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MORPHOLOGICAL, PHYSICAL, AND CHEMICAL CHARACTERISTICS OF DITCHED AND UNDITCHED TIDAL SALT MARSH SOILS

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

A ditched and unditched tidal salt marsh, located on opposite sides of the Palmer River, were characterized to obtain baseline data on New England tidal salt marsh soils, test provisional criteria for their classification, and determine if mosquito ditching had altered soil characteristics.

The marshes were mapped according to vegetative cover and peat depth. Twelve soil profiles were sampled and analysed for state of organic matter decomposition, total nitrogen, organic carbon, pH, heavy metals and particle size.

The 12 soil profiles described met the classification for Sulfihemists and most soil properties were within the range of those reported for Sulfihemists in other areas of the United States. the mean pH, total nitrogen and organic carbon contents of the soils in this study were 6.33, 1.4% and 31.8%, respectively. The concentrations of heavy metals within the soil profiles were also comparable to those found in other tidal salt marsh soils. The data obtained in this study, however, suggest that the organic material is less decomposed than that found in salt marshes south of New England. This phenomena may be related to the cooler climate which exists in New England.

The criteria proposed for describing and classifying tidal salt marsh soils require clarification and refinement. The presence of sulfidic material is frequently determined by the drop in pH as a result of repeated drying and oxidation of the organic material. This study has shown that repeated drying of the organic portion of the soil did not significantly reduce pH and that a single drying cycle was sufficient in characterizing potential acidity. It was also found that chemical properties of the three decomposition classes (i.e. Fibric, Hemic, Sapric) were not significantly different.

Comparison of the ditched and unditched marsh did not demonstrate any major difference in the soil characteristics studied or provide any evidence of effects of drainage due to mosquito ditching.

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It would not be possible to give proper acknowledgment to all the patient individuals who provided technical assistance, guidance and moral support through all stages of my research.

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Frank Golet, who provided aerial photos, was instrumental in my initial program design. I am one of many who appreciates his enthusiasm and keen criticism.

I would like to thank Jon C. Boothroyd for his review of the manuscript; I am truly grateful for the new perspectives he has provided.

I am grateful to, Steve Reinert and Frank Golet for supplying aerial photos, base maps, and initial cover maps of the study areas. Peter Schauer conducted much of the metal analyses, provided technical assistance and instruction through nearly every phase of the study. Charlie Galgowski also provided technical assistance and a philosophical perspective during readings from *Cruel Shoes*. Holly Brown and Bruce Bonenfant served as competent field and lab assistants, throughout the drudgery. Holly Brown and R.D. Van Yahres also provided critical assistance with figure preparations.

In conclusion, the last hands on the manuscript have been those of Barbara Brown and Marlene Niedermann, who have patiently labored with the typing and provided support and friendship I will always be grateful for.

Deliver me out of the mire
and let me not sink.
Psalm 69:14

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INTRODUCTION

Research on tidal salt marshes in New England has centered around marsh vegetation, development and productivity. In recent years, soil scientists have begun to direct some attention to the study of New England tidal salt marshes, particularly to the classification of the organic soil, or Histosols (Hill and Shearin, 1970 and Breeding et al., 1974).

The criteria for characterization of Histosols is only provisional (Soil Survey Staff, 1975), as a broader data base is required for the refinement of these criteria. Few characterizations of tidal marsh Histosols have been reported. Studies conducted in Maryland (Darmody and Foss, 1978) and Florida (Coultas and Gross, 1975; Coultas and Calhoun, 1976; and Coultas, 1980) have demonstrated that more information is required to determine what characteristics differentiate marsh soils on a geographic and physiographic basis.

Most of the research on the properties of organic soils has been limited to fresh water peat. For example, it has been found that hydrologic characteristics of fresh water peat are related to the degree of decomposition and origin of the plant fibers (Boelter, 1974), but similar studies have not been applied to peat from salt marshes. Information on the nature of salt marsh peats, however, is needed to make decisions for proper management of these wetlands. Baseline data on tidal salt marsh soils are needed to determine if human disturbances of the substrate would cause significant alterations of the soil characteristics.

A major disturbance to tidal salt marsh soils has been in the form of ditching for control of mosquito breeding. During the 1930's mosquito ditches were dug throughout much of the Northeast (Bourn and Cottam, 1939) with limited comprehensive research conducted regarding their effects on marshes, particularly the marsh soils. In recent years public pressure for control of mosquito breeding has increased, resulting in renewed ditching activity. In 1976, an experimental program was initiated to determine the effectiveness and impact of a selective ditching program in Barrington, Rhode Island (Boyes and Capotosto, 1980). A study is also being conducted in this area to determine the general effects of ditching on avifauna utilization (Reinert et al., 1981), but the potential impacts on marsh soils had not been addressed.

To provide descriptive data on tidal salt marsh soils and impacts associated with mosquito ditching, the properties of a ditched and unditched marsh soil have been studied. The objectives of this study were:

1. To obtain baseline data on Rhode Island tidal marsh soils to permit a comparison between characteristics of marsh soils here and those described for other regions of the United States.
2. To determine if criteria proposed for describing and classifying marsh soils (Soil Survey Staff,

1975) are appropriate for use in detailed studies, and if they accurately portray conditions throughout a single marsh.

3. To determine if either recent or older ditches have altered the morphological characteristics of the soil of the Barrington marsh.

REVIEW OF LITERATURE

Vegetation. The vegetation of New England tidal salt marshes has been described by Miller and Egler (1950) and Redfield (1972). These and other descriptions have been generalized by Niering and Warren (1980). The first distinction in the zonation of vegetation is that between low marsh, located on intertidal slopes below the level of mean high water, and high marsh which is located on a relatively level plateau to the landward side of low marsh (Niering and Warren, 1980).

The low marsh is characterized by monospecific stands of *Spartina alterniflora*, a species adapted to flooding by every tide. *Spartina alterniflora* grows in other areas of the marsh, but reaches its greatest height (1.2 to 1.9 m) along creek banks and the seaward margin of the marsh (Redfield, 1972).

High marsh begins near the mean high water level. The dominant species of this zone are *Spartina patens* and *Distichlis spicata*, which may grow in monospecific or mixed stands. *Juncus gerardi* is found in better drained areas of the marsh, usually along the upland border. *Iva frutescens*, high-tide bush, is present to the landward side of the zone of *J. gerardi* and in elevated portions of the marsh, such as ditch levees, which are flooded only by the highest astronomic tides (Miller and Egler, 1950 and Redfield, 1972).

The dense mat of grassy vegetation characteristic of the high marsh may be interrupted by creeks, ponded water, and salt pannes. In pannes, where drainage is poor, evaporation of the standing water may result in locally high concentrations of salt, inhibiting the growth of higher plants (Miller and Egler, 1950). Some pannes may be vegetated by the salt-tolerant saltworts, _Salicornia europea_ and _Salicornia bigelovii_ (Redfield, 1972), a dwarf form of _S. alterniflora_, or a mixture of these species (Miller and Egler, 1950). The origin of pannes has also been discussed by Redfield (1972) and Miller and Egler (1950).

Marsh Development. Early theories of the origin and development of tidal salt marshes along the coast of New England were discussed by Johnson (1925). He concluded that the marshes formed during a slow, progressive submergence, due either to a sinking of the land or to a rise in sea level in postglacial times. A comparison of recent rates of accretion of high marsh peat to the rate of sea level rise, as determined by tide gauge records, bears out this hypothesis (McCaffrey, 1977).

Various investigators (Redfield and Rubin, 1962; Kaye and Barghoorn, 1964; and Keene, 1971) have radiocarbon-dated high marsh peat to determine the rate of vertical accretion. McCaffrey (1977) and Redfield and Rubin (1962) have attributed both accretion and changes in its rate to changes in the rate of sea level rise. Redfield and Rubin (1962) determined that the average rate of vertical accretion of high marsh peat has been 1.02 mmy^{-1} since 2,100 B.P. and was 3.07 mmy^{-1} prior to that time for a period extending back to at least 3,700 B.P. Keene (1971) reported an accretion rate of 1.1 mmy^{-1} for the period from 4,000 B.P. to the present for high marsh peat in New Hampshire.

McCaffrey (1977) used the distribution of excess ^{210}Pb with depth to estimate the age of incremental slices of peat from a high marsh near New Haven, Connecticut. His results indicate that the rate of accretion had been generally increasing over the last 203 years, with rates ranging from 0.2 mmy^{-1} 203 years ago (at a depth of 32 cm) to 5.8 mmy^{-1} during the 7-year period previous to 1972.

Investigators (Harrison and Bloom, 1977; Richard, 1978; Letzch and Frey, 1980), who have measured the vertical accumulation of sediment over artificial marker horizons conclude that many conditions, in addition to sea level rise, affect accretion rates. Harrison and Bloom (1977) found that, over a 10-year time period, rates of accretion ranged from 2.0 mmy^{-1} to 6.6 mmy^{-1} on five high marsh sites, and correlated primarily with tidal range. These findings are corroborated by those of Letzch and Frey (1980) and Richard (1978) who concluded that deposition rates vary with season and marsh habitat as well.

Blum and Stuiver (1963) reported that radio-carbon dates and stratigraphic sequences associated with sedge peat deposits demonstrate that submergence of the Connecticut coast was at a rate of 1.83 mmy^{-1} 7000 to 3000 years ago, but during the last 3000 years the rate has been only half as great. For this reason, they suggest that salt marshes along the Connecticut coast cannot be older than 3000 years, since marsh growth would not be able to keep pace with submergence before that time.

Kay and Barghoorn (1964) also suggest that there is a maximum age attributable to present-day salt marshes along the New England coast, but for different reasons. they postulate that salt marsh peat becomes compacted under its own weight and that this fact, along with sea level rise, suggests that for any given level of marsh productivity there is a maximum thickness of marsh possible, estimated at 9.1 m. Kaye and Barghoorn (1964) conclude that most marshes older than about 5500 years B.P. would have been drowned.

The nature of the evolution and stratigraphy of New England salt marshes has been described by Chapman (1960) and Redfield (1972). With rising sea level high marsh peat grows both vertically and laterally, over submerged upland. If the rate of sediment accumulation at the seaward margin of the marsh is faster than the rate of sea level rise, the intertidal marsh, vegetated by S. alterniflora, will grow both vertically and seaward. As the height of intertidal marsh approaches mean sea level, high marsh vegetation extends over the intertidal peat (Chapman, 1960 and Redfield, 1972). Evidence of this process has been provided by those who have studied the morphological and physical properties of tidal salt marsh peat in New England (Johnson, 1925; Redfield, 1965; McCormick, 1968; Niering et al., 1977). These latter investigators have described stratigraphic sequences in which high marsh peat has been found above intertidal peat, as well as overlying those deposits characteristic of freshwater wetlands and upland soils.

Classification of Organic Soil. Criteria for description and classification of organic soils have only recently been proposed, and are still provisional (Soil Survey Staff, 1975). To be classified within the order of organic soils, or Histosols, the top 40 cm of a salt marsh soil must consist of material which contains a minimum of 12 to 18% organic carbon, depending upon the clay content.

There are four Histosol suborders, but only three are found in tidal marshes. These three suborders are distinquished on the basis of the degree of decomposition of the organic matter. The terms fibric, hemic, and sapric describe increasing degrees of decomposition, respectively, and are used as a prefix to modify the ordinal name as Fibrist, Hemist, or Saprist.

Within these suborders 17 great groups have been delineated, 16 of which could occur in tidal salt marshes. These great groups are, for the most part, described by soil temperature regime, which may relate to the rate of decomposition of the organic material. However, if sulfuric material is present, usually indicated by a drop in pH of the soil after it has been dried, the suborder is designated as a Sulfihemist (Soil Survey Staff, 1975).

Histosols have been classified in tidal salt marshes of New Hampshire (Breeding et al., 1974), Maryland (Darmody and Foss, 1978), and Florida (Coultas and Calhoun, 1976 and Coultas, 1980). All have been classified as Sulfihemists, although Deamody and Foss (1978) have pointed out that many soil characteristics varied with differences in physiographic features and salinity of marshes.

In brackish estuarine marshes of Maryland, profiles were composed entirely of hemic material (Darmody, 1975). In coastal and high salinity estuarine marshes, however, profiles consisted of fibric material overlying hemic or sapric horizons (Darmody, 1975). Breeding et al. (1974) did not discuss physiographic features of marshes, but their data suggest that most New Hampshire marshes are composed of both hemic and fibric material, found in various locations within a profile. All Florida marshes described are composed of sapric material (Coultas and Calhoun, 1976 and Coultas, 1980).

Prior to the design of the present classification system, Hill and Shearin (1970) surveyed tidal marshes in Connecticut and southern Rhode Island. These marshes were classified primarily as deep and shallow, coastal and estuarine marshes. However, the term "estuarine" applied only to those marshes of low salinity dominated by reeds and sedges; thus, these are not comparable to the marshes in this study. Organic matter in the upper 1.55 m of most marshes was relatively undecomposed. the pH of coastal marshes was slightly acid to neutral (6.1-7.2) and decreased upon drying (Hill and Shearin, 1970).

Effects of Mosquito Ditching. The study of New England tidal salt marshes has been complicated by the nearly ubiquitous mosquito ditches (Miller and Egler, 1950 and Redfield, 1972). Many of these ditches were dug by depression relief labor during the 1930's (Bourn and Cottam, 1939). Investigators of New England tidal salt marshes have reported that ditches both increased and impeded drainage in the marshes (Miller and Egler, 1950 and Redfield, 1972). Some ditches have drained ponded water off the adjacent marsh surface and accelerated drainage of other areas, encouraging the invasion of *Iva frutescens*, a species normally found along the upland border of the marsh. The levees associated with some ditches have impeded drainage of the marsh and encouraged the development of large pannes between ditches (Miller and Egler, 1950).

Ditching has had similar effects on marshes along other portions of the Atlantic coast (Bourn and Cottam, 1950 and Kuenzler and Marshall, 1973). Bourn and Cottam (1950), who studied effects of grid-style ditching in tidewater marshes of Delaware, reported that ditches caused marked ecological changes in the flora. Shrubby growth of

Baccharis halimifolia and *Iva frutescens* had largely replaced the marshes' natural grass associations. Lesser et al. (1976) conducted a follow-up study on Bourn and Cottam's (1950 work, and found that the vegetative cover had reverted to that which was present prior to ditching. They suggested that river dredging may have had an appreciable effect on the plant succession described by Bourn and Cottam (1950).

Other investigators (Kuenzler and Marshall, 1973 and Shisler, 1973) have reported changes in vegetative cover of marshes, primarily through invasion of shrubs on spoil piles created by ditching. In some areas, new ditching practices have been implemented to avoid the creation of these spoil piles and discourage invasion of shrubs (Ferrigno et al., 1975).

With the exception of a study by Daigh and Stearns (1939), no research had addressed the effects of mosquito control ditching on the soils of tidal salt marshes. Daigh and Stearns (1939) studied the pH of ditched tidal marsh soils in Delaware. They found that the pH of the upper 5 cm of soil increased towards ditches, but did not view it as a significant finding.

MATERIALS AND METHODS

Description of Study Areas

The two tidal salt marshes investigated in this study are located south of the Massachusetts border on opposite sides of the Palmer River (sometimes referred to as the Warren River) which discharges into the north-central region of Narragansett Bay (Figures 1 and 2). The tidal range in this region of the Palmer River is approximately 1.24 m (Spaulding and Swanson, 1974).

The ditched salt marsh is located in the town of Barrington, Rhode Island on the western shore of the Palmer River (Figure 2). The study area includes approximately 19 ha of tidal salt marsh bordered by a large creek to the north and a ditch to the south. Streams discharge into the marsh along the western edge where patches of brackish and freshwater vegetation are present. The upland soils bordering this marsh have been mapped by the Soil Conservation Service as Walpole and Sudbury sandy loams (Rector, 1981).

A series of ditches, which were dug during the 1930's to eliminate mosquito populations (Office of Entomology and Plant Industry, 1939), are evident throughout the marsh. Portions of these mosquito ditches were cleared and redug in 1977. During this time additional ditches were placed in the interior of the marsh, but not directly connected to any tidal waters.

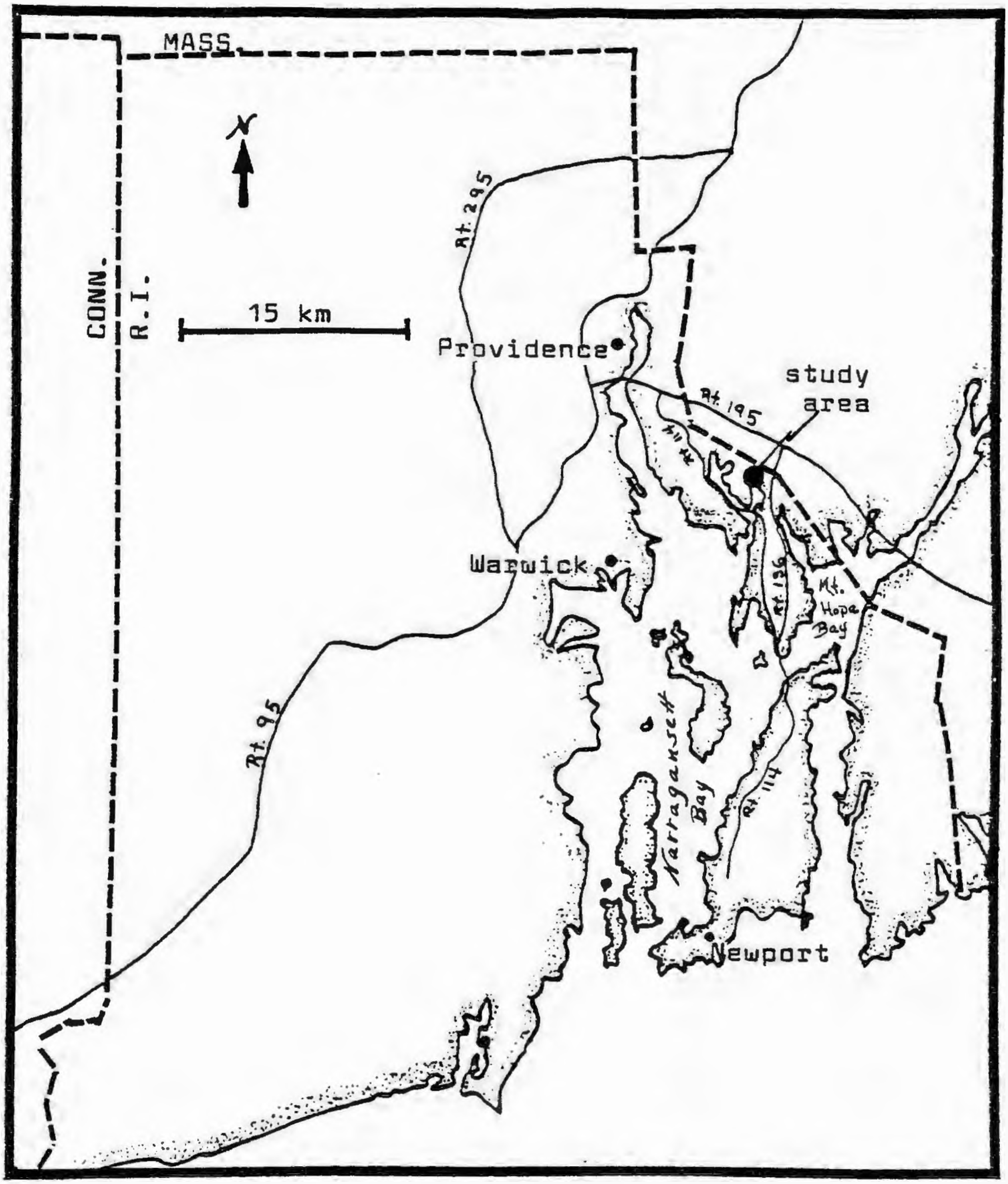
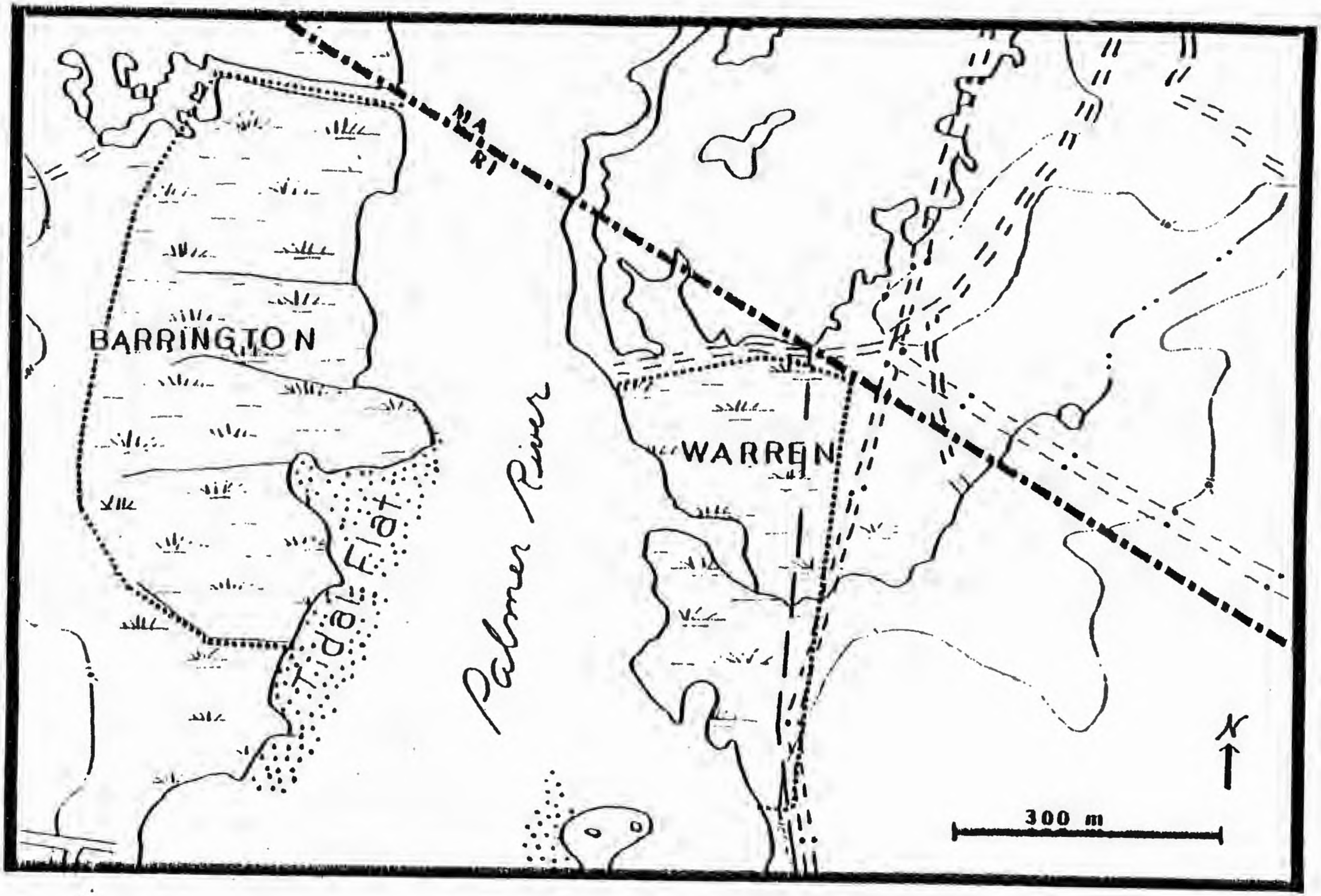


Figure 1. Locus map of Narragansett Bay and study areas.

Figure 2. Locus map of Warren and Barrington marshes (source: USGS East Providence Quadrangle).

LEGEND

················	study area boundary
▬ ▪ ▬ ▪ ▬ ▪	RI/MA state border
– — ——	water main
•= = = •=	power lines
= = = =	unimproved road
——10'—	10 ft contour


NA
RI
BARRINGTON
WARREN
Palmer River
Tidal Flat
N
300 m

The study area on the eastern shore of the Palmer River includes approximately 14 ha of tidal salt marsh located within the town of Warren, Rhode Island (Figure 2). The northern edge of this study area is bounded by a gravel dike, which serves as an access road and impounds freshwater to the north. Eastern portions of the salt marsh grade into fresh water wetlands. A woodland buffers both the freshwater wetlands and southern portions of the study area from a nearby golf course. The adjacent upland soils have been mapped by the Soil Conservation Service as Walpole sandy loam (Rector, 1981).

The eastern half of this marsh has been subjected to disturbances by man. Portions of an abandoned concrete pipeline can be seen crossing some creek beds and a large water main, which is set on pilings, transverses the marsh (Figure 2). At the far eastern edge of the marsh are poles supporting electrical lines.

Field Procedures

Peat Thickness. The depth of peat across both marshes was determined by inserting an 8 mm-diameter metal rod into the soil to refusal. Readings were taken at intervals of 30 m along transects running from the upland edge of each marsh to the shore of the Palmer River (roughly east-west). Transects were spaced approximately 40 m apart in the Warren marsh. The presence of many ditches and associated levees running from east to west did not allow regular spacing on the Barrington marsh. Here transects were approximately

45 m apart.

To confirm the validity of this probing technique a number of holes were excavated on both marshes to measure the actual depth of peat after insertion of the rod. Rod determinations were found to correlate closely with actual peat depths, as the difference was no greater than +10 cm. This variability was caused by the presence of a thin mineral horizon (10 cm or less) containing a high proportion of silt and organic matter which had a density similar to that of the overlying organic horizons.

Surface and Water Table Elevations. Two north-south oriented transects, spaced 120 m apart, were established on each marsh, monitoring wells, obtained by digging a 15 x 15 cm hole with a tile spade, were spaced at 30-m intervals along each transect. Additional wells were placed 5 m apart between selected drainage ditches on the Barrington marsh. In addition, two transects were established perpendicular to the north-south transects on the Barrington marsh to further indicate the effects of ditching on water table elevations. The height of the water table at low tide, during a neap tidal cycle, was determined by measuring the depth to water in each unlined well within one hour of slack tide.

The relative elevation of the marsh surface at each well and the depth of the thalweg of each creek and ditch encountered on the transect were measured with a rod and transit.

Soil Sampling and Description. Six profiles were described and sampled in each marsh. Care was taken to choose locations which were not in close proximity to creeks or the riverbank, and which would be representative of conditions throughout the marsh area.

Saturated soil conditions within the marshes precluded customary soil profile descriptions by means of pits. Therefore, soil profile descriptions were made from excavated samples which had been placed on plastic sheeting in a manner representative of *in situ* conditions.

A tile spade was effective in removing the two uppermost horizons, which contained live rhizomes. Lower organic horizons were removed with a McCauley peat sampler. Most mineral horizons could not be penetrated with the peat sampler and were retrieved with a bucket auger.

Thickness of horizons, depth of live root zones, and depth of peat were described in the field. Samples of each horizon were placed in plastic bags and transported to the laboratory for subsequent analyses. Field-moist color was described in the laboratory using a Munsell Soil Color Chart (Soil Survey Staff, 1975).

Vegetative Cover Maps. The distribution of vegetative communities was mapped from color infrared transparencies taken at an approximate scale of 1:2400. Identification of communities was verified by field reconnaissance.

Map scales posed limitations on the detail to which vegetation could be mapped. Therefore, marsh surfaces were mapped as one of six cover types: 1. ponded water without emergent vegetation; 2. tall *Spartina alterniflora* (low marsh and creekbanks); 3. pannes, including those covered by *Salicornia europea*, stunted *Spartina alterniflora*, stunted *Distichlis spicata*, mixtures of these species or barren soil; 4. *D. spicata*, *Spartina patens*, *Juncus gerardi* or mixtures of these species; 5. *Iva frutescens*; and 6. areas with growth of upland vegetation, primarily tall, woody species. Map scale limitations prohibited delineations smaller than 7 m^2, therefore, numerous inclusions occurred within many vegetative units.

Laboratory Procedures

Rhizome Identification. Rhizomes were removed from moist samples and allowed to air dry to simplify identification. Rhizomes within each horizon were identified by using descriptions reported by Niering et al. (1977), and by comparing samples to known specimens. If possible, the relative abundance of each species of rhizome was recorded.

Classification of Organic Material. The Soil Conservation Service (Soil Survey Staff, 1975) distinguishes three basic types of organic material; fibric, hemic, and sapric, which represent the degree of decomposition of the material. The designation of these groups is based in part on the content of plant fibers and, in part, on the solubility of the material in sodium pyrophosphate (Soil Survey Staff, 1975).

To be classified as fibric, material must have 2/5 rubbed fiber content by volume and a sodium pyrophosphate extract color of 7/1, 7/2, 8/1, 8/2, or 8/3. Sapric material has less than 1/6 rubbed fiber content and a sodium pyrophosphate extract color of 6/3, 5/2, 4/1, 3/1, 2/1, or darker. Organic material which does not meet both criteria is placed in the hemic category. In this study, criteria for classification of organic material were determined by techniques described by Lynn et al. (1974). These techniques are summarized in the following sections on fiber content and sodium pyrophosphate solubility.

Fiber content. Fiber content was determined by measuring the percent by volume of plant fibers in a moist soil sample according to procedures described by Lynn et al. (1974). The measuring device used was a 10 cc plastic syringe which had been cut in half longitudinally.

Unrubbed fiber was determined by filling the half-syringe with a field-moist sample, transferring the sample to a 100-mesh sieve, and rinsing under running water until the effluent was clear. The material remaining on the sieve was repacked in the syringe at approximately the same moisture content and density as the original sample. The volume, as indicated by graduations on the syringe, was recorded as percent unrubbed fiber.

Rubbed fiber content was determined by transferring the unrubbed fiber back to the 100-mesh sieve and rubbing between the thumb and forefinger under running water until the effluent again appeared clear. The syringe was repacked and the volume recorded as percent rubbed fiber.

As described in Soil Taxonomy (Soil Survey Staff, 1975), the determination of fiber percentages requires that any plant parts living at the time of sampling be removed. This step was followed when processing most samples, but in many profiles, the two uppermost layers were predominantly composed of live rhizomes which could not be separated from other material.

Sodium pyrophosphate solubility. The relative solubility of field-moist organic material in sodium pyrophosphate is determined by comparing the color of the solution to a Munsell Color Chart (Lynn et al., 1974). Soil samples were placed in a saturated solution of sodium pyrophosphate, mixed, and allowed to stand overnight. After the sample was mixed again the end of a strip of chromatographic paper (½ by 3 cm) was placed in the solution and left until most of the strip was moistened.

The color of the unsoiled portion of the paper strip was compared with a Munsell Color Chart to obtain a measurement of value and chroma. Lynn et al. (1974) have derived a pyrophosphate index from the Munsell Color Chart notation by subtracting the chroma from the value. This index was also derived for samples in this study.

Organic Matter. The percent organic matter of each horizon was determined by the percent weight lost upon ignition. Live roots were removed from all samples below the second horizon; however, this procedure was essentially impossible for the two upper layers. Samples were air dried, ground in a pulverizing mill to pass through a 2.4 mm screen, and oven dried at 102° C for a minimum of 8 hours. Two grams of each sample were put in acid-washed porcelain crucibles and placed in a muffle furnace for 4 hours at 336°C to reduce the likelihood of explosive combustion and possible sample loss. The temperature was raised to 486° C for at least 8 hours, and the samples were cooled in a dessicator and weighed.

Total Nitrogen. Total nitrogen content of one-gram samples of ground organic material was determined by standard Kjeldahl methods (Association of Official Analytical Chemists, 1980).

Soil pH. Preliminary analyses had indicated that the pH of some samples began to drop soon after their collection. Therefore, pH readings were taken within 5 hr of the collection of samples.

The pH of all horizons was determined from a soil paste prepared with 0.015 M $CaCl_2$. Because a soil paste could not be prepared with fibric and hemic samples, enough $CaCl_2$ was added to allow proper emersion of the glass electrodes. Samples were allowed to equilibrate at least one hour before pH readings were taken with an Orion Ionalyzer.

A second pH reading was taken after samples were allowed to air dry for a minimum of 14 days. Samples were then rewetted with distilled water and allowed to air dry before taking a third pH reading. This process was repeated for a fourth reading if sample size permitted.

Total Metal Content. The ash produced from the determination of organic matter was dissolved in 20 ml of 2N HCl by gently heating. The solution was filtered and diluted to 50 ml with distilled water. Concentrations of total Fe, Cd, Cr, Cu, Mn, Ni, Pb, and Zn in these samples were determined on a Perkin-Elmer Model 5000 atomic absorption spectrophotometer according to recommended procedures (Perkin-Elmer Corporation, 1976).

Particle Size. Samples of mineral horizons were air dried, crushed to pass a 10-mesh sieve, and the <2 mm fraction was used for subsequent analyses. Particle size distribution was determined by using the pipette method (Kilmer and Alexander, 1949). Samples suspected of having a high percentage of organic matter were treated with 30% H_2O_2 prior to dispersion. Many samples, particularly those located at the mineral/organic interface, required a considerable amount of H_2O_2 before the organic fractions were sufficiently oxidized.

Textural class of each mineral horizon was determined according to definitions in the Soil Survey Manual (Soil Survey Staff, 1951). However, data for samples BB8, WE10, and WE12 could not be placed in any textural class with the definitions provided. Franzmeier and Norton (1978) encountered similar problems in applying these definitions, and proposed changes in the definitions of textural classes to make them all-inclusive. Their recommended definitions have been utilized in classifying the three horizons noted above.

RESULTS AND DISCUSSION

Vegetative Cover. The distribution of vegetative zones of the Warren marsh is depicted in Figure 3a. Along the Palmer River intertidal slopes are bordered by a narrow band of low marsh, generally less than 10 m wide. Broader areas of tall *Spartina alterniflora*, up to 30 m wide, border the two . major tidal creeks in the interior of the marsh.

The high marsh of the Warren study area is a mosaic of mixed stands of *Spartina patens* and *Distichlis spicata*, pannes and ponded water. In some areas floating mats of dwarf *S. alterniflora* cover small ponds which are over 1.5 m deep. These areas could only be detected through field observation.

Much of the river margin of the Barrington marsh, depicted in Figure 3b, consists of an abrupt scarp of peat, approximately 1.3 m high. At the base of this scarp is a collapsed shelf of peat upon which *S. alterniflora* is established.

High marsh vegetation covers most of the Barrington marsh and extends riverward to the edge of the scarp. *Juncus gerardi* is dominant along much of this margin, which is an indication of its relatively high elevation and better-drained condition (Redfield, 1972 and Miller and Egler, 1950). The most common species found on the Barrington marsh is *D. spicata*, which grows in monospecific stands, or mixed with *S. patens* and *J. gerardi*. *Distichlis*

Figure 3. Vegetative cover map of study areas.

LEGEND

■	Profile Site
▪▬▪	Transect for water table and surface elevation measurements
■	Permanent Water
⁙	Low Marsh (tall *S. alterniflora*)
□	High Marsh (*S. patens*, *D. spicata*, *J. gerardi*)
░	Panne (stunted *S. alterniflora*, *D. spicata*, and *S. europea*)
▩	High-tide Bush (*Iva frutescens*)
▦	Upland species

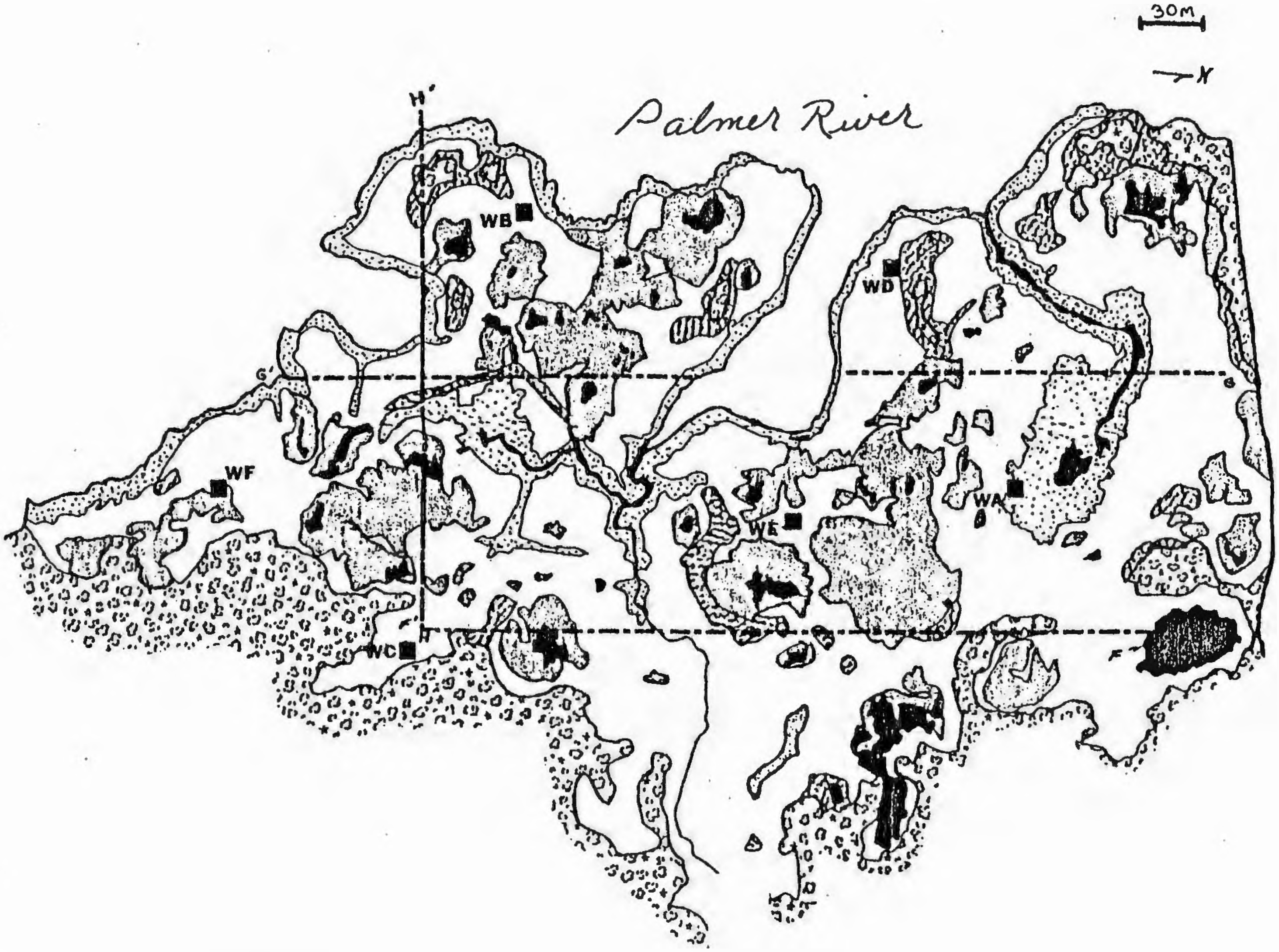


Figure 3a. Warren marsh.

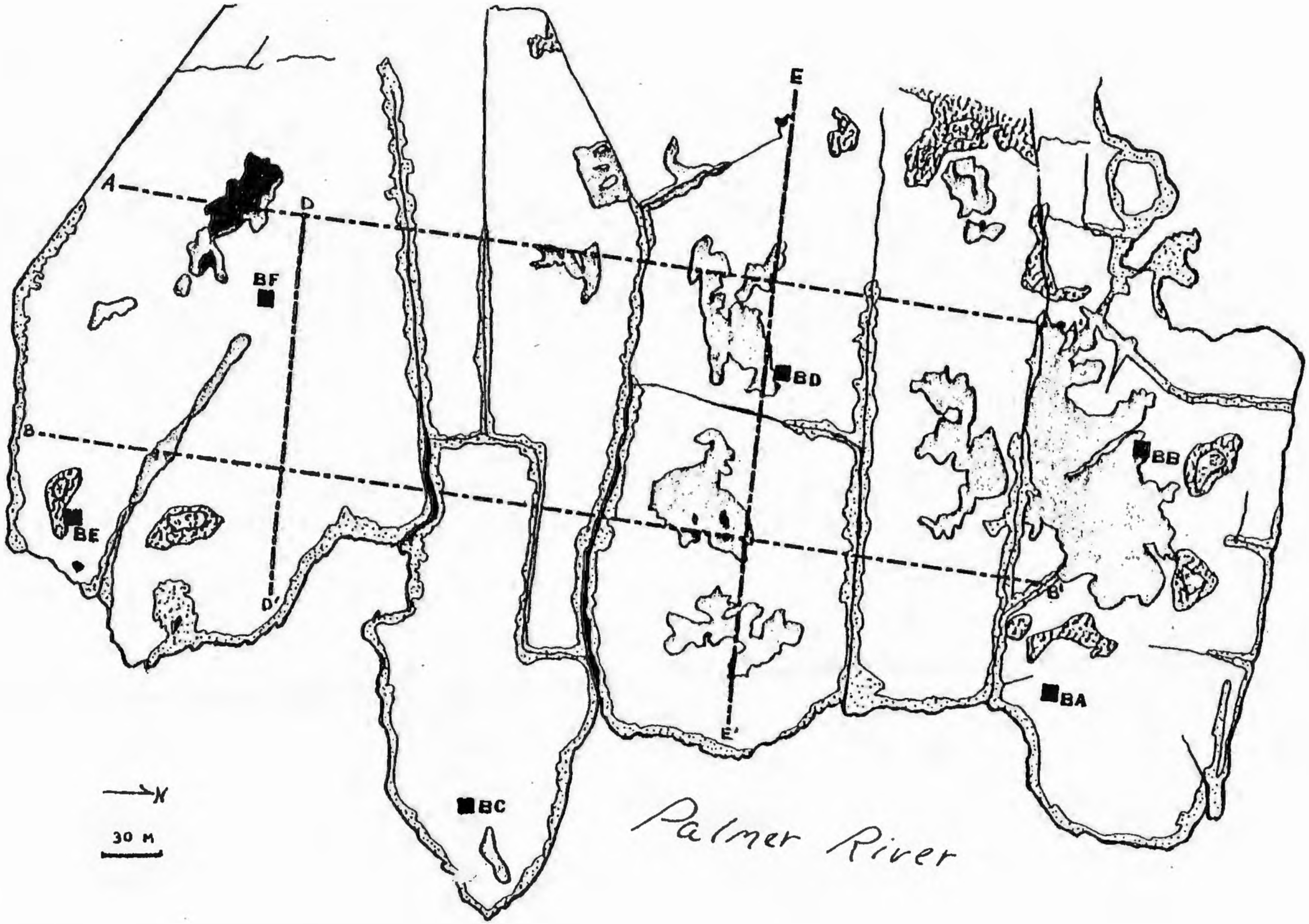


Figure 3b. Barrington marsh.

spicata is also found in a stunted form growing in sparse stands where drainage is poor.

In comparison to the Warren study area, the Barrington high marsh surface is relatively uniform with considerably less area of ponded water and pannes. There are, however, a few large panes in the northern portion of the marsh. Levees are associated with many of the ditches in the marsh appear to hinder drainage. It is believed that they have caused development of "inter-ditch" pannes, similar to those described by Miller and Egler (1950).

The older ditches in this marsh have followed the evolutionary processes described by Miller and Egler (1950). The banks of some have slumped and eroded, allowing considerable widening of the tidal channel. Yet, portions of other ditches have silted in and have become colonized by *S. alterniflora*.

Elevated "islands" of glacial deposits are present in both marshes. These were generally vegetated with woody species bordered by *Iva frutescens* on the lower slope.

Topography and Water Table in Relation to Vegetation. The measurements of surface topography and water table elevations for both marshes are listed in Appendix 3,4. Topography and water table elevations were more irregular on the Warren marsh than on the Barrington marsh, yet the water table was closely associated with surface elevations on both marshes.

The maximum water table elevations on both marshes often occurred in areas of permanent ponds. Although these areas are often associated with local depressions, they do not always correspond to the lowest elevation on the marsh. For example, the "perched" water table and depression located at the southern end of the Barrington marsh is at a higher elevation than other portions of the marsh which are better drained (Figure 4).

The height of the water table increased to a relatively constant level at a distance of 30 m from most tidal channels sampled (Figure 4). Inspection of the vegetative cover maps (Figures 3a and 3b) shows that on both marshes the frequency of pannes and ponded water greatly increases at distances greater than 30-40 m from tidal channels. These data suggest that the effectiveness of mosquito ditches in removing surface and ground water may be limited to a 30-m distance.

Poor drainage has often been noted as a cause of plant zonation within high marshes of New England (Miller and Egler, 1950; Redfield, 1972; and Niering and Warren, 1980). Redfield (1972) reported that large ponds of irregular shape, usually surrounded by many small pannes, were found in regions relatively remote from drainage, but did not quantify "remoteness".

Since ponds and pannes occur in areas less than 30 m from drainage channels and river banks of both marshes, it is assumed that other phenomena, besides absence of drainage channels, contribute to the impedance of drainage. Percolation and lateral movement of water through the

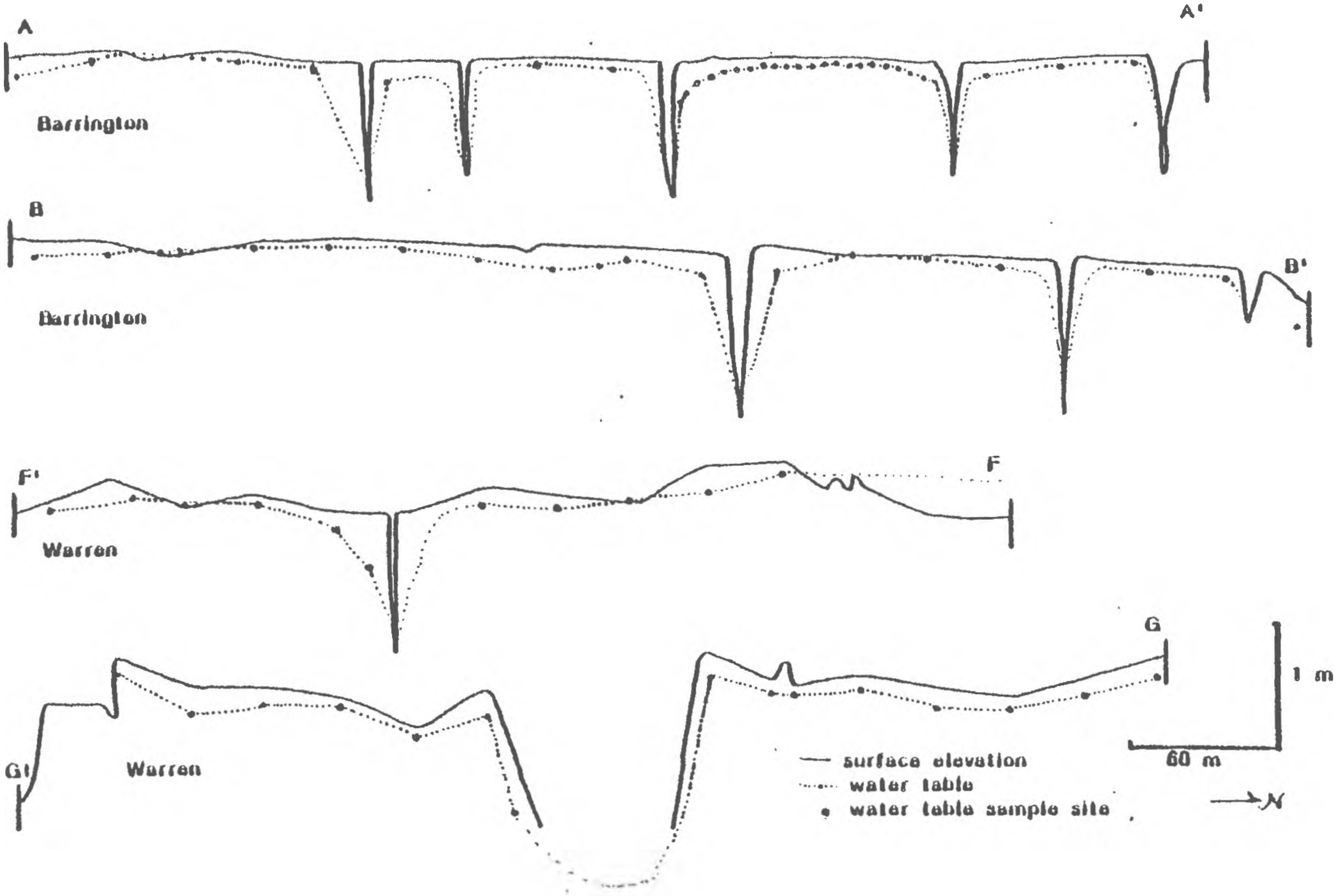


Figure 4. Surface relief and water table of Barrington and Warren marshes.

marsh substrate may be impeded by spoil banks created during the construction of mosquito ditches (Shisler, 1973). Increased weight of the spoil material may have caused compaction and a subsequent reduction of the permeability of the marsh substrate, thus, slowing the drainage of waters in areas behind spoil banks.

Peat Depth. The depth of peat, on both marshes, generally increases from the upland towards the river. Soundings indicated that both marshes had areas of peat over 250 cm deep, which was the limit of the rod used for measurement (Appendix 1,2).

Figures 5a and 5b depict the depth of peat in both marshes as it relates to criteria for the classification of soil series. Since the peat of both marshes is greater than 40 cm in thickness, it meets the criteria for classification as a Histosol (Soil Survey Staff, 1975).

Most of the peat of the Warren marsh is greater than 40 cm, but less than 130 cm deep. This depth range meets the criteria fro both the Westbrook and Pawcatuck Series. Description of additional characteristics indicates that this marsh is within the Pawcatuck series (Established Soil Series Criteria, Soil Survey Staff, U.S.D.A.). Overall, the Barrington marsh is deeper. Over 50% of this marsh is greater than 130 cm deep with considerably more area of peat over 200 cm deep than is found in the Warren marsh. On the basis of peat depth this marsh is part of the

Figure 5. Peat isopach of Warren and Barrington marshes.

LEGEND

⁓6⁓	Peat Depth Contour
•	Depth Reading Station
■	Profile Site
▲	Water Table and/or Surface Elevation Station

Depth readings in decimeters.

Contour interval=20 centimeters.

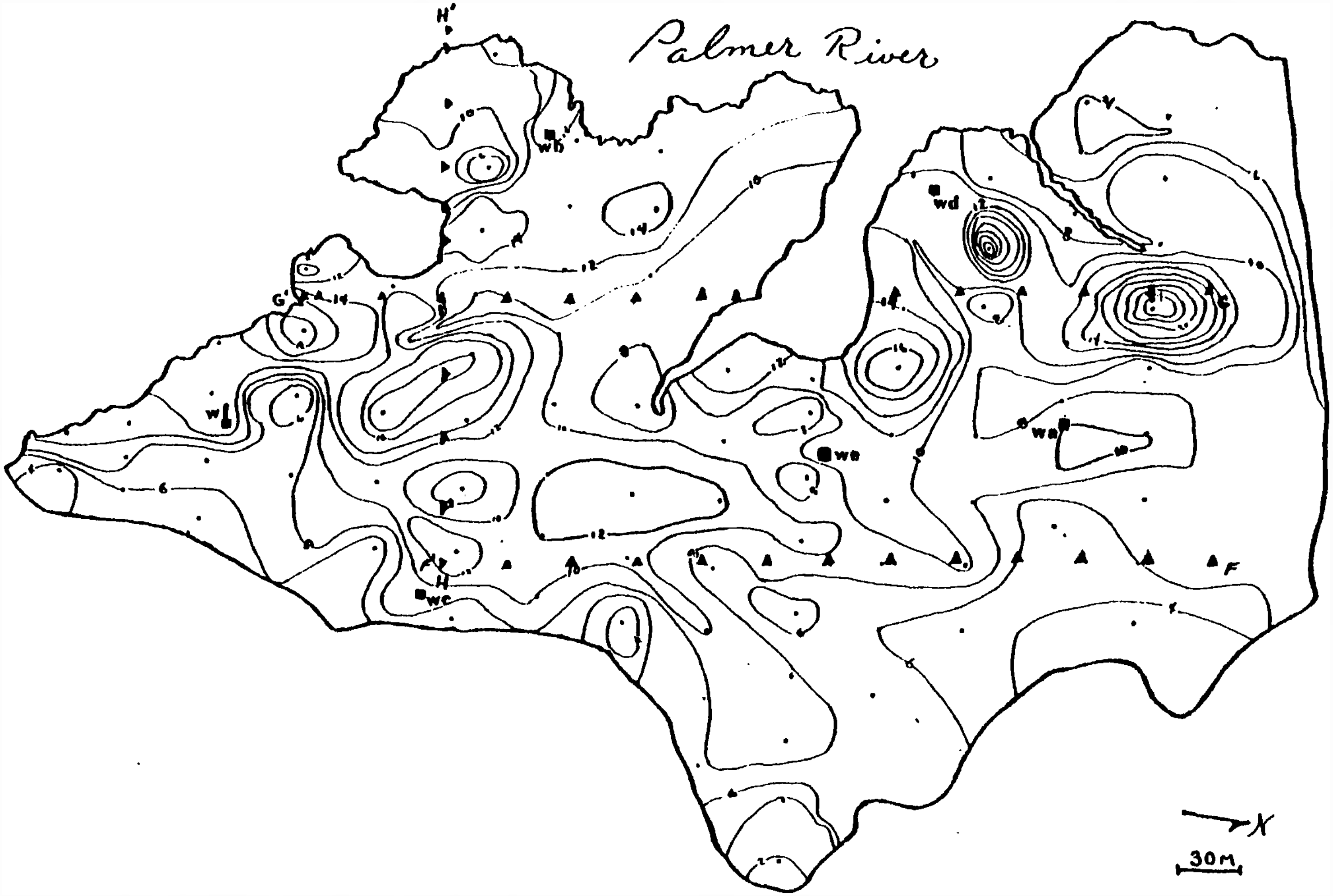


Figure 5a. Warren marsh.

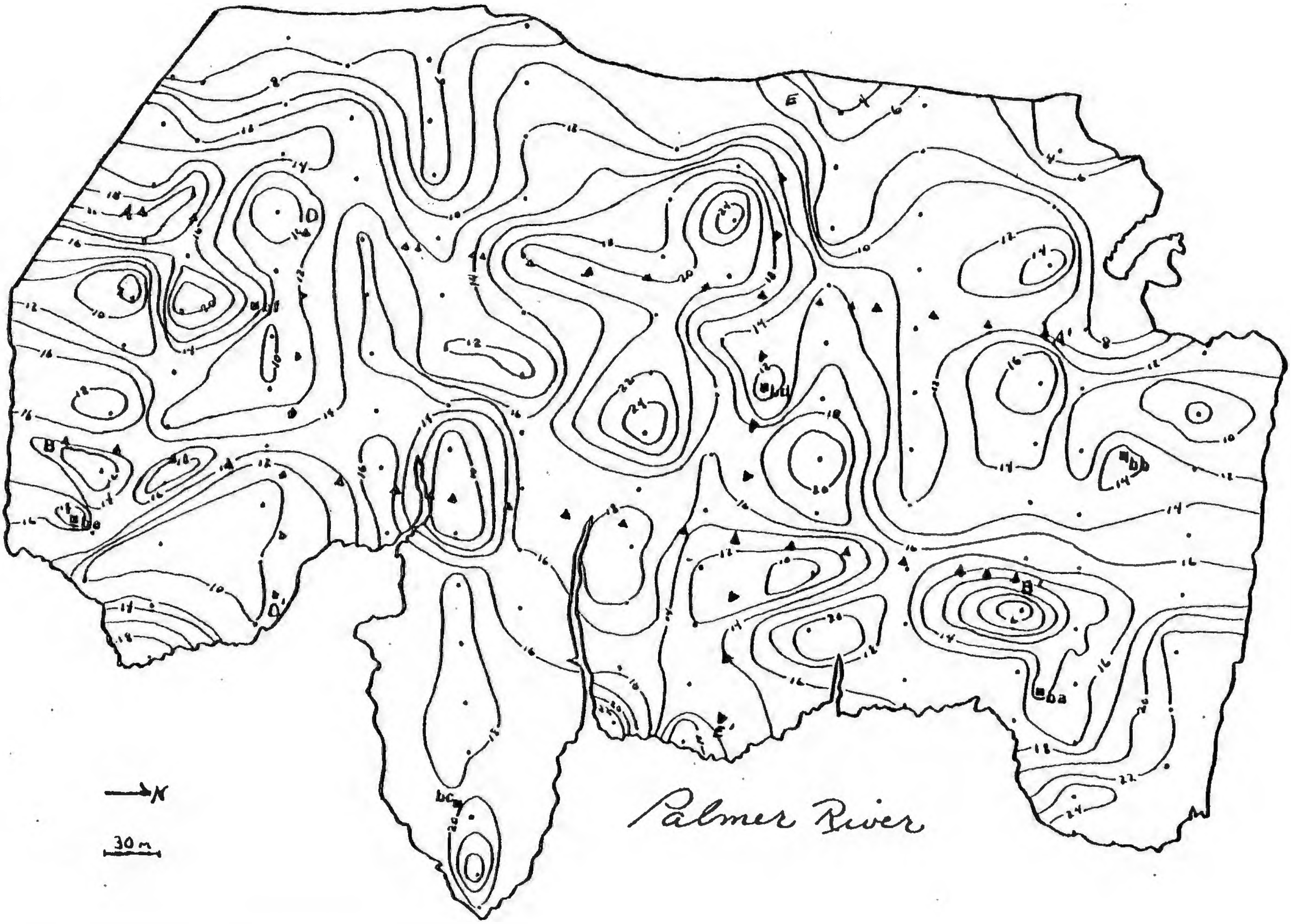


Figure 5b. Barrington marsh.

Ipswich series (Established Soil Series Criteria, Soil Survey Staff, U.S.D.A.).

Greater depths of peat have been reported for other New England marshes: 1.48 m - 7.75 m for marshes in the area of Barnstable, Massachusetts (Redfield and Rubin, 1962); 4.6 m in the area of Plum Island, Massachusetts (McCormick, 1968); 3.7 m in marshes of the Hampton-Seabrook area of New Hampshire (Keene, 1971); and 11.78 m in a marsh in Clinton, Connecticut (Blum and Stuiver, 1963). However, peat deposits of some tidal marshes in Connecticut and southern Rhode Island surveyed by Hill and Shearin (1970) were only 1.28 m deep, which is shallower than both the Barrington and Warren marshes.

The accretion rates reported by Harrison and Bloom (1977) and Richard (1978) have been applied to the marshes in this study to estimate the age of the sediments. Data presented by Harrison and Bloom (1977) indicate that, in _S_. _patens_-_D_. _spicata_ communities with a tidal range of 1.2 m, the accretion rate would be approximately 3.6 mmy^{-1}. Because tidal range has been reported to be a major determinant of accretion rates in the high marsh, a rate of 3.6 mmy^{-1} has also been applied to the _S_. _alterniflora_ high marsh communities in this study. The accretion rate of 4.3 mmy^{-1} which Richard (1978) reported for low marsh sediments has been applied to those horizons assumed to characterize low marsh in this study.

By applying these accretion rates to the Barrington marsh it is estimated that the marsh was approximately 18 cm lower when the mosquito ditches were constructed in the late 1930's.

Since rates of relative sea level rise have varied (McCaffrey, 1977) and peat may have compacted (Kaye and Barghoorn, 1964) these same accretion rates would not apply throughout the entire depth of the marsh. However, if these rates are applied, these marshes would be approximately 700 years old. If rates closer to those reported by investigators using carbon dating techniques (Redfield and Rubin, 1962 and Keene, 1971) are used, the Barrington marsh would be a maximum of 2500 years old.

Rhizome Identification and Interpretation. Rhizomes found in the marsh deposits provide evidence of previous marsh environments. The species identified in each horizon and interpretations of previous marsh environments are presented in Figure 6.

These data suggest that much of the Barrington study area had always been predominantly high marsh, as *D. spicata* was found in all profiles, and in most horizons. These rhizomes were present in organic horizons directly overlying mineral depostis in profiles BE and BD, thus, these profiles probably represent areas where high marsh grew laterally over upland areas. Only one panne was apparent within all six profiles. *Spartina alterniflora* was found mixed with high marsh species in profile BF. Rhizomes of *S. alterni-*

Figure 6. Soil profiles showing marsh development as interpreted by rhizome analyses.

[1] Profile abbreviations:

Oi=fibric organic horizon, Oe=hemic organic horizon, Oa=sapric organic horizon, cs=coarse sand, fs=fine sand, fsl=fine sandy loam, l=loam, lfs=loamy fine sand, s=sand, sil=silt loam, sl=sandy loam, vfsl=very fine sandy loam.

[2] Vegetation listed in order of relative volume of rhizomes of each species identified.

Vegetation abbreviations:

Sa=*Spartina alterniflora*
Sp=*Spartina patens*
Lc=*Limonium carolinianum*
Ds=*Distichlis spicata*
Pa=*Phragmites australis*
Jg=*Juncus gerardi*
V=vegetative fragments present, but not identified.

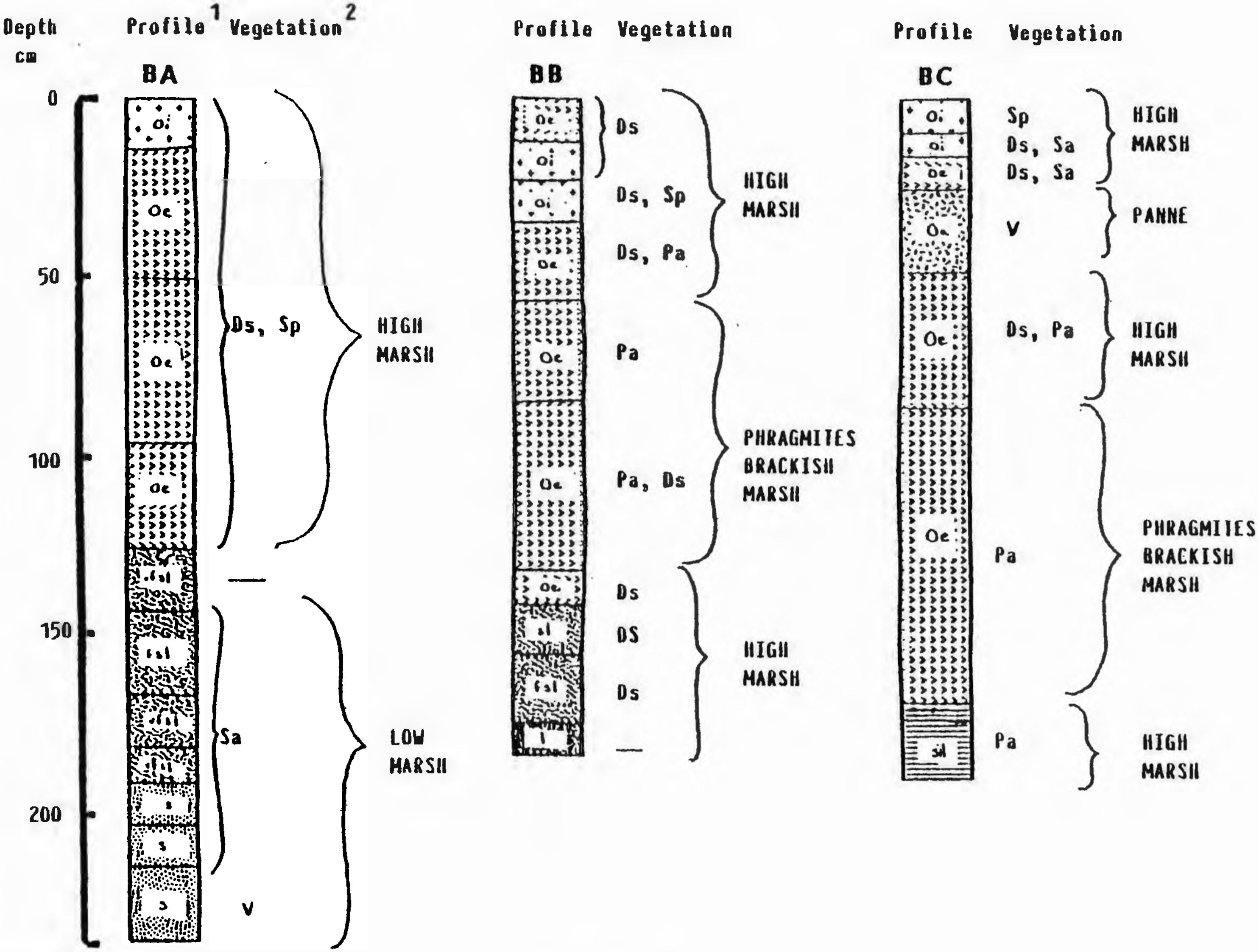

Depth cm
Profile 1
Vegetation 2
BA
0
50
100
150
200
Oi
Oe
Oe
Oe
fsl
fsl
fsl
fsl
s
s
s
Ds, Sp
HIGH MARSH
—
Sa
V
LOW MARSH
Profile
Vegetation
BB
Oe
Oi
Oi
Oe
Oe
Oe
Oe
sl
fsl
l
Ds
Ds, Sp
Ds, Pa
HIGH MARSH
Pa
Pa, Ds
PHRAGMITES BRACKISH MARSH
Ds
DS
Ds
—
HIGH MARSH
Profile
Vegetation
BC
Oi
Oi
Oe
Oa
Oe
Oe
sil
Sp
Ds, Sa
Ds, Sa
HIGH MARSH
V
PANNE
Ds, Pa
HIGH MARSH
Pa
PHRAGMITES BRACKISH MARSH
Pa
HIGH MARSH

Figure 6a.

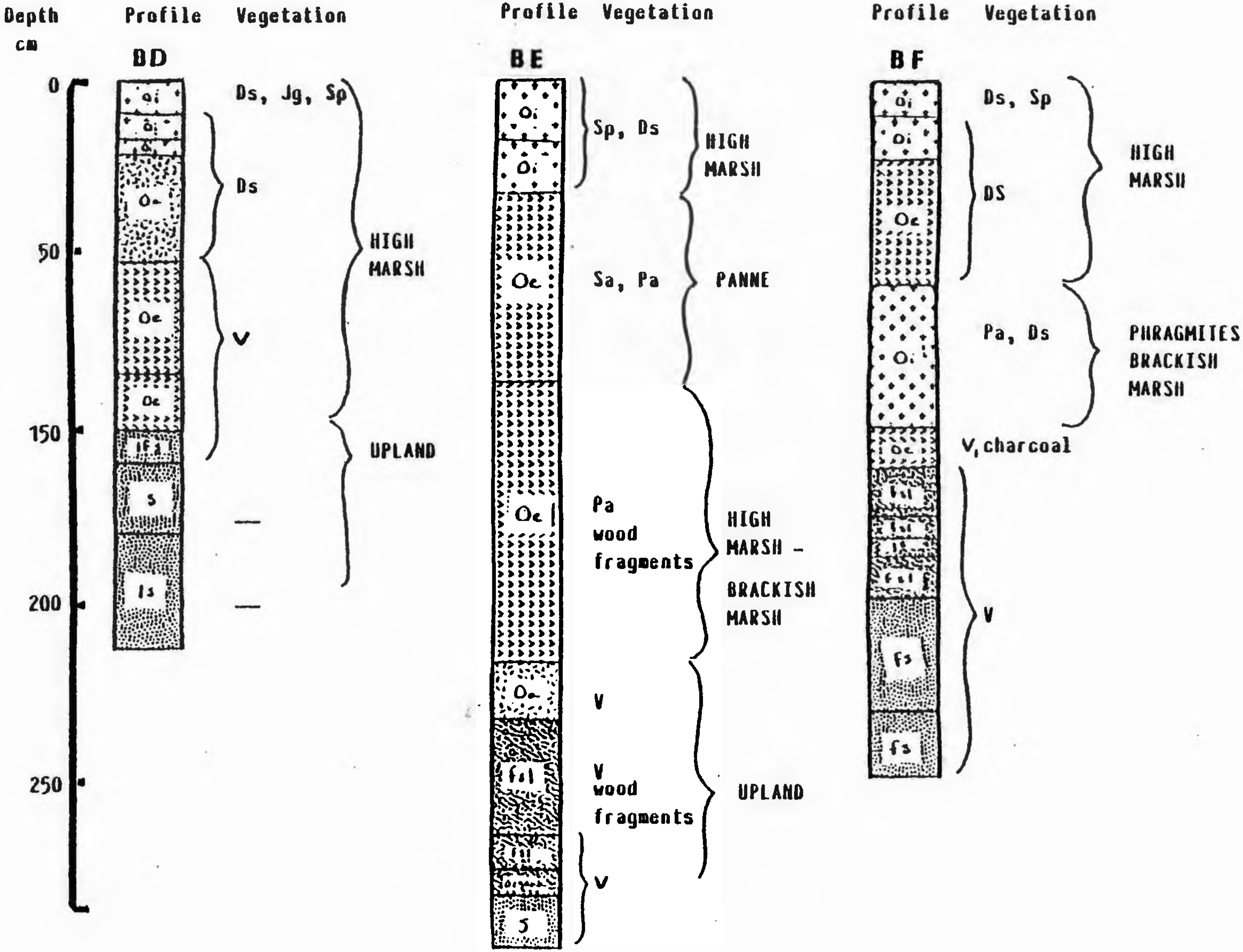

Depth
cm
Profile
Vegetation
BD
0
50
150
200
250
Oi
Oi
Oi
Oa
Oe
Oe
IFs
S
Is
Ds, Jg, Sp
Ds
V
HIGH MARSH
UPLAND
Profile
Vegetation
BE
Oi
Oi
Oe
Oe
Oa
Fsl
Fsl
S
Sp, Ds
HIGH MARSH
Sa, Pa
PANNE
Pa
wood
fragments
HIGH MARSH -
BRACKISH MARSH
V
V
wood
fragments
UPLAND
V
Profile
Vegetation
BF
Oi
Oi
Oe
Oi
Oe
Fsl
Fsl
Is
Fsl
Fs
Fs
Ds, Sp
DS
HIGH MARSH
Pa, Ds
PHRAGMITES
BRACKISH
MARSH
V, charcoal
V

Figure 6b.

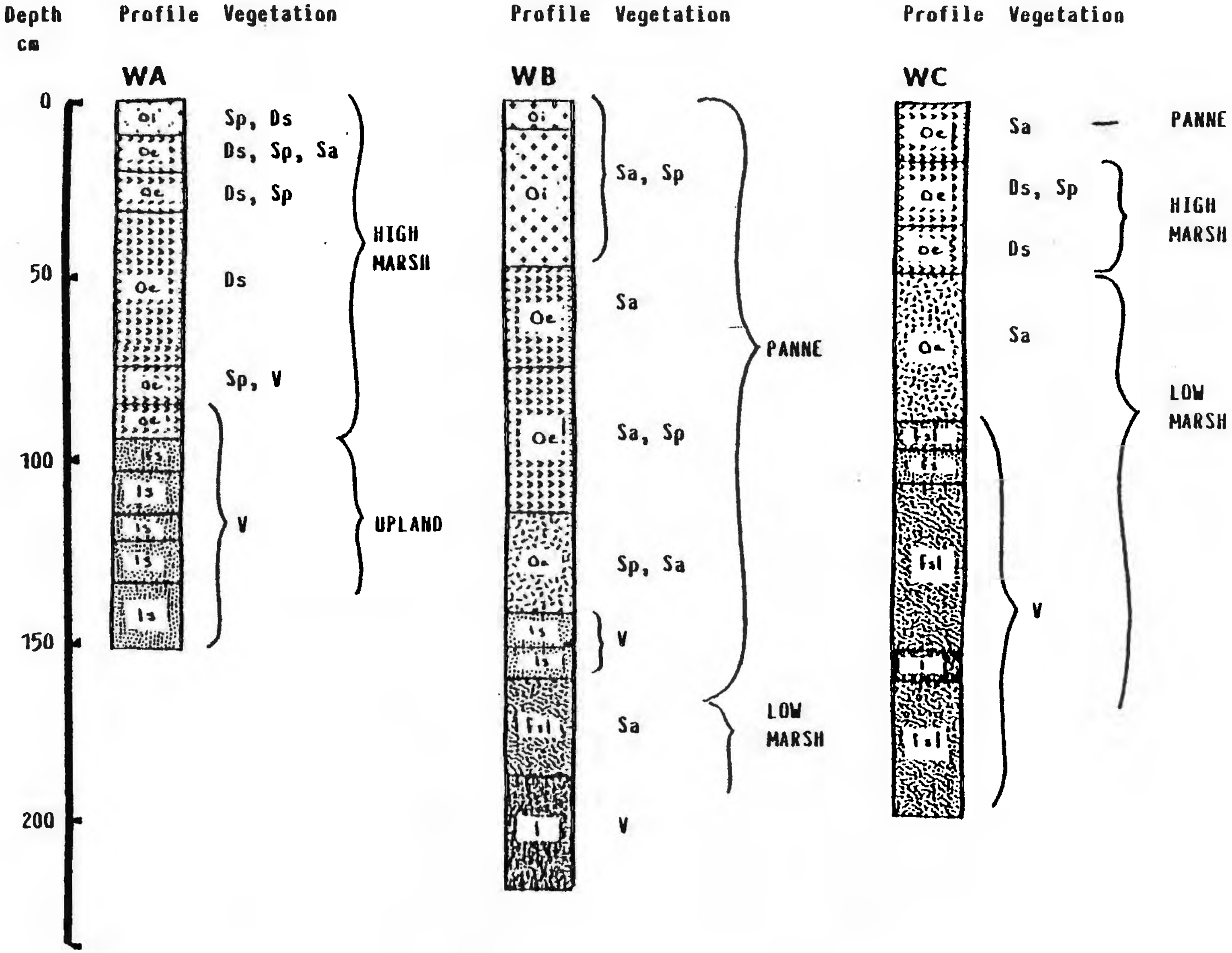

Depth cm
Profile
Vegetation
WA
0
50
100
150
200
Oi
Oe
Oe
Oe
Oe
Oe
ls
ls
ls
ls
ls
Sp, Ds
Ds, Sp, Sa
Ds, Sp
Ds
Sp, V
V
HIGH MARSH
UPLAND
Profile
Vegetation
WB
Oi
Oi
Oe
Oe
Oa
ls
ls
Fsl
l
Sa, Sp
Sa
Sa, Sp
Sp, Sa
V
Sa
V
PANNE
LOW MARSH
Profile
Vegetation
WC
Oe
Oe
Oe
Oa
Fsl
ls
Fsl
l
Fsl
Sa
PANNE
Ds, Sp
Ds
HIGH MARSH
Sa
LOW MARSH
V

Figure 6c.

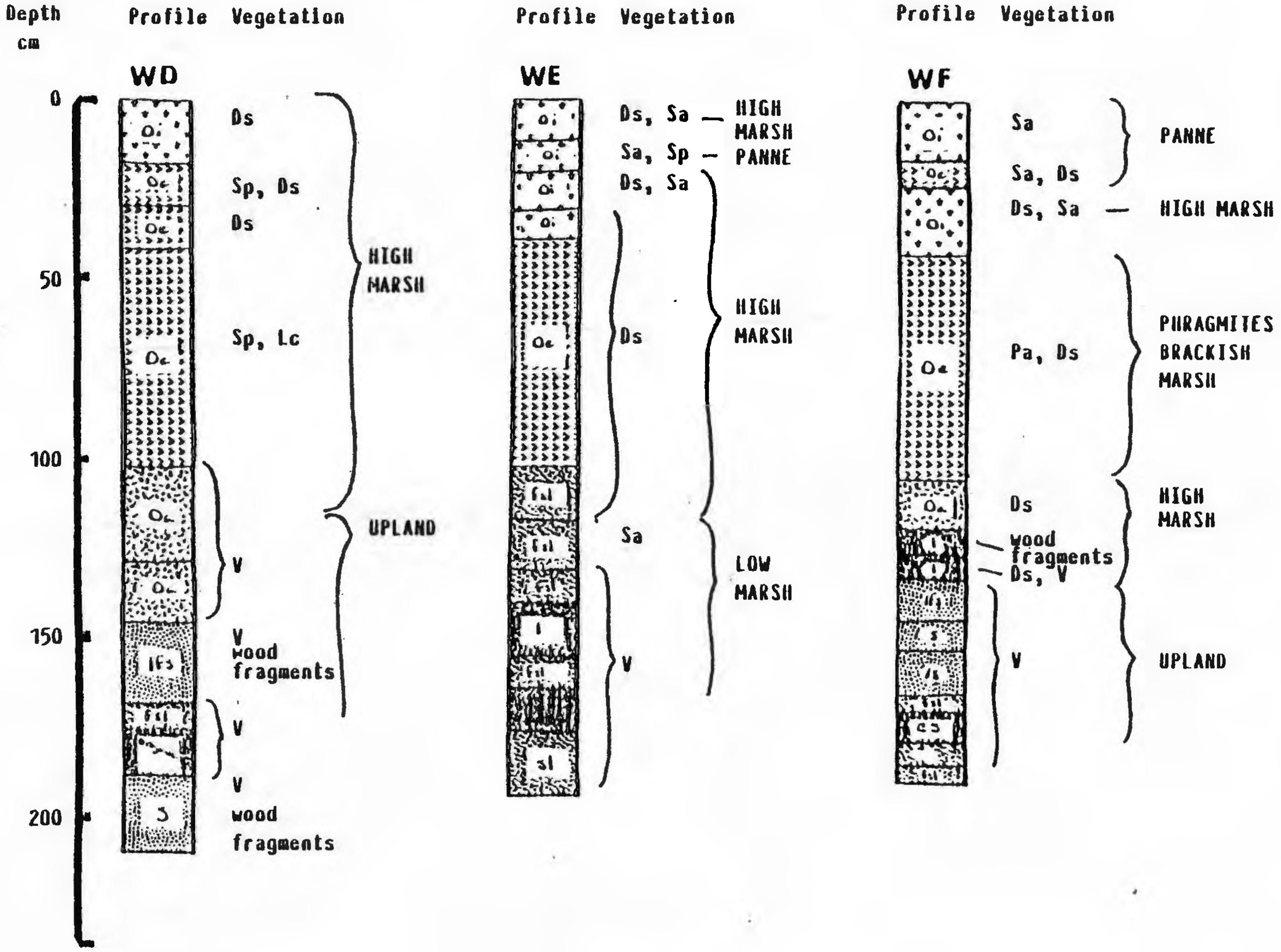

Depth cm
Profile
Vegetation
Profile
Vegetation
Profile
Vegetation
WD
WE
WF
0
50
100
150
200
Ds
Sp, Ds
Ds
Sp, Lc
HIGH MARSH
V
UPLAND
V wood fragments
V
V
wood fragments
Ds, Sa
HIGH MARSH
Sa, Sp
PANNE
Ds, Sa
Ds
HIGH MARSH
Sa
LOW MARSH
V
Sa
PANNE
Sa, Ds
Ds, Sa
HIGH MARSH
Pa, Ds
PHRAGMITES BRACKISH MARSH
Ds
HIGH MARSH
wood fragments
Ds, V
V
UPLAND
Oi
Oe
Fsl
sl
S

Figure 6d.

flora were found throughout the upper 93 cm of mineral soil in profile BA, suggesting the presence of low marsh deposits. *Phragmites* rhizomes were found in the deepest organic horizons of the remaining three Barrington profiles, BB, BC, and BF. This indicates that these deposits were formed in a fresh or brackish environment, before rising sea level allowed the colonization of high marsh vegetation.

In contrast to the Barrington marsh, profiles WB, WC, and WE of the Warren marsh indicate the presence of both low marsh environments and high marsh peat which had developed above it. Rhizomes of *S. alterniflora* were present, or adjacent to the upper mineral horizons of these profiles. Three profiles of the Warren marsh represent areas where high marsh peat has grown laterally over non-tidal deposits. High marsh peat has accumulated over what appears to be upland soil in profiles WA and WD. Peat indicative of a *Phragmites* marsh, similar to that found in Barrington profiles BB, BC and BF, was found under the high marsh peat of profile WF.

Organic Carbon. By definition, organic soils must have a minimum of 12 to 18% organic carbon, depending upon the clay content. In this study, the percent organic carbon was estimated from the loss on ignition divided by a factor of 1.724. Estimated values of organic carbon ranged from 13.1 to 44.0% with a mean value of 31.8% (Appendix).

Wide ranges of organic carbon content have also been reported in earlier studies of marshes of southern Rhode Island and Connecticut (Hill and Shearin, 1970), Louisiana (Brupbacher et al., 1973) and Maryland (Darmody and Foss, 1978). However, in studies of Florida tidal marshes (Coultas and Gross, 1975; Coultas and Calhoun, 1976; and Coultas, 1980) maximum values of organic carbon were somewhat lower than those reported in this study (Table 1).

In this study, the content of organic carbon did not demonstrate any trends with soil depth, a finding consistent with those reported by investigators of other tidal marshes (Hill and Shearin, 1970; Coultas and Gross, 1975; Coultas and Calhoun, 1976; Darmody and Foss, 1978; and Coultas, 1980). Darmody and Foss (1978) have suggested that irregular distribution of organic carbon found in Maryland marshes is due to the burial of pockets or lenses of peaty material in locations protected from erosion and sedimentation. This hypothesis may explain the presence of organic layers interspersed with mineral sediments, but would not account for irregularities within only organic horizons. Differences in the percent organic carbon are most likely due to varying inorganic sediment supply through local changes in marsh physiography subject to different sedimentation rates, a variance in the duration of flooding, or a change in the amount of sediment carried by tidal waters.

Total Nitrogen. The percent total nitrogen of organic

Table 1. Comparison of organic carbon, nitrogen and carbon-nitrogen ratios determined for marshes in this study to those reported in Florida and Louisiana.

Location	% Organic C Maximum	% Total N Range	C-N Ratio Range
RI Marsh (Estuarine)	44.03	0.5-2.4	10.1-53.3
Fl[1]	29.73	0.6-1.4	13.9-30.3
LA[2]			
Brackish Marshes	49.72	0.8-3.1	10.4-36.2
Salt Marshes	44.52	0.8-3.0	14.4-43.8

[1] Coultas and Gross, 1975; Coultas and Calhoun, 1976; and Coultas, 1980.

[2] Brupbacher et al., 1973.

layers ranges from 0.5% to 2.4% with a mean value of 1.4%. The total nitrogen content of each organic horizon is reported in Appendix 5 .

Nitrogen content decreases with depth below the two uppermost horizons, which contain live rhizomes (Figure 7). When all horizons are considered in statistical analyses, the correlation of nitrogen content with depth is poor ($r = -0.37$; $P \leq .01$). However, when the upper two horizons are deleted from the analysis, the correlation coefficient is much higher ($r = 0.67$; $P \leq .01$).

Percent total, or organic nitrogen has not been as widely studied as organic carbon. Values reported for marshes in Louisiana (Brupbacher, et al., 1973) are comparable to those found in this study (Table 1). However, the range of percent nitrogen values reported for Florida tidal marshes (Coultas and Gross, 1975; Coultas and Calhoun, 1976; and Coultas, 1980) is considerably narrower. It is doubtful that differences in marsh vegetation could account for these differences, since the vegetation in the marshes of Louisiana is expected to be more comparable to that found in Florida than Rhode Island. Differences in the ranges of percent total nitrogen may be due to nitrogen enrichment of tidal waters, or differences in technique of the investigators.

Carbon-Nitrogen Ratio. Carbon-nitrogen ratios ranged from 10 to 53 with an average of 23. Values determined for each horizon are reported in Appendix 5 .

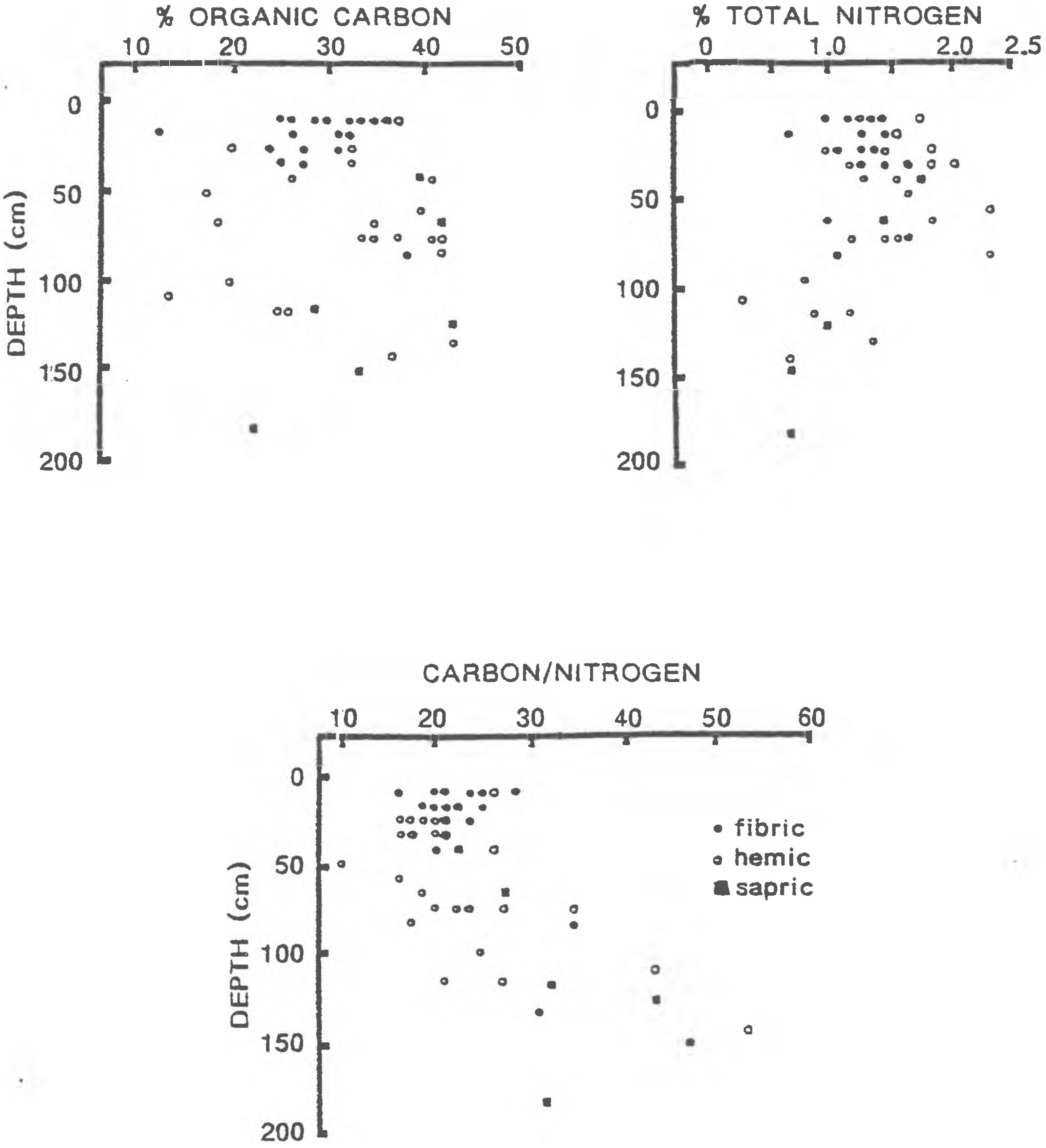


Figure 7. Relationship of organic carbon, total nitrogen, and carbon-nitrogen ratios to soil depth.

Carbon-nitrogen ratios reported for Florida tidal marsh soils (Coultas and Gross, 1975; Coultas and Calhoun, 1976; and Coultas, 1980) were slightly lower and narrower than those reported for brackish and saltwater marshes in Louisiana (Brupbacher et al., 1973) (Table 1).

Within the profiles analysed in this study, the carbon-nitrogen ratios tend to decrease within the first two or three horizons, then increase with depth (Figure 7). This slight decrease most likely is attributable to the presence of live rhizomes in the uppermost two horizons, which have lower nitrogen content. In fact, when values for these horizons are deleted from analyses, the correlation coefficient representing the relationship of carbon-nitrogen ratios with depth becomes higher, with the r value increasing from 0.65 to 0.70 ($P \leq .01$). Since carbon-nitrogen ratios were not derived for mineral horizons, it is not possible to determine if this trend of increasing ratios continues with depth. However, Coultas and Calhoun (1976), who analysed both organic and mineral layers, reported increasing carbon-nitrogen ratios with depth. They believed that this was a reflection of greater microbial activity in surface horizons and denitrification of more permanently anaerobic subsurface horizons.

Brupbacher et al. (1973) did not report any trends in carbon-nitrogen ratios determined for Louisiana soils, but felt that the carbon-nitrogen ratios were an indicator of the degree of organic decomposition of the soil material.

For the organic horizons analyzed in this study, there were no significant statistical relationships between carbon-nitrogen ratios and degree of decomposition, as indicated by fiber content or sodium pyrophosphate color (Table 2).

Fiber Content. The fiber content of each organic horizon is listed in Tables 3 and 4. The content of unrubbed fiber ranged from 30-96% and the content of rubbed fiber ranged from 4-72%. There is little relationship between the two parameters (Figure 8). Although unrubbed fiber content does not demonstrate any trend with horizon depth, rubbed fiber percentages do (Figure 9). Neither measurement correlated with organic carbon, total nitrogen, or carbon-nitrogen ratios (Table 2).

Lynn et al. (1974), who analyzed organic soils from peat bogs, swamps and coastal marshes, reported that rubbed fiber was commonly associated with the mineral content of the soil. In this study, however, no significant correlation was found between rubbed fiber and mineral content, as determined by percent ash by weight (Figure 8).

As the two measurements of fiber content individually bore little relationship to physical or chemical soil properties, it was thought that a combination, or index of the two parameters might be more relevant. Three indices were applied: 1) U-R = % unrubbed fiber - % rubbed fiber, 2) R/U = % rubbed fiber ÷ % unrubbed fiber, and 3) U-R/R = (% unrubbed fiber - % rubbed fiber) ÷ % rubbed fiber.

Table 2. Correlation coefficients of relationship of measurements of fiber, sodium pyrophosphate index, organic carbon, nitrogen and carbon-nitrogen ratios.

	U[1]	R[2]	U-R	R/U	U-R/R	OC[3]	N[4]	C/N[5]	PI[6]
Horizon	-0.22^{ns}	-0.63**	0.53**	-0.67**	0.60**	0.11^{ns}	- 0.37**	0.65**	0.57**
PI	0.38**	0.55**	-0.31*	0.53*	-0.42**	0.03^{ns}	0.031*	-0.43**	
C/N	-0.20^{ns}	-0.20^{ns}	0.02^{ns}	-0.19^{ns}	0.19^{ns}	0.25^{ns}	-0.64**		
Nitrogen	0.18^{ns}	-0.12^{ns}	0.25^{ns}	-0.14^{ns}	0.19^{ns}	0.50**			
Organic Carbon	0.03^{ns}	-0.22^{ns}	0.25^{ns}	-0.25^{ns}	0.31*				
U-R/R	-0.22^{ns}	-0.77**	0.64**	-0.78**					
R/U	0.16^{ns}	0.96^{ns}	-0.89**						
U-R	0.28*	-0.78**							
RF	0.39**								

1) Unrubbed fiber, 2) Rubbed fiber, 3) Organic carbon, 4) Nitrogen, 5) Carbon-nitrogen ratio, 6) Sodium pyrophosphate color index

*,** Significant at the .05 and .01 levels, respectively.

Table 3. Depth, fiber content, sodium pyrophosphate color, and decomposition class of organic horizons of Warren Marsh.

Sample	Depth	Fiber Unrubbed	Fiber Rubbed	S-P[1] Color	Decomposition Class
	cm	%	%		
WA 1	0-10	74	50	8/1	Fibric
2	10-21	50	24	8/1	Hemic
3	21-33	70	22	8/1	Hemic
4	33-79	62	16	8/1	Hemic
5	79-90	80	6	8/2	Hemic
6	90-100	66	10	7/2	Hemic
WB 1	0-9	70	60	8/1	Fibric
2	9-49	70	60	8/1	Hemic
3	49-79	60	36	8/1	Hemic
4	79-121	78	32	8/2	Hemic
5	121-150	62	8	6/3	Sapric
WC 1	0-18	76	36	7/3	Hemic
2	18-27	60	16	8/2	Hemic
3	27-41	70	22	8/2	Hemic
4	41-94	72	18	6/3	Sapric
WD 1	0-19	78	72	8/1	Fibric
2	19-31	74	36	8/1	Fibric
3	31-44	70	22	8/2	Hemic
4	44-109	76	34	7/2	Hemic
5	109-137	52	8	5/3	Sapric
6	137-155	30	4	4/4	Sapric
WE 1	0-13	76	60	8/1	Fibric
2	13-22	72	56	8/1	Fibric
3	22-33	90	40	8/3	Fibric
4	33-42	62	50	7/2	Fibric
5	42-109	70	28	7/3	Hemic
WF 1	0-18	56	40	8/2	Hemic
2	18-25	90	28	8/2	Hemic
3	25-45	86	44	8/2	Fibric
4	45-112	80	22	7/3	Hemic
5	112-126	62	14	5/3	Sapric

---

[1] Sodium pyrophosphate extract.

Table 4. Depth, fiber content, sodium pyrophosphate color, and decomposition class of organic horizons of Barrington marsh.

Sample	Depth	Fiber		S-P[1]	Decomposition
		Unrubbed	Rubbed	Color	Class
	cm	%	%		
BA 1	0-15	80	66	8/1	Fibric
2	15-50	84	48	7/3	Hemic
3	50-103	80	24	7/3	Hemic
4	103-135	72	24	3/1	Hemic
BB 1	0-13	58	28	8/1	Hemic
2	13-24	70	62	8/1	Fibric
3	24-37	78	54	8/1	Fibric
4	37-60	74	34	7/3	Hemic
5	60-90	72	26	8/2	Hemic
6	90-140	72	28	8/2	Hemic
BC 1	0-11	72	50	8/2	Fibric
2	11-18	74	52	8/2	Fibric
3	18-28	70	26	7/3	Hemic
4	28-53	78	18	8/2	Hemic
5	53-94	80	12	8/2	Hemic
6	94-182	82	32	8/2	Hemic
BD 1	0-10	72	56	8/1	Fibric
2	10-18	82	56	8/2	Fibric
3	18-23	68	40	8/3	Fibric
4	23-56	64	16	6/3	Sapric
5	56-90	64	12	8/2	Hemic
BE 1	0-18	72	48	8/1	Fibric
2	18-34	92	52	8/2	Fibric
3	34-92	88	28	8/2	Hemic
4	92-176	82	28	8/1	Hemic
5	176-193	60	8	5/3	Sapric
BF 1	0-11	78	50	8/1	Fibric
2	11-24	78	56	8/2	Fibric
3	24-62	74	22	7/3	Hemic
4	62-105	96	44	8/2	Fibric
5	105-117	54	24	5/3	Hemic

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[1] Sodium pyrophosphate extract.

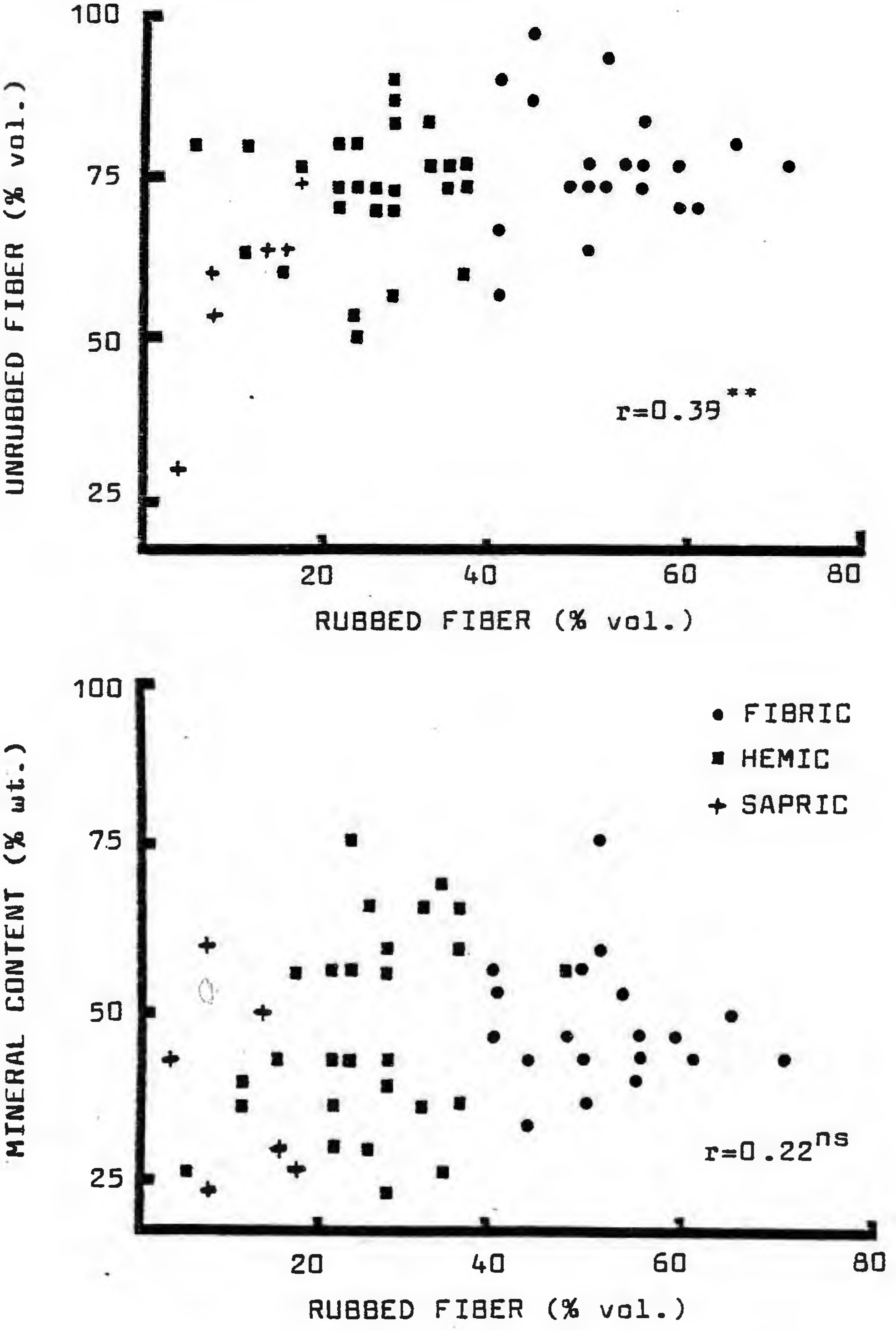

Figure 8. Relationship of rubbed fiber to unrubbed fiber and mineral content.

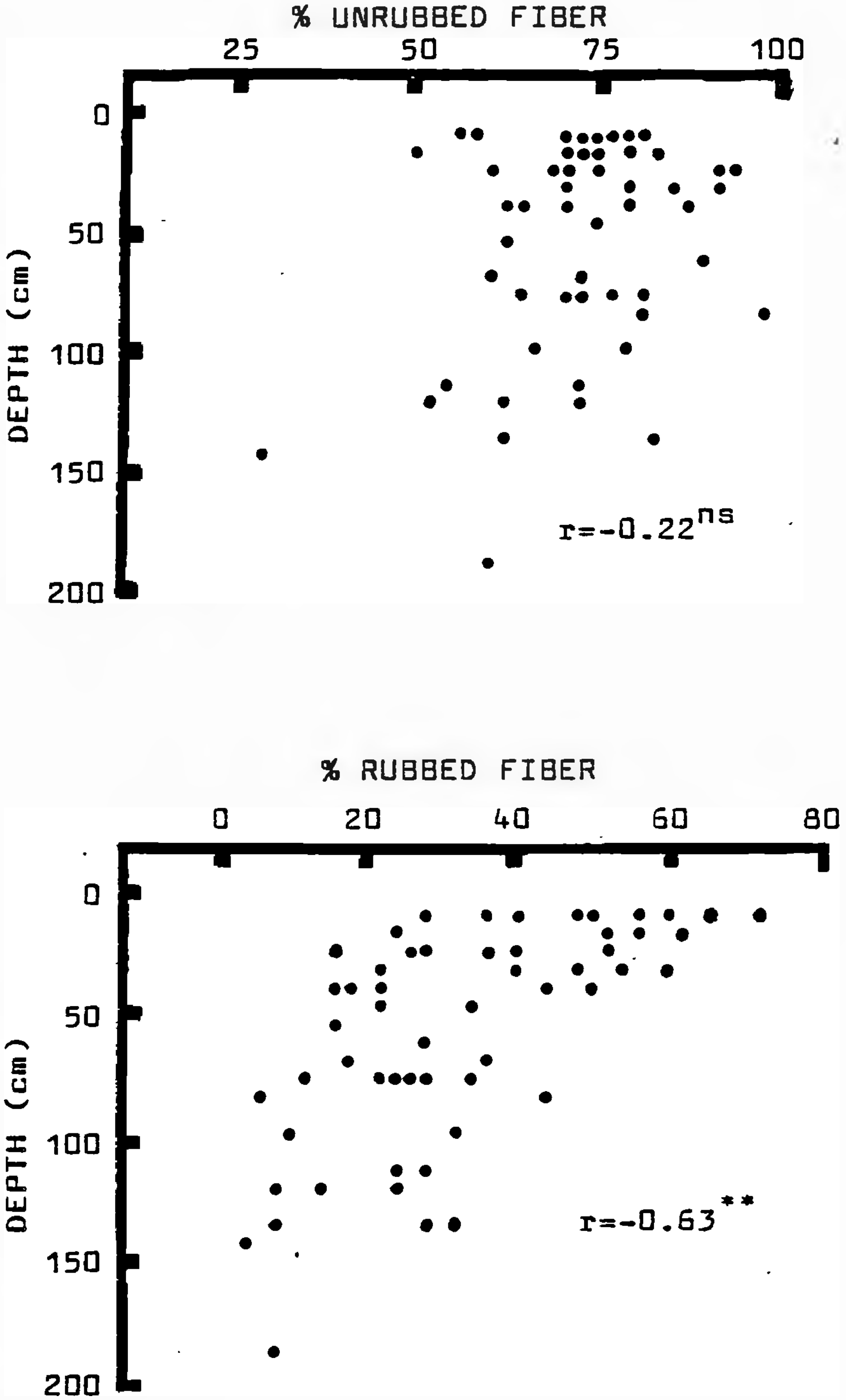

Figure 9. Relationship of fiber content to soil depth.

The mean value and range of each of these indices is provided in Table 5. All indices significantly correlated with mid-horizon depth, but showed little relationship to other soil properties (Table 4).

Sodium Pyrophosphate Color. The value and chroma of the sodium pyrophosphate (S-P) color of each organic horizon are listed in Tables 3 and 4. the index (PI) of S-P color (value - chroma) is significantly correlated to mid-horizon depth ($r = 0.57$, $P \leq .05$). This index is also significantly correlated with both percent unrubbed and rubbed fiber, as well as all three fiber indices (Table 2). Of all these variables, S-P color is most highly correlated to pereent rubbed fiber (Figure 10).

Although no statistical analyses were mentioned, Lynn et al. (1974) reported that a plot of their data (PI vs. RF), similar to that in Figure 10 , indicated "consistency between the two measures of decomposition." In this study the statistical correlation between the pyrophosphate index and rubbed fiber is not high ($r = 0.55$, $P \leq .01$). However, when decomposition classes are considered separately, higher correlations are found within fibric ($r = 0.66$, $P \leq .01$) and sapric ($r = 0.87$, $P \leq .05$) groups (Figure 10). There is no significant correlation between PI and rubbed fiber within the hemic group. This lack of correlation is to be expected, for by definition, hemic material does not have corresponding values for rubbed fiber content and S-P color.

Table 5. Range and mean of unrubbed fiber, rubbed fiber, and fiber index for each decomposition class.

Decomposition Class	N	% Unrubbed Fiber (U)		% Rubbed Fiber (R)		U-R		R/U		(U-R)/R	
		Range	$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$
determined by fiber content and sodium pyrophosphate color											
Fibric	23	56-96	76a[1]	40-72	53a	6-52	23a	0.44-0.92	0.71a	0.08-1.25	0.47a
Hemic	32	50-90	72a	6-48	25b	24-74	47b	0.08-0.60	0.35b	0.67-12.33	2.44b
Sapric	6	30-72	57b	4-18	11c	26-54	45b	0.13-0.25	0.19c	3.00-6.50	4.65c
determined by fiber content alone											
Fibric	24	56-96	76a	40-72	53a	6-52	24a	0.44-0.92	0.70a	0.08-1.25	0.48a
Hemic	26	50-90	73a	18-36	27b	24-62	46b	0.23-0.60	0.38b	0.67-3.33	1.80b
Sapric	11	30-80	62b	4-16	11c	26-74	51b	0.08-0.27	0.18c	2.75-12.33	5.32c
determined by sodium pyrophosphate color alone											
Fibric	45	50-96	74a	6-72	39a	6-74	35a	0.08-0.92	0.52a	0.08-12.33	1.60a
Hemic	8	70-84	76a	22-48	30a	36-58	46a	0.28-0.57	0.39ab	0.75-2.64	1.70a
Sapric	8	30-72	58b	4-24	15b	26-54	44a	0.13-0.44	0.24b	1.25-6.50	3.90b
All Classes	61	30-96	72	4-72	34	6-74	38	0.08-0.92	0.47	0.08-12.33	1.91

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[1] Means within columns followed by the same letter(s) are not significantly different at the .05 level using Duncan's New Multiple Range Test.

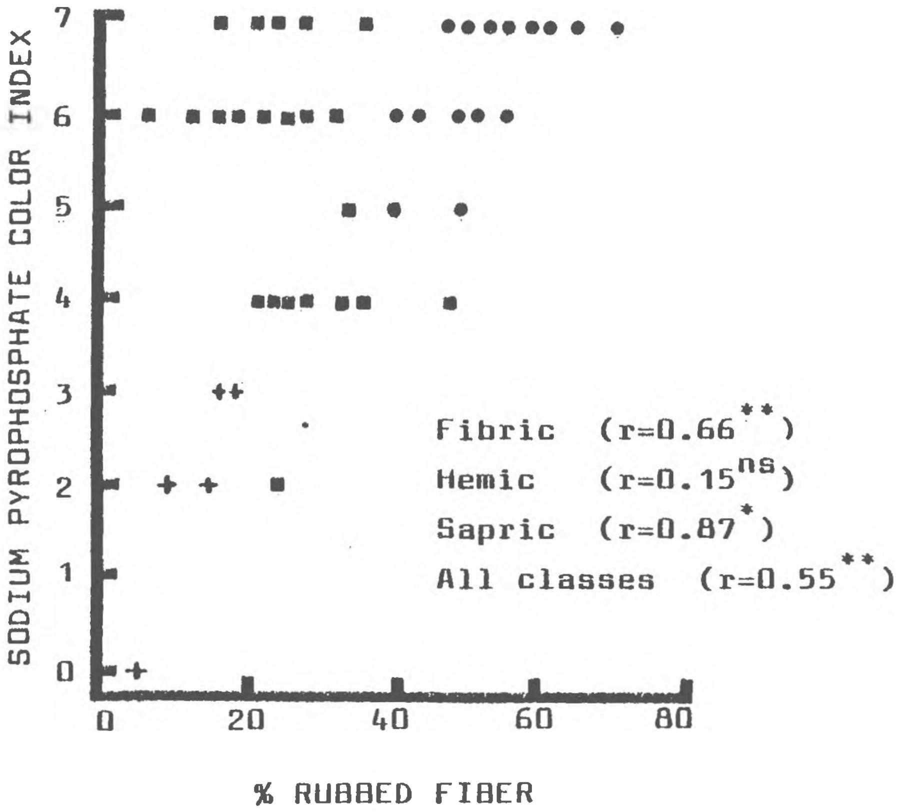

Figure 10. Relationship of rubbed fiber to sodium pyrophosphate color index.

Sodium pyrophosphate color index is not correlated with organic carbon, but it is significantly correlated with total nitrogen ($R = 0.31$, $P \leq .01$) and carbon-nitrogen ratios ($r = 0.43$, $P \leq .05$) (Table 2). These data suggest that PI may be a better indicator of organic matter decomposition than fiber content since neither nitrogen nor carbon-nitrogen ratios correlate with fiber content.

Classification of Organic Material. The state of decomposition as determined by rubbed fiber content and S-P color, is listed for each horizon in Tables 3 and 4. Most of the horizons were classified as hemic, and represented the greatest percentage of all peat inspected from the Barrington (71%) and Warren (59%) marshes. Fibric horizons represented the second greatest percentage of all peat inspected from the Barrington (20%) and Warren (22%) marshes.

Four horizons had rubbed fiber contents in the sapric range, yet had S-P colors in the fibric range, with values of 7 and 8 and chromas of 1 or 2. Such a discrepancy suggests the presence of limnic material, particularly coprogenous earth, a deposit consisting primarily of fecal pellets (Soil Survey Staff, 1975). Inspection with a light microscope provided no evidence that these layers consisted of such material. Thus, for purposes of this study, these layers have been placed in the hemic category.

State of decomposition was generally, but not always, associated with depth. All but two (WC and BB) of the twelve surface horizons were fibric and underlain by more decomposed material at depths ranging from 15-49 cm. Fibric horizons were found below hemic horizons in profiles BB, BF, and WF. Sapric horizons occurred in only six profiles and in four of these, they were found immediately overlying inorganic sediments.

The state of decomposition of organic soils, determined primarily by fiber content, has been found to have little effect on the bulk density of the organic fraction of the soil (Lynn et al., 1974), but is associated with their hydrologic characteristics (Boelter, 1974). There have been no reports, however, regarding the association between state of decomposition for classification purposes and carbon-nitrogen ratios, a common indicator of decomposition in aerobic soils (Alexander, 1977).

To determine if such an association exists, a Duncan's mean separation test was used to compare the average organic carbon content, total nitrogen content, and carbon-nitrogen ratio of each decomposition class (Table 6). This test was also applied to decomposition classes differentiated on the basis of rubbed fiber alone and, on the basis of S-P color alone to see if these parameters allowed better separation of chemical characteristics of decomposition classes.

There appears to be no relationship between the state of decomposition and organic carbon content, as no statistical difference (.05 level) exists among decomposition classes as determined by any of the three methods. Differences in the average total nitrogen content could not be

Table 6. Range and mean of organic carbon, total nitrogen and carbon-nitrogen ratios for each decomposition class.

Decomposition Class	N	% Organic Carbon		% Total Nitrogen		Carbon/Nitrogen	
		Range	X̄	Range	X̄	Range	X̄
		determined by fiber content and sodium pyrophosphate color					
Fibric	24	13.1-38.7	30.0a[1]	0.7-1.7	1.3a	17-35	23a
Hemic	31	13.2-44.0	30.8a	0.3-2.4	1.4a	10-53	24a
Sapric	6	23.0-44.0	35.2a	0.7-1.8	1.1a	22-47	34b
		determined by fiber content alone					
Fibric	24	13.1-38.7	29.7a	0.7-1.7	1.3a	17-35	22a
Hemic	25	13.2-44.0	30.4a	0.3-2.1	1.4a	10-53	24ab
Sapric	11	23.0-43.9	34.6a	0.5-2.4	1.4a	12-48	29b
		determined by sodium pyrophosphate color alone					
Fibric	45	13.1-44.0	31.1a	0.5-2.4	1.4a	16-53	23a
Hemic	7	17.1-41.47	30.1a	1.0-1.8	1.5a	10-26	19a
Sapric	8	13.2-43.9	31.3a	0.3-1.8	1.0b	22-47	34b
All Classes	60	13.1-44.0	30.9	0.3-2.4	0.3	10-53	24

[1] Means within columns followed by the same letter(s) are not significantly different at the .05 level using Duncan's New Multiple Range Test.

detected among decomposition calsses as determined by fiber content alone or fiber content in conjunction with S-P color. However, for decomposition classes determined by S-P color alone the average total nitrogen content of sapric materials was significantly lower than that of the other decomposition classes.

As would be expected from the relationship of organic carbon and total nitrogen to decomposition classes, there were few significant differences between average carbon-nitrogen ratios and decomposition classes. Classes determined by rubbed fiber alone showed no differences between means of organic carbon or nitrogen.

The analyses indicated that carbon-nitrogen ratios of sapric classes, which represent the most decomposed material, are significantly higher than those of other classes. This trend may seem surprising, since in aerobic environments carbon-nitrogen ratios generally decrease with increasing decomposition (Alexander, 1977). However, the physical evidence of decomposition observed during analyses of fiber content is difficult to dispute. The most logical explanation is that carbon-nitrogen ratios are not indicative of decomposition in a tidal marsh environment. These ratios do not follow trends dictated by decomposition of organic carbon, which had erratic distributions. Instead, they follow the strong trend of decreasing nitrogen content with depth.

There appeared to be little association between state of decomposition and vegetation, except for those horizons containing primarily Phragmites australis fragments, in which four out of five horizons were classified as hemic. High marsh species and Spartina alterniflora were found in association with fibric, hemic, and sapric horizons. As studies of other tidal marshes (Hill and Shearin, 1970; Breeding et al., 1974; Coultas and Calhoun, 1978; Darmody and Foss, 1978; and Coultas, 1980) have not included description of the vegetation of subsurface horizons, it cannot be determined if such an association exists.

Soil pH. The range of pH values for the Barrington and Warren marshes was very similar to the ranges reported for tidal marshes of Connecticut and southern Rhode Island (Hill and Shearin, 1970) and Maryland (Darmody, 1975). The first series of pH readings was assumed to be representative of field-moist conditions and included readings of 3.04 to 7.64. The average pH of all organic horizons was 6.33, a value significantly lower (.01 level) than the average field-moist pH of 6.61 found for all mineral horizons (Tables 7 and 8).

After initial drying and rewetting, the average pH of all profiles significantly decreased (.05 level) (Tables 7 and 8). The decrease in pH of organic material was significantly greater (.01 level) than that which occurred in mineral material. The pH of organic layers did not significantly decrease after the initial drying and rewetting

Table 7. Range and mean of sequential pH readings for organic horizons of each profile.

	Field Moist		After 1 Drying		After Rewetting & Second Drying		After Rewetting & Third Drying	
Profile	Range	$\bar{X}$[1]	Range	$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$
BA	6.68-6.85	6.78	4.60-5.82	5.32	4.79-5.90	5.33	4.30-5.50	5.07
BB	5.87-7.14	6.78	5.07-5.63	6.03	4.86-6.56	5.90	5.10-6.40	5.87
BC	6.31-6.67	6.43	4.65-5.76	5.34	5.09-5.97	5.53	5.20-6.00	5.57
BD	5.88-6.91	6.56	4.64-6.29	5.62	4.68-6.26	5.52	4.70-5.80	5.20
BE	4.42-6.20	6.78	3.21-5.76	5.11	3.93-5.47	4.91	4.30-5.50	4.87
BF	5.80-6.28	6.02	5.07-6.19	5.80	5.23-6.15	5.78	5.20-6.00	5.67
WA	3.04-6.78	5.87	3.39-6.18	5.36	3.22-6.12	4.65	3.70-5.90	4.70
WB	5.60-7.10	6.59	4.59-6.29	5.45	4.39-6.33	5.48	4.80-6.30	5.50
WC	5.25-6.40	6.04	4.69-6.01	5.61	4.45-6.06	5.50	4.60-5.90	5.47
WD	4.43-6.66	6.15	4.29-6.15	5.69	4.59-5.98	5.45	3.60-5.70	4.80
WE	5.15-6.70	6.06	4.41-6.12	5.27	4.02-5.87	5.13	4.10-5.50	4.86
WF	5.49-6.90	6.45	5.32-6.23	5.94	5.27-6.07	5.77	5.10-5.90	5.60
Overall	3.04-7.14	6.33a[2]	3.21-6.53	5.56b	3.22-6.56	5.45b	3.60-6.40	5.33b

[1] Means within columns are not significantly different.

[2] Means followed by different letters are significantly different at the .05 level using Duncan's New Multiple Range Test.

Table 8. Range and mean of sequential pH readings for mineral horizons of each profile.

	Field Moist		After 1 Drying		After Rewetting & Second Drying		After Rewetting & Third Drying	
Profile	Range	$\bar{X}$[1]	Range	$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$
BA	6.65-6.87	6.74	6.12-6.54	6.31	5.94-6.25	6.13	5.70-6.10	5.90
BB	6.64-6.81	6.71	5.76-6.61	6.23	4.81-6.42	5.74	4.70-6.30	5.63
BC	6.65-6.80	6.72	5.39-6.01	5.70	--	4.08	--	3.90
BD	6.62-6.76	6.71	6.22-6.96	6.51	6.36-6.74	6.55	6.10-6.20	6.15
BE	6.08-6.23	6.15	5.63-5.84	5.75	5.67-5.77	5.73	5.50-5.80	5.65
BF	6.41-6.72	6.54	5.45-5.86	5.64	5.27-5.76	5.58	5.20-5.70	5.55
WA	6.37-6.56	6.49	4.44-6.23	5.77	3.71-6.30	5.59	3.30-6.10	5.30
WB	6.87-7.64	7.20	5.53-6.98	6.19	4.95-6.62	5.78	4.40-6.40	5.42
WC	5.91-6.45	6.16	5.34-6.10	5.73	5.16-5.90	5.60	4.90-5.80	5.40
WD	--	6.15	--	5.79	--	5.81	--	5.40
WE	6.64-6.82	6.72	5.87-6.72	6.25	4.45-6.45	5.83	4.10-6.00	5.39
WF	6.85-7.28	7.05	6.34-7.22	6.75	5.88-6.87	6.46	5.50-6.60	6.17
Overall	5.80-7.64	6.61a[2]	4.44-7.22	6.13b	3.71-6.87	5.88c	3.30-6.60	5.62d

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[1] Means within columns are not significantly different.

[2] Means followed by different letters are significantly different at the .05 level using Duncan's New Multiple Range Test.

treatment. The pH of mineral material, however, did significantly decrease after the initial drying and rewetting treatments, although each reduction was less than the initial drop occurring in the organic material. Sequential pH readings and the difference in responses of organic and mineral material of two profiles to wetting and drying treatments is graphically portrayed in Figure 11. The pH readings of each sample are listed in Appendix 6,7.

This decrease in pH of marsh soils after drying has been used as an indicator of potential acidity of the soil in a drained condition in studies by Fleming and Alexander (1961), Coultas and Gross (1975), Coultas and Calhoun (1976), and Coultas (1980). The pH of marsh soils decreased upon drying in these studies and, in studies conducted by Hill and Shearin (1970), Breeding et al. (1974), and Darmody (1975). Although these investigators attributed the decrease in pH to the oxidation of sulfides present in the soil, no statistical correlation was shown between concentrations of sulfur compounds and decreases in pH levels.

Bloomfield and Coulter (1973) suggested that neither extended air drying nor alternate drying and rewetting of soils are adequate treatments for the determination of the full acid-sulfate potential of marsh soils. Instead, they recommend that soils be kept permanently moist and aerated, and stored several weeks before determination of pH decrease. Brinkman and Pons (1973) have described another method

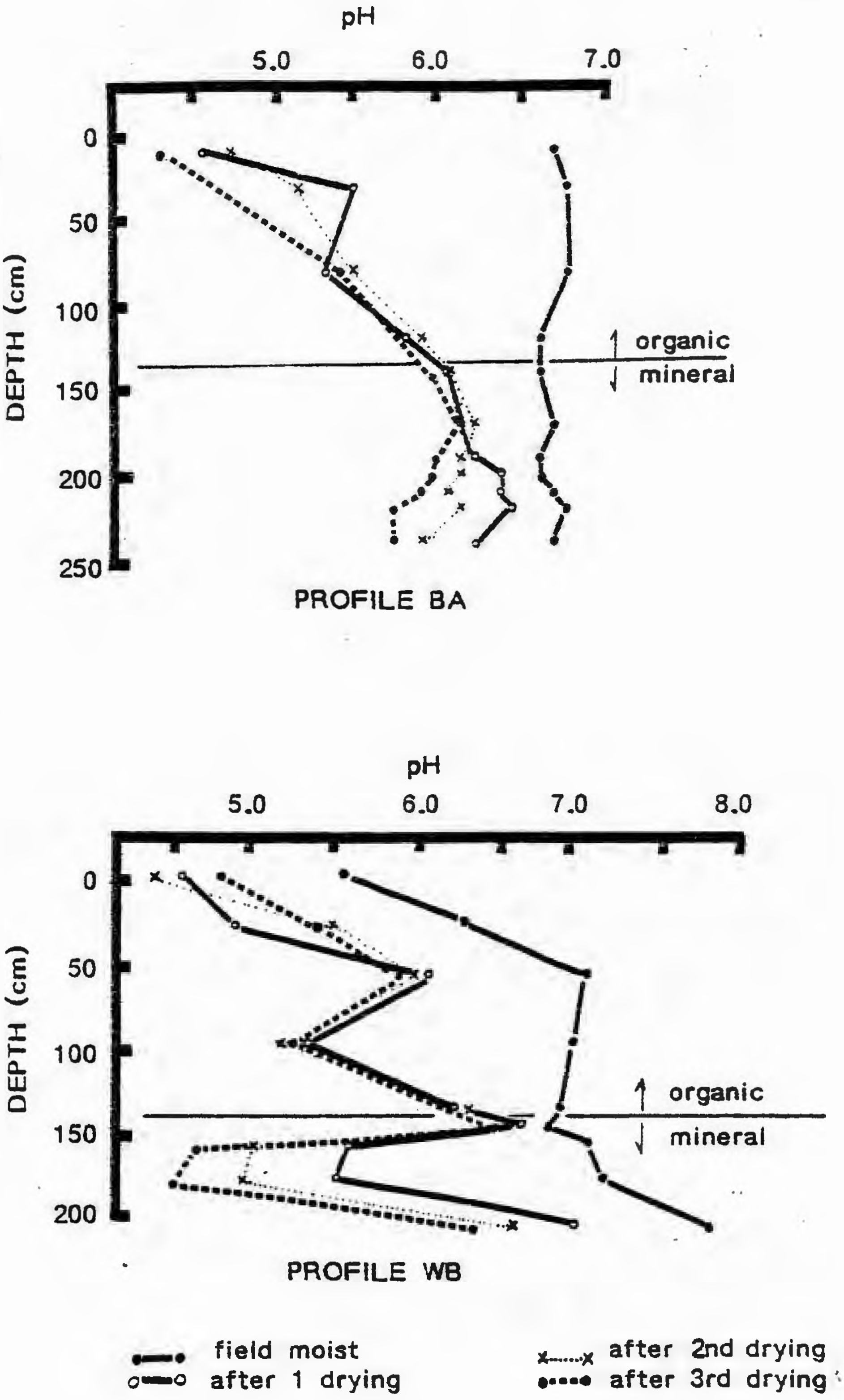


Figure 11. Change in pH with drying treatments of two representative profiles.

developed by Van Beers by which soil is oxidized with 30% H_2O_2 before a second pH determination is made. This method is also recommended for field identification of sulfidic material by the Soil Conservation Service (Soil Survey Staff, 1975). Breeding et al. (1974) used both methods and reported pH values 2 to 3 units lower than air drying after H_2O_2 treatment. However, the noxious fumes associated with H_2O_2 oxidation and the long-term storage required for alternate wetting-drying or slow oxidation make both types of methods impractical for determination of pH in the laboratory or field.

The analyses performed in this study indicate that repeated wetting and drying treatments for determination of change in pH of organic material is not necessary, since the pH does not significantly decrease following one drying cycle. However, special treatment may be required to determine the maximum drop in pH of mineral material underlying organic marsh deposits.

Concentration and Distribution of Metals in Soil Profiles. The concentrations of Cd, Cu, Cr, Fe, Mn, Ni, Pb, and Zn determined for all organic horizons are listed in Appendix 10,11. Table 9 provides a comparison of the mean and range of concentrations of each metal included in this study with those reported by other investigators for soil, seawater, estuarine sediments and waters of the eastern coast of the United States. The values presented for marshes and tidal

Table 9. Average concentrations and ranges* of Cd, Cr, Cu, Pb, Mn, Ni, Zn and Fe in soil, seawater, and southeastern United States estuarine sediments and waters in comparison to those found in Rhode Island tidal salt marshes.

	Cadmium ppm	Chromium ppm	Copper ppm	Lead ppm	Manganese ppm	Nickel ppm	Zinc ppm	Iron ppt
RI Tidal Salt Marsh	0.35	49	68	36	46	36	41	33
	(0.0-2.43)	(2-172)	(3-198)	(4-139)	(10-99)	(2-130)	(2-244)	(1-96)
Other Sediments								
Narragansett Bay[1]	--	--	--	--	--	--	--	--
	(.1-10)	(57-363)	--	--	(70-400)	---	(41-1250)	(2-3300)
MA Tidal Creek[2]	--	--	--	--	--	--	--	--
	(12-20)	(57-363)	--	--	-- --	(48-98)	(45-130)	(2-21)
MA Tidal Salt Marsh[3,4]	--	--	--	--	--	--	--	--
	--	--	(18-57)	--	--	--	--	--
CT Tidal Salt Marsh[5]	--	--	37	54	259	--	84	39
	--	--	(6-149)	(3-217)	(119-896)	--	(19-234)	(33-45)
NC Tidal Salt Marsh[6]	--	28	18	36	59	--	--	--
	--	--	--	--	--	--	--	--
NC Tidal Flat[6]	1.25	35	12	21	--	--	126	--
	(0.6-1.9)	(16-54)	(6-17)	--	--	--	(90-162)	--
NC Tidal Marsh Creek[6]	0.5	9	11	16	18	--	105	8
	(0.1-1.2)	(1-19)	(1-50)	(2-102)	(6-47)	--	(3-441)	(1-38)
SE U.S. Tidal Salt Marshes[7]	1.4	--	11	--	202	--	--	310
	(0.1-5.0)	--	(2-30)	--	(74-366)	--	--	(90-500)
Long Island Sound[8]	--	--	--	--	--	--	--	--
	--	--	(4-75)	(4-59)	--	--	(46-176)	--
Estuarine Water								
Narragansett Bay[1]	5×10^{-5}	$< 5\times10^{-3}$	--	--		--	--	--
	--	--	--	--	$(1.3\text{-}5.3\times10^{-3})$	--	--	$(2.5\times10^{-3}\text{-}4)$
SE U.S. Estuaries[7]	0.8	--	8×10^{-3}	--	19	--	--	2.0×10^{-4}
	(0.1-3.6)	--	$(6\text{-}13\times10^{-3})$	--	(1-85)	--	--	$(1.0\text{-}6.1\times10^{-5})$
Seawater[9]	1×10^{-4}	5×10^{-5}	3×10^{-3}	3×10^{-5}	2×10^{-3}	5.4×10^{-3}	1×10^{-2}	10
Soil[9]	0.06	100	20	10	850	40	50	38
	(0.01-0.7)	(5-3000)	(2-100)	(2-200)	(100-4000)	(10-1000)	(10-300)	(7-550)

[1] Olson and Lee, 1979 [2] Hogan, 1977 [3] Banus et al., 1975 [4] Giblin et al., 1980 [5] McCaffrey, 1977

[6] Whaling et al., 1977 [7] Windom, 1975 [8] Bowen, 1966.

* Ranges in parentheses.

flats represent areas considered pristine, or used for baseline data by the investigators, but in some cases are the result of only limited sampling. This table demonstrates that concentrations of heavy metals in estuarine and coastal waters are considerably lower than concentrations of the same metals in marsh soils. This supports the conclusion of several investigators (Windom, 1975; McCaffrey, 1977; and Nixon, 1980) that tidal salt marshes are "sinks" for heavy metals.

With the exception of Mn, the concentrations of metals analysed in this study appear to be comparable to those reported for other tidal marshes. Concentrations of Mn were found to be lower than those reported for marshes in the Southeast (Windom, 1975 and Whaling et al., 1977).

Iron, as found in other studies, was the most concentrated metal in the marsh sediments, followed in decreasing order by Cu, Cr, Mn, Zn, Pb, Ni, and Cd. Concentrations of Cd were very low, often below the limit of detection.

The concentrations of all metals generally decreased with depth. Concentrations of Pb and Zn sharply decreased to a depth of approximately 40 cm, yet were relatively constant below this depth (Figure 12). Distributions of Ni, Cd, Cr, and Cu with depth are similar to the distributions of Pb and Zn, but there is a wider range of concentrations of the former metals in the deeper horizons (Figures 13 and 14). Plots of Fe and Mn concentrations

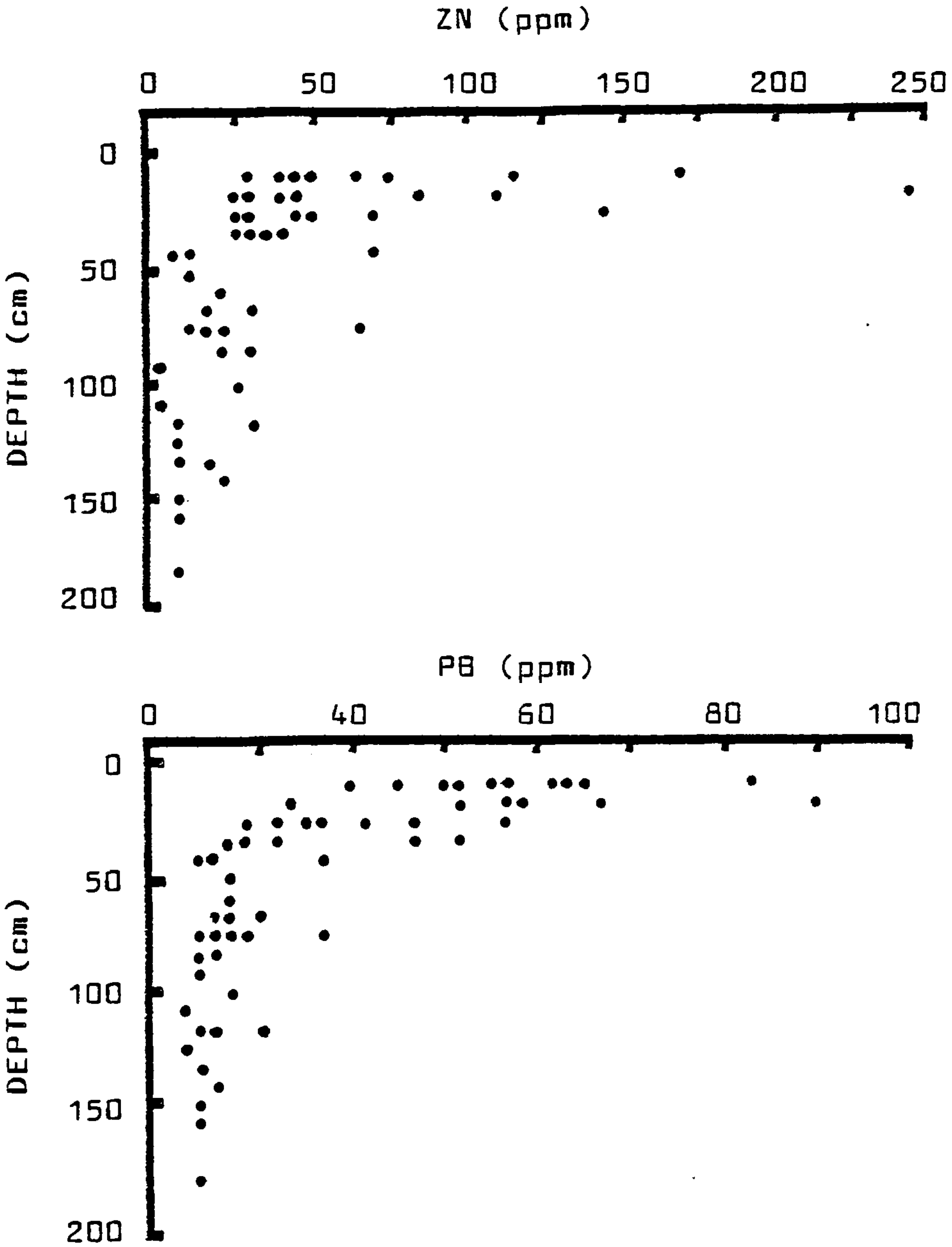


Figure 12. Distribution of total Zn and Pb with depth in 12 tidal salt marsh soil profiles.

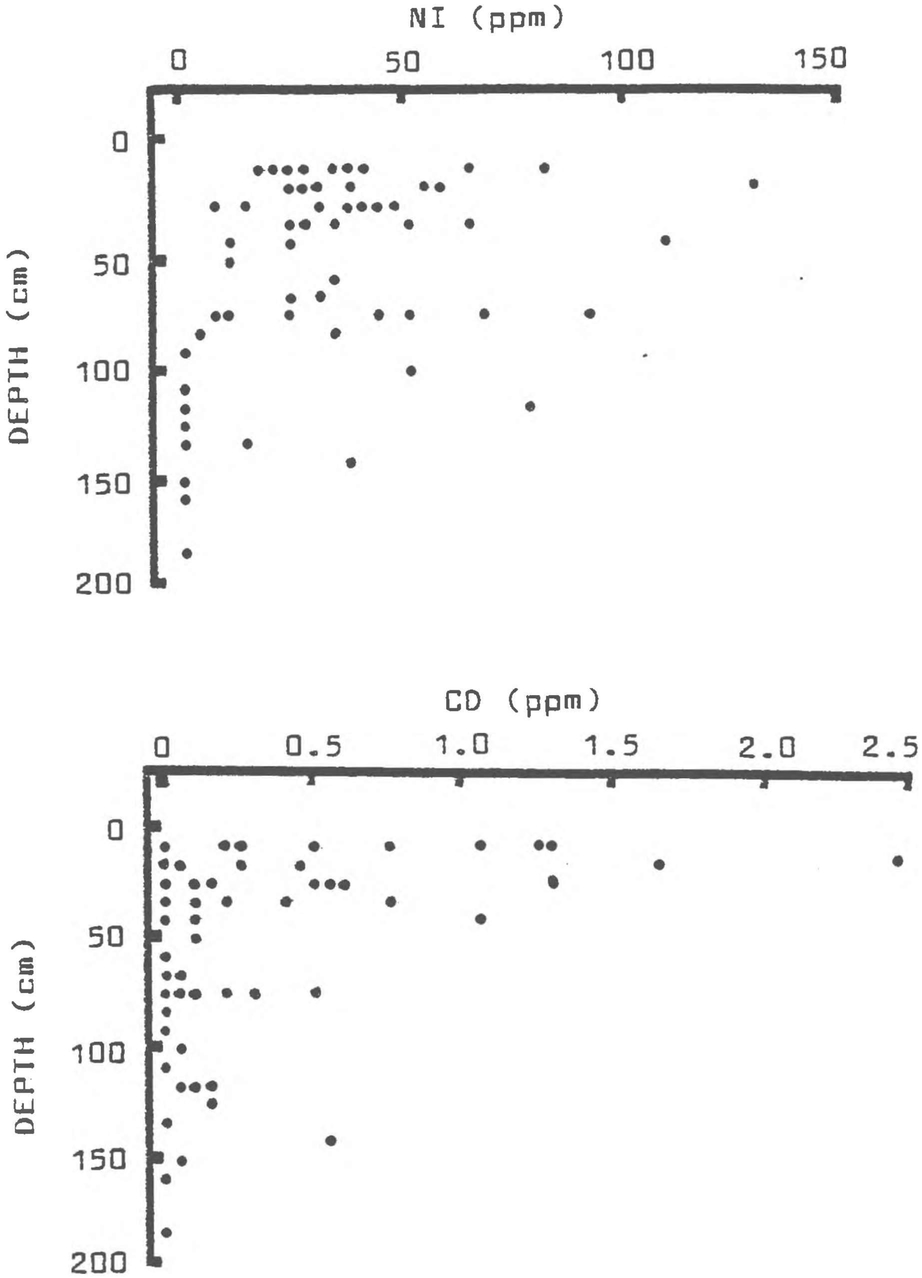


Figure 13. Distribution of total Ni and Cd with depth in 12 tidal salt marsh soil profiles.

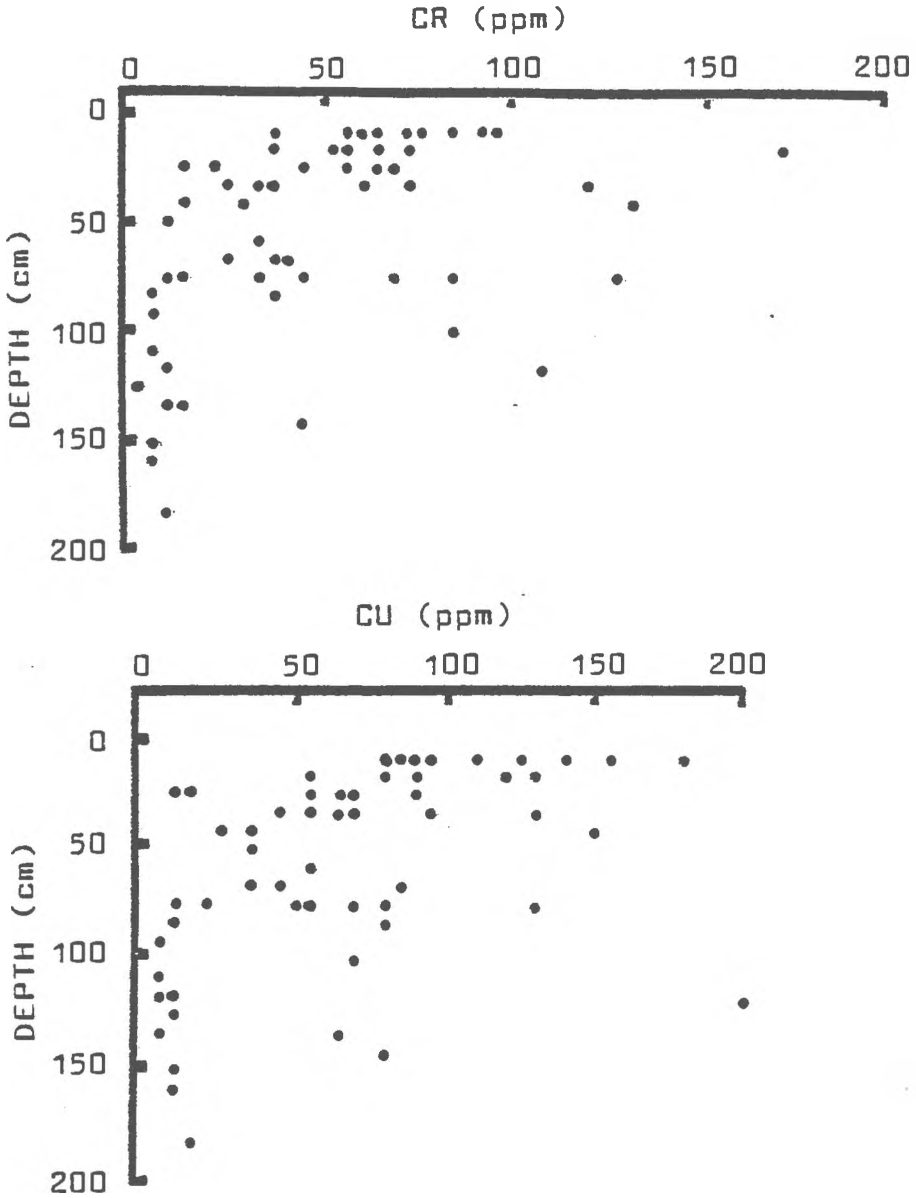


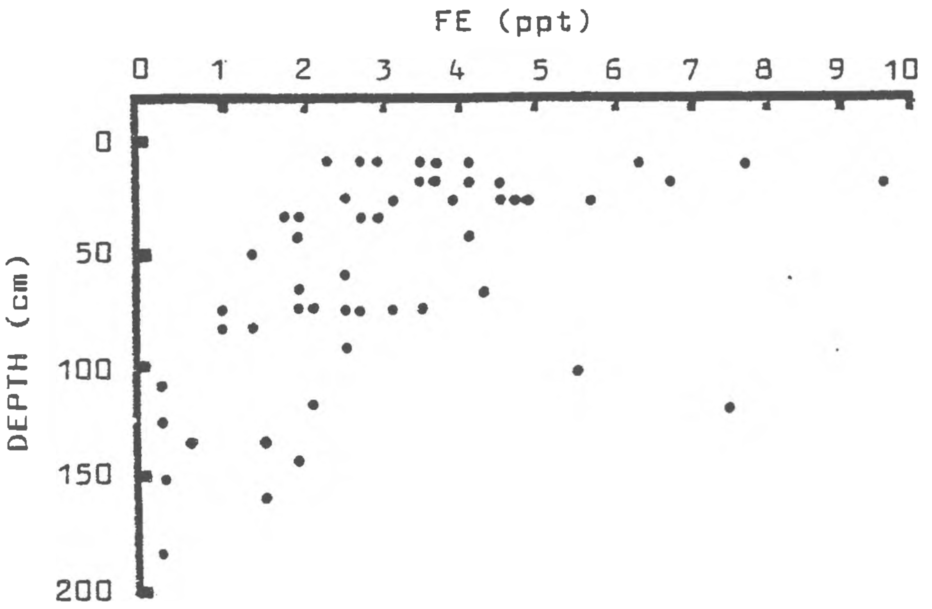
Figure 14. Distribution of total Cr and Cu with depth in 12 tidal salt marsh soil profiles.

(Figure 15) show that there are marked accumulations of these metals in surface layers, but that their decrease with depth is much more gradual than that of the other metals studied.

The concentrations of all metals were significantly correlated with percent rubbed fiber and indices of fiber (U-R, U/R, and U-R/R) but, with the exception of Mn, were not correlated with percent organic carbon in the sediments (Table 10). These correlations may have been an artifact of the increased concentration of metals in surface horizons corresponding to high percentages of rubbed fiber in surface horizons.

These results are consistent with those of other investigators who have analysed the concentrations of metals in cores from tidal salt marshes. Lord (1980) found decreasing concentrations of Fe^{2+} and Mn^{2+} in pore water as a function of depth in a Delaware marsh, McCaffrey (1977) found decreasing concentrations of Cu, Fe, Mn, Pb, and Zn as a function of depth in a Connecticut marsh, and Darmody (1975) found reductions of free iron content with depth in tidal marshes of Maryland.

The surface of a high marsh is exposed for longer periods than it is flooded, thus may be subjected to greater deposition of air-borne constituents than to those of estuarine waters. McCaffrey (1977) recognized this condition and attributed increases of Cu, Pb, and Zn concentrations in upper marsh sediments to increases in at-



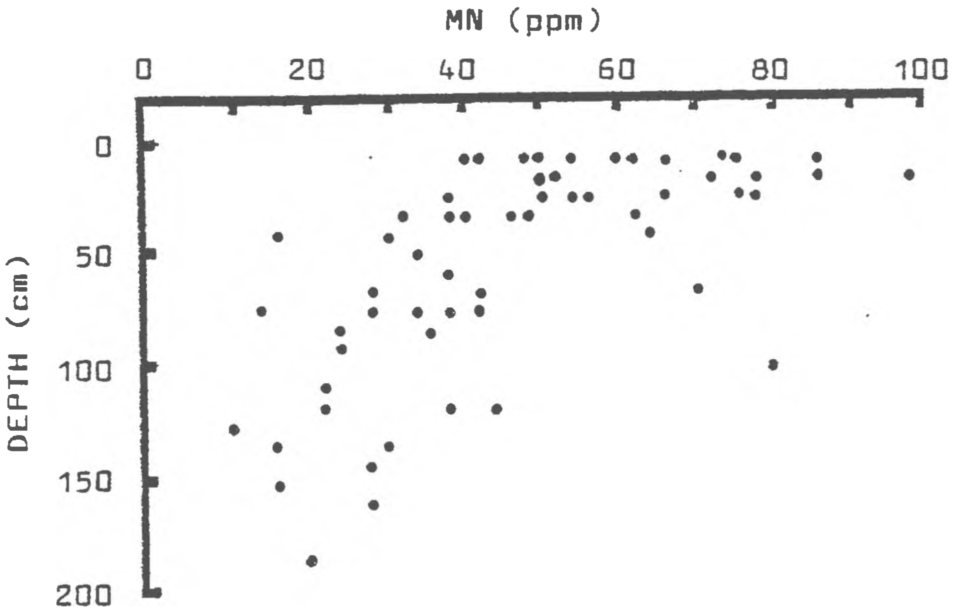


Figure 15. Distribution of total Fe and Mn with depth in 12 tidal salt marsh soil profiles.

Table 10. Correlation coefficients of relationships between metal concentrations and other variables.

	Fe	Mn	Pb	Zn	Cd	Cr	Ni	Cu
Unrubbed Fiber	0.05^{ns}	0.10^{ns}	0.04^{ns}	-0.03^{ns}	0.01^{ns}	0.18^{ns}	0.17^{ns}	0.17^{ns}
Rubbed Fiber	0.36**	0.51**	0.63**	0.32**	0.28*	0.43**	0.27*	0.47**
U-R	-0.35**	-0.47**	-0.63**	-0.36**	-0.29*	-0.33**	-0.17^{ns}	-0.39**
R/U	0.41**	0.56**	0.68**	0.39**	0.32**	0.43**	0.28*	0.50**
UR/R	-0.41**	-0.49**	-0.52**	-0.34**	-0.29*	-0.43**	-0.33**	-0.47**
Organic Carbon	-0.24^{ns}	-0.32**	-0.05^{ns}	-0.04^{ns}	-0.09^{ns}	-0.18^{ns}	-0.11^{ns}	-0.05^{ns}
Nitrogen	0.02^{ns}	0.07^{ns}	0.11^{ns}	0.16^{ns}	0.02^{ns}	0.02^{ns}	0.08^{ns}	0.10^{ns}
Field-moist pH	-0.11^{ns}	-0.25*	-0.51**	-0.43**	-0.39**	-0.17^{ns}	-0.03^{ns}	-0.30*
pH After Drying	-0.29*	-0.45**	-0.73**	-0.50**	-0.51**	-0.45**	-0.25*	-0.55**

*, ** Significant at the .05 and .01 levels, respectively.

mospheric deposition subsequent to increased industrialization during the mid 1800's. However, McCaffrey (1977) did not attribute accumulations of Fe and Mn to this source, because he believed that the atmospheric supply of Fe and Mn was negligible compared to that being deposited from the water column. Lord (1980) studied the cycling of Fe and Mn in marsh sediments and attributed their accumulation in surface layers to the precipitation of Fe and Mn oxides after migration from the more reduced sediments below.

The comparison provided by this study of the distributions of Fe and Mn to that of Pb and Zn with depth lends support to the hypotheses of both McCaffrey (1977) and Lord (1980). Concentrations of Fe and Mn decrease more gradually with depth than do concentrations of Pb and Zn. The gradual decrease of Fe and Mn may be caused by the migration of reduced forms of these elements described by Lord (1980). The abrupt increase of Pb and Zn above a depth of 40 cm may, in turn, result from increases in atmospheric deposition, as suggested by McCaffrey (1977). The hypothesis of atmospheric deposition is also supported by the distributions of Ni, Cd, Cr, and Cu in this study, but not as clearly as those of Pb and Zn. In this study the age of the marshes at a depth of 40 cm (determination of age described previously) is approximately 110 years, which corresponds to the period following the industrialization of the eastern United States.

SUMMARY AND CONCLUSIONS

Effects of Mosquito Ditching. At the onset of this study it was assumed that the origin and subsequent development of the Barrington and Warren study areas had been very similar. It had also been assumed that the lack of numerous pannes and ponds in the Barrington marsh, compared to the Warren marsh, was due to the presence of mosquito ditches which had caused excessive drainage. However, identification of the rhizomes in underlying horizons has shown that the study areas did not have the same developmental history.

Three different types of deposits were found under high marsh peat. Deposits of mineral material mixed with *S. alterniflora* rhizomes, indicating the presence of intertidal marsh was found most often in profiles from the Warren marsh. Organic material containing *Phragmites* rhizomes was found overlying both mineral sediments and unidentifiable organic deposits, primarily in the Barrington marsh. Profiles from the Barrington marsh also contained a greater number of high marsh deposits directly overlying mineral sediments, assumed to be of upland origin. Much of the marsh within the Barrington study area probably has grown over submerged upland and fresh water wetland, while most of the Warren marsh has developed over intertidal sediment. Because of the differences in the development of the two marshes, any difference in the physical or chemical characteristics of the soils cannot necessarily be attributed to effects of ditching.

Although the excavation of mosquito ditches may have increased drainage of the Barrington marsh, no evidence of it can be found through this investigation. Neither is there evidence that characteristics of marsh peat developed over submerged upland are different from peat developed over intertidal marsh. Further study should be conducted by comparing ditched and unditched marshes of similar developmental histories.

Classification of Histosols. The 12 soil profiles described in this study met the classification of Sulfihemists and most of the soil properties were within the range of those reported for Sulfihemists in other areas of the United States. The mean pH, total nitrogen, and organic carbon contents of the soils in this study were 6.33. 1.4% and 31.8%, respectively. The concentrations of heavy metals within the soil profiles were also comparable to those found in other tidal salt marsh soils. The data obtained in this study, however, suggest that the organic material is less decomposed than that found in salt marshes south of New England. This phenomena may be related to the cooler climate which exists in New England.

The characteristics described by the criteria proposed for classification of marsh soils (Soil Survey Staff, 1975) did not vary considerably between marshes and among profiles. It is likely that profile descriptions by these criteria do accurately portray conditions throughout an individual marsh. These criteria, however, do not provide enough information for use in detailed study and their methods of application require clarification and refinement.

Two of the major criteria for differentiation of taxonomic classes within the Histosol order having significance to this study are state of decomposition and the presence of sulfidic material. Three of the four suborders, fibrists, hemists, and saprists are designated on the basis of state of decomposition of the fiber present in the subsurface tier, which is located 30 to 90 cm below the surface (Soil Survey Staff, 1975).

There is no evidence from this study that degree of decomposition is related to the carbon-nitrogen ratio of a horizon, which is considered an indication of the degree of decompositon in mineral soil. Average carbon-nitrogen ratios for each decomposition class were not significantly different (.05 level). This author feels that, after temperature regime, vegetative origin of the fiber may have the greatest effect on the state of decomposition as measured by fiber content.

An organic soil is classified as a sulfihemist if it contains sulfidic material, regardless of the type of fiber present (Soil Survey Staff, 1975). Most tidal salt marshes studied for the purpose of soil classification have had varied states of decomposition, but all contained sulfidic material (Hill and Shearin, 1970; Breeding et al., 1974; Coultas and Calhoun, 1978; Darmody and Foss, 1978; and Coultas, 1980). When classified by this convention, information regarding the degree of decomposition is lost.

Since the degree of decomposition of fresh water peat material is related to its hydrologic characteristics (Boelter, 1974), a similar relationship must exist for salt marsh peat. An understanding of this relationship would be useful when surface waters of these wetlands are managed for mosquito control and waterfowl production. This loss of information should be considered during future revisions of the classification system.

The surface tier of an organic soil is defined in Soil Taxonomy (Soil Survey Staff, 1975) as "the top 30 cm exclusive of loose litter or living mosses", but no reference is made to the presence of living rhizomes. In this study the first horizon of each profile approximates the zone of live rhizomes, which extend to a depth of 9 to 19 cm. The properties of this layer must also be related to drainage characteristics of a marsh. Thus, it should not be discounted and should be considered as part of the surface tier.

The method by which the presence of sulfidic material is determined also requires refinement. The methods presently used, which measure the drop in pH after oxidation (Bloomfield and Coulter, 1973 and Brinkman and Pons, 1973), are impractical for field or laboratory use. This study has shown that repeated drying of the organic portion of the soil does not provide much additional information regarding its potential acidity. No recent studies of marsh soils have shown any statistically significant correlation between sulfur content and drop in pH, as determined by this method (Coultas and Gross, 1975; Darmody, 1975; Coultas and Calhoun, 1976; and Coultas, 1980). It is suggested that the changes in pH of organic soils following mechanical drying in ovens be explored. Mechanical drying techniques have not been tested, but may have considerable merit, in that shorter periods of time would be required. This [illegible] [illegible] samples must be [illegible] [illegible] JC

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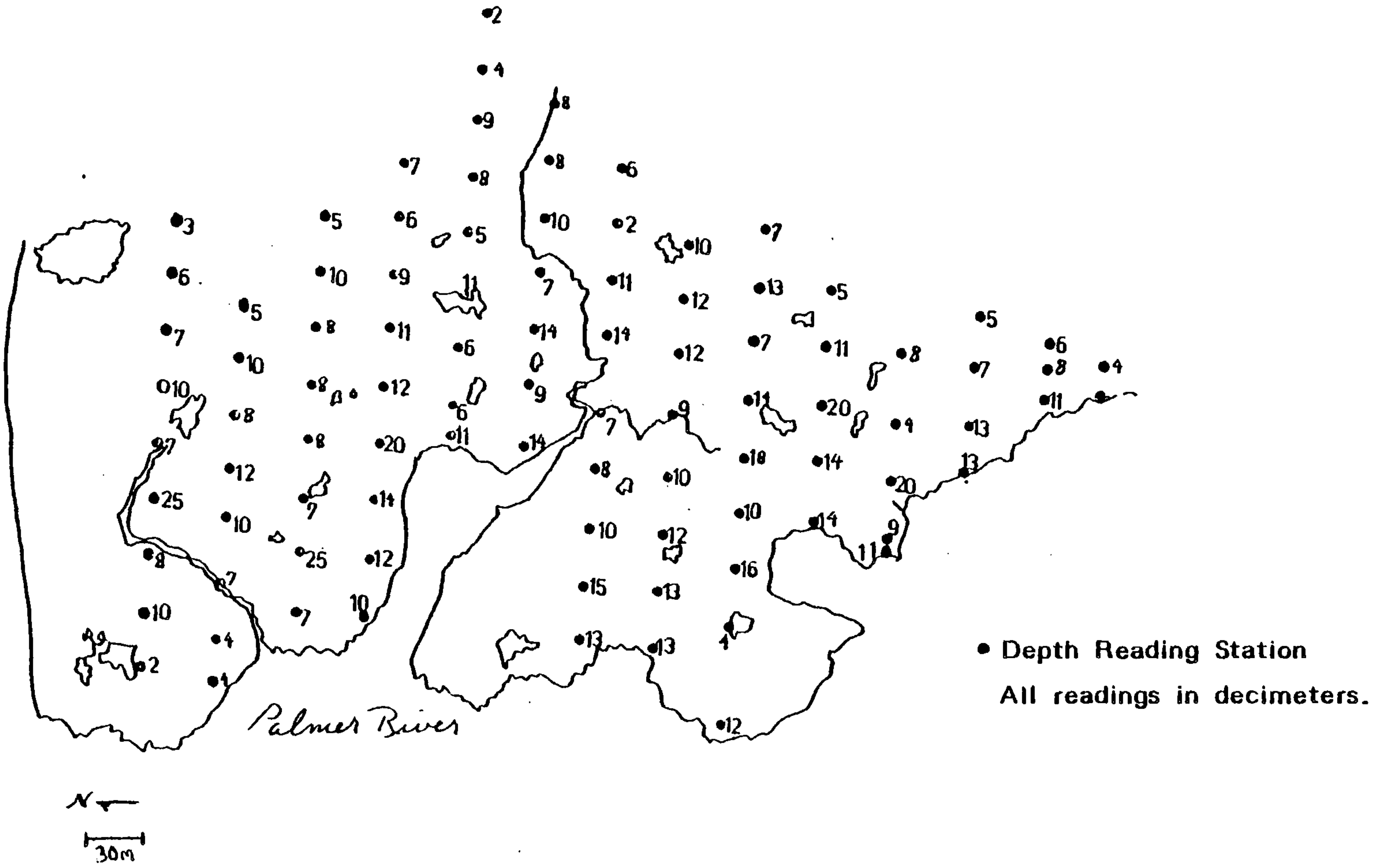
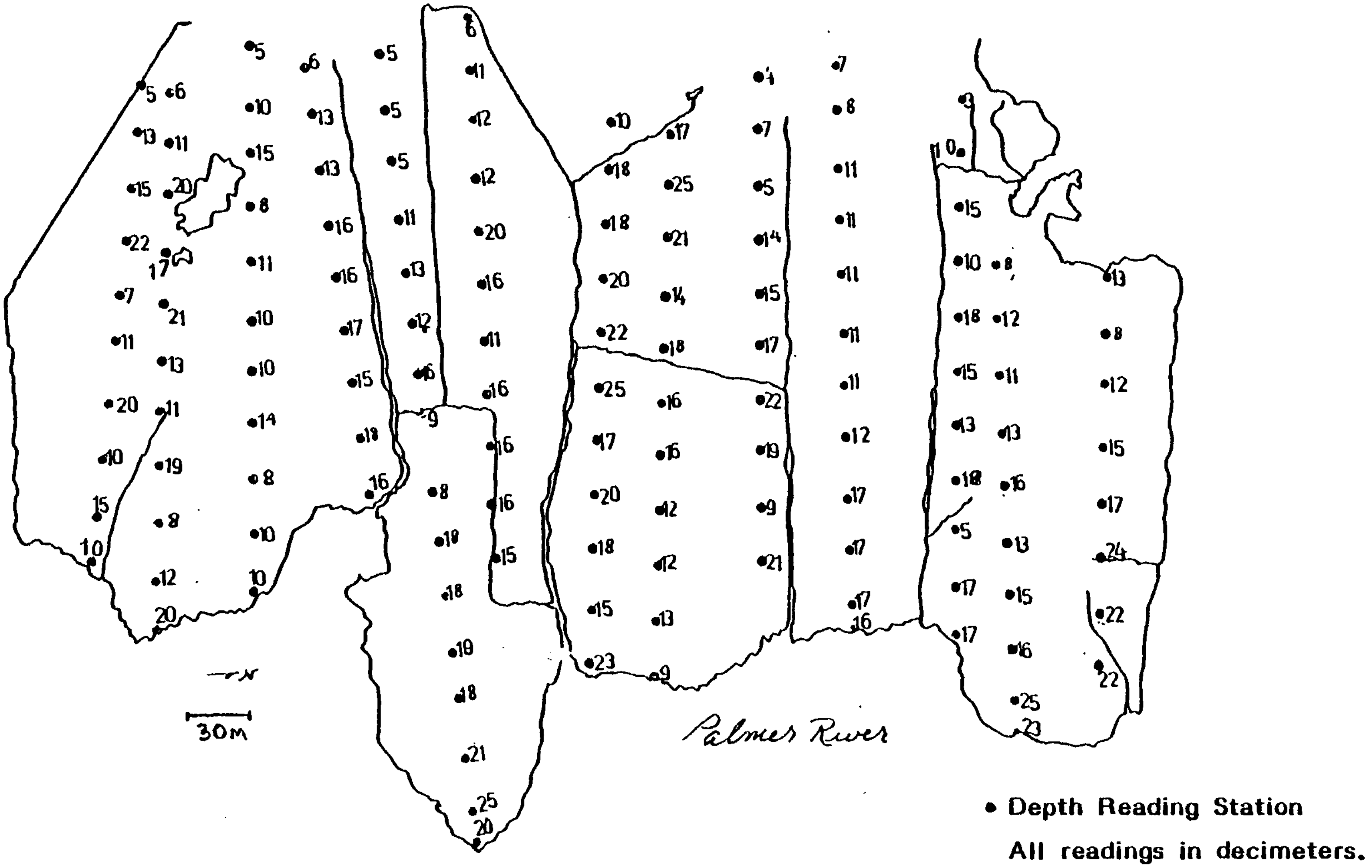
APPENDICES



Appendix 1. Peat depth soundings on Warren marsh.



Appendix 2. Peat depth soundings on Barrington marsh.

Appendix 3. Measurements of relative surface and water table elevations on the Warren marsh.

Transect F → F'

Distance from F m	Relative Elevation cm	Depth to Water cm	Location Note
0	0	-	pond
30	21.3	0	
-	32.0	-	
60	44.2	10.0	
90	38.1	20.0	
120	8.5	0	
150	16.8	10.0	
180	23.2	14.0	
210	4.9	41.0	
240	5.5	13.0	
-	-109.1	-	creek
270	18.6	6.0	
300	11.3	<0	
330	32.0	20.0	
360	12.8	6.0	

Transect H → H'

Distance from F m	Relative Elevation cm	Location Note
0	12.1	
30	15.5	
60	13.7	
90	14.9	
120	19.8	
150	-69.5	
180	-11.9	
210	52.4	
-	-132.2	riveredge
-	-154.4	low water

Appendix 3. (Continued)

Transect G → G'

Distance from G m	Relative Elevation cm	Depth to Water cm	Location Note
0	35.1	11.0	
30	21.3	12.5	
60	5.5	6.0	
90	14.3	15.0	
120	23.5	10.0	
-	17.1	6.0	
150	38.4	-	berm
-	19.2	9.5	
180	41.0	16.5	
210	-	-	river edge
240	-	-	river edge
-	-90.2	-	extent of *S. alterniflora*
270	11.6	22.0	
300	-16.8	5.5	
330	7.3	6.0	
-	41.1	-	berm
360	15.6	13.5	
390	16.8	22.5	
420	41.5	14.5	
-	7.9	-	creek
450	2.7	17.0	
456.05	-72.5	-	

Appendix 4. Measurements of relative surface and water table elevations on the Barrington marsh.

Transect A → A'

Distance from A m	Relative Elevation cm	Depth to Water cm	Location Note
0	-30.0	21.0	
-	-57.0	-	creek
30	-14.3	9.5	
60	-14.0	5.0	
90	-6.7	14.5	creek bank
-	-134.4	-	creek
120	-9.4	6.5	
150	-7.9	2.0	
180	-7.6	0	
210	-1.2	19.5	
-	-138.7	-	creek
240	-5.8	18.5	
270	-2.4	9.0	
300	-0.6	20.0	
-	-3.8	-	creek
330	1.8	13.5	
360	5.2	8.0	
390	4.6	5.5	
420	4.3	4.0	
450	2.4	<0	
480	5.8	9.5	
(A') 510	9.4	15.5	

Transect E → E'

Distance from E m	Relative Elevation cm	Depth to Water cm	Location Note
0	4.6	-	
30	4.0	9.0	
60	4.0	7.0	
90	3.7	4.0	
120	5.5	6.5	
150	3.7	12.5	
-	-22.9	-	creek
180	8.7	6.0	
210	5.5	2.0	
240	24.7	2.5	
270	22.9	5.5	
(E') 300	19.2	-	

Appendix 4. (Continued)

Transect B - B'

Distance from B m	Relative Elevation cm	Depth to Water cm	Location Note
0	0	-	
30	4.9	3.0	
60	3.0	2.0	
90	-0.3	8.5	
-	-87.5	11.0	creek
105	-15.5	14.0	
115	0.6	10.5	
120	1.2	8.0	
125	2.1	6.0	
130	4.0	6.0	
135	3.7	3.5	
140	3.7	5.0	
145	3.4	5.0	
150	3.7	4.0	
155	3.7	5.0	
160	2.4	4.5	
165	3.0	4.5	
170	3.4	5.0	
175	3.7	5.5	
180	3.7	5.0	
185	3.4	7.0	
190	3.0	7.5	
195	3.0	10.0	
200	4.0	12.5	
205	-2.1	16.0	
210	2.4	24.0	
-	-105.8	-	creek
240	2.1	5.0	
270	4.3	3.0	
-	-89.0	-	creek
300	-44.8	-	
330	2.1	15.5	
-	-110.9	-	creek
360	0.6	3.5	
390	9.1	-	
410	-4.6	-	pond
440	9.1	5.5	
(B') 470	7.0	15.0	

Appendix 5. Content of organic carbon, total nitrogen and carbon-nitrogen ratios (C/N) of organic horizons.

Barrington Marsh				Warren Marsh			
Sample	% Organic Carbon	% Total Nitrogen	C/N	Sample	% Organic Carbon	% Total Nitrogen	C/N
BA 1	28.3	1.0	28.3	WA 1	36.0	1.5	24.0
2	24.4	1.2	20.4	2	32.0	1.6	20.0
3		1.6		3	24.2	1.5	16.1
4	44.5	1.2	31.5	4	39.7	2.4	16.5
				5	42.8	2.4	17.8
BB 1	34.5	1.3	26.5	6	23.9	0.5	47.8
2	32.5	1.3	25.0				
3	27.1	1.3	20.9	WB 1	30.5	1.3	23.5
4	17.1	1.7	10.1	2	31.0	1.3	23.9
5	40.9	1.5	27.3	3	19.3	1.0	19.3
6	25.2	0.9	28.0	4	19.8	0.8	24.8
7	29.5	1.3	22.7				
				WC 1	36.9	1.8	20.5
BC 1	25.1	1.5	16.7	2	32.3	1.9	17.0
2	13.1	0.7	18.6	3	33.0	2.1	15.7
3	19.7	1.0	19.7	4	42.1	1.5	28.1
4	25.7	1.3	19.8				
5	37.4	1.7	22.0	WD 1	33.2	1.4	23.7
6	37.3	0.7	53.3	2	24.0	1.3	18.4
				3	33.1	1.9	17.4
BD 1	35.2	1.5	23.5	4	42.0	1.2	35.0
2	33.1	1.5	22.0	5	44.0	1.0	43.9
3	25.7	1.3	19.8	6	33.1	0.7	47.4
4	40.4	1.8	22.5				
5	35.4	1.5	23.6				

Appendix 5. Content of organic carbon, total nitrogen and carbon-nitrogen ratios (C/N) of organic horizons (continued)

Barrington Marsh				Warren Marsh			
Sample	% Organic Carbon	% Total Nitrogen	C/N	Sample	% Organic Carbon	% Total Nitrogen	C/N
BE1	30.6	1.2	25.5	WE 1	32.2	1.5	21.5
2	24.0	1.1	21.8	2	31.3	1.6	19.6
3	35.1	1.9	18.5	3	27.6	1.4	19.7
4	44.0	1.4	31.4	4	32.4	1.5	21.6
5	23.0	0.7	32.8	5	33.5	1.7	19.7
BF1	25.8	1.3	19.9	WF 1	30.4	1.3	23.4
2	32.0	1.5	21.3	2	23.8	1.4	17.0
3	41.5	1.6	25.9	3	33.1	1.7	19.5
4	38.7	1.1	35.2	4	37.6	1.7	22.1
5	13.2	0.3	43.9	5	28.7	0.9	31.9

Appendix 6. Sequential pH readings for horizons within the Barrington marsh.

Sample	Soil Type*	Field Moist pH	pH After 1 Drying	pH After 2 Dryings	pH After 3 Dryings
BA1	O	6.79	4.60	4.79	4.32
BA2	O	6.85	5.52	5.15	5.53
BA3	O	6.81	5.33	5.50	5.41
BA4	O	6.68	5.82	5.90	.
BA5	M	6.65	6.12	6.08	6.00
BA6	M	6.78	6.17	6.25	6.14
BA7	M	6.68	6.27	6.19	6.04
BA8	M	6.67	6.40	6.18	5.99
BA9	M	6.79	6.40	6.12	5.94
BA10	M	6.87	6.54	6.14	5.79
BA11	M	6.76	6.29	5.94	5.78
BB1	O	5.87	5.07	4.86	5.13
BB2	O	6.58	5.72	5.21	5.39
BB3	O	6.94	6.22	5.97	6.04
BB4	O	7.07	6.53	6.56	6.42
BB5	O	7.01	6.29	6.44	6.27
BB6	O	6.82	.	.	.
BB7	O	7.14	6.34	6.39	6.28
BB8	M	6.64	5.76	4.81	4.74
BB9	M	6.69	6.33	6.00	5.94
BB10	M	6.81	6.61	6.42	6.35
BC1	O	6.33	4.65	5.09	5.32
BC2	O	6.38	4.82	5.12	5.26
BC3	O	6.36	5.48	5.38	5.43
BC4	O	6.31	5.76	5.79	5.83
BC5	O	6.51	5.70	5.97	6.00
BC6	O	6.67	5.65	5.83	5.72
BC7	M	6.65	6.01	.	.
BC8	M	6.80	5.39	4.08	3.99
BD1	O	5.88	4.64	4.68	4.70
BD2	O	6.49	5.00	5.20	5.18
BD3	O	6.76	5.99	5.93	5.89
BD4	O	6.91	6.29	6.26	.
BD5	O	6.78	6.18	.	.
BD6	M	6.74	6.22	.	.
BD7	M	6.62	6.32	.	6.25
BD8	M	6.76	6.55	6.36	6.12
BD9	M	.	6.96	6.74	.

Appendix 6. Sequential pH readings for horizons within the Barrington marsh. (continued)

Sample	Soil Type*	Field Moist pH	pH After 1 Drying	pH After 2 Dryings	pH After 3 Dryings
BE1	O	4.42	3.21	3.93	4.39
BE2	O	5.99	5.28	4.92	4.86
BE3	O	6.20	5.76	5.47	5.51
BE4	O	6.14	5.58	5.32	.
BE5	O	6.13	5.70	.	.
BE6	M	6.08	5.82	5.77	5.85
BE7	M	6.13	5.73	5.74	.
BE8	M	6.17	5.63	.	.
BE9	M	6.23	5.84	5.67	5.56
BF1	O	6.41	5.07	5.23	5.21
BF2	O	6.54	5.76	5.71	5.66
BF3	O	6.27	6.19	6.15	6.05
BF4	O	6.63	6.13	6.04	5.97
BF5	O	6.42	5.84	.	.
BF6	M	6.28	5.73	5.76	5.78
BF7	M	6.02	5.56	.	.
BF8	M	5.86	5.45	5.27	5.24
BF9	M	5.80	5.51	.	.
BF10	M	6.03	5.74	5.59	5.60
BF11	M	6.13	5.86	5.71	5.70

* O = Organic

M = Mineral

Appendix 7. Sequential pH readings for horizons within the Warren marsh.

Sample	Soil Type*	Field Moist pH	pH After 1 Drying	pH After 2 Dryings	pH After 3 Dryings
WA1	O	3.04	3.39	3.22	3.77
WA2	O	5.51	4.32	4.62	4.58
WA3	O	6.48	6.12	.	.
WA4	O	6.78	6.08	.	.
WA5	O	6.73	6.18	.	.
WA6	O	6.68	6.10	6.12	5.92
WA7	M	6.56	6.23	6.30	6.09
WA8	M	6.44	6.22	6.29	6.15
WA9	M	6.37	6.11	6.09	5.95
WA10	M	6.54	4.44	3.71	3.37
WA11	M	6.56	5.85	5.54	5.29
WB1	O	5.60	4.59	4.39	4.82
WB2	O	6.31	4.89	5.50	5.39
WB3	O	7.10	6.11	6.00	5.90
WB4	O	7.03	5.35	5.16	5.26
WB5	M	6.91	6.29	6.33	6.30
WB6	M	6.87	6.63	6.57	6.46
WB7	M	7.12	5.62	4.97	4.68
WB8	M	7.17	5.53	4.95	4.46
WB9	M	7.64	6.98	6.62	6.30
WC1	O	5.25	4.69	4.45	4.66
WC2	O	6.17	5.86	5.71	5.71
WC3	O	6.40	6.01	6.06	5.92
WC4	O	6.33	5.89	5.80	5.76
WC5	M	5.95	5.83	.	.
WC6	M	5.91	5.37	5.44	5.24
WC7	M	6.07	5.34	5.16	4.90
WC8	M	6.41	6.10	5.90	5.80
WC9	M	6.45	6.01	5.89	5.79
WD1	O	4.43	4.29	4.59	3.60
WD2	O	6.46	5.58	5.53	.
WD3	O	6.66	6.03	.	.
WD4	O	6.62	5.99	5.72	5.18
WD5	O	6.47	5.93	.	.
WD6	O	6.31	6.00	.	.
WD7	O	6.25	6.15	5.98	5.74
WD8	O	6.08	5.67	.	.
WD9	O	6.06	5.58	.	.
WD10	M	6.15	5.79	5.81	5.43

Appendix 7. Sequential pH readings for horizons within the Warren marsh (continued)

Sample	Soil Type*	Field Moist pH	pH After 1 Drying	pH After 2 Dryings	pH After 3 Dryings
WE1	O	5.15	4.41	4.52	4.29
WE2	O	5.54	4.58	4.02	4.16
WE3	O	6.33	5.54	5.44	5.05
WE4	O	6.59	5.71	5.87	5.57
WE5	O	6.70	6.12	5.79	5.58
WE6	M	6.73	6.14	5.85	5.51
WE7	M	6.75	6.17	6.04	5.69
WE8	M	6.77	5.88	4.45	4.14
WE9	M	6.67	5.87	5.47	4.99
WE10	M	6.82	6.32	6.14	5.74
WE11	M	6.66	6.66	6.38	5.96
WE12	M	6.64	6.72	6.45	6.03
WF1	O	5.49	5.32	5.27	5.12
WF2	O	6.32	6.00	5.90	5.85
WF3	O	6.63	6.13	6.07	5.95
WF4	O	6.90	6.04	5.83	5.64
WF5	O	6.89	6.23	.	.
WF6	M	6.85	6.34	6.31	.
WF7	M	6.91	6.70	6.56	6.54
WF8	M	6.97	6.78	6.47	6.38
WF9	M	7.10	6.48	5.88	5.54
WF10	M	7.09	6.78	.	5.99
WF11	M	7.08	6.88	6.71	6.43
WF12	M	7.28	6.83	6.41	6.02
WF13	M	7.12	7.22	6.87	6.62

* O = Organic

M = Mineral

Appendix 8. Color and particle size distribution of mineral horizons in the Warren marsh.

Horizon		Depth	Color	Sand (mm)					Silt (mm)		Clay (mm)	
				VC	C	M	F	VF	C	F		
					1-	0.5-	0.25	0.1-	0.05	0.02-		Textural
				2-1	0.5	0.25	-0.1	0.05	-0.02	0.002	0.002	Class
		cm		% by weight								
WB	6	150-160	10 YR 2/1	1.1	9.5	16.9	33.0	15.7	5.0	10.8	7.9	fine sandy loam
	7	160-170	7.5 YR 3/10	0.6	5.4	19.4	49.8	10.5	3.0	7.5	3.8	loamy sand
	8	170-198	7.5 YR 5/0 7.5 YR 6/6	0.8	5.4	15.9	42.1	11.1	4.7	11.5	8.5	fine sandy loam
	9	198-232	7.5 YR 6/1	0.6	3.1	10.8	20.6	7.6	2.2	33.7	21.4	loam
WD	7	155-179	10 YR 3/1	1.0	5.6	19.3	53.4	7.3	3.6	6.0	3.8	loamy fine sand
	8	179-186	10 YR 2/1	0.3	4.4	13.3	37.2	15.3	6.1	14.3	9.0	fine sandy loam
	9	186-200	10 YR 2/2									
	10	200-222	10 YR 3/3	2.5	11.0	26.3	43.7	10.9	1.2	2.1	2.3	sand
WF	6	126-134	10 YR 2/1	0.7	3.8	8.9	24.9	8.6	4.7	26.9	21.4	loam
	7	134-141	10 YR 3/2	0.3	3.7	9.5	29.0	8.5	5.6	22.9	19.4	loam
	8	141-153	10 YR 3/1	2.4	7.2	21.1	50.1	11.1	10.9	3.5	3.7	loamy fine sand
	9	153-162	10 YR 4/1	2.4	9.0	24.4	47.7	9.5	2.5	3.3	1.2	sand
	10	162-175	10 YR 5/1	4.0	14.0	26.3	34.8	3.9	7.6	5.6	3.6	loamy sand
	11	175-180	7.5 YR 6/0	0.8	3.1	8.7	40.1	18.5	6.8	12.9	9.1	fine sandy loam
	12	180-189	10 YR 5/0	3.6	23.3	42.4	19.9	6.1	1.5	1.6	1.5	coarse sand
	13	189-196	7.5 YR 6/0	1.8	4.7	12.9	34.0	14.6	8.3	15.1	8.6	fine sandy loam
	14	196-206	7.5 YR 5/0	0.6	3.1	9.5	35.4	23.0	6.3	11.7	8.7	fine sandy loam

Appendix 8. Color and particle size distribution of mineral horizons in the Warren marsh (continued).

				Sand (mm)				Silt (mm)		Clay (mm)	
			VC	C	M	F	VF	C	F		
Horizon	Depth	Color	2-1	1- 0.5	0.5- 0.25	0.25 -0.1	0.1- 0.05	0.06 -0.02	0.02- 0.002	0.002	Textural Class
	cm		& by weight								
WA 7	100-110	10 YR 2/1	1.4	6.1	17.0	45.5	12.2	4.7	8.5	4.5	loamy fine sand
8	110-122	10 YR 2/2	0.8	5.9	20.0	44.2	5.1	12.2	6.0	5.8	loamy sand
9	122-130	10 YR 3/2	2.1	7.7	22.1	42.0	11.6	3.4	6.2	4.9	loamy sand
10	130-142	7.5 YR 6/1 7.5 YR 4/1	0.4	4.0	20.8	40.2	9.4	4.0	15.2	6.0	loamy sand
11	142-162	7.5 YR 6/1 7.5 YR 5/6	3.2	6.8	17.1	41.2	12.9	4.6	10.6	3.6	loamy sand
WC 5	94-102	10 YR 2/1	1.0	0.9	10.1	23.7	18.3	31.5	19.6	13.4	fine sandy loam
6	102-112	10 YR 5/1	2.3	9.7	31.8	50.6	4.0	0.4	0.5	0.8	fine sand
7	112-161	7.5 YR 5/0	3.1	7.0	16.1	34.5	14.9	3.9	14.0	6.6	fine sandy loam
8	161-170	7.5 YR 6/0	1.3	3.5	8.2	17.5	8.2	2.6	46.2	12.5	loam
9	170-210	7.5 YR 5/0	1.6	3.7	14.6	33.4	10.1	2.3	24.5	9.8	fine sandy loam
WE 6	109-125	10 YR 5/2	1.8	7.5	17.9	39.6	10.9	3.6	11.5	7.3	fine sandy loam
7	125-140	10 YR 5/2	1.7	9.2	19.2	34.5	10.3	4.2	12.3	8.6	fine sandy loam
8	140-149	10 YR 5/1 10 YR 5/4	1.4	6.2	14.0	31.8	3.5	11.0	21.1	11.0	fine sandy loam
9	149-165	7.5 YR 6/0 10 YR 5/4	1.0	3.8	9.2	22.8	1.5	12.3	30.2	13.2	loam
10	165-174	7.5 YR 5/0 7.5 YR 5/4	1.4	4.7	10.8	28.1	17.7	3.1	21.2	13.0	fine sandy loam
11	174-187	7.5 YR 5/0 7.5 YR 5/6	1.4	3.0	5.8	22.2	10.8	16.6	28.6	11.6	loam
12	187-206	7.5 YR 5/6 7.5 YR 5/0	1.2	4.7	9.0	23.1	19.2	5.0	36.3	1.5	sandy loam

Appendix 9. Color and particle size distribution of mineral horizons in the Barrington marsh.

Horizon	Depth	Color	Sand (mm) VC 2-1	C 1- 0.5	M 0.5- 0.25	F 0.25 -0.1	VF 0.1- 0.05	Silt (mm) C 0.05 -0.02	F 0.02- 0.002	0.002	Textural Class
	cm		% by weight								
BB 7	140-150	10 YR 2/2									
8	150-165		0.4	3.5	9.6	2.7	10.3	14.4	33.9	1.1	sandy loam
9	165-185		1.7	8.5	14.8	19.5	9.7	5.6	32.1	8.1	fine sandy loam
10	185-195		0.8	3.5	7.9	19.7	7.3	9.9	39.3	11.2	loam
BD 7	107-117		1.0	7.0	19.4	38.8	9.7	5.1	13.3	5.6	loamy fine sand
8	117-137		1.3	7.0	23.4	43.8	12.5	4.7	6.3	1.0	sand
9	137-173		1.3	7.4	23.9	37.8	10.2	8.4	10.0	1.0	loamy sand
BF 6	117-131	10 YR 3/2	0.9	6.4	16.4	32.1	16.2	11.1	13.4	3.4	fine sandy loam
7	131-138	5 YR 2/2	1.7	6.3	15.4	23.0	11.5	11.7	12.1	5.1	fine sandy loam
8	138-144	5 YR 4/3 5 YR 3/3	2.6	8.3	17.4	37.0	11.6	8.6	11.5	3.0	loamy sand
9	144-156	5 Y 3/3 5 Y 4/3	1.3	8.0	11.0	21.8	18.2	17.8	18.8	3.1	fine sandy loam
10	156-190	2.5 Y 4/4	0.2	3.4	21.5	68.0	3.6	2.1	0.2	1.0	fine sand
11	190-210	2.5 Y 3/2	1.1	9.2	28.8	53.0	3.3	2.4	1.0	1.2	fine sand

Appendix 9. Color and particle size distribution of mineral horizons in the Barrington marsh (continued).

Horizon		Depth	Color	Sand (mm) VC 2-1	C 1- 0.5	M 0.5- 0.25	F 0.25 -0.1	VF 0.1- 0.05	Silt (mm) C 0.05 -0.02	F 0.02- 0.002	0.002	Textural Class
		cm		% by weight								
BA	6	153-178	10 YR 4/2	1.3	4.4	11.0	28.0	28.5	13.3	9.5	3.6	fine sandy loam
	7	178-193		0.7	2.9	6.6	21.1	36.5	17.7	11.3	3.2	very fine sandy loam
	8	193-204		0.5	2.7	6.2	14.0	39.6	19.9	14.8	2.3	very fine sandy loam
	9	204-216		1.7	4.7	12.2	29.6	28.5	14.3	7.7	1.9	fine sandy loam
	10	216-228		3.3	7.2	21.9	34.4	23.5	5.4	1.7	2.7	sand
	11	228-250		3.5	13.9	7.3	29.3	12.2	10.1	2.5	1.2	sand
BC	7	182-188										
	8	188-226		0.1	0.3	0.2	1.9	10.6	27.1	48.6	11.2	silt loam
BD	6	193-228	10 YR 3/2	1.2	6.2	17.4	30.1	18.0	8.0	12.6	6.6	fine sandy loam
	7	228-238	10 YR 2/1	0.7	4.4	14.0	28.0	13.6	6.8	21.3	9.1	fine sandy loam
	8	238-246	10 YR 2/2									
	9	246-262	10 YR 3/3	2.6	12.7	30.5	37.3	10.0	2.1	2.5	2.3	sand

Appendix 10. Concentrations of metals in organic horizons of the Warren marsh.

Sample	Fe	Mn	Pb	Zn	Cd	Cr	Cu	Ni
	ppt	ppm						
WA1	3.0	74	41	31	0.00	57	90	21
2	6.8	77	139	244	2.43	73	122	59
3	4.0	65	43	51	0.16	19	13	16
4	2.7	37	14	20	0.00	30	57	36
5	1.4	36	7	31	0.00	5	10	7
6	2.6	24	5	2	0.00	4	3	2
WB1	3.9	60	51	63	0.27	71	109	36
2	4.0	49	53	72	0.52	45	71	34
3	4.4	70	21	32	0.05	36	37	28
4	5.6	79	14	25	0.05	83	68	52
5	1.6	29	6	6	0.00	9	4	5
6	1.7	27	6	5	0.00	5	8	3
WC1	3.1	40	83	115	1.25	34	79	29
2	2.6	38	24	24	0.00	11	10	10
3	2.8	40	13	25	0.00	62	66	53
4	2.0	41	12	17	0.00	40	45	34
WD1	3.6	47	61	48	0.49	64	91	38
2	5.0	77	29	45	0.08	66	65	42
3	3.1	37	17	36	0.19	23	46	27
4	0.9	14	8	19	0.21	7	22	10
5	0.2	10	4	7	0.16	2	10	4
6	0.3	15	5	3	0.04	2	12	3

Appendix 10. Concentrations of metals in organic horizons of the Warren marsh (continued)

Sample	Fe	Mn	Pb	Zn	Cd	Cr	Cu	Ni
	ppt	ppm						
WE1	2.4	53	65	63	0.73	62	86	22
2	4.2	71	74	108	1.65	65	91	40
3	4.9	76	35	32	0.17	43	56	33
4	3.0	61	22	39	0.10	74	128	68
5	3.2	41	34	63	0.09	128	12	92
WF1	7.8	76	87	168	1.28	91	180	82
2	3.3	54	45	72	0.60	55	88	45
3	2.1	31	13	41	0.41	35	57	35
4	2.7	27	8	16	0.22	32	56	27
5	7.7	22	10	5	0.12	7	8	5

Appendix 11. Concentrations of metals in organic horizons of the Barrington marsh.

Sample	Fe	Mn	Pb	Zn	Cd	Cr	Cu	Ni
	ppt	ppm						
BA1	4.2	62	69	39	0.20	95	142	67
2	1.9	45	64	36	0.74	120	93	54
3	2.3	33	17	16	0.30	68	79	53
4	2.2	38	6	5	0.17	8	7	5
BB1	2.9	49	88	49	0.51	84	154	42
2	3.6	49	65	32	0.44	50	79	28
3	2.8	47	53	30	0.20	34	71	30
4	1.4	34	13	12	0.12	9	35	12
5	3.7	41	10	10	0.05	11	51	13
6	2.3	43	20	31	0.07	107	198	79
BC1	3.7	60	73	32	0.23	78	86	27
2	6.9	85	76	85	1.64	172	132	130
3	4.7	66	18	45	0.56	68	63	51
4	4.3	63	35	69	1.05	130	151	111
5	2.1	28	9	14	0.50	43	70	47
6	2.0	28	9	20	0.54	42	80	41
BD1	3.9	66	86	49	0.25	65	125	40
2	3.8	52	76	40	0.23	50	78	32
3	9.6	99	27	45	0.00	58	79	55
4	2.0	30	11	10	0.00	27	36	27
5	2.8	38	13	20	0.00	85	128	70

Appendix 11. Concentrations of metals in organic horizons of the Barrington marsh (continued)

Sample	Fe	Mn	Pb	Zn	Cd	Cr	Cu	Ni
	ppt	ppm						
BE1	3.8	41	125	75	1.04	60	94	36
2	5.9	56	74	143	1.28	65	65	48
3	2.1	28	11	17	0.04	24	87	25
4	0.5	15	8	14	0.00	13	67	15
5	0.2	20	6	3	0.02	6	15	3
BF1	6.5	85	89	43	0.19	73	96	38
2	4.7	51	94	24	0.06	34	53	28
3	2.1	16	8	6	0.11	12	23	15
4	1.1	23	9	22	0.20	35	81	35
5	0.1	21	4	2	0.00	4	3	2