ASSESSMENT OF MARSH STABILITY
AT THE ESTUARINE SANCTUARY SITE
AT MONIE BAY: IMPLICATIONS
FOR MANAGEMENT

Jan 1988

CZIC

Maryland Department of Natural Resources

Tidewater Administration
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401

William Donald Schaefer
Governor

Torrey C. Brown, M.D.
Secretary

January 29, 1988

MEMORANDUM

TO: Jaunice Yates, Program Specialist

FROM: Randy Schneider, RBS Manager, Maryland CBNERR

SUBJECT: Final Report, Research Grant NA86AA-D-CZ037

Please find enclosed three (3) copies of the final technical report for the project entitled, "Assessment of Marsh Stability at the Estuarine Sanctuary Site at Monie Bay: Implications for Management," which was sponsered in part by the above referenced grant. If you have any questions or need additional information, please feel free to contact me at (301) 974-3782.

Enclosures
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RS/rr

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Assessment of Marsh Stability at the Estuarine Sanctuary Site at Monie Bay: Implications for Management

Ward, Kearney, and Stevenson, Jan. 88

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The marshes at the Monie Bay Research Reserve are composed of three sedimentary environments; high wave energy bay bank marshes characterized by low organic coarse-grained storm overwash deposits overlying finer-grained marsh sediments; low energy tidal channel bank deposits composed of moderately organic, fine-grained sediments; and organic rich, fine-grained back marsh sediments. The average grain size of the marsh sediments range from ~1.1 to 10.4 ϕ, but have a major mode between 9.0 to 10.0 ϕ (channel bank and back marshes) and a secondary mode between 4.0 to 5.5 ϕ (bay bank marsh overwash deposits and underlying soil sediments). The dry and wet bulk densities of the marsh sediments vary from ~0.09 to 0.78 gms/cc and ~0.70 to 1.40 gm/cc, respectively, and are inversely related to both organic and moisture content. The organic content of the marsh near the sediment surface is frequently lower than at depth due to storm effects, bank erosion, higher sediment loading of the estuary after deforestation and urbanization, and more frequent flooding of the marsh surface due to sea level rise.

Vertical accretion rates in the marshes based on palynological analysis range from 0.15 to 0.63 cm/yr. Determination of accretion rates using Lead-210 geochronology agree with the pollen derived rates. Approximately 75% of the accretion rates were less than the local rate of sea level rise (0.4 cm/yr). Comparison of vertical aerial photographs taken in 1938 and 1985 indicate little change in the marsh surface despite the low accretion rates. However, first order tidal channels appear to have undergone apical growth and increased in density.

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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean and Coastal Resource Management
Sanctuary Program Division
Washington, D.C.

January, 1988

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ASSESSMENT OF MARSH STABILITY AT THE ESTUARINE SANCTUARY SITE AT MONIE BAY, IMPLICATIONS FOR MANAGEMENT

by

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PREFACE

The project conducted at the estuarine reserve at Monie Bay (supported by NOAA Sanctuary Programs Division) is part of a larger study examining patterns and rates of marsh accretion, accretionary processes, and the impact of sea level rise on marshes in Chesapeake Bay funded by Maryland Department of Natural Resources and Maryland Water Resources Research Center.

The authors gratefully acknowledge the assistance of a number of people who aided in the field work, laboratory analyses, and data analyses. Jane Nussbaum, Jay Capagreco, Scott Lawson, and Sara Koch helped in both the field and lab. We also would like to thank Frank Dawson, Steven Dawson and Bradley Eby of Maryland Department of Natural Resources for additional field assistance and help with logistics. The manuscript was typed by Anna Ruth McGinn and Jane Gilliard. The drafting was done by Julie Metz.

The radionuclide analysis was done under the direction of Dr. Donald Rice, Chesapeake Biological Laboratories, Solomons Island, Maryland.

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ABSTRACT

The marshes at the Monie Bay Research Reserve are composed of three sedimentary environments; high wave energy bay bank marshes characterized by low organic (<10% LOI), coarse-grained storm overwash deposits overlying finer-grained marsh sediments; low energy tidal channel bank deposits composed of moderately organic (10-30% LOI), fine-grained sediments; and organic rich (>30% LOI), fine-grained back marsh sediments. The average grain size of the marsh sediments range from ~ 1.1 to 10.4 ϕ, but have a major mode between 9.0 to 10.0 ϕ (channel bank and back marshes) and a secondary mode between 4.0 to 5.5 ϕ (bay bank marsh overwash deposits and underlying soil sediments). The dry and wet bulk densities of the marsh sediments vary from ~ 0.09 to 0.78 gms/cc and ~ 0.70 to 1.40 gm/cc, respectively, and are inversely related to both organic and moisture content. The organic content of the marsh near the sediment surface is frequently lower than at depth due to storm effects, bank erosion, higher sediment loading of the estuary after deforestation and urbanization, and more frequent flooding of the marsh surface due to sea level rise.

Vertical accretion rates in the marshes based on palynological analysis (shift in *Quercus*:*Ambrosia* ratio due to an agricultural horizon dated ca. 1790) range from 0.15 to 0.63 cm/yr. Determination of accretion rates using Lead-210 geochronology agree with the pollen derived rates. Approximately 75% of the accretion rates were less than the local rate of sea level rise (0.4 cm/yr). Comparison of vertical aerial photographs taken in 1938 and 1985 indicate little change in the marsh surface despite the low accretion rates. However, first order tidal channels appear to have undergone apical growth and increased in density.

INTRODUCTION

Tidal marshes are very important sedimentary environments, accumulating large amounts of inorganic and organic materials. Consequently, marshes are usually considered to be very robust systems, depositing sediments at rates equivalent to or greater than local sea level rise (Stevenson et al., 1986). Most studies concerning marsh loss or degradation cite man as the major cause (e.g. Atwater et al., 1979; Gosselink and Bauman, 1980). However, recent studies have shown that marsh losses have been occurring in areas such as Chesapeake Bay (Stevenson et al., 1985; Kearney et al., in press) and the Mississippi Delta (Boesch et al., 1983; Turner and Groat, 1985) due to sea level rise. Although man may have exasberated the marsh losses (e.g. canal, levee, or road construction), there is a growing recognition that the sediment supply to marsh systems is critical.

Tidal marshes seem to have particular problems keeping abreast of sea level rise in microtidal environments (marine systems where the spring tidal range is less than 2 meters) (Fig. 1). In the Chesapeake Bay region, two micro-tidal, estuarine marshes which have accretion rates less than local sea level rise have undergone varying degrees of submergence. At Blackwater Wildlife Refuge, Maryland (Fig. 2), low accretion rates have been cited as at least part of the cause of the erosion of approximately 50% of marsh area since the 1930's (Stevenson et al., 1985). In several marshes located in the lower Nanticoke River estuary (Fig. 2), accretion rates less than the local rate of sea level rise of ~ 4 mm/yr (Kearney and Ward, 1986) has led to a loss of 50 hectares of marsh to open water over the last 50 years (Grace, 1986).

In this paper, we report on the sedimentologic and accretionary processes in the marshes located along Monie Bay, Maryland (Fig. 2).

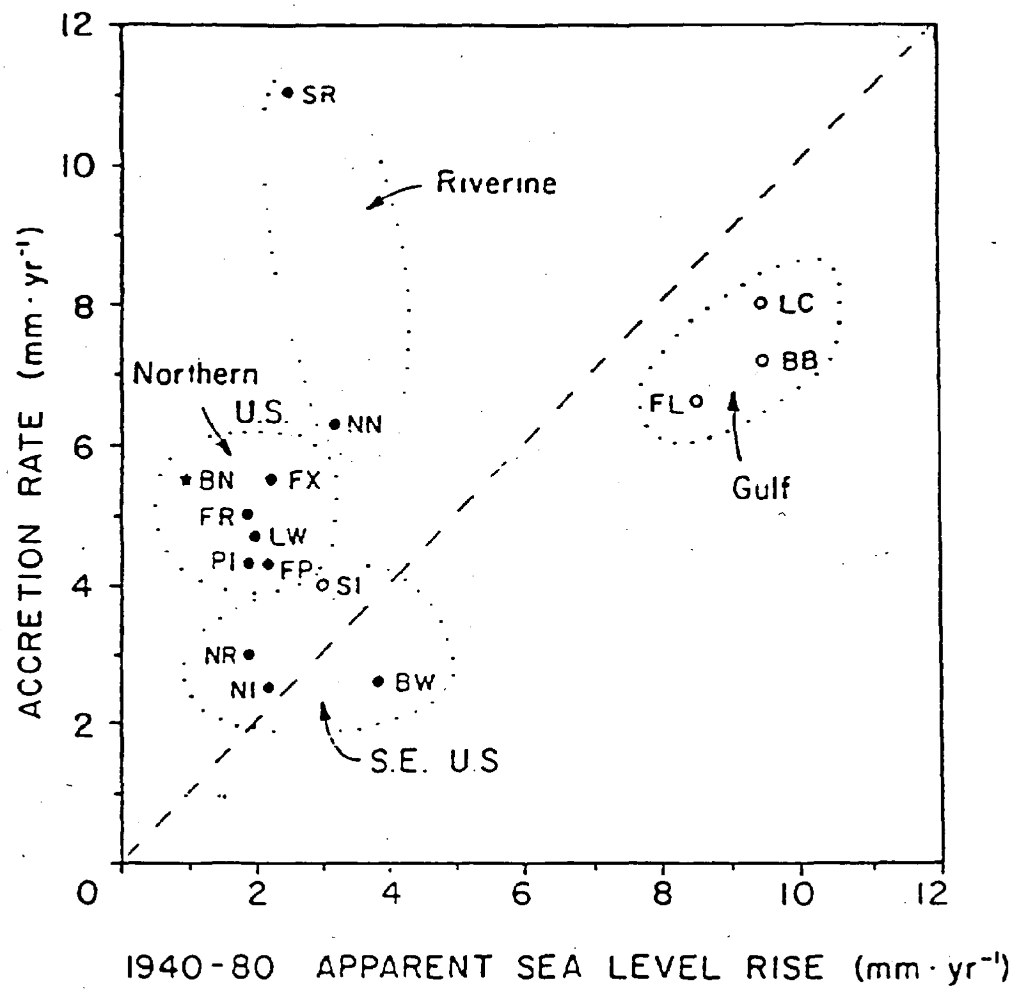


Figure 1. Accretion rates and local sea level rise for selected marshes along the East and Gulf Coasts of the United States. Modified from Stevenson et al. (1986).

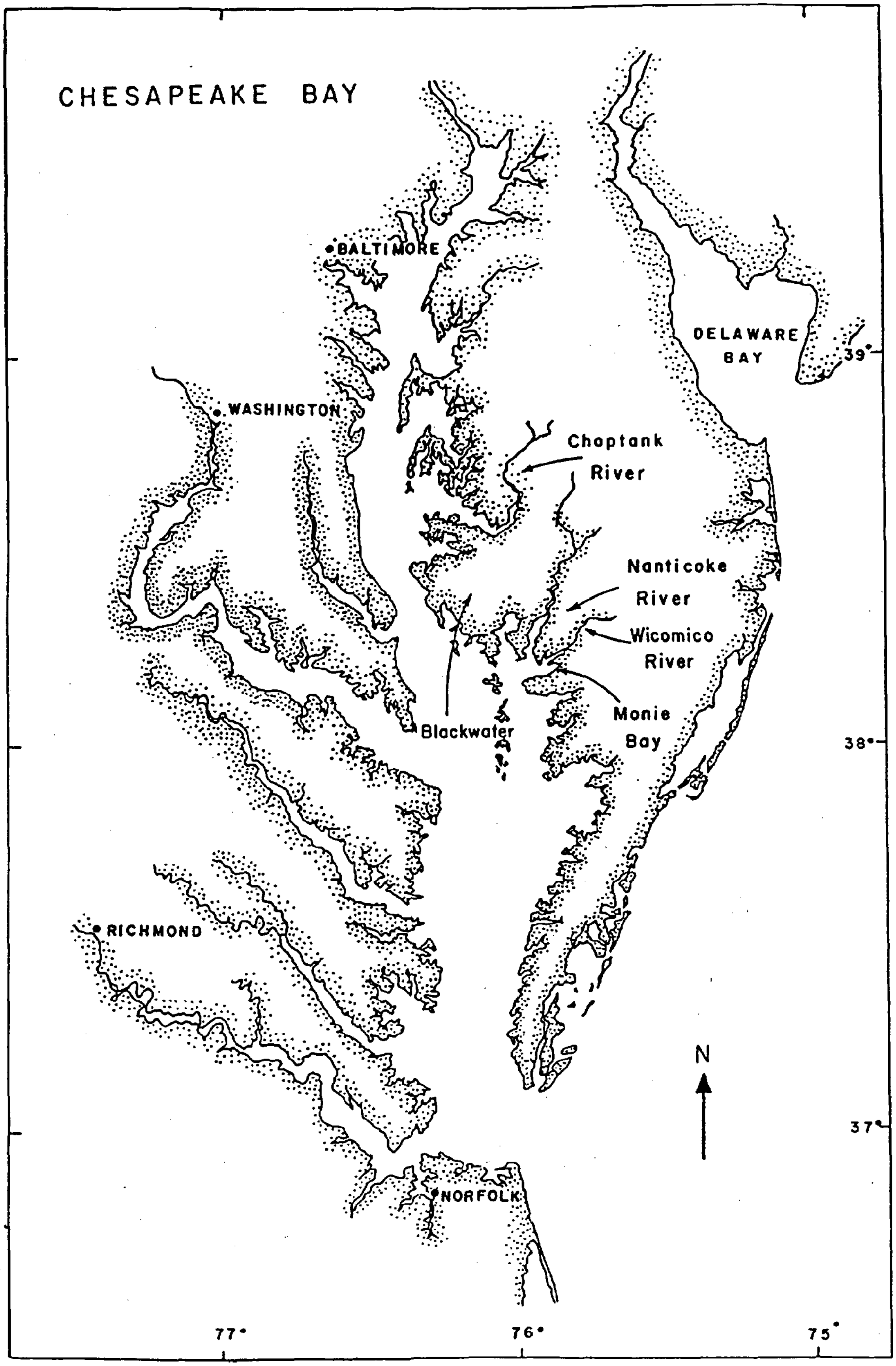


Figure 2. Location map of study sites in Chesapeake Bay.

These marshes, a large portion of which were designated a NOAA Estuarine Research Reserve in 1985, are largely unaltered and pristine. Although there is little geomorphic evidence of marsh loss in Monie Bay, this microtidal, estuarine marsh is located relatively close to areas where marsh erosion or submergence has been documented (e.g. Blackwater Wildlife Refuge, Nanticoke River). Also, there is considerable evidence that the rate of sea level rise will increase appreciably by the middle of the next century (Titus and Seidal, 1986). Wetland areas which are marginally keeping abreast of present sea level rise may not be able to adjust to an increase in the rate of submergence. In addition, reduction of sediment input (either inorganics of marine or riverine orgin or <u>in situ</u> production of organics) may decrease the ability of tidal marshes to keep pace with sea level rise.

Therefore, it is important that the sedimentology, stratigraphy, and accretionary processes of the marshes at the Monie Bay Research Reserve be understood to aid long-term management of the system. Whether the marshes are building (accreting) at rates high enough to keep pace with sea level rise is essential in planning access facilities or any other modifications in the area.

STUDY SITE

Monie Bay, a small embayment on the south side of the Wicomico River, is surrounded by submerged upland marshes (brackish to mesohaline marshes that have developed on recently submerged coastal terraces under low tidal ranges, see Stevenson et al. 1986). The marshes are primarily composed of three different sub-environments including: (i) bank marshes surrounding Monie Bay; (ii) tidal channel bank marshes along the two major tributaries, Monie Creek and Little Monie Creek; and (iii) back marsh areas (Fig. 3). The marsh banks surrounding the perimeter of Monie Bay are exposed to strong wave action which causes bank erosion. Monie Bay is 1 to 2 km wide and over 4 km in length along its longest axis. Additionally, Monie Bay faces into Tangier Sound producing a maximum fetch of nearly 20 km. Therefore, relatively high wave energy can occur during wind events. Storm overwash deposits composed of sandy sediments are common in the bank marshes. This environment contrasts with the lower energy areas found throughout the rest of Monie Bay. Tidal channel bank marshes are found along both Monie and Little Monie Creeks. These bank marshes, which are predominantly composed of fine-grained silts and clays, are frequently flooded by the tides. The back marsh areas which are flooded less frequently than the channel bank marshes, are highly organic, and are composed of very fine-grained muds.

The spatial distribution of plant species in the Monie Bay marsh is variable, resulting from subtle changes in topography which controls the penetration of tidal waters (and salinity) across the marshes. The dominant species in regularly flooded areas include *Spartina alterniflora*, *Spartina patens*, *Spartina cynosuroides*, *Scirpus olneyi*; whereas in less frequently inundated areas *Juncas*, *Distichlis* and *Phragmites* are common.

METHODS

Coring

A total of nineteen cores were collected which varied in length from 0.7 to 3.2 m, with most cores ranging between 1.0 to 1.5 m in length. Cores MC 1, MC 4, MCL 8, MCL 9, MCL 12, MCL 13, MCL 14, MCL 15, and MC 18

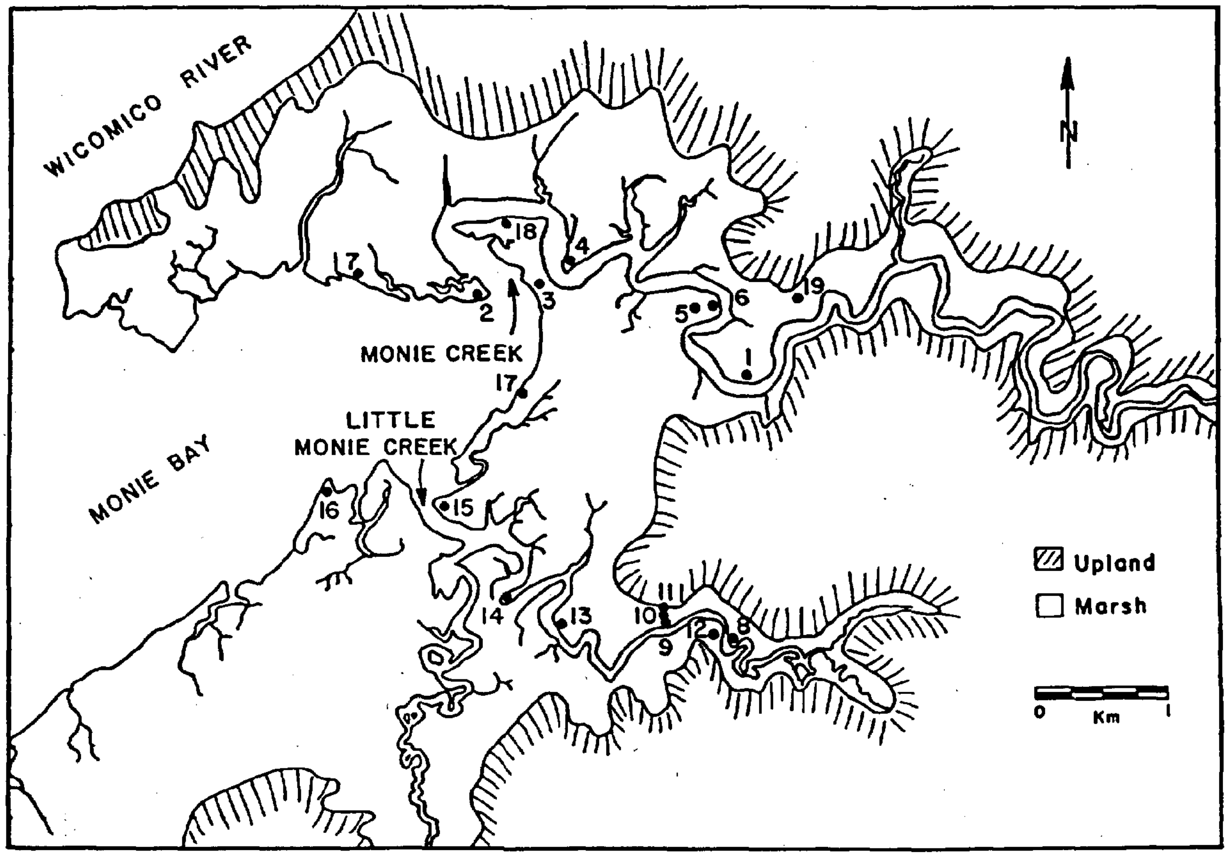


Figure 3. Monie Bay marsh system. Locations where cores were taken are shown by the solid circles.

were taken in tidal bank marshes (Fig. 3). MC 2, MC 3, MB 7, MB 16 and MB 17 were from Monie Bay bank marshes. Back marsh sites were cored at MC 5, MCL 10, MCL 11, and MC 19.

All cores were taken with a vibra-corer using the methodology described by Lanesky et al. (1979). The cores which consisted of 7.5 cm diameter aluminum irrigation pipes, were extruded by hand (digging) from the marsh to minimize disturbances.

The vibracores were transported in a horizontal position to the laboratory and kept cool (but not frozen) before analysis to minimize changes. Cores were extruded by cutting the core barrel lengthways and removing 1/2 of the core barrel. All cores were chilled to 4°C prior to opening in order to maximize the firmness of the sediments. Approximately 1/3 of the sediment core was then removed with piano wire or a serrated knife (to cut through roots). Upon completion of the core description, samples for grain size and bulk density analyses were taken near the top, mid-depth, and near the bottom of the core. Additional samples were collected where changes in sediment composition occurred. Sediment samples for moisture and combustible content were taken every 4 cm shortly (within a few hours) after the opening of the core. These samples were processed immediately to minimize moisture loss. Samples for palynological analysis were collected every 10 cm over the length of the core and stored in sealed plastic bags until analyzed. For the four cores selected for radionuclide analyses, additional sediment samples were taken every 4 cm over the entire length of the core. These samples were sealed in plastic bags and stored at room temperature until analyzed.

Sediment Texture Analysis

The moisture content of samples were determined by drying 5 to 10 gms (wet weight) of sediment in a preweighed aluminum dish at 50°C for ~ 24 hours, cooling in a dessicator, and determining percent weight loss. Subsequently, the sample was combusted (after pulverizing) at 450°C for 4 hours in a muffle furnace, cooled in a dessicator, and reweighed to determine % loss on ignition (LOI), an approximation of organic content (Ball, 1964).

Grain size was determined by first removing the organics by mixing hydrogen peroxide (15-30%) or sodium hypochlorite (bleach) with the sample, and allowing 4 to 7 days for the organics to be removed. Subsequently, the sample was washed with deionized water and wet seived through a 62 μ sieve. The grain size of the silt and clay fraction was determined by pipette analysis (Folk, 1974). The grain size of the sand fraction was measured by sieve analysis (Folk, 1974).

Bulk density was measured by removing approximately 1-2 cc of sediment (being careful not to compress the sample) soon after a core was sectioned. The wet weight of the sediment was determined before the sample was placed in a known amount of deionized water to determine the volume (by displacement). Wet bulk density was then computed. The dry bulk density was determined by filtering the sediment onto a preweighed glass fiber filter (0.3 μ effective diameter), drying at 50°C, and reweighing.

Geochronology

The geochronology of the sediment column was determined utilizing two methodologies, palynology and radionuclide dating. Pollen analysis was done on all cores which had negligible compaction (< 3%) (Table 1).

TABLE 1. QUALITY OF ACCRETION MEASUREMENTS

GOOD ACCRETION RATES (COMPACTION <3%)	ACCEPTABLE RATES (COMPACTION 7 - 9%)	QUESTIONABLE RATES DUE TO BIOTURBATION OR COMPACTION (>10%)
MC 2	MC 1	MC 6 - bioturbated
MC 3	MC 4	MCL 13 - compacted
MC 5	MCL 12	MB 17 - compacted
MC 7		MC 18 - compacted
MCL 8		
MCL 9		
MCL 10		
MCL 14		
MCL 15		
MB 16		

Additional cores which had apparently compacted between 7-9% where analyzed, but were viewed with some uncertainity. The accretion measurements were not adjusted to account for compaction as it is not certain whether the cores were actually compressed or if "rodding" had occurred. Sometimes sediment will stick inside a core barrel, not allowing the barrel to penetrate further into the sediment. Both the sediment core and barrel simply push through the sediment as a single unit (rodding). Lead-210 and Cesium-137 analyses were determined on three cores which appeared not to have been bioturbated and had no compaction (MC 6, MCL 8, and MCL 15). Core MC 4 was also analyzed for Lead-210 and Cesium-137 despite having an apparent 9% compaction, due to the importance of the geographic location.

Palynological Analysis. Samples for pollen analysis were initially taken approximately every 20 cm along each core to determine general trends in the pollen stratigraphy. Subsequently, additional samples (at 10 cm intervals in selected cores) were taken where a possible shift in *Quercus* or *Ambrosia* populations occurred.

Pollen extraction techniques followed standard procedures (Faegri and Iversen, 1975). Approximately one gram (wet weight) samples were initially treated with hot (95°C) 10% hydrochloric acid to remove carbonates from the samples and from the 3 *Lycopodium* pollen tablets (10,850 ± 200 grains per tablet) added as a tracer. Hot 10% NaOH solution was subsequently added to macerate the samples. Silicates were then removed by treatment with full strength hydroflouric acid and acetlyzed with a mixture of sulfuric acid and acetic anhydride. Pollen-rich residues were then washed with tertiary butyl alcohol, stained with saffranin-O, and embedded in glycerol as a mounting medium.

Pollen counts were obtained by conducting regularly-spaced transects across the coverslip under 400x magnification. A minimum of 200 grains (excluding unidentifiable spores) were counted in all samples, with the average pollen sum normally well exceeding 200. Concentrations for *Pinus*, *Quercus*, *Ambrosia*, aboreal, nonaboreal, and total pollen are expressed in grains per gram of dry sediment according to formula:

$$\frac{\#\ \text{Lycopodium grains added}}{\#\ \text{Lycopodium grains counted}} \times \text{pollen grains counted} = \text{grains per gram of dry sediment}$$

Kearney et al. (1985) and Kearney and Ward (1986), following Brush et al. (1982), recently have used *Quercus*:*Ambrosia* (oak:ragweed) pollen ratios as a means of quantifying more precisely the timing of agricultural clearance in the pollen record. Ratios of 10 or less are taken to indicate the initial peak phase of agricultural/settlement clearance on Maryland's Eastern Shore (Kearney et al., 1985).

Radionuclide Analyses. Sediment samples were analyzed for radionuclide activity at 4 cm intervals over the upper 50 cm of each core, and at 10 cm intervals from 50 to 100 cm. Each sediment sample analyzed was from a 2 cm depth interval.

The Lead-210 activity was determined by oxidizing the organics with concentrated Nitric acid, adding Polonium-208 as a yield tracer, and digesting for 8 hours in concentrated Hydrochloric acid. After the iron was chelated, the polonium was spontaneously plated onto silver discs and counted using alpha spectrometry (Flynn, 1968). The specific activity of the Polonium-210 was determined by comparing peak counts to the known Polonium-208 yield tracer peak counts. It is assumed the Lead-210 is in secular equilibrium with the Polonium-210.

Cesium-137 activity was done non-destructively using a Germanium (Lithium) gamma detector. The uncertainties averaged 9% and remained below 12% of the activity.

Historical Mapping

Long term trends in shorelines, tidal creeks, and interior marsh areas were determied by adjusting to a common scale vertical aerial photographs taken of the Monie Bay area in 1938 (scale, 1:20,000) by the U.S. Soil Conservation Service and again in 1985 (scale, 1:20,000) by the Maryland Department of Natural Resources. A Bausch and Lomb stereo zoom transfer scope was used to adjust the photographs to a common scale. Established control points (identifiable cultural features) were compared in each set of photos to minimize errors in the mapping due to the inherent planimetric distortions.

A classification scheme (Fig. 4) was developed for inventorying marsh surface conditions (marsh surface condition index, or MSCI) on the 1938 and 1985 aerial photography (Grace, 1986; Kearney et al., in press). In brief, a marsh which has complete vegetation cover, has sharply defined tidal creeks, and even and regular tonal characteristics of the photographs is considered healthy with no sign of deterioration. Several intermediate stages of deteriorating marsh are recognized, depending on the degree of thinning of the marsh vegetation, the number of rotten spots (Redfield, 1972) and the mottled tone of the vegetation. Class 5 in this scheme essentially indicates open water and is characterized by a vegetation cover of less than 20%.

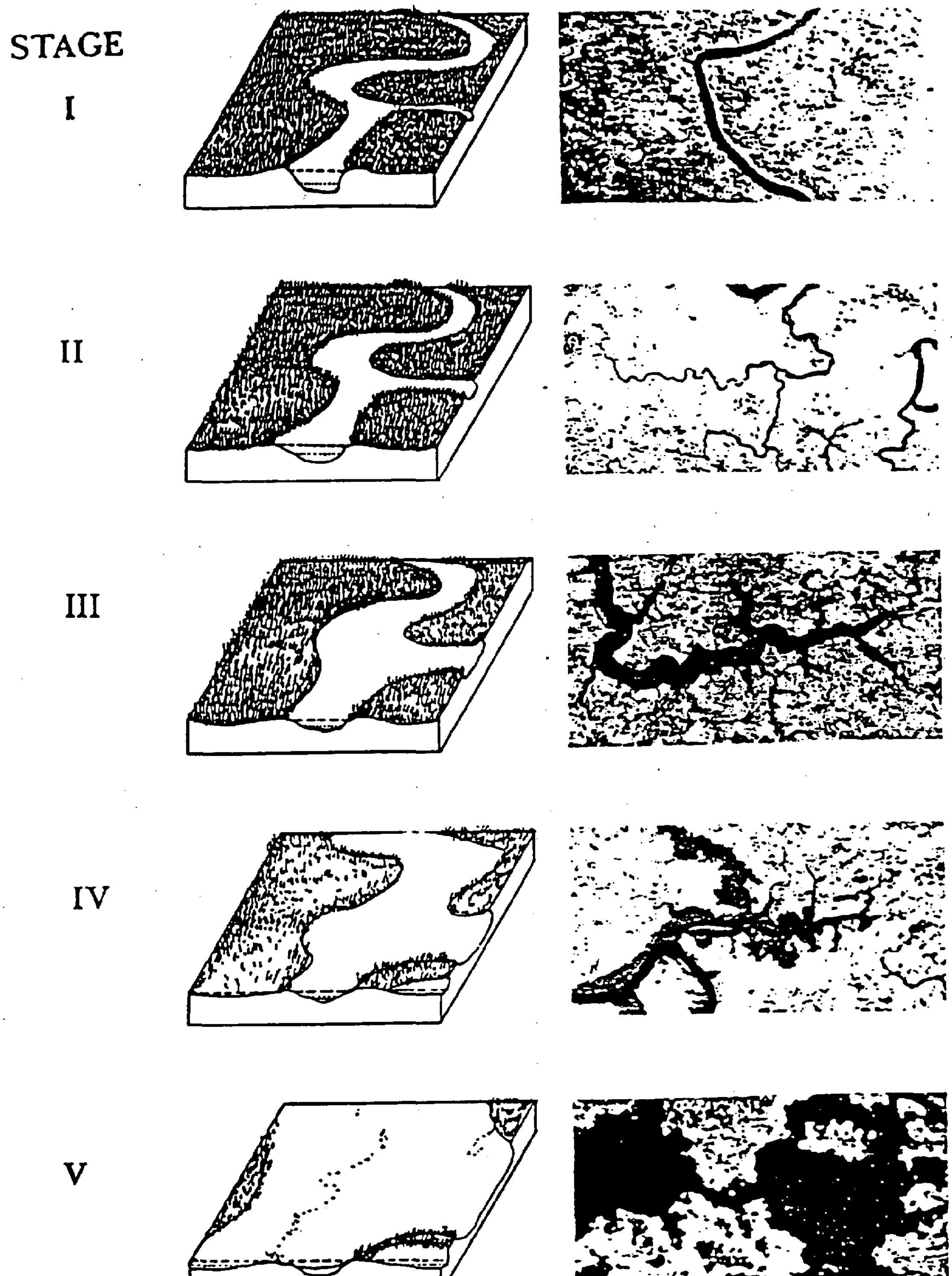


Figure 4. Schematic diagram of the five stages of marsh deterioration (modified from Grace, 1986).

RESULTS

Marsh Composition

Grain Size. The marshes in the Monie Bay area are predominantly composed of very fine-grained (Fig. 5; Appendix A, Table A-1), poorly to extremely poorly sorted (Fig. 6A), symmetric to fine skewed (Fig. 6B) sediments. Although mean grain size varies from 1.1 to 10.4 ϕ (466.5 to 0.7 μ), the primary mode is between 9 to 10 ϕ (2.0 to 1.0 μ). Within low energy environments (Monie Creek and Little Monie Creek tidal channel bank marshes and back marsh sites) the sediments are usually organic rich muds [LOI = 10 to 64%; mean size = 8.3 to 10.4 ϕ (3.2 to 0.7 μ)] which range in thickness from a few centimeters to over 320 cm (the maximum length core obtained during this study). When the entire marsh sequence was penetrated, an organic poor, muddy sand to sandy mud was encountered underlying the marsh [LOI = 1 to 3%; mean size = 1.5 to 6.2 ϕ (353.6 to 11.6 μ)]. Core MC 11 and MC 19 both penetrated pre-marsh sediments. Cores MC 1, MC 4, MC 5, MC 6, MCL 8, MCL 9, MCL 10, MCL 11, MCL 12, MCL 13, MCL 14, MCL 15 and MC 19 typify the low energy marsh environment.

Coarser sediments are found near the surface (20-40 cm) of site MB 2, MC 3, MB 7, MB 16, and MB 17 which are located along the banks of Monie Bay (Fig. 2) and are periodically exposed to high wave energy. For instance, the upper 20 cm of MB 7 is a mostly inorganic, poorly sorted muddy sand [LOI = 2%; mean size = 1.1 ϕ (466.6 μ)], which overlies an organic rich, very poorly sorted marsh mud [LOI = 37%; mean size = 8.9 ϕ (2.1 μ)]. The contact between the two deposits is relatively sharp. The sandy marsh sediments are apparently a storm overwash deposit. Similarly, site MB 16 has an organic poor, moderately sorted sand overlying an organic rich, poorly sorted marsh mud. At site MB 17, which is exposed

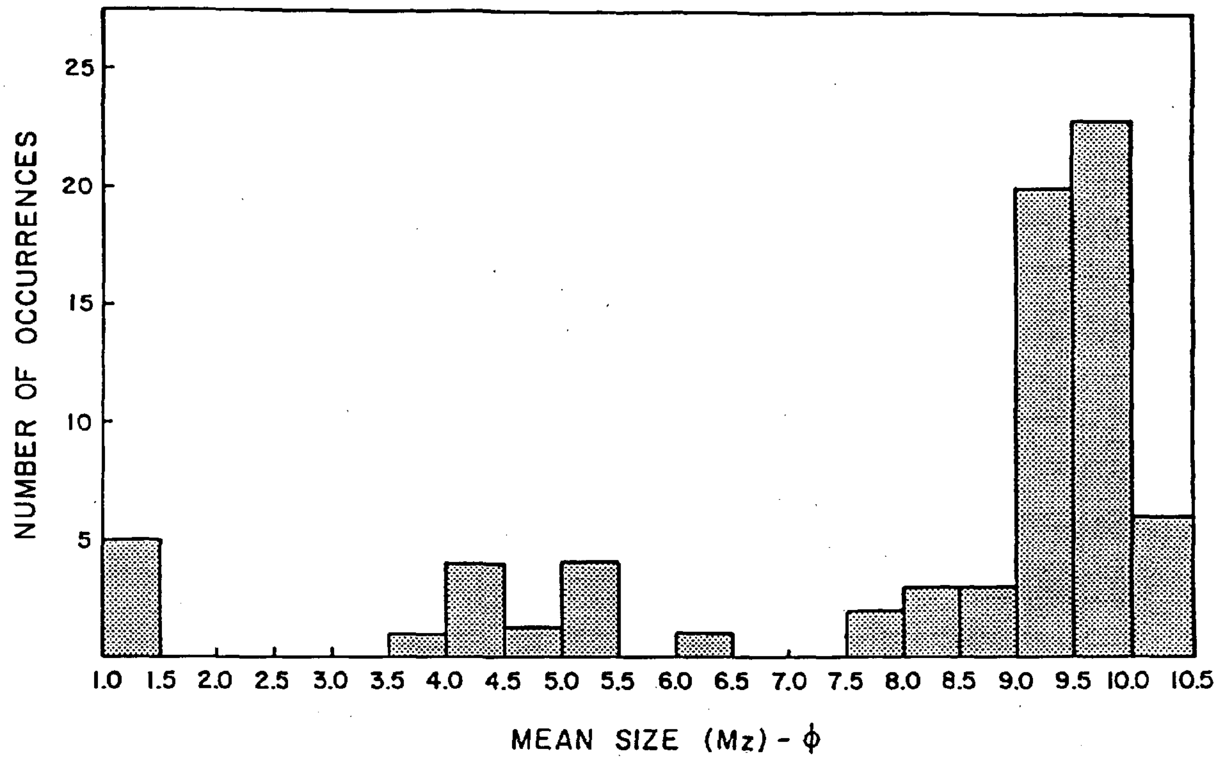


Figure 5. Distribution of mean grain sizes of the sediment samples taken at Monie Bay. The finer sediments (> 7.5 ϕ) typify low energy marsh sediments. The coarser sediment represent storm overwash deposits along the perimeter of Monie Bay or pre-marsh soil deposits. M_z determined after Folk, 1974.

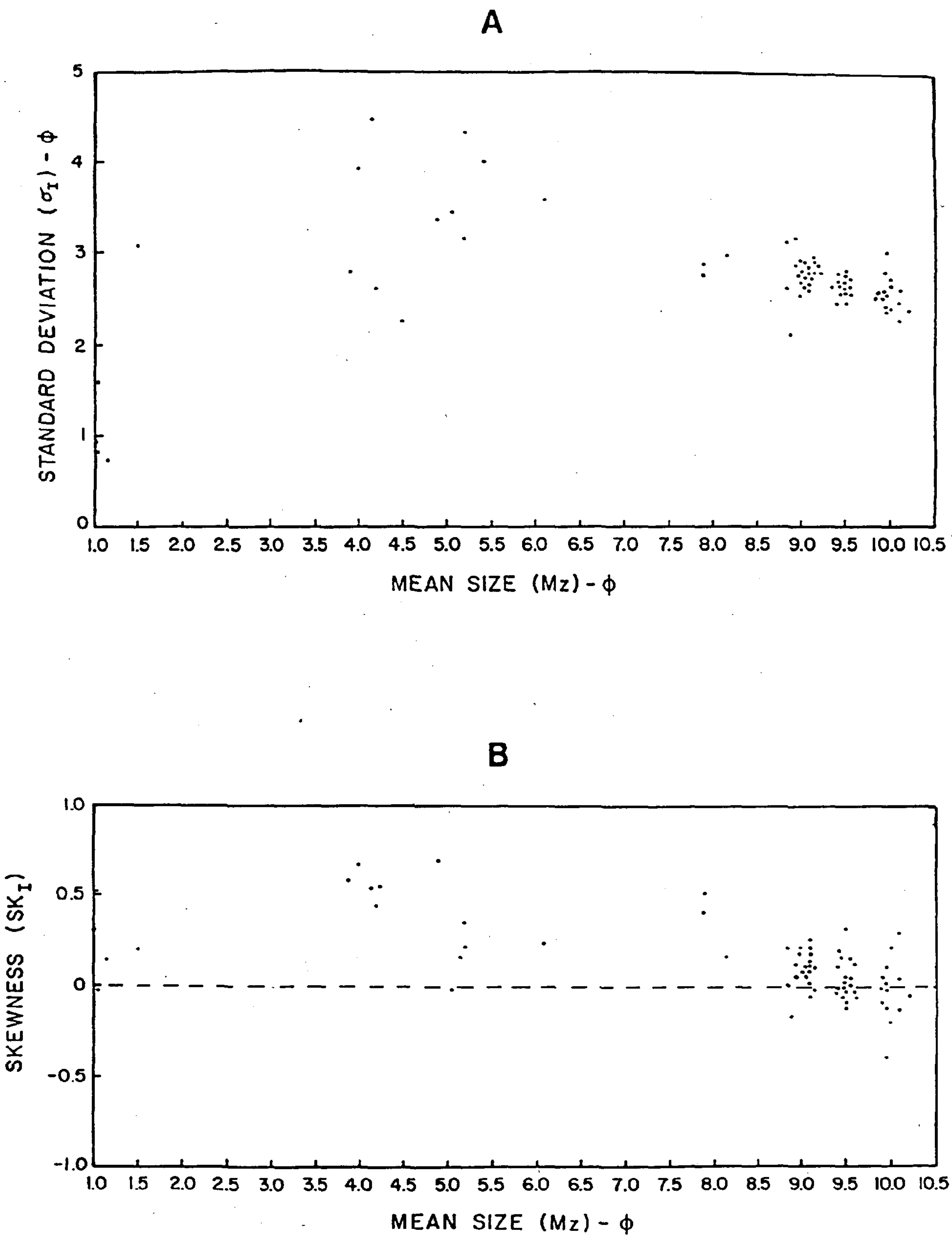


Figure 6. Relationship between (A) standard deviation and mean grain size and (B) skewness and mean grain size of the samples taken at Monie Bay. M_Z, σ_I and M_Z are after Folk, 1974.

to the maximum fetch found in Monie Bay, the upper 20 cm is composed of the typical organic poor, sandy deposit [LOI = 4%; mean size = 1.3 ϕ (406.1 μ)] found around the perimeter of Monie Bay. However, organic poor, coarser sediments are found throughout the 225 cm length of core MB 17, with coarse sands interbedded with silty sands or sandy silts. It appears the marsh at site MB 17 has a series of overwash deposits lying on top of each other.

Organic and Moisture Content. As observed by Redfield (1972) in Barnstable Harbor marsh in Massachusetts both organic content [as measured by loss on ignition (LOI)] and moisture content vary widely, but generally track each other. LOI values range from 1 to 76%, while moisture content varies from 4 to 92%. Channel bank marshes show two different patterns in regard to organic content (Fig. 7 and 8). At sites MC 6 and MCL 9, LOI increases relatively linearly from approximately 10% below 1 m to approximately 20% near the surface. Conversely, the remaining channel bank marsh sites vary from approximately 10% to 70% LOI and decrease towards the surface. This decrease is either abrupt (MC 1, MCL 8, and MC 18) or somewhat gradual (MC 4, MCL 12, MCL 13, MCL 14, and MCL 15). In either case, the decrease in organic content is not accompanied by significant changes in the mean grain size of the inorganic sediment.

Several of the cores taken in the higher energy bank marshes around the perimeter of Monie Bay also show a major decrease in organic content (Fig. 9). However, the low LOI values found near the sediment surface in cores MB 2, MC 3, MB 16, and MB 17 are associated with a major increase in sediment grain size caused by the storm overwash deposits.

The main exception to the trend of lower organics near the sediment surface than at depth occurs at site MB 17 (Fig. 9) which has very low

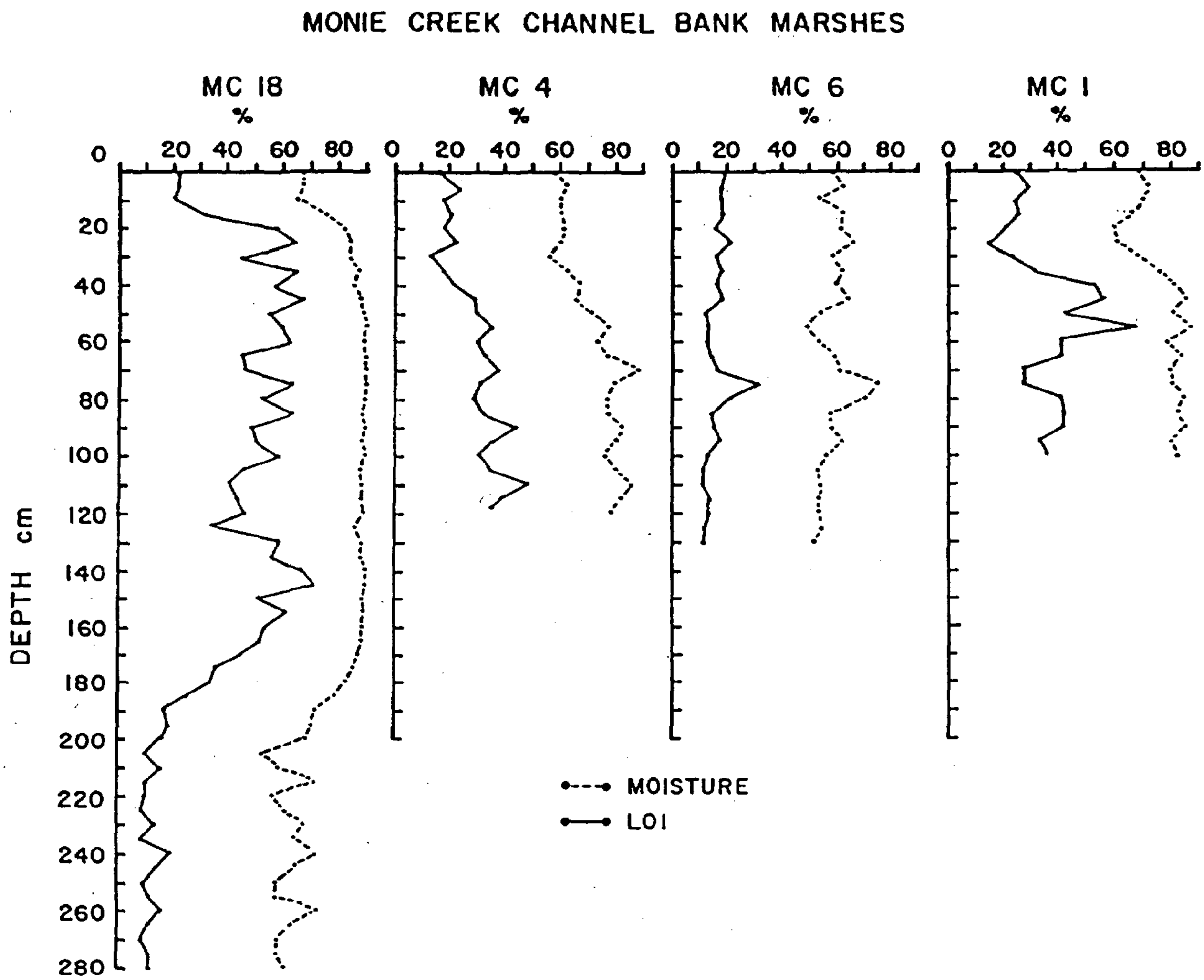


Figure 7. Organic content (measured by LOI) of the cores taken in Monie Creek channel bank marshes.

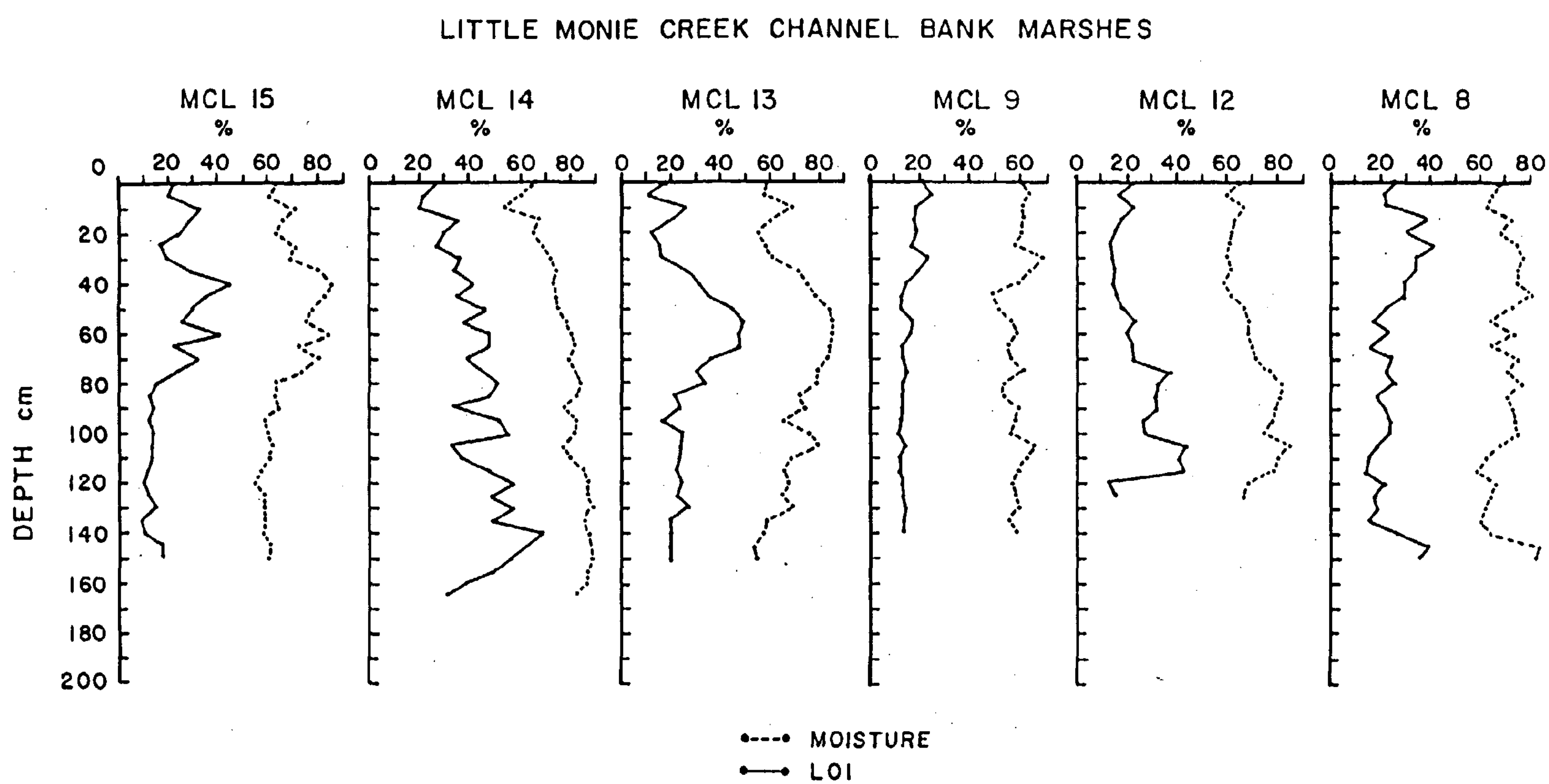


Figure 8. Organic content (measured by LOI) of the cores taken in Little Monie Creek channel bank marshes.

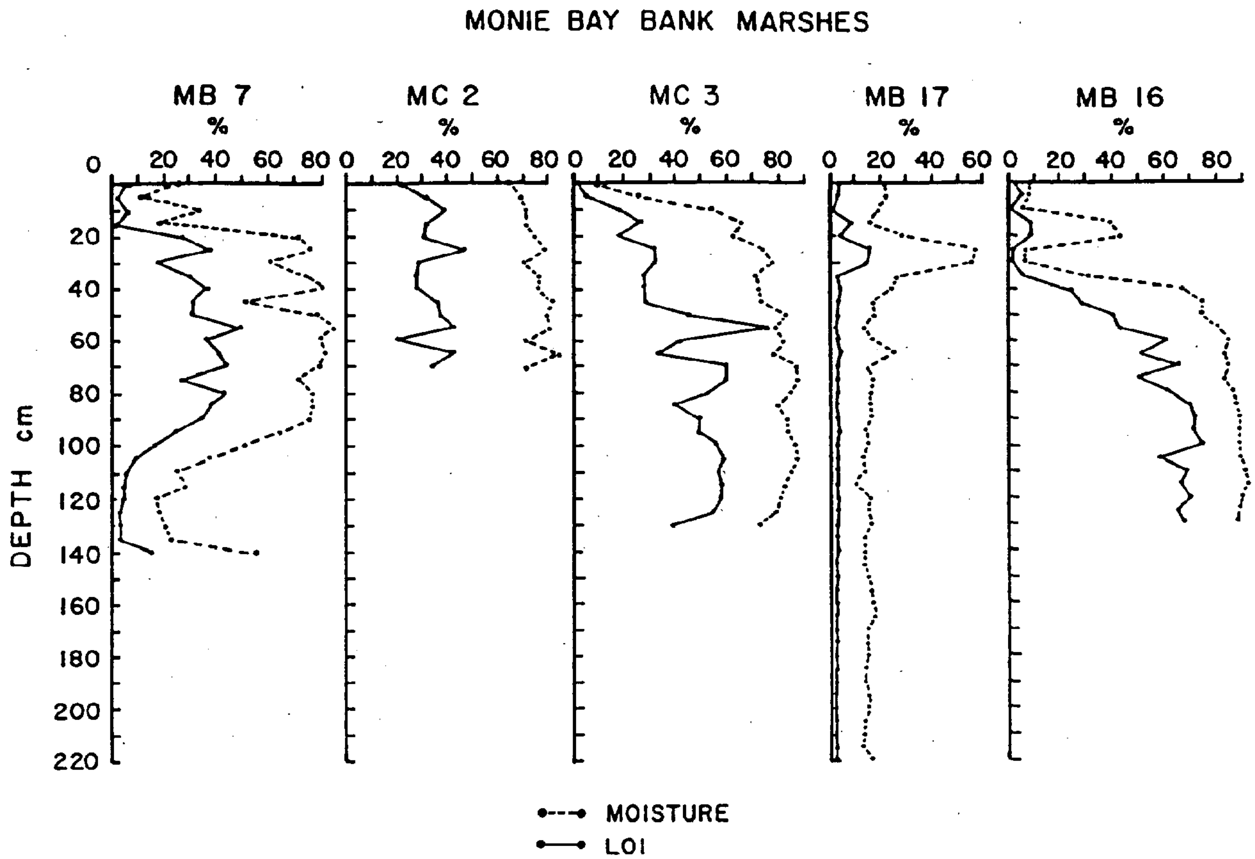


Figure 9. Organic content (measured by LOI) of the cores taken in Monie Bay bank marshes.

LOI (<10%) values throughout the length of the core except between the 20 to 40 cm depth interval where values increase to 16%. As pointed out in the previous section on grain size, the sediments throughout this core are coarse-grained, which tend to have low organic concentrations.

The back marshes are dominated by organic rich deposits shown in cores MCL 10, MCL 11 and MC 19, which have LOI values reaching 72% (Fig. 10). Below 30 to 40 cm, LOI concentrations decrease rapidly as subtidal or old soil profiles are encountered. Cores MCL 11 and MCL 19 were taken within 100 to 200 m of the upland marsh boundary where the marsh sediments were very thin (<40 cm). Here, an old soil profile was encountered as indicated by the very low organic content and the coarse grain size (Appendix A, Table A-1). Core MCL 10 was taken further from the upland boundary and has lower LOI values. Beneath the marsh at site MCL 10, the sediments are predominantly silty clays indicating they were deposited subtidally.

Core MC 5, which was taken from a site well away from the upland forest boundary, has a much different pattern of organic concentration than the other cores taken in the back marsh environment. LOI concentrations vary from approximately 50% to 70% below 50 cm, but drop to less than 30% near the surface. This pattern is similar to the decreases in organic content seen in many of the tidal channel marshes. The high organic content of the sediments below 50 cm is similar to that of back marsh sediments. However, the lower organic content nearer the surface is more typical of tidal channel bank marshes. This shift perhaps indicates a change in depositional environment from an infrequently flooded back marsh to a more frequently flooded marsh.

Bulk Density. The marsh sediments dry bulk densities range from 0.09 to 0.78 gm/cc (Fig. 11; Appendix A, Table A-1). The premarsh

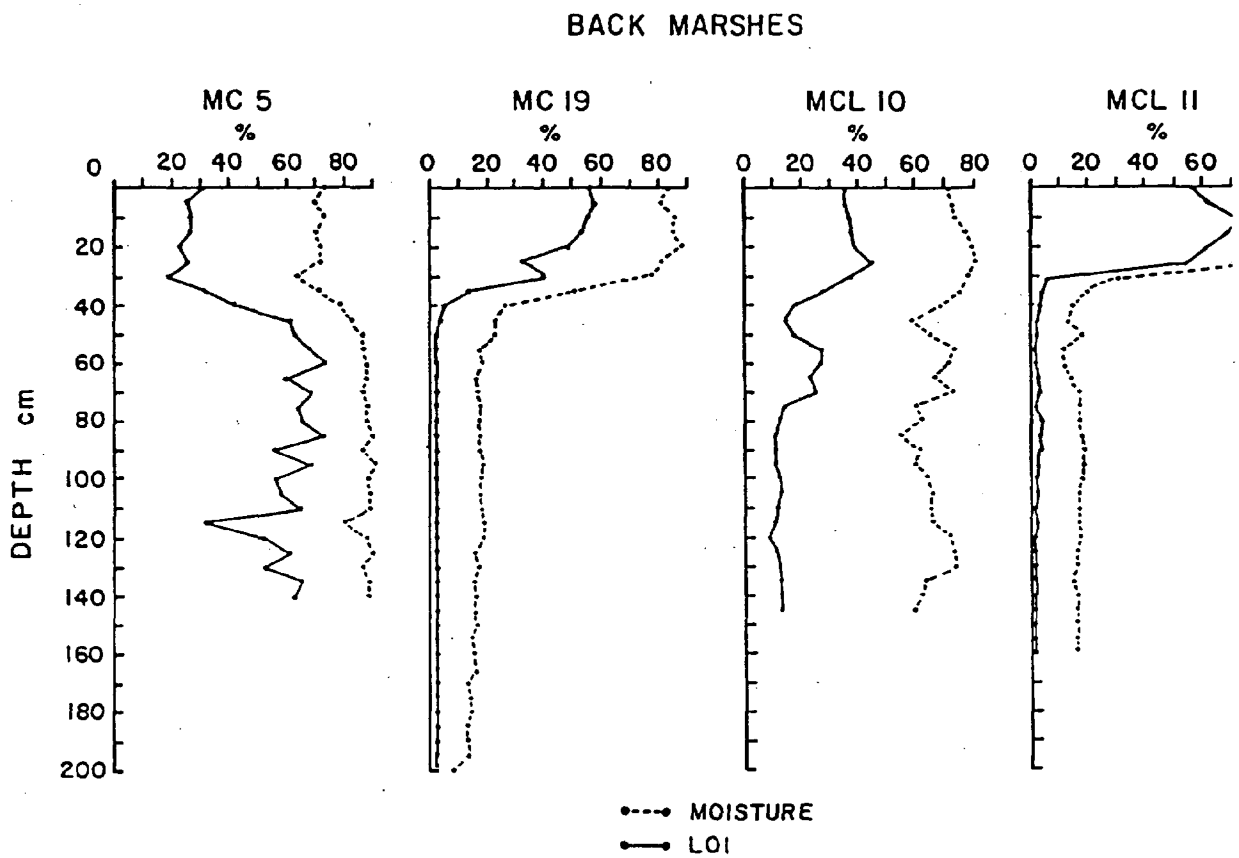


Figure 10. Organic content (measured by LOI) of the cores taken at back marsh sites in the Monie Bay area.

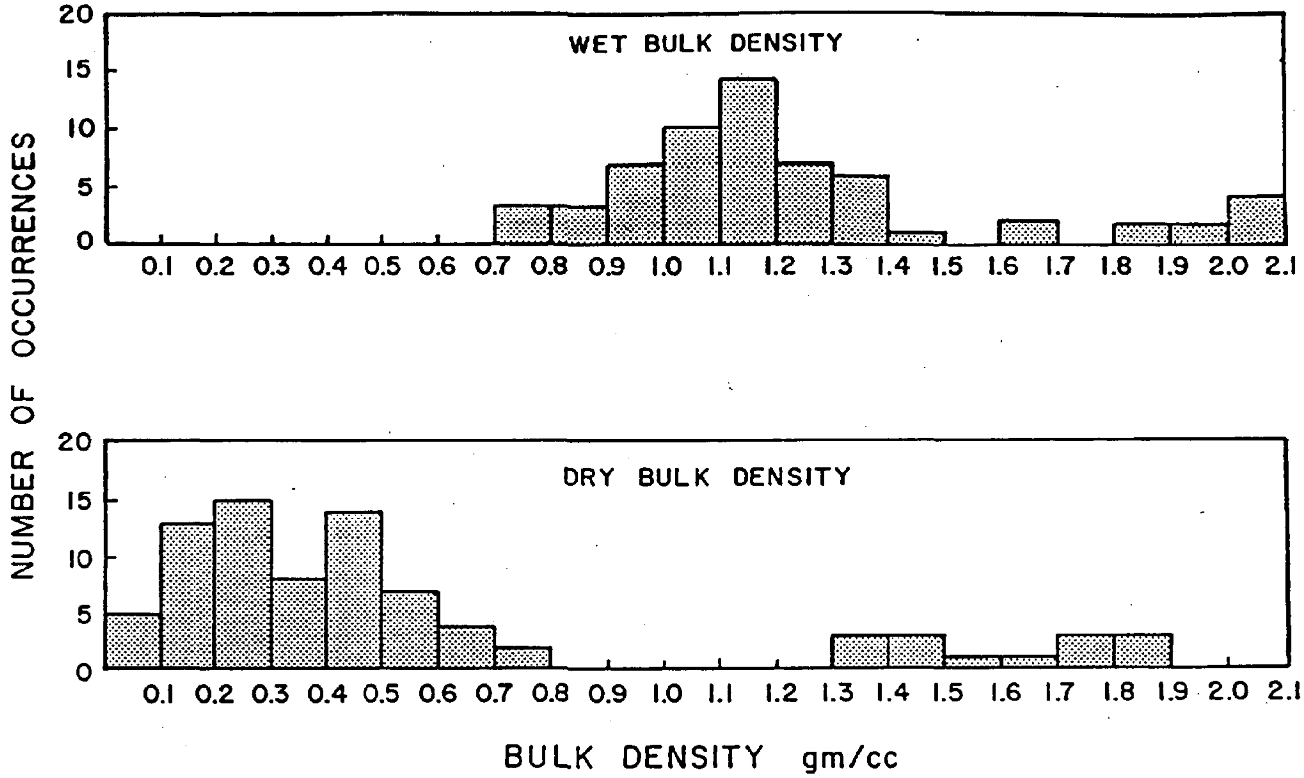


Figure 11. Distribution of wet and dry bulk densities of the samples taken at Monie Bay. The dry bulk densities less than 0.8 gm/cc are predominantly marsh sediments. The higher dry bulk densities are either pre-marsh or storm overwash deposits. Similarly the lower wet bulk density deposits are from marshes.

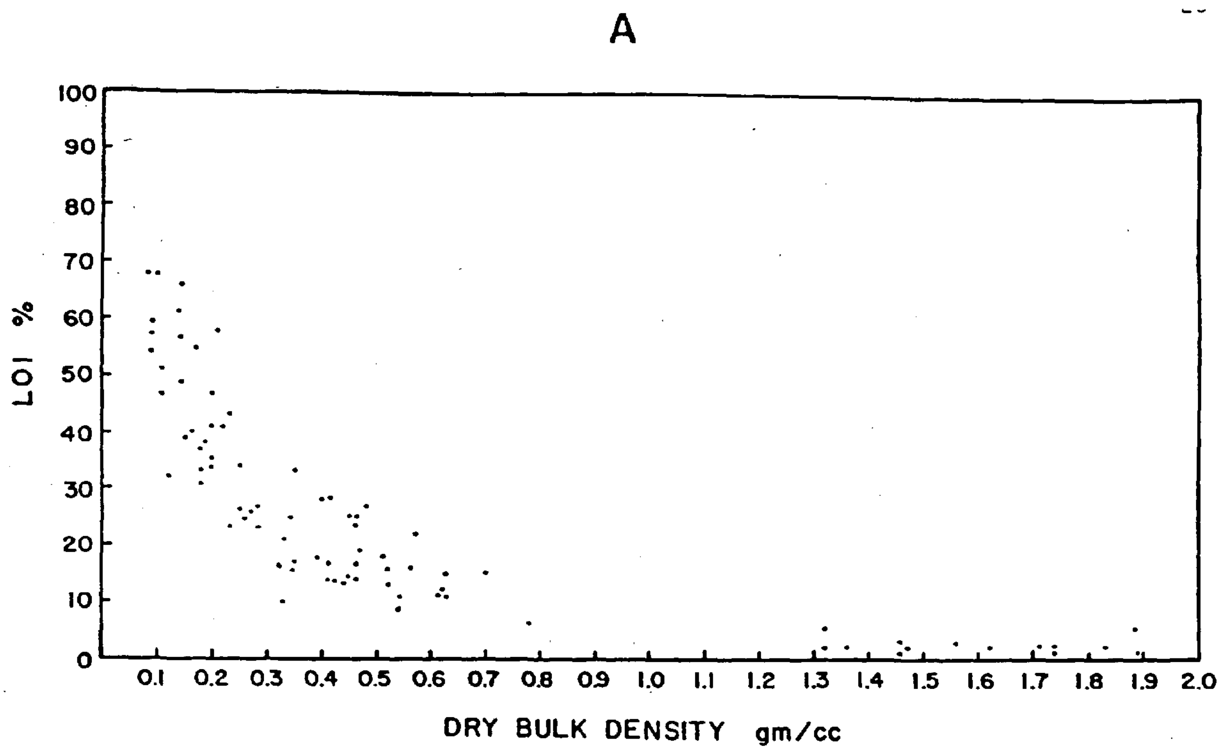
sediments penetrated at sites MB 7, MB 11 and MB 19 as well as the storm overwash deposits found at MC 3, MB 7, MB 16 and MB 17 which have LOI values of < 6% have consistently higher dry bulk densities ranging from 1.32 to 1.82 gm/cc. In fact, there is a strong inverse relationship between the organic content of a sample and its dry bulk density (Fig. 12A). Similarly, moisture content of a sample and its dry bulk density are inversely related (Fig. 12B). This is at least partially caused by the strong relationship between the organic content and moisture content discussed previously.

The wet bulk density of the marsh sediments range from 0.86 to 1.62 gm/cc (Fig. 11; Appendix A, Table A-1), with the higher values occurring near the bottom of cores which undergo autocompaction with increasing depth. The pre-marsh and storm overwash deposits wet bulk densities are again considerably higher varying from 1.66 to 2.23 gm/cc. Due to sampling difficulties caused by the lack of cohesion of the sediments, the number of measurements made on these samples is limited (11) and may not be representative of the entire Monie Bay area.

The wet bulk densities relationship to the organic and moisture content of the sediments is considerably weaker than that of the dry bulk densities (Fig. 13). However, there is a linear relationship between dry and wet bulk densities of the sediments (Fig. 14), which suggests that the increase in density caused by water is relatively constant.

Marsh Geochronology

<u>Radionuclides</u>. Lead-210 analyses of cores from Monie Creek (MC 4 and MC 6) and Little Monie Creek (MCL 8 and MCL 15) indicate accretion rates vary from 0.32 to 0.40 cm/yr. At site MC 4 the upper 20 cm of the



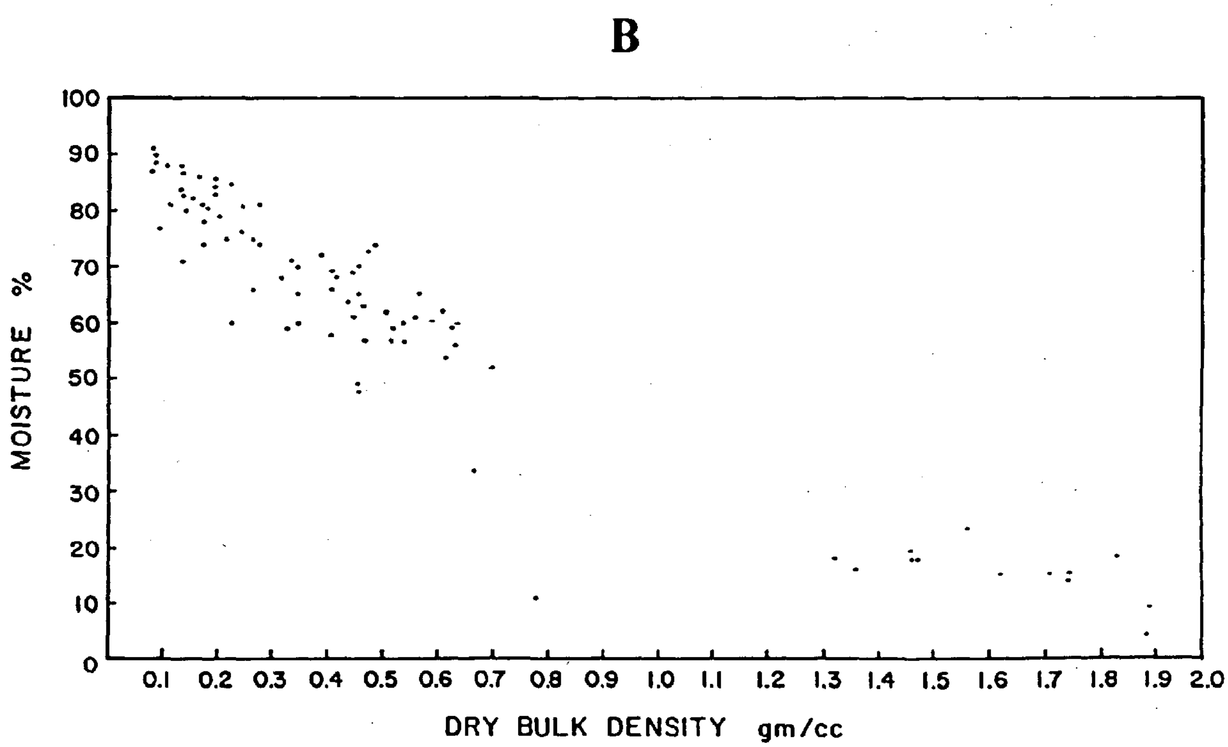
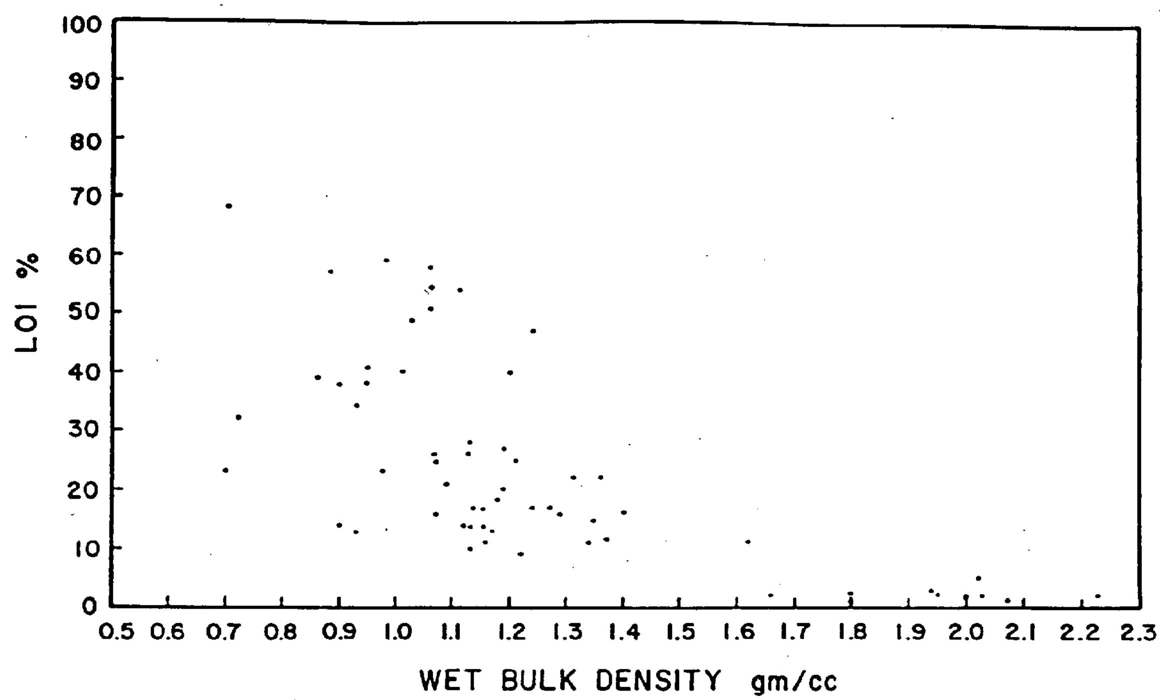


Figure 12. Relationship between (A) organic content (measured by LOI) and dry bulk density and (B) moisture content and dry bulk density of the samples taken at Monie Bay.

A



B

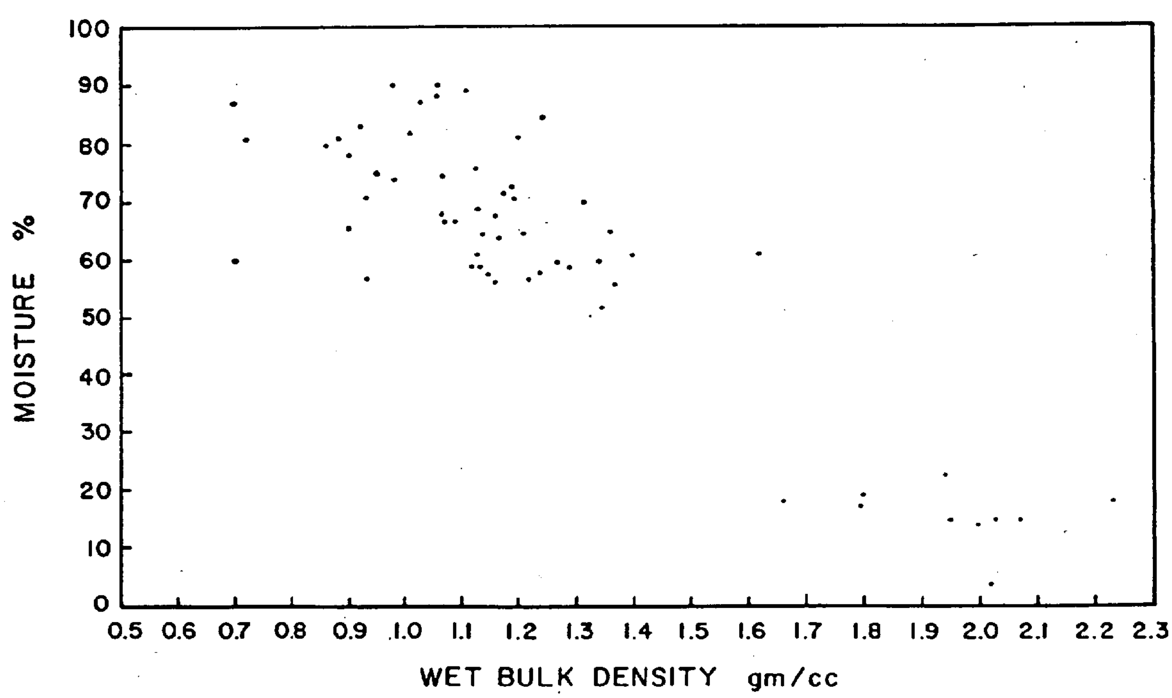


Figure 13. Relationship between (A) organic content (measured by LOI) and wet bulk density and (B) moisture content and wet bulk density of the samples taken at Monie Bay.

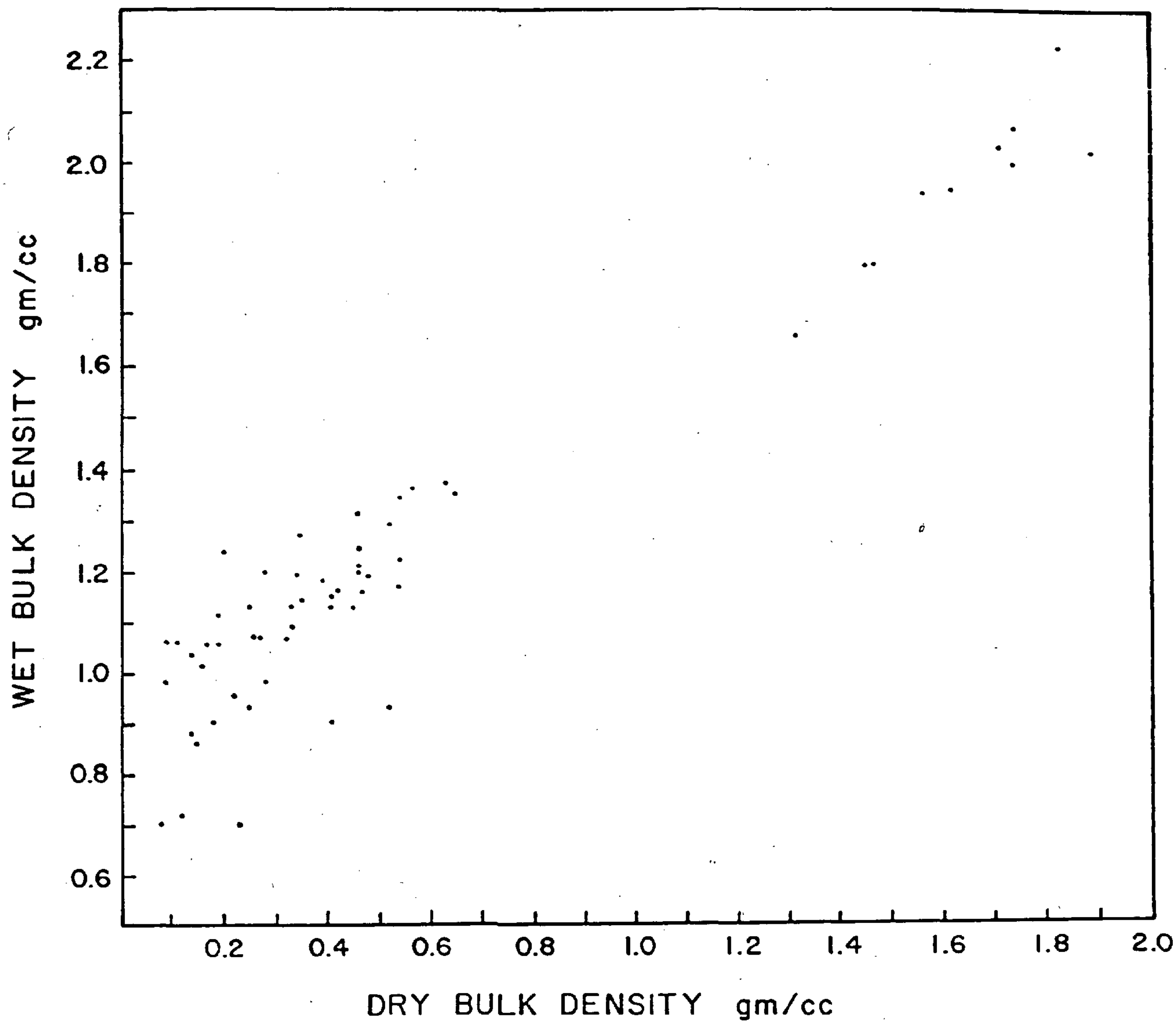


Figure 14. Relationship between dry and wet bulk densities of the samples from Monie Bay.

sediment column is mixed as indicated by uniform Lead-210 activity with depth (Fig. 15A; Appendix A, Table A-2). Below 20 cm to a depth of approximately 50 cm, the log of the excess Lead-210 activity decreases linearly to supported (background) levels. Linear regression of the Lead-210 activity from 20-50 cm gives an accretion rate of 0.40 cm/yr (r = -0.97). Further upstream in Monie Creek at site MC 6 (Fig. 15A), the upper 50-70 cm of the marsh is heavily bioturbated. The Lead-210 activity is nearly uniform to a depth of ~ 60 cm, where the values decrease abruptly to background levels (Appendix A, Table A-2).

In Little Monie Creek, both cores MCL 15 and MCL 8 were apparently bioturbated over the upper ~ 10 cm (Fig. 15B). Accretion rates determined from linear regression of the excess Lead-210 activity below the bioturbated zone indicate accretion rates of 0.32 and 0.34 cm/yr for sites MCL 15 and MCL 8, respectively. Interestingly, both cores MCL 15 and MCL 8 have anomously low total and excess Lead-210 activity at the 8-10 cm depth interval (Appendix A, Table A-2).

The Cesium-137 activity of cores MC 4, MC 6, MCL 15, and MCL 8 all indicate disturbances due to biological, chemical or physical processes (Fig. 16; Appendix A, Table A-3). For instance, the core from site MC 4 (Fig. 16A) has a sharp peak at the 16-18 cm depth interval, but lacks a second, although normally smaller, peak found in unbioturbated cores. Cesium-137 in the marsh sediment profile is assumed to have originated from the atmospheric testing of thermonuclear weapons in the 1950's and 1960's. If continuous accretion has occurred in a sediment column, and no other, more local sources of Cesium-137 (e.g. nuclear reactor releases) are available, a major peak in the Cesium-137 profile should occur as a result of maximum testing in 1963. A smaller, but distinct, peak in

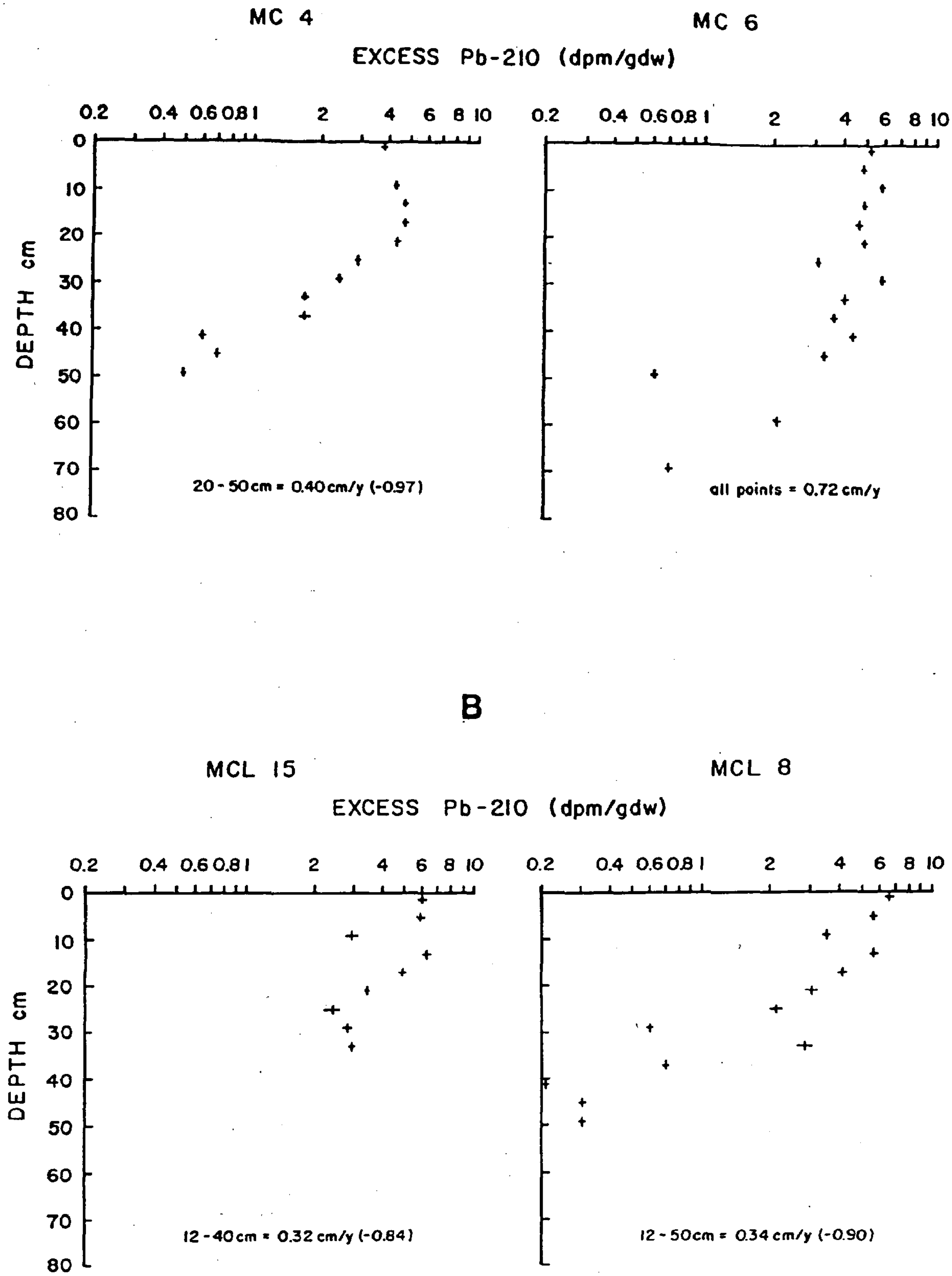


Figure 15. Excess Lead-210 activity (measured by Polonium-210) of the cores taken from (A) Monie Creek and (B) Little Monie Creek. Activity is measured as decays per minute per gram dry weight of sediment (dpm/gdw).

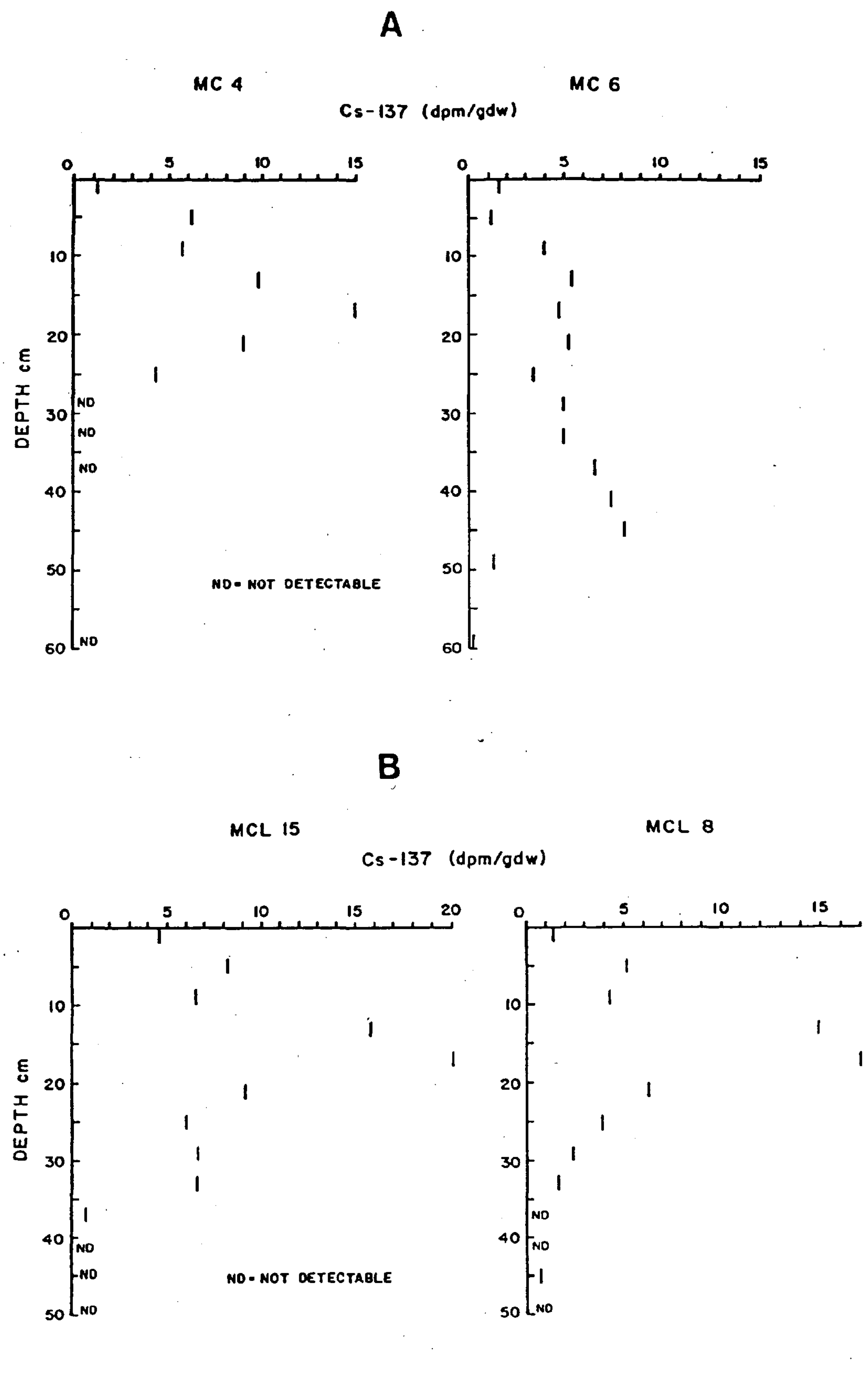


Figure 16. Cesium-137 activity of the cores from (A) Monie Creek and (B) Little Monie Creek. Activity is measured as decays per minute per gram dry weight of sediment (dpm/gdw).

activity should occur at a deeper depth which corresponds to a secondary peak in testing which occurred in 1959. Core MC 4 which was taken in a channel bank marsh appears to be bioturbated over the upper 20 cm as indicated by the appearance of only one peak. No Cesium-137 activity was detected below 20 cm. The Lead-210 activity also indicates the upper 20 cm of MC 4 was bioturbated.

The Cesium-137 distribution in core MC 6 indicates intense mixing of the sediment column to a depth of ~ 60 cm. The activity profile has no distinct peak varying chaotically from 0.1 to 8.0 dpm/gdw with depth. The penetration of Cesium-137 to a depth of at least 60 cm is undoubtedly a result of sediment mixing by benthic organisms, as an accretion rate approaching 2 cm/y would be required without bioturbation.

Cores MCL 8 and 15 from Little Monie Creek show a similar pattern as core MC 4 with a single sharp peak at a depth between ~ 12 to ~ 18 cm (Fig. 16B), which corresponds to the base of the bioturbated zone as indicated by the Lead-210 profiles (Fig. 15B). Mixing by benthic organisms is less intense at sites MCL 8 and 15 as indicated by the existence of a primary peak and the limited (<40 cm depth) downward mixing of Cesium-137.

Palynology

European settlement along the Atlantic seaboard in the 17th century radically changed the landscapes of eastern North America as the pace of settlement increased. One of the major consequences of European settlement was deforestation for agriculture, lumber, and firewood. As the 18th century progressed, rates of land clearance and lumbering increased dramatically; one principal reason being that the burgeoning colonial economy was driving an ever-expanding merchant marine, and timber was needed for shipsbuilding. Moreover, the Royal Navy's pressing need for ships in Britain's wars with France was outstripping the capacity of the few remaining forests in the British Isles to supply lumber.

This rate and extent of land clearance for agriculture and lumbering was unparalleled in eastern North America since retreat of the late Pleistocene ice sheets. Aboriginal Indian populations had certainly cleared land for agriculture, particularly in the Middle Atlantic region, but their agricultural practices were small in scale and had a negligible effect on the native vegetation (Brush et al., 1982). Europeans, moreover, in addition to extensively clearing land, also introduced non-native plants such as sheep sorrel (Rumex acetosella) and English plantain (Plantago anceoplata). However, perhaps the most significant result as far as detecting these vegetation changes in younger sediments were the rapid spread of ragweed (Ambrosia sp.) on newly deforested lands and agricultural fields. Ragweed is an opportunistic weed which quickly colonizes disturbed lands (Bazzaz, 1974). Equally important, it is an abundant pollen producer, with a distinctive grain morphology. Together, these characteristics cause a sharp increase in ragweed pollen in recent sediments creating a reliable geochronologic marker of the period since European colonization.

Pollen geochronology seldom produces an instantaneous time line in sediments because changes in the pollen rain typically lag the actual changes in the vegetation. Much of the disparity between vegetation change and its reflection in pollen deposition probably reflects the fact that many major pollen producers are over-represented in the pollen rain. However, additionally, it is probably due to the fact that actual direct aerial input of pollen at a depositional site comprises a smaller component of the eventual pollen assemblage than water-borne inputs in a watershed.

The natural lagged response of pollen depositional processes is a considerable factor to be weighed in assessing pollen geochronology as a stratigraphic marker; when tied to relatively short-term vegetation disturbances produced by human intervention, some additional uncertainties are introduced. European settlement and land clearance began in 1659 and proceeded comparatively slowly on the Eastern Shore until the 18th century. Even as late as 1730, the total population of Dorchester County, the most populous county of the early colonial period on the southern part of the Eastern Shore, amounted to only 5,700 people (Fig. 17) (Karinen, 1958). The question becomes by what time did clearance become widespread enough to be reflected in the regional pollen deposition? Although population figures for colonial times are flawed, scrutiny of the settlement history of Somerset county can yield an estimate of when this occurred in the study area (Fig. 17).

Initial settlement of Somerset County probably had taken place by 1660. Population growth was slow throughout the remainder of the 17th century, probably totally less than 5,000 by 1700 (Karinen, 1958). From 1700 to 1750, Somerset County's population doubled to somewhat less than 10,000 (Karinen, 1958). Population growth thereafter remained essentially flat throughout the mid-18th century, in part due to emigration spurred by soil exhaustion, until shortly before the Revolutionary War. Between 1760-1800, the population almost doubled, essentially peaking around 1790. In the first half of the 19th century, the population grew very little (Karinen, 1958).

Though the pace of land clearance that perhaps accompanied the population growth of Somerset County is difficult to judge, the rate of population growth suggests that the Revolutionary War period witnessed

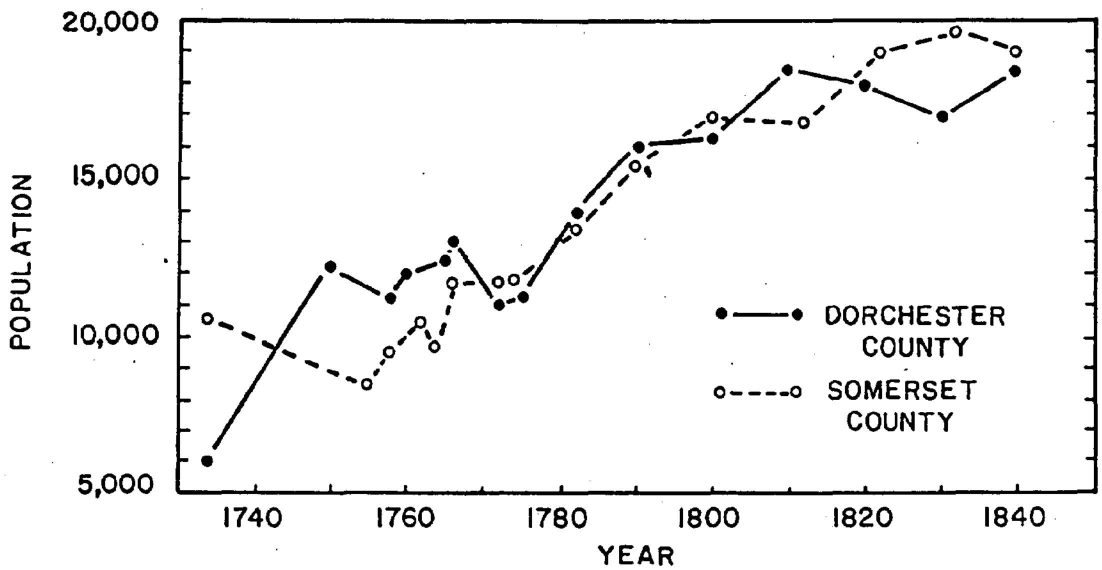


Figure 17. Population history of Dorchester and Somerset Counties, Maryland. (Modified from Karinen, 1958).

the most extensive clearance. By 1790, grains had replaced tobacco on the Eastern Shore as the primary cashcrop which required more land than tobacco. It is likely that the amount of land clearance did not change appreciably after this date. We thus have used 1790 (with a range between 1760-1800) as the approximate "target" date of the peak phase of early colonial/post-colonial settlement and land clearance in the study area.

Pollen Chronology and Accretion Rates. Most marsh sites exhibited clear shifts in the *Quercus*:*Ambrosia* (Q/A) pollen ratios (Appendix A; Table A-4). For instance, cores MC 1, MC 4, and MC 18 (Fig. 18), which were taken along Monie Creek, have sharp decreases in Q/A ratios at 30, 60, and 30 cm, respectively. Assuming this shift corresponds to the horizon of maximum clearing which is assigned a date of circa 1790 (agricultural horizon) gives accretion rates of 0.15, 0.30, and 0.15 cm/yr (Table 2). Core MC 6 pollen history has only a minor increase in the Q/A ratio over the entire length of the core which occurs at ~ 135 cm. This marsh site is heavily bioturbated as indicated by its Lead-210 and Cesium-137 profiles. The seemingly high accretion computed for core MC 6 (0.69 cm/yr) results from downward mixing of *Ambrosia* pollen due to bioturbation, rather than a high accretion rate.

A similar pollen history occurs along Little Monie Creek with clear shifts in Q/A occurring in cores MCL 9, MCL 12, and MCL 14 (Fig. 19). However, in cores MCL 8, MCL 12, and MCL 15 a gradational decrease in Q/A occurs. For the purposes of this study, the depth where the Q/A ratio drops and remains below 10 is considered the agricultural horizon and is used to compute an accretion rate; the actual rate may be higher.

The bank marshes around Monie Bay have clear shifts in Q/A ratios in cores MC 7, and MB 16 (Fig. 20). MC 3 shows more variability, but Q/A

TABLE 2. ACCRETION MEASUREMENTS BASED ON POLLEN ANALYSIS

CORE	QUERCUS:AMBROSIA SHIFT[x] CM	QUERCUS:AMBROSIA ACCRETION CM/Y	LENGTH OF CORE CM	COMPACTION %	COMMENTS
MC 1	35+	0.18	105	7	
MC 2	70*	0.36	70	0	Lost lower 1/2 of core while extruding from marsh
MC 3	35*	0.18	130	2	Upper ~ 10 cm composed of muddy-sand storm-deposit
MC 4	65+	0.33	118	9	
MC 5	45(45-70)*	0.23(0.23-0.36)	140	1	
MC 6	125+	0.63	133	0	Extensive bioturbation
MB 7	55+	0.28	140	3	Upper ~ 20 cm composed of muddy-sand storm-deposit
MCL 8	95*	0.49	148	0	
MCL 9	85+	0.44	138	0	
MCL 10	45(45-55)*	0.23(0.23-0.28)	145	0	
MCL 11	No Shift	-	159	<1	
MCL 12	45*	0.23	125	8	
MCL 13	35+	0.18	148	14	
MCL 14	45+	0.23	163	0	
MCL 15	60(60-80)*	0.31(0.31-0.41)	150	0	
MB 16	55+	0.28	128	<1	Upper ~ 15 cm composed of muddy-sand storm-deposit
MB 17	No Data	-	228	40	
MC 18	30+	0.15	327	25	
MC 19	No Shift	-	202	2	

x Depth at which ratio decreased below 10
+ Distinct shift
* Gradational shift

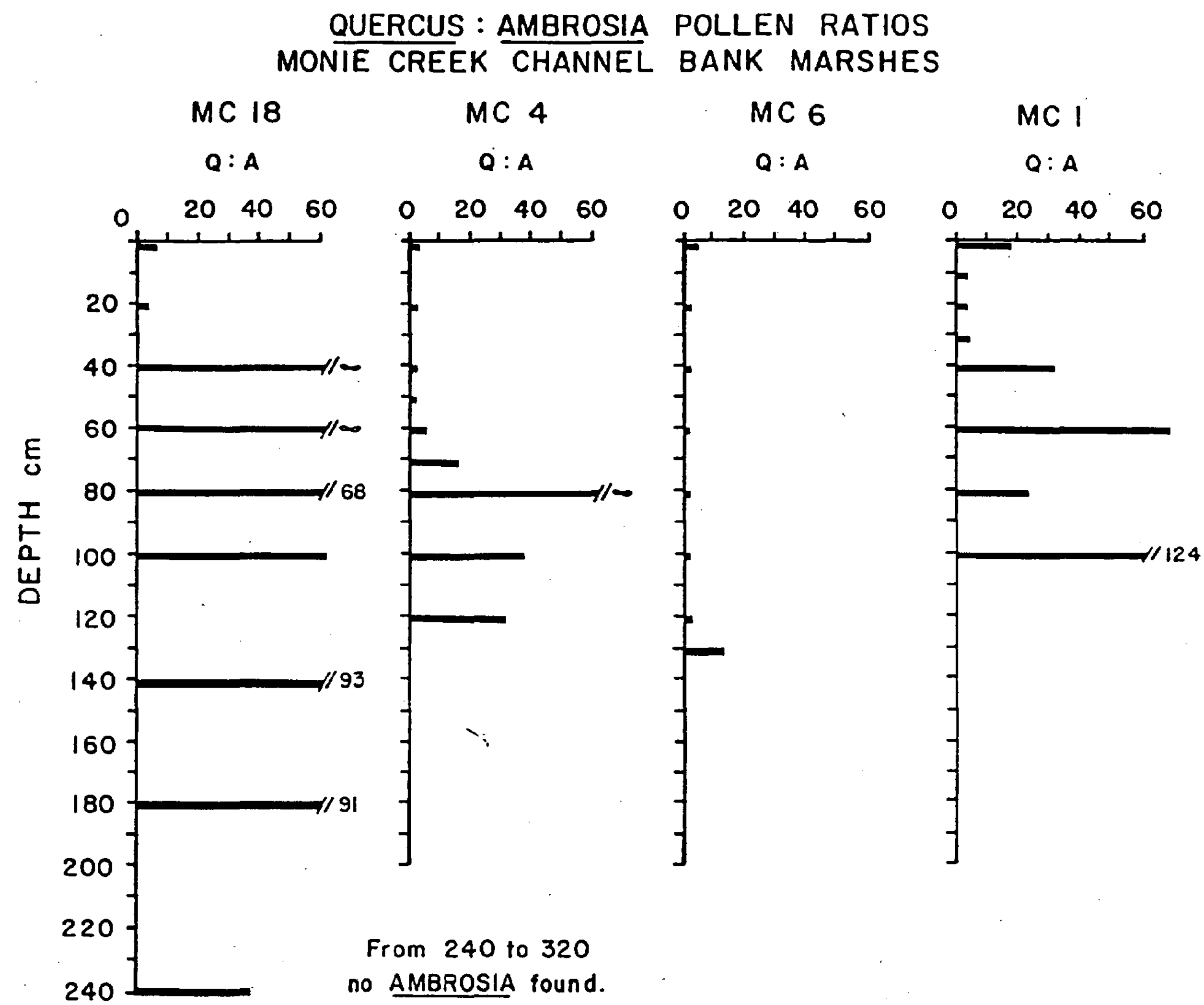


Figure 18. Quercus:Ambrosia ratios for cores taken in channel bank marshes along Monie Creek.

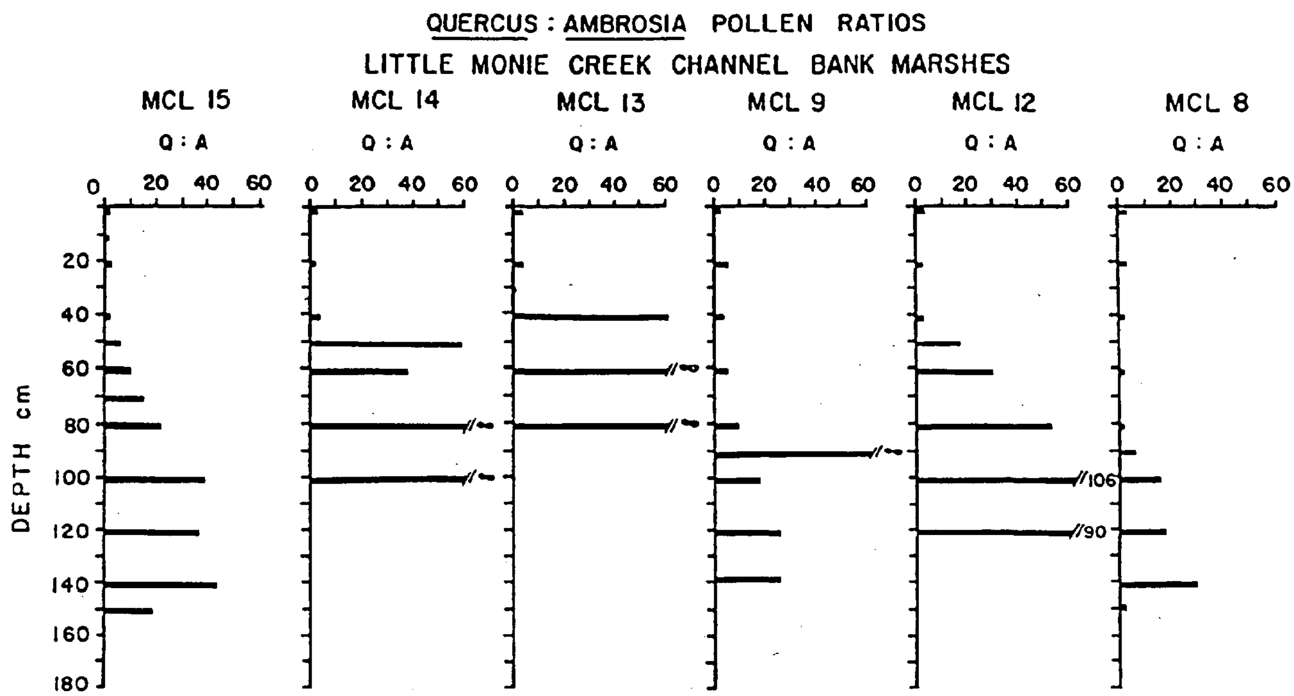


Figure 19. Quercus:Ambrosia ratios for cores taken in channel bank marshes along Little Monie Creek.

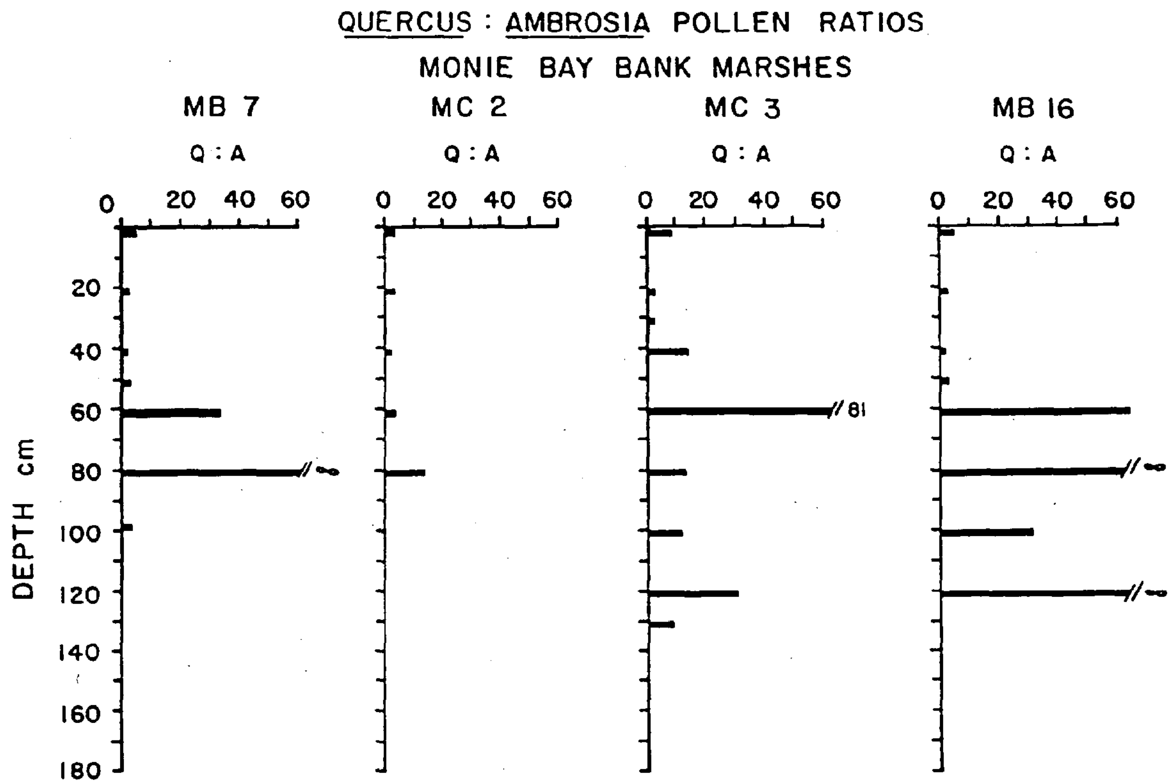


Figure 20. Quercus:Ambrosia ratios for cores taken in Monie Bay bank marshes.

decreases to less than 10 at 30 cm and remains low. All three of these sites have coarse-grained storm overwash deposits at the surface of the marsh. The total counts in these cores are subsequently low (Appendix A; Table A-4) as coarse-grained deposits are typically low in pollen. Coarse-grained sediments are usually deposited in high energy environment, which would simply winnow out much of the available pollen. The shift in Q/A occurs below the overwash deposits at all three of these sites, indicating the shift is not solely a function of grainsize. At site MC 2, the Q/A ratio is relatively constant to a depth of 70 cm, where the ratio increases to a little above 10. No coarse-grained storm deposit occurred at this site.

Accretion rates in the back marsh sites MC 5 and MCL 10 were low (~0.23 cm/yr) and the Q/A shift was apparent (Fig. 21). Conversely, at sites MCL 11 and MC 19, the Q/A ratio remained low through the upper 20-40 cm of the core, which corresponded to the thickness of the marsh sediments. Below the marsh the sediments, which were part of the soil profile prior to the transgression of the marsh, are coarse-grained and pollen concentrations are too low to allow inventorying. The presence of relatively high *Ambrosia* populations through the entire marsh sediments indicates the marsh at these sites post-dates the maximum clearing or the agricultural horizon (ca. 1790).

Historical Mapping of Shoreline and Marsh Changes

Monie Bay Bank Marsh Changes. Comparison of shoreline positions between 1938 and 1985 shows that bank recession or erosion occurred mostly along the protrusion of land at the junction between the Wicomico River and Monie Bay near Monie Point (Locations E, F, G on Fig. 22; Table 3)

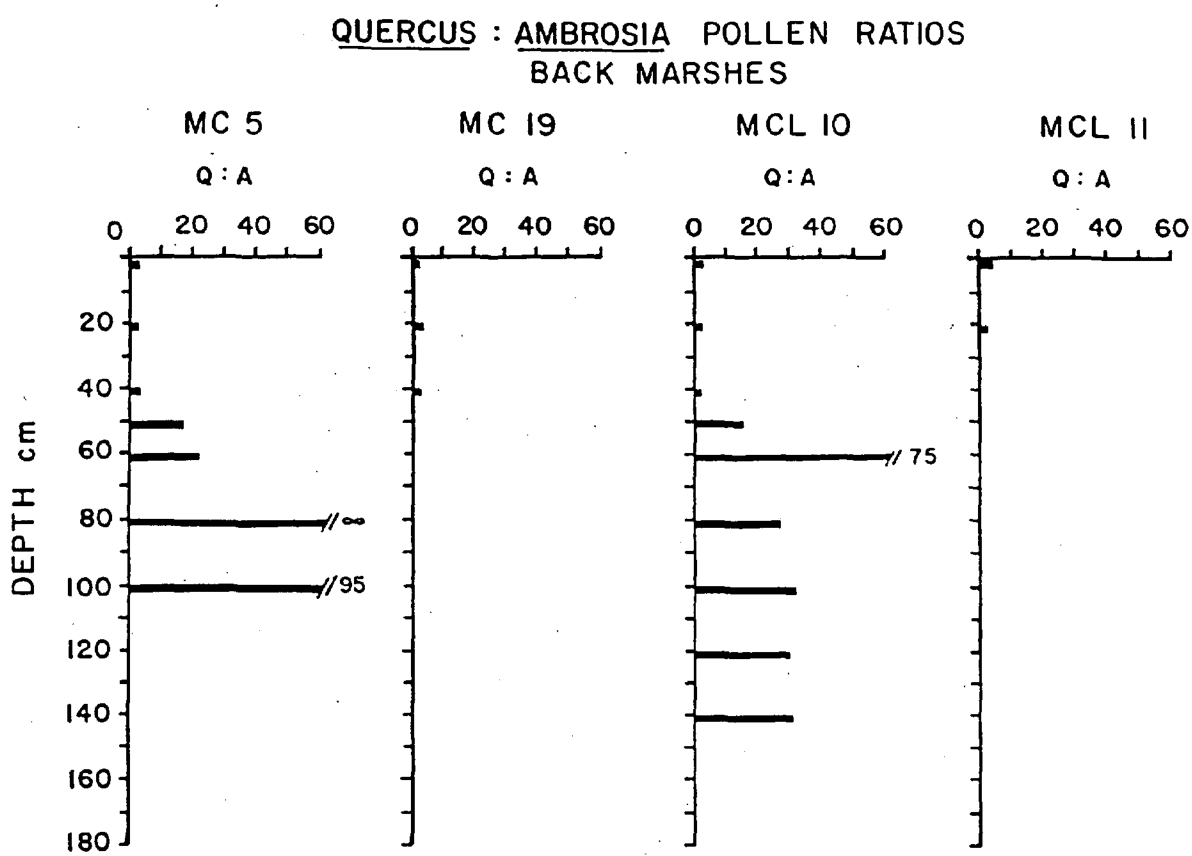


Figure 21. Quercus:Ambrosia ratios for back marsh cores taken in Monie Bay.

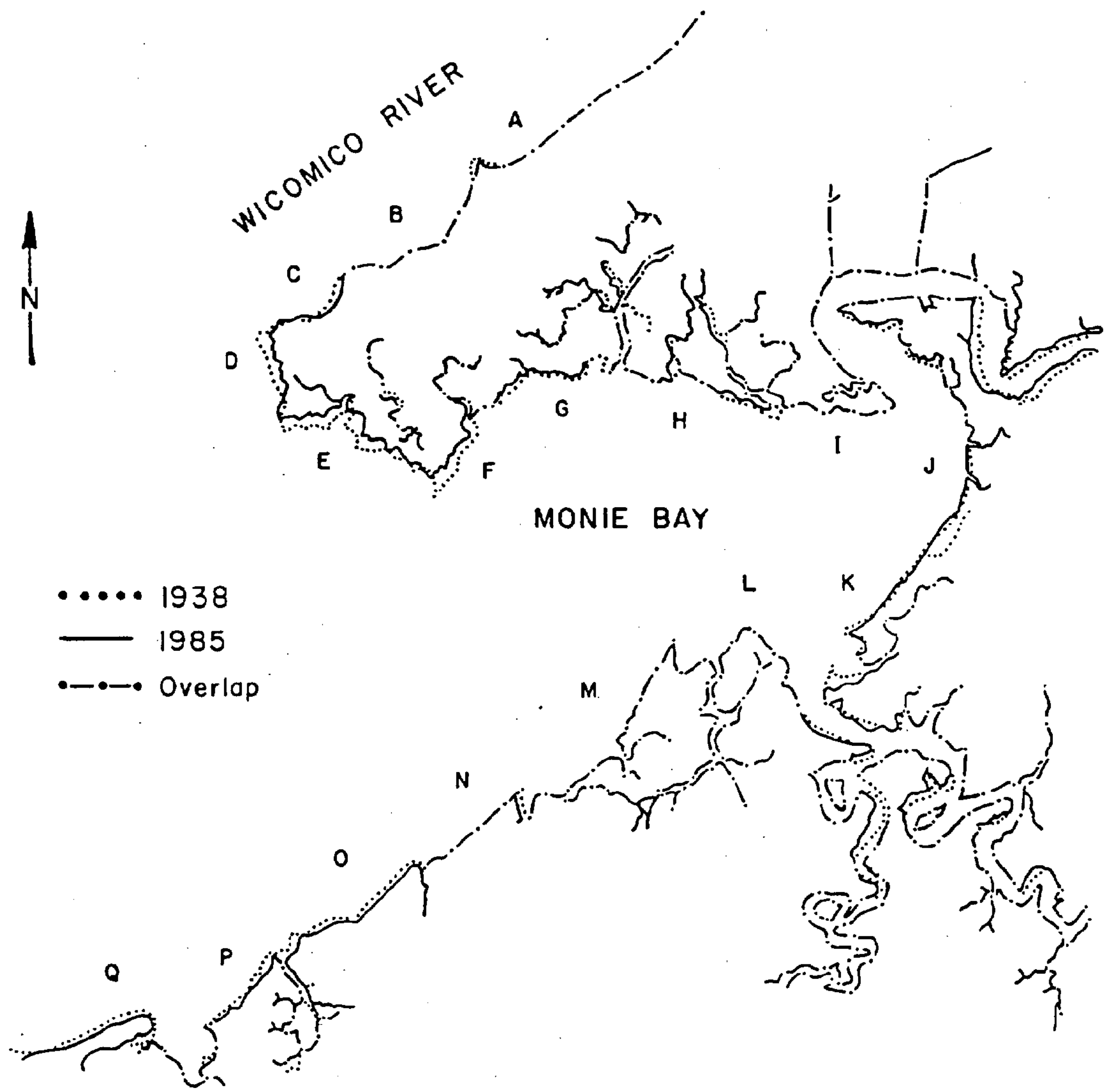


Figure 22. Changes in shoreline position in Monie Bay between 1938 and 1985.

TABLE 3. SHORELINE RECESSION (EROSION) RATES ALONG MONIE BAY FROM 1938 TO 1985.

LOCATION	AMOUNT OF EROSION METERS	RECESSION RATE METERS/YEAR
A	0	0
B	0	0
C	15.3	0.3
D	45.9	1.0
E	61.2	1.3
F	61.2	1.3
G	0	0
H	0	0
I	0	0
J	0	0
K	0	0
L	23.0	0.5
M	0	0
N	0	0
O	30.6	0.6
P	30.6	0.6
Q	23.0	0.5

and at the southern boundary of Monie Bay (Locations O, P, O on Fig. 22; Table 3). Erosion rates average between 0.5 to 1.3 m/yr at these sites. Erosion rates along the northeastern to southeastern margin of Monie Bay are very low, in most instances the rates are unmeasurable.

Marsh Surface Changes. Examination of the 1938 and the 1985 aerial photographs indicate the marsh surface has changed little in the 47 year period. Evaluation of the marsh using the marsh surface condition index (MSCI) shows most of the area is healthy with little sign of deterioration (Figs. 23 and 24). Most changes are variable, exhibiting no consistent pattern of change. However, the Monie Bay bank marshes show some increases in the MSCI rating, especially at sites which have the highest accretion rates. For instance, the marsh at site MB 16 (Fig. 3), has an adjusted accretion rate of over 15 cm/yr (see section on Accretion Rates in the Discussion). Although the actual accretion rate is undoubtedly less, it is apparent that rapid accretion is occurring on the marsh surface. However, some marsh bank recession has occurred in the area.

Qualitative comparisons of the 1938 and 1985 vertical aerial photographs suggest the marsh tidal channels have undergone headward (apical) growth. Additionally, first order tidal channels appear to have increased in density. Higher order tidal channels appear more stable, showing minimal changes in location. Limited migration of the main trunk of the some of the tidal channels has occurred at meander bends. A large oxbow with a cutoff has developed in Little Monie Creek indicating channel migration has occurred. Again, the rates of movement appear to be very low. It is likely that changes in channel position occur during storm events when the tidal prisms within these channels are greatly increased and the marsh surface is flooded.

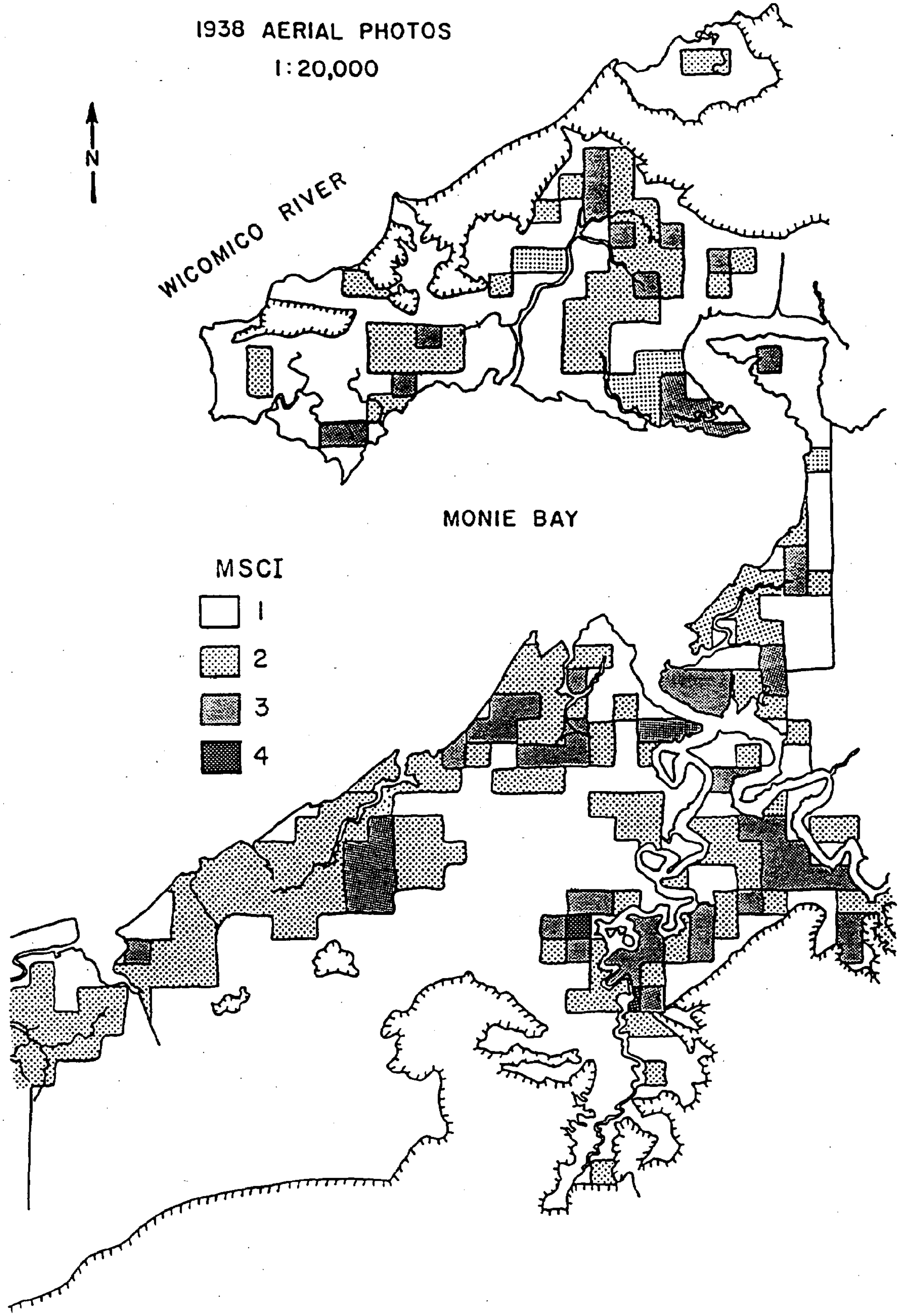


Figure 23. Condition of the marsh at Monie Bay in 1938 based on the MSCI.

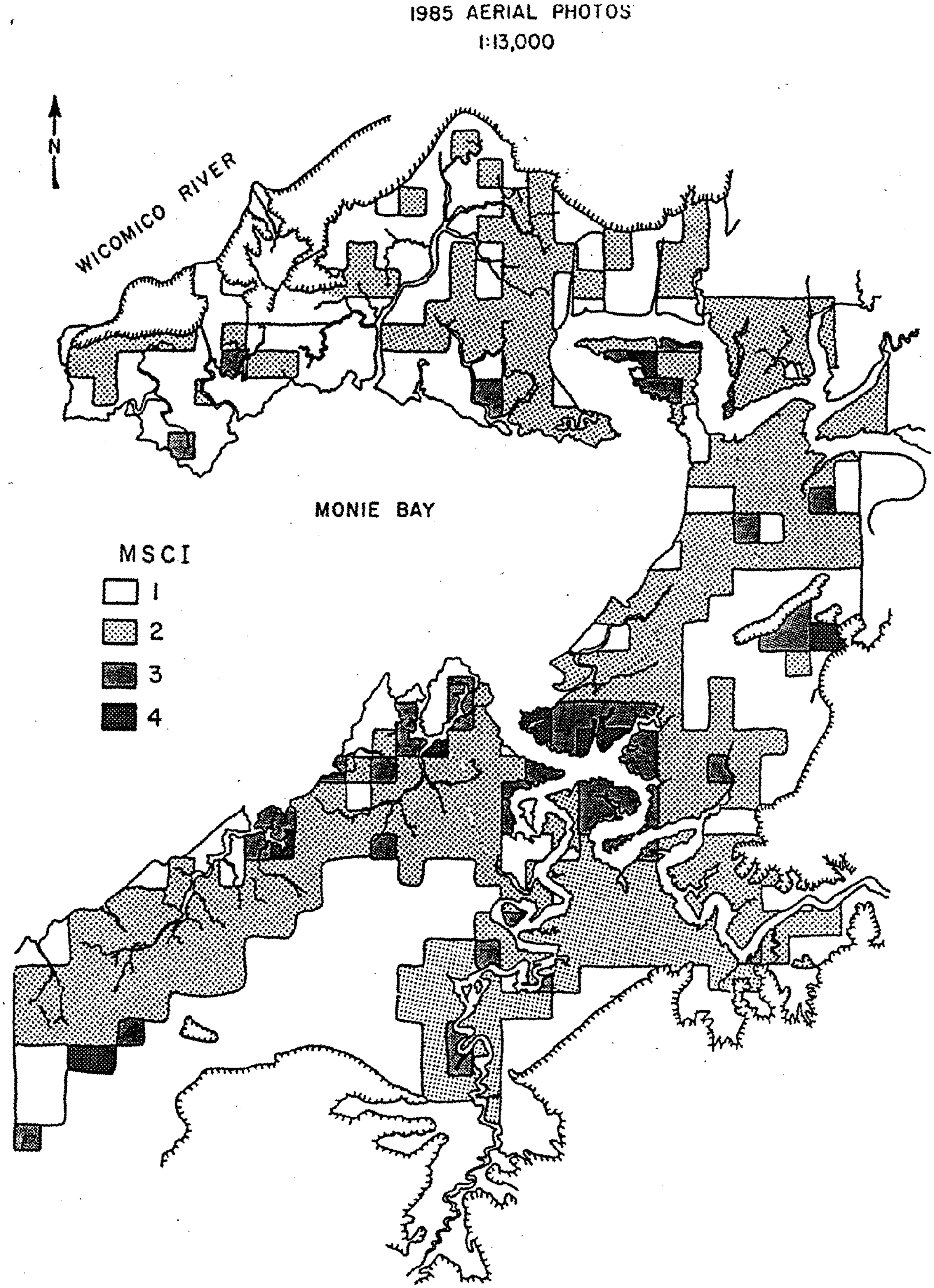


Figure 24. Condition of the marsh at Monie Bay in 1985 based on the MSCI

DISCUSSION

Changes in Organic Content of Marsh Sediments

The marsh system at Monie Bay has three clear patterns in regard to organic content which signify different or changes in depositional histories. The tidal channel bank marsh sites which show an increase from 10% LOI at depths below 1 m to 20% near the surface could have developed through inorganic deposition in a subtidal environment, transgressing from subtidal mudflats, to vegetated intertidal flats, and subsequently to high intertidal marshes. Another possibility is that peat deposited over the previously submerged upland is lost through diagenetic processes resulting in less carbon in deeper horizons. This is similar to the concept of ooze formation documented at Blackwater marsh by Stevenson et al. (1985).

The second type of sequence encountered at Monie Bay occurs in the back marshes which are located close to the marsh-forest boundary (submerged upland marshes). These areas are typically thin (< 2 m), highly organic marshes (~ 40-70% LOI), overlying low organic (< 5% LOI) soil profiles. These wetlands appear to be relatively young, post-dating the original European settlement of the region (as indicated by the lack of any increase in the Quercus:Ambrosia ratio). Accretion is largely through organic deposition as the marsh transgressed the upland forests.

The final pattern encountered, the decrease in organic content of the marsh sediments towards the surface, is a somewhat unexpected trend, espeically in tidal channel bank marshes. Normally, the organic content of marshes increases upward as the elevation increases. The end member of this sequence is an organic rich, high marsh with LOI values exceeding 40%. The decrease in organic content at the surface of the sediment column could be caused by a decrease in primary productivity, or an increase in the influx of inorganic sediments to the marsh, simply diluting the organic content. Decreases in primary productivity (primarily plant growth) have undoubtedly been an important force in marsh loss in the Chesapeake Bay region. However, since there is no obvious evidence of plant deterioration at Monie Bay, an increase in inorganic sediment to the marsh is a more likely explanation. This increase may result from:

1. storm overwash deposition,
2. bank erosion,
3. higher sediment loading of the estuary,
4. and/or more frequent flooding of the marsh surface due to sea level rise.

During storms in Chesapeake Bay, tidal surges are common during which the entire marsh surface is inundated with water. In addition, wave action, created by the wind, resuspends bottom sediment in Monie Bay and Tangier Sound and transports this material into the marshes. In Delaware, this mechanism has been cited as the primary process for depositing inorganic sediments in the marsh systems (Stumpf, 1983). Although, the overall impact of storm sedimentation on marshes is open to debate (Stevenson et al., in press), it is apparent that storm overwash is an important source of coarse-grained sediments around the perimeter of Monie Bay. Here, there appears to be a major decrease in the organic content as a result of storm overwash. However, there is no clear evidence that storms contribute major amounts of material to the marsh surface along the major tidal creeks nor in the back marshes.

Bank erosion may influence the organic content of the marsh sediments by decreasing the distance of a particular marsh site from a channel allowing for increasing proportions of inorganic input from riverine sources. For instance, in several estuarine meander marshes along the Nanticoke River, Maryland, which is located approximately 10 - 20 km north of Monie Bay, a major reduction in the organic content of the upper sediment column occurs in the channel bank marshes (Kearney et al., 1985). Results of a study of the position of these channel bank sites indicate the banks have receded ~ 50-100 m in the last century (Grace, 1986). Consequently, the marsh sediments at a depth ~ 30 to 50 cm below the present marsh surface were deposited previously in a back marsh site between 50 to 100 m from the channels edge. Back marshes characteristically have limited inorganic sediment input, resulting in high organic contents (40-60% LOI).

Marsh bank erosion increasing the deposition of inorganic sediment is especially important along the perimeter of Monie Bay. The recession of the marsh bank would allow coarse-grained overwash deposits to progressively penetrate further inland. However, study of aerial photographs between 1938 and 1985 indicates bank recession was limited. In Monie and Little Monie Creek it is not clear if bank erosion has been extensive based on the 1938 and 1985 vertical aerial photographs (Fig. 22). Due to the limited size of the tidal channels, channel migrations are probably minimal. Therefore, bank erosion probably has a less significant impact on marsh composition in the tidal channel bank marshes than observed in the Nanticoke River which is a much more dynamic system.

The organic content of marsh systems along the East Coast of the United States is heavily influenced by the inorganic sediment loads of the rivers draining the coastal plain. Agricultural practices especially during the post-colonial period (1776-1800), stripped large areas of the various watersheds of vegetation. The practices of early farmers in clearing land for cultivation caused extensive erosion of the topsoil especially where topography was steep (Trimble, 1974). The soil erosion in the southeastern U.S. Piedmont region was a serious problem by the mid-eighteen hundreds, peaking by the 1920's. As a result of the erosion of the topsoil, the sediment loads in coastal plain rivers increased dramatically, perhaps by more than an order of magnitude (Meade, 1982). Prior to the construction of large reservoirs on many of the major rivers draining the coastal plain, much of the eroded sediment which reached the estuaries was deposited in the extensive tidal and non-tidal wetlands (Meade, 1982). Although the sediment load carried by the rivers has decreased with the construction of reservoirs which trap sediment and with better farming practices (Trimble, 1974), urbanization still creates high suspended loads locally. For instance, urbanization in the upstream watershed of the Patuxent River, Maryland doubled the sediment yield in the late 1960's (Roberts and Pierce, 1974).

With the higher sediment loads reaching Chesapeake Bay from agricultural clearing, more inorganic sediment was available for deposition in marshlands. If primary productivity remained relatively unchanged, this higher inorganic sediment input would decrease the organic content of the marsh sediments. In a number of the cores, the decrease in the % LOI occurred at a similar depth as a decrease in the Quercus:Ambrosia ratio (Table 4). This correspondence suggests that agriculture around Monie Bay and elsewhere in Chesapeake Bay contributed to lower organics in the marsh sediments at Monie Bay. This same relationship was observed in some of the marsh sediments along the Nanticoke River (Kearney et al., 1985).

Table 4. COMPARISON OF CHANGES IN MARSH ORGANIC CONTENT(LOI) AND SETTLEMENT HORIZON

CORE	DECREASE IN % LOI	DECREASE IN QUERCUS:AMBROSIA^{x}
MC 1	40 cm^{+}	35^{+} cm
MC 2	10 cm^{+}	70* cm
MC 3	50 cm^{+}	35* cm
MC 4	50 cm*	65^{+} cm
MC 5	50 cm^{+}	45 (45-70)* cm
MC 7	20 cm$^{\#}$	55^{+} cm
MC 8	15 cm^{+}	95* cm
MCL 13	60 cm*	35^{+} cm
MCL 14	140 cm*	45^{+} cm
MCL 15	40 cm*	60 (60-80)*
MB 16	60 cm$^{\#}$	55^{+} cm
MC 18	20 cm^{+}	30^{+} cm

x Depth at which ratio decreased below 10

+ Distinct shift

* Gradational shift

Sandy storm deposit - distinct shift

Although increased inorganic sediment inputs to estuaries due to higher rates of erosion in the watersheds has undoubtedly impacted marsh composition, sea level rise has also played an important role. Vertical accretion rates in the Monie Bay area averaged for the last two centuries (Table 2) are lower than the present local rate of sea level rise (0.4 cm/y). Although the more recent accretion rates (last 50 years) are likely to be higher (Kearney and Ward, 1986), it appears that sea level rise is outpacing vertical marsh growth. In some of the Nanticoke River marshes this same relationship exists resulting in marsh deterioration (Grace, 1986). In Blackwater, accretion rates lower than the rate of sea level rise is one of the key factors in the extensive marsh losses (Stevenson et al., 1986).

Comparison of aerial photographs taken in 1938 and 1985 indicate marsh deterioration (in terms of increases in open water) has not been significant at Monie Bay. However, if the long term accretion rates remain less than local sea level rise, the frequency and duration of tidal flooding will steadily increase as the differences between marsh surface elevations and mean water levels decrease. With more flooding of the marsh surface plant productivity is reduced because of water logging and the transport of inorganic sediment increases. This, coupled with higher sediment concentrations in the estuary increases the deposition of inorganic sediment, resulting in a lower percentage of organics in the marshes.

It would appear that all four mechanisms (storm overwash, bank erosion, higher sediment concentrations in the estuary, and sea level rise) for increasing inorganic sedimentation in Monie Bay marshes have had an impact. Storm overwash periodically contributes sandy deposits to the bank marshes around the perimeter of Monie Bay, while bank erosion causes a landward transgression of these deposits with time. It is unclear whether increased inorganic sedimentation occurs further into the marsh system during storm events. The higher sediment loads (associated with stripping of the topsoil by early European farmers) coming into the Atlantic coastal plain estuaries (including Chesapeake Bay) provides more inorganics to the marshlands. However, Monie Bay is located away from major riverine sources, which would diminish the impact of higher sediment loading. Of course, the influence would be felt indirectly by increasing the overall sediment concentrations in Chesapeake Bay. Increased inundation of marshes by the tides increases accretion rates through the deposition of inorganic sediment (Frey and Basan, 1985). As sea level rise continues, perhaps at a much higher rate, marsh flooding will increase providing a mechanism for bringing more inorganics into the marsh.

Marsh Bank Erosion and Tidal Channel Changes

It is interesting that despite approximately 50% of the shoreline around Monie Bay showing little or no recession (erosion) from 1938 to 1985, geomorphic evidence suggests much of the perimeter undergoes periodic erosion. The marsh edge is usually a vertical bank, with frequent slump blocks, which indicates erosion. In addition, the sandy overwash deposits which characterize much of the edge of the marsh also indicate erosion of the adjacent shallow subtidal deposits.

The lack of erosion along the eastern margin of Monie Bay may stem from shallow offshore depths in this area. Wave action may be attenuated due to shoaling affects; however, the coarse-grained overwash deposits at core site MB 17 argues against this. In addition this site has the maximum fetch in Monie Bay.

An alternative explanation to the lack of measurable erosion along the eastern Monie Bay would be that most, if not all, marsh bank erosion occurs during major storm activity. Most of the bank recession along the eastern margin of Monie Bay may have occurred prior to the earliest available photographs (1938). Two major hurricanes, which heavily damaged areas of Chesapeake Bay in 1933 (Stevenson et al. in press), may have caused much of the marsh bank recession. Comparison of aerial photographs between 1938 and 1985 would not reveal this. However, smaller, but nevertheless significant, storms have occurred in the region since 1938 (e.g. Hurricane Hazel, 1954; Connie, 1955; Dianne, 1955; Donna, 1960; etc.).

Based on the mappings of the shoreline change between 1938 and 1985 as well as observed geomorphic evidence, it appears that most marsh bank recession has occurred along the northern bank of Monie Bay where erosion rates exceed an average of 1 m/yr. Significant erosion rates also have occurred along the southwestern margin where erosion rates are on the order of 0.5 m/yr. Bank erosion is most likely less than 0.5 m/yr along the eastern margin of Monie Bay.

The lack of major changes within the marshes observed in the comparison of 1938 and 1985 aerial photographs may be caused by the limited time over which the measurements were made. However, Redfield (1972) noted that small tidal creeks in the Barnstable Harbor marsh, Massachusetts undergo erosion, but this is counterbalanced by reconstruction causing the channels to remain roughly in place. In addition, Redfield felt the creeks are not formed by recent processes at Barnstable, but are relicts of the marsh building process. However, Redfield did note that meander bends migrate over long periods in an axial direction. Conversely, Ward and Domeracki (1978) noted that marsh tidal channels at Kiawah Island, South Carolina migrated rapidly. Major reaches of some channels were abandoned, filled with sediment, and covered with vegetation during a 24 year period. Due to these channel movements, tidal channel deposits affect large sections of the marshes. The marsh at Kiawah Island is often thin (< 2 m) and underlain by extensive sandy deposits (Duc, 1981). The larger tidal channels at Kiawah Island penetrate the marsh sequence reaching the uncohesive, easily eroded sands which allow them to shift relatively easily. The marsh tidal channels found in the Monie Bay appear to be anchored in more cohesive, fine-grained sediments, prohibiting movement.

Pestrong (1972) noted that the marsh tidal channels in San Francisco Bay are highly dense and display intricate and complex patterns. In his model explaining the evolution of the marshes at Cooley Landing, Pestrong hypothesized as the elevation and areal extent of the marsh surface increased, the length of the drainage system increased. As the marsh front grew bayward, the tidal channels enlarged apically through headward erosion towards the uplands. However, San Francisco Bay has had very little rise in local sea level over the last 40 years (Stevenson et al. 1986). The headward erosion of the first order tidal channels observed at Monie Bay may have resulted simply from the natural evolution of the marsh as it grows both in elevation and bayward. However, historical mapping of the marsh/bay interface indicates no bayward growth. On the contrary, as discussed previously, the marsh bank has remained relatively stable or receded. In addition, the results of the palynological dating at Monie Bay show that the vertical growth of the marsh is low, especially in the back marsh areas. This stability may be an indication that the marsh has reached a dynamic equilibrium where vertical accretion is low and bayward growth is offset by erosion, decreasing net change (Pestrong, 1972). Letsch and Frey (1980) noted that a marsh north of Sapalo Island, Georgia was apparently in this stage of dynamic equilibrium as the seaward growth of the marsh was limited by a large tidal channel and apical growth of tidal channels was small over the last 200 years. Here, lateral erosion or meandering caused tidal channel displacements. At Monie Bay, this equilibrium appears not to exist as evidenced by the increase in the number of first order channels.

The apparent increase in the density as well as the headward growth of first order tidal channels at Monie Bay could also be caused by greater flooding of the marsh. With the low vertical accretion rates occuring in the Monie Bay marshes compared to the high rate of relative sea level rise (Hicks et al., 1983), the difference in elevation between the marsh surface and mean water level is becoming less (as discussed previously). Consequently, larger areas of the marsh surface are inundated during high tides, or storm surges, increasing tidal prisms. As the tidal prisms increase, the channels may enlarge, increase migration rates, and undergo apical or headward erosion.

Accretion Rates at Monie Bay

Accretion rates (based on pollen histories) over the past 200 years in marsh sites sampled in the Monie Bay area vary from 0.15 to 0.63 cm yr^{-1} (Table 2). Such rates are within the ranges reported for other submerged upland and meander-bend marshes north of the study area in the Blackwater Wildlife Refuge and the Nanticoke River (Stevenson et al., 1985; Kearney and Ward, 1986). These studies have also shown that channel bank marshes accrete more rapidly than back marshes and, in addition, upper estuary sites accrete more rapidly than middle and lower estuary sites. Such trends are not particularly evident at Monie Bay, although the highest accretion rates were found in the middle and upper reaches of Monie Creek and Little Monie Creek. Scale differences between the Nanticoke River and the Monie Bay systems may explain most of these disparities. The Nanticoke River is a well-developed estuary that has prominent marshes especially in the turbidity maximum near the town of Vienna. Monie Bay does not have a strong upstream input.

Kearney and Ward (1986) have used post-European land clearance changes in pine pollen concentration in marsh sediments as indices of relative changes in marsh accretion rates. This method is based on the assumption that the average pine pollen concentration in the cores since the peak settlement phase (ca. 1790) is proportional to the long-term accretion rate. Departures from this average concentration figure over shorter intervals are assumed to indicate increases (lower pine pollen concentration) or decreases (higher pine pollen concentration) in short-term accretion rates, holding the average rate of pine pollen deposition at the site through time constant (see Kearney and Ward, 1986). Multiplying the long-term accretion rate by the dividend of average pine pollen concentration and the internal pine pollen concentration in a given interval yields an estimated change in the accretion rate.

Estimates of apparent changes in accretion rates for the sampling sites are presented in Table A-5. These data show an apparent acceleration in marsh accretion rates since the peak phase of settlement, in most cases at least doubling. At two sites directly adjacent to Monie Bay

(MC 7 and MB 16), surface accretion rates are an order of magnitude higher than the long-term trend. Observations suggest that both sites have experienced recent storm overwash. The prevalence of overwash at these sites is not surprising because both as the most bayward of the sites studied are subject to the greatest wave energies. The timing of these events some time in the last quarter century (as suggested by the accretion rates) implys the impact of one of the major storms of this period, possibly the Ash Wednesday northeaster of 1963 or Tropical Storm Agnes of 1972.

Conversely, the anomously high accretion rates found at the washover sites may be an artifact of our computations. The washover deposits are largely composed of sand sized sediments which were deposited under relatively high energy conditions (storm waves). Pollen, with its significantly lower density, is not likely to be deposited under these conditions. This especially true for pine pollen. The method used to compute or adjust the average accretion rate since the agricultural horizon to the recent accretion rate assumes the influx and deposition of pollen in the sediments is constant. This assumption is probably not valid in cases where there are major changes in the depositional environment (calm versus storm), and in sediment grain size. Where the grain size is more uniform throughout the sediment column, the assumptions are more valid.

The general acceleration in recent accretion rates of the other sites must be explained in terms of other processes than storm inputs. Kearney and Ward (1986), in analyzing similar trends in recent accretion rates in estuarine marshes of the Nanticoke River, attributed the apparent increased rate of accretion to the lack of dewatering and compression of the recent marsh sediments. Much the same explanation may apply to the Monie Bay marshes. Sea level rise, as the ultimate driving force behind marsh accretion, nevertheless may at least be partially responsible. Tide gauge records for Chesapeake Bay document a sharp increase in the local rate of sea level rise since about 1920. Moreover, Lead-210 analyses at the Blackwater Wildlife Refuge show relatively close tracking of sea level changes since 1943 by marsh accretionary rates for some back marsh sites (Kearney et al., 1983; Stevenson et al., 1985). Further studies are needed to tie down more firmly the sea level-marsh accretion link.

Marsh Accretion Rates and Sea Level Rise

Although the range of accretion measurements (using pollen and Lead-210) varies from 0.15 to 0.72 cm/yr, 75% of these values fall below the local rate of sea level rise of 0.4 cm/yr. In addition 50% of these accretion rates are less than 0.3 cm/yr. The highest accretion measurement, which occurred at MC 6, is undoubtedly overestimated due to the extensive bioturbation of the sediment column at that site.

The imbalance between the local rate of sea level rise and accretion measurements may be caused by the difference in time scales over which the measurements were made. The rate of sea level rise is based on linear regression of nearby tide gauge records at Solomons Island, Maryland or Annapolis, Maryland which cover the periods from 1937 to 1980 and 1928 to 1980 (Fig. 25). The pollen accretion measurements cover the period from the agricultural horizon which is assigned a late 1700's date and the present (~ 200 years). Thus, the pollen accretion measurements incorporate a period of time when the actual rate of sea level rise is not reliably known. In addition, autocompaction effects (dewatering and collapse due to pressure of the sediment column) decreases the average accretion rate.

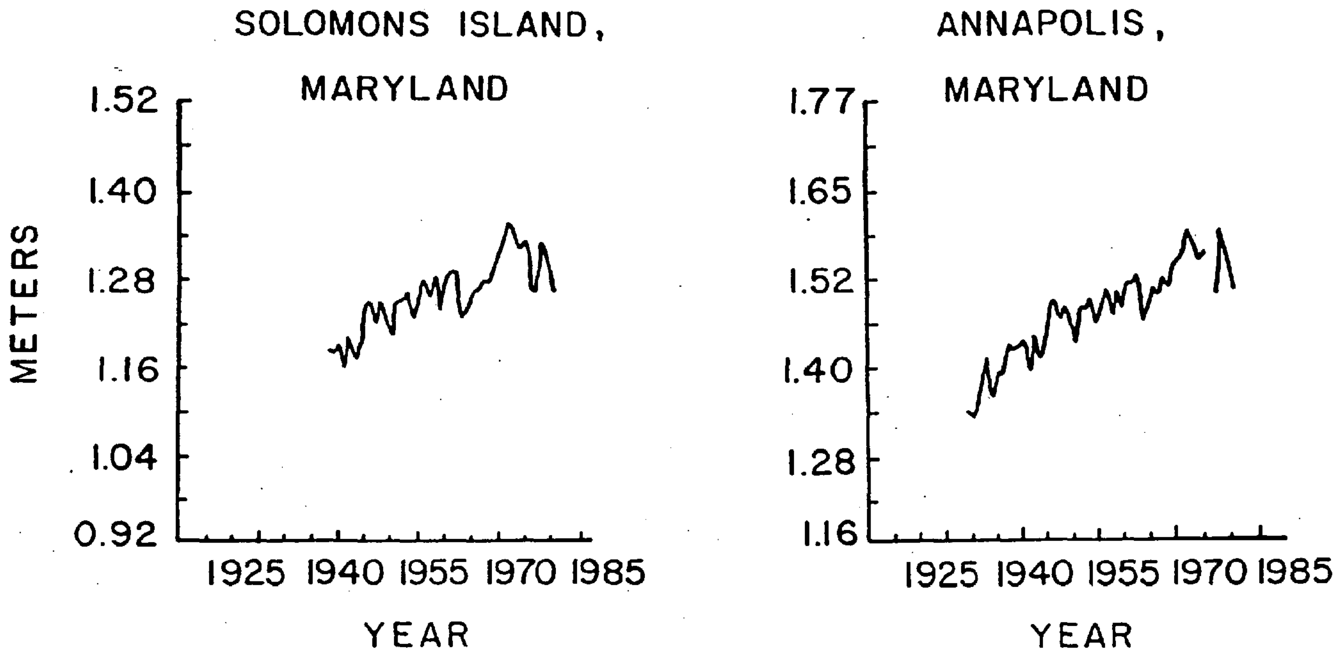


Figure 25. Tide gauge records for Solomons Island and Annapolis, Maryland (Modified from Hicks et al., 1983).

Computation of recent accretion (as previously discussed) yields substantially higher rates. However, these adjusted accretion rates are considered an index rather than actual rates due to the numerous assumptions which have to be made. The Lead-210 measurements of accretion, which are generally considered more accurate, cover the approximate same time period as the tide gauge records. These are all less than the local sea level rise (excluding MC 6 which is invalid due to bioturbation) giving strong indication that there is an accretionary deficit at Monie Bay.

The imbalance between accretion rates and sea level rise just north of Monie Bay in the lower Nanticoke has resulted in significant deterioration of the marsh (Kearney et al., in press). Large increases in the amount of open water on the marsh surface and tidal channel adjustments have occurred. Unlike the lower Nanticoke area, the marshes at Monie Bay show little evidence of increases in open water or other major signs of marsh deterioration despite the low accretion rates.

If the present rate of sea level rise is outpacing marsh accretion at Monie Bay, longer periods of tidal flooding and larger tidal prisms may be recently affecting the system. However, the rate of sea level rise will most likely increase, perhaps dramatically, during the next several decades (Titus and Seidel, 1986). At present, the Monie Bay marshes are delicately poised in terms of sea level rise and accretion rates. Any increase in the rate of sea level rise may result in significant marsh losses if accretion rates do not increase substantially.

CONCLUSIONS

1. The marshes at Monie Bay are predominantly composed of very fine-grained sediments (primary mode between 9.0 to 10.0 ϕ). Coarser sediments

(4.0 to 5.5 ϕ) are found in storm overwash deposits close to the marsh/ water interface around Monie Bay.

2. The dry bulk densities of the marshes vary widely from 0.09 to 0.78 gm/cc and are inversely proportional to the organic and moisture content of the sediments.

3. The organic content of the marsh sediments varies according to depositional environment. Organic contents usually increase from ~ 10% to ~ 20% LOI in an upward direction in the vertically accreting tidal channel bank marshes. Back marshes close to the upland boundary are typically highly organic (~ 40 to 70% LOI). At a number of locations the organic content of the marsh decreases near the surface which is related to storm effects, shore erosion, higher sediment loading of the estuary due to clearing of the land, and more frequent flooding of the marsh due to sea level rise.

4. Comparison of vertical aerial photographs taken in 1938 and 1985 indicate the marsh edge around Monie Bay is receding at rates from near stable (no detectable changes) to ~ 1.3 m/yr. Most of the marsh surface shows little change during this same period with no major increases in open water or other signs of deterioration. However, first order tidal channels appear to have undergone headward erosion and increased in density.

5. Major decreases in the Quercus:Ambrosia pollen ratios occur in most of the marsh sites surveyed during this study. This shift is related to clearing of the watershed by early European farmers and is assigned a date of circa 1790.

6. Accretion measurements in the Monie Bay marshes made from palynological analysis (and verified by Lead-210 dating techniques) range

from 0.15 to 0.63 cm/yr. Seventy-five percent of these rates are less than the local rate of sea level rise.

7. Presently, the marshes show little evidence of deterioration (based on the amount of open water in the marshes, marsh vegetation, and tidal channel changes) despite these predominantly low accretion rates. However, an increase in the rate of sea level rise may lead to marsh loss.

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APPENDIX A

TABLE A-1. SUMMARY OF TEXTURAL CHARACTERISTICS OF ALL SAMPLES ANALYZED

CORE	DEPTH cm	S/S/C	MEAN SIZE ϕ	MEAN SIZE μ	INCLUSIVE STANDARD DEVIATION ϕ	INCLUSIVE SKEWNESS	KURTOSIS	MOISTURE %	COMBUSTIBLE %	*WET BULK DENSITY gm/cc	*DRY BULK DENSITY gm/cc
MC 1	5	1/36/63	8.8	2.2	2.13	-0.17	0.70	71	29	-	-
	30	-	-	-	-	-	-	69	25		0.45
	55	1/39/60	9.5	1.4	2.70	-0.12	0.68	87	66	-	0.14
	95	1/35/64	9.6	1.3	2.66	+0.02	0.68	81	34	-	0.25
MC 2	5	1/52/47	7.8	4.4	2.88	+0.42	0.69	70	33	-	0.35
	60	1/49/50	8.3	3.1	2.99	+0.17	0.67	73	20	-	-
	65	-	-	-	-	-	-	85	44	-	0.23
MC 3	0	95/2/3	0.9	53.6	0.92	+0.30	3.60	4	1	-	-
	60	1/41/58	9.3	1.6	2.80	-0.02	0.61	83	41	-	0.20
	118	-	-	-	-	-	-	81	58	-	0.21
	125	1/29/70	10.2	0.9	2.61	-0.29	0.67	79	55	-	-
MC 4	5	1/37/62	9.2	1.7	2.61	+0.18	0.68	63	23	-	-
	11	-	-	-	-	-	-	60	19	-	0.47
	60	1/46/53	8.7	2.5	2.63	+0.21	0.72	74	31	-	0.18
	104	-	-	-	-	-	-	80	35	-	0.20
	110	1/38/61	8.7	2.4	3.12	0.00	0.66	86	47	-	-
MC 5	10	1/20/79	10.2	0.9	2.28	-0.04	0.69	74	27	-	0.28
	53	-	-	-	-	-	-	87	68	-	0.10
	70	1/20/79	9.9	1.0	3.02	-0.40	0.69	88	69	-	-
	115	1/38/61	9.4	1.4	2.49	+0.16	1.05	81	33	-	0.18
MC 6	5	2/41/57	9.1	1.7	2.75	+0.12	0.68	63	18	-	-
	13	-	-	-	-	-	-	63	18	-	0.51
	55	1/40/59	9.2	1.7	2.77	+0.03	0.68	49	13	-	-
	63	-	-	-	-	-	-	59	15	-	0.63
	110	1/40/59	9.1	1.8	2.70	+0.06	0.66	55	12	-	-
	118	-	-	-	-	-	-	53	12	-	0.62
MR 7	5	90/5/5	1.1	46.7	1.60	+0.51	3.11	11	2	-	-
	12	-	-	-	-	-	-	35	6	-	0.78
	60	1/46/53	8.9	2.1	2.89	+0.12	0.63	81	37	-	0.18
	120	1/61/38	7.8	4.4	2.76	+0.51	0.73	18	5	-	1.32
MCL 8	27	1/34/65	9.5	1.4	2.68	+0.02	0.68	75	41	0.95	0.22
	87	1/31/69	9.9	1.1	2.81	-0.13	0.59	71	20	1.19	0.34
	127	-	-	-	-	-	-	65	17	1.14	0.35
	143	1/30/69	9.7	1.2	2.58	-0.03	0.64	82	40	1.01	0.16
MCL 9	5(2-7)	1/37/62	9.2	1.7	2.79	+0.22	0.62	65	25	1.21	0.46
	10	1/41/58	9.3	1.6	2.9	+0.10	0.63	-	-	-	-
	19	1/39/60	9.2	1.7	2.8	+0.13	0.69	-	-	-	-
	25	-	-	-	-	-	-	58	17	1.24	0.46
	65	1/42/57	9.0	2.0	2.58	+0.18	0.80	57	13	0.93	0.52
	105	-	-	-	-	-	-	66	14	0.90	0.41
	135	2/32/66	9.5	1.4	2.83	-0.04	0.65	56	11	1.37	0.63

* Bulk density measured within 4 cm of given depth

TABLE A-1. CONTINUED

CORE	DEPTH cm	S/S/C	MEAN SIZE ϕ	MEAN SIZE μ	INCLUSIVE STANDARD DEVIATION ϕ	INCLUSIVE SKEWNESS	KURTOSIS	MOISTURE %	COMBUSTIBLE %	*WET BULK DENSITY gm/cc	*DRY BULK DENSITY gm/cc
MCL 10	16(14-17)	1/37/62	9.3	1.6	2.93	-0.04	0.66	78	38	0.90	0.18
	55(52-57)	1/39/60	9.2	1.7	2.69	+0.21	0.66	73	27	1.19	0.48
	93	-	-	-	-	-	-	60	11	1.34	0.54
	130(129-133)	1/29/70	10.0	1.0	2.74	-0.20	0.66	64	13	1.17	0.44
MCL 11	2	-	-	-	-	-	-	81	57	0.88	0.14
	18(14-23)	2/29/69	9.5	1.4	2.66	-0.01	0.73	83	61	-	0.14(23)
	44	54/34/12	4.4	46.4	2.62	+0.45	0.96	14	2	-	-
	72	-	-	-	-	-	-	18	3	-	1.46
	129	78/10/11	4.5	45.1	2.28	+0.57	3.28	18	2	-	1.36
	150	77/9/14	3.8	73.3	2.80	+0.59	2.20	16	1	-	-
MCL 12	2	1/37/62	9.2	1.7	2.64	+0.09	0.77	65	22	1.36	0.57
	10	1/38/61	9.3	1.6	2.90	+0.11	0.63	-	-	-	-
	18	1/39/60	9.4	1.5	2.80	+0.15	0.63	-	-	-	-
	56	1/39/60	9.5	1.4	2.58	+0.03	0.64	70	23	1.31	0.46
	85	-	-	-	-	-	-	81	32	0.72	0.12
	102	-	-	-	-	-	-	75	26	1.07	0.27
	110(106-115)	1/33/66	9.7	1.2	2.51	+0.13	0.63	81	40	1.20	0.28
	122	-	-	-	-	-	-	59	14	1.12	0.46
MCL 13	5(2-7)	1/30/69	10.0	1.0	2.67	-0.24	0.64	59	16	1.29	0.52
	10	1/32/67	9.6	1.3	2.59	+0.15	0.63	-	-	-	-
	18	1/25/74	9.9	1.0	2.55	-0.02	0.72	-	-	-	-
	30	-	-	-	-	-	-	61	16	1.40	0.56
	65(57-71)	0/34/66	9.5	1.4	2.48	+0.32	0.65	84	47	1.24	0.20
	90 -	-	-	-	-	-	-	74	23	0.98	0.28
	120 -	-	-	-	-	-	-	68	14	1.16	0.42
	138	2/37/61	9.2	1.7	2.80	-0.06	0.69	57	9	1.22	0.54
MCL 14	3(0-6)	1/36/63	9.5	1.4	2.75	+0.05	0.64	60	23	0.70	0.23
	25	2/40/58	9.1	1.8	2.91	+0.09	0.68	69	28	1.13	0.41
	70(64-76)	5/40/55	8.9	2.1	3.18	+0.06	0.64	80	39	0.86	0.15
	140	-	-	-	-	-	-	87	68	0.70	0.08
	156(153-160)	1/32/67	9.2	1.7	2.83	+0.11	0.65	88	49	1.03	0.14
MCL 15	12	1/30/69	9.7	1.2	2.65	-0.05	0.68	71	34	0.93	0.25
	27	-	-	-	-	-	-	72	18	1.18	0.39
	57	1/25/74	9.9	1.0	2.41	+0.02	0.68	76	26	1.13	0.25
	102	1/27/72	9.8	1.1	2.51	+0.05	0.70	61	14	1.13	0.45
	147	1/25/74	10.2	0.9	2.48	-0.13	0.67	60	17	1.27	0.35
MR 16	4	97/1/2	1.1	456.9	0.82	-0.02	1.81	4	5	2.02	1.88
	40	3/39/58	9.0	2.0	2.91	+0.18	0.68	67	25	1.07	0.26
	105	-	-	-	-	-	-	90	59	0.98	0.09

* Bulk density measured within 4 cm of given depth

TABLE A-1. CONTINUED

CORE	DEPTH cm	S/S/C	MEAN SIZE ϕ	MEAN SIZE μ	INCLUSIVE STANDARD DEVIATION ϕ	INCLUSIVE SKEWNESS	KURTOSIS	MOISTURE %	COMBUSTIBLE %	*WET BULK DENSITY gm/cc	*DRY BULK DENSITY gm/cc
MR 17	0	97/1/2	1.3	397.8	0.73	+0.13	1.11	21	4	-	-
	10	-	-	-	-	-	-	19	1	1.80	1.46
	25	48/27/25	5.4	23.2	4.32	+0.35	0.79	58	17	1.15	0.41
	50	35/46/19	5.1	28.6	3.45	-0.01	0.84	18	2	1.66	1.32
	100	41/38/21	5.3	25.9	4.02	+0.17	0.93	15	2	2.03	1.71
	150	60/20/20	4.3	50.8	4.48	+0.55	0.97	15	2	1.95	1.62
	200	70/12/18	4.0	61.2	3.93	+0.68	1.08	15	1	2.07	1.74
	225	-	-	-	-	-	-	14	2	2.00	1.74
MC 18	2(0-5)	1/32/67	9.5	1.4	2.59	-0.04	0.72	67	21	1.09	0.33
	50(40-60)	1/30/69	9.8	1.1	2.59	-0.10	0.81	89	54	1.11	0.09
	100(90-110)	1/21/78	9.9	1.0	2.36	-0.01	0.81	90	58	1.06	0.09
	150(145-155)	1/25/74	9.9	1.1	2.40	+0.10	0.69	88	51	1.06	0.11
	200(198-202)	1/36/63	9.5	1.4	2.72	-0.03	0.66	68	16	1.07	0.32
	250	1/37/62	9.4	1.5	2.70	-0.01	0.65	57	11	1.16	0.47
	300	1/32/67	9.5	1.4	2.82	-0.09	0.69	59	10	1.13	0.33
	320	-	-	-	-	-	-	61	11	1.62	0.62
MC 19	0	-	-	-	-	-	-	84	55	1.06	0.17
	10(0-20)	1/22/77	10.4	0.7	2.36	-0.05	0.68	86	55	-	-
	35	-	-	-	-	-	-	52	15	1.35	0.70
	50	38/42/20	5.4	34.3	3.17	+0.22	1.04	23	3	1.94	1.56
	100	33/42/25	6.2	13.9	3.58	+0.23	0.97	18	2	1.80	1.47
	150	70/13/17	4.8	36.7	3.38	+0.70	1.54	18	2	2.23	1.83
	200	87/3/10	1.5	36.1	3.09	+0.20	2.41	9	1	-	1.89

* Bulk density measured within 4 cm of given depth

TABLE A-2. POLONIUM-210 ACTIVITY

CORE	DEPTH cm	TOTAL Po-210 dpm/gdw#	*EXCESS Po-210 dpm/gdw	UNCERTAINTY dpm/gdw	SUPPORTED Po-210 dpm/gdw
MC 4	0-2	4.62	3.80	0.24	0.82 - average of 58-60, 68-70, 78-80, and 88-90 cm depth intervals
	4-6	5.96	5.14	0.32	
	8-10	5.05	4.23	0.35	
	12-14	5.46	4.64	0.23	
	16-18	5.54	4.72	0.28	
	20-22	5.24	4.42	0.27	
	24-26	3.66	2.84	0.20	
	28-30	3.15	2.33	0.12	
	32-34	2.48	1.66	0.15	
	36-38	2.53	1.71	0.12	
	40-42	1.41	0.59	0.14	
	44-46	1.48	0.66	0.08	
	48-50	1.29	0.47	0.10	
	58-60	0.85	0.03	0.09	
	68-70	0.83	0.01	0.09	
	78-80	0.80	-	0.06	
	88-90	0.79	-	0.28	
MC 6+	0-2	6.28	5.16	0.28	1.12 - 128-130 cm depth interval
	4-6	5.93	4.81	0.28	
	8-10	6.92	5.80	0.32	
	12-14	6.06	4.94	0.27	
	16-18	5.75	4.63	0.31	
	20-22	6.00	4.88	0.27	
	24-26	4.26	3.14	0.22	
	28-30	7.02	5.90	0.36	
	32-34	5.11	3.99	0.25	
	36-38	4.68	3.56	0.22	
	40-42	5.38	4.26	0.28	
	44-46	4.45	3.33	0.22	
	48-50	1.76	0.64	0.10	
	58-60	3.21	2.09	0.15	
	68-70	1.78	0.66	0.07	
	78-80	1.18	0.06	0.07	
	88-90	1.14	0.02	0.07	
	128-130	1.12	-	0.11	

* Computed by subtracting supported Po-210 (background) from total Po-210 activity

Decays per minute per gram dry weight of sediment

+ Core was heavily bioturbated

TABLE A-2. CONTINUED

CORE	DEPTH cm	TOTAL Po-210 dpm/gdw#	*EXCESS Po-210 dpm/gdw	UNCERTAINTY dpm/gdw	SUPPORTED Po-210 dpm/gdw
MCL 8	0-2	7.39	6.50	0.28	0.89 - average of 58-60, 68-70, 78-80, 88-90, and 108-110 cm depth intervals
	4-6	6.66	5.77	0.20	
	8-10	4.43	3.54	0.18	
	12-14	6.54	5.65	0.23	
	16-18	4.98	4.09	0.23	
	20-22	3.89	3.00	0.19	
	24-26	3.02	2.13	0.15	
	28-30	1.54	0.65	0.10	
	32-34	3.67	2.78	0.19	
	36-38	1.58	0.89	0.12	
	40-42	1.14	0.25	0.09	
	44-46	1.23	0.34	0.10	
	48-50	1.19	0.30	0.08	
	58-60	0.92	0.03	0.06	
	68-70	0.91	0.02	0.23	
	78-80	0.93	0.04	0.14	
	88-90	0.84	-	0.13	
	108-110	0.86	-	0.08	
MCL 15	0-2	6.68	6.01	0.32	0.67 - average of 40-42, 44-46, 48-50, 58-60, 68-70, 78-80, 88-90, and 98-100 cm depth intervals.
	4-6	6.50	5.83	0.31	
	8-10	3.59	2.92	0.17	
	12-14	6.76	6.09	0.32	
	16-18	5.56	4.89	0.22	
	20-22	4.09	3.42	0.13	
	24-26	3.05	2.38	0.21	
	28-30	3.46	2.79	0.16	
	32-34	3.54	2.87	0.13	
	36-38	0.84	0.17	0.08	
	40-42	0.68	0.01	0.07	
	44-46	0.66	-	0.08	
	48-50	0.56	-	0.06	
	58-60	0.74	0.07	0.07	
	68-70	0.68	0.01	0.06	
	78-80	0.65	-	0.10	
	88-90	0.68	0.01	0.13	
	98-100	0.68	0.01	0.09	

* Computed by subtracting supported Po-210 (background) from total Po-210 activity

Decays per minute per gram dry weight of sediment

TABLE A-3. CESIUM-137 ACTIVITY

DEPTH (CM)	MC 4	MC 6	MCL 8	MCL 15
	DECAYS PER MINUTE PER GRAM DRY WEIGHT[x]			
0- 2	1.24	1.59	1.51	4.63
4- 6	6.33	1.21	5.25	8.34
8- 10	5.82	3.97	4.37	6.57
12- 14	9.67	5.40	14.90	15.85
16- 18	15.16	4.62	17.00	20.20
20- 22	8.94	5.21	6.39	9.23
24- 26	4.29	3.47	3.97	6.14
28- 30	0*	4.97	2.44	6.64
32- 34	0	4.97	1.74	6.64
36- 38	0	6.58	0	0.84
40- 42	-	7.45	0	0
44- 46	-	8.14	0.78	0
48- 50	-	1.39	0	0
58- 60	0	0.16	0	0
78- 80	-	0	0	0
108-110	-	0	-	-

x = Counting uncertainties average 9% of the value given and do not exceed 12% of the value listed.

* = No Cs-137 activity detected;

TABLE A-4. POLLEN CONCENTRATIONS

CORE	DEPTH CM	TOTAL POLLEN COUNT gr/gdw[x]	PINUS %	PINUS x10^5 gr/gdw	QUERCAS %	QUERCAS x10^5 gr/gdw	AMBROSIA %	AMBROSIA x10^5 gr/gdw	QUERCAS:AMBROSIA	ABOREAL:NONABOREAL
MC 1	0	5.07 x 10^5	29	1.46	17	0.86	<<1	0.05	16.3	0.9
	20	2.19 x 10^5	33	0.72	17	0.37	6	0.14	2.7	1.1
	30	3.57 x 10^5	61	2.18	15	0.53	4	0.14	3.7	3.6
	40	6.96 x 10^5	27	1.90	31	2.12	<<1	0.07	31.7	2.0
	60	2.13 x 10^5	32	0.68	36	0.76	<<1	0.01	59.0	2.3
	80	6.39 x 10^5	20	0.13	16	0.10	<<1	0.01	22.3	0.6
	100	8.51 x 10^5	20	0.17	41	0.35	<<1	0.01	124.0	2.3
MC 2	0 *	2.77 x 10^5	34	0.94	17	0.46	7	0.18	2.4	1.4
	20	2.94 x 10^5	31	0.92	20	0.58	7	0.22	2.4	1.4
	40	5.53 x 10^5	47	2.61	17	0.94	15	0.80	1.2	2.0
	60	5.55 x 10^5	46	2.57	16	0.91	8	0.45	2.0	2.1
	70	7.05 x 10^5	57	4.00	21	1.46	2	0.14	10.2	4.4
MC 3	0	0.58 x 10^5	43	0.25	21	0.12	2	0.01	9.3	2.0
	20 *	1.21 x 10^5	33	0.39	14	0.16	13	0.15	1.1	1.2
	30 *	4.80 x 10^5	44	2.11	17	0.82	15	0.73	1.1	2.1
	40	3.69 x 10^5	50	1.83	21	0.76	2	0.06	14.0	2.9
	60	7.58 x 10^5	37	2.81	36	2.74	<<1	0.03	81.0	3.3
	80	9.87 x 10^5	34	3.32	24	2.32	2	0.18	12.8	1.6
	100	8.86 x 10^5	30	2.64	22	1.98	2	0.17	11.9	1.2
	120	12.51 x 10^5	32	4.03	35	4.37	1	0.15	30.0	5.7
	130	5.29 x 10^5	28	1.47	16	0.83	2	0.09	9.3	8.8
MC 4	0 # +	-	21	-	16	-	6	-	2.6	-
	20 # +	-	36	-	13	-	10	-	1.4	-
	40 +	2.41 x 10^5	29	0.70	19	0.46	13	0.31	1.5	-
	50	3.47 x 10^5	48	1.68	12	0.42	8	0.28	1.5	1.7
	60 +	3.14 x 10^5	46	1.43	10	0.31	1	0.04	7.0	-
	70	2.72 x 10^5	47	1.28	18	0.49	1	0.03	17.0	2.5
	80 +	4.01 x 10^5	37	1.50	20	0.80	0	0.00	∞	-
	100	3.04 x 10^5	44	1.32	28	0.84	1	0.02	37.0	3.2
	118	3.41 x 10^5	39	1.33	39	1.32	1	0.04	31.3	7.4
MC 5	0 +	3.63 x 10^5	38	1.36	11	0.41	5	0.19	2.2	-
	20	2.95 x 10^5	21	0.63	19	0.57	11	0.32	1.8	-
	40	7.46 x 10^5	50	3.70	14	1.04	5	0.37	2.8	-
	50	6.85 x 10^5	29	1.98	17	1.16	1	0.07	16.8	1.1
	60	14.92 x 10^5	53	7.91	22	3.31	1	0.15	22.0	-
	80 +	7.20 x 10^5	42	3.03	21	1.48	0	0.00	∞	-
	100	17.24 x 10^5	36	6.15	33	5.72	<<1	0.06	95.0	3.5

x Grains per gram dry weight of sediment
* Two slides counted, totals added together
\# Sample weights were not recorded, therefore total pollen per gram dry weight of sediment could not be computed
\+ Samples had low pollen concentratiaons as indicated by total number of pollen grains on a slide (MC 4, 0 cm = 116; MC 4, 20 cm = 167; MC 4, 40 cm = 196; MC 4, 60 cm = 143; MC 4, 80 cm = 76; MC 5, 0 cm = 196; MC 5, 80 cm = 180) - samples have high organic content.

TABLE A-4. CONTINUED

CORE	DEPTH CM	TOTAL POLLEN COUNT gr/gdw[x]	PINUS %	PINUS $\times 10^5$ gr/gdw	QUERCAS %	QUERCAS $\times 10^5$ gr/gdw	AMBROSIA %	AMBROSIA $\times 10^5$ gr/gdw	QUERCAS:AMBROSIA	ABOREAL:NONABOREAL
MC 6**	0	2.06×10^5	30	0.61	17	0.36	4	0.09	4.1	1.1
	20	3.13×10^5	27	0.83	16	0.51	5	0.16	3.1	0.9
	40	2.55×10^5	29	0.74	19	0.47	7	0.18	2.6	1.4
	60	2.69×10^5	35	0.93	17	0.47	10	0.25	1.9	1.3
	80	4.21×10^5	52	2.19	15	0.63	9	0.37	1.7	2.5
	100	2.14×10^5	44	0.93	14	0.29	6	0.12	2.4	1.5
	120	1.80×10^5	54	0.98	11	0.21	5	0.09	2.2	2.2
	130	1.90×10^5	40	0.76	26	0.49	2	0.04	12.3	2.5
MB 7	0	0.26×10^5	31	0.08	18	0.05	3	0.01	5.4	1.1
	20	0.81×10^5	41	0.33	12	0.09	7	0.06	1.6	1.3
	40	3.70×10^5	41	1.53	9	0.34	10	0.37	0.9	1.1
	50	3.56×10^5	45	1.58	15	0.52	6	0.21	2.5	1.7
	60	4.92×10^5	32	1.56	18	0.86	<<1	0.03	33.0	1.1
	80	22.23×10^5	17	3.67	8	1.76	0	0.00	-	0.4
	100	3.68×10^5	37	1.38	12	0.45	13	0.49	0.9	1.8
MCL 8	0	2.38×10^5	37	0.89	11	0.27	4	0.11	2.6	1.2
	20	2.28×10^5	53	1.21	14	0.31	5	0.10	3.0	2.3
	40	3.26×10^5	29	0.96	12	0.40	16	0.52	0.8	0.8
	60	2.42×10^5	39	0.93	10	0.24	10	0.25	1.0	1.1
	80	2.89×10^5	41	1.17	18	0.51	12	0.35	1.5	1.7
	90	4.35×10^5	46	1.99	24	1.05	4	0.17	6.3	2.6
	100	2.18×10^5	33	0.72	22	0.48	1	0.03	15.5	1.8
	120	3.23×10^5	44	1.42	25	0.81	1	0.05	18.0	2.9
	140	3.38×10^5	38	1.28	22	0.76	<1	0.03	29.5	1.7
	148	3.73×10^5	33	1.25	24	0.89	9	0.34	2.6	1.7
MCL 9	0	2.71×10^5	34	0.91	15	0.40	8	0.23	1.7	1.0
	20	3.30×10^5	48	1.60	15	0.49	4	0.12	4.2	2.1
	40	3.33×10^5	46	1.52	16	0.54	6	0.19	2.9	1.9
	60	2.56×10^5	50	1.29	13	0.33	3	0.07	4.4	2.1
	80	3.82×10^5	43	1.63	21	0.77	2	0.09	8.4	2.1
	90	4.89×10^5	53	2.60	14	0.66	0	0.0	-	2.7
	100	2.66×10^5	33	0.89	20	0.54	1	0.03	17.3	3.5
	120	2.28×10^5	49	1.11	22	0.50	1	0.02	25.8	3.6
	138	5.97×10^5	41	2.46	29	1.74	1	0.07	26.3	3.3
MCL 10	0	3.55×10^5	26	0.90	11	0.39	6	0.20	1.9	0.6
	20	3.97×10^5	31	1.02	19	0.76	21	0.85	0.9	1.2
	40	4.79×10^5	41	1.96	19	0.89	10	0.47	1.9	1.6
	50	4.36×10^5	51	2.22	22	0.94	1	0.06	15.3	3.9
	60	3.14×10^5	36	1.12	25	0.80	<<1	0.01	75.0	1.7
	80	1.92×10^5	53	1.01	20	0.38	<1	0.01	26.5	2.9
	100	2.21×10^5	58	1.28	26	0.57	1	0.02	30.5	6.9
	120	2.19×10^5	47	1.02	23	0.51	1	0.02	30.5	3.8
	140	1.96×10^5	37	0.73	37	0.73	1	0.02	30.3	4.7

x Grains per gram dry weight of sediment
** Core was heavily bioturbated

TABLE A-4. CONTINUED

CORE	DEPTH CM	TOTAL POLLEN COUNT gr/gdw[x]	PINUS %	PINUS x10^5 gr/gdw	QUERCAS %	QUERCAS x10^5 gr/gdw	AMBROSIA %	AMBROSIA x10^5 gr/gdw	QUERCAS:AMBROSIA	ARBOREAL:NONARBOREAL
MCL 11	0	3.27 x 10^5	51	1.66	6	0.21	3	0.10	3.1	1.4
	20	2.17 x 10^5	48	1.04	6	0.13	19	0.41	0.3	1.2
MCL 12	0	5.42 x 10^5	23	1.25	12	0.63	4	0.19	3.3	0.6
	20	2.89 x 10^5	29	0.83	13	0.36	5	0.16	2.3	0.8
	40	2.35 x 10^5	36	0.85	15	0.35	5	0.11	3.2	1.3
	50	5.55 x 10^5	60	3.33	20	1.08	1	0.06	17.3	5.4
	60	2.91 x 10^5	30	0.86	27	0.77	1	0.03	29.0	1.7
	80	6.71 x 10^5	54	3.62	21	1.41	<1	0.03	53.0	4.4
	100	5.35 x 10^5	30	1.61	39	2.11	<<1	0.02	106.0	3.1
	120	2.34 x 10^5	44	1.04	41	0.96	<1	0.01	90.0	10.0
MCL 13++	0	2.09 x 10^5	49	1.01	15	0.32	5	0.10	3.3	2.0
	20	2.58 x 10^5	33	0.84	18	0.47	7	0.17	2.8	1.3
	30	3.72 x 10^5	45	1.68	13	0.48	7	0.26	1.9	1.7
	40	7.90 x 10^5	42	3.35	21	1.62	<<1	0.03	61.0	2.1
	60	5.84 x 10^5	45	2.65	20	1.15	0	0.00	∞	2.8
	80	3.36 x 10^5	36	1.21	35	1.16	0	0.00	∞	3.5
MCL 14	0	2.42 x 10^5	42	1.02	13	0.31	6	0.15	2.1	1.6
	20	2.50 x 10^5	39	0.98	17	0.43	14	0.34	1.3	1.6
	40	4.61 x 10^5	45	2.06	21	0.95	7	0.31	3.1	2.1
	50	5.26 x 10^5	52	2.73	23	1.21	<<1	0.02	60.0	4.1
	60	3.11 x 10^5	42	1.30	26	0.80	1	0.02	37.5	2.6
	80	3.19 x 10^5	48	1.54	29	0.91	0	0.00	∞	4.6
	100	3.56 x 10^5	47	1.68	29	1.02	0	0.00	∞	3.8
MCL 15	0	1.86 x 10^5	40	0.74	14	0.26	7	0.14	1.9	1.4
	20	2.65 x 10^5	36	0.95	13	0.35	9	0.25	1.4	1.1
	40	3.45 x 10^5	39	1.33	20	0.67	11	0.37	1.8	1.6
	50	4.90 x 10^5	36	1.75	16	0.79	4	0.17	4.6	1.5
	60	2.38 x 10^5	35	0.83	22	0.53	2	0.05	9.8	1.5
	70	3.53 x 10^5	41	1.44	19	0.67	2	0.05	14.8	1.8
	80	2.47 x 10^5	40	0.98	21	0.51	1	0.02	21.3	1.8
	100	1.77 x 10^5	30	0.52	47	0.83	1	0.02	40.0	6.1
	120	1.96 x 10^5	46	0.91	30	0.59	1	0.02	36.5	4.9
	140	1.66 x 10^5	37	0.62	35	0.58	1	0.01	44.0	4.3
	150	3.53 x 10^5	39	1.36	37	1.31	2	0.07	18.8	4.5
MB 16	0	0.09 x 10^5	37	0.04	20	0.02	4	0.01	5.1	1.5
	20	0.32 x 10^5	33	0.11	18	0.06	9	0.03	2.0	1.1
	40	4.10 x 10^5	42	1.73	20	0.80	16	0.66	1.2	2.0
	50	11.92 x 10^5	59	7.03	17	1.98	7	0.84	2.4	3.4
	60	6.67 x 10^5	47	3.10	20	1.31	<<1	0.02	63.0	2.4
	80	4.75 x 10^5	66	3.13	20	0.94	0	0.00	∞	9.1
	100	2.92 x 10^5	54	1.59	28	0.83	1	0.03	30.5	6.4
	120	6.81 x 10^5	56	3.83	27	1.81	0	0.00	∞	5.9

x Grains per gram dry weight of sediment
++ Core was significantly compacted (13%)

TABLE A-4. CONTINUED

CORE	DEPTH CM	TOTAL POLLEN COUNT gr/gdw[x]	PINUS %	PINUS $\times 10^5$ gr/gdw	QUERCAS %	QUERCAS $\times 10^5$ gr/gdw	AMBROSIA %	AMBROSIA $\times 10^5$ gr/gdw	QUERCAS:AMBROSIA	ARBOREAL:NONARBOREAL
MC 18 ++	0	2.54×10^5	40	1.01	12	0.31	5	0.14	2.2	1.2
	20	4.55×10^5	48	2.18	13	0.58	10	0.44	1.3	1.7
	40	7.99×10^5	55	4.42	18	1.44	0	0.00	-	4.8
	60	5.19×10^5	52	2.71	29	1.50	0	0.00	-	7.3
	80	4.53×10^5	47	2.14	26	1.19	<<1	0.02	68.0	4.8
	100	10.18×10^5	57	5.84	26	2.63	<<1	0.04	63.0	8.8
	140	4.90×10^5	39	1.89	40	1.96	<<1	0.02	93.0	7.6
	180	2.85×10^5	36	1.02	38	1.07	<<1	0.01	91.0	5.2
	240	1.90×10^5	30	0.57	49	0.93	1	0.03	36.3	8.3
	280	2.63×10^5	25	0.64	54	1.41	0	0.00	-	9.5
	320	3.07×10^5	33	1.01	41	1.26	0	0.00	-	9.5
MC 19	0	4.54×10^5	46	2.10	6	0.27	5	0.24	1.2	1.2
	20	8.71×10^5	52	4.51	13	11.00	8	0.66	1.7	2.2
	40	2.26×10^5	44	0.99	4	0.10	7	0.16	0.7	1.3

x Grains per gram dry weight of sediment
++ Core was significantly compacted (25%)