

Chapter 3

Evidence for long-term cycles in eelgrass (*Zostera marina* L.) abundance
in Massachusetts using sediment cores

Introduction

Analysis of core sections from coastal depositional environments shows great promise for assessing the impact of anthropogenic and natural disturbances that have taken place during recent centuries. For example, in Chesapeake Bay, sediment cores were used to document increases in algal biomass, nutrient loading, and sediment deposition, and decreases in submerged aquatic vegetation as a result of human development (Brush, 1984; Brush and Davis, 1984; Davis, 1985; Orth and Moore, 1983b). In this paper I document past cycles in eelgrass (*Zostera marina* L.) abundance with cores from bays on Cape Cod and Buzzards Bay, Massachusetts.

Eelgrass populations undergo major fluctuations in abundance due to disease, storms, ice scour, and pollution (Harlin and Thorn-Miller, 1981; Orth and Moore, 1983b; Robertson and Mann, 1984; den Hartog, 1987). For example, the wasting disease destroyed at least 90% of all eelgrass in the Western Atlantic during 1931-32 (Rasmussen, 1977; den Hartog, 1987) and less dramatic declines of eelgrass were reported along the eastern seaboard of the US in 1894, in New England in 1908, and in Popponesset Bay (adjacent to Waquoit Bay) during 1915 (Cottam, 1934). In recent decades, nutrient loading has been implicated in local eelgrass declines. Added nutrients elevate the biomass of epiphytes on eelgrass and phytoplankton, both of which decrease light availability, and thereby cause the death of eelgrass beds (Orth and Moore, 1983b; Sand-Jensen and Borum, 1983).

Most macrophyte seeds in marine and estuarine environments sink. Davis (1985) examined the morphology, density, and settling velocities of seeds produced by aquatic vegetation and concluded that most seeds are deposited in or near the beds that produced them, even in moderate currents. Because eelgrass seed coats are resistant to decay and remain in the sediment even if a seed germinates, they are good indicators of eelgrass abundance and distribution over many decades or centuries. Eelgrass leaf and rhizome fragments are also present at considerable depths in cores, but are less quantitative indicators of eelgrass abundance.

Cores can be dated by pollen profiles, radioisotopes, or by remnants of human activity such as coal particles or other refuse (Brush, 1984; Brush and Davis, 1984, Redfield, 1972). Changes in diatom community, invertebrate abundance, and chemical composition can also be used to date core sections if some information is already available on historical changes in the environment. Generally cores are meaningful only when taken in depositional environments, remote from high current velocities, wave action, dredging, or construction (Davis, 1984). When cores are not dated independently, a realistic range for sedimentation rates for depositional environments can be approximated from the depth of the wasting disease event, plant community changes, sea level rise, and cores taken elsewhere. For example, tidal records indicate that sea level is rising relative to the land in the northeast U.S. at a rate of 2-3 mm y^{-1} during the last 2 centuries (Emery, 1980). Because depths of local undredged, quiescent areas have changed little on maps during the last 100 years, sedimentation in many areas, are probably within a

factor or two of the sea level rise rate. Some cores show community transitions from recent *Zostera* beds to *Ruppia* beds to the salt marsh grass *Spartina* with increasing depth (pers. obser.), indicating that overall, sediment deposition rates were less than sea level rise rates.

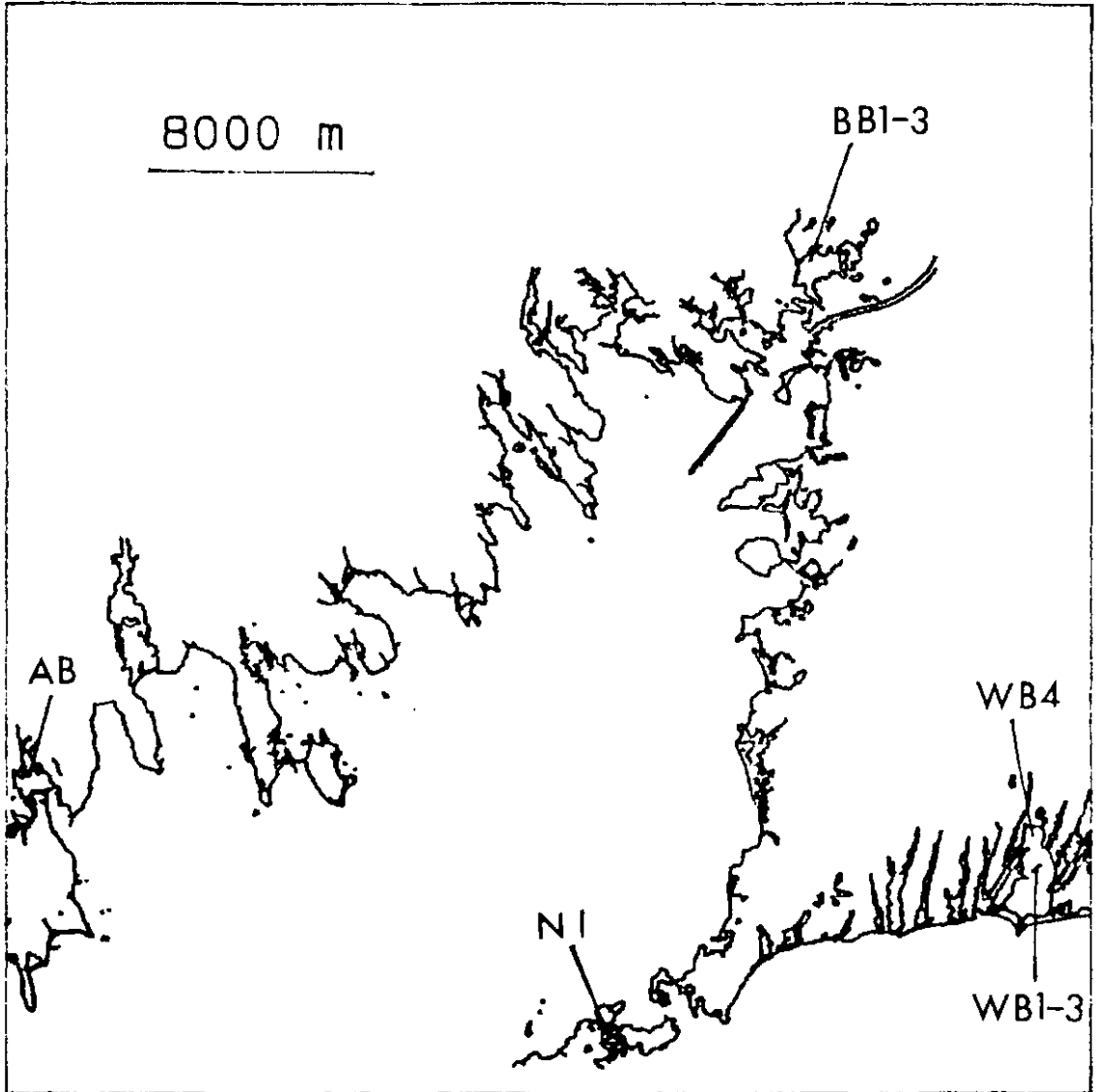
In Chesapeake Bay, recent sedimentation rates for cores taken in quiescent areas ranged from 2 to 10 mm y^{-1} , with higher rates occurring near rivers (Brush, 1984; Davis, 1985). In Boston Harbor, sedimentation rates near a sewage outfall were as high as 30 mm y^{-1} (M. Bothner, pers. comm.). Lower rates may be typical for undisturbed areas in bays on Cape Cod because river discharges are small. For example, if local sediment deposition is 2-10 mm year, declines in seed abundance due to the wasting disease can be expected to occur between 10 and 40 cm in cores. Of course channels, deeper basins, sites near barrier beaches, dredged areas, or streams may experience considerably higher rates of deposition or even sediment removal.

Methods

To determine regional fluctuations in eelgrass abundance, nine cores were taken in 4 bays around Cape Cod (Fig. 1). One core was taken in the north central region of Apponagansett Bay, So. Dartmouth (core AB) at 1.4 m MLW where no eelgrass grows today. Another was taken along Goats Neck, Naushon Is. (GN) at 0.7 m MLW with a shallow eelgrass bed. Three cores taken in Buttermilk Bay, Wareham either within or adjacent to eelgrass beds: one (BB1) on the north side of the flood delta at 1.2 m MLW, one (BB2) 20 m from a marsh at 0.8 m MLW, near the north end of the bay, 60 m east of Red Brook, a small stream there, and the third

Figure 1. Location of sediment cores taken in Buzzards Bay and around Cape Cod.

The four bays examined were Apponagansett Bay (AB), Naushon Is. (NI), Buttermilk Bay (BB1-3), and Waquoit Bay (WB1-4).



(BB3) in the same area but 50 m from shore at 1.1 m MLW. Four cores were taken in Waquoit Bay, at the border of Falmouth and Mashpee. Three of the cores formed a transect from the deep east central part of the bay at 2.1 m MLW (WB1), toward the east within 0.5 km of both the eastern shore and the mouth of the Quashnet river, a large stream entering the Bay. Cores WB2 and WB3 were taken at 1.9 and 1.8 m MLW respectively, and each core was at least 200 m from the nearest core. A fourth core (WB4) was 60 m south of the northern shore of the Bay at 1.1 m.

The cores were taken underwater by pushing a 10 cm diameter PVC pipe into the sediment 40 to 80 cm, plugged, brought to the laboratory, and sectioned in 1.5 or 3 cm intervals. Sections were wet sieved into three fractions: 1-2 mm, 2-10 mm, and >10 mm, to determine the abundance of eelgrass fragments and seed coats, as well as invertebrate remains.

In Waquoit Bay today, sizable beds of eelgrass grows only near the mouth of the Bay, 1.5 km from the nearest any core and is found today. To determine if these beds contribute any seeds to the area where the core was taken, 24 10 cm shallow cores were taken around this bed to determine the distribution of seed dispersion. Four cores were taken near the center of the bed at 0.9 m, 4 were taken at the deep edge of the bed at 1.4 m, and 4 cores each at were taken 5, 20, 50, and 100 m from the edge of the bed at depths between 1.4 and 1.6 m.

Recent changes in eelgrass abundance were determined from aerial photographs, oral and published reports, and nautical charts. *Ruppia maritima* L. (widgeon grass) sometimes co-occurs with eelgrass in this region, but is more abundant in shallow quiescent or estuarine

environments where eelgrass is less common. Its seeds are also found in the sediment and are good indicators of a shallow or estuarine habitat.

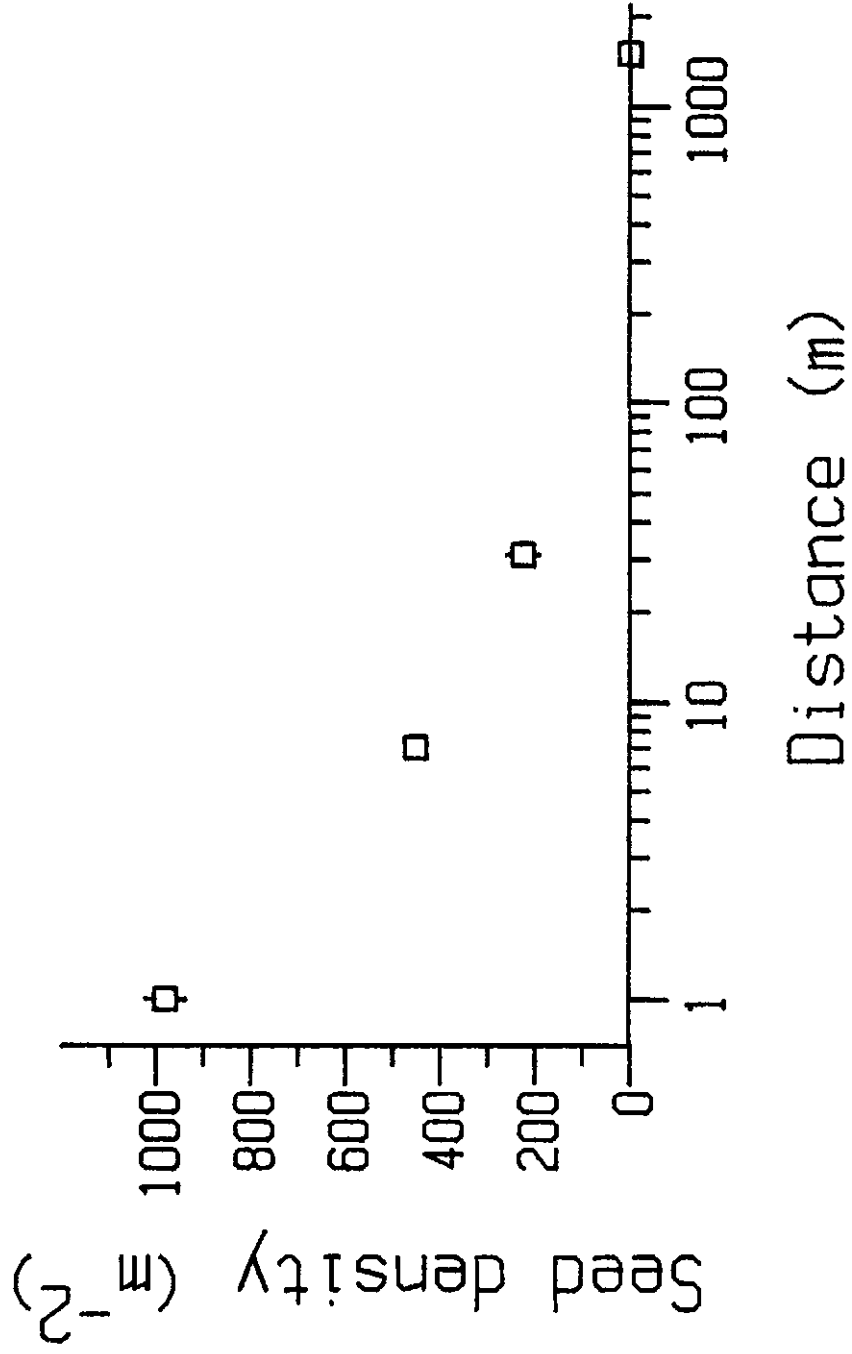
Results

In all the cores, eelgrass seed coats and eelgrass detritus were well preserved in anoxic mud. Whenever eelgrass rhizome fragments were present within core sections, eelgrass seed coats were present as well. Eelgrass seeds may occur without rhizome fragments within a core section, but other eelgrass detritus is usually present. Living eelgrass seeds were found only in cores (near the surface) taken near existing eelgrass beds (Naushon Is. and Buttermilk Bay cores), and not in the other cores.

The annual mean seed deposition rate and propagation distance were calculated from living seed densities measured in surface cores taken from within the bed, and at distances of 1.5-6 m, 12-30 m, and >1500 m (the profile cores), and plotted against distance from the existing bed at the mouth of Waquoit Bay (Fig. 2). The greatest number of seeds were found with the beds (mean annual rate ≈ 1000 seeds m^{-2} , high = 2700 seeds), compared to no seeds found at the core profile stations. Because there were no intermediate stations 30 and 1500 m, it is unclear how far seeds can travel, but these results suggest that most seeds land near the beds that produced them. Thus the contribution of seeds by the existing beds in Waquoit Bay are negligible where the seed profile cores were taken, and instead reflect eelgrass cover in the center of the Bay. These results are also consistent with exponential declines in seed

Figure 2. Seed densities distribution in Waquoit Bay.

Distance values were transformed $\text{Log}(x+1)$. Samples were taken north of eelgrass on the flood delta at the mouth of the Bay, 0 = within the bed.



densities observed in wind dispersed seeds from trees (Sharpe and Fields, 1982).

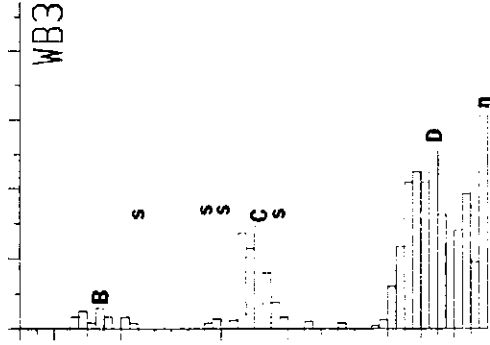
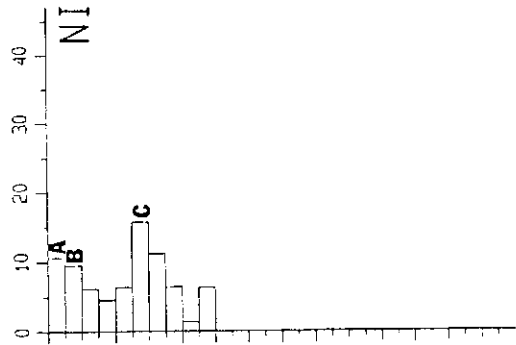
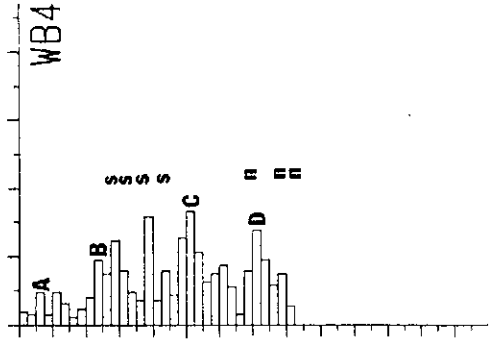
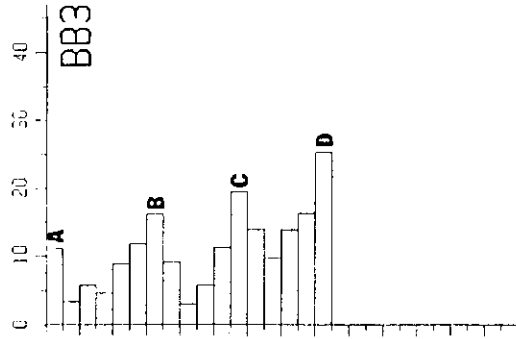
All the cores documented major fluctuations in eelgrass abundance in the past reflecting local fluctuations in abundance (Fig. 3). Because the cores taken in Waquoit Bay were all taken from stable environments, analyzed in more detail, and had more replicates, they will be discussed first.

Waquoit Bay

The cores from the Waquoit Bay transect (WB1-WB3) each showed three major peaks (B-D) in eelgrass abundance, separated by periods when eelgrass was absent (Fig. 3, WB2 not shown). The depth of each these peaks was progressively deeper along the transect toward the Quashnet River and eastern shore, indicating higher rates of sediment deposition from either of these sources. Biogenic depositional markers demonstrate that these three peaks are identical. Three major mortalities of bay scallop *Argopectin* juveniles between peaks B and C occur in the three cores (S's in Fig. 3). For example, in the 31.5-33.0 cm section in core WB2 (117 cm³), 42 valves of *Argopectin* juveniles were found that lacked signs of predation. Furthermore the snail *Bittium alternatum* is abundant on the bottom of Peak B and top of Peak C on all three cores, with densities exceeding 3 *Bittium* per cm³ in some sections. A large population of the mud snail *Nassarius* sp. appear in eelgrass peak D of cores WB2 and WB3 as well, which were sampled to greater depths than core WB1.

Figure 3. Sediment core eelgrass seed profiles in 4 Bays.

Apponagansett Bay (AB), Naushon Is. (NI), Buttermilk Bay (BB) and Waquoit Bay (WB). Symbols indicate peaks *Nassarius* (N) and *Argopectin* juvenile mortality (S). A-D indicate *Zostera* peaks described in text. *Bittium* peaks are not shown.



The seed profile in the core taken along the northern shore of Waquoit Bay (WB4, Fig 3) appears dissimilar from the mid-bay cores, nonetheless, the *Argopectin* mortality, and *Bittium* and *Nassarius* peaks indicate that the three lower, less distinct peaks in this core correspond to peaks B-D in cores WB1-3. In addition, photographs show that eelgrass grew later here (peak A), in this shallow, nearshore area than the deep cores.

The dates of these changes in eelgrass abundance can be deduced from the recent history of eelgrass changes in Waquoit Bay. Today no eelgrass grows near any of the cores, and is largely restricted to the flood delta in the south end of the Bay. The wasting disease of 1931-32 destroyed eelgrass throughout the region, but the cores demonstrate that eelgrass grew even in the deepest parts of the Bay in the past. The photographic record (1938-present) indicates that in 1938 eelgrass was absent throughout the deep areas of the Bay, but grew abundantly nearshore, especially along the eastern margin of the bay, as well as near core 4. In the 1940's eelgrass began to recolonized the central portion of the Bay, and was very abundant there by the late 1950's. After 1965, eelgrass began to disappear in the deepest parts of the bay, and by the mid-1970's had disappeared from the along the Bay margins as well, including near core 4.

This most recent eelgrass decline appears to be to decreased light availability because of increased epiphyte growth and phytoplankton from nutrient loading (Valiela and Costa, in press), and in recent decades, dense layers of drift algae (primarily *Cladophora*, *Gracillaria*, and *Agarhdiella*, up to 70 cm thick) have been accumulating. This dense

layer of algae precludes future recolonization of eelgrass because seedlings cannot survive under dense layers of unconsolidated algae.

From these observations, it appears that the decline of peak C was due to the wasting disease. Peak B documents the recovery of eelgrass in the bay during the 1950's then subsequent decline, and Peak A is present only when eelgrass persisted in recent years as was the case in the vicinity of core WB4. Based on this chronology, the scallop mortalities appear to coincide with the three major hurricanes to impact this region during this century: 1938, 1944, and 1954. Scallop populations have been historically high in Waquoit Bay, accounting for 80% of the fishery in all of Falmouth (Alber, 1987). The bay is large and shallow, which may contribute to the burial of spat during storms.

Within each core, the depositional markers are consistent, but differences exist at each station. The depth of peak B and the most recent *Argopectin* mortality in this core suggests that the recent depositional rate in the north end of the bay (WB4) is similar to the mid-Bay cores (5.5 mm y^{-1}), but slower between 1932 and 1954 (4.8 mm y^{-1}) than comparable periods in the mid-Bay (5.5 mm y^{-1}). During earlier periods at this station the depositional rate here was even lower because peak D is nearer the surface than elsewhere. The more recent increases in sedimentation rate at core WB4 may be due to the enlargement of the flood delta of a small lagoon nearby (Quahog Pond). On recent photographs, this delta is more prominent because of loss of eelgrass cover, and may have expanded during the last 40 years. Boat activity in the Bay has increased appreciably in recent decades and the

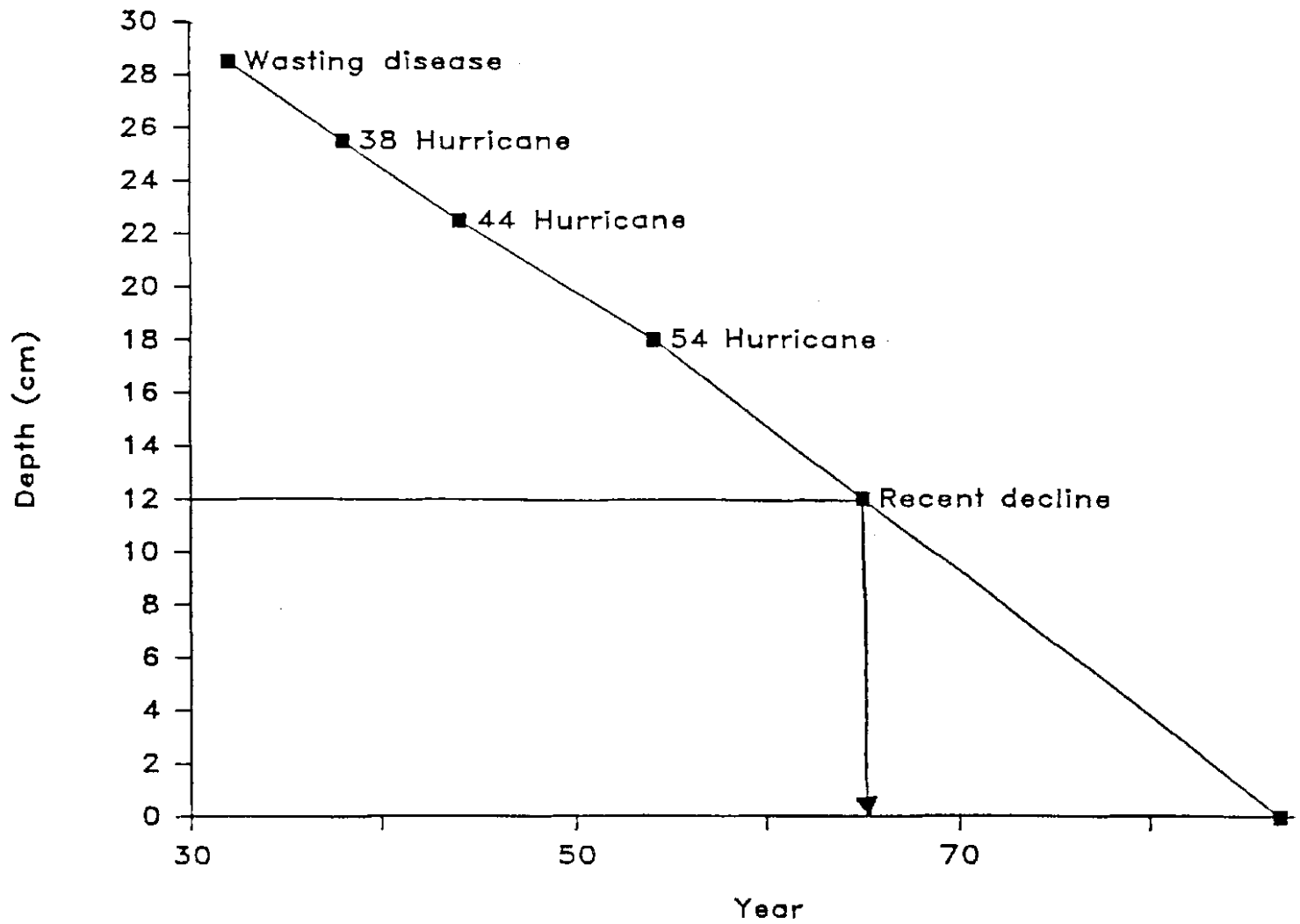
resulting sediment resuspension may have contributed to increases in sedimentation there.

The loss of resolution in the seed peaks in core WB4 may be due to the slower deposition rates, increased disturbance from wave action nearshore, or greater contribution from shallow annual beds that persisted between declines.

The highest rates of sedimentation occurred at the station nearest to the Quashnet River (WB3) during the period 1932-1954 (8.8 mm y^{-1}) which was higher than stations further offshore (5.5) during the same period, and higher than observed later at the same station (1954-1987, 6.4 cm y^{-1}). The higher rates may have been associated with cranberry bog construction and use along the Quashnet River during the earlier period. It is unlikely that the higher rates of deposition were due to storms because deposition in all mid-bay cores would be similarly affected.

Using the biogenic markers and rates of sedimentation, the date of recent and earlier declines can be calculated. If the most recent scallop mortality is used as a marker, the date of the decline in peak B can be calculated for each core. At the deepest mid-Bay station (WB1), eelgrass disappeared first ≈ 1961 , then at the shallow mid-bay stations in ≈ 1971 (core WB2), ≈ 1973 (WB3, Fig. 4). In the north end of the Bay, eelgrass disappeared ≈ 1965 . The loss of eelgrass in deeper and upper bay stations first, supports the hypothesis that these declines were associated with declining light availability, because this pattern has been observed elsewhere nutrient loading has increased (Orth and Moore, 1983b).

Figure 4. Depth of depositional markers in core WB4.
The date of the most recent decline was estimated from its depth and
deposition rates.



If deposition rates prior to the wasting disease are equal to post-disease rates, then the date of the first pre-wasting disease decline appeared circa 1902-1906 for all four Waquoit Bay cores. In addition, the two cores (WB3 and WB4) with the earliest depositional records indicate an even earlier decline circa 1870-1890.

The cause of the 1902-1906 has several plausible explanations. Some shallow coastal lagoons on Cape Cod close periodically, and a closure of Waquoit Bay would reduce mouth would reduce salinity in the Bay and possibly change water transparency. It is unlikely that Waquoit Bay had become fresh during the last 100 y because all nautical charts to 1865 Waquoit Bay with a prominent channel at the mouth, and marine species persist throughout the core including when eelgrass is absent.

Another possibility is that some other factor caused water transparency to decline, and eelgrass disappeared from the deep areas where the cores were taken. This seems unlikely, because prior to 1931, there was little development around the Bay. Farms were common, but levels of fertilization were far less prior to the use of manufactured fertilizer. Cape Cod has undergone considerable deforestation and conversion to farmland in the past, and topsoil runoff on nutrient release from soils could have been a contributing factor, but this too seems unlikely because river flow into the bay is nominal.

Instead the most plausible explanation is that these declines coincide with the eelgrass population collapses due to disease reported by Cottam in 1908 or 1894.

Other areas

Buttermilk Bay core WB1 (taken on the north end of the flood delta) proved undesirable because 2 dense layers of sand occurred within the core indicating this environment was disturbed or altered in the past. A dense layer of sand at 15 appeared to coincide with dredging nearby that occurred between 1943 and 1951 photographs. A layer of sand at 40 cm may coincide with completion of the Cape Cod Canal nearby around 1916 which caused a change in the hydrography of the bay (Stevens, 1935). Core 2 was taken too close to shore, and rapidly graded into *Ruppia* community, then salt marsh peat. The tops of these cores, nonetheless, showed similar patterns of abundance as BB3 which showed eelgrass declines at 12, 27 and 42 cm.

In Buttermilk Bay, eelgrass was widespread prior to the wasting disease (Stevens, 1935, 1936), and photographs show a broad recovery during the 1940's and 1950's. Eelgrass was somewhat less abundant near this core during the early 1960's, but has expanded since then. Given these observations, and assuming rates of deposition are similar to Waquoit Bay, it appears that the wasting disease began at 27 cm. If sedimentation rates were similar prior to the wasting disease, the earlier decline occurred \approx 1903.

The core at Naushon Island was insufficiently deep for comparison to the other cores. This core was taken in a quiescent area 20 m from an undisturbed, protected shore, with no local riverine inputs, therefore sediment deposition rates may be very low here, and the wasting disease may account for the decline in seed abundance at 18 cm. This is supported by the observation that eelgrass declines at the

bottom of the core coincide with large increases in *Ruppia* seeds, which exceed 1 seed per cm^3 . This suggests that either the environment was shallow or more estuarine during deposition. Alternately, *Ruppia* replaced eelgrass when the latter disappeared, because both species occupy the habitat today, and *Ruppia* is a relatively minor component. This seems unlikely, however, because *Ruppia* did not become abundant during the most recent decline. If rates of deposition prior to the wasting disease were similar to post disease rates, then the earlier decline at 27 cm occurred ≈ 1906 .

The Apponagansett Bay core is least typical. Eelgrass seems to be persistent in the bay with minor declines at 60 and 33 cm, until a major decline at 21 cm. Subsequently eelgrass recovered, then again declined. This pattern agrees with other evidence: eelgrass is abundant in the bay on nautical charts from the 19th century, eelgrass was destroyed in 1931-32, then showed recovery on aerial photographs during the 1950's and 60's, then disappeared again. In 1985, no eelgrass was found in the inner Bay. The most recent loss of eelgrass appears due to declining water quality from nutrient loading or increased turbidity from sediment resuspension by boats (Costa, 1988).

If the wasting disease occurred 21 cm here, and sedimentation rates are constant, then the minor declines at 33 and 60 cm would coincide with 1902 and 1834.

Discussion

Based on the estimated sedimentation rates and seed densities, seed deposition rates were as high as $2000-6000 \text{ m}^{-2} \text{ y}^{-1}$ in Waquoit Bay,

which is somewhat higher than the mean deposition of new seeds measured at the mouth of that Bay (≈ 1000 seeds $m^{-2} y^{-1}$). This difference may not be significant because there is considerable variability in the density of recently produced seeds in surface cores within beds. Similarly, cores from the other bays suggest that the seed deposition rates generally peak between 1500-2500 seeds $m^{-2} y^{-1}$. These rates of seed deposition are consistent with seed production rates measured elsewhere (Thayer et al., 1984), and with rates that I have measured locally (up to 15,000 seeds $m^{-2} y^{-1}$).

Other factors may contribute to different seed deposition rates in eelgrass beds. Environmental conditions have a strong effect on the expression of flower abundance in eelgrass, and therefore seed production (Phillips et al., 1983). Some eelgrass beds produce mostly reproductive shoots and others produce mostly vegetative shoots, and there is a high degree of consistency for beds in a particular habitat (Phillips et al., 1983; Keddy, 1987). For example, Allee (1923b) noted that eelgrass beds in the Northwest gutter of Uncatena Island in the Elizabeth Islands always have high flower densities. These beds continue to have high flower densities today (pers. obser).

Thus, eelgrass seed coat abundance is a good indicator of local, relative eelgrass abundance, but not necessarily an absolute indicator of biomass or production. Undoubtedly there are yearly differences in seed production, but because these core sections equal 2.5 - 8 years of deposition, this variation should be diminished. Processes that bioturbate the sediment, such as sediment ingestion and excretion by worms, blur the stratigraphic record of some sediment markers such as

radioactive isotopes or pollen profiles. These processes are relatively unimportant in altering the eelgrass record because eelgrass seeds are too large to be ingested by most deposit feeders.

The rates of seed deposition, sedimentation rates, depths of deposition markers, and photograph documentation are all consistent with the interpretations given here, but additional dating methods should be employed to verify actual dates. Nonetheless, these results demonstrate eelgrass populations in each bay have shown sizable fluctuations in the past, and that some of the trends are regional. Some of these fluctuations like the wasting disease of 1931-32 appear clearly in depositional record. Furthermore, reports of declines prior to the wasting disease are substantiated because all the cores show a decline around the turn of the century. If sedimentation rates were similar prior to the wasting disease, as after, then the declines in each bay most closely match the 1908 eelgrass decline in New England reported by Cottam (1934). It is plausible that sedimentation rates prior to the disease were lower, because the frequency of intense storms increased after 1930 (Aubrey and Speer, 1984; Zeeb, 1985), which could have also increased sedimentation rates. If so, then these declines coincide with the 1894 decline reported by Cottam (1934).

The two bays with evidence of nutrient loading effects (Waquoit and Apponagansett Bays) show eelgrass declines that are well documented in the photographic and sedimentary record. Therefore, the use of sediment cores show promise in assessing the impact of anthropogenic disturbance in coastal depositional environments.