrichment factors such as this are not valid for nutrient elements because of plant physiological processes that control nutrient enrichment. Elements that exhibit similar chemical characteristics to nutrients also may be enriched coincidentally with nutrient uptake. Additionally, enrichment-factor calculations of this nature assume that there is no differential uptake of elements compared to Al from an individual source such as from atmospheric dust, and that the soils used for comparison have not been enriched in a given element concomitantly with the plant. Thus, enrichment factors comparing elements in plants and soils must be used very cautiously in evaluating anthropogenic additions of elements to an environment.

The baseline-element-concentration ranges that we have determined in plants, sediments, and soils of the salt-marsh and barrier-island ecosystems were originally intended for contemporaneous comparisons with other similar locations and comparisons with future measurements made at CRNWR. On September 22, 1989 Hurricane Hugo struck the coast of South Carolina. At Bulls Bay the maximum storm surge was recorded at about 6 m (Schuck-Kolben and Kaufman, 1992). There was severe coastal erosion (see, for example, Mann, 1991) with dramatic changes in barrier-island topography. There was tremendous destruction of the

Bull Island maritime forest. Because of the redistribution of sediment in the salt marsh and the relationship between *S. alterniflora* element uptake and sediment chemistry, the baseline-element-concentration ranges for sediments and for *S. alterniflora* need additional evaluation before quantitative comparisons can be made in the future. For plant species on Bull Island, the canopy structure has changed which may have an influence on element uptake by the Spanish moss and loblolly pine. Hurricane Hugo destroyed almost all of the mature pines, severely pruned the oaks, and removed a large proportion of the Spanish moss from the island. For soils on Bull Island, there was probably a significant input of trace elements because of decaying plant matter as a result of the storm and fires used in post-hurricane cleanup operations. Thus, comparisons in the future must take into account the differences that have occurred in this environment as a result of Hurricane Hugo. Re-sampling and analysis of *S. alterniflora* and sediments would be appropriate to generate current baseline data and assess any effects of Hurricane Hugo.

The intertidal salt-marsh ecosystem is largely dominated by monotypic stands of *S. alterniflora*. The productivity of above- and below-ground biomass is great in this ecosystem, but there is also great seasonal variability and productivity differences between height forms of *S. alterniflora* (Dame and Kenny, 1986; Gallagher and Plumley, 1979; Schubauer and Hopkinson, 1984). Above- and below-ground biomass turnover rates for *S. alterniflora* have been measured, and they too exhibit differences for the ecophenic height forms. Schubauer and Hopkinson (1984) estimated below-ground turnover rates of 3.22 times per year in a medium stand of *S. alterniflora* in Georgia. They found turnover times for below-ground dead material to be much slower, 0.85 times per year, than living material. In North Inlet, South Carolina, Dame and Kenny (1986) estimated both above- and below-ground turnover rates at three types of *S. alterniflora* marsh locations, creekside, mid-marsh and high marsh. Below-ground turnover rates ranged from 0.7 times per year to 1.1 times per year for creekside and high marsh, respectively. In contrast to the results of Schubauer and Hopkinson (1984), they found turnover rates of dead below-ground material, with rates ranging from 1.1 to 1.4 times per year, were faster than rates for living below-ground tissue. They also found rates for above-ground living and dead material were relatively similar: above-ground living material rates were 2.1 times per year at creekside and mid-marsh and 5.1 times per year in the high marsh; above-ground dead material ranged from 2.1 to 3.2 times per year.

Despite the high productivity of *S. alterniflora*, Giblin and others (1983) found that *S. alterniflora* retained less than 5 percent of the added Cd, Cr, Cu, Pb, and Zn in amended-marsh-sediment plots. Copper and Pb appeared to be fixed in the sediment and not readily bioavailable. They suggest that the Pb in the *S. alterniflora* is primarily derived from atmospheric uptake through the stomata. However, based on the high turnover rates and the relatively small uptake of metals by *S. alterniflora* it is not clear that *S. alterniflora* is a reasonable biomonitor of either atmospheric or water-borne anthropogenic contamination.

SULFUR IN ECOSYSTEMS AT CRNWR

Total Sulfur in vegetation and sediments

The high concentration of S in seawater, the anaerobic-sediment environment, and the high biological productivity make the intertidal salt marsh the site of one of the most dynamic

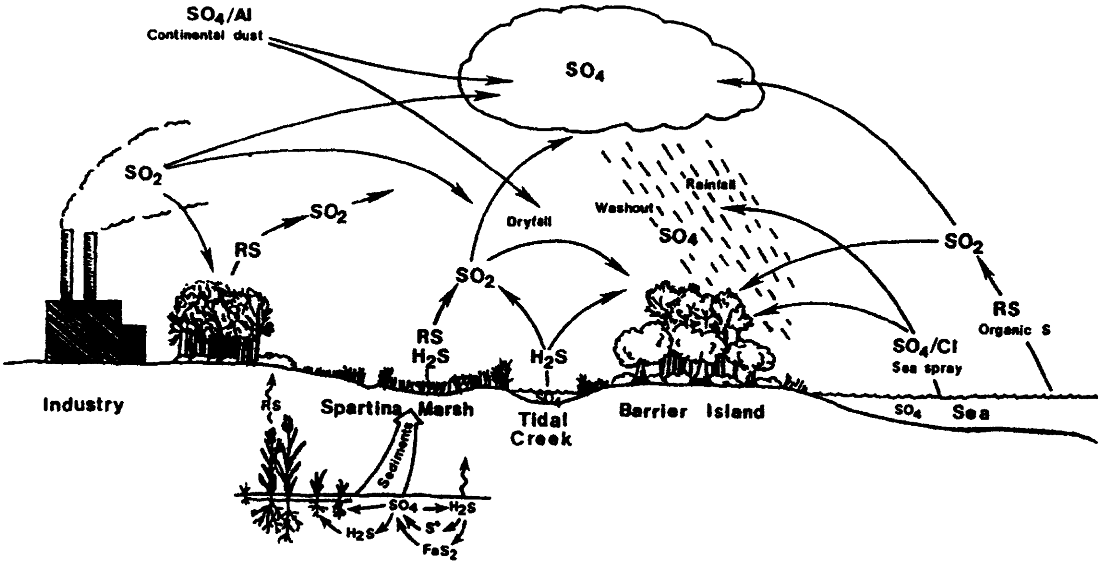

Figure C1. Generalized sulfur cycle for an intertidal salt marsh and its environs. SO_4/Al, SO_4/Cl, and RS represent continental dust, sea salt, and organic sulfur compounds (e.g., dimethyl sulfide), respectively.

sulfur cycles of any ecosystem on earth. Sulfur is added to this system with each tide as seawater contributes sulfate S. Atmospheric deposition plays a role with the addition of sulfate S derived from industrial emissions of SO_2 and from sea-salt spray, volatile organic sulfur compounds from the ocean and coastal wetlands, and direct uptake of SO_2 by plants. In the salt-marsh sediments with ample sulfate available, dissimilatory sulfate reduction is a major controlling process in the anaerobic decomposition of organic matter with sulfate reduction accounting for 50-90 percent of the total respiration in near-shore and salt-marsh sediments (Howarth, 1984). As a result of sulfate reduction, hydrogen sulfide is produced. The sulfide produced may be fixed in the sediment through the formation of metal sulfides (in particular pyrite), it may be evolved to the overlying waters or the atmosphere, it may be oxidized to elemental S and sulfate S by bacteria, and it may be taken up by plants. The sulfur cycle in salt-marsh sediments is extremely complex and difficult to study. Figure C1 gives an overview of many of the major aspects of the estuarine S cycle. *S. alterniflora* plays a complex role in this cycle with its oxidized micro-rhizosphere (Mendelssohn and Postek, 1982), below-ground uptake of sulfide and sulfate S (Carlson and Forrest, 1982; Fry and others, 1982), foliar uptake of SO_2, and foliar emission of dimethyl sulfide (DMS) (Cooper and others, 1989).

The November 1987 field collections at CRNWR showed that there was a large observed range in S concentration in both *S. alterniflora* and sediments. For *S. alterniflora* the mean concentration was 0.57 percent with a range from 0.19 to 1.3 percent and for the sediments the mean was 0.84 percent with a range from 0.08 to 4.55 percent. A large proportion of the total variance for both materials was attributed to differences between sampling grids. Spatial trends in the data were not obvious other than simple spatial heterogeneity; a fact that makes reproducibility of studies involving this marsh difficult. In addition, there was significant seasonal variability and variability with type of tissue sample in *S. alterniflora*. Correlation analysis indicated that there was a moderately strong relationship between S in *S. alterniflora* and S in the upper 5 cm of the sediment. The upper zone of the sediment exhibits the greatest sulfate reduction rate (King, 1988) and may have the highest concentration of roots (Gallagher and Plumley, 1979). Based on these results, it would seem difficult, if not impossible, to relate any anthropogenic influence on this ecosystem to concentrations of S in *S. alterniflora* foliar tissue or to sediments.

On Bull Island, the S concentrations in Spanish moss and loblolly pine needles were more uniform than in the salt marsh. The mean S concentrations for Spanish moss and loblolly pine were 0.14 percent and 0.12 percent, respectively. The range for the moss was 0.09 to 0.21 percent and the range for the pine needles was 0.10 to 0.17 percent. In both cases, the majority of the total variance was at ANOVA levels representing differences within grids. For these two species there was no true seasonal variability in S concentrations. The difference between seasons in S in the loblolly pine needles was statistically significant ($p = 0.05$); however, the difference in means of only 0.01 percent S is more likely to be analytical measurement error and not true seasonal variability in the plants. In order to use these species as biomonitors for anthropogenic S additions to the ecosystem, there would have to be fairly large changes in S concentration in the plants. Benzing (1989) has measured S concentrations in Spanish moss from Big Thicket National Preserve, Texas, with a somewhat higher mean concentration, 0.18 percent S, and range of concentration, 0.13-0.25 percent S. Because Spanish moss obtains its nutrients from atmospheric sources, it is likely to be a better biomonitor than loblolly pine.

Stable sulfur isotope ratios

In order to identify atmospheric contributions to ecosystems, air pollution studies have relied on source-based models, such as emission inventories and dispersion predictions, and receptor-based models, that use element concentration trends or enrichment factors. The use of stable sulfur isotope ratios in ecosystem receptors is a unique application of the enrichment-factor technique. Because of differences in reaction rates, many biological reactions fractionate the stable sulfur isotopes and produce a wide range of sulfur isotope ratios in nature. Biologically mediated anaerobic sulfate reduction is the major sulfur isotope fractionating process. The sulfate reduction process produces sulfide that is enriched in ^{32}S and residual sulfate that is enriched in ^{34}S. Because of the importance of anaerobic sulfate reduction in the global sulfur cycle, a wide range of sulfur isotope ratios occur in natural inorganic and organic products. It is the difference in the sulfur isotope ratios in nature that makes sulfur isotope ratio measurements useful in environmental studies[3] (Jackson and Gough, 1989; Krouse, 1989).

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[3] The sulfur isotope ratio is measured in the sample relative to the isotope ratio in a meteoritic troilite standard. The enrichment factor determined is expressed as δ^{34}S in parts per thousand (‰) or per mil.

$$\delta^{34}S\ ‰ = \left[\frac{(^{34}S/^{32}S)_{sample}}{(^{34}S/^{32}S)_{meteorite}} - 1 \right] x\ 1000$$

In order to use stable S isotope ratios to understand biogeochemical processes or atmospheric dispersion of S, the isotopic ratios of the different S sources must be known, the isotopic ratios of the S sources must be different from each other, and potential isotopic fractionation processes during physical and chemical transformations must be well understood (Calhoun and Bates, 1989). Despite the stringent restrictions that these three conditions place on the use of S isotope ratios, a large number of environmental studies have made successful use of S isotope ratios to define anthropogenic influences and to elucidate biogeochemical processes.

Grey and Jensen (1972) used stable S isotope ratios in precipitation in the Salt Lake City area to examine the influence of S emissions from a smelter, the major S emitter in the region. They found that the isotope ratios in precipitation shifted to heavier values (more positive) when the smelter was not in operation during a prolonged strike. Typically, the smelter plume had ratios of -3.8 to +3.4‰ and the precipitation had values of -1.5 to +5.3‰ for $\delta^{34}S$. During the smelter shutdown the precipitation had values of +4.7 to +6.5‰ which they attributed to a relative increase in the atmospheric dominance of bacteriogenic S.

Krouse and Case (1981) evaluated the environmental impact of a gas processing facility in Alberta, Canada, on the surrounding soils and vegetation. The isotopic signature of the gas plant was greatly different than the local soils and vegetation, thus the isotopic leverage for distinguishing patterns of influence was enhanced. However, they concluded that at the time of the study the plant had relatively little influence on the soils, aspen, and brome grass sampled. Instead, edaphic factors and the subsurface soil isotopic signature controlled the plants isotopic ratios, but the large isotopic difference between the source and the receptor would provide good future monitoring capabilities during continued operation of the facility.

In contrast, at a sour gas processing facility in Alberta, Case and Krouse (1980) found isotopic signatures in vegetation that did indicate an anthropogenic influence on the surrounding area. Isotopic ratios of arboreal and terricolous lichens and *Picea glauca* needles demonstrated that increased S concentrations in the vegetation were owing to atmospheric emissions of SO_2 from the processing facility. In addition, based upon the differences in the isotopic signatures they concluded that: the *Picea glauca* obtained its S from the air and soil; the terricolous lichens took in S from both the air and dry deposition; and the arboreal lichens primarily obtained their S from the atmosphere.

In a more extensive study, Krouse and coworkers (1984) examined S isotope ratios in four components of a forest ecosystem near another sour gas processing facility in Alberta. Atmospheric S isotope signatures identified the gas facility as the major source of S emissions. Isotopic signatures of pine needles, soils, and surface water verified the input of the anthropogenic S emissions into the ecosystem. They also concluded that the foliar isotopic data provided a better assessment of the facilitie's plume behavior than plume modelling.

Stable S isotope ratios in salt-marsh vegetation and sediments

Stable S isotope ratio measurements were made in *S. alterniflora* and sediments at eight sites located throughout the intertidal salt marsh at CRNWR. Selection of the sites was based on a simple hierarchical analysis of variance (ANOVA) barbell design (see Chapter A).

The major axes of the barbell design were 26, 8, and 2 km with four sites located in each of the northern and the southern sections of the refuge. Site replicate samples were obtained at

30 m and at 3 m away from the initial sample location at selected sites. Additional replicates were obtained by splitting samples in the laboratory. The samples analyzed in this portion of the research studies at CRNWR were splits of the samples collected for the determination of the baseline element ranges. Samples collected in November 1987 of the *S. alterniflora* culms, leaves, and flowering stalk (less the seed head) and samples collected in June 1988 of the *S. alterniflora* culms and leaves only were submitted for S isotope analysis. Sediments from each sampling period were also analyzed. Replicate isotopic determinations had a mean difference of about 0.4‰ δ^{34}S.

The S isotope ratio in *S. alterniflora* ranged from about -2.6 to +13.6‰ in the fall and -3.6 to +10.3‰ in the summer. The ANOVA results for both seasons revealed that about 75 percent of the total variance was attributed to differences between locations at distances of 2 km or greater. There may be a slight difference between the northern and southern extent of CRNWR (Figure C2). However, we doubt that it is significant and it cannot be evaluated with the limited data.

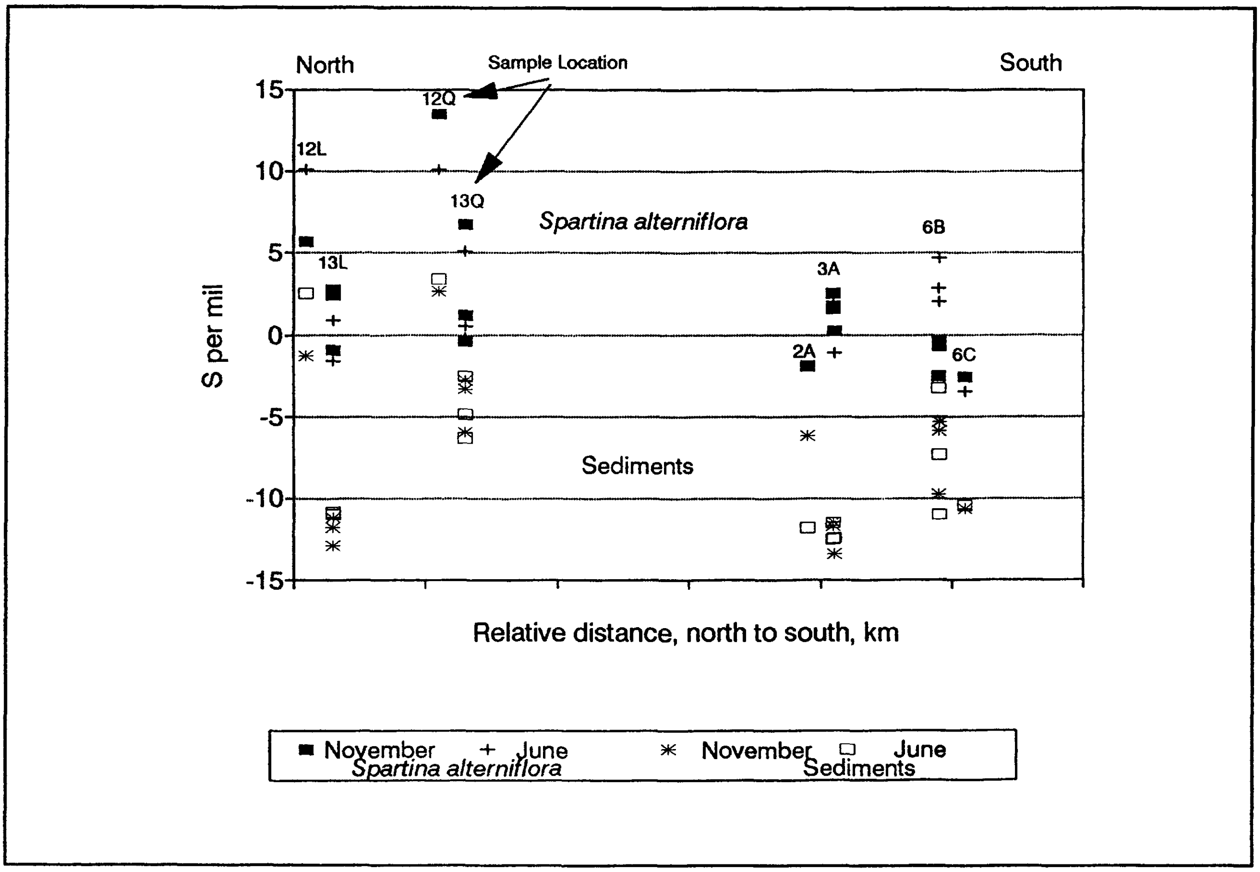

Figure C2. Stable sulfur isotope ratios in *S. alterniflora* and salt-marsh sediments at eight locations.

The sediment isotope ratios varied from -13.4 to +2.7‰ and -12.5 to +3.4‰ in November and June, respectively. In a similar fashion to the plants, the ANOVA results for both seasons attributed about 75 percent of the total variance to differences between locations at distance increments of 2 km or greater.

A paired t-test indicated that there was not a significant difference ($p = 0.01$) between seasons for the isotope ratios in *S. alterniflora*. There was moderate, negative correlation between the S isotope ratio and the total S in the *S. alterniflora* for both seasons ($r = -0.60$ and -0.67, November and June, respectively) that was statistically significant ($p = 0.05$). Almost identical results were obtained for the sediments, in that there was not a significant difference in the isotope ratios for the seasons and there was an even stronger, negative correlation between the isotope ratio and the total S in the sediment ($r = -0.87$ and -0.84, November and June, respectively). The increase in sediment S content with lighter isotopic signature is likely an indication of increased pyritic sulfur in the sediment as a result of differences in drainage and bacteriogenic sulfate reduction between sites. However, pyritic S was not measured in this study.

There was also a positive correlation between the *S. alterniflora* and sediment isotopic ratios. In November, the difference between the *S. alterniflora* and sediment isotope ratios ranged from about 4 to 14‰. The *S. alterniflora* isotope ratios averaged 9.4‰ heavier (more positive) than the ratios for the sediments. Overall the *S. alterniflora* and the sediments had average isotope ratios of about +1.8‰ and -7.6‰ and standard deviations of 4 to 5‰, respectively.

Peterson and coworkers (1985, 1987) measured S isotope ratios in *S. alterniflora* (height form unidentified) at Great Sippewissett Marsh, Massachusetts and at Sapelo Island, Georgia. At the northeastern marsh they observed S isotopic ratios ranging from -7.7 to +5.5‰ with a mean and standard deviation of -2.4 ± 4.4‰. Slightly heavier values were found at Sapelo Island. The S isotope ratios ranged from -6.3 to +8.5‰ with a mean and standard deviation of +0.9 ± 5.2‰. In both locations unspecified upland C_3 plants had isotope ratios of about 2 to 5‰. Fry and others (1982) found S isotope ratios for *S. alterniflora* leaves of +3.5 and +4.5‰ and an isotopic ratio of -9.4‰ in roots at a salt-marsh site in Texas. At CRNWR the range of isotopic ratios measured were slightly heavier than the values observed by these other researchers.

Surface water samples collected from the tidal creeks at each of the *S. alterniflora* and sediment-sampling sites exhibited a very narrow range of S isotope ratios. The mean and standard deviation were +18.9 ± 0.1‰. This ratio is very close to the fairly constant ratio of +21‰ for modern open-ocean seawater (Rees and others, 1978). Chukhrov and others (1978) measured values ranging from +18.2 to +20.2‰ with an average of +19.2‰ in the Caribbean Sea.

Stable S isotope ratios in Bull Island vegetation.

Eight samples each of Spanish moss and loblolly pine needles from the November 1987 and June 1988 collections (total of 32 samples) on Bull Island, CRNWR, were analyzed for stable S isotope ratios. The eight samples of each material represent six grid locations from the northeastern to the southwestern extent of the island. At each location, both Spanish moss and loblolly pine needles were collected during each seasonal sampling. Five samples of loblolly pine needles that were collected in November 1987 from locations in the Francis Marion National Forest on the mainland also were analyzed for S isotope ratios. Soils from Bull Island were not analyzed by this technique because of insufficient total S content.

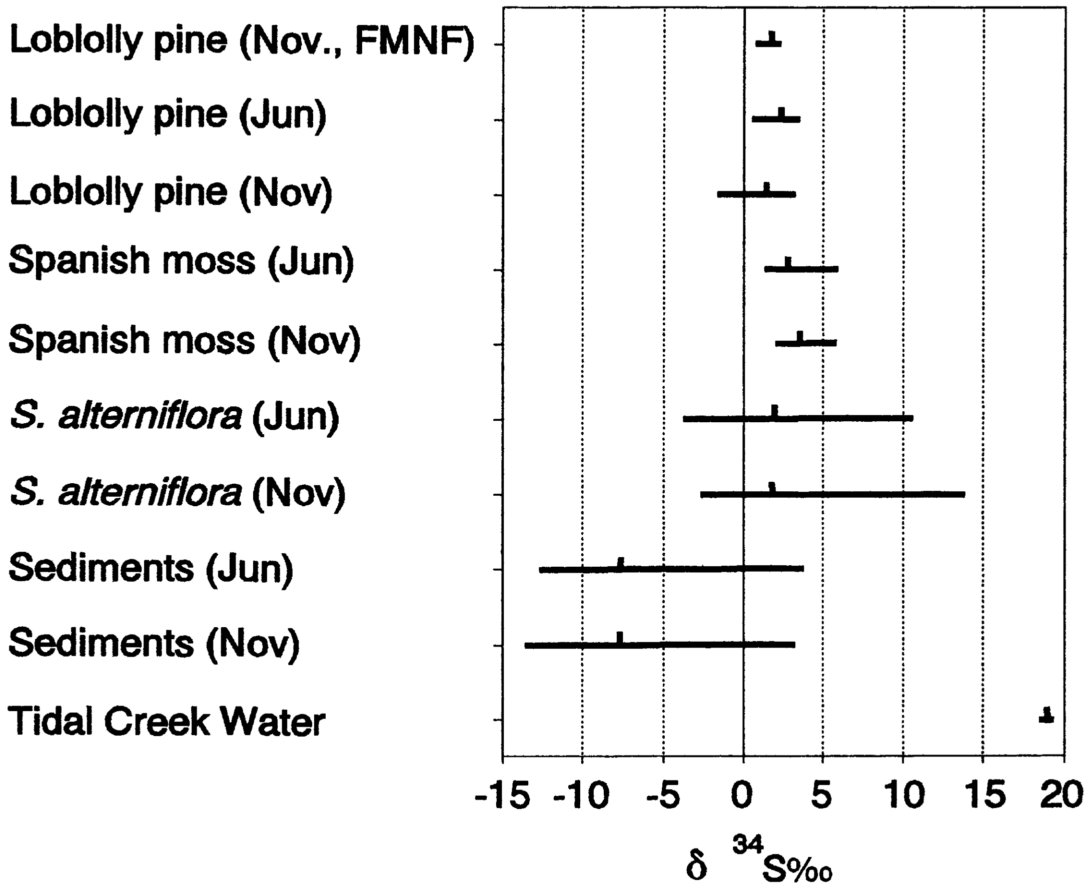

Figure C3. Range of stable sulfur isotope ratios in vegetation and sediments at CRNWR and loblolly pine in the Francis Marion National Forest (FMNF). Vertical tick equals arithmetic mean value.

The S isotopic ratios in Spanish moss and loblolly pine needles were relatively close to each other regardless of the season sampled, although the Spanish moss had a slightly heavier isotopic signature than the pine needles. The means and standard deviations for the Spanish moss were +3.5 ± 1‰ and +2.8 ± 1.5‰ in November and June, respectively (Figure C3). The means and standard deviations for the pine needles were +1.4 ± 1.6‰ and +2.3 ± 1‰ for November and June, respectively. There was not a significant difference ($p = 0.01$) in the isotope ratios for either plant species between the seasons based on paired t-tests.

The five samples of loblolly pine needles that were collected on the mainland between 5 to more than 25 km from the coast had isotope ratios with a mean and standard deviation of +1.7 ± 0.5‰ in November 1987. The mean isotope ratio of the mainland pine needles was very close to that of the Bull Island pine needles.

Implications of stable sulfur isotope ratios in vegetation and sediments at CRNWR

Seawater, the major source of S input to the CRNWR ecosystems, had a very heavy isotopic signature (Figure C3) compared to the ratios measured in the salt marsh and barrier island vegetation and the salt-marsh sediments. If seawater sulfate were the only source of S in this environment and there were no biological-fractionation processes occurring, the measured S isotopic ratios for the vegetation would be very near that of the seawater. Although seawater is the major source of S in this environment, it is not the only source and there are very active biological-fractionation processes occurring in this environment.

A variety of S sources must be considered in this environment. In addition to the direct uptake of sulfate S from seawater, plants and soils in the region are exposed to sulfate resulting from sea spray. The atmospheric sea salt does not undergo isotopic fractionation during entrainment and results in a contribution to the total dry or wet deposition with an isotopic signature similar to seawater (Luecke and Nielsen, 1973). The greatest proportion of dryfall occurs within a few kilometers of the coast (Gambell and Fisher, 1966; Junge, 1972). In remote ocean regions, biogenic production of dimethylsulfide (DMS) from phytoplankton is a major source of atmospheric sulfur (Calhoun and Bates, 1989). Although there is very little direct evidence, the S isotope ratio of the DMS produced by phytoplankton is believed to be just slightly lighter than that of seawater owing to assimilatory sulfate reduction by the phytoplankton (Calhoun and Bates, 1989). The phytoplankton take up seawater sulfate and utilize it in the production of methionine and dimethylsulfonioproprionate (DMSP). DMS emissions to the oceanic atmosphere result from the enzymatic breakdown of the DMSP. There appears to be little isotopic fractionation during the assimilatory uptake of sulfur (Krouse and McCready, 1979) and the subsequent emission of DMS (Calhoun and Bates, 1989).

Biogenic emission of organo-sulfur compounds also occurs in coastal wetlands. DMS and H_2S appear to be the compounds with the greatest emission rates with DMS being primarily emitted from vegetated marsh areas and H_2S from intertidal mudflats or non-vegetated areas (Cooper and others, 1989; Steudler and Peterson, 1984). It has been suggested that the emission of DMS from coastal marshes is predominately controlled by the physiology of marsh grasses, in particular *S. alterniflora* (Wakeham and Dacey, 1989). DMSP occurs in the leaves of *S. alterniflora* and increases in concentration with increased salinity. Presumably the enzymatic breakdown of the DMSP in *S. alterniflora* is the major source of DMS in the marsh atmosphere.

Using the emission of DMS from phytoplankton as an analogy, the S isotopic signature of DMS from the salt marsh should be about that of the plants themselves. At CRNWR the mean S isotope ratio for the short-form *S. alterniflora* was about +1.8‰, although there was a large range of isotope values, -3.6 to +13.6‰. The *S. alterniflora* exhibited a mean $\delta^{34}S$ value that was much lighter than the seawater, apparently as a result of uptake of isotopically light porewater sulfide S. The wide range of values may be owing to differences in sulfate reduction in the sediments and plant sulfate/sulfide uptake from site to site.

We did not measure H_2S isotope ratios in the porewater, but others have noted large fractionation during dissimilatory sulfate reduction with the sulfide being much lighter than the residual sulfate. Peterson and Howarth (1987) measured the S isotope ratio of porewater sulfide and sulfate at one short-form *S. alterniflora* site at Sapelo Island, Georgia. At a depth of 5 cm the $\delta^{34}S$ value for sulfide was about +10‰ and for sulfate it was about +40‰. The isotopic composition of pyrite at the same depth was about -10‰. Thus, at a salt-marsh site like this, the isotopic signature of the H_2S taken up by the *S. alterniflora* and the H_2S that is emitted from the sediments should be much lighter than that of the seawater sulfate and is likely to be similar to the porewater sulfide $\delta^{34}S$ in the upper portion of the sediment. Hitchcock and Black (1984) projected a range of -10 to +5‰ for isotope ratios of H_2S emitted from a salt marsh.

Hitchcock and Black (1984) measured S isotope ratios in atmospheric SO_2 and sulfate at a Virginia barrier-island site near a large salt marsh and on the mainland a few km away. They mathematically corrected the atmospheric $\delta^{34}S$ values for sulfate to exclude the contribution from sea salt spray and thus estimated the $\delta^{34}S$ value for only the excess sulfate. They found $\delta^{34}S$ values ranging from -0.97 to +1.58‰ for atmospheric SO_2 and -9.44 to +1.63 for excess sulfate at the marsh site. The mean values for $\delta^{34}S$ in excess sulfate at the marsh site were +0.66 and -1.88‰ for high and low sulfate days, whereas the $\delta^{34}S$ values for SO_2 were +0.87 and -0.14 on the high and low sulfate days, respectively. The mean $\delta^{34}S$ values were about +1‰ for the excess sulfate on both high and low sulfate days on the mainland. Based on several lines of reasoning, but little direct evidence, they concluded that oxidation of biogenic H_2S was a major source of SO_2 and excess sulfate in this area.

Biogenic emissions from saline wetlands in Florida have been extrapolated for the entire state and used as an estimate of the total global emissions of biogenic S (Cooper and others, 1989). In Florida, the annualized wetlands biogenic emissions were estimated as two orders of magnitude lower than anthropogenic emissions of SO_2. On a global basis, the total annual coastal wetlands emissions of S were also two orders of magnitude lower than oceanic emissions (Cooper and others, 1989), although the flux of DMS in moles/m^2/d from marshes is one to two orders of magnitude higher than from the oceans (Wakeman and Dacey, 1989).

Adams and others (1981) made biogenic S flux measurements at a number of saline marsh areas along the eastern U.S. coast including near Georgetown, South Carolina. They extrapolated their point measurements into annualized S fluxes. At Georgetown they estimated the total biogenic flux to be 1.7 g S/m^2/yr with H_2S and DMS representing 56 percent and 28 percent, respectively, of the total flux. Steudler and Peterson (1984) made monthly flux measurements in a short-form *S. alterniflora* marsh and in the adjacent tidal creek at the Great Sippewissett Marsh in Massachusetts. Their annualized fluxes, which took into account large seasonal flux differences, were 5.8 g S/m^2/yr for the salt marsh and 3.3 g S/m^2/yr for the tidal creek. In the salt marsh DMS was about 50 percent of the total flux and H_2S was about 35 percent. However, for the tidal creek, H_2S was about 71 percent and DMS only 5 percent of the total flux. Other organic-sulfur species, such as carbonyl sulfide, carbon disulfide, and dimethyl disulfide, were emitted at slightly greater concentrations than DMS at the tidal creek site. Using these fluxes, a crude extrapolation of the biogenic S emissions at CRNWR can be made; however, in the absence of flux measurements at CRNWR, the accuracy of estimated biogenic S flux can not be evaluated. This is particularly evident when flux estimates for biogenic S have been measured which varied over four orders of magnitude between and within locations (Adams and others, 1981; Cooper and others, 1989). Guenther and others (1989) have estimated biogenic sulfur emissions for the entire state of South Carolina. They estimated a biogenic flux of 260 metric tons per year for the state, which was about 0.17 percent of the state's total S emissions, anthropogenic and natural. Bates and Lamb (1992) have examined these data further and concluded that biogenic S emissions are at most equal to 7 percent of anthropogenic emissions along the Gulf and East coasts. Nevertheless, biogenic S may be an important contributor to the CRNWR atmosphere that must be addressed in future research.

In the absence of biogenic influences, oceanic rain would be expected to have isotopic ratios of about +20‰, however, Chukrov and others (1978) measured values in the range of +12.1 to +15‰ for Atlantic rain samples. They suggested that a ratio lighter than seawater may be owing to an increase in the proportion of continentally derived air; however, it may be as a result of biogenic contributions (Calhoun and Bates, 1989). Ostlund (1959) measured $\delta^{34}S$ values of +3.2 to +8.2‰ in rain in Sweden and at two coastal locations in the U.S. Jensen and Nakai (1961) found a similar range, +3.2 to +7.3‰, for industrial sites in Japan and a range of +12.8 to +15.6‰ for rain samples from nonindustrial, coastal areas. Jensen and Nakai suggested that the $\delta^{34}S$ values for rain in the coastal areas had lighter values than seawater as a result of biogenically produced H_2S from tidal flats and coastal belts.

Nriagu and Coker (1978) determined monthly averages of $\delta^{34}S$ to be from +4 to +9‰ at an urban station, +3 to +7‰ at a rural station, and +2 to +8‰ at a remote station in the Great Lakes Basin. Holt and others (1972) measured $\delta^{34}S$ in rain in the Chicago area and found similar results with $\delta^{34}S$ values in the range of +2 to +10.

Anthropogenic sources of S arise largely from fossil fuel combustion. The isotopic signature of most fuels tend toward lighter $\delta^{34}S$ values as a result of their biogenic origin. Based on studies of the isotopic ratios of SO_2 in populated areas, Calhoun and Bates (1989) suggest that anthropogenic emissions of S are likely to have $\delta^{34}S$ values of -2 to +6‰ prior to atmospheric oxidation. Newman and others (1975a,b) and Forrest and Newman (1977) have studied the fractionation of S in the combustion of oil and coal and the subsequent oxidation of the emitted SO_2. They found no fractionation in the combustion process; however, the noted decrease in the $\delta^{34}S$ value (about 4‰) for the oil-fired power plant and an increase of about +1 to +6‰ for the coal-fired plant. No isotopic measurements have been made of any SO_2 emitters in the region of CRNWR.

Chukrov and others (1980) have measured $\delta^{34}S$ values in terrestrial plants in Russia from -6.9 to +19‰ with an average of +2.5‰. The average $\delta^{34}S$ value for rainfall was +5.9‰ with a large range of values. In general, they concluded that the $\delta^{34}S$ ratios for plants and rainfall were similar if the atmospheric sulfate was not biogenically derived from the soils. Plants from oceanic islands had $\delta^{34}S$ ratios closer to seawater sulfate and oceanic rainfall (Chukrov and others, 1978). Krouse (1989) came to similar conclusions based on his measurements of plants on Herron Island, Great Barrier Reef, Australia. However, he did note that a lichen sample was about 2‰ lighter than the average of about +18‰ for other plant species and suggested that this may be the result of uptake of oxidized biogenic H_2S.

At CRNWR, the Spanish moss on Bull Island should get all of its S as a result of atmospheric and biogenic processes, including gaseous adsorption, dryfall, and wetfall, either directly or as leaching of bark and foliage. The Spanish moss had an average $\delta^{34}S$ value of about +3‰, which was surprisingly light compared to seawater sulfate. This value is in the range of expected continental rainfall and anthropogenic S emissions. Also, at CRNWR the *S. alterniflora* had an average $\delta^{34}S$ value of about +1.8‰. If *S. alterniflora* is a major source of atmospheric S in this area and the DMS emitted has a similar isotopic signature, plants such as the Spanish moss may be taking up oxidized biogenic S.

The loblolly pine needles on the island and the mainland had similar isotopic signatures of about +1 to +2‰. The similarity of signatures suggests a similar source of S or different sources of S with the same isotopic signature. Pines from the mainland and the barrier island probably experience rainfall with a similar isotopic signature, although an oceanic influence would be expected to be slightly greater on the barrier island pines. The pines should exhibit an isotopic signature that is based on uptake from both the soil and the atmosphere (Krouse and others, 1984). Thus, these results suggest that the influence of sea salt spray on the isotopic signature of the barrier island pines as a result of dry and wet deposition on the trees and in the sandy soils is not a controlling factor. As was suggested for the Spanish moss, the uptake of oxidized biogenic S may play a major role in the isotopic signature of the pines; however, this role should not be as great for the mainland pines despite the abundance of freshwater swamps in the Francis Marion National Forest.

In the absence of isotopic ratio measurements of anthropogenically emitted S, biogenic S, rainfall S, soil sulfate S, and more mainland vegetation samples, firm conclusions regarding the contribution of anthropogenic S to the CRNWR ecosystems can not be made. It is clear that the question of whether the CRNWR plants, which would only be expected to take up sulfate or SO_2 from the atmosphere or the soil, are utilizing anthropogenically or biogenically derived S, or a combination of the two, is the major issue in understanding S cycling in this environment.

CONCLUSIONS

Based on trace element concentrations, S concentrations, and S isotope ratio measurements in vegetation, sediments, and soils at CRNWR, we have drawn the following conclusions:

- The biogeochemistry of vegetation and soils on Bull Island indicate that this environment is not highly contaminated with anthropogenic additions of trace elements. Lead and Ni concentrations in Spanish moss may be symptomatic of anthropogenic additions of this element from atmospheric deposition.

- There is relatively little spatial variability in the trace element content of Spanish moss and loblolly pine needles on Bull Island.

- The biogeochemistry of the *S. alterniflora* and salt marsh sediments indicate that there is no gross contamination from trace elements. However, concentrations of Cu and Pb in the sediment may have been influenced by anthropogenic additions.

- Considerable spatial heterogeneity was found in trace element content of both *S. alterniflora* and sediments. Fairly extensive sampling is required to accurately represent the concentration of elements in these media and to reproducibly map the spatial distribution of elements.

- Baseline element concentrations ranges were measured prior to Hurricane Hugo and may no longer be valid for quantitative comparisons in the future owing to the changes in this environment as a result of the hurricane. Re-sampling is required to assess the effects of Hurricane Hugo and validate existing baseline element concentration ranges or establish new baseline ranges.

- Sulfur concentrations in *S. alterniflora* and sediments were highly variable. Total S concentration in these media is unlikely to be a useful monitor of anthropogenic S additions owing to the great variability and the large oceanic input of sulfate.

- Although *S. alterniflora* is the dominant plant species in CRNWR and a major source of food in the estuarine detrital-based food chain, it may not be a good biomonitor for anthropogenic trace metals additions to this environment because of high turnover rates and relatively small metal uptake.

- Stable S isotope ratios of *S. alterniflora* and sediments indicate that dissimilatory sulfate reduction in the sediment is an important process controlling the isotopic signature of the *S. alterniflora*.

- Spanish moss and loblolly pine exhibited S isotope ratios that indicate that seawater sulfate is not directly the predominant source of S for these two species. The isotopically light signatures of these plants compared to seawater S suggest an anthropogenic and/or a biogenic source of S.

- Estimates of biogenic S flux in this region suggest that anthropogenic emissions are greater than natural emissions of S, but biogenic emissions may be important contributors to the local atmosphere. Insufficient data are available to accurately compare anthropogenic and natural sources of S at CRNWR.

- A better understanding of natural processes controlling the cycling of S and trace elements in the environments at CRNWR is required before the anthropogenic additions of elements can be accurately estimated.

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Chapter D

Chemical Analysis Results for Biogeochemical Studies at Cape Romain National Wildlife Refuge, South Carolina[1]

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ABSTRACT

Tables of chemical analysis results and summaries of the field study quality control results are presented for the biogeochemical studies at Cape Romain National Wildlife Refuge.

INTRODUCTION

This chapter lists all chemical analysis results as reported by the laboratory for the biogeochemical studies at Cape Romain National Wildlife Refuge (CRNWR). *Spartina alterniflora* Loisel. (smooth cordgrass), *Pinus taeda* L. (loblolly pine), *Tillandsia usneoides* L. (Spanish moss), sediments, soils, and surface waters were analyzed as part of these studies. The raw chemical analysis results, which are found in this chapter, are interpreted in other chapters of this report: Chapter A on the determination of baseline element concentrations in the CRNWR salt marsh ecosystem; Chapter B on the determination of baseline element concentrations in the barrier island ecosystem; and Chapter C on the assessment of anthropogenic influences on CRNWR. This chapter summarizes quality control results from the analysis of National Institute of Science and Technology (NIST, formerly the National Bureau of Standards) standard reference materials that were submitted to the laboratory in each suite of plant, soil, and sediment samples. All samples were analyzed in the Denver laboratories of the U.S. Geological Survey Branch of Geochemistry with the exception of the sulfur isotope analyses (Coastal Science Laboratories, Austin, Texas). Quality assurance (QA) and control (QC) practices and most of

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[1] Chapter D of Jackson, L. L., editor, 1993, Biogeochemical studies of the salt marsh and a barrier island at Cape Romain National Wildlife Refuge, South Carolina: U.S. Geological Survey Open-File Report 93-303, 137 p.

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the analysis methods are provided in more detail in the quality assurance manual for the Branch of Geochemistry (Arbogast, 1990).

CHEMICAL ANALYSIS RESULTS

The field numbering system used for the salt marsh orientation study is shown in Figure D1. Table D1 describes the sample field number encoding schemes used for each sample type collected during the primary (November 1987) and the follow-up (June 1988) field studies. Table D2 provides a summary of all samples collected. The lower detection limits for all elements and species determined are shown in Table D3. The chemical analysis results for the different plant, sediment, and soil samples in each collection period are shown in Tables D4-D16. The chemical analysis results of water samples collected in June 1988 are shown in Table D17. Stable sulfur isotope ratios for selected plant, sediment, and salt water samples are shown in Table D18.

For plant species, the ash yield and sulfur content are reported on a dry-weight basis and all other elements are reported on an ash-weight basis. For sediments and soils, all results are reported on a dry-weight basis. As used in this report, dry-weight basis refers to air drying at ambient temperature for soils and sediments and at 40°C for plants; and not to a moisture free basis (i.e., drying at 105°C). This weight basis conforms to laboratory protocols for data reporting and data storage in the archival database (RASS). Elements listed in Table D3 that were below the detection limit for all samples were omitted from Tables D4-D16.

Particle-size fractionation and mineralogical composition of contiguous segments of a core collected at site 12L, near the intersection of Papas and Five Fathom Creeks in the northern portion of CRNWR, are presented in Table D19.

QUALITY CONTROL

Each section of the Branch of Geochemistry laboratories has quality control (QC) methods tailored to the specific analyses. The QC methods generally require the analysis of appropriate reference materials and duplicate analyses of the submitted samples. The data from this part of the laboratory QC program are not reported here. As part of the field study QC program NIST standard reference materials (SRM) were submitted to the laboratories with each suite of plant, soil, and sediment samples. Samples were submitted in suites with a maximum of 40 samples. In each suite of samples, two SRM's were included. All suites of plant samples included NIST SRM's: 1571, Orchard Leaves; 1572, Citrus Leaves; and/or 1575, Pine Needles. All suites of sediment and soil samples included NIST SRM's: 1645, River Sediment; and 1646 Estuarine Sediment. The results of all analyses of these SRM's are summarized in Tables D20 and D21. Results are compared to NIST certified and non-certified concentration values and other published concentration values[3]. In addition to the analysis of SRM's, samples of the plants, soils, and sediments were split in the laboratory and submitted randomized within each suite of samples. The duplicate analysis results were examined as part of the hierarchical analysis of

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[3] The NIST certified values are established on a dried at 110°C basis. The SRM's analyzed were on an as-received basis from the original container. No moisture corrections were made to the data.

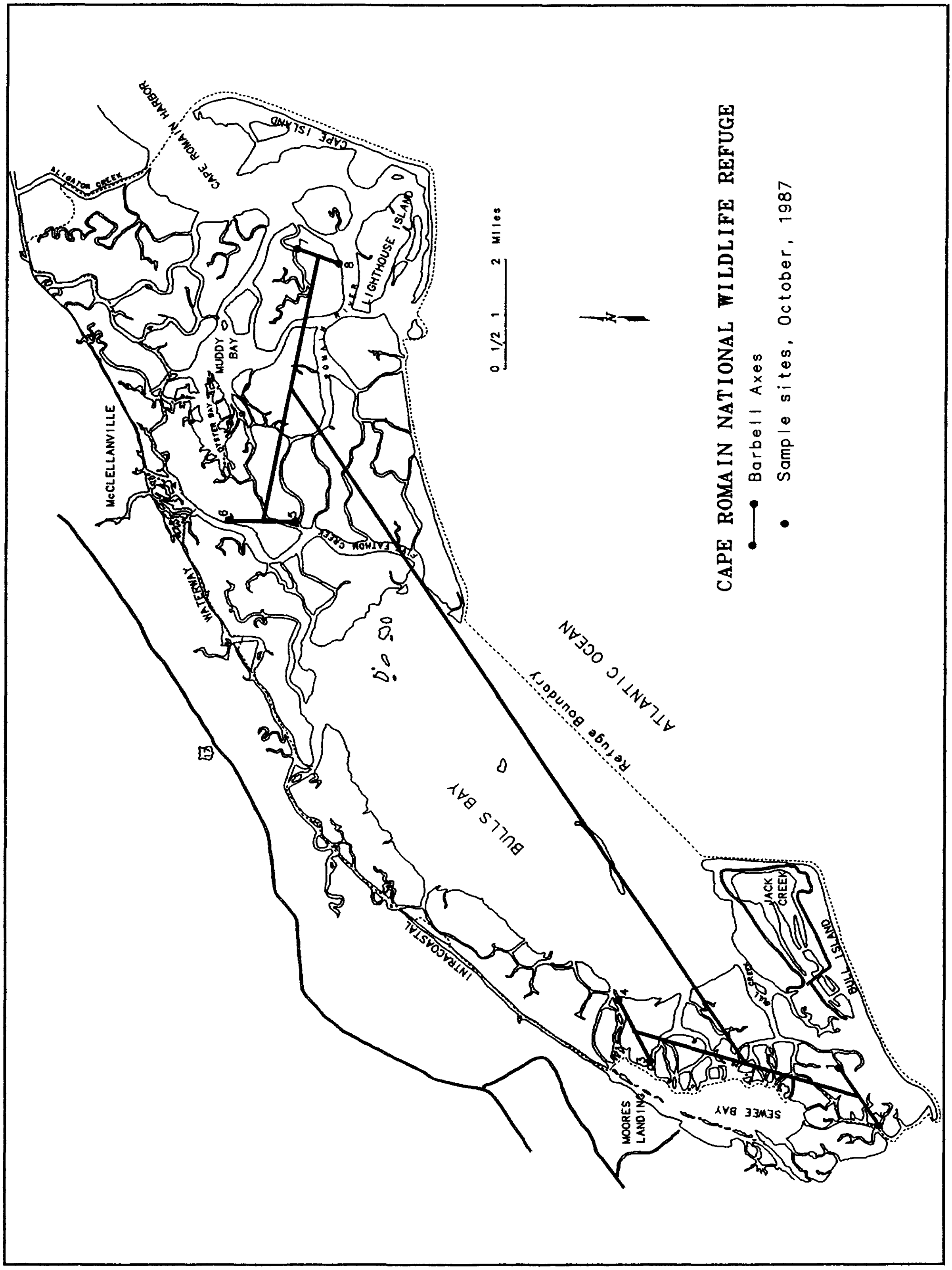

Figure D1. Location map for orientation study sample sites at Cape Romain NWR, October 1987.

variance. The ANOVA results are discussed in Chapters B and C of this report.

In reviewing the analysis results of the SRM's, several factors must be considered. First, the ICP results are reported only to two significant figures and instrumental determination limits are usually a few μg/g. The concentration of several elements that are given in this report could be determined with lower determination limits by individual element analysis techniques instead of by the multielement ICP technique. Arsenic is an example where more detailed investigations should use other techniques such as hydride-generation atomic absorption spectrometry. However, results are generally good for most elements when their concentration exceeded the chemical analysis determination limit by an order of magnitude. For those elements that did not exceed the determination limit by an order of magnitude the results reported are still very useful for screening purposes. Secondly, the NIST certified concentration values have error ranges associated with them that are listed in the Certificates of Analysis. The consensus values (Gladney and others, 1987) are simply arithmetic averages of all published values using an iterative mean approach to eliminate extreme outliers when sufficient data were available. In general there is a paucity of published data for these SRM's, especially for many trace elements. In numerous cases, the number of analyses compiled may only be one or two for an individual element and the consensus value is the mean of the limited available data. Despite the caveats associated with the consensus values, they are very useful for comparison. Lastly, the results for the SRM's are only indicative of the quality of the results for the botanical samples studied at CRNWR. Because of differences in the nature of the samples and their elemental content, only inferences to the quality of chemical analysis results can be made.

The data in Tables D19 and D20 for the botanical and sediment SRM's indicate that the accuracy and among-sample suite precision of the ICP and S determination methods are generally good. For example, concentrations of Al, Ca, Mg, P, As, Ba, Cu, Pb, and Zn in the botanical SRM's fell within the 95 percent uncertainity intervals for the certified concentration values. This was also true for Fe, K, Cr, Mn, and Ni for one of the two SRM's. Sulfur values for all three SRM's were quite close to the certified or informational values. Only SRM 1572 has a certified S content and our results were about 5 percent low (relative) compared to the mean value. However, our sample size used for analysis (about 250 mg) was only half NIST's minimum recommended subsample weight. For those other elements, which fell outside the uncertainities in the certified values, the bias was generally less than 10 percent (relative). For SRM 1572 the Co and La results were unacceptably high compared to the informational values. The results were not as high in SRM 1575 compared to the informational values, however, interpretations of Co and La in botanical samples in this report should be viewed with caution. The NIST informational values are based on a limited number of analyses, frequently only by one method. Therefore, quantitative comparisons with these values must also be viewed with caution.

For the sediment SRM's, results were found similar to those obtained for the botanical SRM's. Results for Fe, Mg, P, Cu, Mn, and Ni were within the tolerance intervals for both SRM's. Results for K, Co, Cr, Pb, V, and Zn were within the uncertainty interval for one of the SRM's and generally only slightly biased for the other SRM's. Frequently the results for the trace elements that were slightly biased only differed from the certified values by a few μg/g or 5-10 percent relative. Aluminum was used as a normalizing element for the sediment and the results for the SRM's gave equivocal results in that the results were about 6 percent high (relative) for SRM 1645 and 6 percent low (relative) for SRM 1646.

We consider the results for most elements to be acceptable for accuracy compared to the certified and informational values and for among-sample suite precision. Barium is an exception. There is an unacceptable level of accuracy and precision believed to be due to precipitation of Ba salts during the acid digestion. However, because the ANOVA results did not indicate that a significant proportion of the total variance was attributable to laboratory imprecision, this element was not deleted from consideration in the interpretation sections of this report. Nevertheless, use of these results for Ba in soils and sediments should be viewed with caution.

LITERATURE CITED

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Snyder, R. L., and Bish, D. L., 1989, Qualitative analysis, *in* Bish, D. L., and Post, J. E., eds., Modern Powder Diffraction, Reviews in Mineralogy, v. 20, Mineralogical Society of Am., Washington, D.C.; pp. 101-144.

Table D1. Sample field number encoding.

S. alterniflora and tidal marsh sediments

- Field number = AB12C345
    - A = sample type
        - G = *S. alterniflora* culms (flowering stems less seed head) and leaves
        - L = *S. alterniflora* culms (excluding flowering stems) and leaves (6/88)
        - S = tidal marsh sediment
        - W = water sample
    - B = collection season and/or area of refuge
        - N or S = November, 1987 collection and north or south area of refuge
        - X = June, 1988 collection
    - 12 = sample grid number (02-16)
    - C = sample grid letter (A-R)
    - 3 = site replication at 30 m (1 or 2)
    - 4 = site replication at 3 m (1 or 2)
    - 5 = laboratory split (1 or 2), not used in the field
- Example: GN12Q111 = *S. alterniflora* sampled at grid cell 12Q in November, 1987

Mainland pine and soil samples

- Field number = A123
    - A = sample type
        - P = *P. taeda*
        - S = soil
    - 123 = sample number (001-005)
- Example: P001 = *P. taeda* collected in the Francis Marion National Forest

Bull Island plant and soil samples

- Field number = A(B)12CDE(F)
    - A(B) = sample type
        - P = *P. taeda*, (B) not used
        - S = *T. usneoides*, (B) not used
        - SS = soil
    - 12 = sample grid number (00-07)
    - C = sample grid letter (A-K)
    - D = between- and within-tree replicate
        - A = primary tree sampled
        - B = between-tree replicate
        - C = within-tree replicate for tree "A"
        - D = within-tree replicate for tree "B"
    - E = laboratory split or June, 1988 resampling
        - blank = primary sample collected in 11/87 or new site collected in 6/88
        - X = second sample split
        - 2 = June, 1988 resampling of November, 1987 sites
    - (F) = laboratory split for June, 1988 resampling only
        - blank = primary sample
        - X = second sample split
- Example: S07DD = *T. usneoides* sampled at site 07D, within-tree replicate sample of second tree sampled at the site (tree "B")

Table D2. Summary of plant, soil, and sediment samples collected.

Area/Date/Sample Type	# Sites	Replicates			Total # samples	Report Table #
		30 m	3 m	Lab. splits		
Tidal Marsh 10/87						
S. alterniflora	8	4	4	4	20	Table D4
Sediments	8	4	4	4	20	Table D5
Tidal Marsh 11/87						
S. alterniflora	51	16	16	16	99	Table D6
Sediments	51	16	16	16	99	Table D7
Tidal Marsh 6/88						
S. alterniflora--leaves & culms with flowering stem	8	4	4	4	20	Table D8
S. alterniflora--leaves & culms without flowering stem	8	4	4	4	20	Table D9
Sediments	8	4	4	4	20	Table D10
Water	8	2	2	-	12	Table D17

Area/Date/Sample Type	# Sites	Replicates			Total # samples	Report Table #
		Between-tree	Within-tree	Lab. splits		
Bull Island 11/87						
P. taeda	32	14	7	6	59	Table D11
T. usneoides	24	9	-	5	38	Table D12
Soils	16	-	-	4	20	Table D13
Bull Island 6/88						
P. taeda--resampled sites	6	3	-	-	9	Table D14
P. taeda--new sites	6	1	1	3	11	Table D14
T. usneoides--resampled sites	6	2	-	2	10	Table D15
T. usneoides--new sites	6	1	-	1	8	Table D15
Soils--resampled sites	4	-	-	2	6	Table D16
Soils--new sites	2	-	-	-	2	Table D16
Water	2	-	-	-	2	Table D17
Francis Marion National Forest 11/87						
P. taeda	5	-	-	-	5	Table D11
Soils	5	-	-	-	5	Table D13

Table D3. Lower determination limits for the analysis of plants and soils.

Inductively-Coupled Plasma Emission					
Element	Plants	Soils	Element	Plants	Soils
Al %	0.1	0.05	Ga µg/g	8	4
Ca %	0.1	0.05	Ho µg/g	8	4
Fe %	0.1	0.05	La µg/g	4	2
K %	0.1	0.05	Li µg/g	4	2
Mg %	0.1	0.05	Mn µg/g	8	4
Na %	0.01	0.005	Mo µg/g	4	2
P %	0.01	0.005	Nb µg/g	8	4
Ti %	0.01	0.005	Nd µg/g	8	4
Ag µg/g	4	2	Ni µg/g	4	2
As µg/g	20	10	Pb µg/g	8	4
Au µg/g	16	8	Sc µg/g	4	2
Ba µg/g	2	1	Sn µg/g	20	10
Be µg/g	2	1	Sr µg/g	4	2
Bi µg/g	20	10	Ta µg/g	80	40
Cd µg/g	4	2	Th µg/g	8	4
Ce µg/g	8	4	U µg/g	200	100
Co µg/g	2	1	V µg/g	4	2
Cr µg/g	2	1	Y µg/g	4	2
Cu µg/g	2	1	Yb µg/g	2	1
Eu µg/g	4	2	Zn µg/g	4	2

Other Methods		
Element	Plants	Soils
C total%	-	0.01
C crbnt%	-	0.01
S total%	0.05	0.05

Table D4. Elemental concentrations in *S. alterniflora*--October 1987 collection.

				Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	Lat	Long	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
1A1	D-289507	325400	0793801	10.4	0.45	0.29	5.3	0.22	5.3	5.2	23	1.4	0.01
1A2	D-289498	325400	0793801	10.3	0.47	0.28	5.1	0.21	5.4	5.2	23	1.4	0.01
1B	D-289495	325400	0793801	12.6	1.15	0.29	4.9	0.24	6.3	5.9	23	0.82	0.01
2A1	D-289493	325317	0793916	12.9	1.11	0.25	3.7	0.19	7.2	3.6	23	0.92	0.01
2A2	D-289500	325317	0793916	12.8	1.12	0.22	3.7	0.17	7.1	3.5	23	0.90	0.01
2B	D-289505	325317	0793916	12.8	1.27	0.28	4.3	0.24	7.2	4.5	23	0.92	0.02
3A	D-289510	325631	0793811	12.6	0.77	0.33	2.8	0.21	7.0	2.6	26	0.89	0.02
3B	D-289496	325631	0793811	13.2	0.98	0.29	3.1	0.24	7.4	2.9	25	0.97	0.02
4A	D-289494	325714	0793706	12.2	1.24	0.98	2.8	0.58	7.0	4.7	21	0.92	0.05
4B	D-289509	325714	0793706	12.0	1.20	0.63	2.9	0.40	6.7	4.5	22	0.92	0.03
5A1	D-289502	330216	0792808	11.6	0.55	0.17	3.7	0.20	7.4	2.3	29	1.6	0.01
5A2	D-289504	330216	0792808	11.4	0.53	0.15	3.3	0.19	6.7	2.1	26	1.4	< 0.01
5B	D-289492	330216	0792808	11.5	0.48	0.19	3.3	0.21	7.7	2.0	26	1.3	0.01
6A	D-289501	330316	0792807	11.7	1.18	0.55	5.0	0.85	6.1	5.5	20	1.1	0.03
6B	D-289506	330316	0792807	13.3	1.36	0.23	4.2	0.21	6.6	4.5	24	0.83	0.01
7A1	D-289503	330216	0792302	9.95	0.42	0.26	3.1	0.19	6.5	3.3	26	1.4	0.01
7A2	D-289497	330216	0792302	9.98	0.43	0.25	3.2	0.18	6.3	3.3	25	1.4	0.01
7B	D-289511	330216	0792302	9.27	0.43	0.36	2.6	0.24	7.6	3.2	24	1.7	0.02
8A	D-289499	330130	0792308	11.4	0.46	0.44	4.0	0.63	5.4	4.4	24	1.8	0.02
8B	D-289508	330130	0792308	12.4	0.49	0.15	3.0	0.18	5.5	2.6	28	1.4	0.01

	µg/g, Ash weight											
Field #	Mn	Ba	Co	Cr	Cu	La	Li	Mo	Ni	Sr	V	Zn
1A1	150	11	< 2	5	21	4	7	< 4	< 4	750	< 4	56
1A2	150	10	< 2	5	20	4	7	< 4	< 4	740	< 4	54
1B	200	10	2	7	12	4	7	< 4	< 4	760	< 4	24
2A1	260	10	< 2	5	12	< 4	5	< 4	< 4	540	< 4	41
2A2	280	9	< 2	5	12	< 4	6	< 4	< 4	540	< 4	41
2B	250	10	< 2	6	12	4	6	< 4	< 4	620	< 4	34
3A	190	10	< 2	6	15	< 4	7	< 4	< 4	370	< 4	54
3B	180	10	< 2	7	29	< 4	7	< 4	< 4	430	< 4	61
4A	210	23	3	16	21	6	14	< 4	4	420	13	41
4B	240	16	< 2	11	21	5	10	< 4	< 4	430	8	36
5A1	320	10	< 2	5	26	< 4	6	< 4	< 4	470	< 4	65
5A2	290	9	< 2	4	22	< 4	6	< 4	< 4	430	< 4	61
5B	270	9	< 2	6	27	< 4	6	< 4	< 4	430	< 4	69
6A	220	32	4	62	18	5	9	< 4	36	730	7	51
6B	480	10	< 2	6	16	< 4	6	< 4	< 4	640	< 4	55
7A1	290	11	< 2	5	27	< 4	6	< 4	< 4	430	< 4	81
7A2	290	10	< 2	5	27	< 4	5	< 4	< 4	430	< 4	82
7B	300	29	< 2	6	34	< 4	6	< 4	< 4	360	4	110
8A	340	21	3	42	27	4	7	6	19	560	7	93
8B	270	9	< 2	5	25	< 4	4	< 4	< 4	420	< 4	70

Table D5. Elemental concentrations in sediments--October 1987 collection.

		Latitude	Longitude	Percent												µg/g			
Field #	Lab #	DegMinSec	DegMinSec	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	As	Ba	Be
1A	D-289518	325400	0793801	3.53	3.51	0.02	0.50	8.6	0.38	4.6	1.0	0.99	2.4	0.11	0.48	360	30	230	2
1B	D-289534	325400	0793801	3.36	3.30	0.06	1.57	7.9	0.61	4.5	1.1	0.99	2.8	0.09	0.48	320	30	250	2
2A	D-289519	325317	0793916	3.14	3.08	0.06	0.92	6.0	0.76	2.9	1.2	0.76	2.4	0.06	0.43	280	20	340	2
2B	D-289527	325317	0793916	3.14	3.02	0.12	0.84	6.4	0.94	3.3	1.2	0.85	2.4	0.07	0.45	290	20	330	2
3A1	D-289535	325631	0793811	3.89	3.87	0.02	1.73	7.5	0.59	4.0	1.1	0.86	2.7	0.07	0.49	330	40	290	2
3A2	D-289529	325631	0793811	3.89	3.87	0.02	1.68	7.5	0.59	4.0	1.1	0.85	2.7	0.07	0.49	330	40	290	2
3B	D-289521	325631	0793811	3.06	2.97	0.09	0.63	7.2	0.79	3.4	1.2	0.92	2.7	0.08	0.49	300	20	300	2
4A	D-289533	325716	0793702	2.72	2.52	0.20	1.07	7.3	1.2	3.7	1.2	0.94	2.4	0.07	0.50	330	20	310	2
4B1	D-289520	325714	0793706	2.58	2.42	0.16	1.21	7.0	1.1	3.6	1.2	0.90	2.4	0.07	0.50	330	20	310	2
4B2	D-289524	325714	0793706	2.55	2.39	0.16	1.25	7.1	1.1	3.6	1.2	0.92	2.5	0.07	0.50	330	30	310	2
5A1	D-289516	330216	0792808	3.27	2.91	0.36	0.52	6.3	1.8	3.4	1.2	0.87	2.4	0.08	0.46	360	30	330	2
5A2	D-289528	330216	0792808	3.25	2.90	0.35	0.55	6.3	1.8	3.4	1.2	0.87	2.4	0.08	0.46	360	20	340	2
5B1	D-289525	330216	0792808	3.03	2.77	0.26	0.48	6.3	1.5	3.4	1.2	0.86	2.5	0.08	0.46	350	20	340	2
5B2	D-289531	330216	0792808	3.05	2.79	0.26	0.48	6.3	1.4	3.4	1.2	0.86	2.4	0.08	0.47	360	20	340	2
6A	D-289532	330316	0792807	3.40	3.16	0.24	1.41	6.9	1.1	3.8	1.0	0.87	2.2	0.07	0.44	300	20	240	2
6B	D-289530	330316	0792807	3.65	3.59	0.06	2.63	7.5	0.64	4.7	1.1	0.93	2.8	0.07	0.48	360	40	210	2
7A	D-289517	330216	0792302	2.65	2.61	0.04	0.36	7.8	0.57	4.3	1.1	0.71	1.9	0.08	0.49	290	30	300	2
7B	D-289523	330216	0792302	3.17	3.14	0.03	0.39	7.9	0.51	4.5	1.1	0.71	1.9	0.08	0.50	280	40	290	2
8A	D-289522	330130	0792308	2.08	2.03	0.05	0.31	7.3	0.34	4.3	0.76	0.60	1.3	0.08	0.41	310	30	200	2
8B	D-289526	330130	0792308	1.99	1.96	0.03	0.20	7.4	0.55	4.9	1.1	0.67	1.8	0.09	0.48	340	50	300	2

	µg/g																		
Field #	Ce	Co	Cr	Cu	Ga	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Yb	Zn
1A	85	12	110	23	20	43	90	< 2	17	40	27	28	15	98	14	130	20	2	76
1B	77	12	98	20	20	39	79	< 2	15	36	24	26	14	110	12	110	18	2	70
2A	65	9	73	14	15	33	50	< 2	13	30	16	21	10	140	10	84	15	2	50
2B	65	10	82	15	15	33	56	< 2	14	31	18	23	11	150	10	91	16	2	55
3A1	74	10	86	19	17	37	71	3	16	33	22	23	13	130	11	110	17	2	60
3A2	77	10	86	18	18	38	71	2	15	36	22	23	13	130	13	110	17	2	60
3B	74	10	88	17	17	37	66	< 2	15	34	20	25	13	130	13	100	18	2	60
4A	77	11	90	17	18	39	68	< 2	14	35	20	26	13	150	11	100	19	2	62
4B1	75	10	86	16	17	38	64	< 2	14	35	20	24	12	150	12	100	18	2	58
4B2	74	10	87	16	18	37	65	< 2	14	34	20	23	12	150	11	100	18	2	60
5A1	70	9	78	15	15	36	53	< 2	14	32	18	21	11	190	10	90	17	2	53
5A2	71	9	79	15	16	36	53	< 2	13	34	17	22	11	190	11	89	17	2	54
5B1	70	9	79	15	15	36	53	< 2	15	32	18	22	11	170	10	90	17	2	52
5B2	67	9	79	14	15	35	52	< 2	14	31	18	22	11	170	11	90	17	2	53
6A	74	10	87	17	17	38	66	< 2	15	35	21	22	12	130	11	100	18	2	62
6B	78	12	92	20	18	39	71	3	15	37	23	25	13	120	12	110	18	2	67
7A	80	10	83	22	19	39	71	3	17	36	22	24	13	120	13	110	18	2	59
7B	82	11	84	22	19	41	72	2	15	35	23	24	14	120	13	110	19	2	62
8A	72	11	73	22	18	34	72	< 2	13	30	23	18	12	78	10	110	15	2	56
8B	78	10	76	20	18	37	68	3	15	33	21	24	12	120	12	110	17	2	57

Table D6. Elemental concentrations in *S. alterniflora*--November 1987 collection.

				Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	Lat	Long	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
GN10K111	D-292579	330037	0792849	10.9	0.72	0.17	3.9	0.11	6.7	3.7	21	0.96	< 0.01
GN10L111	D-292570	330042	0792744	9.88	0.25	0.22	2.6	0.15	5.9	2.8	26	1.5	0.01
GN10L211	D-292585	330042	0792744	10.4	0.39	0.25	3.6	0.17	4.0	4.0	27	1.5	0.01
GN10L221	D-292582	330042	0792744	9.07	0.26	0.19	3.4	0.15	4.3	3.5	25	1.6	0.01
GN11K111	D-292519	330117	0792841	11.5	1.30	0.35	4.3	0.22	7.8	5.9	23	0.73	0.02
GN11K112	D-292617	330117	0792841	11.5	1.27	0.26	4.1	0.17	6.7	4.7	19	0.61	0.02
GN11L111	D-292563	330138	0792749	10.3	0.37	0.19	3.6	0.16	7.0	2.9	24	1.4	0.01
GN11M111	D-292602	330132	0792649	8.84	0.27	0.18	3.7	0.18	5.7	3.8	23	1.5	0.01
GN11N111	D-292581	330132	0792601	9.86	0.42	0.17	3.2	0.14	5.4	3.2	24	1.1	0.01
GN11N112	D-292583	330132	0792601	9.92	0.43	0.19	3.3	0.14	5.4	3.3	24	1.1	0.01
GN11O111	D-292571	330120	0792429	11.0	0.83	0.25	3.9	0.18	5.1	3.2	24	0.75	0.02
GN11P111	D-292598	330132	0792401	10.6	0.84	0.56	4.4	0.34	4.7	4.4	20	0.84	0.03
GN11P112	D-292594	330132	0792401	10.5	0.82	0.60	4.5	0.34	4.8	4.5	20	0.87	0.03
GN12I111	D-292578	330229	0793105	9.85	0.92	0.33	4.0	0.20	5.3	4.5	21	0.78	0.02
GN12I211	D-292573	330229	0793105	10.0	0.93	0.30	4.8	0.17	5.0	5.7	20	0.84	0.02
GN12I221	D-292560	330229	0793105	10.6	0.85	0.28	4.2	0.17	5.1	4.6	22	0.86	0.02
GN12J111	D-292548	330221	0792958	9.32	0.25	0.14	3.0	0.12	8.0	2.7	23	1.5	
GN12K111	D-292564	330217	0792855	10.3	0.72	0.71	4.4	0.39	7.2	5.0	23	1.1	0.04
GN12K121	D-292538	330217	0792855	10.4	0.69	0.71	4.2	0.38	6.1	5.6	20	0.80	0.04
GN12K211	D-292572	330217	0792855	11.0	0.46	0.18	4.1	0.11	4.2	4.2	23	0.80	0.01
GN12L111	D-292514	330226	0792810	10.4	0.43	0.29	4.1	0.29	7.5	2.5	26	1.6	0.02
GN12M111	D-292599	330208	0792647	11.4	0.76	0.71	3.5	0.40	4.1	3.8	22	0.89	0.04
GN12M211	D-292575	330208	0792647	10.0	0.58	0.82	3.2	0.46	3.9	3.5	23	0.95	0.04
GN12M221	D-292607	330208	0792647	11.6	0.95	0.91	4.0	0.47	4.6	3.9	19	0.96	0.05
GN12M222	D-292588	330208	0792647	11.6	0.97	0.86	4.2	0.46	4.6	3.9	20	0.98	0.04
GN12N111	D-292529	330153	0792556	10.5	0.65	0.58	4.4	0.32	6.3	4.2	19	1.0	0.03
GN12O111	D-292528	330208	0792446	12.0	0.72	1.7	3.7	0.92	4.0	5.0	19	0.81	0.09
GN12O121	D-292559	330208	0792446	11.6	0.73	1.7	4.0	0.92	4.3	4.9	19	0.83	0.09
GN12O211	D-292552	330208	0792446	11.7	0.92	1.1	3.8	0.63	4.1	4.2	20	0.45	0.06
GN12P111	D-292592	330217	0792336	10.7	0.34	0.13	3.3	0.12	6.9	2.9	23	1.2	< 0.01
GN12Q111	D-292612	330225	0792304	9.30	0.27	0.22	4.8	0.19	4.2	3.5	23	1.9	0.01
GN12Q112	D-292590	330225	0792304	9.29	0.27	0.21	5.1	0.19	4.4	3.6	23	2.0	0.01
GN13J111	D-292521	330300	0792949	9.46	0.55	0.44	2.7	0.25	4.3	3.1	25	0.95	0.02
GN13K111	D-292589	330302	0792845	10.6	0.84	0.20	3.8	0.14	4.5	4.9	22	0.77	0.01
GN13L111	D-292518	330326	0792808	11.7	1.13	0.27	5.1	0.16	6.9	6.9	26	0.86	0.02
GN13L121	D-292554	330326	0792808	11.7	1.16	0.34	5.1	0.20	6.2	5.8	21	0.64	0.02
GN13L211	D-292613	330326	0792808	10.9	1.00	0.25	5.0	0.13	4.4	4.9	21	0.57	0.01
GN13M111	D-292567	330304	0792649	10.4	0.80	0.12	3.1	0.09	5.8	3.0	23	0.95	< 0.01
GN13M112	D-292608	330304	0792649	10.4	0.80	0.14	3.0	0.09	5.9	3.0	24	0.96	< 0.01
GN13N111	D-292609	330310	0792600	10.2	0.80	0.41	2.8	0.23	3.9	2.9	24	0.86	0.02
GN13O111	D-292580	330305	0792431	10.3	0.73	0.22	4.2	0.15	4.2	4.1	23	0.85	0.02
GN13P111	D-292543	330305	0792339	11.7	1.03	0.98	3.6	0.53	3.5	4.6	21	0.62	0.05
GN13Q111	D-292566	330254	0792236	10.4	0.69	0.41	5.0	0.24	3.5	4.7	21	0.85	0.02
GN13Q121	D-292600	330254	0792236	10.3	0.70	0.40	4.2	0.24	3.6	4.4	21	0.79	0.02
GN13Q122	D-292584	330254	0792236	10.1	0.69	0.43	4.5	0.25	3.7	4.5	22	0.82	0.02
GN13Q211	D-292544	330254	0792236	10.0	0.43	0.45	4.5	0.29	5.4	3.3	22	1.3	0.03
GN13Q212	D-292533	330254	0792236	10.4	0.40	0.43	4.4	0.28	5.5	3.2	23	1.3	0.02
GN14L111	D-292520	330351	0792755	9.30	0.40	0.45	4.7	0.30	4.2	4.4	21	1.2	0.02
GN14N111	D-292551	330404	0792524	10.7	0.79	1.1	4.1	0.52	3.8	6.4	19	0.68	0.05
GN14O111	D-292597	330408	0792437	10.8	0.98	1.1	3.3	0.55	4.6	4.8	21	0.75	0.05

Table D6 (continued). Elemental concentrations in *S. alterniflora*--November 1987 collection.

				Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	Lat	Long	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
GN14O112	D-292527	330408	0792437	10.8	0.99	0.98	3.4	0.49	4.5	4.9	21	0.75	0.05
GN14P111	D-292531	330353	0792335	10.7	0.34	0.37	3.8	0.26	5.5	3.6	22	1.5	0.02
GN14Q111	D-292550	330404	0792246	11.2	0.36	0.13	4.0	0.12	3.8	3.4	24	1.4	< 0.01
GN14Q211	D-292618	330404	0792246	7.68	0.19	0.15	3.0	0.11	6.0	3.1	25	1.4	< 0.01
GN14Q221	D-292545	330404	0792246	8.05	0.20	0.20	3.3	0.16	6.7	3.2	25	1.6	0.01
GN15O111	D-292530	330444	0792423	9.90	0.29	0.49	3.5	0.32	5.5	3.9	23	1.4	0.03
GN15O112	D-292587	330444	0792423	9.89	0.30	0.50	3.6	0.32	5.4	3.8	23	1.4	0.03
GN15P111	D-292556	330447	0792332	8.64	0.23	0.16	4.0	0.13	6.5	3.8	23	1.0	0.01
GN15P121	D-292586	330447	0792332	9.39	0.22	0.15	5.5	0.18	5.3	4.8	20	1.1	< 0.01
GN15P211	D-292615	330447	0792332	9.26	0.23	0.16	4.6	0.16	5.9	4.7	21	1.2	< 0.01
GN15Q111	D-292541	330444	0792231	9.18	0.27	0.37	4.8	0.26	5.2	3.7	21	2.0	0.02
GN15R111	D-292562	330501	0792143	9.02	0.26	0.17	3.8	0.17	6.3	2.6	23	1.7	0.01
GN15R121	D-292532	330501	0792143	9.95	0.59	0.17	4.3	0.13	4.3	3.2	22	1.2	0.01
GN15R211	D-292553	330501	0792143	9.52	0.26	0.10	4.2	0.12	5.9	3.6	23	1.4	< 0.01
GN16P111	D-292539	330534	0792326	9.22	0.26	0.46	3.5	0.31	5.0	3.7	23	1.6	0.02
GN16Q111	D-292534	330533	0792247	9.31	0.26	0.20	4.5	0.24	4.3	3.9	22	1.7	0.01
GS02A111	D-292524	325329	0793923	10.9	0.83	0.40	4.0	0.27	5.1	4.3	21	0.92	0.02
GS02A112	D-292515	325329	0793923	10.8	0.80	0.40	4.0	0.27	5.0	4.3	21	0.95	0.02
GS02B111	D-292536	325345	0793816	11.5	1.23	0.45	5.5	0.24	5.9	6.1	20	0.82	0.02
GS03B111	D-292576	325400	0793820	9.74	0.85	0.83	4.7	0.44	5.4	5.2	19	0.88	0.04
GS03B121	D-292577	325400	0793820	10.5	0.92	0.92	4.2	0.49	5.6	4.9	19	0.90	0.05
GS03B122	D-292569	325400	0793820	10.6	0.92	0.91	4.2	0.48	5.6	4.9	19	0.90	0.05
GS03B211	D-292574	325400	0793820	10.8	0.80	0.94	4.6	0.49	4.1	5.5	20	0.65	0.05
GS03C111	D-292526	325434	0793728	9.63	0.34	0.78	4.8	0.46	4.5	4.9	20	1.4	0.04
GS03C211	D-292611	325434	0793728	11.0	0.72	1.1	3.8	0.59	5.0	3.9	19	0.71	0.06
GS03C221	D-292537	325434	0793728	11.4	0.75	1.5	3.5	0.80	4.6	4.0	19	0.63	0.08
GS04B111	D-292516	325514	0793813	10.9	0.85	0.85	3.4	0.46	4.1	4.8	21	0.65	0.05
GS04C111	D-292535	325510	0793717	11.9	1.12	0.60	4.0	0.33	8.2	5.2	21	0.81	0.04
GS05B111	D-292593	325609	0793809	11.3	0.95	0.45	3.6	0.24	5.2	5.0	22	0.74	0.02
GS05C111	D-292614	325607	0793719	9.54	0.38	0.39	5.2	0.24	5.0	4.4	21	1.4	0.02
GS05C121	D-292604	325607	0793719	9.99	0.50	0.27	4.9	0.17	5.0	4.3	20	1.1	0.02
GS05C122	D-292605	325607	0793719	9.95	0.50	0.26	4.9	0.18	5.0	4.3	20	1.1	0.02
GS05C211	D-292547	325607	0793719	10.0	0.44	0.37	4.1	0.24	5.6	4.0	22	1.2	0.02
GS06B111	D-292561	325653	0793815	12.4	0.61	0.75	2.8	0.38	4.6	3.4	24	0.55	0.04
GS06B211	D-292595	325653	0793815	12.3	0.76	0.47	3.8	0.25	4.6	3.9	22	0.73	0.02
GS06B221	D-292522	325653	0793815	12.0	0.69	0.92	3.1	0.49	3.8	3.7	23	0.72	0.05
GS06C111	D-292591	325723	0793709	13.1	1.21	0.40	2.9	0.22	5.1	4.6	23	0.54	0.02
GS07C111	D-292542	325752	0793708	10.8	0.92	0.26	3.8	0.15	5.9	4.1	21	0.94	0.02
GS08C111	D-292616	325843	0793644	8.26	0.33	0.1	3.5	0.11	6.9	3.1	22	1.3	< 0.01
GS08C112	D-292601	325843	0793644	8.33	0.34	0.1	3.6	0.12	7.0	3.1	22	1.3	< 0.01
GS08D111	D-292610	325852	0793625	10.0	0.35	0.43	3.0	0.27	5.4	3.6	23	1.2	0.02
GS08D211	D-292555	325852	0793625	10.1	0.37	0.85	3.1	0.49	5.0	3.5	23	1.6	0.05
GS08D221	D-292517	325852	0793625	10.5	0.36	0.58	2.5	0.36	4.6	3.1	25	1.3	0.03
GS08D222	D-292540	325852	0793625	10.3	0.35	0.50	2.5	0.32	4.9	3.1	25	1.3	0.03
GS09D111	D-292546	325915	0793607	10.8	0.83	0.87	3.5	0.46	6.2	3.7	20	0.78	0.04
GS09D112	D-292603	325915	0793607	11.0	0.81	0.87	3.5	0.47	6.2	3.7	20	0.77	0.04
GS10B111	D-292558	330022	0793503	10.8	0.69	1.1	3.5	0.60	3.0	4.9	21	0.60	0.06
GS10B121	D-292557	330022	0793503	12.3	0.75	1.1	3.6	0.57	3.0	4.1	21	0.61	0.06
GS10B211	D-292525	330022	0793503	11.0	1.05	0.62	4.2	0.33	4.9	5.2	21	0.75	0.03

Table D6 (continued). Elemental concentrations in *S. alterniflora*--November 1987 collection.

	µg/g, Ash weight												
Field #	**Mn**	**Ba**	**Ce**	**Co**	**Cr**	**Cu**	**La**	**Li**	**Mo**	**Ni**	**Pb**	**Sr**	**V**	**Zn**
GN10K111	520	7	< 8	< 2	4	8	< 4	< 4	< 4	< 4	< 8	540	< 4	100
GN10L111	400	9	< 8	< 2	5	14	< 4	5	< 4	< 4	< 8	340	< 4	60
GN10L211	360	9	< 8	< 2	5	11	< 4	5	< 4	< 4	< 8	480	< 4	44
GN10L221	350	8	< 8	< 2	4	13	< 4	5	< 4	< 4	< 8	440	< 4	53
GN11K111	470	13	< 8	< 2	6	7	4	6	< 4	< 4	< 8	730	5	61
GN11K112	380	10	< 8	< 2	7	30	4	5	< 4	< 4	< 8	630	< 4	53
GN11L111	460	8	< 8	< 2	4	10	< 4	4	< 4	< 4	< 8	470	< 4	70
GN11M111	430	10	< 8	< 2	6	11	< 4	4	< 4	< 4	< 8	570	< 4	77
GN11N111	340	7	< 8	< 2	4	10	< 4	4	< 4	< 4	< 8	450	< 4	49
GN11N112	340	7	< 8	< 2	4	10	< 4	5	< 4	< 4	< 8	460	< 4	50
GN11O111	380	9	< 8	< 2	5	7	< 4	5	4	< 4	< 8	560	< 4	53
GN11P111	440	14	< 8	< 2	10	10	5	8	< 4	< 4	< 8	700	10	51
GN11P112	460	14	< 8	2	11	9	6	8	< 4	< 4	< 8	720	10	53
GN12I111	670	10	< 8	< 2	6	10	< 4	6	< 4	< 4	< 8	590	< 4	56
GN12I211	730	9	< 8	< 2	5	10	< 4	6	< 4	< 4	< 8	740	< 4	78
GN12I221	620	8	< 8	< 2	5	8	< 4	6	< 4	< 4	< 8	620	< 4	82
GN12J111	500	7	< 8	< 2	4	25	< 4	4	< 4	< 4	< 8	440	< 4	83
GN12K111	620	17	< 8	2	10	13	5	10	< 4	< 4	< 8	650	9	56
GN12K121	530	17	< 8	2	9	5	5	9	< 4	< 4	< 8	670	10	52
GN12K211	770	7	< 8	< 2	4	3	< 4	5	< 4	< 4	< 8	590	< 4	27
GN12L111	610	11	< 8	< 2	8	13	5	6	< 4	< 4	< 8	590	< 4	79
GN12M111	600	16	< 8	< 2	11	15	5	10	< 4	< 4	< 8	550	10	35
GN12M211	460	17	< 8	< 2	11	10	5	10	< 4	< 4	< 8	460	11	37
GN12M221	550	20	9	3	11	14	7	11	< 4	< 4	< 8	610	12	47
GN12M222	550	19	< 8	< 2	12	11	6	10	< 4	< 4	< 8	610	11	52
GN12N111	560	14	< 8	< 2	8	2	5	8	< 4	< 4	< 8	660	8	82
GN12O111	320	37	13	3	19	9	10	19	4	6	10	580	28	68
GN12O121	350	36	12	4	21	18	10	18	< 4	6	10	600	27	76
GN12O211	640	26	< 8	2	13	4	7	13	< 4	4	< 8	580	17	28
GN12P111	1000	8	< 8	< 2	4	26	< 4	< 4	< 4	< 4	< 8	460	< 4	88
GN12Q111	620	10	< 8	< 2	5	17	4	5	< 4	< 4	< 8	680	< 4	63
GN12Q112	650	10	< 8	< 2	5	20	4	5	< 4	< 4	< 8	690	< 4	67
GN13J111	600	11	< 8	< 2	7	11	4	7	< 4	< 4	< 8	410	5	65
GN13K111	450	7	< 8	< 2	5	6	< 4	5	< 4	< 4	< 8	560	< 4	54
GN13L111	730	10	< 8	< 2	6	2	5	6	< 4	< 4	< 8	890	< 4	74
GN13L121	570	11	< 8	< 2	7	9	4	6	< 4	< 4	< 8	770	< 4	48
GN13L211	390	9	< 8	< 2	6	9	4	5	< 4	< 4	< 8	760	< 4	30
GN13M111	560	5	< 8	< 2	4	8	< 4	4	< 4	< 4	< 8	460	< 4	52
GN13M112	560	5	< 8	< 2	5	6	< 4	< 4	< 4	< 4	< 8	460	< 4	50
GN13N111	340	10	< 8	< 2	8	12	< 4	6	< 4	< 4	< 8	440	5	26
GN13O111	700	9	< 8	< 2	4	9	< 4	5	< 4	< 4	< 8	620	< 4	32
GN13P111	570	21	< 8	2	11	4	6	12	< 4	< 4	< 8	570	16	33
GN13Q111	540	13	< 8	< 2	7	7	4	6	< 4	< 4	< 8	720	5	32
GN13Q121	490	12	< 8	2	8	13	4	7	< 4	< 4	< 8	640	5	33
GN13Q122	510	13	< 8	< 2	7	10	5	7	< 4	< 4	< 8	650	5	34
GN13Q211	420	13	< 8	< 2	6	12	5	7	< 4	< 4	< 8	670	6	62
GN13Q212	420	13	< 8	< 2	7	8	5	6	< 4	< 4	< 8	650	6	62
GN14L111	630	12	< 8	< 2	7	14	5	7	9	< 4	< 8	670	6	61
GN14N111	750	21	< 8	< 2	12	8	6	13	< 4	< 4	< 8	690	14	64
GN14O111	370	21	10	3	14	7	6	12	< 4	5	< 8	530	16	47

Table D6 (continued). Elemental concentrations in *S. alterniflora*--November 1987 collection.

	µg/g, Ash weight													
Field #	Mn	Ba	Ce	Co	Cr	Cu	La	Li	Mo	Ni	Pb	Sr	V	Zn
GN14O112	350	19	< 8	2	11	2	6	12	< 4	< 4	< 8	550	14	46
GN14P111	590	11	< 8	< 2	6	9	4	5	4	< 4	< 8	550	5	69
GN14Q111	1000	8	< 8	< 2	3	12	< 4	< 4	< 4	< 4	< 8	550	< 4	110
GN14Q211	390	9	< 8	< 2	5	30	< 4	< 4	< 4	< 4	< 8	450	< 4	52
GN14Q221	520	9	< 8	< 2	4	23	< 4	4	< 4	< 4	< 8	490	< 4	65
GN15O111	880	14	< 8	< 2	9	16	4	7	5	< 4	< 8	540	6	82
GN15O112	870	14	< 8	2	7	22	< 4	6	5	< 4	< 8	530	6	78
GN15P111	680	9	< 8	< 2	4	21	< 4	< 4	< 4	< 4	< 8	520	< 4	120
GN15P121	1600	11	< 8	< 2	4	16	< 4	< 4	< 4	< 4	< 8	720	< 4	120
GN15P211	770	8	< 8	< 2	4	24	< 4	< 4	< 4	< 4	< 8	640	< 4	110
GN15Q111	700	12	< 8	< 2	6	20	4	6	5	< 4	< 8	710	5	99
GN15R111	470	8	< 8	< 2	4	13	< 4	< 4	< 4	< 4	< 8	500	< 4	100
GN15R121	380	9	< 8	< 2	4	6	< 4	4	< 4	< 4	< 8	640	< 4	57
GN15R211	1300	8	< 8	< 2	4	22	< 4	< 4	8	< 4	< 8	570	< 4	210
GN16P111	700	13	< 8	< 2	7	14	4	6	5	< 4	< 8	520	6	89
GN16Q111	2000	12	< 8	< 2	5	19	4	< 4	4	< 4	< 8	660	< 4	120
GS02A111	410	12	< 8	< 2	7	6	4	6	< 4	< 4	< 8	610	6	45
GS02A112	420	13	< 8	< 2	6	4	5	6	< 4	9	< 8	620	5	47
GS02B111	550	13	< 8	< 2	6	5	5	7	< 4	< 4	< 8	920	5	45
GS03B111	640	18	< 8	2	11	9	6	10	< 4	< 4	< 8	700	11	40
GS03B121	680	19	< 8	2	12	8	6	11	< 4	< 4	< 8	640	13	43
GS03B122	690	19	< 8	< 2	12	7	6	11	< 4	< 4	< 8	640	12	44
GS03B211	640	22	< 8	2	12	8	6	11	< 4	< 4	< 8	690	14	33
GS03C111	990	21	< 8	< 2	11	10	6	10	< 4	< 4	< 8	750	10	52
GS03C211	990	27	< 8	3	11	12	7	13	< 4	4	< 8	590	17	45
GS03C221	860	35	10	3	19	9	8	18	< 4	6	< 8	550	22	46
GS04B111	830	21	< 8	2	11	5	6	11	< 4	< 4	< 8	560	13	42
GS04C111	520	17	< 8	< 2	8	6	5	8	< 4	< 4	< 8	600	8	43
GS05B111	540	11	< 8	< 2	7	7	4	7	< 4	< 4	< 8	540	5	35
GS05C111	690	16	< 8	< 2	7	17	5	7	< 4	< 4	< 8	770	5	48
GS05C121	650	10	< 8	< 2	6	11	4	7	< 4	< 4	< 8	720	< 4	51
GS05C122	650	10	< 8	< 2	7	11	4	6	< 4	< 4	< 8	720	< 4	51
GS05C211	570	13	< 8	< 2	6	11	4	7	< 4	< 4	< 8	610	4	55
GS06B111	350	17	< 8	2	10	8	5	10	< 4	< 4	< 8	400	9	59
GS06B211	440	13	< 8	< 2	8	6	5	8	< 4	< 4	< 8	580	5	44
GS06B221	340	19	< 8	< 2	11	14	6	12	< 4	< 4	< 8	480	12	56
GS06C111	460	10	< 8	< 2	6	6	< 4	7	< 4	< 4	< 8	440	5	32
GS07C111	970	9	< 8	< 2	4	5	< 4	6	< 4	< 4	< 8	580	< 4	54
GS08C111	750	5	< 8	< 2	4	11	< 4	< 4	< 4	< 4	< 8	480	< 4	77
GS08C112	770	6	< 8	< 2	5	19	< 4	4	< 4	< 4	< 8	490	< 4	80
GS08D111	690	15	< 8	< 2	7	10	4	7	4	< 4	< 8	470	5	78
GS08D211	1000	22	< 8	< 2	11	13	6	12	5	< 4	< 8	460	11	73
GS08D221	780	16	< 8	< 2	9	5	4	8	< 4	< 4	< 8	390	7	52
GS08D222	790	14	< 8	< 2	8	6	4	8	< 4	< 4	< 8	390	6	50
GS09D111	730	20	< 8	< 2	11	3	6	12	< 4	< 4	< 8	540	12	31
GS09D112	720	20	< 8	< 2	14	9	6	11	< 4	4	< 8	540	12	29
GS10E111	820	26	< 8	2	15	10	7	13	< 4	4	< 8	540	16	54
GS10E121	880	24	< 8	3	14	8	7	13	< 4	4	8	510	15	50
GS10E211	830	16	< 8	< 2	9	7	5	8	< 4	< 4	< 8	690	8	46

Table D7. Elemental concentrations in sediments--November 1987 collection.

		Latitude	Longitude	Percent												µg/g	
Field #	Lab #	DegMinSec	DegMinSec	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	As
SN10K111	D-292808	330037	0792849	3.72	3.54	0.18	1.39	7.3	1.3	3.7	1.2	0.99	2.9	0.08	0.47	360	20
SN10L111	D-292799	330042	0792744	2.47	2.31	0.16	0.20	6.8	1.1	4.0	1.3	0.84	2.0	0.09	0.50	400	30
SN10L211	D-292814	330042	0792744	3.35	3.22	0.13	0.58	6.6	1.1	3.3	1.3	0.84	2.4	0.07	0.48	290	20
SN10L221	D-292811	330042	0792744	2.96	2.87	0.09	0.30	6.7	0.88	3.5	1.3	0.84	2.2	0.08	0.49	300	20
SN11K111	D-292748	330117	0792841	3.41	3.10	0.31	1.53	7.7	1.7	4.0	1.2	1.0	2.6	0.08	0.48	350	20
SN11K112	D-293028	330117	0792841	3.42	3.11	0.31	1.48	7.8	1.8	4.2	1.1	1.0	2.6	0.09	0.49	370	20
SN11L111	D-292792	330138	0792749	3.48	3.20	0.28	0.56	7.1	1.5	3.5	1.2	0.99	2.8	0.08	0.47	330	20
SN11M111	D-293013	330132	0792649	2.82	2.78	0.04	0.27	9.2	0.52	5.7	1.1	0.99	2.3	0.12	0.53	360	40
SN11N111	D-292810	330132	0792601	3.46	3.22	0.24	0.61	7.0	1.4	3.4	1.3	0.94	2.7	0.07	0.48	300	20
SN11N112	D-292812	330132	0792601	3.46	3.22	0.24	0.61	7.0	1.4	3.3	1.3	0.94	2.7	0.07	0.47	300	20
SN11O111	D-292800	330120	0792429	3.24	3.24	< 0.01	0.96	7.1	0.67	2.9	1.3	0.72	2.3	0.05	0.50	250	20
SN11P111	D-293009	330132	0792401	4.17	4.17	< 0.01	2.87	6.0	0.60	4.4	1.0	0.68	2.3	0.05	0.45	340	40
SN11P112	D-293005	330132	0792401	4.06	4.06	< 0.01	2.96	5.9	0.60	4.3	1.0	0.66	2.3	0.04	0.44	340	40
SN12I111	D-292807	330229	0793105	3.94	3.94	< 0.01	2.05	7.8	0.50	4.1	1.2	0.90	2.7	0.07	0.50	290	30
SN12I211	D-292802	330229	0793105	3.85	3.85	< 0.01	1.97	8.0	0.45	4.1	1.1	0.91	2.6	0.07	0.50	270	30
SN12I221	D-292789	330229	0793105	4.61	4.61	< 0.01	2.63	7.9	0.44	4.6	1.1	0.87	2.8	0.07	0.50	280	40
SN12J111	D-292777	330221	0792958	2.43	2.43	< 0.01	0.18	8.2	0.39	3.7	1.1	0.75	1.6	0.08	0.48	280	10
SN12K111	D-292793	330217	0792855	3.64	3.56	0.08	1.69	8.1	0.90	4.6	1.2	1.0	2.7	0.08	0.50	350	30
SN12K121	D-292767	330217	0792855	3.62	3.53	0.09	2.07	8.1	0.90	4.6	1.1	1.0	2.8	0.08	0.48	380	30
SN12K211	D-292801	330217	0792855	4.43	4.43	< 0.01	3.24	7.4	0.52	5.3	1.0	0.90	2.9	0.07	0.46	310	40
SN12L111	D-292743	330226	0792810	3.04	2.83	0.21	0.39	6.0	0.81	2.6	1.4	0.72	2.1	0.06	0.47	270	10
SN12M111	D-293010	330208	0792647	3.71	3.69	0.02	1.39	7.4	0.68	3.6	1.1	0.85	2.5	0.07	0.50	300	20
SN12M211	D-292804	330208	0792647	3.82	3.81	0.01	0.84	7.7	0.58	3.4	1.2	0.86	2.7	0.07	0.51	260	20
SN12M221	D-293017	330208	0792647	4.18	4.16	0.02	1.09	7.7	0.65	3.7	1.1	0.91	2.9	0.08	0.49	270	20
SN12M222	D-292817	330208	0792647	4.12	4.09	0.03	1.10	7.5	0.65	3.5	1.1	0.90	2.8	0.07	0.48	260	20
SN12N111	D-292758	330153	0792556	3.68	3.54	0.14	1.60	7.7	1.1	3.9	1.1	1.0	2.9	0.07	0.47	320	20
SN12O111	D-292757	330208	0792446	4.31	4.31	< 0.01	0.96	7.7	0.54	3.6	1.1	0.73	2.4	0.06	0.49	210	30
SN12O121	D-292788	330208	0792446	4.06	4.04	0.02	0.81	7.6	0.61	3.6	1.2	0.76	2.5	0.07	0.50	240	30
SN12O211	D-292781	330208	0792446	4.31	4.30	0.01	3.07	6.7	0.68	4.3	1.0	0.73	2.5	0.05	0.46	350	40
SN12P111	D-292821	330217	0792336	2.05	2.03	0.02	0.12	8.7	0.46	4.5	1.2	0.81	1.6	0.09	0.55	500	20
SN12Q111	D-293023	330225	0792304	2.55	2.45	0.10	0.21	7.0	0.87	3.9	1.2	0.82	2.1	0.08	0.51	380	20
SN12Q112	D-292819	330225	0792304	2.51	2.41	0.10	0.21	6.8	0.87	3.6	1.3	0.78	2.0	0.08	0.49	360	20
SN13J111	D-292750	330300	0792949	4.82	4.82	< 0.01	2.32	7.9	0.51	4.2	1.1	0.87	2.6	0.06	0.47	300	30
SN13K111	D-292818	330302	0792845	3.55	3.51	0.04	0.91	7.4	0.81	3.6	1.2	0.88	2.5	0.08	0.50	320	20
SN13L111	D-292747	330326	0792808	3.47	3.39	0.08	2.09	8.2	0.88	4.4	1.2	1.0	2.7	0.07	0.50	350	30
SN13L121	D-292783	330326	0792808	3.43	3.34	0.09	1.97	8.1	0.95	4.4	1.2	1.0	2.6	0.07	0.50	360	20
SN13L211	D-293024	330326	0792808	3.57	3.44	0.13	2.00	8.3	1.1	4.6	1.1	1.0	2.7	0.08	0.51	350	20
SN13M111	D-292796	330304	0792649	3.38	3.34	0.04	1.31	8.0	0.67	3.7	1.2	0.96	2.7	0.07	0.51	290	20
SN13M112	D-293019	330304	0792649	3.44	3.40	0.04	1.31	8.2	0.67	3.9	1.1	0.98	2.8	0.08	0.51	310	20
SN13N111	D-293020	330310	0792600	4.05	4.05	< 0.01	3.84	8.8	0.41	6.1	0.97	0.86	2.8	0.07	0.51	320	40
SN13O111	D-292809	330305	0792431	3.89	3.89	< 0.01	2.82	7.1	0.64	4.4	1.2	0.77	2.5	0.06	0.49	340	30
SN13P111	D-292772	330305	0792339	5.18	5.18	< 0.01	4.22	7.8	0.43	5.6	0.97	0.75	2.5	0.05	0.48	380	40
SN13Q111	D-292795	330254	0792236	6.01	5.98	0.03	1.37	7.3	0.67	3.6	1.1	0.92	2.9	0.08	0.48	310	20
SN13Q121	D-293011	330254	0792236	5.44	5.41	0.03	1.25	7.5	0.69	3.8	1.0	0.94	2.9	0.08	0.49	340	20
SN13Q122	D-292813	330254	0792236	5.49	5.46	0.03	1.29	7.3	0.69	3.5	1.1	0.90	2.8	0.07	0.48	320	20
SN13Q211	D-292773	330254	0792236	4.24	4.18	0.06	0.67	8.1	0.70	3.8	1.1	0.98	2.7	0.08	0.50	290	10
SN13Q212	D-292762	330254	0792236	4.26	4.20	0.06	0.69	8.0	0.69	3.7	1.1	0.98	2.8	0.08	0.50	290	10
SN14L111	D-292749	330351	0792755	3.69	3.67	0.02	0.40	8.2	0.50	3.9	1.2	0.91	2.6	0.09	0.50	280	20
SN14N111	D-292780	330404	0792524	4.71	4.71	< 0.01	4.55	9.1	0.43	6.1	0.94	0.82	2.8	0.07	0.51	540	30
SN14O111	D-293008	330408	0792437	6.14	6.14	< 0.01	3.47	8.0	0.40	5.1	0.89	0.76	2.6	0.06	0.46	280	50

Table D7 (continued). Elemental concentrations in sediments--November 1987 collection.

		Latitude	Longitude	Percent												µg/g	
Field #	Lab #	DegMinSec	DegMinSec	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	As
SN14O112	D-292756	330408	0792437	5.97	5.97	< 0.01	3.57	8.0	0.40	4.8	0.96	0.73	2.6	0.06	0.46	260	40
SN14P111	D-292760	330353	0792335	3.76	3.70	0.06	0.46	8.7	0.57	4.1	1.1	0.95	2.5	0.09	0.51	290	20
SN14Q111	D-292779	330404	0792246	3.19	3.13	0.06	0.28	7.5	0.69	4.0	1.2	0.83	2.1	0.09	0.49	360	20
SN14Q211	D-293029	330404	0792246	3.12	3.07	0.05	0.22	8.1	0.62	4.6	1.1	0.87	2.2	0.10	0.51	370	20
SN14Q221	D-292774	330404	0792246	3.42	3.36	0.06	0.25	7.8	0.66	4.2	1.1	0.87	2.3	0.09	0.49	360	20
SN15O111	D-292759	330444	0792423	2.54	2.54	< 0.01	0.29	9.4	0.45	5.4	1.1	0.78	2.2	0.10	0.54	390	30
SN15O112	D-292816	330444	0792423	2.53	2.53	< 0.01	0.30	9.4	0.46	5.5	1.1	0.79	2.2	0.11	0.56	390	30
SN15P111	D-292785	330447	0792332	3.02	2.96	0.06	0.26	8.7	0.63	4.8	1.2	0.92	1.9	0.1	0.55	510	20
SN15P121	D-292815	330447	0792332	2.96	2.91	0.05	0.27	8.5	0.60	4.8	1.2	0.89	2.0	0.1	0.54	540	20
SN15P211	D-293026	330447	0792332	3.54	3.52	0.02	0.30	8.3	0.47	4.5	1.1	0.85	2.2	0.10	0.51	320	20
SN15Q111	D-292770	330444	0792231	3.12	3.12	< 0.01	0.37	8.6	0.48	4.2	1.1	0.86	2.5	0.09	0.51	320	20
SN15R111	D-292791	330501	0792143	3.86	3.70	0.16	0.57	8.3	1.0	4.4	1.1	1.0	2.7	0.1	0.51	420	20
SN15R121	D-292761	330501	0792143	3.74	3.59	0.15	0.56	8.5	0.98	4.4	1.2	1.0	2.6	0.1	0.53	380	20
SN15R211	D-292782	330501	0792143	3.69	3.61	0.08	0.31	8.2	0.67	4.5	1.1	0.95	2.3	0.1	0.50	460	20
SN16P111	D-292768	330534	0792326	3.88	3.83	0.05	0.35	8.6	0.66	4.6	1.2	0.79	2.4	0.10	0.51	290	30
SN16Q111	D-292763	330533	0792247	2.88	2.85	0.03	0.25	9.1	0.46	5.5	1.1	0.80	1.9	0.11	0.54	580	30
SS02A111	D-292753	325329	0793923	2.41	2.36	0.05	0.46	5.6	0.78	2.3	1.3	0.67	2.0	0.05	0.41	250	< 10
SS02A112	D-292744	325329	0793923	2.48	2.43	0.05	0.45	5.9	0.82	2.5	1.4	0.71	2.1	0.06	0.45	260	10
SS02B111	D-292765	325345	0793816	3.38	3.28	0.10	1.11	8.3	0.91	4.0	1.1	1.0	2.6	0.08	0.48	310	20
SS03B111	D-292805	325400	0793820	2.96	2.85	0.11	1.65	8.1	0.98	4.2	1.2	1.0	2.8	0.08	0.50	350	30
SS03B121	D-292806	325400	0793820	2.88	2.78	0.10	1.60	8.1	0.97	4.3	1.2	1.0	2.8	0.08	0.50	360	30
SS03B122	D-292798	325400	0793820	2.94	2.85	0.09	1.58	8.1	0.96	4.3	1.2	1.1	2.8	0.08	0.50	360	20
SS03B211	D-292803	325400	0793820	2.84	2.74	0.10	1.74	7.6	0.86	4.2	1.2	0.96	2.6	0.07	0.51	370	30
SS03C111	D-292755	325434	0793728	1.98	1.85	0.13	0.23	8.2	0.85	4.6	1.2	0.97	2.1	0.10	0.51	440	30
SS03C211	D-293022	325434	0793728	5.20	5.20	< 0.01	3.53	7.9	0.48	5.3	0.97	0.84	2.6	0.06	0.48	370	50
SS03C221	D-292766	325434	0793728	4.35	4.33	0.02	3.13	7.7	0.59	4.9	1.1	0.89	2.7	0.06	0.48	350	50
SS04B111	D-292745	325514	0793813	4.80	4.80	< 0.01	3.38	7.4	0.59	4.7	1.1	0.86	2.7	0.06	0.48	470	40
SS04C111	D-292764	325510	0793717	3.07	2.65	0.42	1.02	7.2	1.9	3.6	1.2	0.94	2.2	0.07	0.50	350	20
SS05B111	D-292822	325609	0793809	3.49	3.45	0.04	1.78	7.3	0.80	3.7	1.2	0.87	2.5	0.06	0.50	350	30
SS05C111	D-293025	325607	0793719	2.68	2.50	0.18	0.30	6.9	1.2	3.5	1.2	0.91	2.4	0.08	0.50	360	10
SS05C121	D-293015	325607	0793719	2.99	2.81	0.18	0.49	7.0	1.1	3.4	1.2	0.94	2.5	0.08	0.47	330	10
SS05C122	D-293016	325607	0793719	2.99	2.82	0.17	0.49	7.0	1.1	3.4	1.2	0.94	2.5	0.08	0.48	330	10
SS05C211	D-292776	325607	0793719	2.88	2.71	0.17	0.40	7.0	1.1	3.3	1.2	0.93	2.5	0.08	0.48	320	10
SS06B111	D-292790	325653	0793815	4.32	4.31	0.01	1.04	7.1	0.60	3.4	1.2	0.80	2.5	0.07	0.49	270	30
SS06B211	D-293006	325653	0793815	2.93	2.83	0.10	0.54	7.2	0.96	3.4	1.2	0.92	2.6	0.08	0.49	330	10
SS06B221	D-292751	325653	0793815	2.84	2.69	0.15	0.64	7.1	1.1	3.2	1.3	0.93	2.7	0.07	0.50	360	10
SS06C111	D-292820	325723	0793709	3.14	3.09	0.05	1.27	7.2	0.81	3.6	1.2	0.91	2.6	0.07	0.51	330	20
SS07C111	D-292771	325752	0793708	2.67	2.63	0.04	1.06	7.5	0.79	3.5	1.2	0.92	2.5	0.07	0.51	350	20
SS08C111	D-293027	325843	0793644	3.54	3.40	0.14	0.42	8.1	0.99	4.1	1.1	1.1	2.7	0.10	0.49	360	10
SS08C112	D-293012	325843	0793644	3.51	3.37	0.14	0.45	7.8	0.98	3.9	1.1	1.1	2.7	0.1	0.47	360	10
SS08D111	D-293021	325852	0793625	1.77	1.75	0.02	0.16	6.7	0.64	3.7	1.2	0.69	1.9	0.08	0.51	380	20
SS08D211	D-292784	325852	0793625	1.69	1.64	0.05	0.18	6.2	0.81	3.1	1.4	0.71	1.9	0.07	0.52	440	20
SS08D221	D-292746	325852	0793625	1.10	1.04	0.06	0.09	6.7	0.77	3.6	1.4	0.75	1.6	0.08	0.55	700	20
SS08D222	D-292769	325852	0793625	1.12	1.06	0.06	0.08	6.5	0.79	3.5	1.4	0.72	1.6	0.07	0.54	690	20
SS09D111	D-292775	325915	0793607	3.05	2.94	0.11	0.99	8.0	0.95	4.1	1.1	1.0	2.5	0.08	0.49	410	20
SS09D112	D-293014	325915	0793607	3.10	2.99	0.11	1.06	8.2	0.99	4.3	1.1	1.1	2.7	0.09	0.50	440	20
SS10B111	D-292787	330022	0793503	3.21	3.18	0.03	1.78	7.2	0.75	3.8	1.2	0.89	2.6	0.07	0.51	420	20
SS10B121	D-292786	330022	0793503	3.42	3.39	0.03	1.94	7.1	0.68	3.8	1.2	0.88	2.6	0.07	0.51	400	20
SS10B211	D-292754	330022	0793503	2.94	2.92	0.02	1.29	7.0	0.52	3.5	0.89	0.89	2.3	0.07	0.23	310	20

Table D7 (continued). Elemental concentrations in sediments--November 1987 collection.

	μg/g																			
Field #	Ba	Be	Ce	Co	Cr	Cu	Ga	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Yb	Zn
SN10K111	120	2	70	10	76	21	15	34	67	< 2	11	30	23	25	12	140	10	110	17	2	67
SN10L111	340	2	75	9	70	19	14	37	57	< 2	11	32	19	27	11	150	11	100	17	2	57
SN10L211	290	2	68	9	69	14	14	32	54	< 2	8	31	19	23	11	150	11	95	16	2	56
SN10L221	330	2	72	9	73	15	14	34	55	< 2	8	31	19	26	11	140	11	98	17	2	58
SN11K111	92	2	73	10	110	19	16	37	72	< 2	9	33	23	24	12	160	11	110	18	2	71
SN11K112	78	2	78	10	86	19	17	37	73	2	10	33	24	23	12	160	11	110	18	2	67
SN11L111	280	2	71	10	81	17	16	35	63	< 2	9	31	21	26	11	160	10	100	17	2	74
SN11M111	300	2	87	12	92	24	20	40	87	< 2	11	36	28	28	14	110	13	140	19	2	74
SN11N111	300	2	71	10	75	16	15	34	60	< 2	8	31	21	25	11	160	9	100	17	2	62
SN11N112	270	2	70	10	74	19	15	34	60	< 2	9	31	21	26	11	160	8	100	17	2	62
SN11O111	230	2	66	9	65	16	15	30	61	< 2	14	29	20	24	11	140	10	100	16	2	55
SN11P111	36	1	68	9	62	16	13	31	52	5	9	29	17	15	9	120	9	89	14	2	39
SN11P112	37	1	62	9	61	13	13	28	50	6	9	26	17	15	9	120	9	87	14	2	29
SN12I111	64	2	75	11	81	21	16	34	74	3	11	32	24	26	12	110	10	120	17	2	71
SN12I211	64	2	78	11	84	21	17	37	76	2	10	34	25	26	13	100	12	120	18	2	73
SN12I221	41	2	74	13	99	26	17	33	76	4	13	33	25	25	12	100	12	120	17	2	73
SN12J111	260	2	73	10	81	20	17	35	78	< 2	10	31	25	29	13	99	11	120	17	2	68
SN12K111	87	2	79	12	160	22	18	38	79	3	11	34	25	27	13	120	11	120	18	2	79
SN12K121	49	2	74	11	83	18	18	36	81	3	10	34	26	22	13	120	12	120	18	2	74
SN12K211	58	2	70	11	75	19	16	33	72	6	10	30	24	21	12	100	11	110	17	2	66
SN12L111	350	2	66	8	64	7	13	33	47	< 2	9	29	16	25	9	150	10	82	15	2	51
SN12M111	72	2	75	10	77	17	17	34	65	2	9	32	22	20	12	120	10	100	17	2	57
SN12M211	190	2	76	9	78	20	16	36	69	< 2	10	33	23	27	12	120	12	110	18	2	65
SN12M221	96	2	74	10	82	21	17	34	69	2	10	32	22	23	12	120	11	110	17	2	62
SN12M222	140	2	72	10	76	21	15	34	68	2	10	31	23	25	12	120	10	110	17	2	65
SN12N111	100	2	71	10	79	18	16	35	72	< 2	9	32	23	25	12	130	11	110	17	2	70
SN12O111	140	2	71	10	68	20	17	34	71	3	9	30	23	25	12	110	11	110	16	2	60
SN12O121	290	2	73	10	79	19	16	33	69	3	11	29	23	26	12	120	11	110	16	2	61
SN12O211	41	2	62	11	61	20	14	30	63	7	10	28	20	21	10	120	10	97	14	2	54
SN12P111	300	2	88	12	84	22	19	40	79	< 2	13	37	27	31	13	110	14	130	19	2	73
SN12Q111	370	2	82	9	74	17	15	38	57	< 2	7	35	20	25	11	140	12	98	17	2	55
SN12Q112	330	2	76	9	69	19	15	36	55	< 2	9	34	19	26	11	140	12	97	17	2	56
SN13J111	50	2	70	11	78	21	17	34	76	4	9	32	24	25	12	100	11	120	16	2	69
SN13K111	240	2	77	10	79	17	16	37	65	< 2	10	35	22	27	12	130	12	110	18	2	67
SN13L111	70	2	75	11	110	21	18	37	79	2	10	34	25	25	13	120	12	120	18	2	76
SN13L121	81	2	77	11	84	23	18	36	76	< 2	11	33	25	25	13	120	11	120	18	2	75
SN13L211	63	2	80	12	87	22	19	37	79	2	11	35	26	23	13	130	11	120	18	2	74
SN13M111	130	2	79	11	83	22	17	37	75	< 2	10	35	25	25	13	110	12	120	18	2	71
SN13M112	75	2	82	11	88	20	19	37	76	< 2	10	34	25	23	13	110	11	120	18	2	70
SN13N111	24	2	80	13	79	27	20	33	88	5	12	31	28	22	13	95	11	130	17	2	71
SN13O111	40	2	71	11	65	22	15	31	64	4	10	30	22	19	11	120	11	100	15	2	60
SN13P111	24	2	71	13	65	26	17	32	80	7	10	31	25	19	12	97	12	120	15	2	67
SN13Q111	130	2	79	10	79	23	16	37	66	< 2	11	34	23	27	12	120	11	110	19	2	67
SN13Q121	110	2	81	10	83	22	17	37	67	< 2	11	36	24	24	12	120	12	110	19	2	64
SN13Q122	160	2	78	10	78	20	16	36	65	< 2	11	33	23	26	12	120	12	110	18	2	66
SN13Q211	240	2	77	11	85	22	18	37	74	< 2	11	35	25	31	13	120	13	120	19	2	74
SN13Q212	250	2	78	11	81	28	18	38	74	< 2	10	36	25	29	13	120	13	120	19	2	75
SN14L111	260	2	77	10	86	21	17	38	76	< 2	11	34	25	31	13	110	12	120	19	2	72
SN14N111	27	2	75	12	72	27	20	34	95	6	12	30	28	22	13	93	14	130	16	2	73
SN14O111	26	2	73	14	70	25	18	31	77	8	10	29	26	20	12	91	11	120	15	2	61

Table D7 (continued). Elemental concentrations in sediments--November 1987 collection.

	µg/g																				
Field #	Ba	Be	Ce	Co	Cr	Cu	Ga	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Yb	Zn
SN14O112	37	2	69	14	67	21	17	32	77	8	10	30	26	20	12	92	12	120	15	2	68
SN14P111	250	2	83	12	72	23	19	40	80	< 2	9	36	28	31	14	110	13	130	19	2	79
SN14Q111	310	2	77	10	76	18	16	37	64	< 2	9	33	23	30	12	130	11	110	18	2	83
SN14Q211	330	2	86	10	85	21	18	39	69	< 2	10	36	23	28	13	120	12	120	19	2	67
SN14Q221	280	2	77	10	79	24	16	37	68	< 2	11	34	23	32	12	120	11	120	19	2	70
SN15O111	280	2	88	12	79	28	20	41	83	3	12	38	29	33	14	110	14	140	19	2	75
SN15O112	260	2	95	13	78	31	20	42	84	< 2	12	37	29	33	14	110	13	150	20	3	77
SN15P111	300	2	92	12	88	23	19	43	77	< 2	12	38	27	34	14	120	12	130	20	2	77
SN15P121	290	2	89	12	83	24	19	41	75	< 2	11	38	26	32	13	120	13	130	20	3	75
SN15P211	300	2	88	11	86	23	19	40	73	< 2	10	37	25	28	13	110	12	120	20	2	70
SN15Q111	260	2	78	11	83	24	18	38	77	< 2	9	35	26	31	13	110	13	130	19	2	73
SN15R111	250	2	82	11	87	23	18	39	74	< 2	12	35	26	29	13	130	11	120	20	2	77
SN15R121	250	2	78	12	85	23	19	38	78	< 2	14	36	26	30	13	130	14	130	18	2	81
SN15R211	260	2	79	12	85	23	18	38	73	< 2	10	33	26	34	13	120	12	120	20	2	77
SN16P111	290	2	79	11	84	23	18	39	76	2	10	35	25	31	13	130	13	130	19	2	72
SN16Q111	260	2	94	13	80	26	20	43	81	< 2	11	40	28	32	14	110	15	140	21	3	80
SS02A111	300	1	58	7	52	10	12	29	44	< 2	4	25	16	25	9	140	9	76	13	2	48
SS02A112	340	2	60	7	63	6	13	30	46	< 2	8	26	16	26	9	150	8	80	14	2	50
SS02B111	210	2	74	11	87	21	18	37	82	< 2	9	33	26	29	13	120	13	120	18	2	76
SS03B111	77	2	77	11	84	23	18	36	80	< 2	12	35	25	24	13	130	12	120	18	2	73
SS03B121	98	2	78	11	86	21	17	37	80	< 2	11	34	25	25	13	120	11	120	18	2	73
SS03B122	110	2	77	11	89	21	18	37	80	< 2	11	34	25	26	13	130	11	120	18	2	72
SS03B211	170	2	74	10	80	22	16	36	73	< 2	10	34	23	26	12	130	11	110	18	2	68
SS03C111	280	2	77	11	68	20	18	38	79	< 2	9	34	25	29	13	130	14	120	17	2	67
SS03C211	28	2	73	12	74	23	18	32	82	8	11	30	25	21	12	96	10	120	15	2	64
SS03C221	31	2	71	11	70	22	16	33	76	6	11	31	24	22	12	110	12	110	16	2	66
SS04B111	27	2	64	10	69	17	16	31	74	7	10	29	23	21	11	110	10	110	15	2	62
SS04C111	190	2	74	9	63	16	16	37	66	< 2	9	32	22	25	11	180	12	100	17	2	64
SS05B111	88	2	71	10	75	18	16	34	67	3	10	31	22	21	12	130	11	110	16	2	60
SS05C111	370	2	77	9	77	16	16	36	60	< 2	7	33	20	26	11	150	11	98	17	2	57
SS05C121	340	2	74	9	83	16	16	36	61	< 2	7	33	20	25	11	140	11	98	17	2	57
SS05C122	340	2	75	9	77	17	16	36	61	< 2	7	33	20	25	11	140	10	99	17	2	57
SS05C211	300	2	70	9	74	14	15	35	62	< 2	7	31	21	28	11	140	12	100	17	2	61
SS06B111	160	2	69	9	74	19	15	32	64	2	10	29	21	25	11	120	10	100	16	2	60
SS06B211	230	2	74	9	80	17	16	35	64	< 2	9	31	21	25	12	140	11	100	17	2	46
SS06B221	260	2	70	9	74	13	15	36	64	< 2	9	32	20	27	11	150	12	100	17	2	60
SS06C111	130	2	74	10	76	15	16	36	66	< 2	10	33	22	24	12	130	12	110	17	2	62
SS07C111	170	2	70	10	76	19	16	35	69	< 2	9	33	22	25	12	130	13	110	17	2	64
SS08C111	260	2	80	11	88	20	18	37	77	< 2	10	35	24	28	13	130	10	110	18	2	69
SS08C112	290	2	76	10	84	20	16	36	75	< 2	8	32	23	27	12	130	10	110	18	2	65
SS08D111	360	2	82	8	69	15	14	39	55	< 2	8	35	18	24	11	130	12	93	16	2	47
SS08D211	350	2	73	8	64	12	13	36	49	< 2	8	33	16	24	10	150	13	86	16	2	48
SS08D221	360	2	77	9	73	10	14	39	56	< 2	9	35	18	26	11	150	13	91	17	2	50
SS08D222	370	2	72	9	64	12	15	36	53	< 2	8	33	17	24	10	160	12	88	16	2	47
SS09D111	180	2	74	11	85	21	17	37	77	< 2	10	34	24	28	13	130	12	110	18	2	71
SS09D112	83	2	80	11	89	21	19	37	79	< 2	10	34	26	25	13	130	11	120	18	2	70
SS10E111	72	2	73	10	77	14	15	34	66	3	10	31	21	23	12	130	11	100	17	2	65
SS10E121	66	2	76	9	74	17	15	36	65	3	11	33	21	22	11	120	11	100	17	2	61
SS10E211	87	2	74	10	61	13	15	36	70	< 2	< 4	32	22	24	11	89	11	97	16	2	64

Table D8. Elemental concentrations in *S. alterniflora* (culms and leaves including flowering stalk)--June 1988 collection.

				Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	Lat	Long	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
GX02A111	D-307777	325329	0793923	4.61	0.30	3.4	4.0	1.9	2.0	5.5	10	1.5	0.19
GX03B111	D-307775	325402	0793820	5.80	0.29	5.3	3.3	2.8	1.7	4.2	8.0	1.0	0.29
GX03B121	D-307768	325402	0793820	5.87	0.29	5.2	3.3	2.8	1.8	4.1	7.9	1.1	0.29
GX03B122	D-307772	325402	0793820	5.94	0.27	5.3	3.3	2.8	1.8	4.1	7.9	1.1	0.29
GX03B211	D-307776	325402	0793820	6.08	0.33	5.1	3.3	2.8	1.7	4.6	10	0.96	0.29
GX06B111	D-307763	325653	0793815	5.98	0.30	4.4	3.1	2.4	1.9	5.0	13	1.1	0.25
GX06B112	D-307771	325653	0793815	5.88	0.30	4.4	3.2	2.4	1.9	5.0	12	1.1	0.25
GX06B211	D-307760	325653	0793815	5.30	0.28	4.3	3.4	2.3	1.9	4.8	12	1.0	0.24
GX06B221	D-307770	325653	0793815	6.38	0.31	4.6	3.1	2.5	1.5	4.8	11	0.76	0.26
GX06C111	D-307765	325723	0793709	5.32	0.30	4.4	3.3	2.4	1.6	5.0	10	1.0	0.24
GX12L111	D-307774	330226	0792810	5.39	0.26	3.1	4.0	1.8	1.9	4.7	9.8	1.5	0.19
GX12Q111	D-307778	330225	0792304	3.78	0.19	2.3	6.2	1.5	2.1	5.4	6.7	2.6	0.14
GX13L111	D-307767	330326	0792808	6.46	0.34	3.7	2.7	2.0	1.7	4.7	13	0.77	0.20
GX13L121	D-307769	330326	0792808	5.93	0.35	3.5	2.9	1.9	1.5	5.2	14	0.76	0.20
GX13L211	D-307761	330326	0792808	6.48	0.35	4.0	3.0	2.2	1.6	5.0	13	0.87	0.22
GX13L212	D-307780	330326	0792808	6.61	0.33	3.8	2.9	2.1	1.6	5.0	14	0.86	0.22
GX13Q111	D-307779	330254	0792236	4.98	0.29	3.6	4.1	2.1	1.6	5.4	11	1.1	0.21
GX13Q121	D-307764	330254	0792236	4.37	0.28	3.0	4.4	1.8	2.1	5.7	13	1.5	0.17
GX13Q211	D-307773	330254	0792236	7.20	0.33	4.1	3.2	2.3	1.8	4.8	13	1.2	0.25
GX13Q212	D-307762	330254	0792236	6.87	0.33	4.0	3.2	2.2	1.7	4.9	13	1.2	0.23

	µg/g, Ash weight																
Field #	Mn	Ba	Ce	Co	Cr	Cu	Ga	La	Li	Nd	Ni	Pb	Sc	Sr	V	Y	Zn
GX02A111	710	96	36	7	37	28	< 8	21	32	16	16	34	5	620	58	9	200
GX03B111	670	120	52	9	45	30	12	28	51	22	22	31	8	460	87	13	110
GX03B121	670	120	52	9	67	28	13	28	52	23	21	31	8	460	87	13	110
GX03B122	660	120	51	9	56	27	12	28	51	20	21	31	8	460	87	13	120
GX03B211	580	120	52	9	47	28	12	28	50	22	20	27	8	490	85	14	110
GX06B111	550	110	48	8	55	32	10	25	43	19	18	27	7	500	72	13	170
GX06B112	550	110	47	8	39	28	9	26	43	22	19	27	7	500	72	13	170
GX06B211	520	97	44	8	54	23	12	25	42	20	19	27	7	490	69	12	150
GX06B221	450	110	49	8	39	26	9	26	45	20	18	25	7	460	74	13	150
GX06C111	420	100	45	9	57	25	12	24	44	22	19	36	7	520	81	12	140
GX12L111	880	98	30	6	33	34	< 8	19	29	13	13	24	5	600	50	8	160
GX12Q111	1600	82	26	6	35	41	9	17	20	13	13	28	< 4	1000	41	7	190
GX13L111	420	88	39	7	40	17	9	21	36	17	16	23	6	440	61	10	110
GX13L121	460	87	38	7	40	23	< 8	21	35	17	15	22	6	490	59	10	110
GX13L211	470	94	39	7	42	22	10	22	40	17	17	22	6	470	64	10	100
GX13L212	450	93	38	7	31	23	10	21	37	18	16	21	6	470	61	10	97
GX13Q111	550	91	40	8	49	29	9	23	35	19	18	33	6	610	65	11	140
GX13Q121	580	83	31	7	45	30	< 8	19	28	14	17	35	5	660	54	9	140
GX13Q211	550	110	42	7	49	27	12	22	39	19	16	23	7	500	66	10	130
GX13Q212	570	99	39	7	46	25	10	22	37	19	15	23	6	500	64	10	130

Table D9. Elemental concentrations in *S. alterniflora* (culms and leaves only)--June 1988 collection.

				Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	Lat	Long	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
LX02A111	D-307802	325329	0793923	12.4	0.49	1.3	3.0	0.75	8.5	2.4	19	1.5	0.07
LX03B111	D-307792	325402	0793820	12.3	0.40	2.3	2.7	1.3	8.0	2.4	18	1.3	0.12
LX03B121	D-307786	325402	0793820	11.9	0.36	1.9	2.2	1.1	9.3	2.0	18	1.4	0.1
LX03B122	D-307799	325402	0793820	12.0	0.35	2.0	2.2	1.1	9.2	2.0	18	1.4	0.10
LX03B211	D-307787	325402	0793820	13.1	0.53	1.8	2.9	0.98	9.3	2.7	17	1.2	0.09
LX06B111	D-307797	325653	0793815	13.6	0.44	1.6	3.3	0.88	8.4	2.3	19	1.2	0.08
LX06B112	D-307782	325653	0793815	13.8	0.45	1.6	3.4	0.88	8.8	2.4	19	1.3	0.08
LX06B211	D-307795	325653	0793815	13.2	0.38	1.2	3.2	0.68	8.6	2.3	20	1.3	0.06
LX06B221	D-307796	325653	0793815	13.5	0.36	1.3	3.1	0.71	9.2	2.4	20	1.2	0.07
LX06C111	D-307789	325723	0793709	12.8	0.68	1.4	2.5	0.79	8.9	2.7	18	1.4	0.07
LX12L111	D-307800	330226	0792810	12.6	0.38	0.8	3.2	0.48	9.3	1.8	21	1.5	0.04
LX12Q111	D-307798	330225	0792304	12.3	0.26	0.9	3.1	0.55	7.9	2.4	21	2.0	0.05
LX13L111	D-307794	330326	0792808	13.8	0.65	1.4	2.9	0.78	9.2	2.6	19	1.4	0.07
LX13L121	D-307801	330326	0792808	13.8	0.58	1.1	3.1	0.63	9.2	2.7	18	1.3	0.05
LX13L211	D-307784	330326	0792808	13.8	0.52	1.7	2.8	0.94	9.3	2.2	19	1.2	0.09
LX13L212	D-307790	330326	0792808	13.6	0.51	1.7	2.8	0.92	9.2	2.2	19	1.2	0.08
LX13Q111	D-307793	330254	0792236	12.0	0.50	2.1	3.1	1.2	9.8	2.7	17	1.5	0.11
LX13Q121	D-307803	330254	0792236	12.0	0.44	1.9	3.3	1.0	9.4	2.9	17	1.5	0.1
LX13Q211	D-307783	330254	0792236	13.0	0.44	1.1	3.1	0.64	8.9	2.7	18	1.6	0.06
LX13Q212	D-307785	330254	0792236	12.9	0.44	1.1	3.3	0.63	9.1	2.8	19	1.6	0.06

	µg/g, Ash weight														
Field #	Mn	Ba	Ce	Co	Cr	Cu	La	Li	Mo	Nd	Ni	Pb	Sr	V	Zn
LX02A111	850	27	< 8	3	11	18	7	16	5	< 8	5	< 8	410	23	85
LX03B111	660	43	15	4	21	16	11	25	< 4	10	8	11	390	38	61
LX03B121	590	36	11	4	24	17	9	20	< 4	9	7	< 8	310	32	65
LX03B122	580	39	12	4	18	17	9	23	< 4	9	7	9	310	33	66
LX03B211	790	35	14	3	21	16	10	21	5	< 8	6	< 8	400	29	58
LX06B111	950	33	< 8	4	13	19	10	20	< 4	< 8	5	< 8	420	26	71
LX06B112	980	33	9	4	20	16	9	20	< 4	< 8	6	< 8	440	27	72
LX06B211	1100	24	< 8	3	16	23	7	14	< 4	< 8	< 4	< 8	430	20	77
LX06B221	920	25	< 8	3	14	13	7	16	< 4	< 8	< 4	< 8	420	22	73
LX06C111	820	27	< 8	3	16	21	7	17	5	< 8	5	< 8	330	25	91
LX12L111	660	18	< 8	2	13	21	6	12	< 4	< 8	< 4	< 8	410	13	70
LX12Q111	650	20	< 8	3	11	30	7	12	5	< 8	< 4	< 8	430	14	94
LX13L111	540	26	10	3	14	12	8	17	< 4	< 8	5	< 8	390	24	63
LX13L121	630	21	9	3	16	18	7	15	< 4	< 8	5	< 8	420	20	62
LX13L211	480	32	11	3	21	8	9	20	< 4	< 8	6	< 8	380	31	65
LX13L212	470	32	13	3	21	14	8	19	< 4	< 8	5	< 8	370	31	66
LX13Q111	590	41	12	4	17	19	11	21	< 4	9	7	9	470	38	77
LX13Q121	710	37	11	3	22	18	10	20	< 4	< 8	5	< 8	500	34	75
LX13Q211	780	23	< 8	3	15	17	7	14	5	< 8	< 4	< 8	440	19	72
LX13Q212	800	23	< 8	3	15	19	6	13	5	< 8	< 4	< 8	450	18	73

Table D10. Elemental concentrations in sediments--June 1988 collection.

		Latitude	Longitude	Percent												µg/g			
Field #	Lab #	DegMinSec	DegMinSec	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	As	Ba	Be
SX02A111	D-307825	325329	0793923	2.16	2.16	< 0.01	0.96	4.1	0.62	2.0	1.2	0.39	1.6	0.03	0.37	220	20	150	1
SX03B111	D-307812	325402	0793820	3.00	2.91	0.09	1.66	7.7	0.86	4.3	1.1	0.98	2.6	0.08	0.49	330	20	81	2
SX03B121	D-307815	325402	0793820	3.01	2.90	0.11	1.59	7.8	0.95	4.3	1.1	1.0	2.6	0.08	0.48	340	20	110	2
SX03B122	D-307820	325402	0793820	2.99	2.89	0.10	1.59	7.8	0.95	4.3	1.1	0.99	2.6	0.08	0.48	330	20	67	2
SX03B211	D-307819	325402	0793820	3.06	2.98	0.08	1.54	7.8	0.83	4.3	1.1	0.97	2.5	0.09	0.49	330	30	65	2
SX06B111	D-307824	325653	0793815	2.90	2.84	0.06	0.59	6.9	0.82	3.2	1.2	0.88	2.8	0.08	0.51	310	10	310	2
SX06B112	D-307808	325653	0793815	2.82	2.76	0.06	0.58	6.7	0.81	3.1	1.2	0.86	2.7	0.07	0.48	300	10	310	2
SX06B211	D-307809	325653	0793815	3.23	3.23	< 0.01	0.91	6.7	0.66	3.2	1.2	0.83	2.7	0.08	0.49	290	20	300	2
SX06B221	D-307818	325653	0793815	3.28	3.28	< 0.01	1.60	6.8	0.62	3.6	1.2	0.84	2.7	0.07	0.48	300	20	63	2
SX06C111	D-307813	325723	0793709	2.89	2.81	0.08	1.14	7.1	0.83	3.7	1.1	0.90	2.5	0.08	0.50	370	20	210	2
SX12L111	D-307821	330226	0792810	3.05	2.92	0.13	0.36	6.8	1.1	3.7	1.2	0.91	2.7	0.08	0.45	350	20	320	2
SX12Q111	D-307822	330225	0792304	2.82	2.75	0.07	0.27	6.8	0.79	3.8	1.2	0.82	2.4	0.08	0.50	360	20	330	2
SX13L111	D-307811	330326	0792808	3.59	3.54	0.05	1.78	7.9	0.71	4.5	1.1	0.97	2.6	0.09	0.48	340	30	64	2
SX13L121	D-307814	330326	0792808	3.51	3.46	0.05	2.02	7.7	0.70	4.4	1.1	0.95	2.6	0.08	0.48	350	30	52	2
SX13L211	D-307810	330326	0792808	3.54	3.37	0.17	1.84	7.7	1.2	4.5	1.1	0.97	2.6	0.08	0.47	350	30	49	2
SX13L212	D-307816	330326	0792808	3.56	3.40	0.16	1.82	7.8	1.1	4.5	1.1	0.98	2.5	0.08	0.47	360	30	44	2
SX13Q111	D-307804	330254	0792236	6.08	6.08	< 0.01	1.20	6.8	0.56	3.2	1.0	0.82	3.0	0.07	0.46	250	20	79	2
SX13Q121	D-307806	330254	0792236	5.81	5.80	0.01	1.33	7.2	0.60	3.5	1.0	0.80	2.9	0.07	0.47	250	20	71	2
SX13Q211	D-307807	330254	0792236	5.37	5.37	< 0.01	0.92	7.2	0.57	3.5	1.1	0.93	3.2	0.08	0.47	260	20	180	2
SX13Q212	D-307805	330254	0792236	5.32	5.32	< 0.01	0.93	7.1	0.55	3.4	1.0	0.91	3.1	0.08	0.46	250	20	170	2

	µg/g																		
Field #	Ce	Co	Cr	Cu	Ga	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Yb	Zn
SX02A111	53	6	37	6	10	26	27	4	< 4	24	10	15	7	140	8	54	10	1	27
SX03B111	78	11	85	20	19	39	76	3	11	34	26	25	13	120	12	120	19	2	68
SX03B121	78	11	89	19	19	39	78	2	11	34	26	25	14	120	13	120	19	2	69
SX03B122	76	11	93	20	19	39	78	< 2	11	33	26	24	14	120	12	120	19	2	69
SX03B211	77	11	110	21	19	38	77	2	11	33	26	24	13	120	12	120	19	2	71
SX06B111	79	9	79	16	17	40	61	< 2	9	36	21	25	12	140	13	100	18	2	60
SX06B112	72	9	80	15	16	36	59	< 2	7	33	21	24	12	140	12	100	17	2	56
SX06B211	69	9	75	15	17	35	60	< 2	10	31	21	24	12	130	12	100	17	2	55
SX06B221	70	10	85	15	17	36	61	3	10	31	21	22	12	120	11	100	17	2	58
SX06C111	77	10	84	16	17	39	66	2	10	33	23	26	13	130	12	110	18	2	62
SX12L111	73	10	76	16	17	37	59	< 2	< 4	33	22	25	12	150	12	100	18	2	61
SX12Q111	79	10	73	17	17	39	57	< 2	8	34	21	25	12	140	12	100	18	2	59
SX13L111	77	12	89	21	20	38	78	< 2	11	34	27	25	14	110	12	120	19	3	75
SX13L121	77	11	87	21	20	39	75	3	11	34	27	22	13	110	13	120	19	2	71
SX13L211	76	12	84	20	18	38	75	3	11	33	26	22	13	130	11	120	19	2	71
SX13L212	74	12	85	20	19	37	76	3	11	32	27	25	14	130	12	120	19	2	72
SX13Q111	75	10	74	19	17	37	60	3	10	33	23	22	12	120	11	110	19	2	58
SX13Q121	73	10	73	21	18	36	65	4	11	30	24	21	12	120	12	110	18	2	59
SX13Q211	78	11	81	21	18	38	65	2	10	35	24	25	13	120	12	120	19	2	65
SX13Q212	77	10	73	21	18	38	63	2	10	35	24	25	13	110	13	110	19	2	64

Table D11. Elemental concentrations in *P. taeda*--November 1987 collection.

		Latitude	Longitude	Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	DegMin	DegMin	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
P001	D-297340	3255	07936	2.64	0.11	1.2	9.3	0.15	10	3.1	2.9	2.3	0.01
P002	D-297341	3255	07936	3.00	0.11	1.4	9.1	0.12	7.9	4.3	1.6	1.9	0.01
P003	D-297342	3255	07936	2.74	0.10	1.9	12	0.13	10	3.9	0.64	2.0	< 0.01
P004	D-297343	3255	07936	3.39	0.10	1.4	16	0.44	8.2	2.8	0.83	2.9	< 0.01
P005	D-297344	3255	07936	3.78	0.14	0.71	17	0.11	4.7	2.6	2.5	1.4	< 0.01
P00IA	D-297323	3255	07936	4.24	0.12	0.40	7.9	0.13	6.3	3.1	2.7	3.7	0.01
P00IAX	D-297285	3255	07936	4.14	0.12	0.43	8.1	0.14	6.5	3.1	2.6	3.6	0.01
P00JA	D-297287	3255	07936	3.13	0.12	0.44	4.9	0.23	7.6	4.6	12	3.6	0.02
P00KA	D-297298	3255	07936	2.98	0.11	0.51	3.6	0.25	12	3.7	14	4.0	0.02
P01JA	D-297292	3255	07936	2.88	0.11	0.53	5.1	0.13	15	3.3	7.0	5.3	< 0.01
P01JB	D-297314	3255	07936	2.92	0.11	0.48	6.6	0.12	13	3.9	7.6	4.2	< 0.01
P02GA	D-297280	3255	07936	3.35	0.12	0.68	6.2	0.12	7.9	3.8	1.5	3.2	< 0.01
P02GB	D-297284	3255	07936	3.69	0.12	0.53	5.9	0.18	9.7	4.3	3.7	2.6	0.01
P02JA	D-297322	3255	07936	3.00	0.13	1.1	7.9	0.18	14	3.9	3.7	5.7	0.01
P03DA	D-297332	3255	07936	3.70	0.14	0.20	3.1	0.11	32	3.2	0.38	6.8	< 0.01
P03EA	D-297310	3255	07936	2.53	0.13	0.89	7.5	0.19	13	5.2	0.23	4.7	< 0.01
P03EB	D-297338	3255	07936	2.80	0.12	0.78	8.0	0.10	17	5.6	0.39	5.4	< 0.01
P03EC	D-297282	3255	07936	2.93	0.13	1.0	8.7	0.11	14	5.5	0.27	4.8	0.01
P03FA	D-297319	3255	07936	3.05	0.12	0.40	6.7	0.14	6.4	4.8	0.75	4.6	0.01
P03FAX	D-297305	3255	07936	3.02	0.10	0.41	6.7	0.15	10	4.6	0.71	4.3	0.01
P03GA	D-297301	3255	07936	2.97	0.12	0.99	7.3	0.16	20	4.2	0.30	5.4	< 0.01
P03GB	D-297324	3255	07936	3.24	0.12	0.58	7.7	0.14	11	4.6	0.34	5.0	< 0.01
P03JA	D-297283	3255	07936	3.08	0.12	1.2	6.1	0.22	12	3.5	3.5	4.5	< 0.01
P03JB	D-297297	3255	07936	3.62	0.15	1.1	7.2	0.17	12	4.0	0.78	3.8	< 0.01
P04DA	D-297308	3255	07936	3.38	0.13	0.64	7.0	0.10	9.1	4.5	0.70	4.2	< 0.01
P04EA	D-297329	3255	07936	3.95	0.11	0.30	4.6	0.18	16	4.2	0.64	5.3	< 0.01
P04FA	D-297300	3255	07936	3.36	0.13	1.2	7.6	0.19	10	5.1	1.4	3.6	< 0.01
P04FB	D-297279	3255	07936	3.53	0.14	1.0	6.6	0.17	8.2	4.5	1.0	3.7	0.01
P04FBX	D-297320	3255	07936	3.64	0.14	0.96	6.1	0.15	7.1	4.3	1.0	3.6	0.01
P04FC	D-297299	3255	07936	3.21	0.15	1.3	7.8	0.23	14	5.5	1.5	5.1	0.01
P04GA	D-297316	3255	07936	2.94	0.12	0.59	7.1	0.18	14	5.5	4.7	5.3	< 0.01
P04GC	D-297311	3255	07936	3.22	0.13	0.52	7.4	0.17	13	5.6	6.1	4.5	0.01
P04GCX	D-297307	3255	07936	3.14	0.13	0.53	7.7	0.18	13	5.8	6.3	4.7	0.01
P04IA	D-297328	3255	07936	3.14	0.12	0.70	6.8	0.26	17	3.9	4.1	5.2	0.02
P04IB	D-297289	3255	07936	3.53	0.13	1.2	8.0	0.14	12	5.0	1.7	3.7	< 0.01
P04JA	D-297309	3255	07936	3.52	0.14	0.47	6.2	0.22	14	3.6	8.2	4.7	0.01
P05CA	D-297336	3255	07936	3.00	0.11	0.42	6.3	0.11	11	3.7	7.7	6.3	< 0.01
P05DA	D-297303	3255	07936	3.66	0.13	0.68	4.3	0.26	17	3.0	0.25	5.5	< 0.01
P05EA	D-297313	3255	07936	3.17	0.13	0.07	6.6	0.11	15	4.7	0.90	5.0	< 0.01
P05EAX	D-297325	3255	07936	3.20	0.14	0.06	6.3	0.11	13	4.7	0.89	5.0	< 0.01

Table D11 (continued). Elemental concentrations in *P. taeda*--November 1987 collection.

		Latitude	Longitude	Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	DegMin	DegMin	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
P05EC	D-297293	3255	07936	2.98	0.13	0.07	6.0	0.12	15	4.3	1.2	5.0	< 0.01
P05FA	D-297335	3255	07936	3.24	0.13	0.67	8.4	0.09	12	6.9	0.34	6.7	< 0.01
P05GA	D-297286	3255	07936	2.77	0.11	1.3	6.5	0.14	8.2	4.6	0.34	4.0	< 0.01
P05GB	D-297333	3255	07936	3.03	0.12	1.3	6.4	0.11	10	5.1	0.24	4.2	< 0.01
P05HA	D-297331	3255	07936	3.28	0.10	0.58	9.0	0.08	8.7	4.9	0.39	4.2	< 0.01
P05HB	D-297334	3255	07936	3.04	0.11	0.64	9.1	0.17	12	3.9	1.4	5.1	< 0.01
P05HC	D-297337	3255	07936	3.24	0.12	0.63	8.4	0.1	8.9	4.8	0.16	4.8	< 0.01
P05IA	D-297306	3255	07936	4.03	0.13	0.57	4.8	0.23	13	3.1	1.4	4.4	< 0.01
P05IB	D-297327	3255	07936	4.28	0.14	0.58	5.0	0.24	8.9	3.1	1.9	5.0	< 0.01
P05JA	D-297294	3255	07936	3.40	0.12	0.54	6.4	0.19	11	3.5	9.4	4.4	0.01
P06DA	D-297315	3255	07936	2.72	0.12	0.22	9.4	0.26	13	7.3	3.0	6.0	0.01
P06EA	D-297312	3255	07936	3.70	0.12	0.58	7.0	0.20	13	3.4	1.5	4.5	< 0.01
P06EB	D-297302	3255	07936	3.31	0.13	0.73	7.9	0.16	9.8	4.6	0.72	4.3	< 0.01
P06FA	D-297321	3255	07936	4.33	0.16	0.55	6.9	0.10	11	2.8	0.35	5.2	< 0.01
P06GA	D-297288	3255	07936	3.57	0.11	0.17	8.5	0.09	8.9	5.4	4.0	5.1	< 0.01
P06GB	D-297291	3255	07936	4.44	0.17	0.23	6.5	0.09	18	3.7	3.3	5.6	< 0.01
P07BA	D-297326	3255	07936	2.49	0.13	0.73	5.8	0.17	15	3.7	4.8	7.0	< 0.01
P07BB	D-297304	3255	07936	2.48	0.11	0.38	6.6	0.16	11	4.4	0.60	5.4	< 0.01
P07CA	D-297295	3255	07936	2.95	0.11	0.24	5.4	0.16	13	4.5	1.1	4.6	0.01
P07DA	D-297290	3255	07936	3.02	0.11	0.80	8.1	0.11	12	4.8	0.71	4.7	< 0.01
P07DB	D-297330	3255	07936	2.79	0.11	0.38	5.2	0.18	16	4.1	3.9	5.2	0.01
P07DBX	D-297296	3255	07936	2.68	0.12	0.39	5.3	0.19	16	4.1	3.9	5.1	0.01
P07DC	D-297281	3255	07936	2.32	0.12	0.51	6.6	0.21	15	5.2	4.3	5.0	0.01
P07DD	D-297339	3255	07936	2.45	0.12	0.57	6.7	0.21	16	5.2	4.0	5.7	0.01

Table D11 (continued). Elemental concentrations in *P. taeda*--November 1987 collection.

Field #	µg/g, Ash weight														
	Mn	Ba	Cd	Co	Cr	Cu	Ga	La	Li	Nb	Ni	Pb	Sr	V	Zn
P001	12000	120	< 4	4	11	63	< 8	5	< 4	< 8	10	19	230	< 4	570
P002	4700	360	< 4	9	8	63	< 8	7	< 4	< 8	12	18	370	< 4	720
P003	7400	190	< 4	3	7	44	< 8	6	< 4	< 8	10	19	260	< 4	670
P004	26000	160	32	6	9	68	13	6	< 4	< 8	18	22	220	< 4	4400
P005	660	63	< 4	3	7	36	< 8	6	< 4	< 8	7	21	160	< 4	600
P00IA	3700	10	< 4	4	9	70	< 8	4	16	< 8	4	11	160	< 4	750
P00IAX	3600	9	< 4	4	8	74	< 8	5	15	< 8	4	13	150	< 4	790
P00JA	4000	11	< 4	4	9	87	< 8	4	11	< 8	7	15	160	4	890
P00KA	3600	13	< 4	4	11	90	< 8	4	9	< 8	5	15	130	4	610
P01JA	8300	5	4	5	6	120	< 8	< 4	6	< 8	5	< 8	120	< 4	940
P01JB	7000	8	< 4	5	6	110	< 8	5	7	< 8	5	< 8	140	< 4	1000
P02GA	2300	7	< 4	< 2	7	71	< 8	4	< 4	< 8	4	10	190	< 4	770
P02GB	1700	12	< 4	2	8	61	< 8	4	6	< 8	4	16	120	< 4	580
P02JA	11000	13	< 4	5	10	120	8	5	7	< 8	8	< 8	240	< 4	1600
P03DA	2600	8	< 4	3	9	160	< 8	< 4	< 4	< 8	27	< 8	36	< 4	1200
P03EA	4800	10	5	5	5	98	< 8	4	5	< 8	10	< 8	150	< 4	1200
P03EB	4500	13	< 4	5	8	96	< 8	< 4	5	< 8	9	< 8	190	< 4	1000
P03EC	4900	12	< 4	5	7	83	< 8	5	5	18	10	9	200	< 4	1200
P03FA	5700	9	< 4	5	11	92	< 8	4	5	< 8	6	10	130	< 4	970
P03FAX	5500	11	< 4	4	10	84	< 8	4	4	< 8	6	10	120	< 4	970
P03GA	4700	9	4	7	7	93	< 8	< 4	< 4	< 8	9	< 8	190	< 4	970
P03GB	7100	5	5	6	7	93	< 8	< 4	6	< 8	5	< 8	160	< 4	1100
P03JA	8200	7	< 4	3	9	110	< 8	4	9	< 8	8	8	180	< 4	910
P03JB	7600	11	< 4	3	6	95	< 8	4	8	< 8	5	< 8	300	< 4	1100
P04DA	11000	10	5	4	7	83	< 8	4	< 4	< 8	5	11	98	< 4	1100
P04EA	2200	5	< 4	5	7	71	< 8	< 4	7	< 8	5	< 8	100	< 4	790
P04FA	6700	12	< 4	7	8	62	< 8	4	8	< 8	9	9	300	< 4	1200
P04FB	5500	13	< 4	8	10	56	< 8	4	6	< 8	7	10	420	< 4	770
P04FBX	5300	12	< 4	9	11	62	< 8	4	6	< 8	7	9	420	< 4	720
P04FC	8500	11	< 4	9	9	88	8	4	9	< 8	10	9	340	< 4	1500
P04GA	5400	8	< 4	3	9	94	< 8	4	4	< 8	< 4	9	150	< 4	930
P04GC	4500	10	< 4	3	9	85	< 8	5	< 4	18	4	12	150	< 4	900
P04GCX	4700	11	< 4	4	12	100	< 8	5	5	< 8	4	14	160	< 4	940
P04IA	4900	16	< 4	6	13	91	< 8	5	5	< 8	5	15	230	6	770
P04IB	5900	14	< 4	4	6	94	< 8	4	7	< 8	6	< 8	370	< 4	1400
P04JA	9500	12	< 4	5	10	120	< 8	5	22	< 8	8	12	100	< 4	1300
P05CA	1900	11	< 4	< 2	9	97	< 8	4	6	< 8	< 4	< 8	310	< 4	890
P05DA	3300	11	< 4	7	6	89	< 8	< 4	< 4	< 8	35	< 8	89	< 4	800
P05EA	4500	6	< 4	2	7	89	< 8	< 4	< 4	< 8	< 4	9	110	< 4	760
P05EAX	4500	9	< 4	2	9	91	< 8	4	< 4	< 8	< 4	< 8	110	< 4	720

Table D11 (continued). Elemental concentrations in *P. taeda*--November 1987 collection.

Field #	μg/g, Ash weight														
	Mn	Ba	Cd	Co	Cr	Cu	Ga	La	Li	Nb	Ni	Pb	Sr	V	Zn
P05EC	4000	5	< 4	2	7	88	< 8	< 4	< 4	< 8	< 4	< 8	99	< 4	640
P05FA	13000	13	4	3	7	100	9	4	< 4	< 8	7	< 8	160	< 4	700
P05GA	13000	6	< 4	< 2	6	110	11	< 4	< 4	< 8	9	< 8	40	< 4	1000
P05GB	22000	7	< 4	2	5	97	13	< 4	< 4	< 8	6	< 8	66	< 4	1400
P05HA	12000	13	< 4	8	6	90	< 8	5	< 4	< 8	5	< 8	400	< 4	730
P05HB	11000	15	< 4	7	9	110	< 8	5	5	< 8	5	< 8	370	< 4	980
P05HC	12000	11	< 4	7	5	120	< 8	4	< 4	< 8	6	< 8	360	< 4	890
P05IA	10000	5	< 4	6	7	66	8	< 4	23	< 8	11	< 8	94	< 4	840
P05IB	11000	6	< 4	7	8	67	< 8	< 4	25	< 8	8	< 8	110	< 4	800
P05JA	5200	11	5	5	8	99	< 8	4	19	< 8	10	9	210	< 4	830
P06DA	3200	12	< 4	3	11	89	< 8	5	12	< 8	< 4	14	250	< 4	960
P06EA	10000	19	< 4	6	5	77	< 8	4	< 4	< 8	5	< 8	250	< 4	730
P06EB	7600	20	< 4	8	6	98	< 8	4	< 4	< 8	6	8	230	< 4	1200
P06FA	5000	4	< 4	4	5	82	< 8	4	4	< 8	5	< 8	170	< 4	970
P06GA	2800	6	< 4	3	6	60	< 8	5	5	< 8	< 4	< 8	180	< 4	890
P06GB	1700	4	< 4	3	6	66	< 8	< 4	4	< 8	6	< 8	85	< 4	750
P07BA	7000	8	< 4	4	11	120	< 8	4	13	< 8	5	9	120	< 4	1200
P07BB	10000	4	< 4	4	8	110	10	< 4	7	< 8	8	< 8	83	< 4	1000
P07CA	3900	12	< 4	2	12	82	< 8	4	< 4	< 8	6	11	95	< 4	730
P07DA	17000	8	< 4	5	7	95	15	4	13	< 8	6	< 8	150	< 4	1400
P07DB	9600	28	< 4	5	10	110	< 8	4	18	< 8	7	< 8	79	< 4	1000
P07DBX	9600	9	< 4	4	12	110	10	4	18	< 8	7	9	76	< 4	1100
P07DC	5700	9	< 4	4	12	120	< 8	5	15	< 8	7	12	130	< 4	730
P07DD	7200	8	< 4	6	10	120	< 8	5	19	< 8	6	9	120	< 4	830

Table D12. Elemental concentrations in *T. usneoides*--November 1987 collection.

		Latitude	Longitude	Percent, Dry weight		Percent, Ash weight								µg/g, Ash weight		
Field #	Lab #	DegMin	DegMin	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	Ba	Cd
S00IA	D-297273	3255	07936	3.02	0.12	0.89	6.7	0.78	12	6.7	15	1.2	0.07	1200	120	< 4
S00JA	D-297254	3255	07936	4.09	0.18	1.9	3.8	1.3	12	7.5	12	1.1	0.14	3700	120	4
S01JA	D-297248	3255	07936	4.26	0.18	0.94	6.1	0.75	14	7.1	12	1.5	0.08	3600	110	< 4
S01JB	D-297241	3255	07936	3.68	0.18	1.1	6.2	0.80	18	7.1	9.1	1.8	0.09	2100	120	< 4
S02GA	D-297272	3255	07936	1.96	0.13	1.7	13	1.4	12	6.9	4.1	1.5	0.11	1700	230	5
S02JA	D-297244	3255	07936	3.92	0.14	1.4	3.6	1.1	11	6.7	17	1.0	0.10	3500	100	4
S03DA	D-297239	3255	07936	2.94	0.15	1.2	6.6	0.89	21	6.4	3.8	2.3	0.09	3700	150	6
S03EA	D-297259	3255	07936	2.86	0.13	0.67	13	0.55	17	8.0	4.8	2.5	0.05	8800	180	5
S03EB	D-297246	3255	07936	3.28	0.14	0.84	11	0.65	18	6.6	5.4	1.9	0.06	6500	190	5
S03FA	D-297245	3255	07936	2.38	0.11	1.4	11	1.2	16	6.7	4.3	2.0	0.11	5500	230	5
S03GA	D-297270	3255	07936	2.45	0.18	1.3	12	0.92	15	5.7	4.5	2.7	0.1	4400	230	5
S03GAX	D-297253	3255	07936	2.38	0.18	1.3	13	0.94	15	5.8	4.7	2.7	0.1	4500	230	5
S03JA	D-297260	3255	07936	3.70	0.13	1.3	6.8	0.92	12	6.9	13	1.7	0.09	3400	120	< 4
S03JB	D-297250	3255	07936	3.24	0.14	1.4	6.1	1.0	15	10	7.6	1.6	0.10	5700	110	5
S03JBX	D-297256	3255	07936	3.27	0.14	1.4	6.1	1.0	15	10	7.5	1.6	0.10	5700	110	5
S04DA	D-297240	3255	07936	3.86	0.14	0.62	9.9	0.52	23	6.6	2.5	2.4	0.05	3000	120	< 4
S04FA	D-297242	3255	07936	2.27	0.11	1.2	9.2	1.2	14	8.8	8.4	1.1	0.1	3200	200	6
S04FB	D-297257	3255	07936	2.58	0.12	0.83	9.8	0.69	18	9.3	6.9	1.3	0.07	5700	180	6
S04IA	D-297243	3255	07936	3.40	0.10	0.77	5.6	0.63	19	7.1	7.9	1.7	0.06	3200	86	< 4
S04IB	D-297269	3255	07936	4.56	0.21	1.1	5.7	0.79	13	6.7	13	0.90	0.08	2500	93	< 4
S04IBX	D-297258	3255	07936	4.64	0.21	1.1	5.7	0.82	13	6.7	13	0.90	0.09	2500	94	< 4
S04JA	D-297264	3255	07936	4.70	0.14	1.3	4.7	0.85	12	7.5	15	1.3	0.09	3100	81	< 4
S05CA	D-297262	3255	07936	2.51	0.13	1.3	6.9	1.0	19	8.5	5.2	1.4	0.10	2700	130	6
S05DA	D-297251	3255	07936	2.67	0.14	1.3	9.3	0.99	16	7.1	5.6	2.0	0.10	6800	180	5
S05FA	D-297261	3255	07936	2.78	0.14	1.4	8.2	1.1	17	8.0	5.6	1.7	0.11	8300	190	7
S05GA	D-297252	3255	07936	1.66	0.10	1.8	6.7	1.8	12	8.8	8.3	1.1	0.15	6900	200	11
S05GB	D-297255	3255	07936	2.73	0.12	0.97	7.7	0.74	19	8.4	4.9	1.5	0.07	14000	170	7
S05HA	D-297265	3255	07936	2.94	0.11	0.70	7.6	0.54	19	7.8	7.3	1.6	0.05	7600	100	< 4
S05IA	D-297268	3255	07936	3.36	0.17	1.2	9.5	0.81	19	8.2	1.3	2.3	0.09	9200	220	6
S05IB	D-297271	3255	07936	3.11	0.15	1.0	16	0.73	15	6.7	3.3	2.2	0.08	4900	130	< 4
S06DA	D-297274	3255	07936	2.74	0.13	0.75	5.2	0.72	13	8.1	13	1.2	0.06	1900	100	4
S06DAX	D-297275	3255	07936	2.72	0.12	0.78	5.4	0.73	13	8.3	14	1.2	0.06	2000	100	4
S07BA	D-297249	3255	07936	4.25	0.16	1.2	4.3	1.0	12	6.3	16	2.3	0.1	1900	91	< 4
S07BB	D-297267	3255	07936	3.25	0.12	0.97	5.7	0.93	20	6.2	8.6	1.8	0.08	3000	92	4
S07BBX	D-297247	3255	07936	3.39	0.12	0.97	5.5	0.92	19	6.0	8.3	1.7	0.08	2900	90	< 4
S07CA	D-297266	3255	07936	3.29	0.12	0.83	9.7	0.66	17	7.9	8.0	1.7	0.06	3200	140	4
S07DA	D-297263	3255	07936	2.62	0.09	0.97	9.7	0.80	17	8.1	7.1	1.4	0.07	6200	140	< 4
S07DB	D-297276	3255	07936	2.73	0.14	1.8	8.4	1.3	17	8.6	4.9	1.7	0.14	6300	150	4

Table D12 (continued). Elemental concentrations in *T. usneoides*--November 1987 collection.

Field #	µg/g, Ash weight														
	Ce	Co	Cr	Cu	Ga	La	Li	Mo	Nd	Ni	Pb	Sr	V	Y	Zn
S00IA	9	8	47	170	< 8	10	8	< 4	< 8	32	120	440	27	< 4	440
S00JA	29	10	99	100	9	16	14	< 4	13	35	160	340	49	7	530
S01JA	14	7	46	180	< 8	10	11	< 4	< 8	26	97	470	25	< 4	380
S01JB	12	7	58	180	< 8	11	8	< 4	< 8	32	110	440	31	< 4	480
S02GA	24	11	99	390	< 8	18	10	8	14	58	490	910	130	7	660
S02JA	17	9	85	91	< 8	13	12	< 4	9	29	160	310	38	6	590
S03DA	12	9	84	120	< 8	11	7	< 4	< 8	43	180	330	42	4	690
S03EA	< 8	7	67	250	9	9	6	< 4	< 8	36	160	610	28	< 4	600
S03EB	< 8	7	55	200	< 8	10	6	< 4	< 8	29	140	530	33	< 4	450
S03FA	17	9	88	280	9	14	8	4	10	70	260	630	63	5	730
S03GA	12	7	87	650	< 8	14	8	5	11	63	210	590	78	< 4	660
S03GAX	14	7	92	660	< 8	13	8	5	8	68	230	610	83	4	680
S03JA	16	6	73	200	< 8	12	12	< 4	< 8	23	97	530	30	4	390
S03JB	17	8	58	99	8	12	10	< 4	< 8	33	130	520	38	5	630
S03JBX	14	8	59	97	< 8	12	10	< 4	9	32	130	510	38	5	620
S04DA	< 8	6	47	240	< 8	8	5	< 4	< 8	30	120	560	23	< 4	490
S04FA	18	13	80	330	< 8	14	9	4	11	76	290	640	52	6	730
S04FB	11	11	57	290	< 8	10	6	< 4	< 8	55	230	640	42	< 4	600
S04IA	11	7	48	73	< 8	8	6	< 4	< 8	26	100	370	21	< 4	400
S04IB	14	8	51	73	< 8	11	10	< 4	10	27	100	380	31	4	560
S04IBX	12	8	66	72	< 8	11	10	< 4	< 8	27	110	380	32	4	560
S04JA	14	6	42	77	< 8	10	14	< 4	< 8	19	86	420	27	< 4	370
S05CA	13	10	88	120	< 8	12	8	< 4	10	46	160	390	43	5	800
S05DA	15	8	95	110	10	13	8	< 4	9	42	210	440	51	5	630
S05FA	18	8	85	210	9	13	9	4	8	36	190	560	47	5	890
S05GA	34	12	110	140	11	21	9	< 4	12	76	520	530	96	11	840
S05GB	10	6	63	96	12	10	6	< 4	< 8	38	150	360	35	< 4	1000
S05HA	< 8	6	48	90	< 8	8	5	< 4	< 8	30	110	480	20	< 4	500
S05IA	15	7	72	110	11	12	8	< 4	11	35	140	540	48	4	760
S05IB	10	7	66	77	< 8	12	9	< 4	< 8	30	110	750	30	< 4	380
S06DA	9	9	49	82	< 8	9	8	< 4	< 8	36	170	380	33	< 4	450
S06DAX	10	10	53	88	< 8	9	8	< 4	< 8	36	180	390	34	< 4	460
S07BA	19	6	66	110	< 8	13	11	< 4	10	33	120	280	34	6	350
S07BB	11	9	91	150	< 8	10	8	< 4	< 8	44	200	330	38	< 4	480
S07BBX	11	9	110	140	< 8	10	8	< 4	< 8	42	190	310	38	< 4	470
S07CA	10	8	49	300	< 8	9	8	< 4	< 8	35	160	600	28	< 4	430
S07DA	13	8	59	230	< 8	11	10	< 4	< 8	31	150	690	29	< 4	520
S07DB	18	8	120	110	9	16	13	< 4	10	40	190	580	56	6	580

Table D13. Elemental concentrations in soils--November 1987 collection.

		Latitude	Longitude	Percent												µg/g	
Field #	Lab #	DegMinSec	DegMinSec	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	Ba
S001	D-297390	330723	0792919	1.80	1.80	< 0.01	< 0.05	1.4	0.43	0.63	0.55	0.11	0.21	0.007	0.28	200	240
S002	D-297377	331250	0793712	3.95	3.95	< 0.01	< 0.05	1.5	0.06	0.76	0.55	0.04	0.06	0.01	0.58	210	240
S003	D-297391	331359	0794536	1.74	1.74	< 0.01	< 0.05	0.81	0.12	0.17	0.30	0.02	0.03	0.006	0.14	86	140
S004	D-297389	330432	0794554	1.92	1.92	< 0.01	< 0.05	0.38	0.04	0.14	0.17	0.01	0.03	0.007	0.15	40	91
S005	D-297381	330237	0793854	6.82	6.81	0.01	< 0.05	0.52	0.24	0.33	0.11	0.03	0.03	0.01	0.23	74	66
SS00JA	D-297383	3255	07936	0.44	0.44	< 0.01	< 0.05	1.6	0.58	1.0	0.74	0.17	0.37	0.02	0.40	270	270
SS00JAX	D-297396	3255	07936	0.79	0.79	< 0.01	< 0.05	1.4	0.53	0.94	0.55	0.16	0.34	0.02	0.39	250	260
SS01JA	D-297384	3255	07936	3.49	3.49	< 0.01	< 0.05	1.6	0.36	0.45	0.84	0.09	0.42	0.01	0.10	66	310
SS02GA	D-297379	3255	07936	1.88	1.88	< 0.01	< 0.05	1.0	0.33	0.33	0.46	0.07	0.24	0.007	0.17	100	180
SS03FA	D-297397	3255	07936	1.20	1.20	< 0.01	< 0.05	1.2	0.54	0.61	0.44	0.12	0.29	0.01	0.30	210	210
SS03JA	D-297378	3255	07936	1.08	1.08	< 0.01	< 0.05	1.3	0.34	0.24	0.73	0.07	0.35	< 0.005	0.11	73	260
SS04DA	D-297395	3255	07936	1.33	1.33	< 0.01	< 0.05	1.0	0.61	0.78	0.29	0.15	0.20	0.01	0.41	270	140
SS04DAX	D-297387	3255	07936	1.27	1.27	< 0.01	< 0.05	1.0	0.58	0.75	0.36	0.15	0.21	0.01	0.38	260	150
SS04EA	D-297386	3255	07936	16.8	16.8	< 0.01	0.07	0.93	0.38	0.32	0.35	0.08	0.21	0.03	0.17	91	150
SS04GA	D-297399	3255	07936	2.49	2.49	< 0.01	< 0.05	1.6	0.38	0.36	0.66	0.12	0.38	0.01	0.12	72	300
SS04IA	D-297401	3255	07936	1.73	1.73	< 0.01	< 0.05	1.6	0.37	0.41	0.69	0.09	0.41	0.008	0.11	70	310
SS05CA	D-297385	3255	07936	0.80	0.80	< 0.01	< 0.05	1.1	0.51	0.62	0.43	0.12	0.25	0.01	0.28	200	170
SS05CAX	D-297400	3255	07936	0.78	0.78	< 0.01	< 0.05	1.0	0.51	0.59	0.36	0.12	0.24	0.009	0.27	190	170
SS05FA	D-297388	3255	07936	1.32	1.32	< 0.01	< 0.05	1.1	0.42	0.45	0.45	0.10	0.25	0.008	0.23	150	200
SS05GA	D-297392	3355	07936	1.63	1.63	< 0.01	< 0.05	1.1	0.43	0.46	0.45	0.09	0.28	0.009	0.23	180	210
SS05JA	D-297380	3255	07936	1.01	1.01	< 0.01	< 0.05	1.4	0.63	0.94	0.62	0.15	0.33	0.01	0.54	360	240
SS06GA	D-297394	3355	07936	4.62	4.62	< 0.01	< 0.05	1.7	0.48	0.49	0.65	0.11	0.42	0.02	0.20	110	290
SS07BA	D-297393	3355	07936	0.81	0.81	< 0.01	< 0.05	1.2	0.72	0.97	0.35	0.15	0.23	0.007	0.62	390	160
SS07CA	D-297398	3255	07936	1.02	1.02	< 0.01	< 0.05	0.99	0.49	0.55	0.33	0.11	0.22	< 0.005	0.29	190	160
SS07CAX	D-297382	3255	07936	0.97	0.97	< 0.01	< 0.05	1.1	0.51	0.59	0.47	0.12	0.24	0.006	0.31	210	190

Table D13 (continued). Elemental concentrations in soils--November 1987 collection.

	µg/g															
Field #	Ce	Co	Cr	Cu	La	Li	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Zn
S001	20	2	15	2	10	3	6	9	3	11	3	73	< 4	21	4	6
S002	23	1	25	5	11	6	10	9	3	23	2	33	5	33	4	9
S003	12	< 1	7	2	7	3	< 4	7	< 2	8	< 2	23	4	9	< 2	4
S004	8	< 1	6	2	4	2	< 4	< 4	< 2	8	< 2	15	< 4	7	< 2	3
S005	15	< 1	14	2	7	3	5	6	2	21	< 2	16	< 4	14	< 2	7
SS00JA	37	2	19	< 1	17	3	6	16	3	11	4	100	7	24	6	9
SS00JAX	39	2	18	< 1	19	2	5	17	3	10	4	93	7	22	6	8
SS01JA	10	1	10	2	5	2	< 4	6	3	16	< 2	95	< 4	13	< 2	9
SS02GA	15	< 1	9	3	8	< 2	< 4	7	2	6	2	62	< 4	12	3	4
SS03FA	37	1	16	2	18	< 2	< 4	16	2	10	4	88	8	19	5	6
SS03JA	5	< 1	7	2	3	< 2	< 4	< 4	2	8	< 2	82	< 4	9	< 2	3
SS04DA	28	2	19	< 1	14	< 2	5	13	3	9	5	74	5	24	5	7
SS04DAX	38	2	18	1	19	< 2	< 4	17	3	9	4	76	8	23	6	8
SS04EA	9	< 1	10	2	4	< 2	4	5	2	11	< 2	69	< 4	11	2	5
SS04GA	7	1	11	< 1	4	2	< 4	4	3	11	< 2	92	< 4	12	2	3
SS04IA	8	1	10	3	4	2	< 4	< 4	< 2	11	< 2	95	< 4	12	< 2	6
SS05CA	20	1	15	< 1	9	< 2	< 4	9	2	7	4	76	< 4	18	4	5
SS05CAX	21	1	16	< 1	10	< 2	< 4	7	< 2	7	4	75	< 4	17	4	4
SS05FA	17	1	12	2	9	< 2	< 4	10	< 2	7	3	72	< 4	15	3	8
SS05GA	23	1	22	< 1	12	< 2	< 4	12	2	8	3	76	5	14	4	6
SS05JA	72	2	20	1	36	< 2	7	32	3	10	5	98	14	27	8	9
SS06GA	14	1	15	2	7	3	5	7	3	11	3	100	< 4	16	4	5
SS07BA	51	2	23	2	25	< 2	6	23	3	9	6	90	10	30	8	9
SS07CA	16	1	15	< 1	8	< 2	< 4	8	< 2	7	3	71	5	18	4	6
SS07CAX	21	1	20	1	10	< 2	4	10	2	8	4	77	4	19	4	5

Table D14. Elemental concentrations in *P. taeda*--June 1988 collection.

		Latitude	Longitude	Percent, Dry weight		Percent, Ash weight							
Field #	Lab #	DegMinSec	DegMinSec	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti
P00IA2	D-319339	325548	0793454	4.37	0.12	0.54	8.6	0.18	8.4	2.8	2.3	3.9	< 0.01
P01HA	D-319346	3255	07936	3.41	0.12	0.22	10	0.18	11	4.0	4.6	5.2	< 0.01
P02EA	D-319349	3255	07936	4.71	0.13	0.70	6.7	0.13	9.2	2.6	2.4	2.9	< 0.01
P02EC	D-319352	3255	07936	5.31	0.13	0.67	7.4	0.12	8.3	2.6	2.3	2.8	< 0.01
P02ECX	D-319343	3255	07936	5.05	0.13	0.68	7.4	0.13	8.3	2.6	2.3	2.8	< 0.01
P02FA	D-319356	3255	07936	5.12	0.12	0.73	8.2	0.13	9.1	2.6	1.2	2.1	< 0.01
P02GA2	D-319351	325522	0793537	4.29	0.12	0.62	6.4	0.12	11	2.5	1.1	2.9	< 0.01
P02GB2	D-319350	325522	0793537	4.52	0.16	0.34	7.3	0.14	11	3.6	1.9	3.1	< 0.01
P03EA2	D-319344	325501	0793611	3.06	0.14	0.83	10	0.21	15	4.4	0.52	4.8	< 0.01
P03EB2	D-319335	325501	0793611	3.18	0.14	1.0	11	0.16	11	4.8	0.53	4.3	< 0.01
P03FA2	D-319337	325511	0793553	3.36	0.11	0.41	8.0	0.17	12	4.2	1.8	4.4	< 0.01
P04CA	D-319338	3255	07936	3.51	0.12	0.55	7.6	0.34	12	2.2	9.4	3.9	< 0.01
P04CAX	D-319340	3255	07936	3.51	0.12	0.52	7.4	0.33	11	2.1	9.2	3.8	0.01
P04DA2	D-319355	325501	0793338	4.07	0.15	0.60	7.9	0.13	9.0	3.6	0.89	3.2	< 0.01
P06BA	D-319341	3255	07936	3.40	0.12	0.71	7.2	0.19	12	3.0	1.3	3.5	< 0.01
P06BAX	D-319348	3255	07936	3.50	0.13	0.71	7.2	0.19	12	3.0	1.3	3.4	< 0.01
P06BB	D-319342	3255	07936	3.17	0.09	0.46	8.6	0.14	7.1	3.5	2.3	3.3	< 0.01
P06CA	D-319345	3255	07936	3.76	0.14	0.44	11	0.15	12	4.3	2.9	3.4	< 0.01
P07BA2	D-319336	325359	0793723	3.77	0.16	0.99	8.4	0.29	8.8	4.0	7.5	4.2	< 0.01
P07BB2	D-319353	325359	0793723	3.13	0.12	0.31	8.3	0.25	12	3.2	1.5	4.7	< 0.01

	µg/g, Ash weight													
Field #	Mn	Ba	Cd	Co	Cr	Cu	La	Li	Nd	Ni	Pb	Sr	V	Zn
P00IA2	3500	12	< 4	4	12	61	5	21	< 8	5	21	150	< 4	700
P01HA	2500	12	< 4	3	12	71	4	19	< 8	4	22	190	< 4	920
P02EA	2700	13	< 4	2	12	56	< 4	10	< 8	4	10	190	< 4	610
P02EC	3100	12	< 4	2	10	50	< 4	10	< 8	< 4	9	210	< 4	690
P02ECX	3100	13	< 4	2	9	47	< 4	10	< 8	4	9	210	< 4	700
P02FA	1500	12	< 4	2	8	40	< 4	6	< 8	< 4	60	290	< 4	550
P02GA2	1300	10	< 4	< 2	9	63	< 4	< 4	< 8	4	10	180	< 4	430
P02GB2	1100	10	< 4	< 2	8	63	< 4	7	< 8	< 4	210	160	< 4	690
P03EA2	3600	15	< 4	5	10	83	5	11	< 8	7	8	180	< 4	790
P03EB2	4500	18	< 4	6	14	73	< 4	9	15	7	10	240	4	970
P03FA2	4400	14	< 4	5	13	77	4	8	< 8	5	13	140	4	700
P04CA	3100	25	< 4	< 2	29	76	6	11	< 8	7	32	150	12	880
P04CAX	3000	25	< 4	2	27	73	6	11	< 8	7	33	150	11	860
P04DA2	11000	14	5	4	11	60	< 4	6	< 8	5	11	110	< 4	1100
P06BA	5400	12	< 4	2	11	70	< 4	8	< 8	< 4	15	180	< 4	960
P06BAX	5500	12	< 4	< 2	11	68	< 4	7	< 8	< 4	12	180	< 4	950
P06BB	2700	10	< 4	< 2	10	52	< 4	8	< 8	4	10	250	< 4	840
P06CA	6300	13	< 4	3	8	70	5	4	< 8	< 4	< 8	240	< 4	770
P07BA2	2700	16	< 4	3	18	78	6	22	< 8	6	24	200	8	990
P07BB2	9600	8	< 4	4	15	95	5	12	< 8	5	11	94	< 4	800

Table D15. Elemental concentrations in *T. usneoides*--June 1988 collection.

		Latitude	Longitude	Percent, Dry weight		Percent, Ash weight								μg/g, Ash weight		
Field #	Lab #	DegMinSec	DegMinSec	Ash	S	Al	Ca	Fe	K	Mg	Na	P	Ti	Mn	Ba	Cd
S00IA2	D-319211	325548	0793454	3.81	0.14	1.0	8.0	1.4	19	7.0	8.7	2.3	0.06	2100	110	< 4
S01HA	D-319212	3255	07936	2.90	0.13	0.82	6.3	0.96	14	8.3	14	1.4	0.05	2900	120	6
S02EA	D-319205	3255	07936	2.44	0.10	1.1	7.2	0.99	15	6.3	12	1.8	0.07	2500	150	4
S02EAX	D-319200	3255	07936	2.44	0.10	1.1	7.3	1.0	16	6.5	13	1.8	0.07	2500	150	4
S02FA	D-319207	3255	07936	2.16	0.10	1.0	8.9	1.0	20	7.7	5.4	2.0	0.06	4800	160	6
S02GA2	D-319208	325522	0793537	2.50	0.09	0.67	7.9	0.72	26	7.9	5.5	2.9	0.03	2000	94	6
S02GA2X	D-319201	325522	0793537	2.45	0.09	0.69	7.9	0.71	26	7.9	5.4	2.8	0.03	2000	100	5
S03EA2	D-319209	325501	0793611	2.34	0.10	0.72	9.7	0.74	16	9.9	8.7	2.1	0.04	7100	140	7
S03EB2	D-319210	325501	0793611	3.32	0.12	0.49	11	0.44	26	7.0	4.2	1.7	0.03	6300	160	4
S03EB2X	D-319199	325501	0793611	3.34	0.12	0.51	11	0.44	26	7.1	4.2	1.7	0.02	6300	160	5
S03FA2	D-319206	325511	0793553	2.71	0.11	1.3	8.7	1.3	23	7.4	3.6	1.6	0.08	7900	180	6
S04CA	D-319196	3255	07936	3.16	0.13	1.3	9.2	1.1	17	6.3	9.0	1.9	0.08	2500	130	5
S04DA2	D-319203	325501	0793338	2.93	0.12	0.82	10	0.67	25	8.2	3.6	1.8	0.05	7300	170	5
S06BA	D-319213	3255	07936	3.02	0.12	0.82	15	0.86	14	6.5	8.4	1.3	0.05	2700	120	< 4
S06BB	D-319195	3255	07936	3.49	0.14	0.80	17	0.64	15	6.6	4.4	1.5	0.04	4500	140	5
S06CA	D-319198	3255	07936	3.67	0.12	0.66	4.5	0.54	19	8.1	13	1.2	0.04	2100	70	< 4
S07BA2	D-319202	325359	0793723	3.62	0.14	0.68	8.0	0.68	17	8.4	12	1.4	0.04	3700	94	5
S07BB2	D-319197	325359	0793723	3.41	0.14	1.0	5.9	1.0	18	7.8	12	1.5	0.06	2500	96	5

	μg/g, Ash weight														
Field #	Ce	Co	Cr	Cu	La	Li	Mo	Nd	Ni	Pb	Sn	Sr	V	Y	Zn
S00IA2	15	10	39	100	12	10	< 4	< 8	39	92	< 20	370	28	6	530
S01HA	12	11	36	140	9	8	< 4	< 8	49	160	< 20	370	34	4	720
S02EA	15	9	55	120	11	8	< 4	< 8	44	200	< 20	350	53	5	770
S02EAX	14	11	57	120	11	8	< 4	8	47	210	< 20	350	53	5	770
S02FA	9	9	69	160	12	7	< 4	10	53	240	< 20	480	66	4	940
S02GA2	11	8	32	150	7	6	< 4	< 8	47	230	20	480	32	< 4	530
S02GA2X	< 8	8	34	150	7	6	< 4	14	47	230	30	480	32	< 4	500
S03EA2	10	10	51	110	8	6	< 4	10	47	200	< 20	450	41	< 4	670
S03EB2	< 8	6	33	86	7	5	< 4	< 8	29	110	< 20	380	19	< 4	430
S03EB2X	< 8	7	37	85	7	5	< 4	< 8	29	110	< 20	380	20	< 4	450
S03FA2	15	11	59	140	12	7	< 4	9	50	220	< 20	390	50	6	760
S04CA	17	10	88	150	12	10	< 4	10	46	180	< 20	410	50	6	680
S04DA2	12	8	63	120	8	5	< 4	< 8	44	180	< 20	410	40	< 4	700
S06BA	13	8	49	94	9	7	< 4	< 8	35	170	< 20	810	48	< 4	440
S06BB	17	6	53	100	7	7	< 4	15	34	170	< 20	710	36	< 4	630
S06CA	< 8	10	34	52	7	6	< 4	< 8	22	82	< 20	470	22	< 4	350
S07BA2	< 8	9	48	130	8	9	< 4	< 8	51	140	< 20	440	34	< 4	590
S07BB2	17	9	79	150	10	10	< 4	< 8	53	190	< 20	370	52	6	560

Table D16. Elemental concentrations in soils--June 1988 collection.

		Latitude	Longitude		Percent											
Field #	Lab #	DegMinSec	DegMinSec	pH	C total	C org	C crbnt	S	Al	Ca	Fe	K	Mg	Na	P	Ti
SS02EA	D-319221	3255	07936	4.8	4.36	4.36	< 0.01	< 0.05	1.0	0.37	0.39	0.48	0.08	0.29	0.01	0.25
SS02GA2	D-319223	325522	07936	4.6	3.46	3.46	< 0.01	< 0.05	0.96	0.33	0.38	0.42	0.08	0.23	0.009	0.20
SS02GA2X	D-319217	325322	0793723	4.7	3.24	3.24	< 0.01	< 0.05	0.99	0.34	0.38	0.43	0.08	0.24	0.009	0.20
SS03FA2	D-319222	325511	07936	4.4	1.26	1.26	< 0.01	< 0.05	1.1	0.49	0.53	0.52	0.10	0.27	0.008	0.29
SS03FA2X	D-319215	325511	0793611	4.4	1.29	1.29	< 0.01	< 0.05	1.0	0.43	0.44	0.47	0.09	0.25	0.007	0.21
SS04DA2	D-319220	325501	07936	4.6	1.09	1.09	< 0.01	< 0.05	0.97	0.47	0.53	0.41	0.10	0.22	0.008	0.29
SS06CA	D-319216	3255	0793723	4.4	2.15	2.15	< 0.01	< 0.05	1.2	0.53	0.66	0.54	0.12	0.28	0.01	0.33
SS07BA2	D-319218	325359	0793537	6.4	1.55	1,54	0.01	< 0.05	0.93	0.44	0.42	0.46	0.09	0.23	0.02	0.18

	μg/g																		
Field #	Mn	Ba	Ce	Co	Cr	Cu	Ga	La	Li	Nb	Nd	Ni	Pb	Sc	Sr	Th	V	Y	Zn
SS02EA	140	180	25	1	11	< 1	< 4	12	< 2	5	10	< 2	8	3	73	< 4	14	3	< 2
SS02GA2	120	160	18	1	11	< 1	< 4	9	< 2	5	7	2	7	3	62	< 4	14	3	< 2
SS02GA2X	120	170	23	1	10	< 1	< 4	11	2	5	8	< 2	7	3	64	< 4	14	3	< 2
SS03FA2	190	200	34	1	14	< 1	4	17	< 2	5	15	< 2	10	4	84	5	18	5	3
SS03FA2X	150	180	19	2	12	< 1	< 4	9	< 2	5	8	< 2	9	3	75	< 4	15	3	< 2
SS04DA2	190	160	32	1	14	< 1	< 4	17	< 2	5	13	< 2	7	4	73	5	17	5	3
SS06CA	210	200	30	2	91	< 1	< 4	15	< 2	6	13	2	12	4	88	5	20	5	8
SS07BA2	120	170	15	1	10	3	< 4	7	< 2	< 4	6	2	7	3	75	< 4	13	3	2

Table D17. pH, chloride, and sulfate concentrations in surface water samples--June 1988 collection.

Field #	pH	Chloride, mg/ml	Sulfate, μg/ml
WX02A11	7.76	21	2600
WX02A21	7.77	22	2600
WX03B11	7.43	22	2700
WX04F11	7.45	0.20	2.5
WX06B11	7.73	22	2600
WX06B21	7.75	22	2600
WX06C11	7.78	22	2600
WX07C11	8.65	0.98	26
WX12L11	7.74	22	2600
WX12L12	7.76	22	2600
WX12Q11	7.79	22	2600
WX13L11	7.61	22	2600
WX13L12	7.62	21	2600
WX13Q11	7.82	21	2600

WX04F = Big Pond & WX07C = Lower Summerhouse Pond, Bull Island.

Table D18. Stable sulfur isotope ratios--November 1987 and June 1988 collections.

Spartina alterniflora

	δ^{34}S			δ^{34}S	
Field #	per mil	replicate	Field #	per mil	replicate
GN12L111	5.7		LX12L111	10.1	
GN12Q111	13.3	13.6	LX12Q111	10.3	9.9
GN13L111	2.7		LX13L111	-1.0	
GN13L121	2.4		LX13L121	0.9	
GN13L211	-0.9		LX13L211	-1.6	
GN13Q111	1.2		LX13Q111	-0.2	
GN13Q121	-0.4		LX13Q121	0.5	
GN13Q211	6.5		LX13Q211	4.7	
GN13Q212	7.0		LX13Q212	5.3	5.6
GS02A111	-1.9		LX02A111	-1.9	
GS02A112	-1.9		LX03B111	1.7	
GS03B111	2.5		LX03B121	2.0	
GS03B121	1.6		LX03B211	-1.1	
GS03B211	0.2		LX06B111	2.5	
GS06B111	-2.5		LX06B112	3.2	
GS06B211	-0.4		LX06B211	4.7	
GS06B221	-0.7		LX06B221	2.0	
GS06C111	-2.6		LX06C111	-3.4	-3.6

Sediments

	δ^{34}S			δ^{34}S	
Field #	per mil	replicate	Field #	per mil	replicate
SN12L111	-1.3		SX12L111	2.3	2.7
SN12Q111	2.4	2.9	SX12Q111	3.5	3.3
SN13L111	-11.2		SX13L111	-10.9	
SN13L121	-11.8		SX13L121	-11.0	
SN13L211	-12.9	-12.9	SX13L211	-10.8	
SN13Q111	-6.1		SX13Q111	-4.9	
SN13Q121	-5.8		SX13Q121	-6.3	
SN13Q211	-3.3		SX13Q211	-2.6	
SN13Q212	-2.8		SX13Q212	-2.3	-2.6
SS02A111	-6.1		SX02A111	-11.8	
SS03B111	-11.7		SX03B111	-12.5	
SS03B121	-11.6		SX03B121	-11.5	
SS03B122	-11.3		SX03B211	-12.4	
SS03B211	-13.4	-13.4	SX06B111	-3.1	
SS06B111	-9.7	-9.8	SX06B112	-3.4	
SS06B211	-5.9		SX06B211	-7.3	
SS06B221	-5.3		SX06B221	-11.0	
SS06C111	-10.6		SX06C111	-10.4	

Tillandsia usneoides

	δ^{34}S			δ^{34}S	
Field #	per mil	replicate	Field #	per mil	replicate
S00IA	3.6		S00IA2	1.9	
S02GA	5.6		S02GA2	1.6	1.9
S03EA	3.7		S03EA2	1.5	
S03EB	3.1		S03EB2	1.9	
S03FA	3.3		S03FA2	2.7	
S04DA	2.5		S04DA2	2.3	
S07BA	2.7	2.2	S07BA2	4.6	
S07BB	3.7		S07BB2	5.6	

Pinus taeda

	δ^{34}S			δ^{34}S	
Field #	per mil	replicate	Field #	per mil	replicate
P00IA	-1.1	-1.4	P00IA2	0.9	
P02GA	2.9		P02GA2	3.3	
P03EA	2.6		P03EA2	0.7	
P03EB	3.0		P03EB2	3.0	
P03FA	1.0		P03FA2	2.8	
P04DA	-0.1	0.3	P04DA2	2.1	
P07BA	2.5		P07BA2	2.8	
P07BB	0.0		P07BB2	2.6	
P001	2.1				
P002	1.8				
P003	2.1				
P004	1.7				
P005	0.9				

Tidal creek surface water samples

	δ^{34}S	
Field #	per mil	replicate
WX02A1	18.6	19.0
WX03B1	18.8	
WX06B1	19.1	
WX06C1	18.9	
WX12L1	19.0	18.7
WX12Q1	18.7	
WX13L1	18.9	
WX13Q1	19.0	

Table D19. Distribution of particle size fractions and mineralogical composition of sediment core C12L11C collected November 1987.

	Weight percent of sediment particle size fractions				Mineralogy[2]		
Depth[1], cm	Sand	Silt	Clay	Summation	Bulk Sediment[3]	Silt-sized fraction[4]	Clay-sized fraction
0-1	16	69	12	97	Qtz, Plag, Kao	--	Kao
1-2	11	69	17	97	Qtz, Plag, Kao	--	Kao
2-3	9	71	17	97	Qtz, Plag, Kao	--	Kao, Ill
3-4	7	75	17	99	Qtz, Plag, Kao	Qtz, Plag, tr Kao	Kao
4-5	6	72	21	99	Qtz, Plag, Kao	--	Kao
5-6	8	72	18	98	Qtz, Plag, Kao	--	Kao, Ill
6-7	11	73	15	99	Qtz, Plag, Kao	--	Kao, Ill, Mont
7-8	9	74	15	98	Qtz, Kao, tr Plag	Qtz, Plag, Kao	Kao, tr Mont
8-9	7	74	17	98	Qtz, Plag, Kao	--	Kao, Ill, Mont
9-10	12	81	6	99	Qtz, Plag, Kao	--	Kao
10-12	11	83	5	99	Qtz, Ill, Plag, Kao	--	Kao, Ill
12-14	6	72	16	94	Qtz, Ill, Plag, Kao	Qtz, Plag, Ill, Kao	Kao
14-16	8	78	13	99	Qtz, Pyr, Kao, Plag	--	Kao, Ill
16-18	5	78	15	98	Qtz, Kao	--	Kao, Ill
18-20	4	90	4	98	Qtz, Pyr, Kao, Plag	--	Kao, Ill
20-22	4	86	7	97	Qtz, Pyr, Kao, Ill, Plag	Qtz, Plag, Ill	Kao, Ill
22-24	3	93	1	97	Qtz, Pyr, Kao, Plag	--	Kao, Ill
24-26	2	96	1	97	Qtz, Pyr, Kao, Plag	--	Kao, Ill
26-28	1	96	< 1	97	Qtz, Pyr, Kao, Plag	--	Kao, Ill
28-30	1	92	5	98	Qtz, Pyr, Kao, Ill, Plag	Qtz, Ill, Kao, Plag	Kao, Ill
30-32	1	93	3	97	Qtz, Pyr, Kao, Plag	--	Kao, Ill
32-34	< 1	96	2	98	Pyr, Qtz, Kao, Plag	--	Kao, Ill
34-36	< 1	--	--	--	Pyr, Qtz, Kao, Plag	--	Kao, Ill
36-38	< 1	95	1	96	Pyr, Qtz, Kao, Plag	Qtz, Plag, Kao	Kao, Ill

[1] Depths in table must be corrected for 19% compaction during coring: true depth = compacted depth x (1/(1-0.19)).

[2] Mineralogy of the crystalline material is listed in descending order of estimated abundance based on the reference intensity ratio method (Snyder and Bish, 1989); Ill = illite, Kao = kaolinite, Mont = montmorillonite, Plag = plagioclase, Pyr = pyrite, Qtz = quartz, tr = trace.

[3] Halite, an artifact of drying the sediments, was observed in all bulk mineralogical analyses.

[4] Clay-sized particles may contaminate silt-sized fraction and result in kaolinite in this fraction.

Table D20. Summary of analysis results on a dry-weight basis for botanical quality control standards.

	SRM 1571, Orchard Leaves, n=6			SRM 1572, Citrus Leaves, n=8				SRM 1575, Pine Needles, n=7			
	This work			This work				This work			
Element	Average	Std. Dev.	NIST value[1]	Average[2]	Std. Dev.[3]	NIST value	Consensus value[4]	Average	Std. Dev.	NIST value	Consensus value
Ash%				13.1	0.2			2.64	0.03		
S%	0.20	0.01	(0.19)	0.39	0.01	0.407	0.408	0.13	0.01		0.13
Al µg/g				82	10	92	76	570	20	545	510
Ca%				3.1	0.2	3.15	3.13	0.40	0.02	0.41	0.42
Fe µg/g				89	12	90	101	180	10	200	185
K%				1.8	0.1	1.82	1.83	0.32	0.04	0.37	0.37
Mg%				0.57	0.01	0.58	0.56	0.11	0.002		0.12
Na µg/g				200	10	160	163	43	4		50
P%				0.15	0.005	0.13	0.131	0.13	0.004	0.12	0.12
Ti µg/g				< 10			22	11	3		14
As µg/g				2.9	0.5	3.1	3.0	< 0.5		0.21	0.21
Ba µg/g				19	0.7	21	24	6.5	0.6		7.2
Cd µg/g				< 0.5		0.03	0.046	0.16	0.01	(<0.5)	0.22
Ce µg/g				< 0.5		(0.28)	0.45	< 1		(0.4)	0.21
Co µg/g				0.36*	0.07	(0.02)	0.016	0.17	0.01	(0.1)	0.12
Cr µg/g				1.1	0.1	0.8	1	2.8	0.1	2.6	2.6
Cu µg/g				16	0.6	16.5	16	2.8	0.2	3.0	3.0
La µg/g				0.92	0.12	(0.19)	0.20	0.27	0.03	(0.2)	0.16
Li µg/g				< 0.5			0.23	0.20	0.01		0.34
Mn µg/g				21	0.4	23	23	620	14	675	650
Mo µg/g				< 0.5		0.17	0.15	0.11*	0.01		0.15
Ni µg/g				0.53*	0.004	0.6	0.72	2.1	0.2	(3.5)	2.5
Pb µg/g				13	0.9	13.3	13.4	10	1	10.8	10.7
Sr µg/g				97	2	100	98	4.5	0.1	4.8	5.0
V µg/g				< 0.5			0.24	0.29	0.01		0.39
Zn µg/g				29	1	29	30	69	6		67

[1] NIST values from Certificate of Analysis for each reference material; values in parentheses are non-certified values.

[2] Average of all non-qualified values; averages indicated with * had one or two qualified values (i.e., below the determination limit) that were omitted from the calculations.

[3] Sample standard deviation.

[4] Arithmetic average of all published values as of 3/86, frequently n equals only 1 or 2 (Gladney and others, 1987).

Table D21. Summary of analysis results for sediment quality control standards.

	SRM 1645, River Sediment, n=6				SRM 1646, Estuarine Sediment, n=7			
	This work				This work			
Element	Average[1]	Std. Dev.[2]	NIST value[3]	Consensus value[4]	Average	Std. Dev.	NIST value	Consensus value
C total%	5.42	0.51			1.72	0.04		
C org%	4.28	0.48			1.62	0.04		
C crbnt%	1.14	0.03			0.10	0.01		
S%	1.26	0.11	(1.1)	4.35	0.91	0.02	(0.96)	
Al%	2.4	0.1	2.26	2.2	5.9	0.1	6.25	5.54
Ca%	3.1	0.1	(2.9)	2.65	0.88	0.02	0.83	0.84
Fe%	10	0.6	11.3	10.2	3.3	0.1	3.35	3.22
K%	1.2	0.08	1.26	1.02	1.8	0.2	(1.4)	1.83
Mg%	0.77	0.03	0.74	0.72	1.1	0	1.09	0.97
Na%	0.59	0.03	0.54	0.51	2.0	0.04	(2.0)	2.04
P%	0.05	0.004	0.051	0.047	0.06	0	0.054	0.048
Ti%	0.06	0.004		0.05	0.40	0.02	(0.51)	0.42
As µg/g	40	10	(66)	67	< 10		11.6	11.1
Ba µg/g	270	70		374	220	160		409
Be µg/g	1	0		1	2	0	(1.5)	1.5
Bi µg/g	20	4		0.6	< 10			
Cd µg/g	8	1	10.2	10	< 2		0.36	0.325
Ce µg/g	8	1		24	65	2	(80)	80
Co µg/g	12	1	10.1	9.4	11	0.5	10.5	9.1
Cr µg/g	30000	2300	29600	29300	86	12	76	76
Cu µg/g	110	9	109	108	17	1	18	17
Eu µg/g	7	1		0.5	< 2		(1.5)	1.4
Ga µg/g	26	1		41	15	1		19
La µg/g	10	1	(9)	24	32	1		37
Li µg/g	7	0			47	1	(49)	46
Mn µg/g	740	39	785	752	360	8	375	330
Mo µg/g	18	5		34	< 2		(2.0)	14
Nb µg/g	< 4			16	8	2		53
Nd µg/g	8	1			31	2		36
Ni µg/g	44	6	45.8	46	29	1	32	31.7
Pb µg/g	710	49	714	710	25	2	28.2	27.8
Sc µg/g	< 2		(2)	2.6	10	0	(10.8)	10.8
Sn µg/g	400	50		360	< 10			
Sr µg/g	850	64		880	150	5		220
Th µg/g	< 4		1.62	18	8	1	(10)	10
V µg/g	25	2	23.5	26	89	1	94	86
Y µg/g	24	1		7.2	19	0.5		18
Yb µg/g	< 1				2	0		2.6
Zn µg/g	1700	120	1720	1700	120	8	138	124

[1] Average of all non-qualified values.

[2] Sample standard deviation.

[3] NIST values from Certificate of Analysis for each reference material; values in parentheses are non-certified values.

[4] Arithmetic average of all published values as of 3/86, frequently n equals only 1 or 2 (Gladney and others, 1987).