Maryland Coastal Zone Management Program

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Final Report-Task 15

THE EFFECTS OF ANTHROPOGENIC ACTIVITIES AND NATURAL EVENTS ON A FRESHWATER TIDAL MARSH

Final Report

submitted to

Maryland Department of Natural Resources

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INTRODUCTION

This study was conducted at the Jug Bay Wetlands Sanctuary in order to investigate the impacts of historical changes in land use and climate (storms) on sedimentation rates and vegetation composition in a tidal freshwater wetland, and on its ability to protect estuarine water quality through time.

Increased research in the 1970s and 80s led to a recognition of wetland values. Tidal freshwater wetlands are now known to be important fish and wildlife habitats (Odum, 1988), help curb shoreline erosion and control potentially damaging runoff from storms or floods (Tiner, 1985). One of the supposed values most often debated by wetland researchers and managers is their role in the maintenance of water quality in rivers and estuaries.

Research of the past twenty years or so suggests that wetlands maintain water quality in adjacent rivers, lakes and estuaries by removing and retaining nutrients, sediment, organic wastes and heavy metals (Grant and Patrick, 1970; Whigham and Simpson, 1976; Klopatek 1978; Sloey et al, 1978; Tilton and Kadlec, 1979; Simpson et al, 1981, 1983b). Retention of nutrients may take place in two ways. One is through plant uptake by which they are stored temporarily or permanently (see below). The other is by deposition of water-borne sediments on the marsh surface. Many sediment particles, especially clay, have nutrients adsorbed on their surfaces so that nutrient retention occurs when these particles are deposited on the marsh (Boto and Patrick, 1979).

Many workers, through measurements on surface sediments of both salt and freshwater marshes, believe that the largest and longest term retention of nutrients such as nitrogen and phosphorus, occurs in peaty and organic substrate where they are either immobilized in peat or their reactive forms are sorbed on organic material (Farnham and Boelter, 1976; DeLaune et al, 1981; Dolan et al, 1981; Howard-Williams, 1985). Nitrogen may also be removed by denitrification. Other studies indicate that nutrients are taken up by marsh plants during the growing season but are exported out into the estuary when dieback of vegetation takes place so that nutrient retention occurs only on a seasonal basis (Simpson et al, 1978; Whigham and Simpson, 1980; Richardson, 1985). Therefore the question of whether tidal freshwater marshes act as net sinks for incoming nutrients on a long term or only on a seasonal basis can be answered by conducting historical studies of nutrient fluxes in these marshes. Previous work is confined to only one or two years of data (Simpson et al, 1983a).

APPROACH

A stratigraphic study was carried out to test the hypothesis that historical changes in regional land use and natural events have impact on sedimentation rates, vegetation dynamics and nutrient uptake capabilities of a tidal freshwater marsh.

Environmental changes, both due to natural (storms, water level) and anthropogenic (cultural eutrophication, land use) causes, and their effects on the vegetation structure, sedimentation rates and nutrient uptake ability of the marsh were investigated. Since anthropogenic influence came largely after European settlement in the region, environmental conditions in the pre- and post-European periods and their effects on ~~the marsh were compared. This was~~ done by using the information contained in the sedimentary record. There are various organic and inorganic substances preserved in the sediment that reflect environmental conditions at the time of their deposition (Birks and Birks, 1980), stretching from the present to thousands of years in the past.

Cores were collected in the high and low marsh and in the estuary upstream and downstream from it. The purpose of estuarine cores was to compare sediment fluxes and nutrient content in portions of the estuary just above and below the marsh during different time periods. Fluxes of these materials were measured in the marsh cores as well.

Flux changes seen in the estuarine cores were time-correlated and compared with those in the marsh cores. Inferences about the influe-nce of the marsh on downstream water quality were based on statisti-cally significant differences in nutrient content observed in the marsh and estuarine cores. For example, lower nutrient levels in the marsh cores during pre-European but higher levels in post-European era would show that the marsh was affected by upstream pollution and trapped some of the nutrients on a permanent basis. If an increase in nutrient content was seen in the upstream core but no significant increase occurred concurrently in the marsh then it was not a long-term sink for the nutrients. Elevated levels, if detected in the downstream core for the same time intervals, were further evide-nce that the marsh did not affect downstream water quality.

Paleoecological indicators used in the study:

Substances found in the sediment that are used in constructing past environments are - pollen, macrofossils such as seeds, rhizomes and roots, peat, parts of insects or other animals, chlorophyll degradation products, nutrients, total organic carbon, heavy metals and PCBs. In this study, total and organic carbon, nitrogen, and phosphorus, and pollen and seeds of aquatic and terrestrial plants were used to investigate environmental changes in the Jug Bay marsh/estuarine system since European settlement in the region.

1) Pollen and Seeds - Pollen grains are easily retrieved and studied. Their resistant outer layer, the exine, enables them to be well-preserved, especially in acidic sediments. They are also produced in enormous quantities. Pollen can tell us much about the vegetational and environmental history of a region. Close correspondence between pollen assemblages and vegetation has been found in all parts of the world (Davis, 1969). A similar conclusion is reached by studies of surface sediment pollen assemblages and modern vegetational regions in eastern North America (Davis and Webb, 1975; Brush and DeFries, 1981). Knowing the plant species and their ecologic requirements enables one to infer past climatic and ecologic conditions. It is also possible to attribute temporal changes in vegetation to changing climatic and anthropogenic influences (Faegri and Iversen, 1989).

Another measure of temporal vegetational change in response to natural and man-induced changes are plant macro-fossils such as seeds. Seeds have been used to determine long-term trends in macrophyte populations (Watts and Winter, 1966; Birks et al, 1976; Brush and Davis, 1984; Davis, 1985). They also give a more local record of vegetation since in many plants, seeds are not dispersed very far from the parent plant (Davis, 1985). Research has shown that seed bank species in tidal freshwater marshes strongly reflect those of the standing vegetation (Leck and Graveline, 1979; Parker and Leck, 1985). My previous work at Jug Bay in 1989 also showed that about 75% of the observed species along a marsh transect are represented in surface sediment (Khan, unpublished Final Report to the DNR, 1989). Therefore seeds of emergent and submerged plants were used to trace the history of water level in different parts of the marsh. This showed us if conditions in these areas have changed from low to high marsh or vice versa due to changing sedimentation rates.

2) Total and organic carbon, nitrogen and phosphorus - Elevated levels of nitrogen and phosphorus in sediments are considered good indicators of nutrient loading in estuaries and lakes; total organic carbon is an indicator of primary productivity and organic content of sediments.

Several workers have found that concentration of P and TOC stays more or less constant in the pre-cultural period but increases significantly in post-cultural periods (Shapiro et al, 1971; Bortleson and Lee, 1972; Jaworski, 1979). Bortleson and Lee (1972) attribute the increased P level to a combination of greater supply of P to the lake and a higher efficiency of P precipitation and retention due to more Fe, Al and Mn oxides and clay minerals in the sediment. These nutrients show higher concentrations in marsh surface sediments too when the watershed has experienced heavy agriculture and urbanization (Kadlec and Tilton, 1978; Simpson et al, 1983b). Dolan et al (1981) found that a Florida freshwater marsh receiving effluent assimilated over 97% of the phosphorus and of this, 69.2% was taken up by the soil. Incoming nitrogen is mainly removed by marsh plants. On the higher marsh a large part of the organic detritus from primary production is retained (DeLaune and Patrick, 1980) and so is the nitrogen immobilized in it. Most of this nitrogen is recycled internally through mineralization and plant uptake. In comparison to this, hydrologic exports and denitrification of sedimentary N are much smaller for most marshes (Bowden, 1987).

DESCRIPTION OF THE RESEARCH SITE

Location and History:

Jug Bay is a tidal freshwater marsh on the Patuxent River estuary, about 70 km upstream from its mouth at the Chesapeake Bay. It covers an area of over 133 ha and is located on the Coastal Plain of Maryland in a heavily populated region, with the metropolitan area of Washington, D.C., 45 km to the west. The surrounding land has been settled for centuries, first by the Indians and then by the Europeans. Evidence of human habitation along the Patuxent goes back 8000 years. However, from the 17th century to mid 19th century, European settlers cleared individual plots for tobacco growing. The area under cultivation during this time was about 1.4-3% of the total land (Froomer, 1978). In early 19th century, agriculture expanded so that by 1840, 40-50% of the land had been cleared (Craven, 1925). In the past few decades, however, agricultural activities in the region have been diminishing, giving way to second-growth forests and urbanization. Thus, in 1930 50% of the land was under cultivation, 10% urban and 40% forested. In 1982, these land uses were 37%, 12% and 51% respectively (Maryland Dept. of State Planning, MAGI data, 1982).

Nutrient input into the estuary has increased over time, first from fertilizers which came into general use in the 19th century (non-point sources) and then from the discharge of wastewater treatment plants (point sources), concentrated around and upstream from Jug Bay. A large plant, the Western Branch Treatment Plant, is located about 3 km upstream from Jug Bay on a tributary of the Patuxent and has been discharging effluent into the river since the early 1970s. However, from mid-80s onward, it has been removing phosphorus from the effluent and in the spring of 1991 it will start removing nitrogen also (Western Branch Treatment Plant staff, pers. comm.).

Soils and Plants:

The soils at this site range from sandy and silty along the main channel to clayey and very peaty in the actual marsh (Soil Survey of Anne Arundel County, MD, 1973). Organic content of soils increases from low to high marsh.

Jug Bay is typical of tidal freshwater marshes along the mid-Atlantic coast of the US. It supports a large variety of plants, both emergent and submergent, and is very productive. The dominant plants are grasses and sedges, which distinguish it from other types of wetlands such as swamps, bogs and fens. Arboreal species like maple, ash, sweetgum, alder, oak, beech and birch are found on the fringes of the high marsh while floating and submerged plants occur in and around the main channel.

METHODS

Collection and dating of cores:

The location of the cores is shown on the map. They were collected with a piston Vibrocorer which can penetrate the marsh sediments easily, resulting in minimum compaction. Preliminary work at Jug Bay in the summer of 1989 showed that, due to high sedimenta- tion rates, pre-European time is not represented in cores less than 70cm long. Therefore all the cores were one meter or more in length. They were extruded from the corer in the laboratory, cut into half lengthwise and examined for sedimentological features. Each half was then cut into one centimeter intervals, sealed in plastic bags and stored at 4 C. Four representative cores from high and low marsh and upstream and downstream from the marsh were selected for fossil and chemical analysis.

These cores were dated by pollen analysis (Brush and Davis, 1984). This method entails the recognition of datable horizons in the core and the assignment of chronologies to each interval. One of these horizons is 1650 A.D. in the Jug Bay area. It is called the agricultural horizon and occurs where the oak to ragweed ratio drops sharply, from >15 or 20 to between 5 and 10. Another horizon is 1840 A.D. where the oak/ragweed ratio drops again to <5 and percentage of ragweed in the pollen sum becomes >10. Recognition of datable horizons in the core enables average sedimentation rates to be calculated by dividing the depth of the dated horizon by the number of years represented from the date the core was taken to the date of that horizon. Total pollen concentration in all the levels above the dated horizon and the average number of pollen grains per interval was computed and sedimentation rates for each interval found by the following equation:

$$R_{0-1} = \frac{n}{n_{0-1}} R$$

where R_{0-1} = sedimentation rate for interval 0-1

n = average no. of pollen grains per interval

n_{0-1} = number of pollen grains in interval 0-1

R = average sedimentation rate (d/t)

d = depth of dated horizon in the core

t = time in years

The years represented by each interval, Δt, were then determined by dividing the depth of the interval (in this case 1 cm) by its sedimentation rate. Below the 1650 horizon, sedimentation rates were calculated by C-14 dating the lowest level of the core.

Pollen and Seeds:

Pollen was extracted from sediments by standard procedures (Faegri and Iversen, 1989). 1.5 ml of wet sediment from each interval were oven-dried, treated with hydrochloric and hydrofluoric acids, an acetolysis mixture of sulfuric acid and acetic anhydride, then washed with glacial acetic acid, distilled water, ethanol and tertiary butanol. The residue was stored in 25 ml of tertiary butanol. Aliquots from each subsample were examined for pollen with a light microscope at 400x. All grains were counted and identified with the help of reference slides and texts.

Seeds were extracted by soaking about 20 g of sediment from each interval in 10% nitric acid. The acid helps break down the organic matter (Birks and Birks, 1980). After washing the sediment with water into a sieve, seeds were examined under a binocular microscope and identified to the species level using reference material and texts. All the seeds were stored in a mixture of distilled water and formalin.

Since sediment deposition is very variable temporally and spatially in an estuarine environment, concentrations were converted to fluxes for a meaningful comparison between different time intervals in and among cores (Brush, 1989). Thus pollen and seed fluxes (no./cm^2/yr) for individual intervals in the cores were obtained by multiplying their concentration (no./ cm^3) by the appropriate sedimentation rates (cm/yr).

Total and organic carbon, nitrogen and phosphorus:

TOC was measured by the method of Krom and Berner (1983). Samples were first dried overnight at 105°C and then finely ground with mortar and pestel. A portion (1-2 g) from the ground sample was ashed for 16 hours at 450°C in a muffle furnace and both the dried and the ashed samples were run for percent total carbon on a Carlo Erba CNS analyzer at the Maryland Geological Survey. The difference between the two measurements gave percent total organic carbon. Total and total organic nitrogen were obtained in a similar way.

Total phosphorus was measured by first digesting the sediment with 70% perchloric acid on a digestion block for 75 minutes (Sommers and Nelson, 1972) and then analyzing the digestant for total P on a spectrophotometer using the Murphy and Riley (1962) method. This method is also recommended for total P analysis by Standard Methods, 1989 edition. Total organic phosphorus was determined by treating ashed and unashed portions of the sediment sample with sulfuric acid and analyzing both for orthophosphate. Organic P is the difference between orthophosphate in the ashed and unashed samples.

RESULTS

Sedimentation rates in this area since European settlement are not only high but also vary considerably over short distances (Appendix 1). Calculations of sedimentation rates for individual intervals show that Jug Bay has experienced variable sediment influx over time. Big storm events increase sediment influx into the marsh and estuary by many fold. This is reflected in the cores where sedimentation rates in this period increase to as high as 1.3 cm/yr (Appendix 1). Sedimentation rates of upto 1.67 cm/yr have been reported in a Delaware freshwater tidal marsh during the increased storm activity of 1954-65 (Orson et al, 1990).

Arboreal pollen, especially oak, hickory, maple, sweetgum and pine is well represented in the cores and reflects the species growing in and around Jug Bay. However, there are some species such as Liriodendron tulipifera (tulip poplar) which, although present in the area, do not leave any pollen record in the sediment. The same is true of marsh plants like Peltandra virginica and Sagittaria latifolia. Also, pollen of SAV, except forPotamogeton, was not detected in the cores. Other marsh plants like Typha, Impatiens, Nuphar and Gramineae are well-represented in the pollen record.

Arboreal pollen, as a percentage of total pollen sum, decreases above the 1650 agricultural horizon and increases below it. This reflects forest clearings by settlers for agriculture. It reaches a minimum in the nineteenth century when between 40 to 50% of the land was cleared and then increases again in the twentieth century. Pollen of Ambrosia and other composites which colonize open, disturbed habitats (Bazzaz, 1974) also increases in the 18th and 19th centuries. The ratio of oak to ragweed pollen, which is a measure of land clearance (Brush and Davis, 1984), reaches a minimum value in mid-nineteenth century, reflecting large tracts of previously forested areas brought under cultivation at that time.

Seeds in all four cores are generally well preserved. The most frequently found seeds are Cyperaceae and Gramineae, followed by Polygonum arifolium, Peltandra virginica, Bidens laevis and Acnida cannabina. There were very few seeds of Pontederia cordata in the cores even though this species grows abundantly in the marsh. This may be because its seeds disintegrate more easily than those of other species. Seeds of Zizania aquatica and Leersia oryzoides were also present in small numbers in all the cores.

In contrast to the pollen record, SAV was well represented in the seed profile. The most abundant were *Zanichellia palustris*, *Potamogeton diversifolius*, *Elodea canadensis* and *Najas guadalupensis*.

Nutrient data for the cores indicate that there has been an increase in sedimentary nitrogen and phosphorus at Jug Bay in post-cultural period. This increase is closely related to the total organic carbon content of the sediment in the marsh cores (r=0.61).

Analysis of Core JUG 1

Sedimentation rates - JUG 1 is a high marsh core and 149 cm long. The 1650 horizon is found at 83 cm and the 1840 horizon at 66 cm. Average sedimentation rate for this core in the post-European era are - from 1840 to the present 0.44 cm/yr and from 1650 to 1840, 0.09 cm/yr. The lowest portion of the core (148-149 cm) has a C-14 date of 1,540 ± 100 yr B.P. However, sedimentation rates for individual intervals vary considerably around these averages. For example, rates as high as 1.30 cm/yr are recorded in this core and appear to be related to storm activity in the area around 1954-55, as determined from historical records. They rise to 0.55-0.61 cm/yr during the mid-1800s when agricultural activity in the area was at its maximum. Another maximum is seen during the mid-1900s when the Patuxent watershed was undergoing urbanization and development. Wolman (1967) found that areas experiencing construction yield several hundred times more sediment than those that are forested or farmed, but after completion of development and construction, sediment yields decline to low values. Decrease in sedimentation rates towards the top of this core may be partly explained by urbanization and partly by the presence of second growth forests.

Pollen - All pollen types identified in this core are shown in Table 1. The most abundant and persistent pollen in this core is of the grasses, mostly Zizania and Phragmites. It occurs down to the lowest level but increases in abundance from about 95 cm upward, comprising >15% of total pollen in succeeding intervals, and >20% in the top 70 cm. This increase suggests two things. First, the marsh had come into existence around 300 years ago and second, ecologically disturbed habitat due to human activities in the area encouraged the establishment of Phragmites (reedgrass) in the marsh, which contributed to the significant increase in grass pollen in the upper 55-60 cm. Other numerically significant (>5% of total pollen) species is Typha, though it is absent from about 90 cm down. It reaches its greatest abundance (>10% of total pollen) in the top 30 cm. Pollen of Impatiens is present sporadically from the top of the core to 85 cm. These are all high marsh species (Odum et al, 1984) which suggests that this site has been high marsh for the past 300 years or so. Smaller numbers, < 3% of total, of Nuphar pollen are also found in the upper 80 cm but increase in the lower part of the core (Fig.5) . Cyperaceae pollen shows a reciprocal relationship with Gramineae, increasing in the lower 30 cm and decreasing upward in the core. Such trends indicate higher water levels at this site in precultural times.

Changes in vegetation and land use taking place in the watershed are also reflected in the pollen profile, with Ambrosia and other composites like Chenopodium increasing and arboreal taxa decreasing sharply with the advent of agriculture in the region. Towards the top, there is a slight relative decrease in Ambrosia and increase in arboreal, especially Quercus, Carya and Pinus, pollen influx, again reflecting declining agricultural activities in the region in recent decades. Oak/ragweed pollen ratio depicts this trend (Fig. 1).

Seeds - All the seed species found in JUG 1 are shown in Table 1. The most abundant seeds were those of Gramineae, Polygonum arifolium and Bidens laevis (over 25 per 100 ml). Arboreal seeds were few and sporadic. The number of all SAV seeds was small, under 10 per 100 ml, except from 115 cm to the bottom of the core, where there is a slight increase in their number (± 10 per 100 ml). Almost no SAV seeds are found in the upper few intervals.

The seed record of JUG 1 indicates that this site has been high marsh for the past three centuries or so and thus supports the pollen record. The increase in SAV seeds in the lower part of the core was found statistically significant ($p<0.05$), using the Mann-Whitney test (Snedecor and Cochran, 1967). This suggests, like the pollen record, that water level was higher here in the pre-cultural period. Thus low marsh, or even open water, may have existed previously at the present high marsh site. Froomer (1980) reports that in many Chesapeake estuaries, post-European sediment depositional rates have created new marshes in previously open water areas. This is the most likely cause of change from low to high marsh at this site. Decrease of SAV seeds in the upper intervals is probably due to the onset of eutrophication and reduction of SAV population in the region.

Nutrients _ Variation of % TOC, N and P with depth in JUG 1 is shown in Fig. 2 and Table 5. Before mid nineteenth century, ie, below 50 cm, all three parameters are more or less constant, with the exception of an increase around 94-96 cm. The reason for this is not known, but there may have been allochthonous input of organic matter and associated N and P due to increased runoff from a storm or flood. There is an increase in their value between 50cm and the surface layer, most probably resulting from increased enrichment of the estuary by farming and urbanization in the watershed. A higher value for TOC in the upper 2-3 centimeters is most likely due to the freshness of organic matter in surface layers. However, P decreases in the top 0-5 cm, reflecting a decrease in the amount of nutrients, especially phosphorus, entering the estuary. One of the reductions comes from the removal of P from the effluent discharged by the nearby wastewater treatment plant since the early 1980s (Western Branch Wastewater Treatment Plant staff, pers. comm.)

Analysis of core JUG 3

Sedimentation rates - This is a low marsh core, 107 cm long, from the north side of the railroad bed. The 1650 A.D. horizon occurs at 88 cm and the 1840 horizon at 70 cm. So the average sedimentation rate from 1840 to the present is 0.47 cm/yr and from 1650 to 1840 it is 0.10 cm/yr. Individual sedimentation rates vary, being lower in the upper intervals of the core and higher in the lower intervals. (Appendix 1).

These values again clearly reflect changing land use in the Jug Bay area, with low rates when the land was forested and high rates when it was cleared for agriculture. A sharp increase in sediment input rate around 8-9 cm (0.61 cm/yr) may have been caused by heavy runoff following three hurricanes in 1954-55 (Ashbaugh and Brancato, 1958).

Pollen - The pollen taxa identified here are similar to those of JUG 1 (see Tables 1 & 2). However, the relative abundances of the taxa are different. Grasses comprise a significant percentage of total pollen, but Nuphar and Nymphea pollen is much more abundant than in JUG 1. Arboreal pollen of Quercus, Pinus, Carya, Alnus, Betula, Acer, Juglans and Liquidambar is also present but except for Quercus, no pattern is seen. Ambrosia, Chenopodium, Dryopteris and Solidago are among the more abundant non-arboreals (5-10% of total pollen). Typha percentage is much lower (~5%) than in JUG 1 and is virtually absent in the lower 30 cm or so. This, and a high percentage (>15 %) of Nuphar and Nymphea pollen throughout the core indicates that low marsh or open, shallow water conditions have existed here in the last 1000 years represented by the core. Minimum oak/ragweed ratio occurs from 60 upto 30 cm (Fig. 3), reflecting the height of agricultural activities in the region. Decline in agricultural land is shown by increasing arboreal pollen and oak/ragweed ratio in the upper part of the core.

Seeds - Seed record in this core also shows a low marsh/open water environment in the past three centuries. Most abundant seeds are Potamogeton, Peltandra virginica and Gramineae (> 30 per 100 ml). A few sporadic seeds of Bidens laevis and Acnida cannabina are also present. SAV seeds are abundant (> 25 per 100 ml) until the upper 5 cm where they become very rare. Arboreal seeds occur infrequently (approx. 1-2 seeds per 10 cm). ~~Very few seeds are preserved~~ below 90 cm, so it is hard to interpret conditions in pre-European times. However, judging by the pollen record of lower marsh/open water habitat at that time, one would expect to find more SAV seeds here. The reason for their absence is not known. A list of all seed species recovered from JUG 3 is given in Table 2.

Nutrients - The nutrient profile for JUG 3 (Fig. 4 and Table 6) shows a decrease in TOC, N and P in the sediment between 30 and 50 cm. This decrease occurs in spite of increasing eutrophication in the area. Apart from this, no other clear pattern is discernible. The levels of TOC and total N in this core are consistently lower than in JUG 1.

Analysis of core JUG 5

Sedimentation rates - This core was taken at the confluence of Western Branch and Patuxent rivers. It is 127 cm long and its 1650 horizon is located at 86 cm and the 1840 horizon at 62 cm. The average sedimentation rate for the period 1840-1990 is 0.41 cm/yr and for the period 1650-1840 it is 0.13 cm/yr. Before 1650 sedimentation rates are assumed even lower. Changing land use patterns are reflected in the individual sedimentation rates. Very high rates are attained in the mid to late 1800s during maximum land clearance for agriculture and in the mid 1900s when heavy urbanisation of the watershed was taking took place. They decline in the last three decades due to less land under agriculture, regrowth of forests and completion of urbanization in the region (Appendix 1).

Pollen - The pollen taxa found in JUG 5 are given in Table 3. All the taxa in this core are similar to those in JUG 1, which is a high marsh core (see Table 1). However, relative abundances of various pollen species are more like those of JUG 3 than of JUG 1. In JUG 5, very little Typha pollen is found (< 5% of total pollen); many intervals do not have any Typha pollen at all. On the other hand, pollen of Nuphar in this core is much more numerous than in JUG 1. It increases steadily from the bottom of the core to about 70 cm and then remains a significant part of total pollen (13-16%) to the top of the core. Fig. 5 shows the difference between JUG 1 and JUG 5.

More Cyperaceae pollen is found in this core than in JUG 1. Gramineae are also represented here but they do not comprise more than 10% of the total pollen in any interval, in contrast to the marsh core. There is no significant difference in the abundance of arboreal pollen between JUG 5 and JUG 1 (p=0.17), although Quercus and Pinus pollen increases significantly around 95-100 cm. Ambrosia and Chenopodium pollen increases in the 19th century and decreases slightly in recent decades.

The oak/ragweed ratio of JUG 5, like that of the marsh cores, shows land use changes taking place in the region since European settlement, from limited land clearance in the 17th century to maximum in the 19th and a decline in cultivated acreage from the mid 20th century onward (Fig.6).

Greater abundance of deeper water species like Cyperaceae and Nuphar throughout this core suggests that this site has been shallow open water since the precultural era. A C-14 date on the lowest interval of this core is not available, but it is reasonable to assume, judging from the C-14 date on JUG 1, that JUG 5 represents at least 1000 years of environmental record. The small number of grass pollen found in this core most likely was blown in from the nearby marsh, as was the pollen of high marsh taxa like Impatiens, Typha, Rosa and Dryopteris. Increase in Quercus and Pinus pollen around 900 B.P. suggests a drier period in this area and may be associated with the Medieval Warming Period of 1000-1400 A.D. (Ingram et al, 1981).

Seeds - Taxa represented by seeds in this core are the same as those in JUG 1 and JUG 3. However, there are more streambank emergents and SAV seeds in JUG 5 than in JUG 1. The most abundant seeds (>20 per 100 ml) through most of the core are those of Potamogeton, Cyperaceae spp., Elodea canadensis, Zanichellia palustris and Najas guadalupensis. In the 19th century, species that grow in moderately eutrophic waters such as Zanichellia palustris and Potamogeton diversifolius (Hellquist, 1975), appear in the record. But in the top layers even these species disappear. This reflects increased eutrophication of waters around Jug Bay with the introduction of sewage treatment facilities in the area in the late 1960s to early 1970s. Further reduction in the SAV population occurred after the tropical storm Agnes passed through in 1972. There are very few seeds in the top 3-4 cm, and none of Najas and Elodea.

Nutrients - The P profile presents a good record of environmental conditions in this part of the estuary through time. Fig. 7 and Table 7 show a rise in P around late 19th century (50-40 cm) and then again in the 1960s and 70s (10-5 cm). The first increase is the result of fertilizer runoff from the watershed, where they were in common useage at this time. The second rise reflects enrichment of the tributary from wastewater effluent and from domestic and industrial sources further up the estuary. The slight decrease in nutrients, notably phosphorus, in the upper few cm of the core resulted from controls on the use of P, in the early 1980s, in domestic products like detergents and also its removal from treated effluent of the Western Branch treatment plant since the mid-80s. TOC variation corresponds closely with that of P and is most likely due to increased algal productivity in the estuary. Nitrogen values are small and do not show a clear trend.

Analysis of Core JUG 7

Sedimentation rates - This core, taken downstream from Jug Bay in the estuary, is 190 cm long. The 1650 horizon is located at 92 cm and the 1840 horizon at 73 cm. Average sedimentation rate from 1840 to the present is 0.49 cm/yr and from 1650 to 1840 this rate is 0.11 cm/yr. As in the other cores, individual sedimentation rates are variable, and are affected by changing land use and storms.

Pollen - The pollen taxa of JUG 7 (Table 4) are similar to those of JUG 5 in that among the non-arboreal taxa, the most common are Cyperaceae, Nuphar and Nymphaceae, with fewer but persistent grains of Gramineae, Dryopteris and Polypodiaceae. High marsh species like Typha, Impatiens, Rosa and Bidens are found sporadically and in small numbers (< 5% of total pollen). Representation of arboreal pollen is similar to other cores, with oak, pine and hickory constituting the largest portion. There is a considerable increase (from ~10% to >25% of total pollen) in oak and pine pollen at 115 cm which persists upto 120 cm.

The pollen record shows that the site has been under shalllow water continually for the length of time represented by the core. This time will be known as soon as a C-14 date on the lowest part of the core is available. There is no evidence, such as abundant pollen of higher ground species, that this site was ever a supratidal zone. It is hard to say however, from the pollen record, whether the water was deeper at any time in the past than it is now. The increase in oak and pine pollen at 115-120 cm, about 1000 years ago, points to drier conditions in the region at that time. This is similar to the trend seen in JUG 5.

Seeds - Seeds (Table 4) of Najas guadalupensis, Potamogeton diversifolius and Elodea canadensis are abundant in JUG 7 in intervals covering the time before European settlement and up until early 20th century. Zanichellia palustris appears in late 19th century and persists in considerable numbers until the 1970s. Towards the top 5 cm, very few seeds of any SAV species are present. A moderate number (10-20 per 100 ml) of grass seeds are also present which were presumably carried and deposited here by tidal waters. The few seeds of Acnida cannabina, Alnus serrulata, Polygonum punctatum, Pontederia cordata and Zizania aquatica found in some intervals also seem to be deposited here by tidal currents.

The seed record of JUG 7 indicates, like that of JUG 5, that there has been a sharp reduction in SAV population at Jug Bay in recent decades. The abundance of SAV seeds deeper down in the core supports evidence from the pollen profile that this site has been submerged for the entire time period represented by the core.

Nutrients - N and P in this core show an interesting pattern (Fig.9 and Table 8). Their % values are low before mid 19th century. Thereafter they begin to rise steadily between 50 and 30 cm and then decrease between 20 to 5 cm. In the top 4 cm their fluxes slightly increase again. This increase is significant ($p<0.05$). TOC variation corresponds closely with those of total N and P although its value is much lower compared to JUG 1 and JUG 3. The nutrient record more or less reflects the history of eutrophication in the region, except for the 5-20 cm interval. This trend appears to be related to marsh influence and will be discussed next.

DISCUSSION AND CONCLUSIONS

All the cores show a well-preserved pollen and seed record, except in the lower 15 cm of JUG 3 where almost no seeds are found. Sedimentation rates and pollen and seed assemblages in these cores reflect changing environmental conditions in the Jug Bay region, particularly land use and varying water levels and storms. However, effects of all the historically recorded storms and hurricanes on sediment influx in Jug Bay were not found in the sedimentary record. The clearest effect of storm activity on sediment influxes is seen for the heavy storms of 1954-55 in JUG 1 and JUG 3.

Such heavy influxes of sediment in a short period of time are accompanied by a decrease in the organic matter content of the marsh substrate, like the one at 10 cm (Fig. 2 and Table 5). This is due to the dilution of organic content of marsh substrate by large amounts of mineral sediment brought in with storm runoff and deposited on the marsh surface. Such an effect is not seen in the estuarine cores where the organic content of sediments is already low compared to those of the marsh.

High sedimentation rates in the post-cultural period have given rise to infilling of marshes and open water areas. The tendency of marshes to progress from low to high elevations over time is well documented (Redfield, 1972). This trend is visible at Jug Bay also. Here, previously low marsh or open, shallow water areas have turned into high marsh. It is quite likely, judging from the stratigraphic record, that the present low marsh will be raised and become a high marsh environment in the next couple of hundred years. The high marsh may eventually turn into forested floodplain. The time for this transformation will be shortened if sedimentation rates rise again in the future; if not, this time will be lengthened, provided factors such as sea level or precipitation do not vary much.

Other environmental changes induced by man, namely eutrophication of the Patuxent estuary, can be seen more clearly in the high marsh (JUG 1) and the estuarine cores (JUG 5 and JUG 7) than in the low marsh core (JUG 3). Moreover, TOC and P show a clearer trend in the estuarine cores than does N. This may be because, in estuaries, some nitrogen is inevitably lost via denitrification (Smith and DeLaune, 1983). However, eutrophication of incoming waters in the last 60-70 years have resulted in elevated levels of nitrogen in the high marsh core. In the marsh, a large proportion of incoming inorganic nitrogen is incorporated in the organic matter and gets recycled internally. Phosphorus fluxes show a corresponding increase. TOC also rises, most likely due to increased primary productivity in the marsh, stimulated by incoming nutrients. This means that the marsh has been affected by upstream pollution, experiencing an increase in biomass and acting as a long term sink for at least a portion of the incoming N and P.

The low marsh core does not show any clear pattern (Fig.4). TOC, N and P are consistently low and do not increase in reponse to cultural eutrophication in the region. In the low marsh, decomposition rates and flushing of litter are greater than in high marsh (Odum, 1988) so that very little becomes incorporated into the sediment, resulting in low organic and peat content. Research, on the other hand, has shown that greater amount of nutrients, especially P, are retained by organic and peaty sediments than by largely inorganic sediments (Zoltek et al, 1979; Dolan et al, 1981). This may explain why no change in nutrients was observed in JUG 3 when the estuary became eutrophic. Another possibility is that this part of the marsh may be a sink for nutrients only on a seasonal basis, with uptake by plants occurring in the growing season and export during dieback of vegetation in winter. But this cannot be confirmed by the sedimentary record.

JUG 5 has preserved the best record of anthropogenic eutrophication. The strongest correspondence with historical record of eutrophication is shown by TOC and P. No trend is observed for nitrogen. Comparing its profile with that of JUG 1, it can be seen that both cores register a rise in P at about the same time. Thus nutrient pollution in the region affected both the marsh and the estuary upstream from it.

It is also interesting to compare nutrient profiles of JUG 1 and JUG 7. There is a rise in TOC, P and N in JUG 7 around late 1800s (40 cm), when a similar rise occurs in JUG 1 and JUG 5. This increase continues for a few years (40 to 30 cm) and then begins to decline (20-5 cm). Such trends indicate that the marsh did not protect downstream water quality throughout its history. However, its nutrient retaining capacity increased with time so that finally the downstream water quality seems to improve. This may be a result of increasing biomass from elevated levels of nutrients in the marsh leading to sediment richer in organic and peaty material (Fig.2) and of greater quantities of Fe, Al and Mn oxides in the sediment as a result of upland erosion and increased sedimentation. These three substances bind P very well (Patrick and Khalid, 1974; Richardson, 1985). Hence it seems that higher nutrient and sediment influx into the marsh initially enhances its ability to protect estuarine water quality.

Towards the top of JUG 7, nutrient values show an increase, in spite of the fact that efforts have been made in recent years to control nutrient input into the estuary. A possible explanation for this is that the marsh is no longer acting as a long term sink for nutrients so that all of the upstream nutrient discharge (albeit smaller than before) is going downstream past the marsh. This may be because the marsh is no longer nutrient limited, its organic production has levelled off or perhaps even the chemical nature of the soil has changed, ie, the P binding substances in the soil have diminished through leaching or other chemical processes. All these factors may have exhausted the marsh's capacity to assimilate additional nutrients on a permanent basis. The marsh vegetation may also be trapping less nutrients than before since nutrient limitation in the marsh does not exist anymore. Therefore, at present there appears to be no significant difference in water quality upstream and downstream from the marsh.

The effect of vegetation on nutrient trapping ability of the marsh seems to exist only insofar as higher marsh plants produce a peatier sediment than do low marsh plants. It is not possible to conclude, from the sedimentary record, if individual plant species differ in their nutrient entrapment abilities, which may well be the case.

The results of this study indicate that the stratigraphic record can be used to study the effects of changing environmental conditions on the marsh through a longer period of time than is otherwise possible. Such information is useful in evaluating the response of the ecosystem to environmental changes occurring at present and predicting its reponse to changes in the future.

Addenda to the " Final Report' - The Effects of Anthropogenic Activities and Natural Events on a Freshwater Tidal Marsh".

The seed record of core JUG1, taken from the high marsh, shows an increase in SAV below 115 cm. There are very few SAV seeds above this interval. This suggests a higher water level at this site prior to European settlement. The submerged aquatics represented by seeds in this core include Elodea canadensis, Najas guadalupensis, Potamogeton diversifolius and Zanichellia palustris. These plants typically grow along the channel edges where, at Jug Bay, water depth at low tide is 40-50 cm. They are also found further into the channel at water depths of upto 2 meters, if the turbidity is not too high (Odum et al, 1984). In contrast, high marsh species such as Bidens laevis, Gramineae and Polygonum arifolium, which are more abundant from 115 cm to the top of the core, do not survive in continously flooded conditions (Simpson et al, 1983a). They grow best where maximum water depth is 20-30 cm, but frequently falls close to zero, such as during low tide. Thus the presence of greater number of SAV at this site below 115 cm, as shown by the seed record, indicates that water here would have been at least 20 cm deeper than today with almost permanent inundation, representing stream edge conditions. However, since SAV can grow in water depths of upto 2 meters, water level at this site may well have been 50-100 cm higher around 300 years ago, but this cannot be verified from the seed record. It can be concluded, however, that within three centuries this site has evolved from a continously submerged habitat, with water levels at least 20-30 cm higher than today, to a high marsh environment where alternate flooding and draining of the surface takes place.

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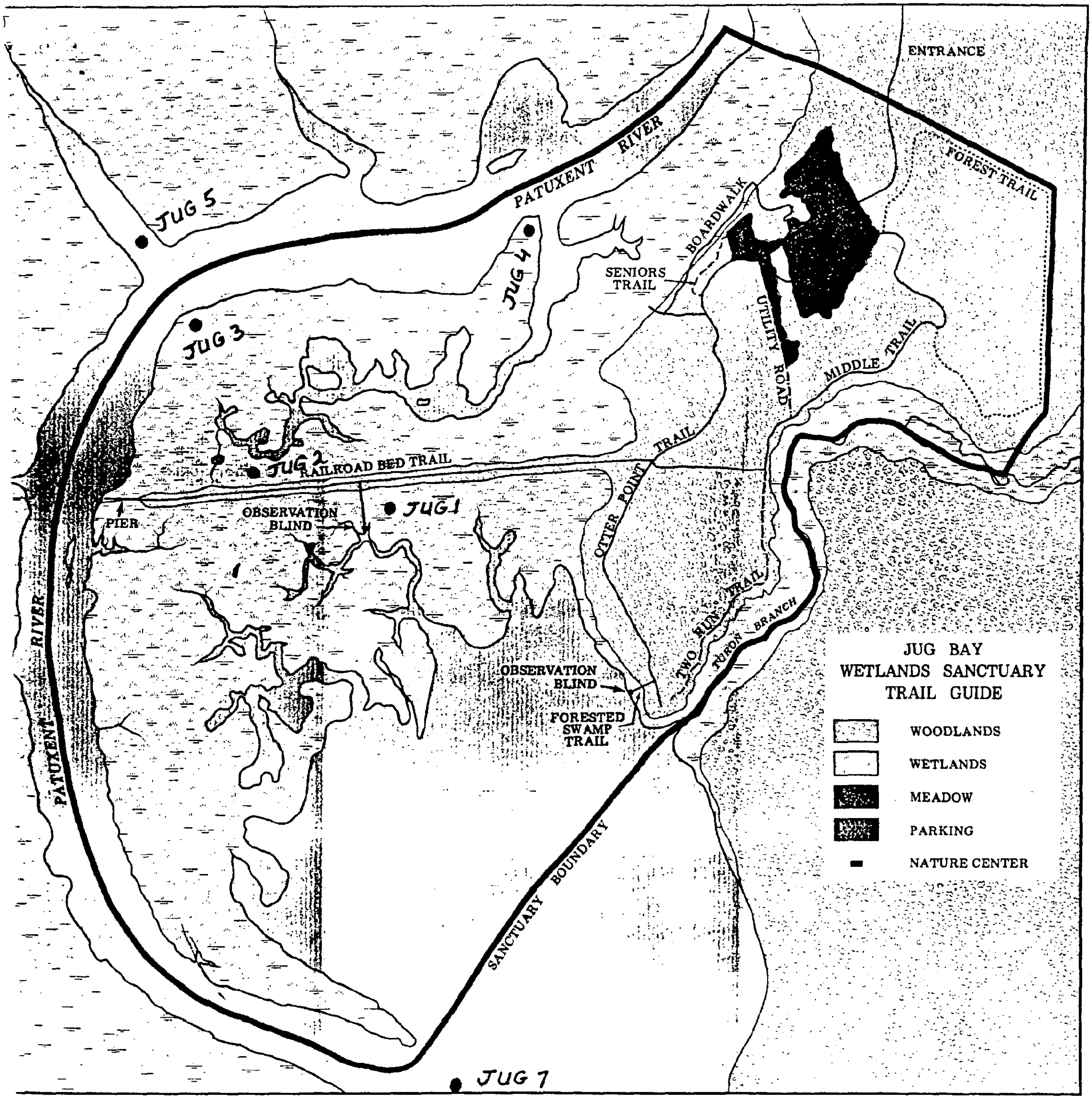


MAP SCALE IS 1"=780'

MAP OF JUG BAY SHOWING LOCATION OF CORES

Table 1. Pollen & Seed Taxa identified in JUG 1.

Pollen	Seeds
Arboreal:	Arboreal & nonarboreal emergents:
Acer (maple), Alnus (alder) Betula (birch), Carya (hickory) Castenea (chestnut), Cornus (dogwood), Corylus (hazel) Fraxinus (ash), Ilex (holly) Juglans (walnut) Liquidambar (sweet gum) Nyssa (black gum) Pinus (pine), Prunus (cherry) Quercus (oak), Salix (willow) Tilia (linden)	Acnida cannabina (water hemp) Alnus (alder) Bidens laevis (burmarigold) Betula nigra (river birch) Carex spp. (sedges) Carya (hickory) Gramineae (grasses) Polygonum arifolium (tearthumb) Polygonum punctatum (water smartweed) Pontederia cordata (pickerelweed) Rubus (bramble) Sagittaria latifolia (arrowhead) Zizania aquatica (wild rice)
Non-arboreal:	SAV:
Ambrosia (ragweed) Artemisia (mugwort) Bidens (burmarigold) Chenopodium (pigweed) Cyperaceae spp. (sedges) Dryopteris (wood fern) Gramineae spp. (grasses) Impatiens (jewelweed) Lycopodium (club moss) Nuphar (spatterdock) Nymphea (water lily) Osmunda (fern) Plantago (plantain) Polypodium (polypody) Rosa (marsh rose) Solidago (goldenrod) Typha (cattail) Umbelliferae (parsley family) Viburnum (arrowwood)	Elodea canadensis (common elodea) Najas guadalupensis (naiad) Potamogeton diversifolius (pondweed) Zanichellia palustris (horned pondweed)

Table 2. Pollen and Seed taxa identified in JUG 3.

Pollen	Seeds
Arboreal:	Arboreal & Non-arboreal emergents:
Acer (maple), Alnus (alder)	Acnida cannabina (water hemp)
Betula (birch),	Alnus (alder)
Carya (hickory)	Bidens laevis (burmarigold)
Castanea (chestnut)	Carex spp. (sedges)
Cornus (dogwood)	Gramineae (grasses)
Fraxinus (ash),	Polygonum arifolium (tearthumb)
Ilex (holly)	Polygonum punctatum
Juglans (walnut)	Pontederia cordata (pickerelweed)
Liquidambar (sweet gum)	Sagittaria latifolia (arrowhead)
Nyssa (black gum)	Zizania aquatica (wild rice)
Pinus (pine)	
Platanus (sycamore)	
Prunus (cherry)	
Quercus (oak)	
Salix (willow)	
Non-arboreal:	SAV:
Ambrosia (ragweed)	Elodea canadensis (common elodea)
Artemisia (mugwort)	Najas guadalupensis (naiad)
Bidens (burmarigold)	Potamogeton diversifolius (pondweed)
Chenopodium (pigweed)	Zanichellia palustris (horned pondweed)
Cyperaceae (sedges)	
Dryopteris (wood fern)	
Gramineae (grasses)	
Impatiens (jewelweed)	
Lycopodium (club moss)	
Nuphar (spatterdock)	
Nymphea (water lily)	
Plantago (plantain)	
Pteridium (bracken fern)	
Rosa (marsh rose)	
Solidago (goldenrod)	
Stellaria (chickweed)	
Typha (cattail)	
Umbelliferae (parsley family)	
Viburnum (arrowwood)	

Table 3. Pollen and Seed taxa identified in JUG 5.

Pollen	Seeds
Arboreal:	Arboreal & nonarboreal emergents:
Acer (maple)	Acnida cannabina (waterhemp)
Alnus (alder)	Alnus (alder)
Carya (hickory)	Bidens laevis (burmarigold)
Castanea (chestnut)	Carex spp. (sedges)
Fraxinus (ash)	Cyperaceae (sedges)
Juglans (walnut)	Gramineae (grasses)
Liquidambar (sweet gum)	Polygonum punctatum (smartweed)
Nyssa (black gum)	Pontederia cordata (pickerelweed)
Pinus (pine)	Zizania aquatica (wild rice)
Platanus (sycamore)	
Quercus (oak)	
Salix (willow)	
Tilia (linden)	
Non-arboreal:	SAV:
Ambrosia (ragweed)	Elodea canadensis (common elodea)
Artemisia (mugwort)	Najas guadalupensis (naiad)
Bidens (burmarigold)	Potamogeton diversifolius (pondweed)
Chenopodium (pigweed)	Zanichellia palustris (horned pondweed)
Cyperaceae (sedges)	
Dryopteris (wood fern)	
Gramineae (grasses)	
Lycopodium (club moss)	
Nuphar (spatterdock)	
Nymphea (water lily)	
Plantago (plantain)	
Rosa (marsh rose)	
Solidago (goldenrod)	
Stellaria (chickweed)	
Typha (cattail)	
Umbelliferae (parsley family)	

Table 4. Pollen and Seed taxa identified in JUG 7.

Pollen	Seeds
Arboreal:	Arboreal & nonarboreal emergents:
Acer (maple)	Acnida cannabina (waterhemp)
Alnus (alder)	Alnus (alder)
Betula (birch)	Bidens laevis (burmarigold)
Carya (hickory)	Carex spp. (sedges)
Castanea (chestnut)	Cyperaceae (sedges)
Cornus (dogwood)	Gramineae (grasses)
Fraxinus (ash)	Polygonum punctatum (smartweed)
Juglans (walnut)	Pontederia cordata (pickerelweed)
Liquidambar (sweetgum)	Zizania aquatica (wild rice)
Nyssa (blackgum)	
Pinus (pine)	
Platanus (sycamore)	
Prunus (cherry)	
Quercus (oak)	
Salix (willow)	
Tilia (linden)	
Non-arboreal:	SAV:
Ambrosia (ragweed)	Elodea canadensis (common elodea)
Artemisia (mugwort)	Najas guadalupensis (naiad)
Bidens (burmarigold)	Potamogeton diversifolius (pondweed)
Cephalanthus (buttonbush)	Zanichellia palustris (horned pondweed)
Chenopodium (pigweed)	
Cyperaceae (sedges)	
Dryopteris (wood fern)	
Gramineae (grasses)	
Lycopodium (club moss)	
Nuphar (spatterdock)	
Nymphea (water lily)	
Plantago (plantain)	
Pteridium (bracken fern)	
Rosa (marsh rose)	
Solidago (goldenrod)	
Typha (cattail)	
Umbelliferae (parsley family)	

Table 5. Nutrient data for JUG 1.

Depth (cm)	TOC (%)	Total N (%)	Total P (%)
0	17.33	0.80	0.16
5	16.21	0.81	0.29
10	14.79	0.68	0.15
20	15.56	0.77	0.19
30	13.71	0.74	0.20
40	11.83	0.64	0.17
50	9.88	0.61	0.072
60	6.51	0.56	0.077
70	8.87	0.53	0.069
80	7.09	0.49	0.071
90	11.47	0.78	0.123
100	8.53	0.44	0.049

Table 6. Nutrient data for JUG 3

Depth (cm)	TOC (%)	Total N (%)	Total P (%)
0	9.89	0.51	0.16
5	10.71	0.55	0.14
10	8.42	0.49	0.18
20	8.79	0.55	0.19
30	7.62	0.32	0.11
40	7.88	0.41	0.10
50	8.12	0.43	0.09
60	10.08	0.48	0.13
70	11.21	0.51	0.15
80	8.99	0.50	0.09
90	10.45	0.46	0.11
100	9.67	0.43	0.07

Note: % C, N and P are calculated as grams C, N and P per gram dry weight sediment respectively.

Table 7. Nutrient data for JUG 5.

Depth (cm)	TOC (%)	Total N (%)	Total P (%)
0	2.93	0.25	0.059
5	3.33	0.27	0.063
10	4.48	0.22	0.071
20	3.09	0.16	0.051
30	4.17	0.18	0.061
40	4.26	0.25	0.082
50	2.81	0.20	0.054
60	3.56	0.33	0.048
70	2.16	0.22	0.017
80	2.25	0.23	0.004
90	2.34	0.18	0.001
100	2.09	0.24	0.006

Table 8. Nutrient data for JUG 7.

Depth (cm)	TOC (%)	Total N (%)	Total P (%)
0	4.01	0.31	0.041
5	2.23	0.30	0.020
10	3.01	0.28	0.025
20	2.37	0.18	0.019
30	4.11	0.29	0.060
40	4.33	0.27	0.052
50	3.06	0.24	0.028
60	2.87	0.21	0.021
70	2.45	0.13	0.005
80	1.98	0.17	0.002
90	2.05	0.18	0.003
100	2.18	0.11	0.003

Note: % C, N and P are calculated as grams C, N and P per gram dry weight sediment respectively.

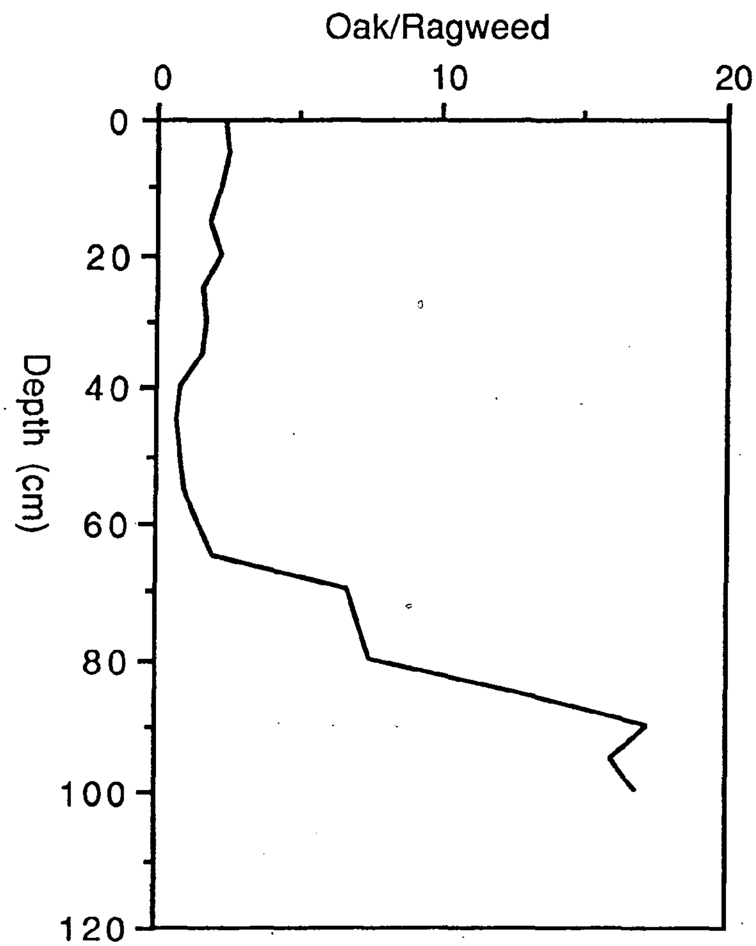
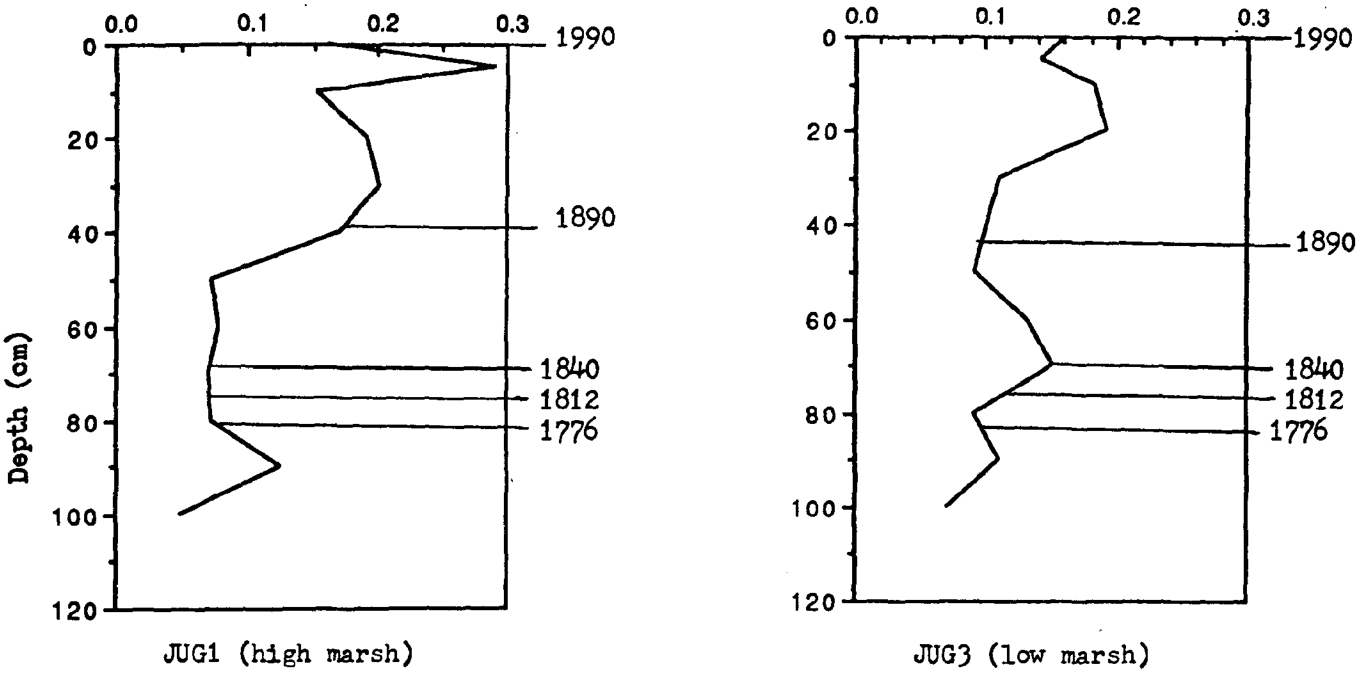


Fig.1. Oak/Ragweed Pollen Ratio for JUG 1



1890 = construction of railroad bed across the marsh
1840 = 40-50% land cleared for agriculture
1812 = The War of 1812
1776 = The Revolutionary War

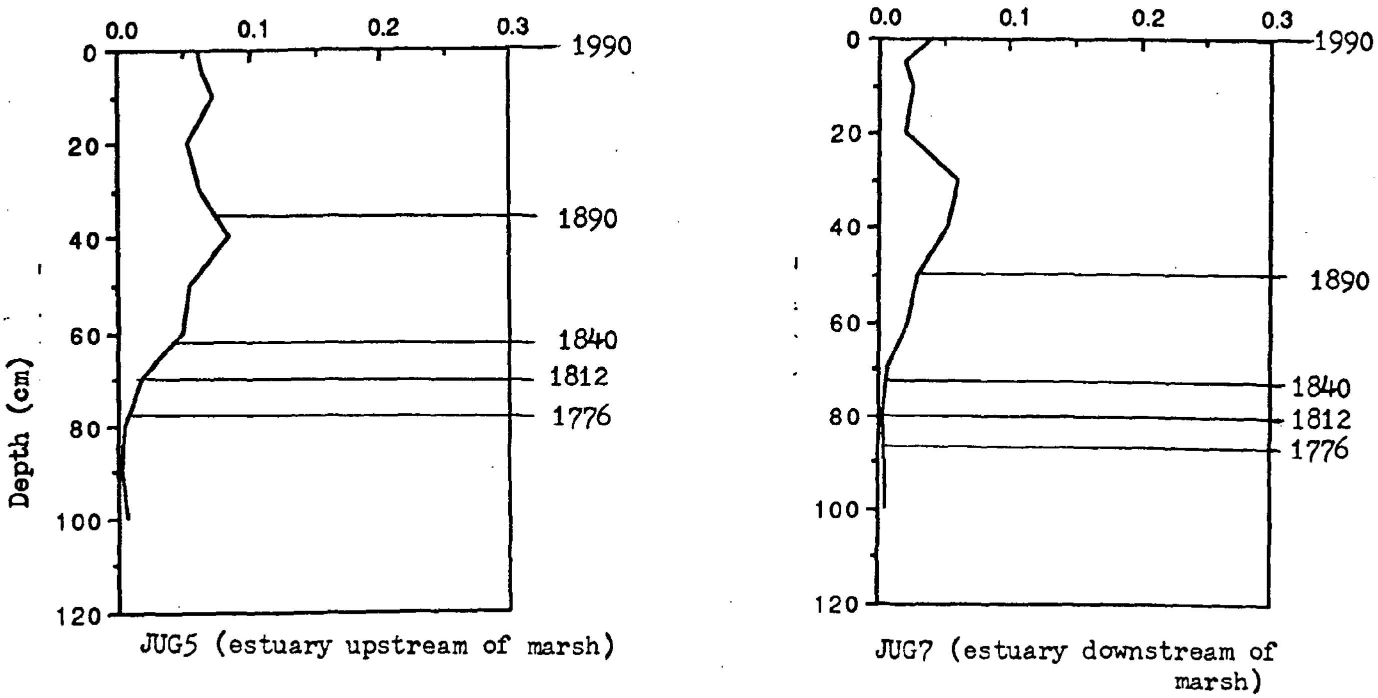


Fig.1. % Total P for cores analyzed with timelines showing historic dates

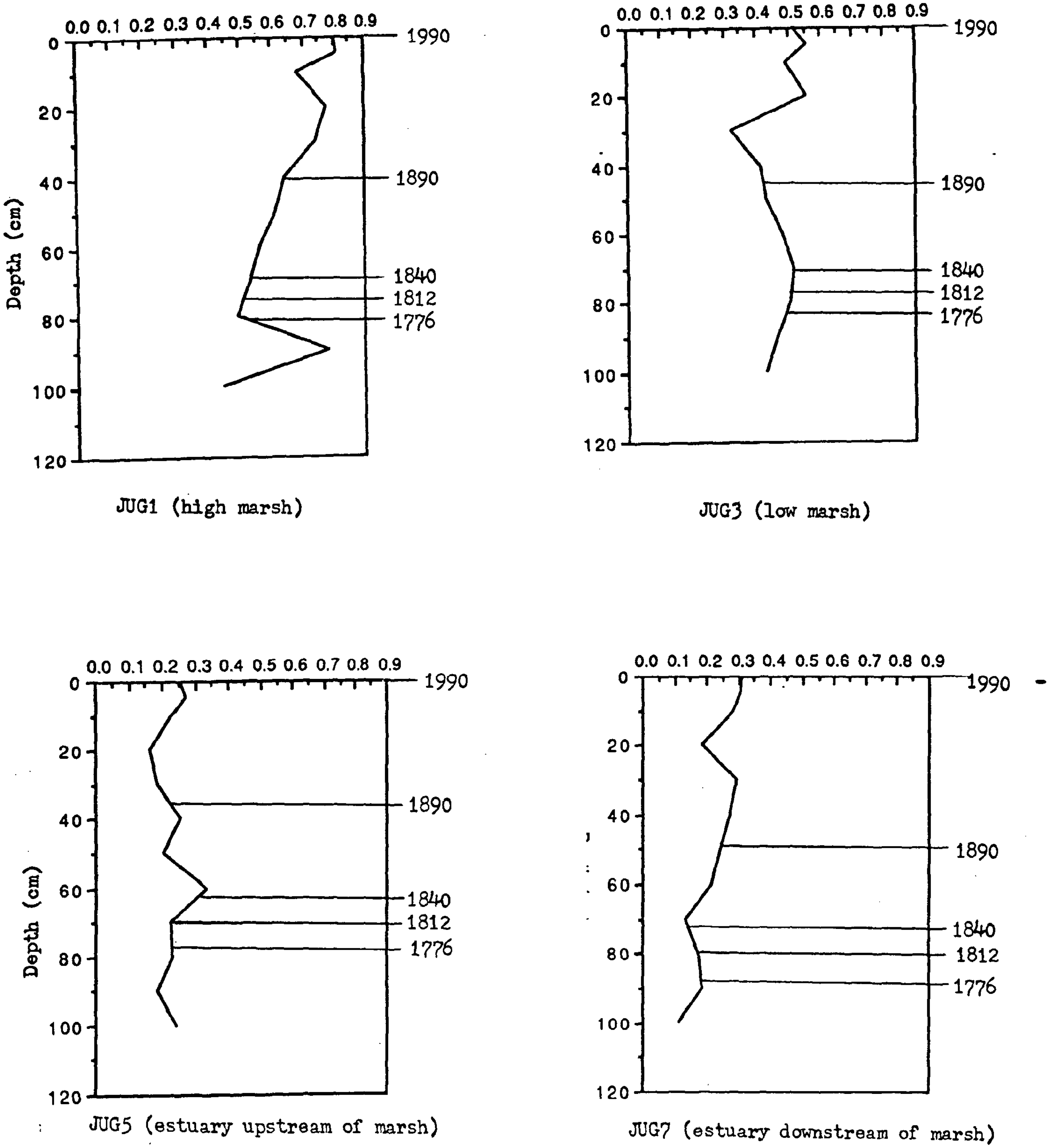


Fig.2. % Total N for cores analyzed with timelines showing historic dates

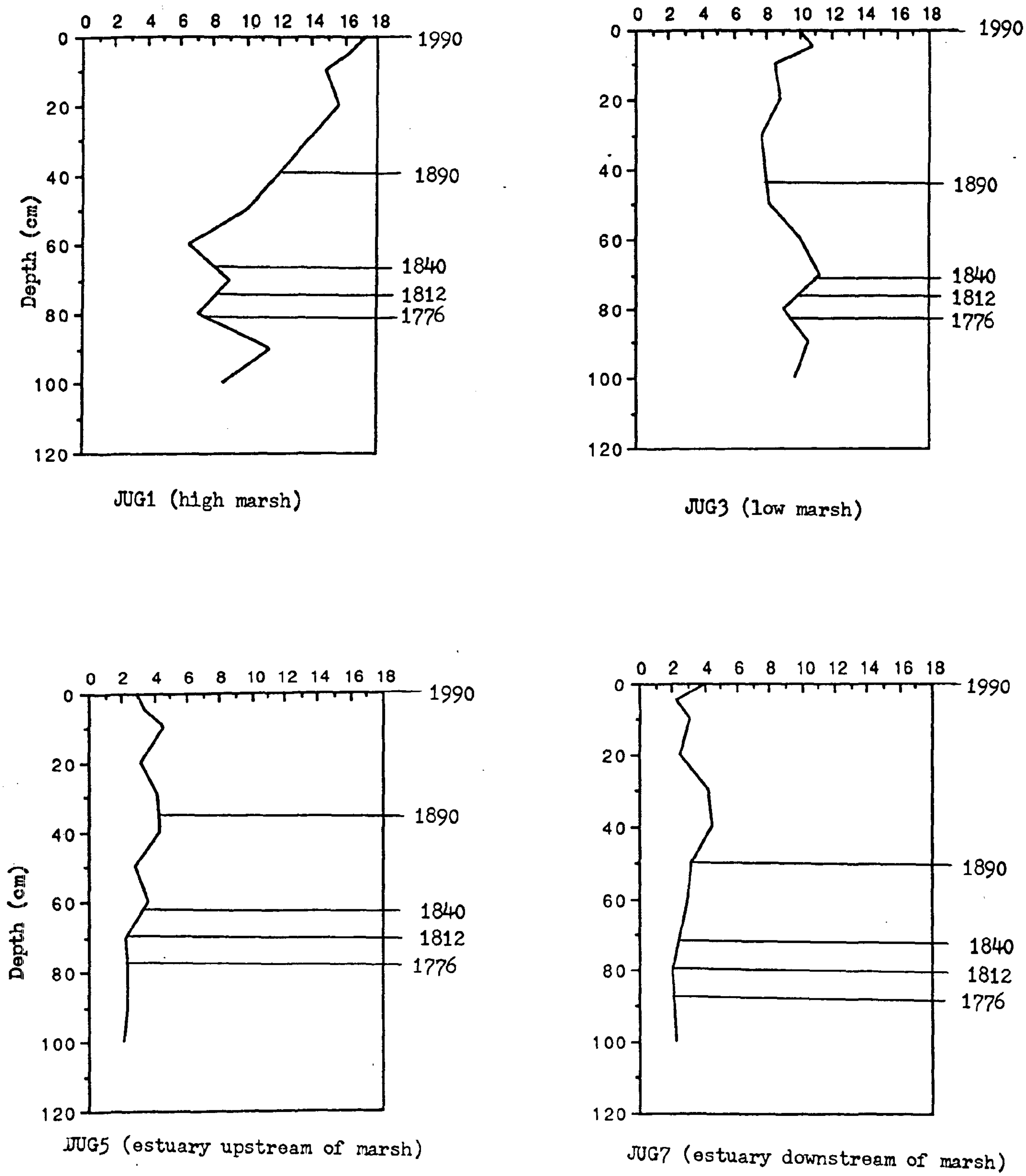


Fig.3. % TOC for cores analyzed with timelines showing historic dates

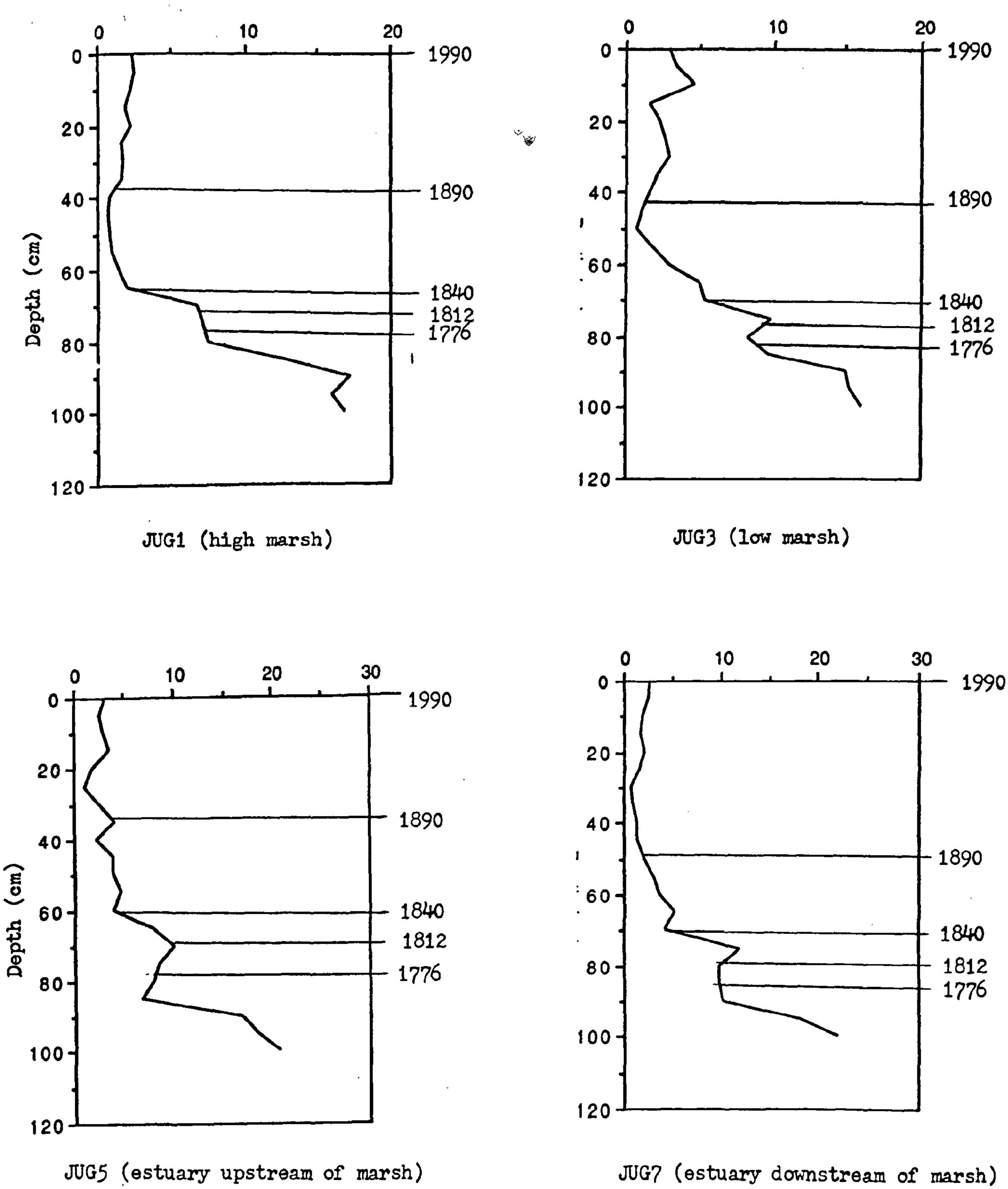


Fig.4. Oak/Ragweed Pollen Ratio for cores analyzed with timelines showing historic dates

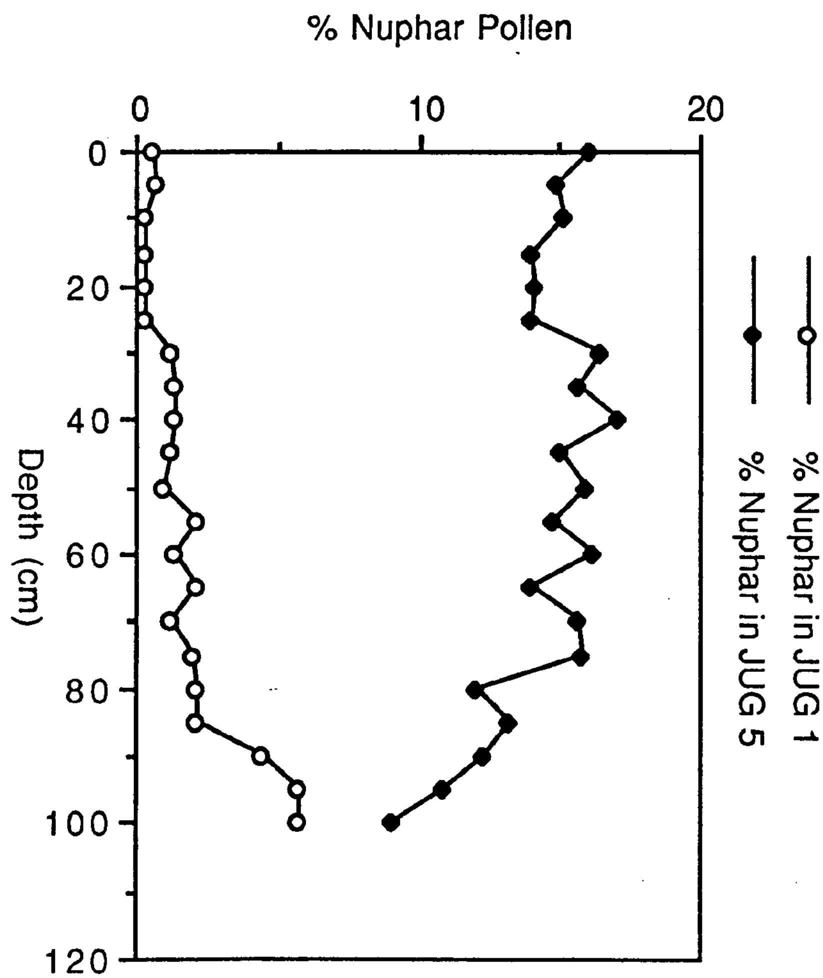


Fig.5. % Nuphar Pollen in JUG 1 and JUG 5

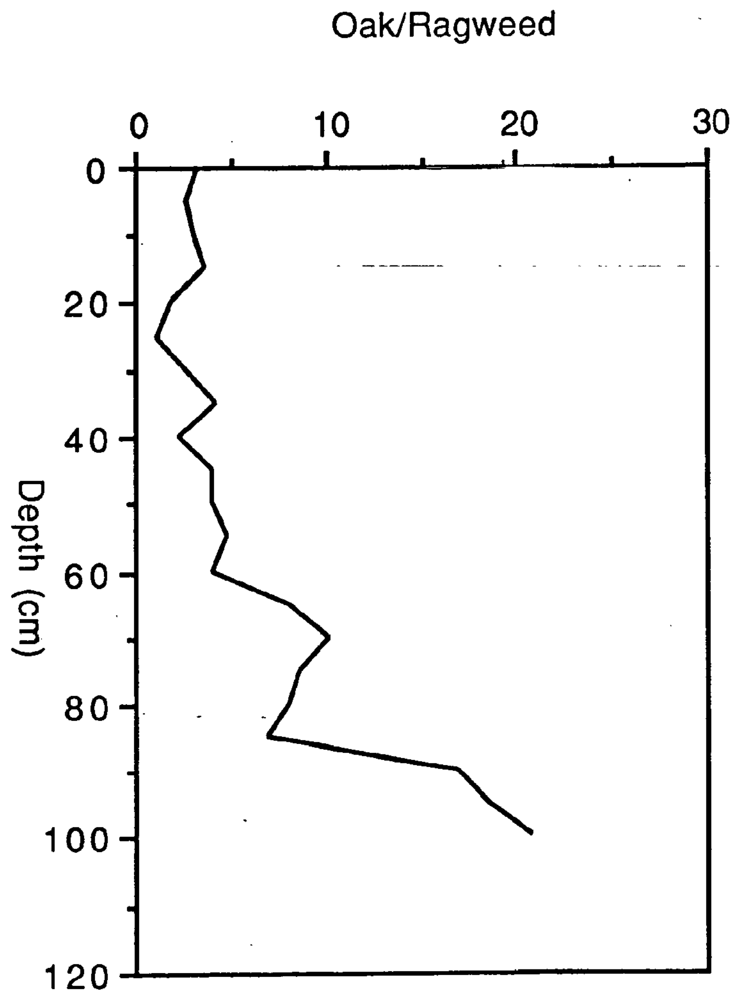


Fig.6. Oak/Ragweed Pollen Ratio for JUG 5

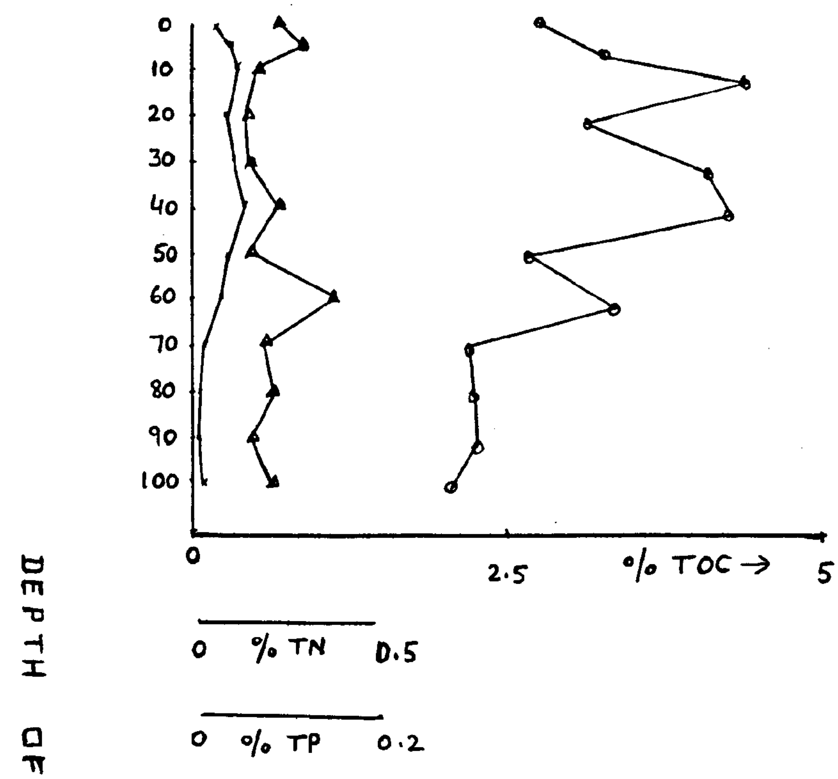


Fig. 7. Nutrient Profile for JUG 5.

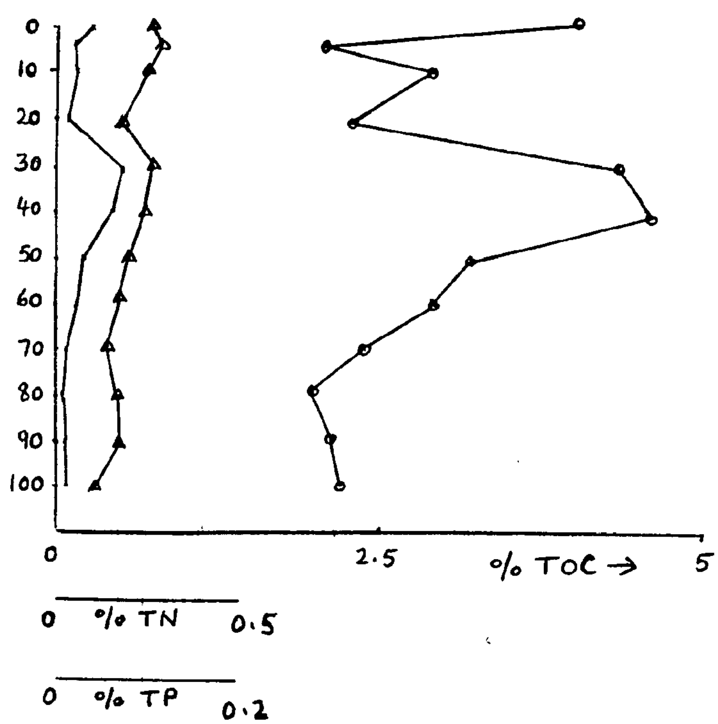


Fig. 9. Nutrient Profile for JUG 7.

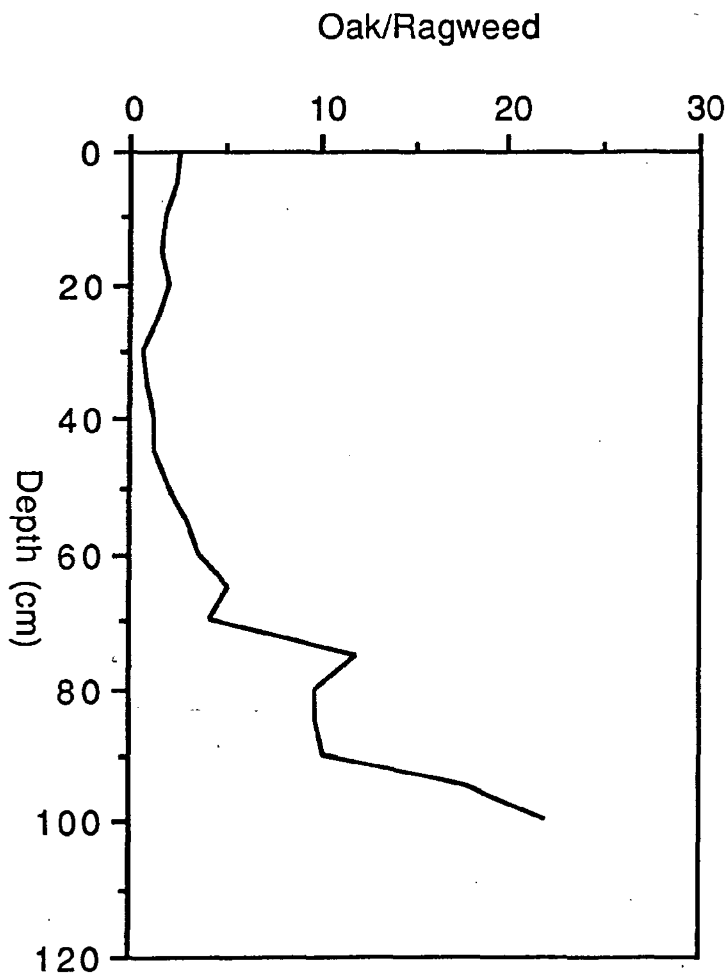


Fig.8. Oak/Ragweed Pollen Ratio for JUG 7

Appendix 1. Sedimentation rates and chronologies.

JUG 1.

Depth (cm)	Sedimentation rate (cm/yr)	Years
0-1	0.34	1990-1987
1-2	0.37	1987-1984
2-3	0.20	1984-1979
3-4	0.24	1979-1975
4-5	0.26	1974-1970
5-6	0.23	1970-1966
6-7	0.25	1966-1962
7-8	0.23	1962-1958
8-9	0.33	1958-1955
9-10	1.30	1955-1954
10-11	1.00	1954-1953
11-12	0.50	1953-1951
12-13	0.62	1951-1949
13-14	0.56	1949-1947
14-15	0.49	1947-1945
15-16	0.44	1945-1943
16-17	0.51	1943-1941
17-18	0.34	1941-1938
18-19	0.33	1938-1935
19-20	0.26	1935-1931
20-21	0.37	1931-1928
21-22	0.21	1928-1923
22-23	0.57	1923-1921
23-24	0.54	1921-1919
24-25	0.63	1919-1917
25-26	0.40	1917-1914
26-27	0.45	1914-1912
27-28	0.47	1912-1910
28-29	0.48	1910-1908
29-30	0.37	1908-1905
30-31	0.33	1905-1902
31-32	0.41	1902-1900
32-33	0.52	1900-1898
33-34	0.31	1898-1895
34-35	0.29	1895-1892
35-36	0.30	1892-1889
36-37	0.42	1889-1887
37-38	0.46	1887-1885
38-39	0.21	1885-1880
39-40	0.33	1880-1877
40-41	0.48	1877-1875
41-42	0.53	1875-1873
42-43	0.55	1873-1871
43-44	0.49	1871-1869
44-45	0.61	1869-1867

JUG 3

Depth (cm)	Sedimentation rate (cm/yr)	Years
0-1	0.26	1990-1986
1-2	0.31	1986-1983
2-3	0.32	1983-1980
3-4	0.29	1980-1977
4-5	0.22	1977-1972
5-6	0.21	1972-1967
6-7	0.39	1967-1964
7-8	0.43	1964-1962
8-9	0.48	1962-1960
9-10	0.50	1960-1958
10-11	0.51	1958-1956
11-12	0.61	1956-1954
12-13	0.55	1954-1952
13-14	0.58	1952-1950
14-15	0.52	1950-1948
15-16	0.60	1948-1946
16-17	0.55	1946-1944
17-18	0.46	1944-1942
18-19	0.51	1942-1940
19-20	0.35	1940-1937

JUG 5

0-1	0.22	1990-1986
1-2	0.32	1986-1983
2-3	0.25	1983-1979
3-4	0.23	1979-1975
4-5	0.27	1975-1971
5-6	0.29	1971-1968
6-7	0.30	1968-1965
7-8	0.34	1965-1962
8-9	0.41	1962-1960
9-10	0.38	1960-1957
39-40	0.51	
40-41	0.55	
41-42	0.49	
42-43	0.57	

JUG 7

0-1	0.27	1990-1986
1-2	0.21	1986-1981
2-3	0.22	1981-1977
3-4	0.19	1977-1972
4-5	0.28	1972-1969
5-6	0.30	1969-1966
6-7	0.29	1966-1963
7-8	0.34	1963-1960
8-9	0.36	1960-1957
9-10	0.41	1957-1955
10-11	0.44	1955-1953
11-12	0.44	1953-1951