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Modern Pollen Deposition in Long Island Sound

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ABSTRACT

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Palynological analyses of 20 surface sediment samples collected from Long Island Sound show a pollen assemblage dominated by *Carya, Betula, Pinus, Quercus, Tsuga,* and *Ambrosia,* as is consistent with the regional vegetation. No trends in relative abundance of these pollen types occur either from west to east or associated with modern riverine inputs throughout the basin. Despite the large-scale, long-term removal of fine-grained sediment from winnowed portions of the eastern Sound, the composition of the pollen and spore component of the sedimentary matrix conforms to a basin-wide homogeneous signal. These results strongly support the use of select regional palynological boundaries as chronostratigraphic tools to provide a framework for interpretation of the late glacial and Holocene history of the Long Island Sound basin sediments.

ADDITIONAL INDEX WORDS: *Long Island Sound, pollen, vegetation, dating*

INTRODUCTION

Numerous investigations of the pollen record in lake sediments throughout southern New England have demonstrated a regionally consistent and synchronous pattern of postglacial vegetation history (DEEVEY, 1939; DAVIS, 1969; DAVIS *et al.,* 1980; GAUDREAU and WEBB, 1985; GAUDREAU, 1986; PETEET *et al.,* 1993; WEBB *et al.,* 1993; SHUMAN *et al.,* 1999). Throughout the deglaciation and Holocene, deciduous arboreal species responded to the ameliorating climate by migrating northward at a pace consistent with the dispersal and life-history characteristics of individual taxa. As a result, a temporally consistent, identifiable pattern of introductions of 'new' taxa to the deciduous forest assemblage occurred throughout the Holocene. The timing of these "new" introductions is well constrained. Historically dated 'events' in the vegetational history of southern New England can also be identified in pollen records. Such events include the chestnut *(Castanea)* decline at ~ 1910 AD and expansion of European settlement at ~1680 AD (associated with an initial rise in ragweed *(Ambrosia)* pollen (BRUGAM, 1978; RUSSELL *et al.,* 1993). Thus, pollen profiles within this floristically coherent area demonstrate broadly comparable and coeval signals of vegetation change over the last 15,000 years that can be used as robust chronological tools. However, application of the chronology of this well-constrained land-based pollen-vegetation history to adjacent marine environments (e.g. Long Island Sound, LIS) requires careful consideration of the depositional setting from which the marine pollen record is derived. In particular, differential preservation of pollen and spore types, spatial variability in pollen deposition, and post-depositional reworking could affect the integrity of this regional vegetation signal and, thus, the potential identification and synchroneity of chronological markers. This study seeks to test the feasibility of using pollen-stratigraphic profiles from LIS as a record of regional environmental change and as a tool for constructing a time frame for linkage of land-based and marine events.

LIS is a large estuarine basin bounded in the north by Connecticut and on the south by Long Island, New York (Figure 1). The large surface area of this estuary functions much like a large lake system by capturing and integrating the pollen signal of an extensive geographic area into the sedimentary matrix (SUGITA, 1993). Transport of pollen to this "collecting basin" occurs primarily by wind and water. Previous palynological studies from nearshore marine environments and large lakes report variable relative importance of these two transport vectors (*e.g.* STANLEY, 1965; HEUSSER, 1983; VINCENS and BONNEFILLE, 1988; LEZINE, 1991; SUC and DRIVALIARI, 1991, VAN CAMPO, 1991). Significant riverine transport of pollen is usually reflected in spatial variability in pollen deposition with either increased total concentrations or increased abundance of specific pollen types near river inflows to a basin (HOLMES, 1990; BEUNING, 1997; DEBUSK, 1997). For example, in Lake Malawi, East Africa, DEBUSK (1997) found almost double the total pollen concentration/cm^3 of sediment near river inflows as opposed to the other areas of the basin. However, even with wind as the predominant transport vector of pollen to a lake, spatial variability in pollen deposition within a basin can still occur. Small, light pollen types (*e.g.* Asteraceae) may be focussed towards the center of a basin or preferentially deposited near the edges (DAVIS and BRUBAKER, 1973; DAVIS *et al.,* 1984; HOLMES, 1990; BEUNING, 1996).

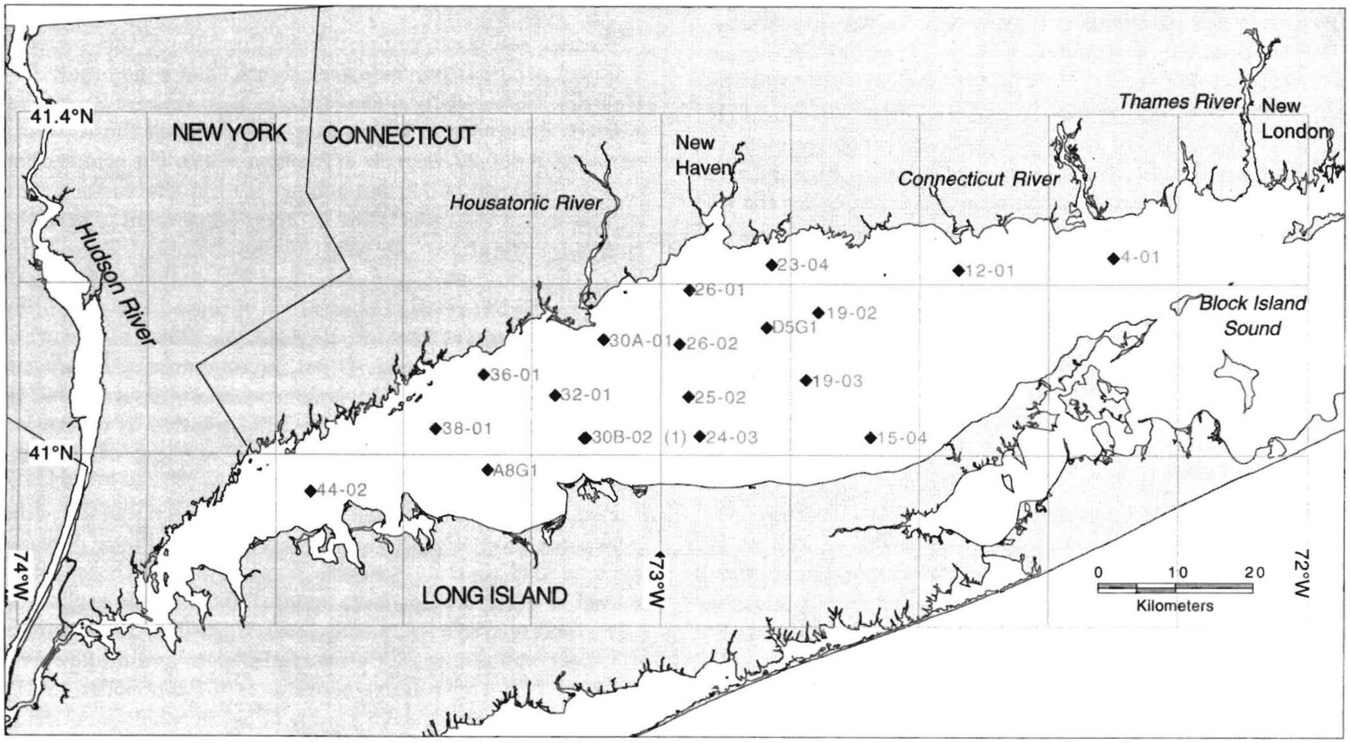

Figure 1. Map of Long Island Sound showing location of surface sediment samples processed for palynological analysis. Two samples were completed from site 30B-02 (See Figure 2).

Spatial variability in pollen deposition can be particularly pronounced in large basins. Because of their extensive size, large lake systems commonly have complex internal water flow and sediment transport patterns that result in abundant sediment deposition in one area of the basin and possible sediment winnowing from other portions of the basin (JOHNSON, 1996; JOHNSON *et al.*, 2000). In LIS, basin bottom currents drive a dynamic sedimentary system in which currents of up to 20 cm/s can resuspend fine sediments with each tidal cycle, even in areas of continual deposition (CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION, 1977; KNEBEL *et al.*, 1999; KNEBEL and POPPE *et al.*, this volume; SIGNELL *et al.*, this volume). This sediment sorting and post-depositional reworking could result in pollen assemblages from *single* sediment samples that do not provide a representative composite of the surrounding 'modern' vegetation (BEUNING, 1997). Alternatively, these strong tidal and salinity currents could mix the sinking sediment, even near river inflows, and effectively integrate both minor spatial and temporal variability such that the resultant palynological signal in the sediments is a well-mixed and spatially uniform record of regional vegetation.

STUDY SITE AND REGIONAL VEGETATION

As an estuary, LIS (72° to 73°50′W and 40°50′ to 41°20′N) opens to the Atlantic Ocean on the eastern end and to New York Harbor via a narrow tidal strait on the western end (Figure 1). The basin comprises an area of approximately 3300 km^2 with a mean water depth of 24 m (KNEBEL *et al.*, 1999). The Connecticut, Thames, and Housatonic rivers flow into the Sound from the north bringing inorganic and fine-grained organic particles, including pollen (which is primarily 20–50 μm in diameter), into the Sound (HORNE and PATTON, 1989). The sedimentary environment within the Sound is patchy. However, a general trend of coarse substrate deposition caused by erosion occurs in the east and accretion of a more fine-grained sedimentary matrix occurs in the central and western sectors of the basin (KNEBEL *et al.*, 1999; KNEBEL and POPPE, this volume).

A secondary mixed deciduous forest, characteristic of southern New England, covers the modern landscape of the principal pollen source area to LIS. Primary hardwood constituents of the forest consist of *Quercus alba* (white oak), *Quercus rubra* (red oak), *Liriodendron tulipifera* (yellow poplar), and *Carya ovata* (shagbark hickory). Depending upon the exposure, drainage, and underlying bedrock, *Fagus grandifolia* (beech), *Fraxinus americana* (white ash), *Betula populifolia* (gray birch), *Acer rubrum* and *A. saccharum* (red and sugar maple), *Chamaecyparis thyoides* (Atlantic white cedar), and other species of oak and hickory may comprise a significant portion of the arboreal biomass (BRAUN, 1964; LULL, 1968; FARRAR, 1995). *Pinus strobus* (white pine) and *Pinus* *rigida* (pitch pine), along with other coniferous trees such as *Tsuga canadensis* (hemlock), grow among the hardwoods. Most of the forest is secondary and is of even-age over much of the region due to regrowth following clear-cutting at the end of the last century (BROMLEY, 1935; BRUGHAM, 1978; RUSSELL *et al.,* 1993). Today, large areas of the forest have been replaced with urban settlements due to high human densities in the region. Mean annual precipitation for the region ranges from 1050–1150 mm/y with a mean January temperature of −1.5°C, and a mean July temperature of 22°C (WEBB *et al.,* 1993).

METHODS

Surface sediments (0–2 cm) were collected using a Van Veen grab sampler equipped with a video and still camera system. The *R/V Seaward Explorer* was used on two cruises in 1996 to collect 191 samples from 130 stations within LIS. Samples were taken in north-south transects as well as in inter-transect areas to achieve an even sample distribution. The upper 2 cms of sediment were sampled from the grabs using clean metal spatulas to prevent cross-sample contamination. Sediment was placed in acid-washed, polyethylene containers, sealed, and transported to the laboratory for further analysis.

A random subset of 20 samples from throughout the basin was selected from the grab collection to be processed for pollen analysis (Figure 1). Aliquots of the wet sediment (3–5 g) were removed from the grab samples and sent from the United States Geological Survey in Woods Hole, MA, to Wesleyan University, CT. At Wesleyan, volumetric subsamples of 0.5 to 1.5 cc of sediment were measured from each grab sample for palynological processing. Size of the subsample was based on visual inspection of sediment grain size (with larger samples taken from coarser-grained sediments). Processing of volumetric samples for palynological analyses followed standard procedures (FAEGRI and IVERSEN, 1989) with the following exceptions: (1) sieving of sediment at 120 rather than 180 μm to remove abundant 120–180 μm sand particles, and (2) use of two or three treatments of hydrofluoric acid to digest abundant inorganic silicates. Processed samples were mounted in 2000 c.s. silicon oil. Over 500 identifiable grains per sample were counted at magnifications of between 400 and 1000×, depending upon the sample. One ml of a polystyrene microsphere spike solution (7.6×10^4 spikes/ml) was added to the volumetric samples to allow calculation of pollen concentrations. "Spikes" were counted along with pollen grains during sample analysis and pollen concentration of the sample (grains/cm^3) was calculated from the ratio of spikes to pollen grains counted. All unidentified pollen grain "bladders" deriving from coniferous grains were tallied and divided by two to determine the equivalent conifer grains that these bladders represent. This equivalent total was used when calculating the relative percentage of "Conifer Equivalent" grains shown in Figure 2. Conifer bodies without bladders were not counted. Pollen count data from this study are archived in the North American pollen database.

RESULTS AND DISCUSSION

Surface sediment samples from throughout LIS record a uniform arboreal palynological signal that is dominated by *Quercus, Carya, Betula, Pinus,* and *Tsuga* (Figure 2). No significant difference in pollen rain exists among these twenty samples ($p < 0.20$, degrees of freedom = 48). The composition of this 'modern' pollen assemblage within the surface sediments accurately reflects the primary constituent taxa of the regional vegetation. The relative abundances of *Quercus* (~ 20%), *Carya* (~4%), and *Tsuga* (~6%) pollen corresponds closely with the relative abundance of these taxa within the surrounding forest (BRAUN, 1964; LULL, 1968; DELCOURT *et al.*, 1984; RUSSELL *et al.,* 1993). In comparison, *Betula,* an abundant pollen producer, is somewhat overrepresented in the palynological assemblage (~10%) relative to vegetation abundance (< 10% of basal area of regional vegetation) (JACKSON, 1990; CALCOTE, 1995) (Figure 2).

Pinus is prevalent in the regional vegetation and a prolific pollen producer (CALCOTE, 1995) (Figure 2). *Pinus* percentages in LIS (5–12%) compare favorably with those determined in other studies from smaller lakes in the region (5–15%) (DAVIS, 1969; JACKSON, 1990; BEUNING, 1998, unpub. data). An abundance of "Conifer Equivalent' grains, however, suggests a greater relative abundance of *Pinus* pollen in LIS than in surrounding lake basins. The morphology of many coniferous pollen grains, like *Pinus, Picea,* and *Abies,* includes two "bladders", or air sacs, that aid in wind transport of the grains. These bladders frequently break off from the body of the grain. In isolation, it is difficult to assign a bladder confidently to a specific type of coniferous grain. The "Conifer Equivalent" type in Figure 2 includes these unidentified bladders. Undoubtedly, over 90% of the "Conifer Equivalent" grains derive from *Pinus* based on ratios of identified coniferous grain genera and abundance of the potentially contributing coniferous species on the southern New England landscape. Note that the few samples with relatively low *Pinus* concentrations (*i.e.* #26–01 and #23–04) also have the highest percentages of conifer equivalents (Figure 2). Combining the identified *Pinus* grains with the "Conifer Equivalents" makes the total percentage of *Pinus* in the 'modern' pollen of LIS between 20 and 30% (Figure 2). These relatively higher percentages of *Pinus* pollen in LIS (20 to 30%), as compared with nearby smaller lakes to the north (5 to 15% *Pinus* pollen), probably result from long distance transport of *Pinus* pollen from abundant *Pinus* populations to the west and south of southern New England to the LIS surface.

The predominant, identified, non-arboreal taxon in the pollen rain is *Ambrosia artemisiifolia* comprising between 5 and 15% of the modern pollen rain. An abundance of *Ambrosia* is expected due to extensive vegetation "disturbance" and human settlement in the LIS pollen source area (BRUGAM, 1978).

The modern pollen data from LIS shows a strong correspondence with surface sediment samples from adjacent lakes in southern Connecticut. Analysis of pollen in surface sediments of Rogers Lake (41°22′N; 72°7′W) (DAVIS, 1969) and Lake Quonnipaug (41°27′N; 72°38′W) (BEUNING, unpub. data) confirms a 'modern' regional pollen rain in southern

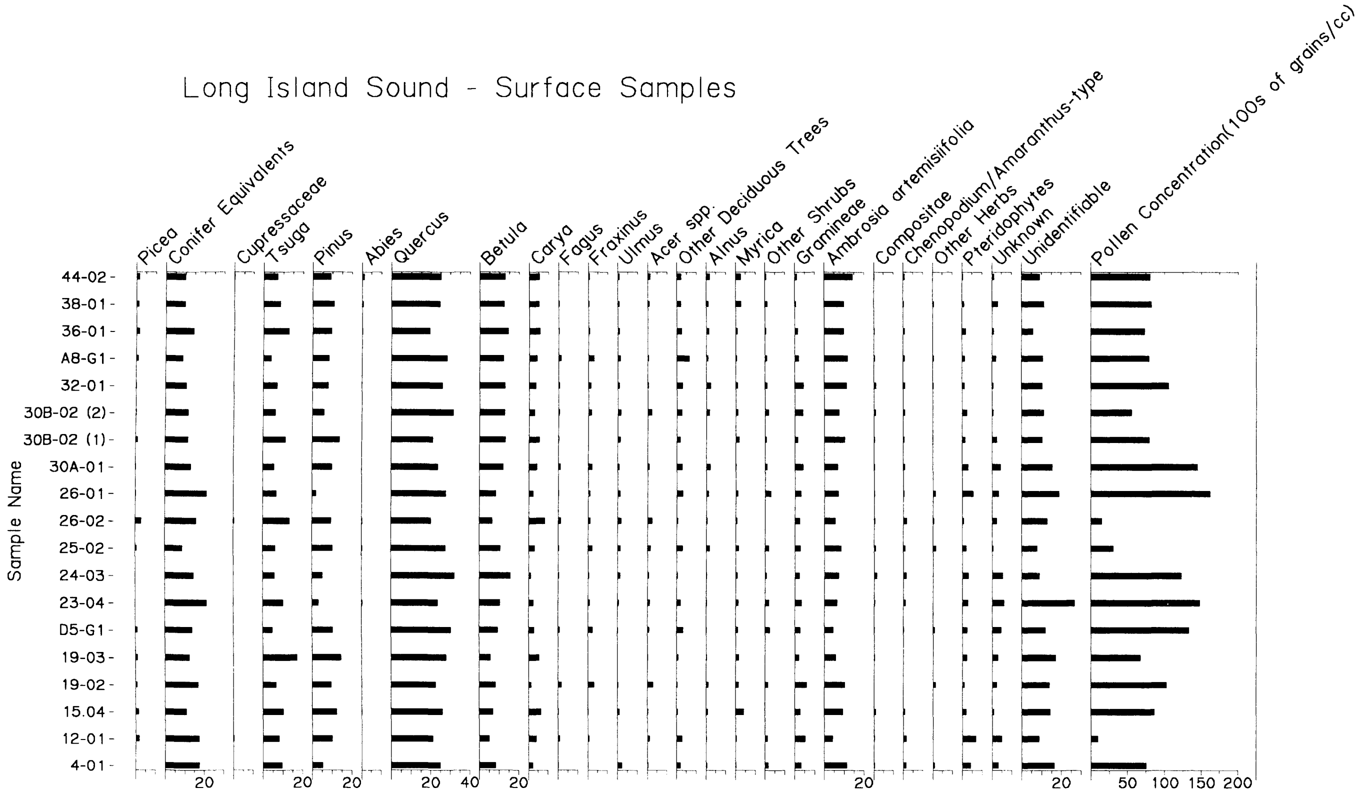

Figure 2. Pollen diagram of surface sediment samples from Long Island Sound. All samples are derived from cruise SEAX 96017 with station names provided along the y-axis. Stations are arranged in this figure from west to east geographically with the first sample, #44-02, from the westernmost site, and bottom sample, #4-01, from the easternmost site. Percentages were determined as the percent total of all identified, non-aquatic pollen grains. "Conifer Equivalents" refer to unidentifiable 'bladders' of coniferous grains with two bladders equivalent to one pollen grain. Genera compiled under "Other Deciduous Trees" include: *Celtis, Nyssa, Liquidambar, Ostrya/Carpinus, Juglans, Castanea, Salix* and *Tilia*. "Other Shrubs" include: *Ilex, Corylus* and *Cephalanthus* and "Other Herbs" include Ericaceae, *Plantago, Thalictrum,* and *Typha*. Unidentifiable grains include those that were broken, crumpled or corroded due to poor pollen preservation in LIS sediments and abundant pyrite that often obscures the surface texture and shape of the grains.

New England dominated by *Quercus, Carya, Pinus,* and *Betula*. This consistency is maintained despite intersite differences in the size and depositional nature of the basins. Terrestrial vegetation within the LIS pollen source area represents a combination of secondary white oak-pine-hickory forest, agricultural land, and urban environments. Although the Connecticut landscape may have a somewhat larger forested component than Long Island or the New York City metropolitan area, the composite vegetation composition at the spatial scale of the entire LIS pollen source area is reasonably uniform. Thus, a regionally consistent pollen rain is transported to the LIS surface that is then further mixed within the water column. As a result, any small-scale patchiness in the surrounding vegetation is not recorded by spatial variability in pollen-type composition or abundance in LIS sediments.

The uniform composition of the 'modern' pollen assemblage within the Sound provides clues as to pollen transport mechanisms and depositional processes acting within LIS. Some pollen must be transported by wind to the basin and then well-mixed within the water column both prior to deposition and by mixing of "new pollen" with pollen in resuspended sediments. This process averages the variable monthly pollen deposition over the course of a year as well as integrates the pollen signal of multiple years. In addition, riverine input must be minimal, or pollen transported by rivers to the Sound must be rapidly incorporated into the mixing waters without differential settling near river inflows. These results are consistent with work of other researchers who have demonstrated that most fine-grained sediments are well-mixed prior to sedimentation within the tidally-influenced Sound (BUCHHOLTZ TEN BRINK *et al.,* this volume; KNEBEL and POPPE, this volume; MECRAY and BUCHHOLTZ TEN BRINK, this volume; SIGNELL *et al.,* this volume).

Minor variations in pollen concentration among LIS surface samples do occur (900 to 16,000 grains/cm^3) (Figure 2, Table 1). Weak relationships between weight % fines and pollen concentration (r^2 = .30) suggest increased pollen deposition in zones of the Sound with fine-grained sediment accretion (Figure 3). Samples with pollen concentrations less than 5000 grains/ cm^3 derive from the eastern erosional zone or the central sand/shoal complex (Figures 1, 2). Greatest con-

Table 1. *Locations and pollen concentrations of select LIS surface sediment samples from the SEAX96017 cruise.*

Sample Name	Longitude (W, decimal degrees)	Latitude (N, decimal degrees)	Pollen concentration (grains/cm³)
4-01	−72.30	41.23	7600 ± 760
12-01	−72.54	41.22	900 ± 90
15-04	−72.68	41.02	8700 ± 870
19-02	−72.76	41.17	10300 ± 1030
19-03	−72.78	41.09	6700 ± 670
23-04	−72.83	41.22	14800 ± 1480
24-03	−72.94	41.02	12300 ± 1230
25-02	−72.96	41.07	3000 ± 300
26-01	−72.96	41.19	16200 ± 1620
26-02	−72.97	41.13	1500 ± 150
30A-01	−73.09	41.14	14500 ± 1450
30B-02 (1)	−73.12	41.02	7900 ± 790
30B-02 (2)	−73.12	41.02	5600 ± 560
32-01	−73.16	41.07	10500 ± 1050
36-01	−73.27	41.09	7300 ± 730
38-01	−73.35	41.03	8200 ± 820
44-02	−73.55	40.96	8100 ± 810
A8G1	−73.27	40.98	7900 ± 790
D5G1	−72.84	41.15	13300 ± 1330

centrations of pollen (samples > 10,000 grains/cm³) occur only in the central portion of the basin where fine-grained sediment accretion occurs today (Figure 2, Table 1). Samples in this region do not have significantly higher TOC (Total Organic Carbon) concentrations than other samples in the basin (Figure 4). These results suggest that the central region has either a relatively low sedimentation rate of well-mixed, inorganic and organic depositional sources or that an alternative mechanism exists for concentrating pollen within these centrally-located sediments (*e.g.* possible scavenging by animals). Since these "high" pollen concentration samples include both nearshore and offshore samples, increased pollen concentrations due to local terrestrial or riverine deposition is unlikely. Ongoing analyses of short-core data will provide additional information on mass accumulation rates throughout the basin.

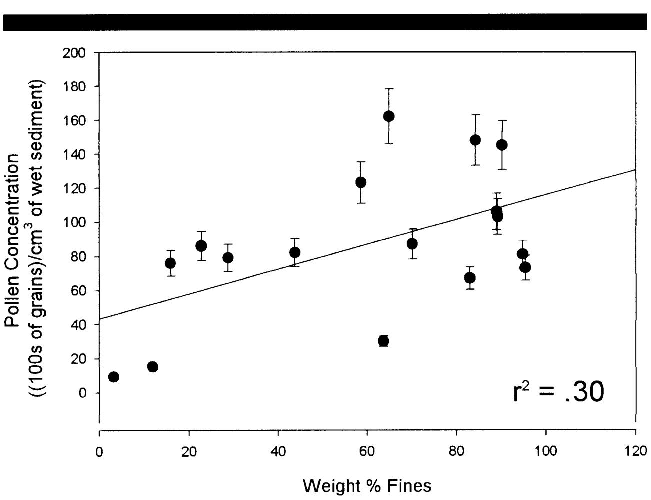

Figure 3. Pollen concentration (grains/cm³ × 100) vs. weight percent of fine-grained material in Long Island Sound surface sediment samples.

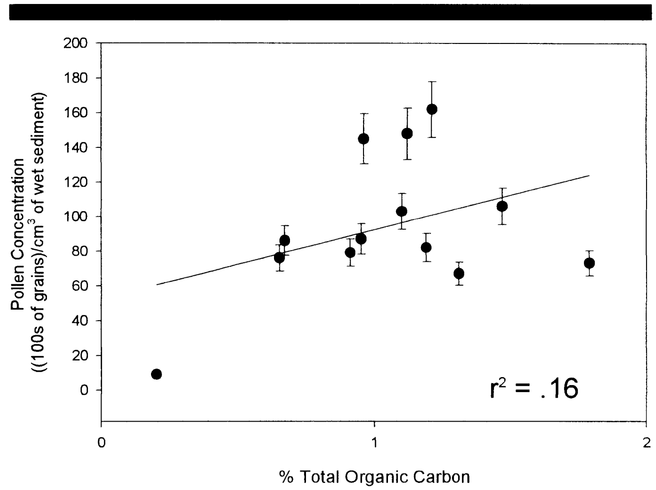

Figure 4. Pollen concentration (grains/cm³ × 100) vs. percent total organic carbon in Long Island Sound surface sediment samples.

IMPLICATIONS FOR RECONSTRUCTION OF ENVIRONMENTAL CHANGE FROM LONG ISLAND SOUND SEDIMENTS

This study demonstrates that a uniform pollen assemblage is deposited in the surface sediments throughout the LIS basin. As a result of thorough mixing of input pollen, palynological analysis of single sediment cores from LIS should be representative of the basin as a whole. This uniform pollen deposition strongly supports use of select regional palynological boundaries as chronostratigraphic tools for interpretation of the late glacial and Holocene history of the LIS basin. Internal consistency among data contributing to regional isopollen and paleovegetation maps confirms the feasibility of this technique in southern New England (WEBB *et al.,* 1993). In addition, independent tests (*e.g.* ^{210}Pb) of the synchroneity of similar pollen events in Chesapeake Bay demonstrate the viability of using pollen stratigraphic horizons as dating tools in large estuarine depositional environments (BRUSH *et al.,* 1982; BRUSH, 1989; COOPER and BRUSH, 1991; CRONIN *et al.,* 2000). However, the robustness of this chronological tool depends upon use of only predominant arboreal taxa and careful consideration of taphonomic processes across regional, radiocarbon-dated sites prior to application of regional coeval pollen-stratigraphic markers for dating of LIS sediments (BRUSH *et al.,* 1982; NEWNHAM and LOWE, 1999). Furthermore, while mixing of LIS sediments by tidal and other currents provides a well-mixed, spatially-uniform palynological assemblage, this same mixing should result in a smoothed temporal signal of vegetation change. As a result, an abrupt terrestrial vegetation change may appear gradual in the LIS sediments and result in some uncertainty when assigning a pollen-stratigraphic date. Yet, the *Ambrosia* rise, *Castanea* decline and deciduous species' "introductions" into the southern New England landscape during the Holocene are expected to provide excellent age-constraints for developing a chronology of Holocene environmental change derived from the sedimentary records of LIS.

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