PALEOBOTANICAL ANALYSES OF THREE TIDAL STREAM VALLEYS ALONG THE PROPOSED STATE ROUTE 1 CORRIDOR, KENT COUNTY DELAWARE

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INTRODUCTION

The purpose of this study was to reconstruct the vegetation and climatic conditions over several centuries along tidal stream valleys occupied by native American populations prior to European settlement. These stream valleys are adjacent to archaeological sites along the corridor of the proposed State Route 1.

The method used for reconstructing vegetation and making inferences regarding climate change is to construct vertical profiles of pollen, seed, and charcoal extracted from sediments deposited in these tidal tributaries over long time periods, on the order of centuries and millennia. Pollen grains are produced by both terrestrial and aquatic plants generally in great abundance; when deposited in areas of high sedimentation where burial is rapid, preservation can be very good. Pollen grains are small (10 to 70 microns) light (specific gravities slightly greater than 1) particles. The majority of pollen are transported from the source trees and shrubs atmospherically, so that pollen preserved in sediments represents more or less the regional vegetation. Seeds on the other hand, because they are heavier and larger, are not transported as far, and are generally representative of the local vegetation. Whereas pollen grains are rarely identifiable to species, seeds can be related to the species taxon, and hence provide considerably more information with regard to vegetation type. Pollen grains and seeds together can provide a rather complete history of vegetation change.

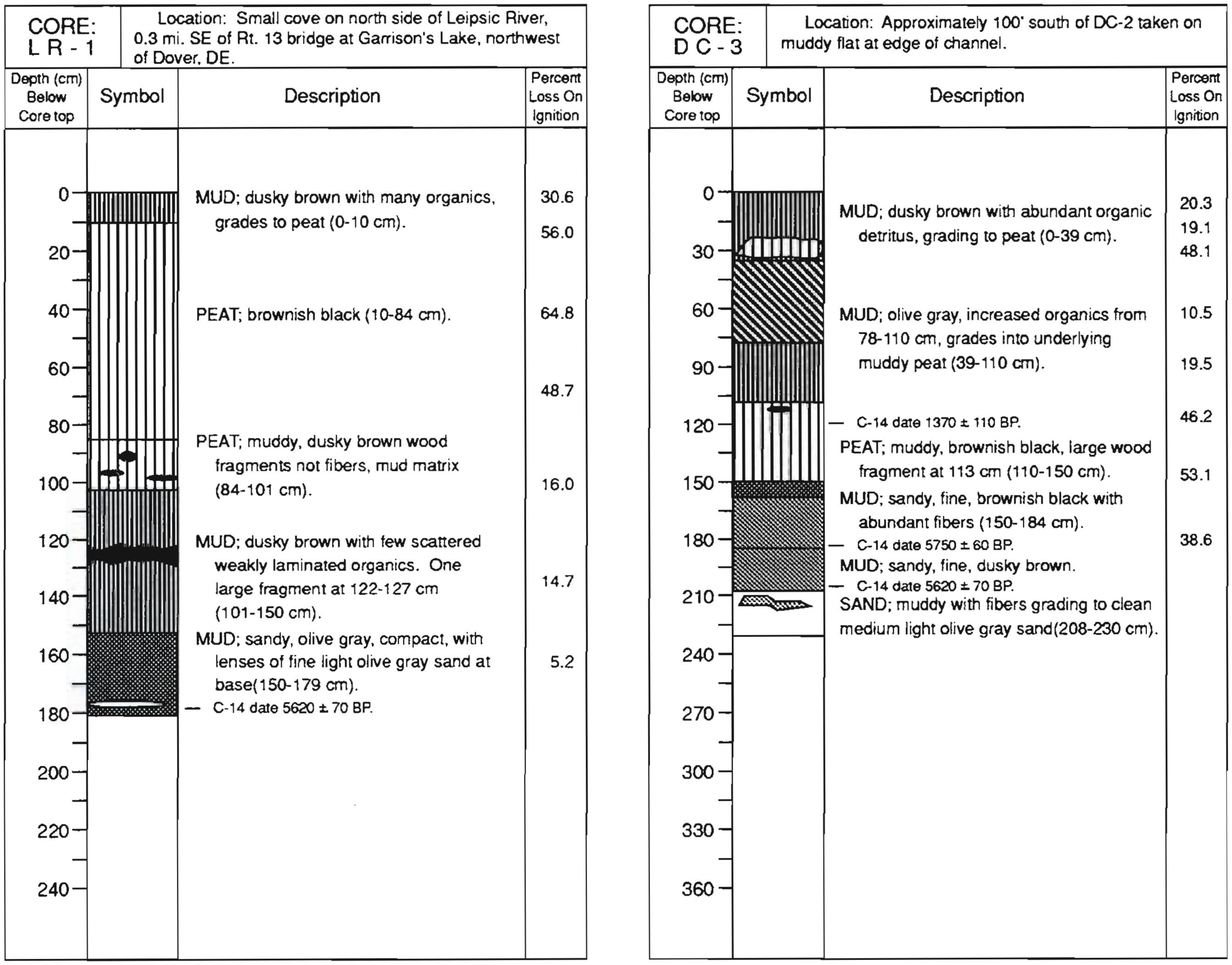
Because many plants have rather specific ecological requirements with respect to temperature and water availability, changes in the composition of fossil populations provide a record translatable to climatic change. Transfer functions have been described for plants to reconstruct past temperatures (for example Huntley and Prentice 1988), but not precipitation. However, if the pollen and seed composition of a particular horizon within a core changes from predominantly sedge to predominantly goldenrod for example, it is reasonable to conclude that there has been a change in water level due either to sediment filling or to a drop in the water table caused by decreased precipitation, even though quantitative assessments cannot be made. Such changes would be of fundamental economic and cultural importance to human societies.

METHODS

Three sediment cores were selected from among 31 collected by Elizabeth Rogers and James Pizzuto (in this volume) of the University of Delaware at three locations in northeastern Delaware (Figure 2). Sediment core DC-3 was analyzed from the Duck Creek locality (Figure 34), SJ-3 from the Saint Jones Creek locality (Figure 37), and LR-1 from the Leipsic River locality (Figure 40). The cores were collected

FIGURE 51

Stratigraphy of Cores Studied for Pollen



See Figure 47 for core SJ-3.

with a vibrocorer and are 220 cm long for DC-3, 180 cm for LR-1, and 425 cm for SJ-3. Stratigraphically, all three cores consist of alternating layers of mud and peat, with bottom layers containing sand (Figures 38 and 51). The cores are remarkably homogeneous and appear stratigraphically intact. Each core was split in two lengthwise, and the one-half of the core assigned for paleobotanical analyses divided into 1 cm intervals. Each 1 cm sample was stored in a plastic "Ziploc" bag at 4°C until processed for pollen and seed extraction.

Dating of Cores

Radiocarbon dates were obtained for three levels in core DC-3, the bottom level of LR-1, and three levels in SJ-3 (Figure 38). In addition, the European settlement horizon is identified in each of the cores based on an increase in ragweed pollen. With initial clearing of the land by the early settlers and ensuing intensive agriculture, ragweed which colonizes disturbed ground (Bazzaz 1974) increased rapidly and, being a prolific pollen producer, resulted in a dramatic increase in the amount of ragweed pollen deposited in sedimentary basins. Along with the increase in ragweed, the flux of arboreal pollen into the sediments

TABLE 11

Sedimentation Rates for Pollen Cores

Core	Depth of Sediment (cm)	Date (BP)	Sedimentation Rate (cm/ yr)
	17	267 (pollen)	0.064 (0 - 17 cm)
DC-3	120-124	1370 ± 110 (C^{14})	0.095 (17 - 122 cm)
	204-208	5620 ± 70 (C^{14})	0.02 (122 - 206 cm)
LR-1	15	267 (pollen)	0.06 (0 - 15 cm)
	172-178	6230 ± 270 (C^{14})	0.03 (15 - 175 cm)
	23	267 (pollen)	0.09 (0 - 23 cm)
SJ-3	76-80	1040 ± 120 (C^{14})	0.07 (23 - 78 cm)
	156-160	1360 ± 100 (C^{14})	0.25 (78 - 158 cm)
	336-340	1920 ± 70 (C^{14})	0.32 (158 - 338 cm)

changed with deforestation of the land. Because oak is a dominant tree in eastern USA and the relationship between basal area of oak trees and pollen in surface sediments in given areas is fairly close (Brush and DeFries 1981), ratios of oak to ragweed pollen are used along with the percentage of ragweed pollen as markers of initial European settlement (Brush 1984). The actual time of settlement can be obtained from historical documents, and will vary in different places, because settlement was not synchronous, regionally. The time of initial settlement for north central Delaware is approximately 1720. Consequently, the stratigraphic horizon where ragweed becomes an important component of the pollen profile is dated 1720.

The dated horizons in these cores show high variability in sedimentation rates both within and between cores (Table 11). Core SJ-3 has the highest sedimentation rate with a date of 1920±70 radiocarbon years before the present at 336-340 cm depth. The European agricultural horizon is also at a lower depth in this core, indicating a higher sedimentation rate since European settlement also at this location.

When sedimentation is highly variable in a depositional basin, it is necessary to convert concentrations (number contained in a volume of sediment) of fossilized components (pollen, seeds, etc.) to influxes (number deposited per area per year). If, for example, the sedimentation rate is 0.1 cm/yr, 100 pollen grains in a cm^3 means that 100 grains were deposited in 10 years or 10 grains in one year, whereas if the sedimentation rate were 0.01 cm/yr, 100 grains in 1 cm^3 means 100 grains deposited in 100 years or 1 grain per year. The high variability of sedimentation in tidal tributaries suggests that average rates calculated between dated horizons does not provide a reliable means for calculating influxes. Consequently, sedimentation rates have been calculated for each 1 cm interval of the core by adjusting the average sedimentation rate according to the ratio of pollen concentration to sediment concentration in each 1 cm interval (Brush 1989). The method is based on the assumption that pollen input into a basin is relatively uniform if species composition has not changed, and if the area of vegetated landscape is uniform. If the rate of sediment accumulation increases, the concentration of pollen in the sediment will be correspondingly less and if sediment accumulation decreases, pollen concentration will be correspondingly lower.

The sedimentation rate for individual core segments can then be calculated using the following equation:

$$r = \frac{N}{n} R,$$

where r = the sedimentation rate for an individual core segment,
N = the average number of pollen grains per core segment,
n = the number of pollen grains in the core segment,
R = the average sedimentation rate of a core interval (d/t),
d = the length of a dated core interval, and
t = time in years.

The following procedure is used to determine values for N and n:

1) cut the sediment core into equal segments (for example, 1 cm);

2) obtain average sedimentation rates throughout the core, using carbon-14, lead-210, and/or the identification of historically dated pollen horizons;

3) extract a known volume (for example 1 cm^3) of sediment from each core segment (for example, 1 cm) and weigh the sediment (g/cm^3);

4) extract the pollen from the entire volume of sediment using standard methods for pollen extraction (Faegri and Iversen 1975);

5) count all of the pollen in an aliquot (e.g., 0.1 cm^3) of all core segments (duplicate aliquots should be counted in order to estimate the experimental error);

6) calculate the number of pollen grains in the entire 1 cm^3 segment (number of grains/cm^3).

7) multiply the number of grains/cm^3 by the depth of the segment (e.g.,1 cm) to give the number of grains/cm^2;

8) add the number of grains/cm^2 for all segments between dated horizons and divide by the number of segments.

Once sedimentation rates are calculated, the number of years required for deposition of each 1 cm segment within a core is calculated by dividing the depth of the segment by the sedimentation rate. Chronologies assigning years to each depth level are then constructed for the entire core.

Extraction of Pollen

A volume of 1.5 ml of sediment was removed from each subsample analyzed from the core and treated with hydrochloric and hydrofluoric acids to remove carbonates and silicates. The sample was then treated with potassium hydroxide and boiled in an acetolysis mixture consisting of nine parts of acetic anhydride to one part sulfuric acid in order to clean the sample of humic and extraneous organic material. The residue was washed in glacial acetic acid, water, and ethanol, and the entire residue stored in 25 ml tertiary butyl alcohol. A measured aliquot from each subsample, generally 0.1 ml, was pipetted on a drop of silicone oil on a microscope slide and all of the pollen on the slide identified and counted, under 400x magnification. The influx value was then calculated by multiplying the numbers of pollen in the volume of sample (taking into account the dilution factor) by the appropriate sedimentation rate for that level of the core.

Extraction of Charcoal

Charcoal was retrieved with the pollen extraction and pieces of charcoal were counted on slides in the same manner that pollen was counted. Numbers of charcoal pieces were then multiplied by the sedimentation rate to give the charcoal influx or number of charcoal pieces deposited/cm^2/yr.

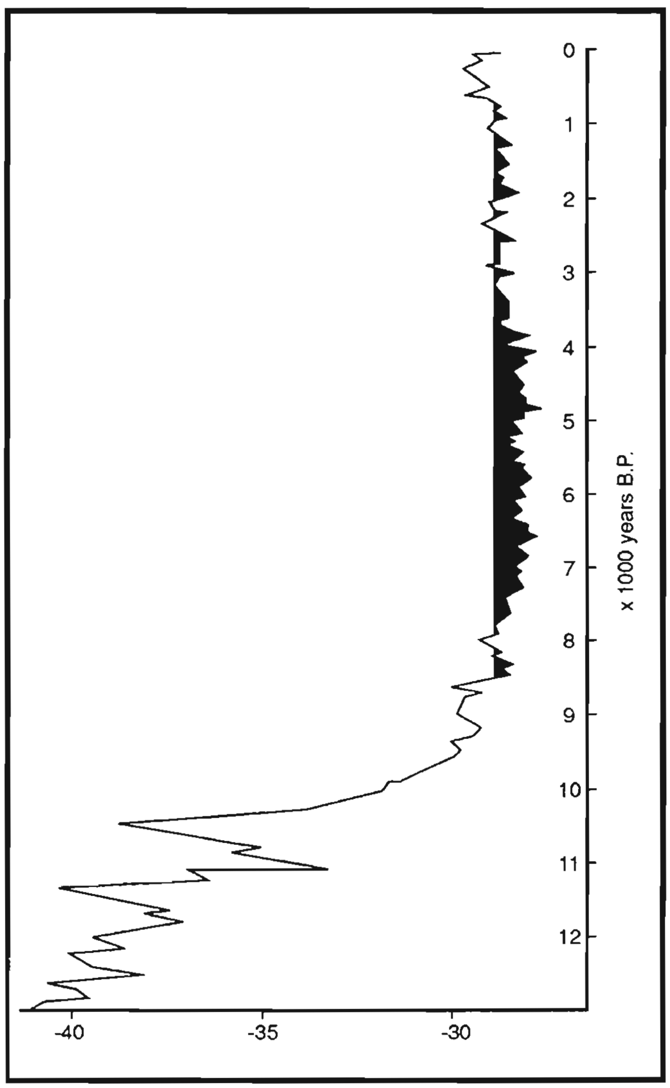
Extraction of Seeds

A volume of sediment from each subsample analyzed for seeds was removed from the subsample and submersed in 50 ml of 10% nitric acid in a graduated cup. The volume of sediment was measured by measuring the volume of liquid displaced to the nearest millimeter. The sediment is disaggregated by soaking in nitric acid (Godwin 1975; Birks and Birks 1980), after which it is washed through a column of nested 20 mesh (0.8 mm) and 60 mesh (0.25 mm) sieves. Seeds and other remaining material are then placed in water in a clear petri dish and examined under 15x to 40x magnification, using a binocular microscope. Seeds were isolated with forceps and stored in vials of water and formalin. All of the seeds in a sample were identified and counted, and influxes of seeds (number deposited/cm^2/yr) calculated by multiplying the number of seeds in the volume of sediment by the sedimentation rate for that particular level of the core.

FIGURE 52

Camp Century, Greenland

Ice Core Profile



(From Dansgaard 1981) Climate warmer than today is shown in black.

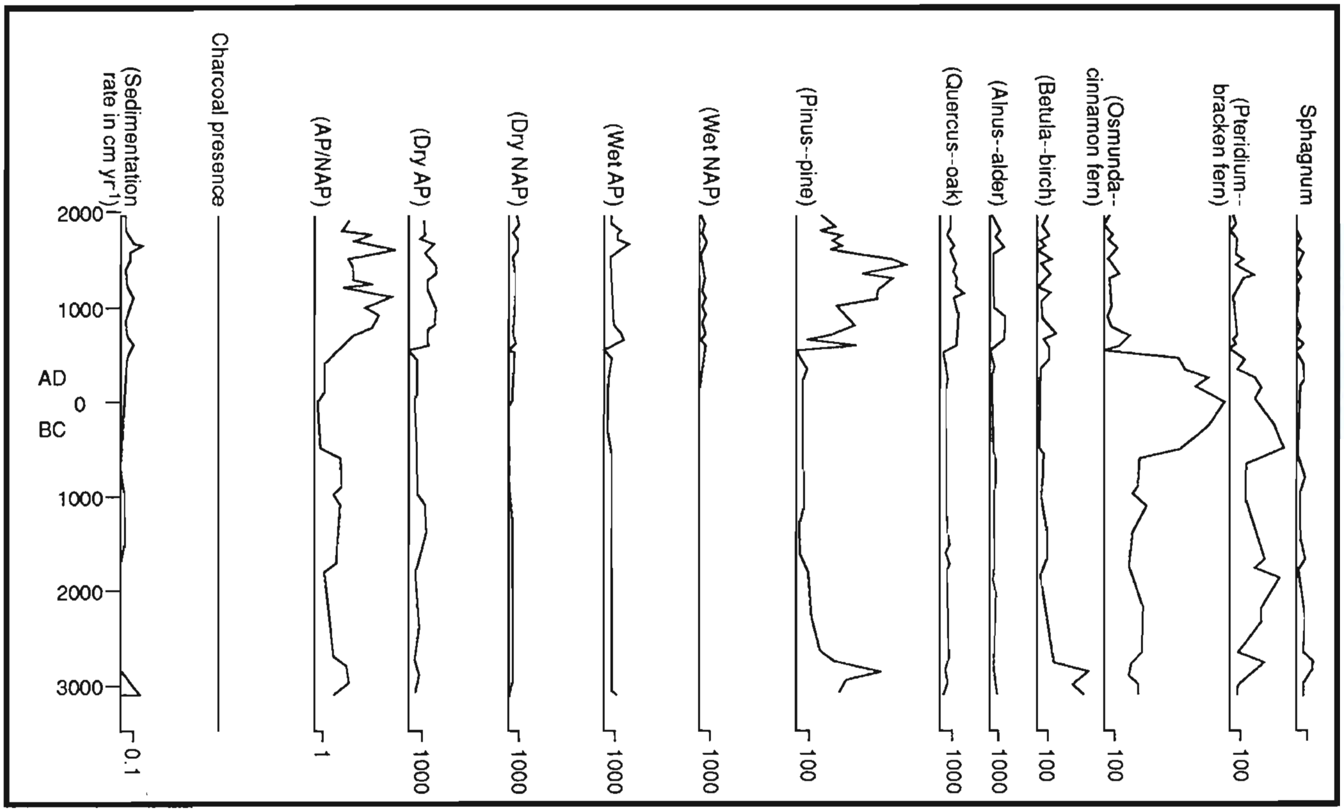
Analysis of Data

Core depths were converted to years using the chronologies constructed for each core. Samples were then arranged in a series of equal time intervals. The time interval depends on the resolution or sedimentation rate; time intervals were 50 years for DC-3, 100 years for LR-1, and 10 years for SJ-3. Sedimentation rates, charcoal, pollen and seed influxes were then plotted against a time axis of equal time intervals. This was done so that time series analyses of the data can be performed, and the results compared with other time series data, such as those recovered from ice cores or varved sediments.

A profile showing changes in the amount of oxygen-18 ($\delta^{18}O$) in the Camp Century core (Dansgaard 1981) is plotted alongside the pollen profile for each of the cores on the same time scale (Figure 52). The amount of oxygen-18 contained in ice cores is derived from precipitation in the area. Isotopic ratios in precipitation are sensitive to temperature. The greater the drop in temperature,

FIGURE 53

Pollen Diagram for Duck Creek Core DC-3



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

the more condensation will occur and the lower will be the heavy isotope concentration relative to sea water. The departure of oxygen-18 in ice cores from its concentration in standard mean ocean water ($\delta^{18}O$) is used to calibrate the air temperature. For example, a $\delta^{18}O$ value of -10 indicates a sample with 1% less oxygen-18 than in sea water. Figure 52 is taken from Dansgaard (1981) and shows the $\delta^{18}O$ profile for the last 10,000 years in the Camp Dentury ice core from Greenland. The black areas indicate warm periods. Air temperatures were considerably colder than present 10,000 to 9000 years ago when the continental glaciers were retreating northward. The period from 7000 to 4000 years ago was warmer than at present. From 3000 years to the present is characterized by a greater number of oscillations. From 3000 to 2000 years ago climate was cooler, from 2000 to 1000 years ago warmer than the present, and from 1000 years to the present cooler. Historical records indicate that 1000 to 1200 AD was warm over most of the earth. This was followed by the Little Ice Age during which time the average global temperature decreased by 2°C.

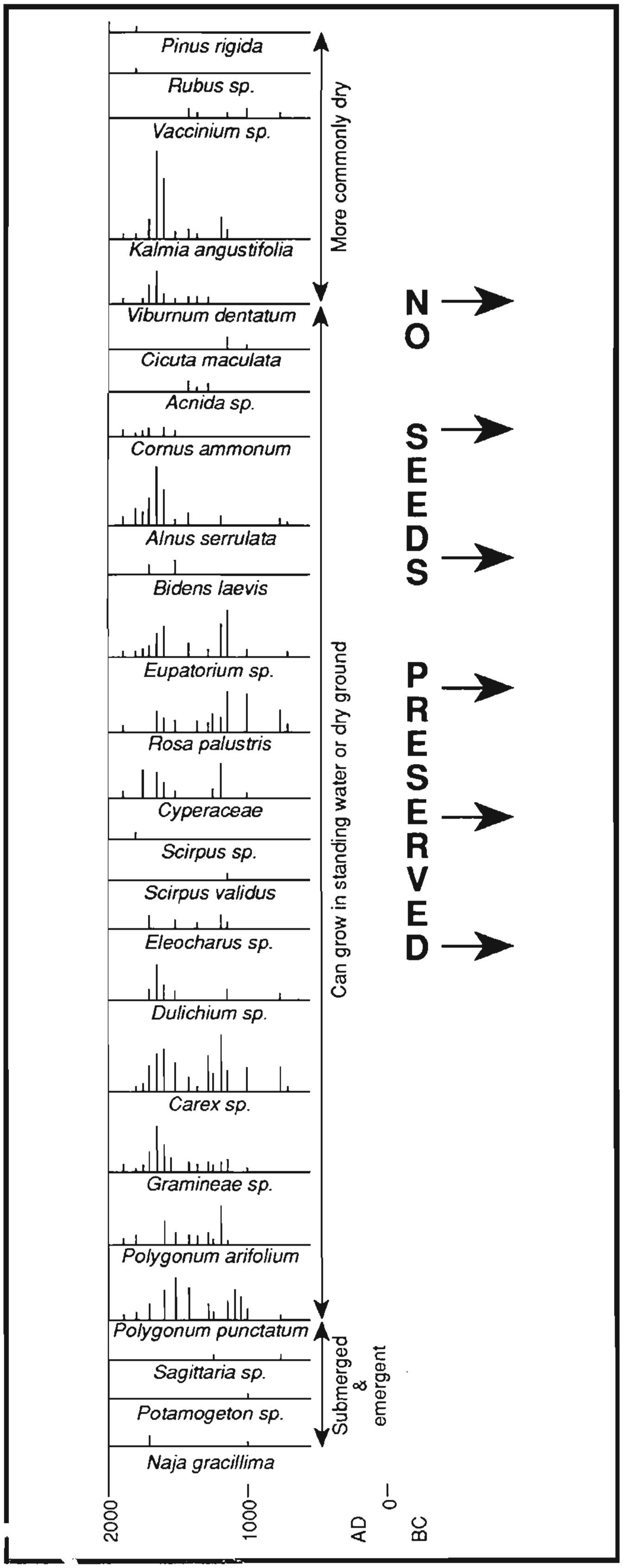
RESULTS

Duck Creek Core DC-3

Sedimentation Rates (Figure 53). Sedimentation rates are highest at the bottom of this core, and increase again about 1500 years ago. There is not much change after that time until approximately the time of European settlement, when the rate reaches 0.23 cm/yr for about 50 years. It then decreases to <0.1 cm/yr from about 1200 to the present.

FIGURE 54

Seed Diagram for Duck Creek Core DC-3



Charcoal (Figure 53). Although charcoal is present in many levels of the core, it is not present in any great abundance.

Pollen (Figure 53 and Appendix VI). The ratio of arboreal to non-arboreal pollen changes throughout the core, but most dramatically from 1500 years ago to the present, when arboreal vegetation dominated the landscape. This ratio is influenced by very large fluctuations in Pinus (pine) pollen and spores of Osmunda cinnamoneum (cinnamon fern). Apparently there were few trees on the landscape from 2500 to 2000 years ago. Pollen of all arboreal taxa increased 1500 years ago. Pine pollen was abundant about 5000 years ago, and tapered off from that time to about 3700 years ago, when the pollen influx was extremely low. Pine became the most important component of the landscape 1500 years ago, with largest influxes occurring from 1000 years ago to the time of European settlement. Quercus (oak) pollen is relatively uniform throughout the core until 1500 years ago when it increases, and remains uniformly higher to the present, with a slight decrease after European settlement. Alnus (alder) is uniformly unimportant until 1500 years ago, increases for 500 years, decreases for another 500 to 600 years, and increases again. Betula (birch), likely Betula nigra (river birch) at this locality, is high at the bottom of the core and has the same general distributional pattern as pine, tapering off to very low values, and then increasing 1500 years ago, and oscillating since that time. The other tree pollen identified in this core are listed in Appendix VI. Their occurrences are sporadic and influxes low. The ferns constitute the most important non-arboreal taxa. Cinnamon fern is important from 5000 to 2500 years ago, at which time influxes triple until 1500 years ago, when there is a drastic decrease in its abundance. Pteridium (bracken fern) is present in very low numbers 5000 years ago, then increases, decreases and increases to large populations about 3800 years ago. It then decreases somewhat, and reaches its greatest abundance 2500 years ago, coincident with the large increase in cinnamon fern. It is a minor component of the landscape after 1500 years, except for a period of about a century some 500 years ago.

The moss Sphagnum is present throughout, but never important. Other non-arboreal taxa present throughout the core are listed in Appendix VI.

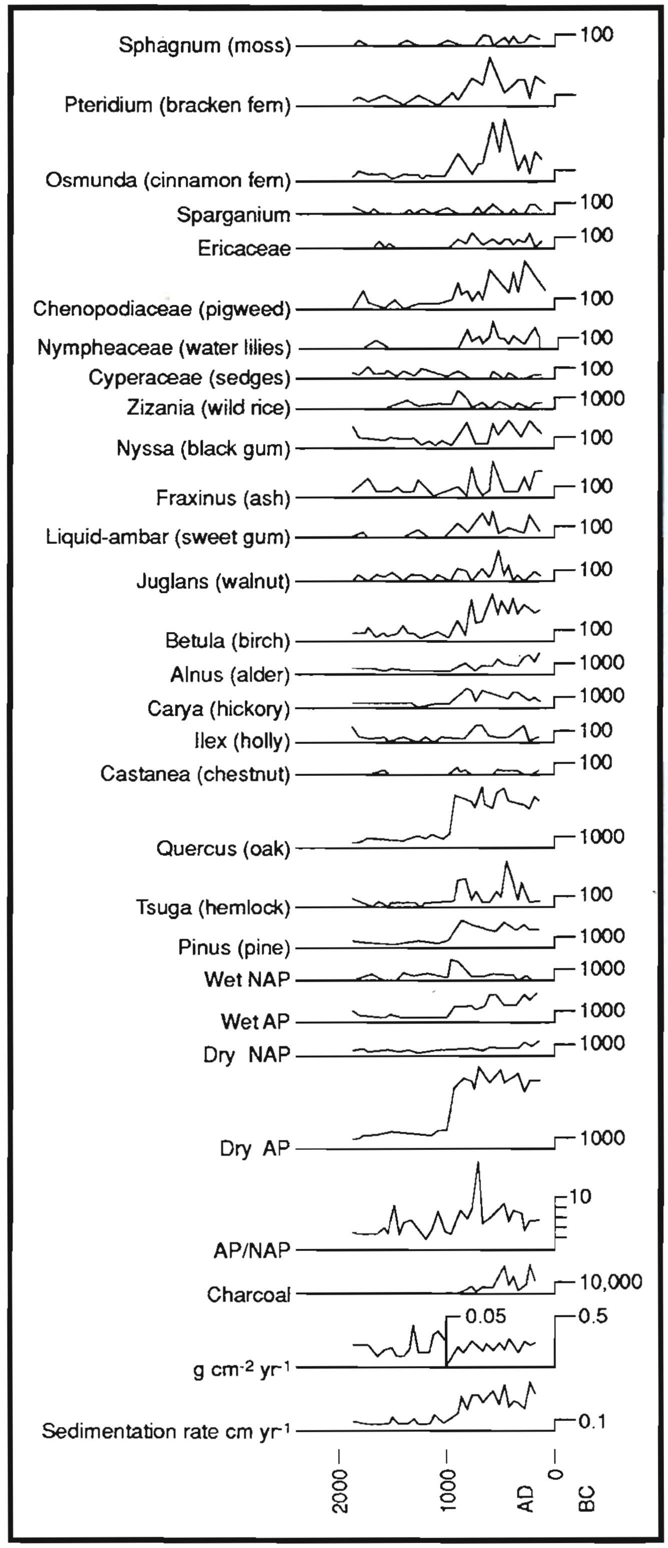
Seeds (Figure 54). Species are organized with those that grow only in standing water, either as submerged aquatics or emergents on the left side of the figure, followed by species that grow both in standing water and dry ground, with those with drier ranges to the right. On the far right, are plotted species which can grow in standing water, but are more commonly found on dry ground. There are no seeds present in sediments deposited prior to 1500 years ago. The graph shows a trend from predominantly wetter floras 1200 years ago to progressively drier about 400 years ago. Carex (sedge) produced extremely large numbers of seeds from 900 to 700 years ago, at which time Eupatorium, another sedge and Rosa palustris (marsh rose) were also abundant. These taxa become less abundant after 700 years ago. From 400 years ago to about the time of European settlement, Alnus serrulata (common alder) and Kalmia angustifolia (lambkill) became dominant. Although these plants can grow in open water, they can also grow permanently on dry ground.

Interpretation of Core DC-3

The pollen record indicates that for 1000 years from 2500 to 1500 years ago, conditions were dry with fire possibly frequent. The evidence for this is the large amount of spores of Pteridium (bracken fern), a fire indicator, present at that time, and the very low pollen influxes of all tree and shrub taxa. If there were frequent fires, pollen production could be expected to be low. Osmunda (cinnamon fern), although not a direct indicator of fire, does grow well in open areas of bare soil. Clark (1988) has shown that, due to transport and depositional processes, the absence of charcoal in sediment does not preclude fire. Low influxes of Pinus (pine) pollen during this interval and for some time prior to 2500 years ago, could be the result of fire if the species represented is Pinus taeda (loblolly pine) which is non-resistant to fire.

FIGURE 55

Pollen Diagram for St. Jones River Core SJ-3



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

The next thousand years, from 1500 to 500 years ago, show a dramatic change both in the pollen and seed profiles indicating initially very wet conditions becoming progressively drier in more recent times. The ferns decrease dramatically, and pine becomes dominant. The seeds show a gradual progression from plants growing in standing water to those that grow generally in standing water to those that can grow on dry ground, as well as wet ground.

Saint Jones Creek Core SJ-3

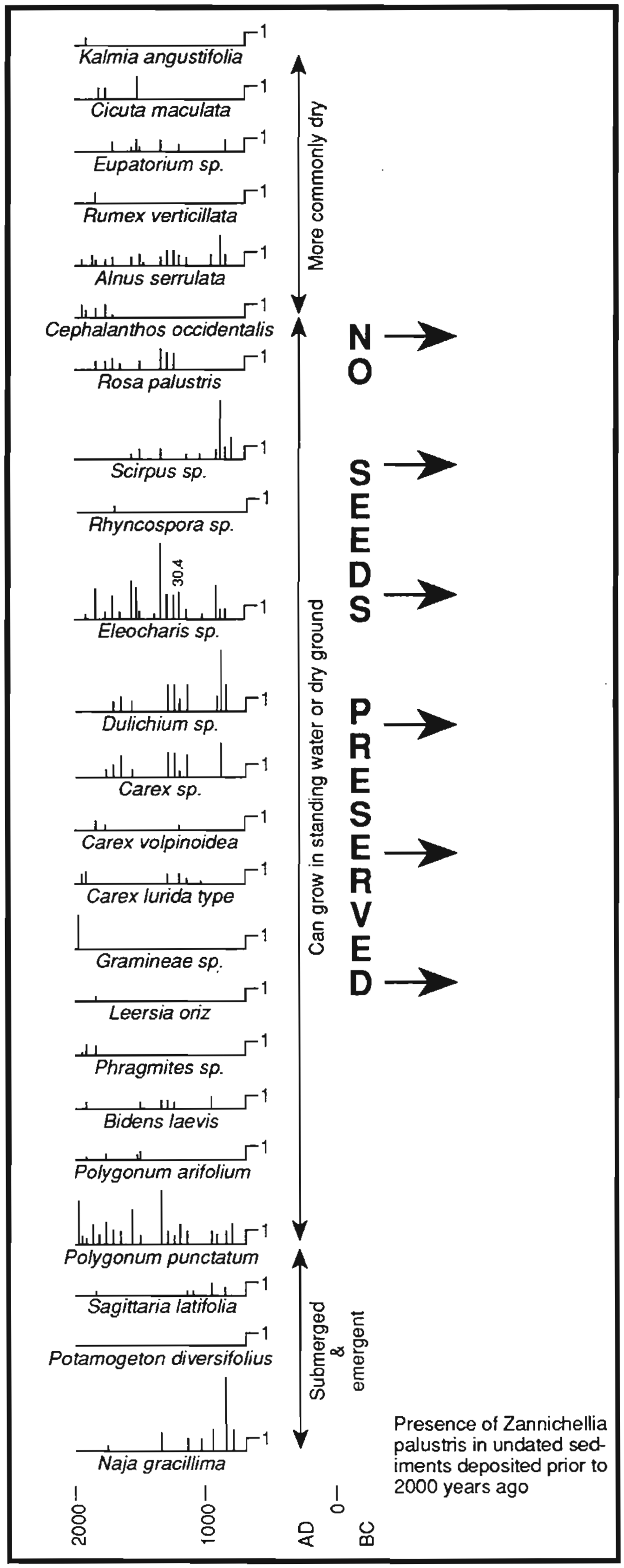
Sedimentation Rates (Figure 55). The average sedimentation rate in this core is very high (2000 years in 4 m of sediment). Sedimentation rates, both linear (cm/yr) and mass (g/cm²/yr) show a dramatic decrease 1000 years ago. Sedimentation rates varied between 0.2 to 0.48 cm/yr for 1000 years from 2000 to 1000 years ago, and decreased to an average 0.1 cm/yr, with only a very slight rise during the last century.

Charcoal (Figure 55). The charcoal profile shows large influxes for about 500 years from 2000 to 1500 years ago. Influxes for the next 500 years are about 1/4 the amount of the previous 500 years, and become a very minor component of the sediment in the last 1000 years.

Pollen (Figure 55 and Appendix VI). The pollen profile shows a large decrease in pollen influxes of arboreal pollen 1000 years ago, but the non-arboreal pollen seems to be less affected. Tsuga (hemlock) as well as Pinus (pine) were present in fairly large numbers during the earlier 1000 years. A moderately diverse flora is represented in this core. The most common taxa are plotted in Figure 55 and other species which occur rarely and sporadically are listed in Appendix VI. Juglans (walnut), Fraxinus (ash), and possibly Nyssa (black gum) show less change 1000 years ago than the other tree taxa. Among the non-arboreal pollen, Cyperaceae (sedges) and Sparganium (burreed) show little overall change. However, the Nympheaceae (water lilies) essentially disappear, and the Chenopodiaceae (pigweed family) show a large decrease. The Ericaceae (blueberry

FIGURE 56

Seed Diagram for
St. Jones River Core SJ-3



family) also drop out 1000 years ago, and do not reappear until 400 years ago and then only in small amounts. The ferns, Osmunda (cinnamon fern) and Pteridium (bracken fern) were both abundant from 2000 to 1000 years ago, and present in small numbers during the last 1000 years. Sphagnum, too, is uniformly present until 1200 years ago, when its occurrence becomes sporadic.

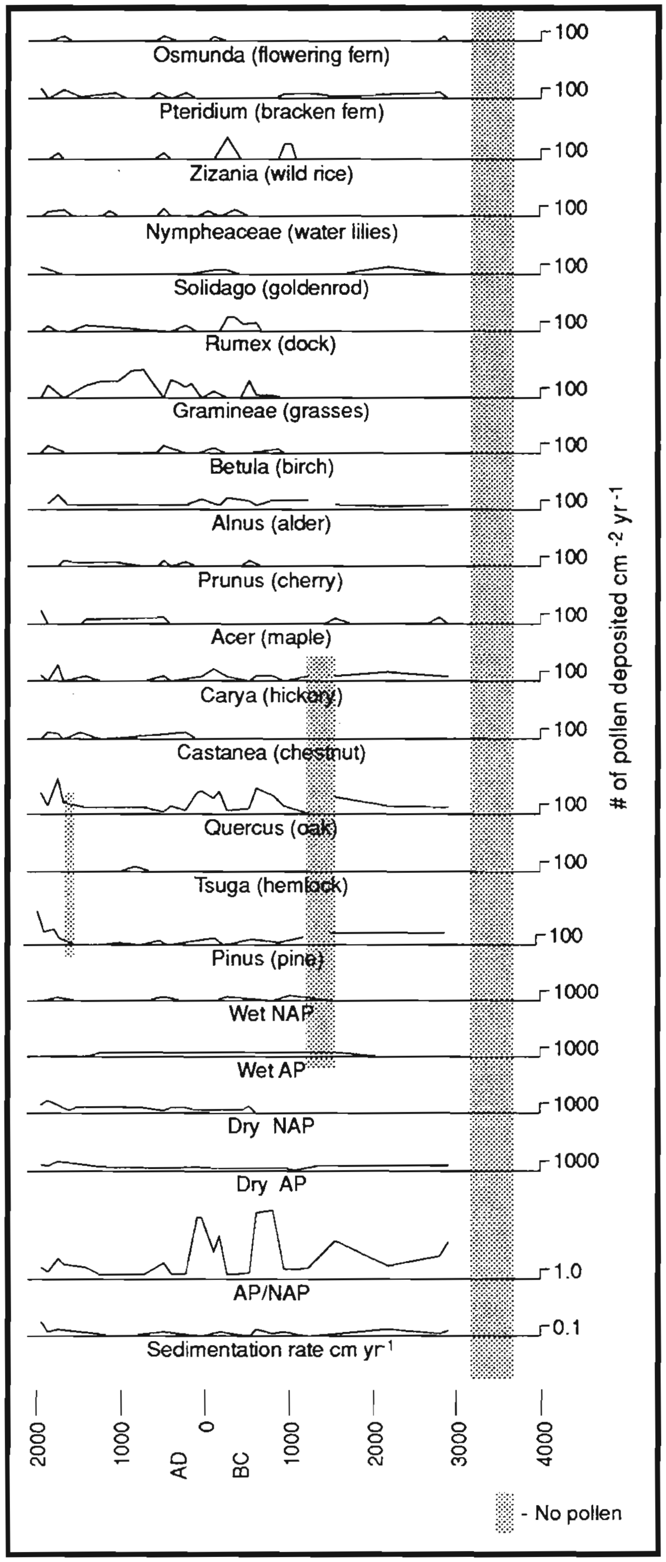
Seeds (Figure 56). Seeds of the submerged aquatics Zannichellia palustris (horned pondweed) and Najas gracillima (naiad) are present in undated sediments deposited prior to 2000 years ago. This is the only occurrence of Zannichellia in this core. There are no seeds preserved in sediment deposited from 2000 to 1200 years ago. From 1200 years ago to about 650 years ago, the plants represented by the seed populations include submerged aquatics, emergents and large numbers of sedges, particularly Eleocharis from 800 to 650 years ago. This is the same time when sedges and other "wet" plants were dominant in core DC-3. Gradually, these plants decreased in number, and other species such as Cephalanthus occidentalis (buttonbush), Rumex verticillata (dock) and others which can grow permanently on dry ground appear for the first time about 350 years ago.

Interpretation of Core SJ-3

The large amounts of charcoal and high sedimentation rates from 2000 to 1000 years ago, along with abundant spores of Pteridium (bracken fern), Osmunda (cinnamon fern) suggest that this was a dry period with frequent fires. However, fires were not sufficiently severe to affect flowering and pollination, as all of the species were producing abundant pollen during this time. The pine species could be Pinus rigida (pitch pine) which is fire resistant, and which can reproduce only with fire. This period was succeeded by extremely wet conditions, which probably began about 1200 years ago, when pollen of Zizania (wild rice) and seeds of submerged aquatics and emergents were most numerous. During the past 1000 years,, pollen influxes of all tree species decreased rather drastically, but the decreases were less severe for

FIGURE 57

Pollen Diagram for Leipsic River Core LR-1



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

wet species, such as Fraxinus (ash) and Juglans (walnut). The seed profiles show a gradual change to drier conditions about 400 years ago, coinciding with the trend in core DC-3.

Leipsic River Core LR-1

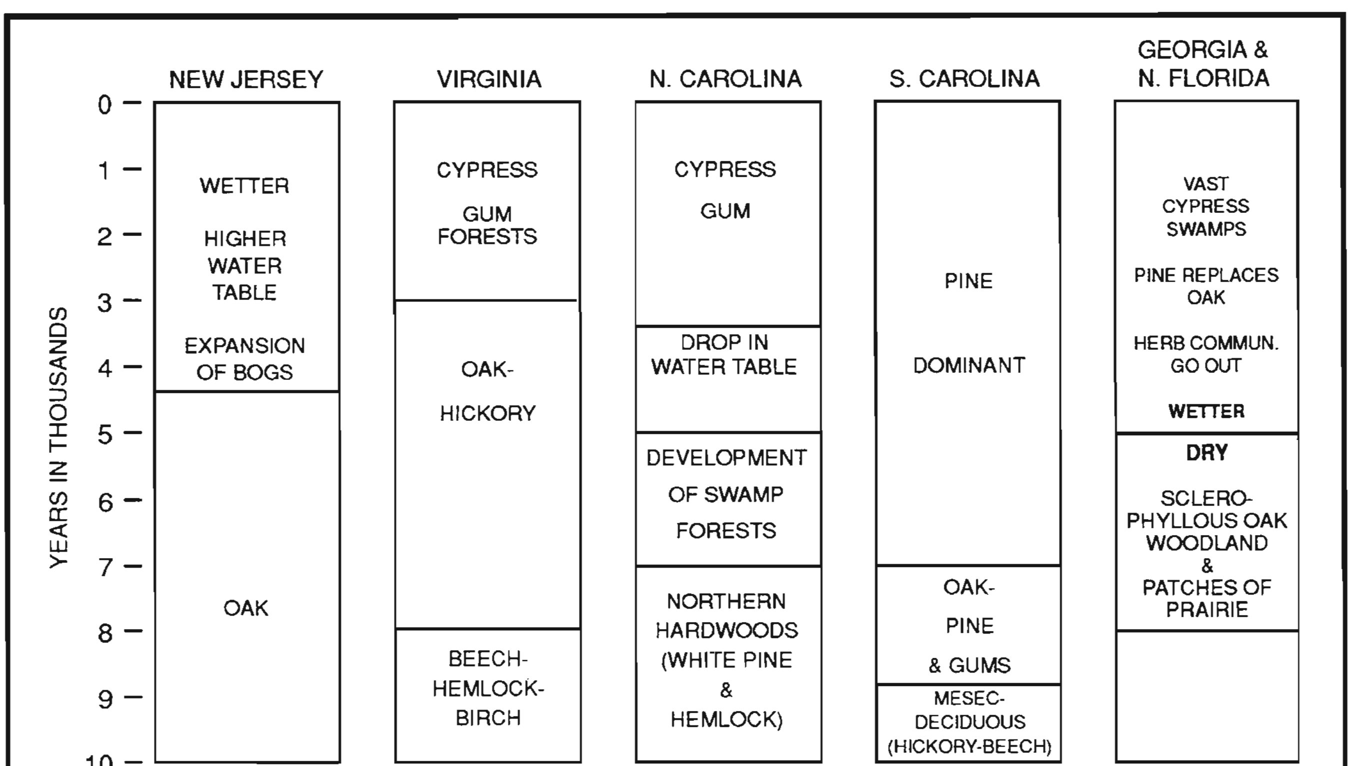
This core has a relatively low sedimentation rate (180 cm in 6200 years). Preservation was not as good as in cores DC-3 or SJ-3. The core was not analyzed for seeds or charcoal.

Sedimentation Rates (Figure 57). Sedimentation rates are very low in this core, ranging from 0.02 to 0.12 cm/yr, and show little fluctuation.

Pollen (Figure 57 and Appendix VI). The bottom portion of the core extending in time from 6000 to 5000 years ago contains some sand and no pollen. For a period of 2000 years from 5000 to 3000 years ago, Pinus (pine) is important, Solidago (goldenrod) is present part of the time and Pteridium (bracken fern) for the entire period, when it drops out. Following this period, there is a short interval of 500 years when Zizania (wild rice) is important briefly, followed by Quercus (oak) and Gramineae (grasses). Then for about 300 years, oak decreases, Rumex (dock) and wild rice are important, and this is followed by another period of a few centuries when oak increases abruptly again accompanied by grasses which continue to increase thereafter. There are very few fluctuations in the profiles during the last 1800 years, with the exception of a period just prior to European settlement when no pollen was deposited or preserved. After

FIGURE 58

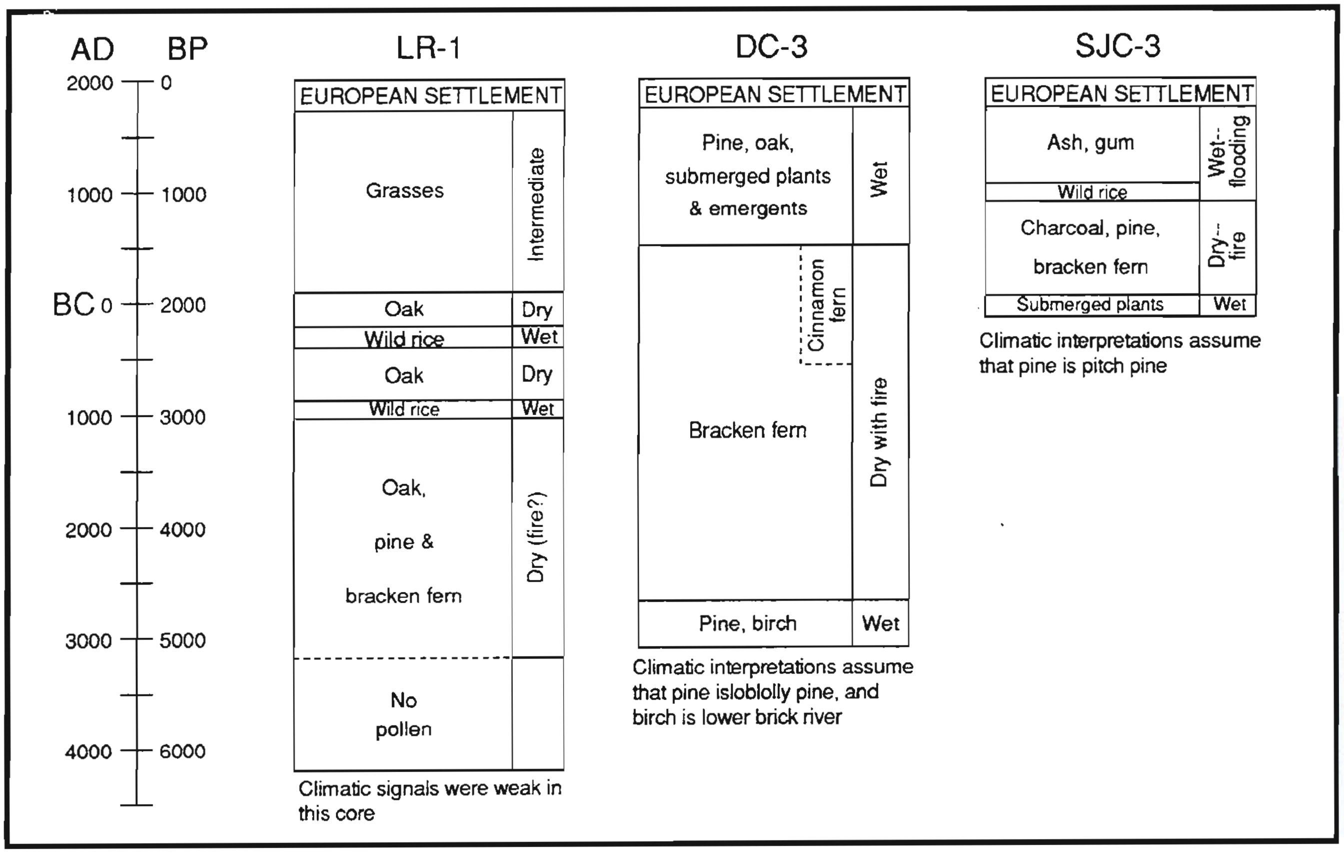
Regional Vegetation Correlation Chart



Summary of Holocene vegetation in the eastern United States south of the maximum extent of the last glaciation.

FIGURE 59

Summary of Vegetation and Climate



European settlement, most pollen types increase initially. This is followed by a decrease in the dominant species, with the exception of pine which reaches its greatest abundance in the last century.

Interpretation of Core LR-1

The most dramatic change in this core is registered between 3000 and 1800 years ago, where for a period of 1200 years, there are major oscillations between what appear to be dry and wet conditions. Prior to 3000 years ago, the flora suggests a landscape characterized by dry ground, with at least intermittent fires. This was followed by a century of wet conditions (wild rice); then 200 to 300 years of dry conditions (oak and grasses), 100 to 200 years wet (wild rice), and then another 300 to 400 dry years. Conditions appear to have remained dry until the present, or at least drier than at the other study localities. However, the preservation in this core and the low resolution do not allow for definitive climatic interpretations.

DISCUSSION AND CONCLUSIONS

Pollen and seed profiles from the Atlantic coastal region of the USA south of the glacial border show the development and expansion of cypress-gum forests from 5000 to 3000 years ago (Watts 1979, 1980; Whitehead 1981, Colquohn and Brooks 1987) (Figure 58). Except for deterioration due to deforestation and siltation since European settlement, these forests still characterize much of the region.

TABLE 12

Vegetation and Climate Inferred from the Pollen Cores

		Total Taxa	------- Non-Tree Taxa ------- % Taxa	% Influx	Diversity		
EUROPEAN COLONIZATION							
	1980's - Mid 1800's	20	36	21	0.92		
1	Mid 1800's - Mid 1700's	23	45	21	1.48		350 years
	Mid 1700's - Mid 1600's	20	52	21	1.45	Deforestation	
WET- DRY							
	1650 - 1500	20	38	14	1.14	150 years - Drier	
2	1500 - 950	21	43	17	1.22	550 years - Wet	775 years
	950 - 875	14	36	11	0.55	75 years - Extremely wet (flooding)	
DRY- WET							
	875 - 550	23	45	11	1.27	325 years - Less dry	
3							775 years
	550 - 100	22	44	12	1.17	450 years - Extremely dry (fires)	
WET- DRY							
4	? - A.D.100	Sequence of seeds similiar to **2**					
(Based on Date from CoreSJ-3)							

Except for Clark's (1986) study of barrier islands off Long Island, few studies show the kind of temporal variation that occurs within the longer time frame of millennia. The cores from Delaware provide information with respect to shorter term oscillations. A summary of these cores (Figure 59) shows a complex spatial and temporal pattern of dry periods, sometimes (or maybe always) characterized by fire alternating with wet periods, including periods of inundation. The variability of the water table can be influenced by sea level change. However, the changes must be influenced indirectly if not directly by climate, because similar oscillations have been identified in cores from New Jersey and Maryland (Brush, Hinnov, and Thornton, unpublished data). One could hypothesize that extensive fires through the Coastal Plain would eventually provide enough exotic materials into the atmosphere to provide nucleation conditions for cloud formation, with a feedback of high precipitation resulting initially in much of the landscape being inundated. Although the existing cores suggest such a scenario, a much larger and more intensive sampling procedure is required to test the hypothesis.

A comparison of the major oscillations in cores SJ-3 and DC-3 with the $\delta^{18}O$ oscillations in the ice core (Figure 55) shows good correspondence. Although the record for SJ-3 is fairly short, the period prior to 2000 years ago was wet according to the seed record. This corresponds with the colder interval of 3000 to 2000 years ago in the ice core. The period of intensive fires, and presumably dry conditions from 2000 to 1000 years ago corresponds with a warm interval of 1000 years in the ice core. This was followed by very wet to wet conditions in both cores SJ-3 and DC-3, corresponding with cooler conditions in the ice core. Within these 1000 year intervals there are oscillations in the ice core, and also in sediment cores where the resolution is high.

The effect of these climatic events registered in the flora would have a profound influence on the landscape. The most immediate effect is a change in the water table, but fire also denudes the landscape of vegetation and allows for soil erosion and subsequent sedimentation and turbidity of aquatic systems. Total taxa, percent of arboreal and non-arboreal taxa, and the diversity of the non-arboreal taxa show that the lowest number and diversity of taxa of shrubs and herbaceous plants occurred at the end of the dry period 1000 years ago (Table 12). This period was followed by approximately 75 years of flooding and inundation of much of the landscape, when few habitats were available for land plants. The diversity was highest during the subsequent interval as the land became drier, producing a variety of both wet and dry habitats. Although the number of taxa did not change significantly as conditions became still drier, diversity decreased, indicating a loss of wet habitats. Diversity was highest during initial and developing agriculture, although again a number of taxa did not change. The high diversity is probably due to the opening of numerous gaps with initial deforestation, allowing for the growth of shade-intolerant species and also the migration of other species into new areas. However, with the change to mechanized agriculture and a deep plow zone, diversity decreased to the lowest at any time. From the beginning of European agriculture, the number of non-arboreal taxa underwent a steady decline.