Sediment-Based Reconstruction of Submersed Aquatic Vegetation Distribution in the Severn River, a Sub-Estuary of Chesapeake Bay†

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ABSTRACT ▰

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A paleo-ecological reconstruction of long-term changes in the distribution of submersed aquatic vegetation (SAV) in a Chesapeake sub-estuary was made using dated sediment cores on transects going from shallow (< 0.5 m) to deep (> 2 m) waters. Maynedier and Saltworks Creeks, branches of the Severn River, have had substantial losses of SAV, similar to many parts of the upper Chesapeake Bay. Dating via ^{210}Pb established that sediment accretion rates were 0.5–0.7 cm yr^{-1} in these two systems, double the rate of sea level rise in this region. Seeds of only two SAV species were found in the sediments despite evidence others were present at one time or another in other tributaries of the Severn Estuary. Of the two species found, *Zannichellia palustris* seeds were much more abundant than *Ruppia maritima* seeds, reflecting the high dispersibility of the former species. The vertical pattern of seed distribution in these cores indicates that over the past 100 years, SAV (particularly *Z. palustris*) has been increasingly confined to shallower water depths. Although there is less riverine pulsing in the two study creeks, than at the head of the Bay (where previous seed records are available), both data sets are consistent with the hypothesis that decreasing light availability due to eutrophication and sediment erosion has been a problem for SAV in Chesapeake Bay, particularly over the last several decades. Furthermore this study suggests that historically low species diversity may be attributable to more chronic and longer term stress in the shallows of the Severn River than present in SAV beds at the head of the Bay.

ADDITIONAL INDEX WORDS: *Eutrophication, ^{210}Pb, geochronology, SAV, seeds, sedimentation rates, seagrass, shore erosion.*

INTRODUCTION

Empirical and anecdotal evidence indicates that during the present century the distribution of submersed aquatic vegetation (SAV) in coastal environments has declined in many parts of the world (GIESEN *et al.*, 1990, CAMBRIDGE and MCCOMB, 1984,). In Chesapeake Bay, submerged aquatic vegetation ranges from 3 to 10% of historical coverage (STEVENSON and CONFER, 1978; ORTH and MOORE, 1984, BATIUK *et al.* 1992). Temporal fluctuations of abundance have occurred in part as a response to disease, the introduction of exotic species, and storm events (BAYLEY *et al.*, 1978). While catastrophic events no doubt have had an effect on SAV abundance, they are not fully responsible for population declines. In Chesapeake Bay, the primary cause of SAV loss is thought to be deterioration of water quality from high inputs of sed-

iments and nutrients from point and non-point sources (KEMP *et al.*, 1983).

Although diminished light is the overall factor limiting SAV distribution (HUTCHINSON, 1975; WETZEL and PENHALE, 1983; WETZEL and NECKLES, 1986; DENNISON, 1987), other, often co-varying perturbations, including nutrient enrichment, salinity fluctuations, sediment loading and sediment resuspension, have been instrumental in recent declines in SAV (DEN HARTOG and POLDERMAN, 1975; KEMP *et al.*, 1983; ORTH and MOORE, 1983; CAMBRIDGE and MCCOMB, 1984; GIESEN *et al.*, 1990). The synergistic effect of these perturbations has altered the light regime below levels at which SAV can effectively photosynthesize and thus survive (MOSS, 1976; PHILLIPS *et al.*, 1978; KEMP *et al.*, 1983; TWILLEY *et al.*, 1985).

The Severn River, like most tributaries in the western drainage of the Chesapeake Bay (Figure 1), no longer supports the extensive SAV beds that once existed. Aerial and ground truth surveys of SAV abundance, conducted on the Severn River since 1969, found only sparse populations of *Potamogeton perfoliatus* (STEVENSON and CONFER, 1978), *Zannichellia palustris* (ORTH *et al.*, 1987), and *Ruppia maritima* (ORTH *et al.*, 1990). Prior to these surveys, only records
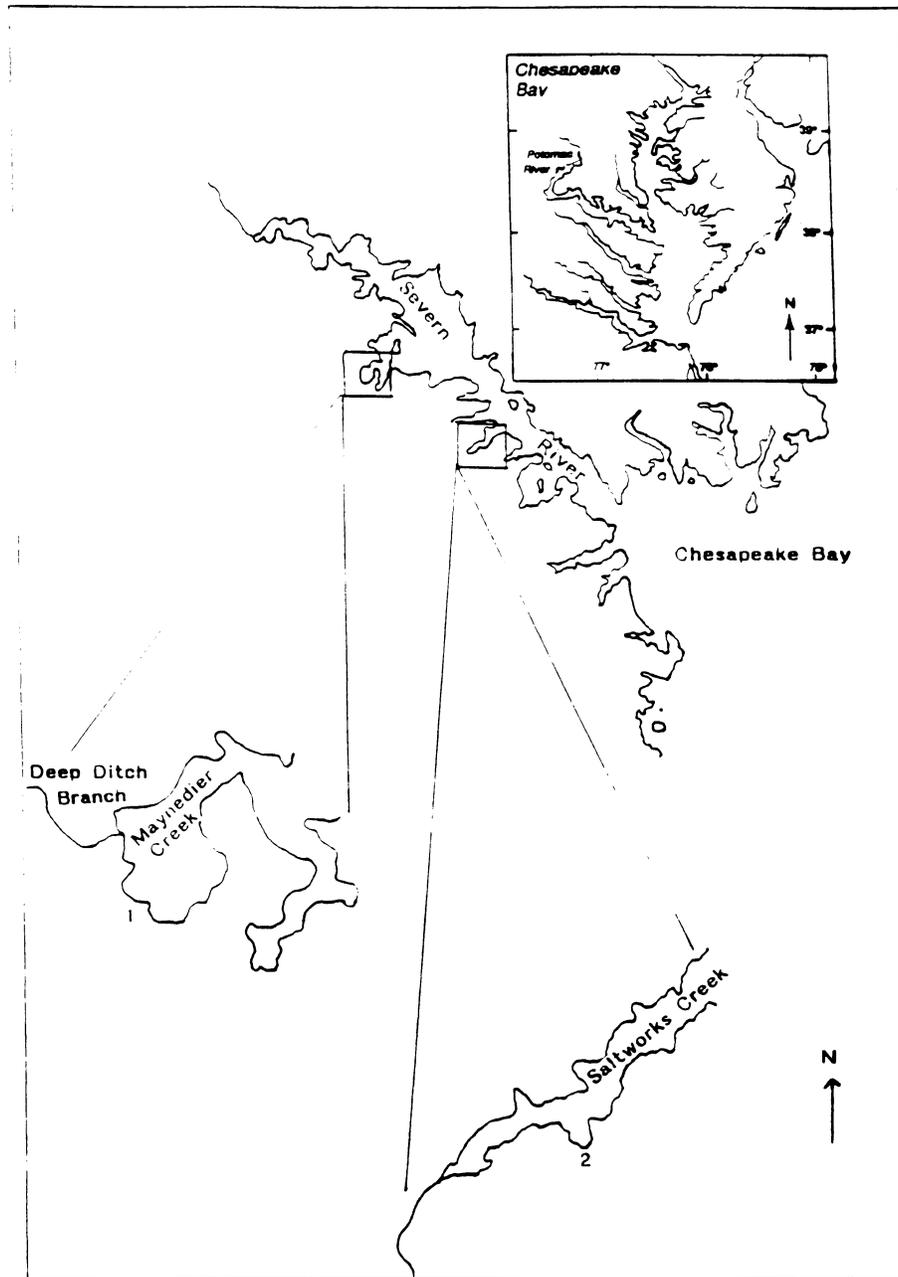
Figure 1. Map showing station locations of Maynedier Creek (MC) and Saltworks Creek (SW), sub-estuaries of Chesapeake Bay, U.S.A. Sediment cores for seed and sedimentation rate analyses were collected along water depth transects indicated by solid lines adjacent to MC and SW. Inset; Severn River within Chesapeake Bay.

of species occurrence had been kept, with little documentation regarding the extent of their cover and progression of their decline.

Fossil pollen and seed assemblages have been used to determine long-term trends in SAV populations in response to changing climatological and water quality conditions (WATTS and WINTER, 1966; BIRKS et al., 1976; BIRKS, 1980;, BRUSH et al., 1980; BRUSH and DAVIS, 1984, DAVIS, 1985). For ex-

ample, at the head of Chesapeake Bay, DAVIS (1985) showed that despite floods and hurricanes dating from the colonial era, communities of SAV remained surprisingly intact from early European settlement (~ 1730) until the early 1970's. In 1972, tropical storm Agnes scoured the Susquehanna flats and caused massive deposition of silts and clay further down the Bay. In addition, the massive runoff from Agnes introduced large quantities of nutrients and other materials (in-

cluding herbicides) into the water column at the head of the Bay. Thereafter SAV were absent in freshwater portions of the Upper Bay such as Susquehanna flats and adjacent Furnace Bay where DAVIS' (1985) cores came from. In the present study, we use ^{210}Pb-derived rates of sedimentation and SAV seed abundance to determine if the scenario for the upper Bay was repeatable in mesohaline environments where the species composition of SAV is different and where the area more is protected from high Susquehanna River flows. We also focus on the question of whether there is any discernable difference in seed assemblages attributable to water depth. After the 1970's, as SAV was becoming scarce in deeper waters in many parts of the Chesapeake, it appeared to be more abundant in the shallows (< 0.5 m) in mesohaline portions of the upper Bay. Unlike previous Chesapeake Bay studies where depth of water was not actually noted, we were particularly interested to know whether this phenomenon could be quantified using the sedimentary record.

Study Site

Two mesohaline sub-tributaries of the Severn River were selected based on the presence of reduced levels of SAV and well-preserved seed banks. Maynedier Creek (39° 01.93' N; 76° 34.30' W) is a small (~ 0.19 km^2), shallow (2.0–2.5 m) creek which drains into Little Round Bay, Round Bay, and the Severn River (Figure 1). The drainage west of Maynedier Creek exhibits a sloping terrain with grades up to 15% and a maximum elevation of 30 m. The mean summer salinity at this site was 7–8‰ (ARNOLD, 1992). Deep Ditch Branch, a small creek that receives large inputs of pulp, sawdust, and wood chips from a saw mill, is the primary terrestrial surface water input. Maynedier Creek's watershed covers 4.2 km^2 and consists primarily of low density residential and forested areas. The study transect at Maynedier Creek extended from a small *Spartina* saltmarsh adjacent to Deep Ditch Branch to the center of the creek.

Saltworks Creek (39°01.99 N; 76°34.90' W) is a narrow embayment which is connected to the Severn River ~ 7 km southeast of Maynedier Creek. It was chosen as a comparison site because of its similarity to Maynedier Creek in terms of size, watershed area, and tidal/salinity ranges. Its watershed contains higher density residential areas, an industrial park, and impermeable surfaces associated with watershed development. The study site at Saltworks Creek extended from a small *Spartina* saltmarsh to the middle of a protected cove.

METHODS

A transect was extended in each creek from mean low water to a water depth of 200 cm. Water depth was recorded at 5 m intervals in order to determine bathymetry along the transect. Overlying sampling depths at the sample locations were 0, 50, 100, 150, and 200 cm below mean low water (mlw). Sediment cores (50 cm long) were collected using a McAuley corer (BRICKER-URSO *et al.*, 1989). Care was taken to ensure that the cores were collected with minimal disturbance to the sediments. Sediment floc at the uppermost layers of the core indicated that the core integrity was main-

tained (BRUSH *et al.*, 1982). The core samples were immediately extruded at 2 cm intervals into plastic bags.

Seed abundance was determined by rinsing the remaining sediment through a 1 mm sieve, with material on the sieve being thoroughly examined for SAV seeds. Seed abundance was expressed per gram sediment dry weight. Seed viability was estimated in a 4 week, 25 °C incubation after rinsing the seeds in a 10% solution of chlorine bleach for 5 seconds to minimize problems with fungi and bacteria. Samples were incubated in a petri dish containing 5‰ seawater, reflecting mean annual salinity in the Round Bay vicinity of the Severn River (R. WALEY, unpublished data and W. BOICOURT personal communication).

The analysis of ^{210}Pb activity was conducted on the first, third and fifth transect cores corresponding to water depths of 0, 100, and 200 cm from each creek. The activity of ^{210}Pb ($t_{1/2} = 22.3$ d) was determined by analysis of its daughter nuclide, ^{210}Po ($t_{1/2} = 138$ d). Secular equilibrium was assumed. Sediments were dried at 70 °C to determine percent water content. Analysis of ^{210}Po followed SUGAI (1990).

Calculations of sediment accumulation rates were made using a "constant rate of supply" (CRS) model (APPLEBY and OLDFIELD, 1978). All model calculations were made using cumulative mass as a depth scale, with the cumulative mass estimated from the percent water data and an assumption of sediment dry bulk density of 2.5 g cm^{-3}. The APPLEBY and OLDFIELD (1978) model requires the determination of "unsupported" ^{210}Pb, with ^{226}Ra-supported ^{210}Pb activity estimated from the asymptotic ^{210}Po concentration at depth. The major assumption of this model is that ^{210}Pb fluxes into the sediment are constant while the rate of sedimentation can vary (APPLEBY and OLDFIELD, 1978). To determine the age of a sediment at a given depth, we calculated the cumulative amount of unsupported ^{210}Pb at a given point within the core (ROBBINS, 1978), and sediment ages were calculated using the following formula:

$$t = [\ln(1 - \Sigma\ M\ /\ \Sigma\ \infty)]/k \qquad (1)$$

where Σ M is the cumulative amount of unsupported ^{210}Pb (dpm m^{-2}) above a given core section, $\Sigma \infty$ is the total excess ^{210}Pb inventory in the core (dpm cm^{-2}), and t is the time (yr). Sediment ages for cores that were not analyzed for ^{210}Pb were estimated from the mean age of adjacent cores on each transect.

RESULTS

The cores collected from both creeks consisted primarily of silts and clay with relatively high ($> 80\%$) water content. Surficial sediment layers appeared oxidized, with some deeper horizons black from the presence of iron monosulfides. Macrobenthos, mostly annelid worms, were apparent only in the oxidized sediment horizons. Deeper sediment horizons in Maynedier Creek cores often contained large quantities of plant detrital material and wood chips. Although the more recent horizons of the shoreward cores were fine-grained, deeper horizons often consisted of compacted clay or coarse grained sand, which were interpreted as beach sand.

The ^{210}Po profiles generally decreased with depth (except
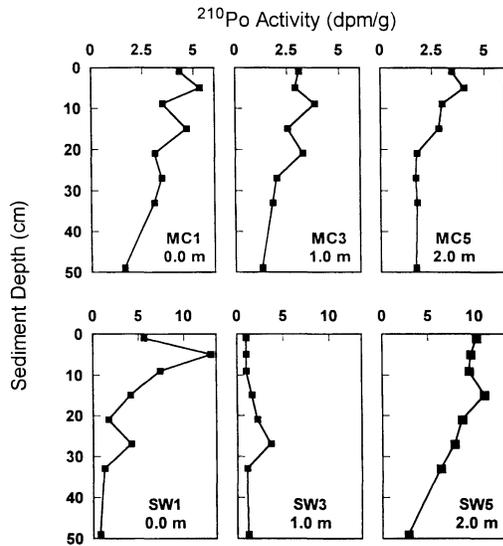
Figure 2. Vertical profiles of ^{210}Po activity (dpm g^{-1}) in the top 50 cm of sediment from six cores from Maynedier Creek (MC) and Saltworks Creek (SW) collected from 0, 1.0 and 2.0 m water depths (mean low water) using a McAuley corer.

Figure 3. Sediment age at various sediment depths calculated from constant rate of supply model of ^{210}Pb distribution (APPLEBY and OLDFIELD, 1978) for sediment cores collected at Maynedier Creek (MC) and Saltworks Creek (SW). Sediment cores collected at water depths of a) mean low water (MC1; SW1), b) 1.0 m (MC3), and c) 2.0 m (MC5; SW5).

core SW3), with cores SW1 and SW5 having the highest surficial ^{210}Po activity (Figure 2). Most cores reached an asymptotic activity level, though in SW5 the supported activity was assumed to be similar to that in cores SW1 and SW3. Most of the sediment profiles did not fit a simple exponential decay model, perhaps due to variable sediment input, so the constant rate of supply sedimentation model was used. The constant rate of supply estimated model years are not well constrained at ages greater than ~ 80 years because the calculation becomes increasingly sensitive to small errors in the assessment of ^{210}Pb inventories. The age depth curves of cores MC1, MC3, SW1 and SW5 were similar in recent sediments (Figure 3), with the exception of MC5 which had a lower sedimentation rate than the other cores. No ages were calculated from the SW3 ^{210}Po data because of the anomalous ^{210}Po depth profile. The sediment accretion rate over the past 100 yr averaged 0.7 cm yr^{-1} for Maynedier and 0.5 cm yr^{-1} for Saltworks Creek. This rate is substantially above relative sea level rise over the last 100 years (KEARNEY, 1996) in this region (0.25–0.35 cm yr^{-1}) and suggests rapid infilling of these tributaries. These rates are consistent with the fact that Maynedier Creek is the upriver site and more proximal to the fluvial sediment sources from the upper watershed. Also the transect at Maynedier extended outward from a > 10 meter high eroding cliff face. MARCUS and KEARNEY (1991) have shown that in the nearby South River, 4–12 times as much sediments comes from cliff erosion as from riverine sources.

Surprisingly, only two species of SAV were represented in the seed assemblages of both study sites (Figure 4). The most abundant seeds were those of *Zannichellia palustris* (Horned Pondweed) which were found in every core. The seeds of *Ruppia maritima* (Widgeon Grass) were also represented in a ma-

jority of the cores. None of the seeds of *R. maritima* were found to be viable. Only the *Z. palustris* seeds from the shallow portions of the cores were viable, with the highest germination rate of 14% in a single sample. In Maynedier Creek, only sparse *Z. palustris* was found growing and in Saltworks Creek, both dense *Z. palustris* and sparse *R. maritima* were found. No *Potamogeton perfoliatus* was observed at either site, even though historic records indicated this species was present nearby. In Maynedier Creek, seed abundance was highest for both species in the core collected at 50 cm water depth. Average abundance in this core was 2.4 *Z. palustris* seeds gdw^{-1} and only 0.5 *R. maritima* seeds gdw^{-1}. In general, seed abundance was lowest in cores collected at greater water depth. In Saltworks Creek, the seeds of *Z. palustris* were most abundant (mean = 3.8 seeds gdw^{-1}) with the seeds of *R. maritima* most abundant (mean = 0.33 seeds gdw^{-1}) in core 2.
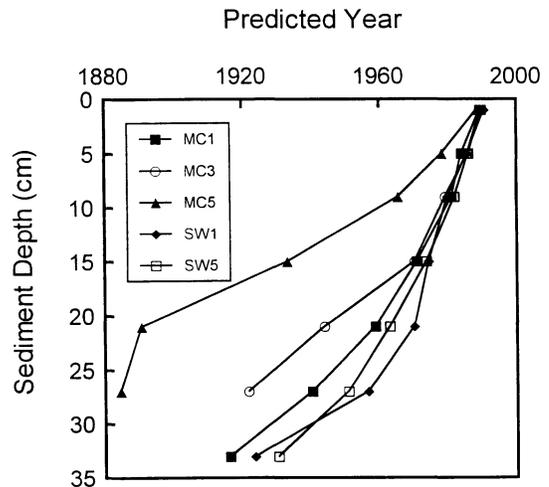
The greatest abundance of *Z. palustris* seeds generally occurred progressively deeper in the core as water depth increased (Figure 4). In Saltworks Creek, this trend was particularly obvious with the peaks in seed abundance occurring deeper in the core as water depth increased. The occurrence of *R. maritima* seeds at both sites was very sporadic. Although disturbances associated with biota in the root zone of oxygenated sediments in SAV beds is sometimes a problem in paleo-ecological studies, the Severn River cores generally had minimal bioturbatation (as indicated by the radionuclide profiles). However, there is a possibility of grazing on seeds accounting for sparse distributions. In Maynedier Creek, *R. maritima* seeds were found only in the most recent sediments of core MC1 and were entirely absent from core MC5. Cores MC2 and MC3 contained the largest quantities of the seeds with the greatest concentration occurring deep in the core. The episodic abundance of *R. maritima* seeds was most evi-
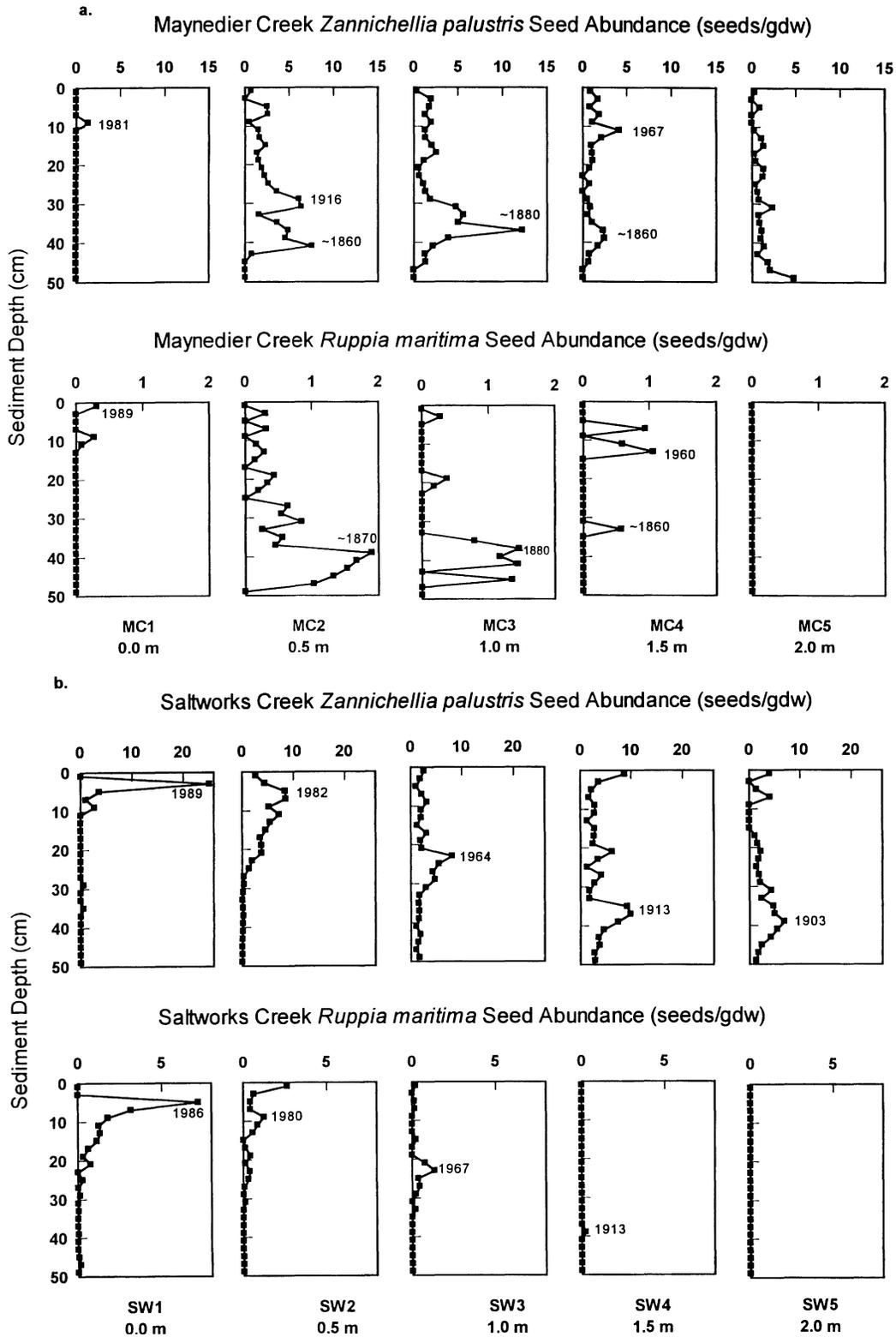
Figure 4.   Vertical profiles within top 50 cm of sediments of submerged aquatic vegetation (*Zannichellia palustris; Ruppia maritima*) seed abundance in (a) Maynedier Creek and (b) Saltworks Creek. Sediment cores obtained along a water depth transect (0, 0.5, 1.0, 1.5, and 2.0 m). Approximate sediment ages, determined by ^{210}Pb dating and represented as years, of the peaks in seed abundance are indicated.
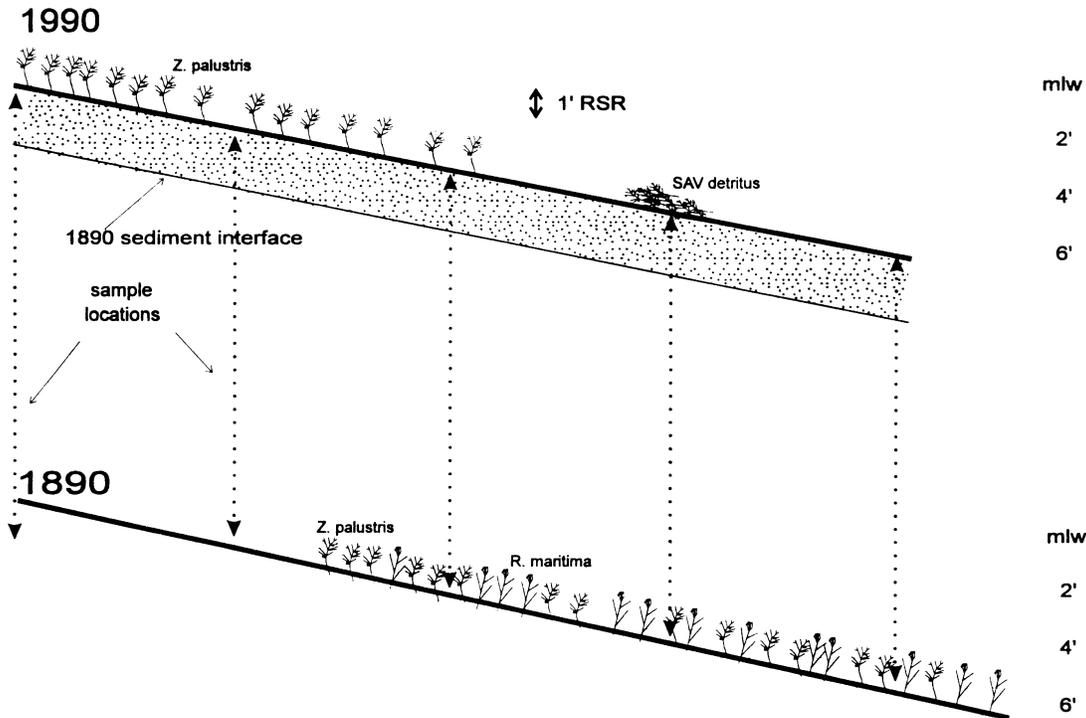
Figure 5. Schematic representation of submersed aquatic vegetation distribution in Maynedier and Saltworks Creeks over ~ 100 year time frame. Abbreviations: RSR = Relative Sea Level Rise, mlr = mean low water. *Zannichellia palustris* is represented by the dichotomously branched plant and *Ruppia maritima* has alternate leaves with a terminal infructescence where the seeds are formed after fertilization. SAV Detritus is from senescing *Zannichellia palustris* during the summer.

dent in cores MC3 and MC4, with distinct peaks of *R. maritima* seed abundance interspersed with no seeds. In Saltworks Creek, peak abundance of *R. maritima* seeds also appeared deeper in the cores as water depth increased. *R. maritima* was absent from core MC5 and occurred only at one place in core MC3.

DISCUSSION

Determining sediment ages is particularly difficult in shallow-water nearshore estuarine sediments. Resuspension from storms, physical mixing, compositional changes and episodic inputs from the surrounding terrestrial ecosystem are all potential difficulties in any dating procedure (HIRSCHBERG and SCHUBEL, 1979). In addition, bioturbation by infauna could a) redistribute SAV seeds and b) affect dating techniques. Despite such difficulties, shallow water habitats are important for study because they are the first zones of estuaries affected by anthropogenic inputs and are more susceptible to long term environmental changes, such as sea-level rise, than deeper waters. The overall trends in seed distribution and ^{210}Po profiles with sediment depth indicate reasonable consistency between cores and between creeks sampled. Hence, interpretations of historical sedimentation and SAV distributions were made despite the potential caveats of the available dating techniques in these shallow water environments.

The ^{210}Po profiles in the present study illustrate the diffi-

culties of radiometric dating in environments where the history of SAV distributions are of interest. Particularly, the idealized exponential decrease in activity is generally not found. The constant rate of supply model is the sedimentation accumulation rate model best suited for handling variable sedimentation rates, though it is difficult to put error bars on the age–depth relationship. The overall sedimentation rates calculated from the present study (0.5–0.7 cm yr^{-1}) were similar to other studies in other mesohaline Chesapeake Bay subestuaries; South River (0.3–1.0 cm yr^{-1}; MARCUS and KEARNEY, 1991), the Potomac River (0.8 ± 0.5 cm yr^{-1}; BRUSH *et al.*, 1982), and the Choptank River (0.2–0.8 cm yr^{-1}; YARBRO *et al.*, 1983). The time-versus-depth curves (Figure 3) were generally linear for the last 30–40 yr, but a break in the slope is evident for older sediments. This suggests that sediment accretion rates are presently higher than they were earlier in the century, though changes in porosity and the breakdown in model stability may account for part of the difference.

Using ^{210}Pb-derived sedimentation rates, abundance patterns of SAV seeds, and present rate measurements of sea-level rise (approximately 2.5 mm yr^{-1}; KEARNEY and STEVENSON, 1991), historic SAV beds were reconstructed relative to sea level and benthic topography at both sites (Figure 5). Since ~ 1890, rates of sedimentation have exceeded sea level rise, resulting in the Severn River becoming more shal-

low. This is particularly evident in the protected coves off the main stem of the Severn where we would expect sedimentation is greatest. The sandy, coarse grained sediments from the historic shoreline have been covered by silt, but still can be found deep in the core samples. This pattern of deposition is characteristic of shores of many tributaries on the western side of Chesapeake Bay (STEVENSON and KEARNEY, 1996)

The trends of seed assemblages indicate that, over time, SAV beds have migrated shoreward in response to environmental factors. Over the past century, peak seed abundance, particularly in Saltworks Creek, occurred in progressively younger sediments as water depth decreased. This shoreward migration probably occurred as a result of increased light attenuation due to suspended particulates in the water column (ORTH and MOORE, 1983). As light became less available in deeper areas, seed germination and plant survival primarily occurs in the shallower areas. *Zannichellia* and *Ruppia* have been found to be fast colonizers (STEVENSON *et al.* 1993) when water quality can support growth. Although DAVIS' (1985) analysis of seed density and settling behavior suggests limited transport of seeds, his study neglected the mode of transport of *Zannichellia*. Although *Zannichellia* seeds sink rapidly when the peduncle is disconnected from the stem of the plant, HURLEY (1990) notes that seeds of this species (unlike Ruppia) are actually transported *with* the plants as they senesce and float on the surface of the estuary in late June and July. Eventually the plants (including seeds) may come to rest many kilometers from their origin (Stevenson *personal communication*).

The data generated from seed bank analysis provides insight into historic SAV distribution and diversity in the Severn River, but the distribution of *Zannichellia* seed can not be interpreted as strictly local in origin. Maynedier Creek has had recent reports (ORTH *et al.*, 1990) of *Zannichellia palustris* (Horned Pondweed), however, only sparse amounts of living *Z. palustris* were found when we sampled the creek in 1991. The comparatively large amount of seed may have been advected from Round Bay or Little Round Bay or other nearby areas of the Severn where *Zannichellia* populations were more evident. The absence of *P. pectinatus* from the seed banks at both locations could have been due to the poor preservation qualities of its seed (DAVIS, 1985) and/or sporadic distributions not encountered by the limited core sampling.

In Chesapeake Bay, it is thought that *Z. palustris* did not become widely established until the late 1950's and early 1960's (STEVENSON and CONFER, 1978). However, in the Severn River, *Z. palustris* was represented in the sediment cores at depths dating back one hundred years. The presence of *Z. palustris* may have been neglected by botanists earlier in the Century because of its short spring growth period and because it may have been confined to shallow waters where sampling was not abundant. The presence of *Z. palustris* and *R. maritima* in the seed banks, both of which are well adapted to surviving in eutrophic systems (STEVENSON and CONFER, 1978), would further suggest that the Severn River has had at least a hundred-year history of poor water quality. However it is impossible to determine whether this was the result of sediment input and resuspension or of nutrient load-

ings which increase plankton and epiphytic fouling on the leaves of SAV (STEVENSON *et al.* 1993).

At the time of the cores were taken in 1991, water quality in the Severn River did not favor the existence of SAV (ARNOLD, 1992). Levels of light attenuation and dissolved inorganic phosphorus concentrations exceeded SAV survival thresholds for mesohaline systems (DENNISON *et al.*, 1993; STEVENSON *et al.*, 1993). Unsuccessful attempts to find healthy SAV populations in either creek supported this assessment. These observations along with the increasing rates of sedimentation inferred from sediment dating, supports the idea that the SAV decline in this system has occurred as a result of light attenuation due to fine-grained sediment loading, sediment resuspension and, to a lesser extent, nutrient-enhanced phytoplankton biomass.

CONCLUSIONS

Based on seed deposition in the sediments, this study suggests that there have been significant changes in populations of SAV in the Severn River over the last one hundred years. Through the use of transects and radiometric dating, it is obvious that as the sea-level has risen and the turbidity of the water column has increased, one species in particular has been able to exploit the near shore environment. The details of how *Zannichellia palustris* has managed to adapt have not been researched in detail, but the proliferation of seed we found in these cores suggests that this is an important mechanism for colonization and survival of this species in Chesapeake Bay. Thus, although the Severn River has definite patterns of change associated with deterioration of water quality in the past, its history of low diversity sets it apart from DAVIS' (1985) description of a high diversity SAV community at Furnace Bay before 1972. The latter location has much greater excursions of water quality and is susceptible to extreme events such as Tropical Storm Agnes in 1972. In contrast the Severn River creeks we studied are more protected, but suffer nevertheless from long term chronic water quality problems associated with sediment inputs from eroding shorelines, as well as fluvial inputs of sediment and nutrients.

ACKNOWLEDGEMENTS

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