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A record of environmental change during recent millennia in the Hackensack tidal marsh, New Jersey[1]

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CARMICHAEL, DOROTHY P. (New York Univ., New York, N.Y.). A record of environmental change during recent millennia in the Hackensack tidal marsh, New Jersey. Bull. Torrey Bot. Club 107: 514–524. 1980.—A 3.8 m section taken from the Hackensack tidal marsh, New Jersey indicates changes in land-sea relationships during the past approximately 2,600 years. Because a much older glacial clay underlies the organic sediments, an unconformity is indicated in the stratigraphic record. Three hypotheses are proposed to explain this hiatus, including a possible marine transgression, constant estuarine conditions, or a fluvial erosional regime. The stratigraphy defined from pollen, spores, seeds, bracts and foraminifera traces the development of the marsh from initial *Alnus* detritus deposition through a sedge peat to the present-day silty muck. Seven pollen assemblage zones are found in the record. Fluctuations in the profiles of Cyperaceae, Gramineae, and Polypodiaceae suggest periodic tidal inundation at the site. Greater tidal influence at approximately 1,800 B.P. is reflected by increasing numbers of foraminifera and by the dominance of cyperaceous pollen and seeds. Invasion of species characteristic of human disturbance is indicated in the uppermost sediments. Correlation of radiocarbon dates and pollen, spore, seed, and foraminifera stratigraphy in sediment from the Hackensack tidal marsh substantiates changes evident from studies in other coastal marshes of the northeastern United States.

Key words: Hackensack tidal marsh; stratigraphy; pollen; foraminifera; marine transgression; fluvial erosion.

Global climatic trends in the Quaternary have been correlated with changes in sea level observed in coastal regions of the eastern United States. Such coastal investigations have examined radiocarbon-dated tidal marsh sediments deposited over basal sand, gravel, or clay (Bloom and Stuiver 1963; Stuiver and Daddario 1963; Milliman and Emery 1968; Rampino 1979). Pollen analyses of stratigraphic sections from the marshes are the basis for the reconstruction of the vegetational and climatic changes represented by the sediments (Deevey 1948; Butler 1959; Heusser 1963; Sears 1963; Rosenwinkel 1964; Newman *et al.* 1969; Meyerson 1972). These investigators are in general agreement concerning the pattern of eustatic rise in sea level since the last glaciation.

Scott and Medioli (1978) found marsh foraminifera to be accurate indicators of former sea levels in Nova Scotia and California, and Weiss (1974) used foraminifera as well as pollen to determine the paleoecology of the Hudson River estuary. Macroscopic plant remains were used to trace the late-Holocene history of a bog at Secaucus in the Hackensack tidal marsh of northeastern New Jersey (Heusser 1949), and pollen, spores, foraminifera and dinoflagellates in addition to macrofossils served to trace the sequence of events at Flax Pond, Long Island, New York (Heusser, Heusser and Weiss 1975).

The present study of a new section from the Hackensack tidal marsh involves pollen, spores, macrofossils, foraminifera and estimates of organic content based upon loss-on-ignition. Its purpose is to further examine the history of this marsh by correlating radiocarbon dates with the preserved components of the sediment and interpreting the record found in terms of land-sea relationships during recent millennia.

The history of the events leading to formation of the partially drowned Hack-

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ensack Valley was reviewed by Heusser (1963). Glacial Lake Hackensack, based upon varved counts of the clay (Antevs 1928), evidently lasted for 2,500–3,000 years following the retreat of the Wisconsin ice sheet. The lake's drainage was eventually followed by entry of the tides into the valley which resulted in the tidal marsh apparent today.

The oldest radiocarbon date recorded for the Hackensack marsh previously was 2,025 ± 300 yr B.P. (Before Present = A.D. 1950) from the 3.3 m base of the Secaucus bog (Heusser 1963). The present study reveals a 3.8 m basal age of 2,610 ± 130 yr B.P. (RL-1033), somewhat older than the Secaucus date but still eliciting the problem of the hiatus in the sedimentary record from the time of drainage of glacial Lake Hackensack to the onset of tidal peat accumulation. Changes in the preserved flora and fauna reflect environmental changes ranging from sea level fluctuations to man's deforestation, ditching, burning and settlement. The Hackensack tidal marsh today at the section site is characterized by vast coverage of *Phragmites communis*.

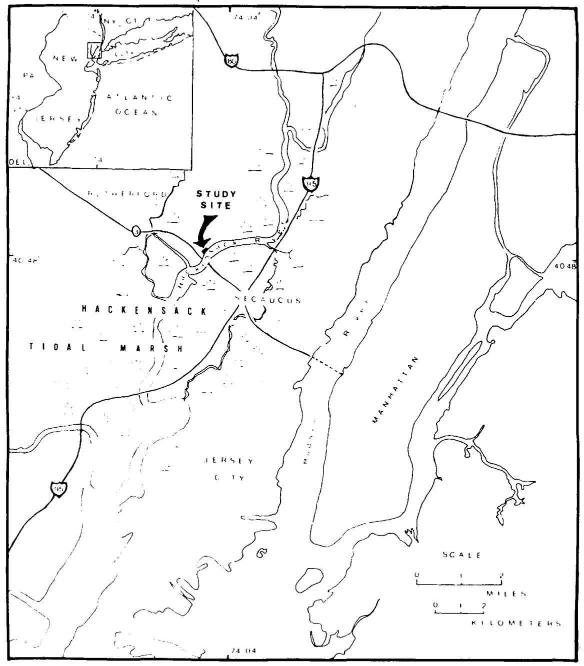
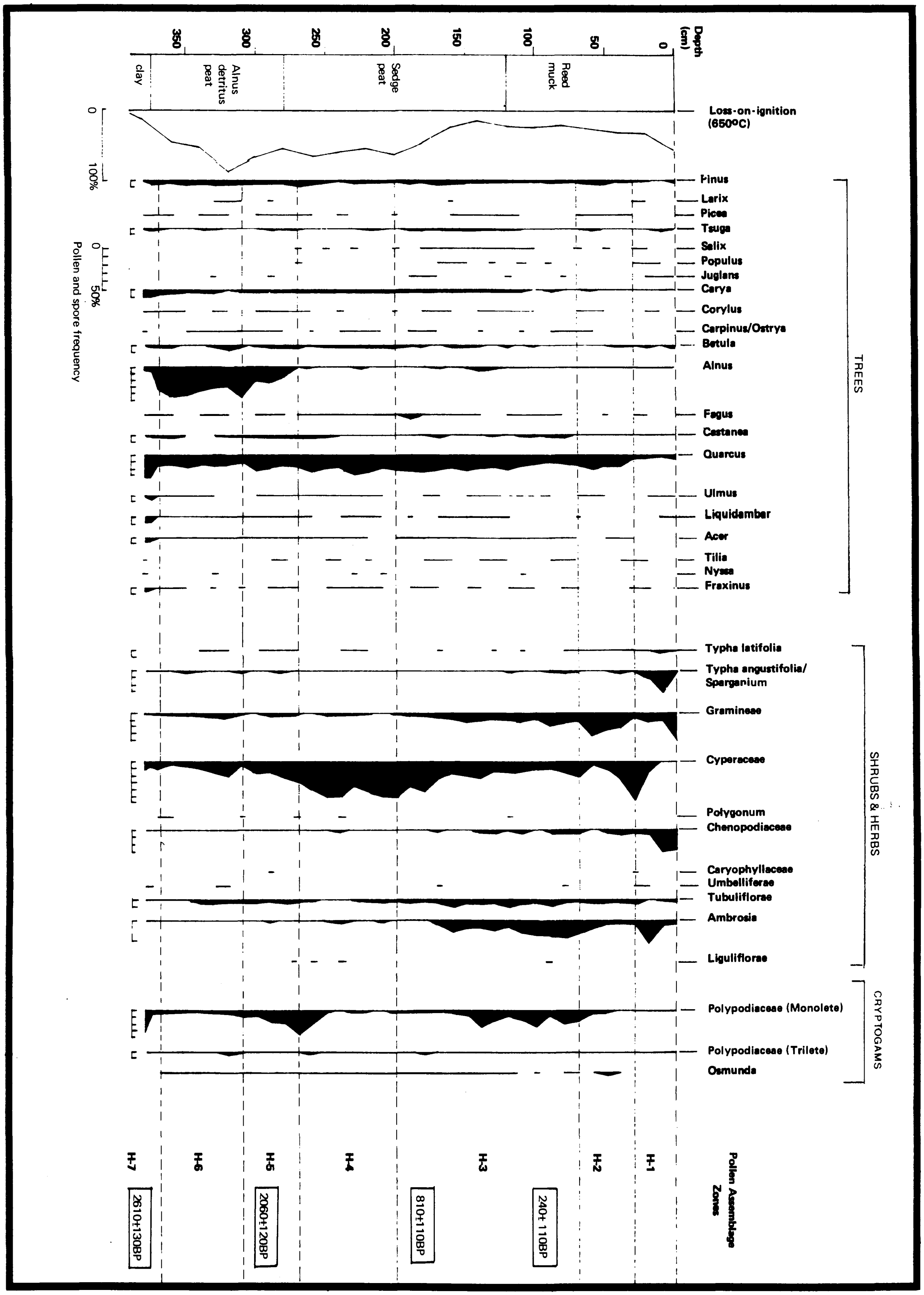


Fig. 1. Sketch map showing the location of study site in the Hackensack tidal marsh, New Jersey.

Materials and methods. Two stratigraphic sections were taken with a Hiller borer a meter apart at a site located 20 meters west of the the Hackensack River, just north of the New Jersey Route 3 bridge (40°48′10″N, 74°04′05″W; Fig. 1). Samples of the two sections were pooled to provide ample material for study of macrofossils. Samples were collected at 10-cm intervals including surface sediments, placed in plastic bags in the field, and the sediment description noted. A third section in proximity to the other two was sampled at four key depths for the purpose of radiocarbon dating. Loss-on-ignition as an estimate of organic content was determined at 20-cm intervals by combustion (650 C for 2 hrs) of samples previously dried at 100 C.

Samples (1 cm^3) taken at 10-cm intervals were processed for pollen and spore analysis according to the procedure given by Faegri and Iversen (1975). This included KOH deflocculation, HF treatment, acetolysis, safranin staining, and mounting with glycerin gelatin medium. To facilitate the determination of pollen concentration, a known number of pollen grains of the exotic plant *Eucalyptus* was added to each sample before processing (Benninghoff 1962). For relative frequency, at least 500 pollen grains excluding *Eucalyptus* were counted from each sample except at level 0 where the sum was 300. Spores were tallied in addition to the pollen grains. All counts were made at a magnification of 450×; more detailed examinations were made when needed at 1000× with an oil immersion objective. All pollen and spore determinations were made by comparison with a modern reference collection and by use of taxonomic keys and descriptions in Kapp (1969), McAndrews, Berti and Norris (1973), and Faegri and Iversen (1975). Relative frequency of all determinable pollen of extant vascular plants is expressed as a percentage of the sum of such types. Percentage of spores is based upon the sum of pollen and spores counted. Pollen influx rates are presented for the local taxa as grains/cm^2/yr. These figures were derived by dividing the pollen concentrations (grains/cm^3) by the sediment deposition time estimated from radiocarbon dates.

Macrofossils were examined after adding water to 100 cm^3 of sediment from each decimeter interval, soaking overnight, shaking to disaggregate, and then washing through screens of 2.0, 1.0, 0.5, and 0.25 mm


Depth (cm)
0
50
100
150
200
250
300
350
Reed muck
Sedge peat
Alnus detritus peat
clay
Loss-on-ignition (650°C)
0
100%
0
50%
Pollen and spore frequency
Pinus
Larix
Picea
Tsuga
Salix
Populus
Juglans
Carya
Corylus
Carpinus/Ostrya
Betula
Alnus
Fagus
Castanea
Quercus
Ulmus
Liquidambar
Acer
Tilia
Nyssa
Fraxinus
TREES
Typha latifolia
Typha angustifolia/ Sparganium
Gramineae
Cyperaceae
Polygonum
Chenopodiaceae
Caryophyllaceae
Umbelliferae
Tubuliflorae
Ambrosia
Liguliflorae
SHRUBS & HERBS
Polypodiaceae (Monolete)
Polypodiaceae (Trilete)
Osmunda
CRYPTOGAMS
Pollen Assemblage Zones
H-1
H-2
H-3
H-4
H-5
H-6
H-7
240± 110BP
810±110BP
2060±120BP
2610±130BP

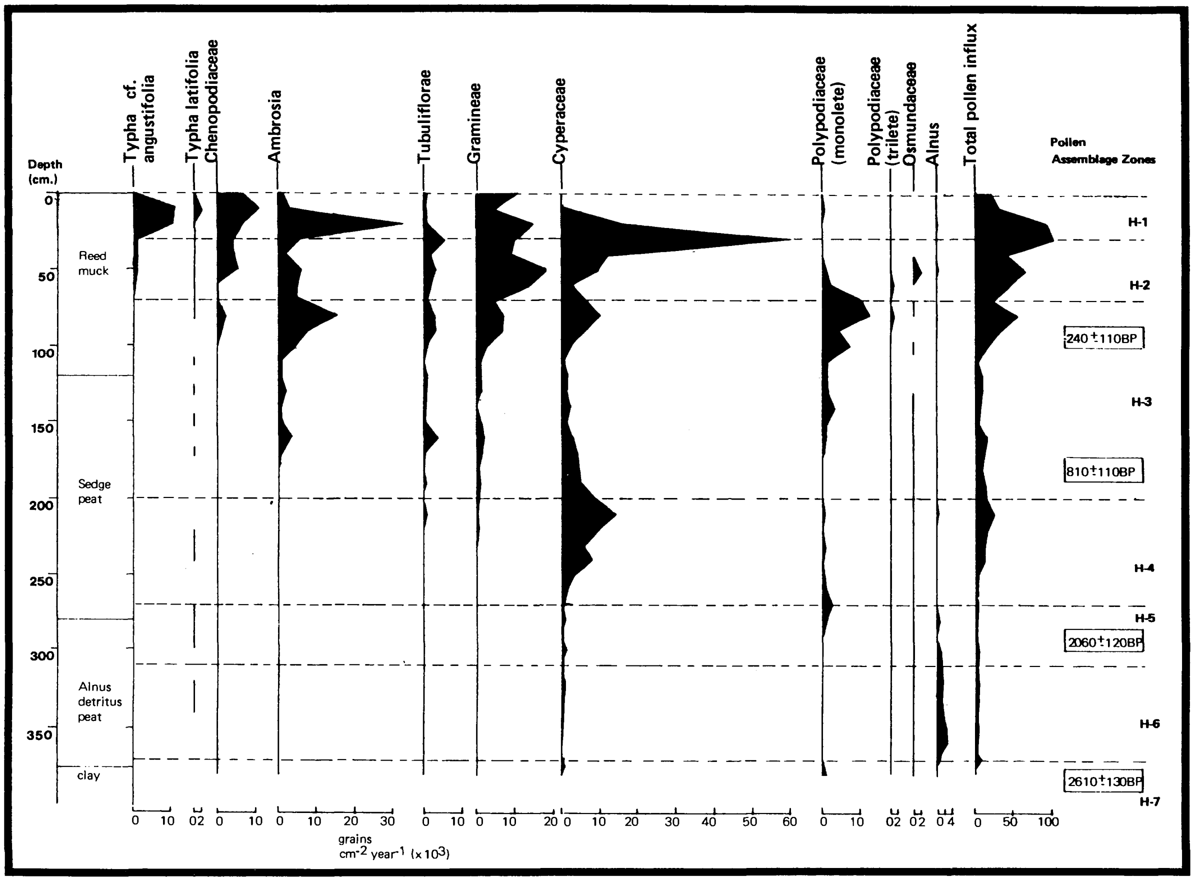
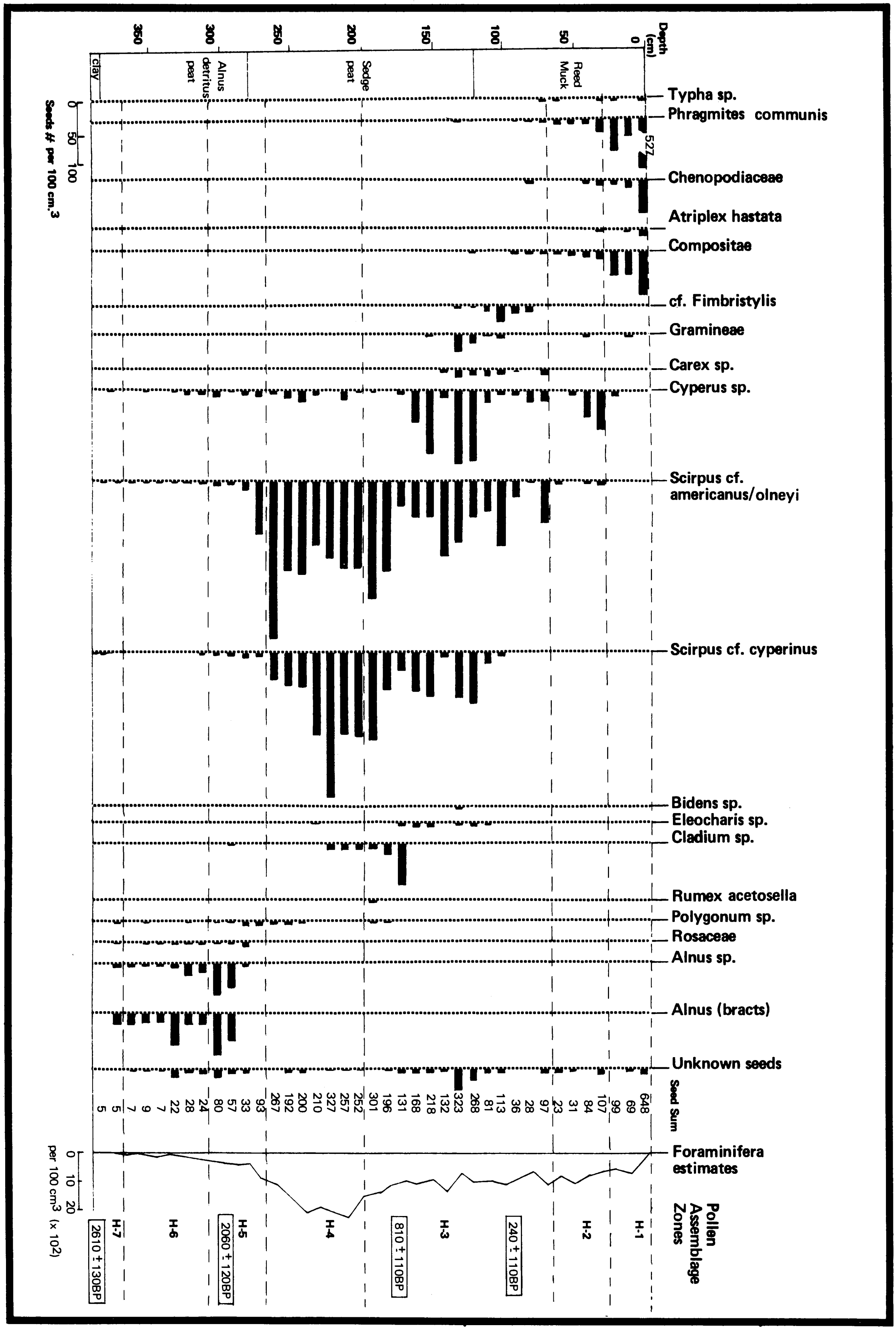


Fig. 3. Pollen and spore influx diagram of principal taxa in the Hackensack tidal marsh, New Jersey. Radiocarbon dates are indicated on the right.

mesh. The residues, comprised of seeds, bracts, roots, rhizomes, twigs and foraminifera, were examined using a dissecting microscope with magnifications between 20 and 60×. Plant macrofossils were counted and stored in a formalin-water mixture. Seed identifications were made using a reference collection, herbarium specimens from the New York Botanical Garden, and published keys and descriptions (Martin and Barkley 1961; Musil 1963; Schopmeyer 1974; Montgomery 1977). Roots, rhizomes, twigs and bracts were identified by comparison with herbarium specimens and prepared slides of known species. Nomenclature for plants follows Fernald (1970). Foraminifera were counted, mounted on slides and identified using published descriptions (Parker 1952; Parker and Athearn 1959; Phleger and Walton 1950).

Results. Section stratigraphy is presented in Figs. 2–4. The sedimentary sequence originates atop a gray basal clay (3.8 m), radiocarbon dated at 2,610 ± 130 yr. B.P. (RL-1033). Overlying the clay are 100 cm of woody peat, primarily *Alnus* detritus, and in turn 160 cm of compact sedge peat which is dated below at 2,060 ± 120 B.P. (RL-1032) and at the 170-cm horizon at 810 ± 110 yr. B.P. (RL-1031). The top 120 cm of the section consists of silty reed muck dated 240 ± 110 yr. B.P. (RL-1030) at the 90 cm level. Throughout the sequence, loss-on-ignition ranges from 3.7% at the base of the section to a maximum of 87% in the woody peat. The loss is greater than 50% in much of the sedge peat, but decreases substantially below 50% in the silty reed muck. Such decreases in organic material in more recent sediments suggest increases in mineral deposition

Fig. 2. Pollen and spore frequency diagram of the section from the Hackensack tidal marsh, New Jersey. Radiocarbon dates are indicated on the right.


Typha sp.
Phragmites communis
Chenopodiaceae
Atriplex hastata
Compositae
cf. Fimbristylis
Gramineae
Carex sp.
Cyperus sp.
Scirpus cf. americanus/olneyi
Scirpus cf. cyperinus
Bidens sp.
Eleocharis sp.
Cladium sp.
Rumex acetosella
Polygonum sp.
Rosaceae
Alnus sp.
Alnus (bracts)
Unknown seeds
Foraminifera estimates
Pollen Assemblage Zones

from erosion and silt deposition. A reversal of the trend in the uppermost reed muck may be a result of the dense rhizoid reed growth.

Relative frequencies of all pollen and spores are diagrammed in Fig. 2. The order of taxa is from arboreal gymnosperms and angiosperms at the left to nonarboreal monocotyledons, dicotyledons, and vascular cryptogams at the right. *Quercus* and *Pinus* are noteworthy contributors to the arboreal representation throughout. However, nonarboreal pollen accounts for more than 50% of the pollen sum, excepting in the *Alnus* detritus peat where *Alnus* reaches values close to 50%. Represented amongst the nonarboreal pollen best are *Typha angustifolia/Sparganium*, Gramineae, Cyperaceae, Chenopodiaceae, *Ambrosia* and members of the Tubuliflorae. Of the vascular cryptogams, monolete polypodiaceous spores are most numerous.

Seven pollen assemblage zones are recognized, characterized as follows: H-1 *Typha*-Gramineae-Chenopodiaceae-*Ambrosia*, H-2 Gramineae-Cyperaceae-*Ambrosia*, H-3 Polypodiaceae-*Ambrosia*, H-4 Cyperaceae, H-5 Polypodiaceae, H-6 *Alnus*, and H-7 *Carya*-*Quercus*-*Ulmus*-*Liquidambar*. Uppermost zone H-1 reveals prominent profiles for species of *Typha*, Gramineae, Chenopodiaceae and *Ambrosia* with increasing Cyperaceae at its base. Zone H-2 features an interplay of Cyperaceae with Gramineae. Strong profiles of Polypodiaceae and *Ambrosia* represent zone H-3, tapering off dramatically with Tubuliflorae and Gramineae at lower levels of this zone. The Cyperaceae and *Quercus* develop prominences in zone H-4, the most noteworthy taxon of zone H-5 is the Polypodiaceae, and in zone H-6 *Alnus* is strikingly evident. Zone H-7, overlying the gray basal clay, is delineated by a sudden influx of arboreal types including *Carya*, *Quercus*, *Ulmus*, *Liquidambar*, *Acer*, and *Fraxinus*.

Significant in this study is the evidence that pollen represented is chiefly of local derivation, as most of the upland species do not contribute substantially to the pollen sum. Fig. 3 shows pollen and spore influx of the principal taxa (grains/cm^2/yr). Total pollen influx reveals greatest values in the upper parts of zones H-1 and H-2, and drastic decreases in zones H-5 and H-6.

Seed stratigraphy (Fig. 4) shows seed sums ranging from 648 at the surface to 5 in the lowest peat sediment. The taxa represented by seeds are presented in sequence of their dominance at the top of the section at the left of the diagram to the oldest sediments on the right. Maximum numbers of seeds (Fig. 4) of the Compositae, Chenopodiaceae, *Typha*, *Phragmites communis, and Atriplex hastata* are found in zone H-1 and parallel the pollen record of these taxa. Large *P. communis* rhizomes dominate the macrofossil record at the surface level. Flaccid roots and rhizomes of the Gramineae characterize zone H-2 where all of the above taxa are decreasingly represented. *Cyperus* seeds are noteworthy in zone H-2, paralleling the peak of Cyperaceae in the pollen profile, and seeds of cf. *Fimbristylis*, *Cyperus*, *Scirpus*, *Cladium*, *Carex*, *Eleocharis*, *Rumex acetosella* and Gramineae are all present in zone H-3. *Scirpus americanus*, *S. olneyi*, and *S. cyperinus* achenes together with fibrous, closely packed cyperaceous culms dominate zone H-4; *Polygonum sp.* appears in this zone and underlying zones. Cyperaceous seeds are scarce below zone H-4, substantiating the trend of the cyperaceous pollen profile. Rosaceous seeds appear in zone H-5. *Alnus* twigs, floral bracts, and seeds characterize zone H-6 and match the *Alnus* pollen record. Bryophytic remains and members of the freshwater rhizopoda such as *Assulina* make an appearance in zone H-6. The basal sediment shows an increase in total pollen influx, but an absence of seeds.

Foraminifera found throughout the core are all benthonic arenaceous types. Five species predominate: *Trochammina advena*, *T. inflata*, *T. squamata*, *Milliamina fusca*, and *Ammoastata salsa*. Surface levels contain few foraminifera, but numbers increase with some fluctuations in zones H-2 and H-3. Maximum numbers of tests are found in cyperaceous pollen zone H-4, while underlying sediments contain decreasing amounts.

Discussion. The interpretation of the results of this study focuses on the im-

Fig. 4. Seed diagram and foraminifera estimates of the section from the Hackensack tidal marsh, New Jersey. Radiocarbon dates are indicated on the right.

portance of postglacial sea level. Tectonic uplift may contribute to the changes reflected in the micro- and macrofossil data. Although differential crustal warping of the Atlantic coast has been indicated from coastal submergence studies (Newman and Rusnak 1965), difficulty in discerning uplift at this site focuses interpretation of vegetational changes upon the changing sea level. The profiles presented suggest alternating transgression and regression of the sea throughout the 3.8 m section. Pollen, spores, and macrofossils indicate that deposition was predominantly derived from local input near the section site. The basal ligneous peat dated 2,610 ± 130 yr B.P. (RL-1033) overlies a substantially older varved clay. While the reason for this discontinuity is speculative, three hypotheses are proposed.

Following the retreat of the Wisconsin ice sheet, by approximately 15,000 yr B.P., southern New York and northern New Jersey were ice free (Connally and Sirkin 1970). According to Reeds (1933) and Antevs (1928), Lake Hackensack developed from meltwater behind the moraine barrier. Laminated clays were the result of seasonal deposits from glacial meltwater, and Antevs (1928) concluded that glacial Lake Hackensack must have existed for 2,500 to 3,000 years. Isostatic readjustment caused the eventual drainage of the lake (Reeds 1927). As meltwater returned to the ocean, sea level rose eustatically. The fluctuating inundation of the sea over the varved clay for thousands of years suggests one explanation for the lack of any organic remains. This hypothesis is supported by the occurrence of a foraminiferal assemblage in the Narrows of the Hudson River estuary, indicating marine encroachment at approximately 11,000 yr B.P. (Weiss 1974). Marine-brackish diatoms in sediment dated at 12,000 yr B.P. (Newman *et al.* 1969) were identified at Iona Island, just south of the New York highlands, although foraminifera did not occupy that area until about 6,000 to 6,500 yr B.P. (Weiss 1974). It is therefore possible that tidal conditions were present at this time in the lower Hudson River valley, as Weiss postulates. The more recent marine transgression of 5,000–6,000 yr B.P. is additionally supported by studies at Barnstable Marsh (Butler 1959) and along the Connecticut coast (Bloom and Stuiver 1963).

A second hypothesis is that the uppermost varved clay is not of freshwater origin, but is the result of estuarine and tidal deposits, as proposed by Weiss for the Hudson River valley. Support for the development of varves caused by diatom blooms in this type of environment is demonstrated by Bradley (1931) and Gross *et al.* (1965), and it is possible that these varves could be the result of such marine formation. Reeds (1933) mentions the possibility of varve formation in the upper regions of estuaries, but for the Hackensack region he supports Antevs' (1925) contention, based on the great number of varve counts, that varve formation took place in freshwater Lake Hackensack. The present study indicates that no visible organic matter remains. Moreover, the loss-on-ignition of the clay shows that organic matter constitutes only 3.7% of the sample. It is conceivable that over several thousand years a sequence of lake formation, drainage, and tidal submergence accounted for the situation existing today. No substantial evidence, however, is present to support the possibility that the clay's origin is estuarine.

A third hypothesis is that after varved sediments were deposited and drainage took place, broad channels were formed in the thick clay by streams taking runoff south. Such channels, partially eroding the varves, would allow little or no vegetational buildup. This erosional process is evidenced by scattered deposits of sand, gravel and silt found throughout Lake Hackensack's boundaries at locations other than the particular site under investigation (Reeds 1927; Averill 1980). Furthermore, this fluvial erosion must have necessarily encompassed large areas, for previous studies indicate the presence of clay (blue mud) under peat at depths comparable to this site (Vermeule 1897; Heusser 1949).

The submergence of the eastern Atlantic coast over the last 7,000 years is thought to be the result of eustatic sea level rise (Bloom and Stuiver 1963). An apparent reduction in the rate of this rise from 3,000 to 2,000 yr B.P. is noted in many investigations involving coastal peat (Redfield and Rubin 1962; Bloom and Stuiver 1963; Heusser 1963; Sears 1963; Stuiver and Daddario 1963; Newman and Rusnak 1965; Newman *et al.* 1969; Weiss 1974; Rampino 1979). The basal *Alnus* detritus peat in the section of this study then represents the first organic deposition following the long interval of submergence or erosion. This dated level (2,610 ± 130 yr B.P.) is fairly compatible with the sea level curve presented by Stuiver and Daddario (1963) for New Jersey and is corroborated by Heusser (1963), suggesting a sea level rise of approximately 15 cm/century since that time. Meyerson (1972) supports this pattern with evidence from Cape May County, New Jersey. A higher rate of sea level rise at Cheesequake, N.J., about 45 km to the south, is calculated by Rosenwinkel (1964) as approximately 39 cm/century, but this estimate lacks a radiocarbon control.

In order for the initial peat to accumulate, an environmental change was necessary, presumably a sea level regression or substantial uplift. The presence of a few foraminifera at the 370-cm level of the section indicates a slight tidal influence or transport from nearby creeks. The five species of foraminifera throughout the section are estuarine indicators that have been found in high marsh areas of Barnstable Harbor (Phleger and Walton 1950), Poponesset Bay (Parker and Athearn 1959), Buzzards Bay (Parker 1952), the Hudson River estuary (Weiss 1974), and both Nova Scotia and California (Scott and Medioli 1978). The presence of these foraminifera also indicates low availability of $CaCO_3$ (Greiner 1969) and shallow water depths (Weiss 1974). Among the five species represented, it is difficult to characterize species dominance relative to salinity if it indeed exists; other environmental factors such as pH, temperature and nutrients also play large roles in environmental preferences (Phleger and Bradshaw 1966).

Evidence of the typical *Spartina alterniflora* and *S. patens* zonational pattern, present in most salt marsh studies, is not recognized at this site. Salinities are not high enough for these *Spartina* zones to cover more than limited areas. The overrepresentation of the local vegetation in the record also precludes an interpretation of the vegetational history of the regional upland. This upland forest was previously defined and correlated with Deevey's (1939, 1943) pollen zones for New England (Heusser 1963). The local flora of the Hackensack tidal marsh, described by Harshberger and Burns (1919) and Heusser (1949), reveals plant assemblages based upon variance in soil salinity. Species more tolerant of salt water include *Juncus gerardi, Distichlis spicata, Limonium carolinianum, Suaeda maritima,* and *Atriplex patula.* This flora is also characteristic of other salt marshes of the New Jersey coast (Harshberger 1900; Rosenwinkel 1964; Meyerson 1972). Areas with more freshwater access include such species as *Typha latifolia, T. angustifolia, Hibiscus moscheutos, Sagittaria latifolia, Scirpus cyperinus, Bidens laevis,* and members of the Umbelliferae such as *Cicuta maculata* and *Sium cicutaefolium.* Polypodiaceae represented are *Onoclea sensibilis* and *Dryopteris thelypteris* (Harshberger and Burns 1919; Heusser 1949). Microfossil and macrofossil representatives of some of the same species in this section suggest the previous existence of similar communities based upon variations in salinity at the site, probably caused by tidal fluctuation.

The basal peat at the site, composed of *Alnus* seeds, floral bracts, twigs and rosaceous seeds and containing freshwater rhizopoda and bryophyte remains suggests primarily a freshwater environment. Drainage evidently was sufficient to allow enough root aeration to support this woody assemblage. Weiss (1974) indicates a change in the foraminifera assemblages at this time in the lower Hudson River estuary which points toward reduced salinity. The subsequent decrease of *Alnus* and increase in polypodiaceous spores possibly indicates an ensuing wetter, slightly brackish environment. This change recorded in zone H-5 (2,060 ± 120 yr B.P.), suggesting a higher water table, is paralleled by Heusser's (1963) results for sediments close to the same age at the opening of his pollen zone C3b. It appears likely from studies of this marsh and similar coastal marshes that the polypodiaceous representatives are *Onoclea sensibilis* and *Dryopteris thelypteris* (Harshberger and Burns 1919; Heusser 1949; Rosenwinkel 1964). The fluctuation of the Polypodiaceae with Cyperaceae throughout the succeeding levels suggests their differing environmental habitats. In zone H-4, the profile for cyperaceous pollen and the sedge achenes such as *Scirpus americanus, S. olneyi, S. cyperinus, Cype-*

rus, Eleocharis, Carex, and *Cladium* indicate the presence of marsh vegetation, possibly tidal. These taxa vary with species as to salt tolerance, making it difficult to establish the salinity of the high Cyperaceae interval. However, foraminifera increase sharply in zone H-4, indicating a greater tidal influence. This interval is correlated with Meyerson's (1972) record of a marine transgression at 1,800 yr B.P. in a tidal marsh at Cape May County, New Jersey.

Pollen zone H-3 opens with a decline in cyperaceous pollen, macrofossils and a number of foraminifera and a fluctuating increase in Polypodiaceae, Gramineae, and Compositae. Again sea level appears to have fluctuated, creating less brackish conditions. The rise in Gramineae and Tubuliflorae, as well as *Ambrosia* pollen, indicates comparatively drier conditions and the impact of early settlement in the area some 300 years ago. *Rumex acetosella, Bidens* sp., and graminaceous seeds present further evidence for these changes. This trend increases with the prominence of Gramineae in zone H-2. A striking pattern of alternating Gramineae and Cyperaceae fluctuation is evident from this zone to the surface. The succession again reflects the changes in water level. Rosenwinkel (1964) relates comparable Cyperaceae profiles at Cheesequake tidal marsh to a higher water table caused by increased precipitation, while Sears (1963) attributes Connecticut salt marsh changes of the same type to a rise in sea level. In the Hackensack tidal marsh, the increases of Cyperaceae, concurrent with the decreases of Polypodiaceae, would seem to indicate a rise in sea level, while more recent successive replacements of Gramineae with Cyperaceae suggest water table changes from increased precipitation or discharge resulting from man's use of water upstream. Foraminifera numbers substantiate this pattern with their overall decrease in zones H-2 and H-1. The numbers of seeds of *Phragmites,* Chenopodiaceae, Compositae Gramineae, and *Cyperus* mirror the changes in the pollen profiles.

As man increased his alteration of the environment in the last 150 years through fire, ditching, dredging, clearing and industrialization, the pollen and seed record traces an increase of adventive species. *Typha,* Gramineae, Cyperaceae, Chenopodiaceae and *Ambrosia* all make dramatic increases in the pollen record, while seeds of *Typha, Phragmites, Atriplex hastata,* Chenopodiaceae and Compositae again confirm their local significance. Invasion of these species is to be expected after disturbances, and many coastal studies have recognized a similar increase in weed taxa (Butler 1959; Heusser 1949, 1963; Sears 1963; Rosenwinkel 1964; Meyerson 1972).

The most recent decrease in foraminifera is presumably related to the same man-made interference, as much of the marsh has experienced extensive landfilling. Weiss (1974) notes a modern trend toward decreasing salinity in the Hudson River through foraminiferal changes, and attributes his observation primarily to increased sedimentation. The accepted increases in sea level for the western North Atlantic (Redfield 1967) thus remain compatible with the history of human occupation and influence in the Hackensack tidal marsh.

Conclusions. Fluctuations between brackish and freshwater environments since approximately 2,600 yr B.P. are recorded in a 3.8 m stratigraphic section from the Hackensack tidal marsh, New Jersey. Before this time, no vegetational record is found, suggesting a marine transgression or fluvial erosion of the area. 2. Pollen stratigraphy indicates seven assemblage zones: H-1, *Typha*-Gramineae-Chenopodiaceae-*Ambrosia;* H-2, Gramineae-Cyperaceae-*Ambrosia;* H-3, Polypodiaceae-*Ambrosia;* H-4, Cyperaceae; H-5, Polypodiaceae; H-6, *Alnus;* and H-7, *Carya-Quercus-Ulmus-Liquidambar*. Plant macrofossils consisting primarily of seeds substantiate the trends evident in the pollen stratigraphy. These remains and arenaceous tests of estuarine foraminifera, *Trochammina advena, T. inflata, T. squamata, Milliamina fusca* and *Ammoastata salsa,* which occur throughout the sediments indicate oscillating tidal influence in the development of the marsh. 3. Greater tidal influence at the site approximately 1,800 yr B.P. is reflected by increasing numbers of foraminifera and the dominance of cyperaceous pollen and seeds. Subsequent fluctuations of Cyperaceae and also of Gramineae suggest variations in the water table as a consequence of tidal influence. Impressive evidence of human disturbance upon the area both directly and indirectly is visible in the influx of adventive species particularly in the past two centuries. 4. Correlation of radiocarbon dates and pollen, seed, and foraminifera stratigraphy in sediment in the Hackensack tidal marsh substantiate changes evident from studies in other northeastern coastal marshes.

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