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Development of a Tidal Marsh in a New England River Valley

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ABSTRACT: A model for the geomorphic and vegetation development of a river valley tidal marsh in southern New England (Connecticut) is based on both the species composition of roots and rhizomes and on the mineralogic sediments preserved in peat. The maximum depth of salt marsh peat is 3.8 m and in the deepest areas this can overlie up to 1.9 m of fresh to brackish water peat. Based on a radiocarbon date of 3670 ± 140 yr before the present (B.P.) for basal peat at a depth of 4.0 m, vertical accretion rates have averaged ca. 1.1 mm yr^{-1}. Salt marsh formation began in response to rising sea level 3800–4000 yr B.P., as brackish marshes, dominated by bulrush (*Scirpus* sp.), replaced freshwater wetlands along stream and river channels. Gradually salt marsh vegetation developed over submerging brackish marshes, adjacent uplands, and accreting tidal flats. By 3000 yr B.P. the lower estuary was tidal, with sufficient salinity for salt marsh to dominate most wetlands. Spikegrass (*Distichlis spicata*) was an important early colonizer in salt marsh formation and its role in marsh development has not been documented previously. Blackgrass (*Juncus gerardi*), currently a typical upper border species, appears in the peat record relatively recently, perhaps within the last few centuries. In contrast, reed (*Phragmites australis*) has been present for at least 3500 yr. The dominance of reed along the upper border today, however, appears to be a relatively recent phenomenon.

Introduction

The present tidal marshes of New England began forming in response to significant reductions in postglacial coastal submergence rates approximately 4,000 years ago (Bloom and Stuiver 1963; Shepard 1963; Bloom and Ellis 1965; Redfield 1967). As a result, sediment accumulation within protected bays and estuaries kept pace with coastal submergence. Environments with these relatively higher sedimentation rates produced a habitat of accreting tidal flats, and in combination with submerging uplands, provided sites suitable for colonization by halophytic graminoids. The continued development of these tidal wetlands has been dependent upon their ability to maintain vertical accretion rates comparable to relative rates of coastal submergence. Roots and rhizomes embedded in the sediments have preserved a record of tidal marsh development in the form of peat. The organic and mineralogic components of this peat, combined with the known environmental limits of various plant species, have been important tools in constructing models of marsh development (Mudge 1858; Shaler 1886; Davis 1910; Knight 1934; Bloom and Ellis 1965; Redfield 1972).

Early theories of tidal marsh development concluded that peat accumulation occurred either over submerging upland areas (Mudge 1858; Davis 1910) or over aggrading tidal flats (Shaler 1886). Redfield (1965) combined these ideas and proposed that development was bi-directional with high marsh peat forming over submerged upland, as proposed by Mudge and Davis, and low marsh peat accumulating outward over tidal flats, as a wedge of decreasing thickness.

Modern concepts of marsh ontogeny in New England come from the work of Redfield (1965, 1972) on a coastal embayment marsh on Cape Cod, Massachusetts; Bloom and Ellis (1965) on three Connecticut tidal marshes; and Keene (1971) in New Hampshire. Based on sediment stratigraphy Bloom and Ellis described three distinct marsh types: the estuarine–freshwater marsh; the former deep (9–50 ft) bay or lagoon; and the shallow coastal marsh. Aspects of their developmental models for deep bay and for shallow marshes can both be seen in the tidal marshes that have formed in the lower Pataguanset River valley over the past ca. 4,000 years.

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Study Site

The Pataguanset tidal wetlands are located within the Pataguanset River estuary, East Lyme, Connecticut, ca. 10 km east of the Connecticut River (Fig. 1). The estuary is approximately 1.7 km in length and includes about 25 ha of marsh, owned primarily by The Nature Conservancy and a local land trust. The system is subjected to semidiurnal tides with a mean tidal range of 1.0 m. Tidal water flows through the wetlands via creeks, inlets and mosquito control ditches. Freshwater input includes river discharge and upland runoff. Average salinities for the lower estuary during the 1982 season were 26 to 28‰, slightly below those of Long Island Sound (28–30‰).

The marsh is protected from Long Island Sound by a barrier beach to the south, Black Point Peninsula to the east and a series of rock outcrop islands to the west (Fig. 1). The largest expanse of marsh is located on Watts Island. For this study the lower Pataguanset estuary was divided into four major areas: (1) Watts Island, (2) East Beach, the marsh along Black Point Peninsula, (3) South Beach, the marshland located on the leeward side of the barrier beach, and (4) North Marsh, wetlands north of Watts Island and south of the railroad (Fig. 1).

The present vegetation is typical of southern New England tidal marshes (Niering and Warren 1980; Nixon 1982). The high marsh is dominated by *Spartina patens* (salt meadow grass), often intermixed with *Distichlis spicata* (spike grass). *Spartina alterniflora* (tall, salt water cord grass) low marsh is limited to narrow belts along creek banks, ditches and bayfront borders. The stunted form of this species is found frequently in pannes throughout the high marsh. Along the upper borders, *Juncus gerardi* (black grass) often forms a conspicuous belt, frequently mixed with *D. spicata* and *Iva frutescens* (marsh elder). The marsh-upland border is a *Panicum virgatum* (switch grass) and *I. frutescens* community along undisturbed areas of South Beach, North Marsh and Watts Island. The upper border of East Beach, along Old Black Point Road, is dominated by a dense, almost monotypic stand of *Phragmites australis* (reed grass).

Methods

Field work was conducted over three years (1979–81). A 15-m grid system was established (oriented magnetic north–south), originating from a bench mark (BMX) on Watts Island (Fig. 1). All mapping and grid coordinates originate from this point.

The topography of the land overlain by marsh sediments was mapped by measuring "resistance depth" at 7.5 m intervals along grid lines. Resistance depth is defined as the maximum depth from the marsh surface that a flatheaded 1.25 cm diameter steel rod could be manually forced through the marsh sediments. This is taken as a reasonable estimate of the relative land surface prior to marsh development or basin filling by marine or riverine sediments. The model presented here is based on over 750 such resistance depth measurements.

Using a Russian peat sampler and a Davis piston corer, surface-to-basal peat cores were removed in successive half-meter sections. Over 100 cores were taken, ranging in depth from less than 0.5 m to 5.75 m. Color changes along the length of each core were recorded within three hours of removal. Cores were stored in plastic bags at room temperature for further analysis, which was usually completed within one week. Mineral sediments were felt and identified according to texture for three major grain-size classes: clay, silt, and sand. Within

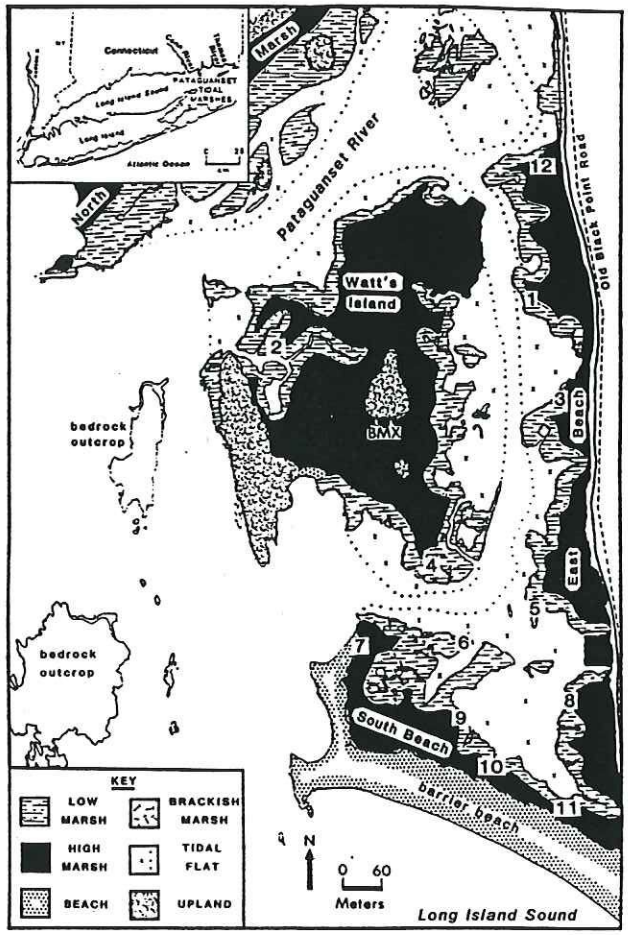

Fig. 1. Vegetation map of the lower Pataguanset River salt marshes. Numbers 1–12 indicate the location of cores shown in Fig. 3: BMX is the grid origin point used in mapping. Insert: map showing location of the study site.

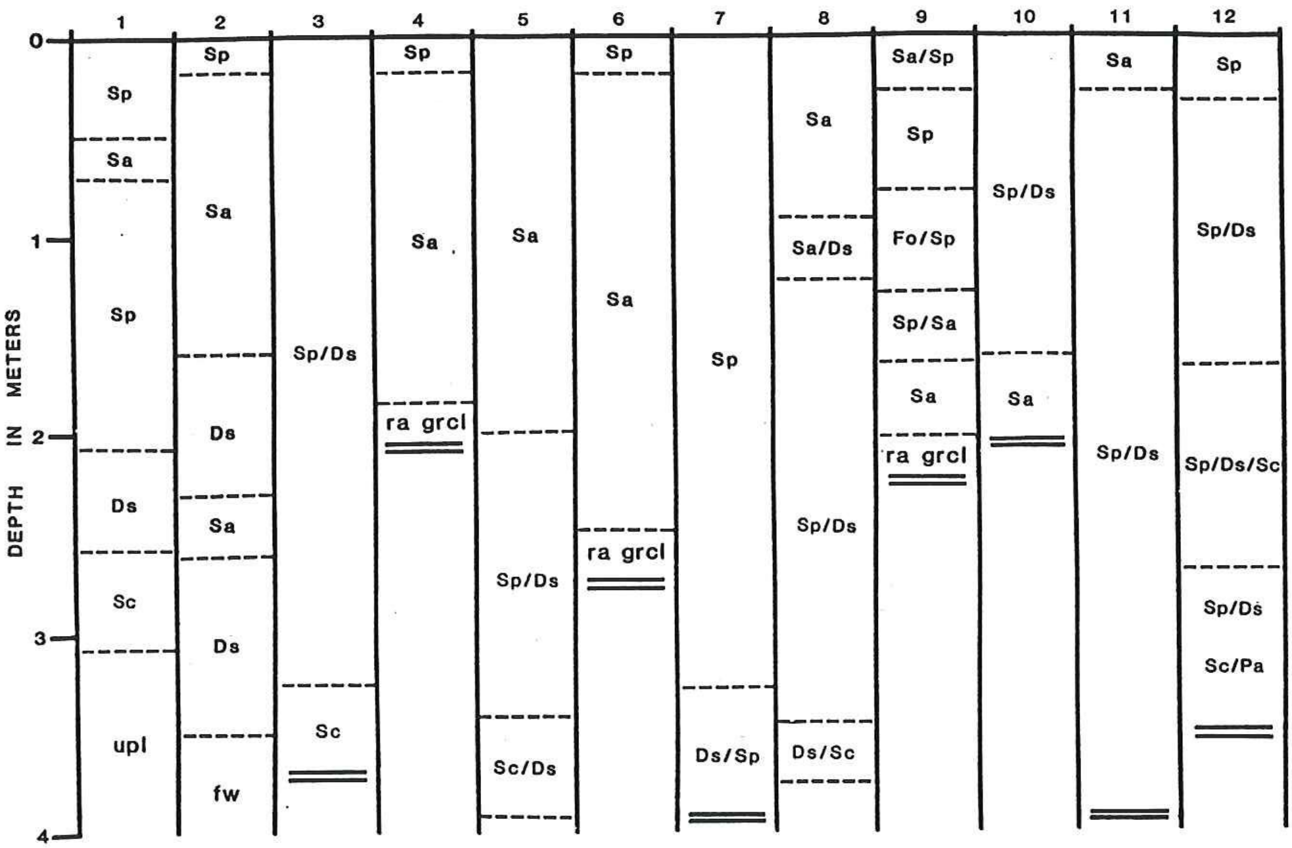

Fig. 2. Representative cores showing dominant vegetation changes with depth. Core locations are shown in Fig. 1. Key: Sa—*Spartina alterniflora*, Sp—*Spartina patens*, Ds—*Distichlis spicata*, Pa—*Phgramites australis*, Fo—forbs, Sc—*Scirpus* spp.-dominated sedge peat, fw—freshwater peat, ra—rhizomes and roots absent, grcl—grey clays, upl—upland soil. No significant plant remains were found below double bars.

the peat cores, preserved rhizome fragments of the dominant graminoids were identified using a key to species in salt marsh peat (Niering et al. 1977). Size, texture, nature of leaf scars and anatomical cross sections of rhizomes were among the more important criteria used in the identifications. Species not included in the original key were identified by comparison to peat samples of known species composition.

A radiocarbon date was obtained for a sample of basal peat collected at a depth of 4 m (Beta Analytic Inc., sample no. 6215).

Results and Discussion

Sequence of Marsh Development

The present tidal marshes in the Pataguanset River estuary began to form when the effects of rising sea level started to reach preexisting freshwater marshes. This is seen in the deepest cores of continuous salt marsh peat, which directly overlie peat of fresh to brackish water origin (Fig. 2, cores 1, 2, 3, 5, 8, and 12). At that time freshwater wetlands were accumulating peat along stream and river channels. As sea level rose, patches of brackish marsh characterized by *Scirpus robustus* and *Scirpus americanus* began to invade these freshwater marshes as well as the margins of submerging uplands. This sequence is similar to that described at Hammock River, 30 km to the west (Bloom 1964; Bloom and Ellis 1965). The transition from riverine brackish wetland to *Spartina*-dominated salt marsh first appears in cores 3.6 to 3.8 m below the present surface. The radiocarbon date for the 4 m sample of basal brackish peat is 3670 ± 140 yr before the present (B.P.). This gives an average vertical accretion rate during the last 3,700 years of about 1.1 mm yr^{-1}, a value consistent with investigations elsewhere in New England (Redfield and Rubin 1962; Bloom and Stuiver 1963; Hill and Shearin 1970; Keene 1971). Using this estimate of vertical accretion rate, the salt marshes seen today at Pataguanset started forming 3,500 to 3,300 years ago.

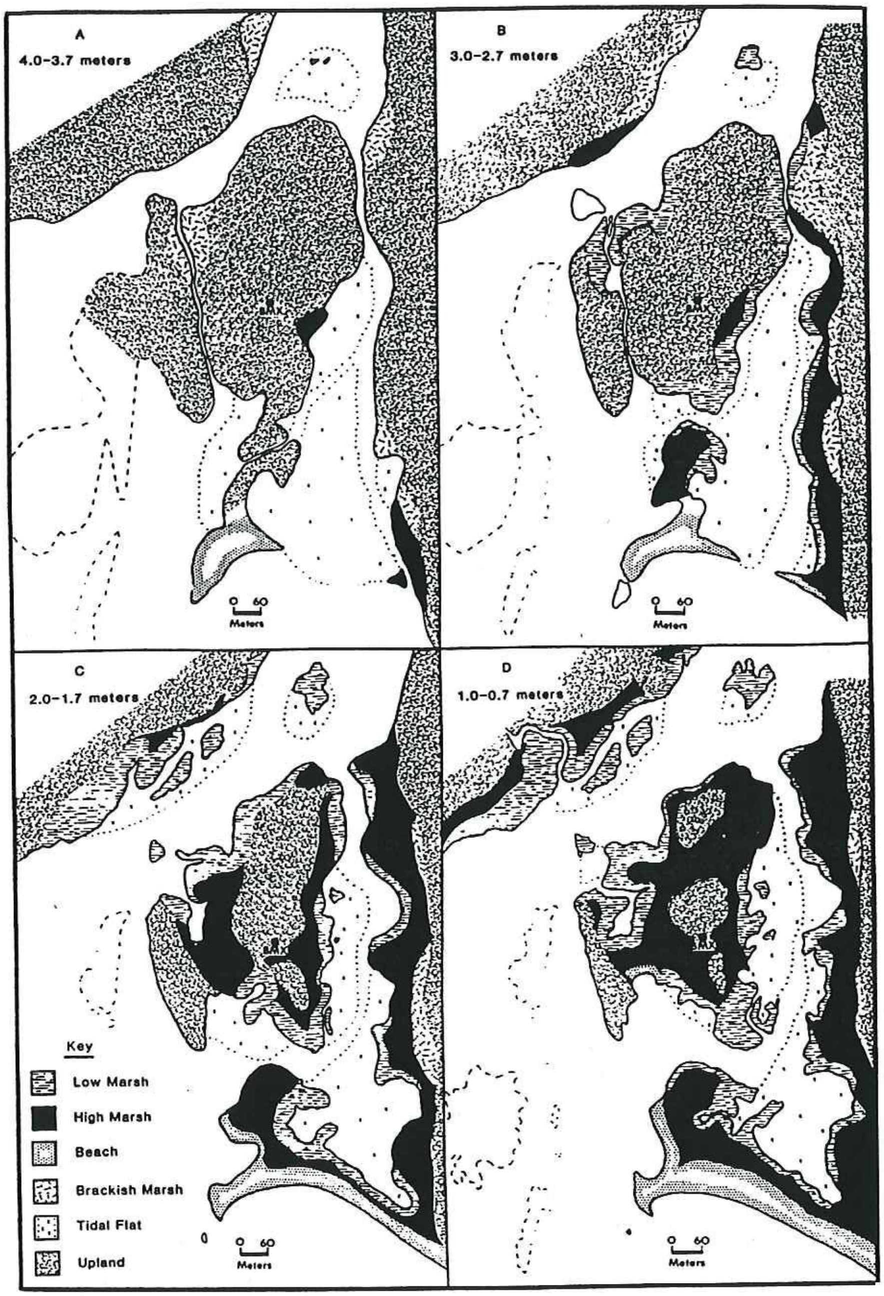

Fig. 3. Proposed development of tidal salt marsh within the lower Pataguanset River estuary. The model progresses at ca. 1-m intervals from 4 m in depth (A) to 1 m in depth (D).

Based upon peat analysis, basement topography and an average vertical accretion rate of ca. 1 m 1,000 yr^{-1}, a chronological sequence is proposed for the development of the lower Pataguanset tidal marshes. This hypothesized sequence is presented at 1-m intervals from a depth of 4 m to the present surface. The four stages in this model are represented in Figure 3.

Marsh Development from 4 to 3 m

Sea level in New England 4,000 thousand years ago was approximately 4.4 m lower than today (Bloom and Stuiver 1963; Stuiver and Suess 1966) and the shore of Long Island Sound was about a kilometer south of its present location. The basal submarsh topography shows that the mouth of the

Pataguanset River at that time divided into two major channels, both of which survive in some form today (Figs. 1 and 3A).

Peat 3.8 m and deeper is dominated by sedges, primarily *Scirpus* sp., indicating fresh to brackish marsh (Fig. 2, cores 2, 5 and 8). These wetlands were limited in distribution to lower elevations along larger stream and river banks (Fig. 3A).

As the sea level rose, Long Island Sound became an increasingly significant sediment source. The environment became more saline, and salt marsh species became an important component of the wetland vegetation. This transition is marked by the appearance of gray marine clay and sand at a depth of about 3.6 m in the cores from the lowest reaches of the estuary and by peat containing *D. spicata* rhizomes at a depth of 3.8 m (Fig. 2, cores 5, 7 and 8; Fig. 3A). This can be seen most clearly in areas along the southern edge of East Beach and the western point of South Beach where high marsh peat is found as deep as 3.8 m (Fig. 2, cores 7 and 11; Fig. 3A).

Marsh Development from 3 to 2 m

Three thousand years ago sea level was approximately 2.75 m below that of today (Bloom and Stuiver 1963). The stratigraphy between 2.7 and 3.0 m suggests that South Beach at this stage of development was not yet continuous, although the two spits had grown significantly (Fig. 3B). As the two arms of the beach continued to build inward, they provided increased protection from erosion and probably favored sedimentation behind the developing tombolo. *Ruppia maritima* roots and rhizomes were found in sediments at 4 m along the river channel north of Watts Island, suggesting that building of mud flats was helped by rooted aquatic plants (Shaler 1886). *Ruppia* still is present on the mud flats today. The two arms of the tombolo apparently came together at a time comparable to a peat depth of 2.2 to 2.5 m. Cores of peat near the center of South Beach are not more than 2.2 m deep (Fig. 2, cores 9 and 10), whereas peat depth increases to over 3.5 m at both east and west ends of the beach, as noted above (Fig. 2, cores 7 and 11). The bottom vegetation in these center cores is *S. alterniflora* in gray marine clays, suggesting that marsh development here began over mud flats and has proceeded uninterrupted since. The formation of a continuous barrier beach changed the river channel direction and undoubtedly encouraged marsh development throughout the system by creating a lower energy environment.

With continued coastal submergence the marine transgression extended farther inland and the influence of salt water on the system increased significantly. Species composition of peat samples at 3.0 m indicates that all areas of marshland present at that time were regularly flooded by brackish or salt water. Rising salinities in the older freshwater wetlands favored establishment of the halophytic grasses, especially *D. spicata* (Fig. 3, cores 2 and 8). All low-lying bay and channel borders were almost completely dominated by an expanse of salt marsh, limiting brackish wetlands to areas along the upper border.

Marsh Development from 2 to 1 m

Two thousand years B.P. sea level was about 1.9 m below present (Bloom and Stuiver 1963). Peat at 2.0 m shows salt marsh dominating the lower Pataguanset estuary (Fig. 3C). Upland areas were being replaced with high marsh along much of Watts Island. The major stream bed on Watts Island had closed and marsh peats were accumulating in its place. Brackish marsh was limited to isolated pockets along the upper borders, probably reflecting surface and subsurface runoff rather than direct river influences. *S. alterniflora* islands were forming in the river channels east and north of Watts Island, and, as the sea level kept rising, salt marsh development continued over submerging uplands and accreting tidal flats.

Marsh Development from 1 m to Present Surface

During the last 1.0 m of vertical growth (ca. 800–1,000 yrs) the marsh has had the gross morphology of today. Peat cores over the top meter show that although the marsh was accreting vertically and still growing landward, rates of lateral expansion towards the bayfront were not as pronounced as in the past. This may reflect a number of factors including bayfront erosion (Stevenson and Emery 1958), autocompaction of peat (Bloom 1964; Kaye and Barghoorn 1964), increases in rates of sea level rise during the last few centuries (Flessa et al. 1977; McCaffrey 1977; Boesch et al. 1983; Hoffman et al. 1983), or some combination of all three.

In classifying the salt marshes of Connecticut, those east of the Connecticut River have been designated as "shallow," with an average peat depth of 2.0 m or less (Hill and Shearin 1970). This designation is similar to the "shallow coastal marsh" of Bloom and Ellis (1965). The Pataguanset marshes average 2.7 m in depth, with individual locations exceeding 3.5 m of salt marsh peat and freshwater peat extending to 5.7 m. The Pataguanset marshes are therefore more typical of those deeper systems found west of the Connecticut River and fit "the formerly deep bay or lagoon" designation of Bloom and Ellis (1965).

Historical Changes in Species Composition

The vegetation changes revealed in the Pataguanset cores are consistent with observations made on tidal marshes elsewhere in New England (Shaler 1886; Johnson 1925; Knight 1934; Bloom 1964; Bloom and Ellis 1965; Redfield 1972). Intertidal *S. alterniflora* peat was commonly found in gray clays, indicating development over accreting tidal flats (Fig. 2, cores 4 and 6). In contrast, *S. patens* and *S. patens-D. spicata* peat occurs over low marsh *S. alterniflora* and, more frequently, over submerged upland soils (Fig. 2, cores 1 and 3). Also *S. patens*, and high marsh *S. alterniflora* show layering patterns that may indicate relatively short term fluctuations in rates of coastal submergence.

Previous studies (Niering et al. 1977; Niering and Warren 1980) have suggested that *D. spicata* plays an important role in the initial colonization of submerging upland by salt marsh vegetation. Niering and Warren (1980) have also proposed that this species may increase in systems undergoing sharp environmental change or mild stress. Evidence from this investigation is consistent with these interpretations. When mean percent species composition is related to depth, *D. spicata* shows an increase in abundance at 3.6 m and again at 2.3 m below the marsh surface. In the lower estuary both of these depths correspond to major stages in salt marsh development. The system was first inundated on a regular basis by salt to brackish water at ca. 3.6 m and *D. spicata* was the first halophyte to appear overlying freshwater peat at this depth. Cores 1, 2, 3, 5, and 8 in Fig. 2 show *D. spicata* as an early associate with fresh water and *Scirpus* spp. peat, as well as with upland soil. The 2.3 m level corresponds roughly with the completed formation of the beach and with a probable major change in patterns of sedimentation and water movement.

Along the marsh-upland border *J. gerardi* is currently a common high marsh species. There is, however, no evidence of its presence in peat deeper than 0.65 m below the surface, probably less than 500 years ago. The reason for this is not clear, but these findings are consistent with cores taken from a number of other marshes along the Connecticut coast (Niering et al. 1977). It is possible that *J. gerardi* is an introduced species, transported to this continent from Europe sometime over the last few centuries. The lack of information on its autecology makes further speculation difficult. Even if *J. gerardi* is a native species, clearly it did not become an important member of the marsh community until relatively recently.

Phragmites australis has been present as a transitional marsh/upland species throughout the ontogeny of these marshes. It typically occurred in association with *Scirpus* spp. and other brackish water species (Fig. 2, core 12). The greater contemporary importance and extensive monotypic stands of *Phragmites* probably reflect increasing disturbance due to upland development (Roman et al. 1984).

Comparison with Other Marsh Systems

The ontogeny of the Pataguanset marshes resembles patterns found both at Barnstable (Redfield 1972) and at two Connecticut systems, Hammock River and Chittendon Beach (Bloom 1964; Bloom and Ellis 1965). These similarities can be seen in Fig. 4, which represents a topographic bisect through the marsh due east of the bench mark located on Watts Island. Up to ca. 90 m east of the bench mark (0–6) high marsh developed over submerging upland (core 0, 4E). Continuing eastward another 90 m (6–12) the marsh expanded out over accreting mud flats (clay). The wedge of high marsh peat underlain by intertidal peat, described by Redfield and Rubin (1962), is apparent in this bisect (cores 0, 8E and 0, 10E). The sequence is summarized in the inset. Fifty km west of the study site, in a former deep bay, Hammock River, most of the salt marsh peat also lies over marine sediment (Bloom 1964; Bloom and Ellis 1965). In addition, like the shallow Chittendon Beach marsh, (Bloom and Ellis 1965) extensive areas of marsh at Pataguanset have developed directly over upland soils.

Marsh development at Pataguanset also shows some differences between a drowned river valley and a submerging coastal embayment, as typified by Barnstable Harbor (Redfield 1972). In particular, the role of freshwater marshes in the ontogeny of the Pataguanset salt marsh appears to have been more important than reported for other New England systems. Increasing salinity in these low coastal freshwater wetlands provided a favorable environment for colonization by halophytic graminoids, especially *D. spicata* (Fig. 2, cores 3, 5 and 8). With further coastal submergence, salt marsh replaced freshwater wetlands and, once established, was able to extend landward over submerging uplands and seaward over emerging mud flats.

Initial salt marsh development typically occurs in low energy environments, often behind barrier beaches or along river estuaries. At Barnstable the marshes developed in response to the formation of a growing sand spit, whereas at Hammock River the marsh started over mud flats in a well protected coastal lagoon. In contrast, at Pataguanset initial salt marsh formation and early development were independent of barrier beach formation and began

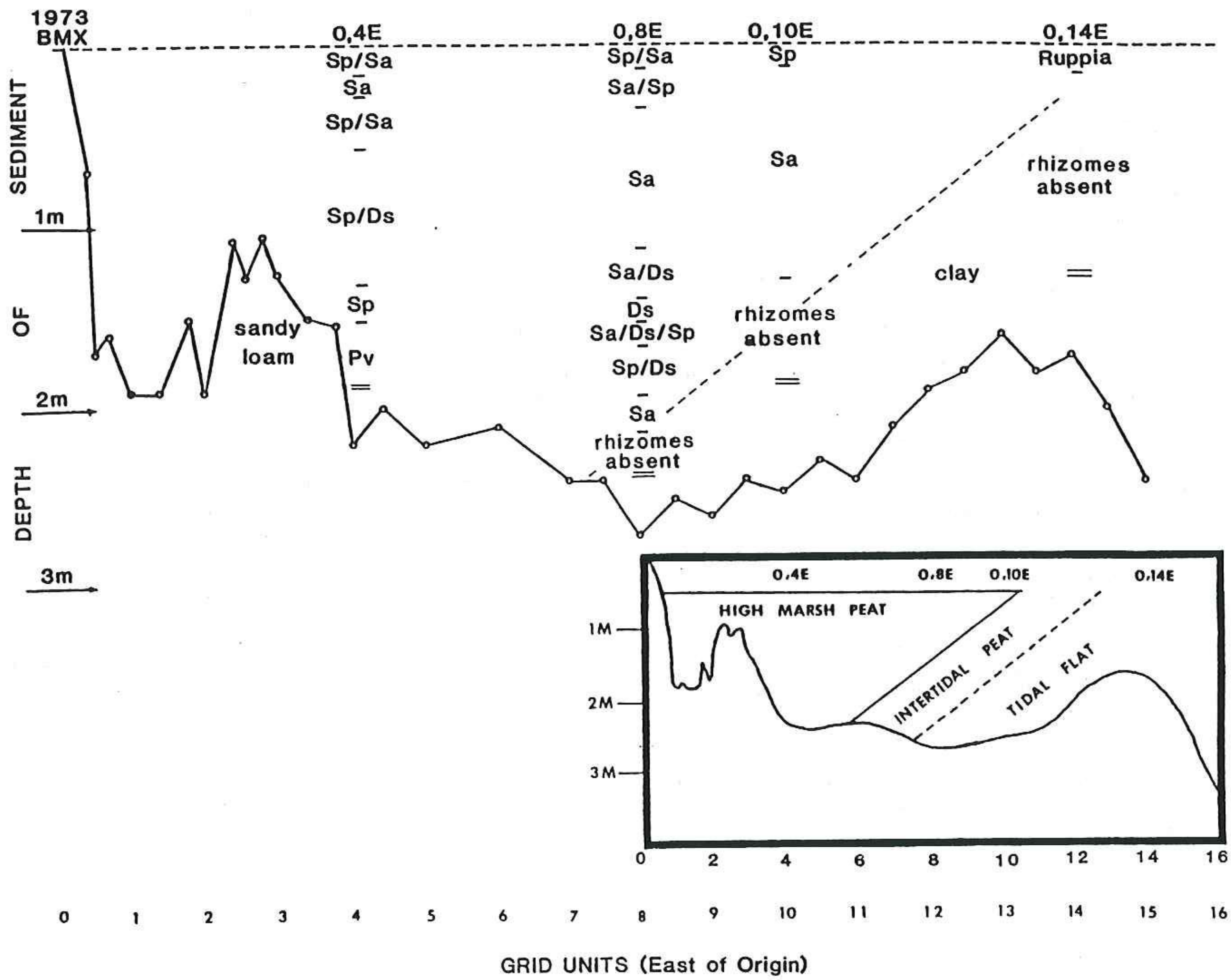

Fig. 4. Topographic bisect running due east from BMX, across high marsh (grid units 0–10), low marsh (grid units 10–11), and tidal mud flat (grid units 11–16) showing bidirectional marsh development over upland and over tidal flat. Vegetation changes within the four peat cores taken along this line are also shown (grid coordinates are above each core). A simplified interpretation of the bisect (after Redfield 1972) is presented in the insert. Key: Pv—*Panicum virgatum*; see Fig. 3 for other species.

in a more open valley with protection from wave action provided by Black Point Peninsula and rock outcrops at the mouth of the river.

Recent reports of accelerations in relative rates of eustatic sea level rise over the last few centuries may have significant effects on future development of coastal salt marshes (Harrison and Bloom 1977; Flessa et al. 1977; McCaffrey 1977; Boesch et al. 1983). If the rates of coastal submergence exceed the marsh's ability to accrete vertically, then losses in marsh area due to drowning may be expected (Orson et al. 1985). If, on the other hand, vertical marsh accretion can maintain rates comparable to relative rates of submergence, the marsh will continue to develop.

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