

**MACROFOSSIL EVIDENCE FOR MIDDLE TO LATE HOLOCENE  
VEGETATION SHIFTS AT IONA ISLAND MARSH, HUDSON VALLEY, NY**

A Final Report of the Tibor T. Polgar Fellowship Program

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## **ABSTRACT**

As a continuum from past to present, environmental change cannot be understood by analyzing modern day ecosystems alone. The sediments of marshes can be used for analysis of paleoenvironment, as exemplified by previous work on the tidal marshes of the Connecticut River, the Hackensack Meadowlands, and the Chesapeake Bay. Fewer such studies have been completed on tidal marshes of the Hudson River Estuary. Using 202 macrofossil samples and 198 loss-on-ignition samples covering a 900 cm depth sediment core, a high resolution paleoenvironmental record was constructed for the Iona Island Marsh component of the Hudson River National Estuarine Research Reserve. Macrofossil samples from seven depths throughout the core were dated using radiocarbon accelerator mass spectrometry, and a sedimentation rate graph was extrapolated. The sediment core contained six distinct paleoecological zones and had a bottom date of 4384 BCE. The modern zone from 1300 to 2000 CE was characterized by invasive macrophyte species and increased inorganic sedimentation rates correlated with anthropogenic impact. Shifts in climate, including the Medieval Warm Interval at 800 to 1300 CE, were seen through vegetational species composition and charcoal levels. Knowledge of Iona Island Marsh's paleoenvironment is useful for understanding paleoclimate and current climate change, realizing the effects of anthropogenic activity, and facilitating educated tidal marsh restoration efforts in the Hudson Valley.

## TABLE OF CONTENTS

Abstract.....	II-2
Table of Contents.....	II-3
Lists of Figures and Tables.....	II-4
Introduction.....	II-5
Methods.....	II-8
Study Site.....	II-8
Sediment Coring.....	II-9
Macrofossils.....	II-11
Radiocarbon Dating.....	II-13
Loss-on-ignition.....	II-14
Results.....	II-14
Discussion.....	II-23
Acknowledgments.....	II-30
Literature Cited.....	II-31

## LIST OF FIGURES AND TABLES

Figure 1 – Map of study site.....	II-9
Figure 2 – Map of sediment core sites.....	II-11
Figure 3 – Select photos of macrofossil seeds.....	II-13
Figure 4 – Cesium-137 profile.....	II-15
Figure 5 – Sedimentation rate graph .....	II-16
Figure 6 – Macrofossil and LOI diagram .....	II-17
Figure 7 – Pollen diagram.....	II-28
Table 1 – AMS carbon-14 dates.....	II-15

## INTRODUCTION

Tidal marshes are valuable archives of environmental change because they generally keep pace with changing sea levels instead of being subject to erosion, resulting in uninterrupted sediment accumulation (McCaffrey and Thomson 1980). They are also one of the most productive and diverse types of ecosystems on the planet (Mitsch and Gosselink 2007). These characteristics make them useful study sites in the field of paleo-environment where a rich and continuous historical record is needed to reconstruct and understand the past. In particular, the marshes of the Hudson River are high depositional wetlands with depths ranging from 10-12 m over the last 4000-6000 years, allowing for high resolution analysis (Newman et al. 1987; Wong and Peteet 1999; Pederson et al. 2005; Peteet et al. 2006).

On the eastern coast of the United States, paleoenvironmental research includes studies of the tidal marshes of Connecticut (Thomas and Varekamp 1991; Varekamp and Thomas 1998), the Hackensack Meadowlands of New Jersey (Carmichael 1980), and Chesapeake Bay (Brush et al. 1982; Pasternack et al. 2001; Willard et al. 2003). However, not until recent years have detailed studies on the tidal marshes of the Hudson River begun (Pederson et al. 2005; Peteet et al 2006). Hudson tidal marsh studies presently include a transect from south to north from Jamaica Bay's JoCo Marsh, Jamaica Bay's Yellow Bar Marsh, and Staten Island's Arthur Kill Marsh northward to Piermont Marsh, Croton Point Marsh, Iona Island Marsh, Tivoli Bays Marsh, and Stockport Flats Marsh (Peteet et al. 2006; Peteet et al. in 2010; Sritrairat et al. in prep). Because Piermont Marsh, Iona Island, Tivoli Bays, and Stockport Flats are the four component sites of the Hudson River National Estuarine Research Reserve (HRNERR), these

wetland paleorecords are especially meaningful because the sites are designated protected areas established for longterm research, education, and stewardship (NERR 2008).

Downcore results from pollen and/or macrofossil analysis from the Hackensack Meadowlands (Carmichael 1980), Piermont Marsh (Pederson et al. 2005), and Tivoli Bays (Sritairat et al. in prep) all show variations in species composition due to both the effects of climate change and anthropogenic activity. The main objective of this study was to perform a macrofossil analysis on a sediment core from Iona Island Marsh. Macrofossil analysis reconstructs the changes in local vegetation over time by examining the fossil seeds, stems, leaves, and other plant or animal parts found in the marsh sediment. Because seeds deposited in the surface sediment of fluvially and tidally dynamic environments such as estuarine marshes have been found to represent the local mature vegetation (Carmichael 1980; Goman 2001), fossil seeds deposited at depth in the accumulated sediment of the marshes are assumed to be representative of the communities throughout millennia. Wetland cores are valuable for this type of analysis because the environment is dynamic, and there can be yearly changes in species composition, distribution, and dominance that reflect changes in surface soil, artificial destruction, pollution, fluctuating water levels, and salinity (Senerchia-Nardone et al. 1986). As a HRNERR site, Iona Island Marsh provides a valuable regional comparison for ongoing research at the other three HRNERR sites and for the Hudson Valley. The macrofossil analysis for Iona Island Marsh was used in conjunction with the pollen analysis that was already completed for the top meter of the sediment core (Peteet et al. personal communication). Because seeds are heavier and do not travel as far as pollen, the macrofossil results are more site specific, while pollen provides a regional overview

of ecosystem history. Macrofossils can also be identified to the species level more often than pollen which is usually only identified to the family or genus.

To achieve a more complete paleoenvironmental picture of Iona Island Marsh, loss-on-ignition (LOI) was performed on the sediment samples to determine the organic content of the marsh through time. Accelerator mass spectrometry (AMS) radiocarbon dating was used to find the age of the individual seeds through time and to understand sediment accumulation rate. A complete cesium-137 profile for a different Iona core from the same location provides another means for recent dating (Peteet and Chillrud unpublished). The peak in cesium-137 fallout seen in the profile occurs just before the 1963 nuclear test ban treaty (Mahara 1993).

By reconstructing the paleoenvironment of Iona Island Marsh, this study answers the following questions: (1) How has the vegetative species composition in the local area changed over time? (2) How have the deposition rate and organic content of the marsh sediments changed? (3) What does the paleoenvironmental record indicate about changes in climate? (4) In what ways has anthropogenic activity impacted the marsh? (5) How does the paleoenvironmental record at Iona Island Marsh compare to the records of other marshes in the area?

## METHODS

### *Study site*

Iona Island, located on the western shore of the Hudson River in Rockland County, New York, is one of the four HRNERR component sites (Figure 1). The Iona Island reserve consists of Iona Island, Ring Meadow, Salisbury Meadow, and Round Island. Covering 556 acres, the reserve contains brackish intertidal mudflats, brackish tidal marsh, freshwater tidal marsh, and deciduous upland forests. Doodletown Bight is its principle tributary (NERR 2004). Iona Island Marsh, which is the focus of this study, refers to the brackish tidal marsh formed by the Salisbury Meadow and Ring Meadow portions of the reserve. The marsh, along with shallows and mudflats, extends one mile westward from Iona Island to U.S. Highway 9W. A causeway extends from 9W in a northeasterly direction into the marsh near its midsection and a railroad line bisects the site in a southeasterly direction (Figure 2).



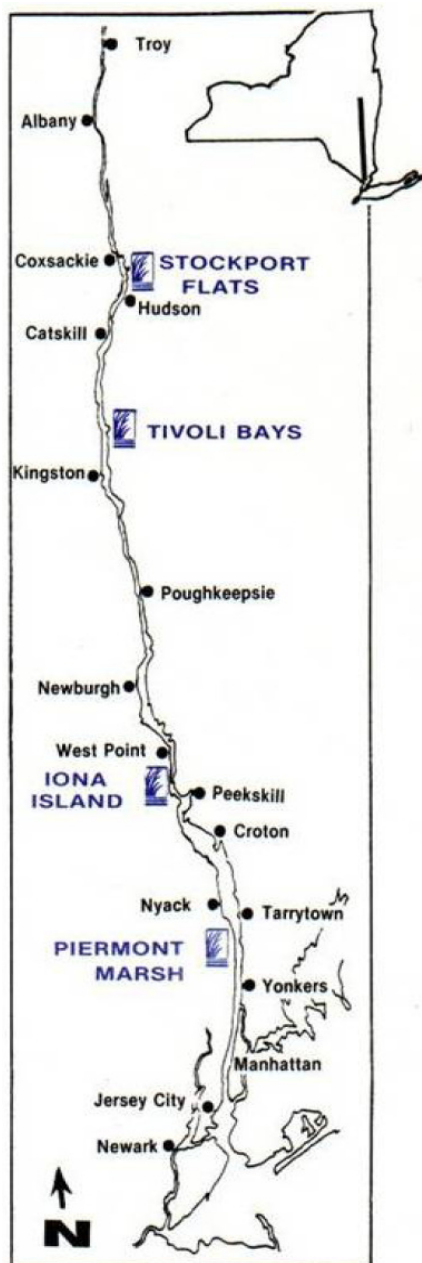


Figure 1. Map of the four NERR components for the Hudson River, including Iona Island (HRNERR 1992).

### *Sediment coring*

The 00-Iona1 core was taken in June of 2000 just west of the railroad tracks and slightly south of the causeway that runs east through the island, at 41°18' N and 73°58'

W. A 5-cm diameter modified Livingstone piston corer (Wright et al. 1984) was used to retrieve 5.35 m of sediment, after hitting silt, sand, and gravel at the base. The 00-Iona2 core was taken on the same field trip 250 m northeast of the first core, just south of the causeway, halfway between 9W and the railroad at 41°18' N and 73°58' W (Figure 2). A modified Livingstone piston corer was again used to retrieve 9.3 m of peat atop gravelly silt. These two cores were wrapped with polyethylene and an outer layer of aluminum foil in 1 m sections and stored horizontally in a refrigerator at Lamont-Doherty Earth Observatory, NY. The 00-Iona2 core is the focus of the macrofossil and LOI analyses in this study and the pollen diagram that is consulted.

Another core, called 01-Iona3, was taken from the same location as the 00-Iona2 in 2001, using a 60 cm clear plastic pipe (Figure 2) and stored in the same way. Cesium-137 analysis was performed on this core.

In 2007, a 10-cm diameter Dachnowski corer was used to take the 1 m long Iona07-RC01 core from the same coordinates as the 00-Iona2 core (Figure 2). At the same time, a second 1 m length core, Iona07-RC02, was taken using the Dachnowski corer at 41°18' N and 73°59' W, which is south of the causeway and close to 9W and the entrance of the marsh. These cores were stored in PVC half pipe liners and D-tube containers with a wet sponge to preserve moisture levels and kept in a refrigerator. X-ray fluorescence spectrometry analysis is being performed on the Iona07-RC01 core.

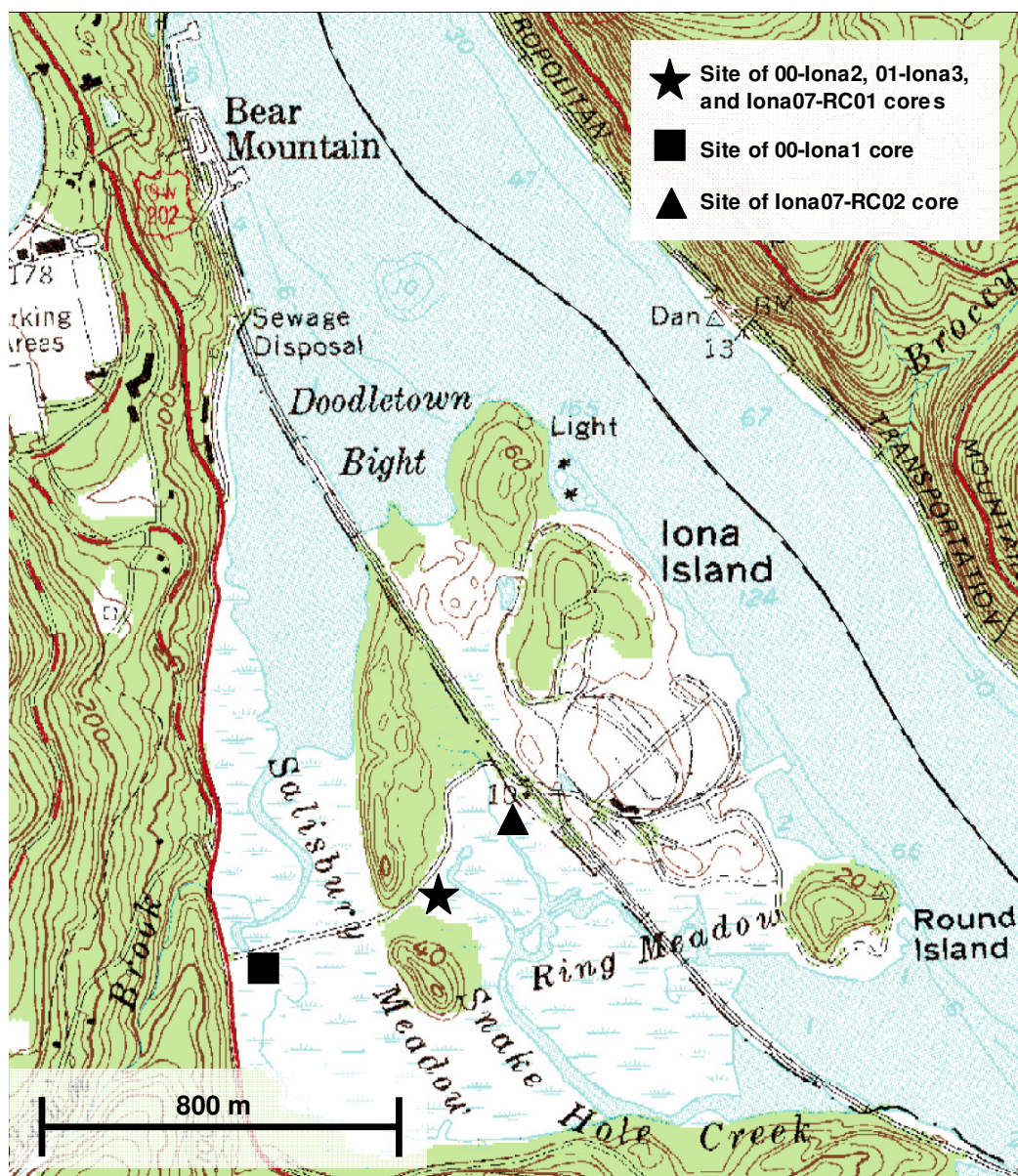


Figure 2. Topographical map of Iona Island and core locations.

### *Macrofossils*

The 00-Iona2 core was vertically split to preserve an archive half. The working half of the core was then divided into 5 cm long samples for the first meter and then 4 cm long samples for the remaining meters to make 202 samples of approximately 20 cc. The samples were soaked overnight in water if extremely dry, and then washed through

screens of 0.5 and 0.125 mm or directly washed using water through the screens if moist. The seeds, charcoal, insects, foraminifera, and other plant parts in the screened sediment were picked out using tweezers and examined using a dissecting microscope with magnifications between 20X and 60X. The samples were stored in distilled water and kept refrigerated (Watts and Winter 1966).

Macrofossil seeds (Figure 3) found were identified using photos, drawings, and descriptions in seed and fruit identification manuals (Berggren 1981; Katz et al. 1965; Knobel 1980; Martin and Barkley 1961; Montgomery 1977), other botanical publications such as *Gray's Manual of Botany* (Fernald 1970) and Britton and Brown (1970), Fassett (1957), Hotchkiss (1970), and the USDA's online PLANTS database (USDA PLANTS 2009). Seeds and other plant parts were also compared to a reference collection and reference slides in the lab. A macrofossil diagram was produced using Tilia and Tiliagraph (Grimm 1992), and the core was divided into six macrofossil zones based on visual inspection of broad patterns in vegetation composition. The sampling intervals used in the diagram were corrected for compression that occurred in each meter section during coring with Equation 1:

$$\frac{\text{Sample interval size (cm)}}{\text{Core section length (cm)}} = \frac{\text{Stretched interval size (cm)}}{\text{Corrected core section length (100 cm)}} \quad [\text{Equation 1}]$$



**Figure 3. Macrofossil seeds found in Iona Island Marsh sediment core, clockwise from top left: *Schoenoplectus americanus*, *Cladium mariscoides*, *Phragmites australis*, and Unknown seed A.**

### *Radiocarbon dating*

Four dried macrofossil samples from various depths throughout the 00-Iona2 core were sent either to the Center for Accelerator Mass Spectrometry (CAMS) at Lawrence Livermore National Laboratory (LLNL) in California or the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) at Woods Hole Oceanographic Institution (WHOI) in Massachusetts for radiocarbon dating (Table 1). Three additional macrofossil samples have been sent for analysis, chosen judiciously after the diagram had been plotted, to date significant transitions in vegetation. The second group of samples includes six *Cladium mariscoides* seeds at 105-100 cm, ten *Schoenoplectus americanus* seeds at 313-309 cm, and one *Pinus rigida* needle plus two *Schoenoplectus americanus* seeds at 812-808 cm. Objects least likely to have been contaminated with older or younger organic materials, such as seeds with tough outer coats, were selected to be dated, and objects that were likely to be different in age from the rest of the sample, such as living plant roots, were avoided. The radiocarbon dates were calibrated into calendar

year dates using CALIB 5.0.1. from Queen's University Belfast (Stuiver et al. 2005), and results are presented in calendar years before common era (BCE) and common era (CE).

### *Loss-on-ignition*

LOI has thus far been calculated for the top three meters of the 00-Iona2 core. A 1 cc subsample was taken every 5 cm for the top meter and then every 4 cm for the other two meters. The wet samples were weighed on a gram balance and then dried at 100°C for 24 hours. The dry samples were weighed and then combusted at 450°C for one hour (Dean 1974). The combusted samples were then weighed and the organic content of the samples was calculated according to Equation 2:

$$\text{Loss-on-ignition (\%)} = \frac{\text{Dry weight} - \text{Combusted weight}}{\text{Dry weight}} \times 100 \quad [\text{Equation 2}]$$

Like the macrofossil data, the LOI results were plotted in the macrofossil diagram on Tilia and Tiliagraph and the intervals were corrected for shrinkage that occurred to each meter during longterm storage, using Equation 1.

## **RESULTS**

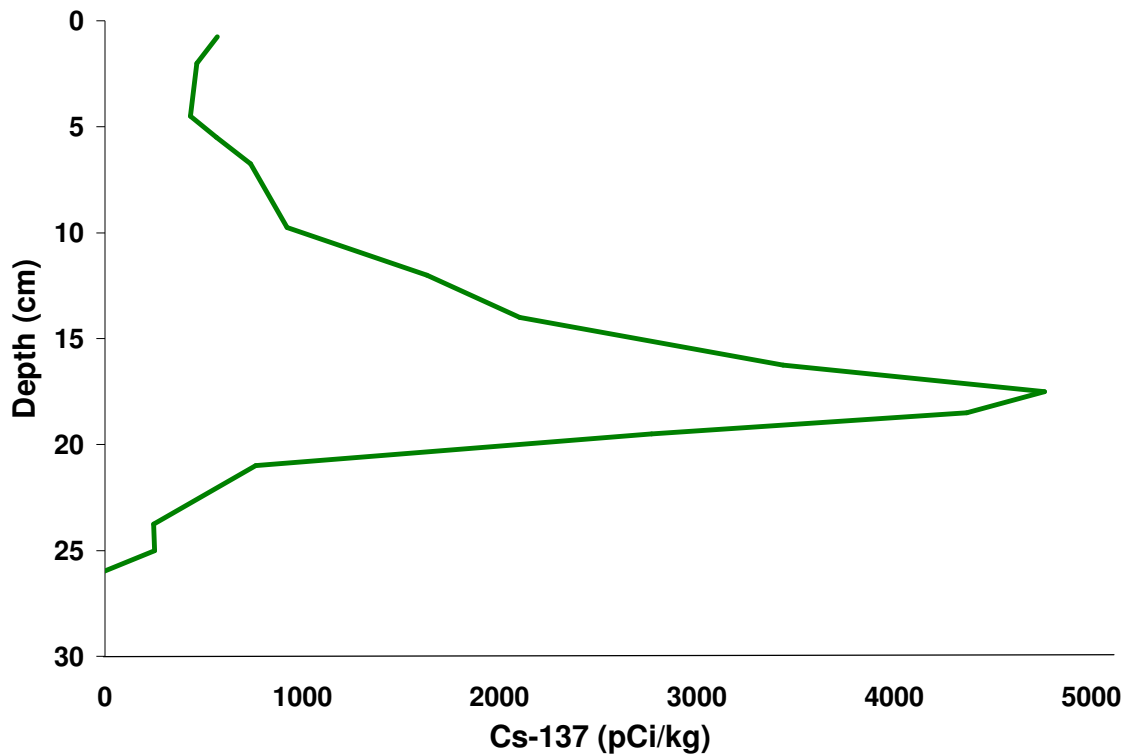
The macrofossil sample from the bottom of the core dated Iona Island Marsh to be  $6834 \pm 65$  years old (Table 1). The cesium-137 profile (Figure 4) showed the 1963 bomb peak to be at 17.5 cm, which was calibrated to 29 cm after accounting for compression, using Equation 1. A sediment accumulation rate graph was created using linear interpolation between the radiocarbon and cesium-137 dates (Figure 5). The graph shows that between 4384 BCE and 1963 CE, the sedimentation rate was fairly constant, staying

below 0.20 cm/yr. However, since 1963, the sedimentation rate has increased dramatically to 0.78 cm/yr.

**Table 1. AMS carbon-14 data including sample descriptions and calibrated dates.**

Lab ID Number	Sample depth (cm)	Items analyzed	Uncorrected $^{14}\text{C}$ year B.P. age	Calibrated 2-sigma age range (cal years)	Calendar age (cal years)
83754 (CAMS)	55-50	3 <i>Schoenoplectus</i> sp. seeds	$145 \pm 40$	1796 CE-1892 CE (36%)	$1844 \pm 48$ CE
83229 (CAMS)	70-65	1 sedge node, 2 charcoal pieces	$105 \pm 40$	1679 CE-1764 CE (33%)	$1722 \pm 58$ CE
83756 (CAMS)	162-157	2 sedge nodes	$1550 \pm 60$	399 CE-634 CE (100%)	$516 \pm 117$ CE
29006 (NOSAMS)	900-894	Rhizomes	$5500 \pm 40$	4449 BCE-4319 BCE (87%)	$4384 \pm 64$ BCE

Relative percent area represented by the calendar range is shown in parentheses ( ).



**Figure 4. Cesium-137 profile for 01-Iona3 core (Peteet and Chillrud unpublished).**



The macrofossil results showed that the vegetation at Iona Island Marsh has developed through 6 distinct zones of species assemblages (Figure 6). Dates for the zones were estimated using the sedimentation rate graph. Fossil seeds were abundant throughout the core and found in every sample, with the largest count for one species being 178 *Schoenoplectus americanus* seeds at 553-548 cm. *Schoenoplectus americanus* also had the greatest relative abundance throughout the core, followed by *Cladium mariscoides*. The percent loss-on-ignition, sampled from 300 to 0 cm in 65 samples, ranged from 20% to 73% and is presented in the leftmost column.

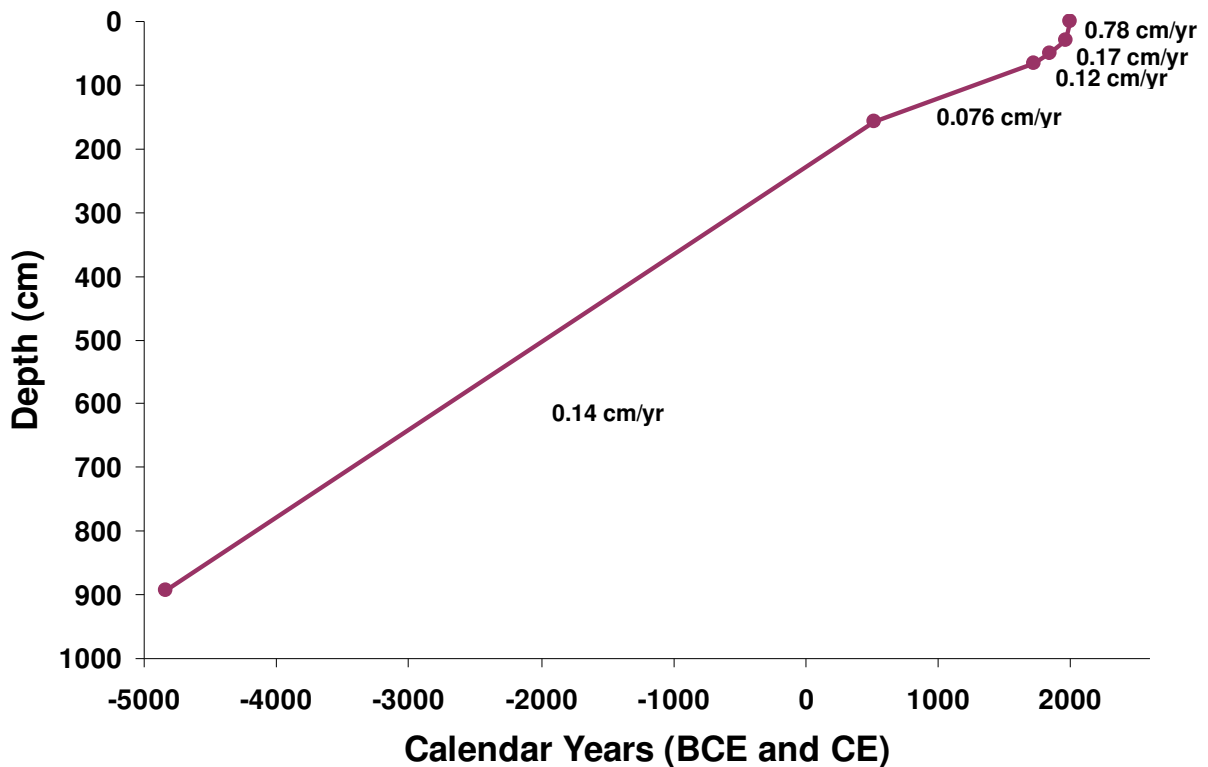


Figure 5. Sedimentation rate graph for 00-Iona2 core.





*Zone I-1 (900-808 cm; 4384 BCE to ~4180 BCE)*

Upland species not found in the rest of the core such as *Juniperus virginiana*, *Pinus rigida*, *Carya tomentosa*, *Ostrya virginiana*, *Vaccinium sp.*, and *Gaylussacia sp.* were found in this zone. *Pinus rigida* was especially well documented, with cone scales, needle scales, seeds, and both single needle fragments and fascicles of three needles found. The needle fragments were most abundant, with up to 11, 12, 14, and 17 estimated whole needles found per sample. Up to four *Pinus rigida* seeds were observed per sample. *Pinus strobus*, although also found further up the core, was seen in this zone as well.

Charcoal was more abundant in this zone than throughout most of the rest of the core, and peaked towards the middle of the zone at 21 pieces. This mid-zone peak was similarly seen in the abundance of *Schoenoplectus americanus*. *Schoenoplectus americanus* was found in every sample, in moderately abundant amounts, as compared to its abundance in Zones 2 and 4. Samples contained between 10 and 60 *Schoenoplectus americanus* seeds each. There was also a moderate amount of *Schoenoplectus robustus* compared to its abundance in the rest of the core, although it was much less abundant than *Schoenoplectus americanus*, appearing once in four of the samples. A lenticular *Carex sp.* and a few unidentified seeds were also present.

*Zone I-2 (808-692 cm; ~4180 BCE to ~3400 BCE)*

This zone differs from the previous in having no upland species except for a single *Pinus strobus* seed. It had high species richness in terms of the *Cyperaceae* (sedge) family, with lenticular *Carex sp.*, *Schoenoplectus americanus*, *Schoenoplectus*

*robustus*, *Scirpus atrovirens*, *Eleocharis palustris*, and *Cladium mariscoides* all present. *Schoenoplectus robustus* reached its peak abundance in this zone with eleven samples having up to six seeds each. *Schoenoplectus americanus* was also more abundant in this zone than the previous one, in a gradually increasing trend as the top of the zone is reached with a maximum of 143 seeds. Charcoal levels were generally lower than the previous zone, with one sample containing 49 pieces but most other samples containing less than 20 pieces.

#### *Zone I-3 (692-633 cm; ~3400 BCE to ~2900 BCE)*

This was the smallest zone, spanning only 59 cm. It was characterized by Unknown seed C, an approximately  $1.5 \times 1.0 \times 1.2$  mm cuneate brown seed with sparse vertical seams that was unique to this zone. Unknown seed C was found in seven samples in abundances of up to 25 seeds each. This zone also had the greatest abundance of lenticular *Carex sp.* as compared to its abundance throughout the rest of the core, appearing in eight samples, peaking with 13 seeds at 692-687 cm and 18 seeds at 675-671 cm. It had a relatively high abundance of *Eleocharis palustris* as compared to the rest of the core, with four samples having up to six seeds each. Another characteristic of this zone, compared to the previous and the next zones, was lower levels of *Schoenoplectus americanus*. Although every sample had *Schoenoplectus americanus*, they all contained 71 or fewer seeds. Charcoal levels in this zone were similar to the previous, while insect parts were slightly more common, found in most samples. Other species found in low amounts were *Schoenoplectus robustus* and *Cladium mariscoides*.

*Zone I-4 (633-304 cm; ~2900 BCE to ~600 BCE)*

Comprising of 329 cm of sediment, this zone spanned about 2300 years. There was a return to the high levels of *Schoenoplectus americanus* as seen in Zone I-2. *Schoenoplectus americanus* was found in every sample, with up to 178 seeds per sample, making it even slightly more abundant than previously. *Eleocharis palustris* continued to be more abundant than it was in the other zones, with five of the samples having up to 5 seeds each. This was also the first zone to have *Cyperus polystachyos*, with four samples near the top of the zone having up to six seeds each. Lenticular *Carex sp.* was found in 15 samples throughout the zone, but in less abundant quantities than in the previous zone, with a maximum of four seeds per sample. Other *Cyperaceae* species found in small amounts were *Schoenoplectus robustus*, *Scirpus atrovirens*, a pale *Scirpus sp.*, and *Cladium mariscoides*.

Upland species unique to this zone were *Betula sp.* and *Nyssa sylvatica*. A *Pinus strobus* seed and needle scale were also found. One lenticular *Polygonum sp.* seed, five unknown seeds, and one foraminifera test was seen. This zone contained the largest amount of moss, with ten samples having up to six pieces each. Charcoal was seen less frequently than in previous samples, but the greatest amount of charcoal in the entire sediment core was found at 374-370 cm, at 105 pieces. There was a similar level of insect parts as in the previous zone.

*Zone I-5 (304-100 cm; ~600 BCE to ~1300 CE)*

There were several shifts in this zone compared to the previous ones. *Cladium mariscoides* was the dominant species found in almost every sample, with up to 49 seeds

in each. *Scirpus atrovirens* was also abundant, found in twenty samples with a maximum of 163 seeds per sample. *Schoenoplectus americanus*, which was previously the dominant species, had a large drop in abundance, with the greatest number of seeds in a sample only 33. However, it was present in almost every sample in lower quantities. *Scirpus robustus*, found in all previous zones, disappeared in this zone. Lenticular *Carex* sp. stayed at a similar level as in the previous zone, as did the level of *Cyperus polystachyos* while *Eleocharis palustris* became less abundant, with only three samples containing one seed each.

Another unique aspect of this zone was the appearance of trigonous *Polygonum* sp., found in three samples with up to three seeds each. This was the only zone with the aquatic cf. *Proserpinaca pectinata*, found in eight samples in the top half of the zone, at up to six seeds per sample. A few unknown seeds, a piece of moss, and a foraminifera test were documented as well. Insect parts reached their peak abundance in this zone.

Only about half the samples in this zone had charcoal present, with most samples having less than eight pieces each, other than one sample with twenty-four pieces at 269-265 cm. Percent LOI data were also available for this zone, with the amount of organic matter fluctuating but then increasing from a low of 20% to a high of 73% at the top of the zone.

#### *Zone I-6 (100-0 cm; ~1300 CE to 2000 CE)*

This recent zone also showed several shifts compared to previous zones. Weedy seeds from *Phragmites australis*, *Typha* sp., and lenticular *Polygonum* sp. became more common. Lenticular *Polygonum* sp. appeared in five samples, with one or two seeds

found each time. *Typha sp.* appeared earlier than *Phragmites australis* at the bottom of the zone, but it was less abundant, with ten seeds at maximum in four samples whereas *Phragmites australis* appeared in fourteen samples of up to 137 seeds each. *P. australis* drastically increased from the bottom to the top of the zone, ranging from 3 to 137 seeds.

The species of the *Cyperaceae* family were much less abundant in this zone, with only a few lenticular *Carex sp.*, trigonous *Carex sp.*, *Cyperus polystachyos*, and pale *Scirpus sp.* seeds found. *Cladium mariscoides* was present in five samples near the bottom of the zone at five or fewer seeds per sample and then disappeared from the sediment. *Schoenoplectus americanus*, found in almost every sample of the core prior to this time, appeared in drastically lower quantities of no more than six seeds per sample in the lower half of the zone and was not found in the upper half.

Unknown seed A, an approximately  $1.0 \times 0.5 \times 0.5$  mm oval fuzzy gray seed was the most abundant species found in this zone and also exclusive to it. It was found in sixteen samples with a maximum of 40 seeds and had an overall increasing trend to the top of the zone, starting from a low presence of two seeds. Unknown seed B, an approximately  $2.5 \times 2.0 \times 2.0$  mm slightly obovate tan colored hard seed with a cream interior, was also exclusive to this zone. It was found in six samples with a maximum of nine seeds each.

There were nine samples with one or two unknown seeds each and one sample with a piece of moss. Insect parts were slightly less abundant than the previous zone. Charcoal was found in most samples, with 17 being the greatest number of pieces in one sample. Percent LOI showed a decreasing trend in the amount of organic matter in the

sediment moving towards the top of the zone, from a high of around 44% to a low of around 25%.

## DISCUSSION

Changes in species composition and the percentage of organic sediment were observed throughout the Iona Island Marsh sediment record and are likely to be indicators of changing climatic conditions and human impact. Between the formation of the marsh around 4384 BCE and the arrival of the first humans around 3500 BCE (NERR 2004), changes in the marsh can solely be attributed to shifts in environmental conditions. Two major shifts in marsh composition occurred during the pre-human period. Between about 4384 and 4180 BCE (Zone I-1), there was an abundance of *Pinus rigida* and elevated charcoal levels, both suggesting a warmer and drier climate. The large presence of upland species not found in the rest of the sediment core may also be a sign of a different physical environment, such as a shift in water levels or depositional environment that allowed the upland seeds to wash into the marsh. At Lake Mohonk, 50 miles to the northwest in the Hudson Valley, a dominance of pitch pine and shallow aquatics indicate dry conditions (Peteet et al. 2009). Regional evidence for a warmer and drier climate at this time in the northeastern US was documented from sites which showed an increase in *Carya* pollen throughout the northeastern US (Deevey 1939; Maenza-Gmelch 1997; Shuman et al. 2004). Between about 4180 and 3400 BCE (Zone I-2), the *Pinus rigida* disappeared and charcoal levels were lower, suggesting a shift in the hydrologic regime.

The next shift in species composition was seen in the period between 3400 and 2900 BCE, shortly after the first Native Americans arrived in the area at 3500 BCE (NERR 2004). Unknown seed C was found only in this zone, so it is possible that it was a species brought to the area by the Native Americans. *Schoenoplectus americanus* declined during this interval, which could be an outcome of Native Americans using the marsh and decreasing its dominance. However, there is no explanation in the macrofossil or cultural record as to why the species differences that appeared about 3400 to 2900 BCE (Zone I-3) were not characteristic of the overlying interval from 2900 to 600 BCE (Zone I-4), which was also quite similar to the previous assemblage 4180 to 3400 BCE (Zone I-2). Thus, environmental change is the more probable reason for the vegetational shifts, and a better understanding of the ecology of these marsh species will enhance our understanding of the nature of these changes. There was no marked increase in charcoal starting at this depth of the core, and charcoal levels were higher in previous zones, so it is likely that fires used by the Native Americans and the later European settlers did not have a huge impact on the record whereas warm periods and droughts in the climate record did affect charcoal levels on a larger scale.

Another interesting shift in local species composition was found at about 600 BCE to 1300 CE (Zone I-5), where the previously dominant *Schoenoplectus americanus* was found at even lower levels than during approximately 3400 to 2900 BCE (Zone I-3), and *Scirpus atrovirens* and *Cladium mariscoides* become the two dominant species. The LOI for this zone showed very high levels of organic sediment, with peaks at 73%, 72%, and 56%. *Cladium mariscoides* prefers oligohaline conditions with a salinity of 0.5-5 ppt, which is the level of salinity found at Iona Island marsh today (Virginia DCR 2006).



Higher salinity levels suggest a warmer and drier climate, and although the marsh is still brackish today, no *Cladium mariscoides* is present. Lack of *Cladium* today is probably due to competition by invasive species such as *Typha* and *Phragmites* in recent millennia. The abundant *Cladium mariscoides* and elevated percentage of organic sediment (up to 73% in the upper part of Zone I-5) from 800 to 1300 CE corresponds to the Medieval Warm Interval which appeared in Piermont Marsh as a time of abundant charcoal along with increased *Pinus* and *Carya* (Pederson et al. 2005). An interesting difference between this interval at Iona and Piermont is in organic content, which was elevated at Iona but declined at Piermont, probably due to differences in their depositional environments. While Piermont recorded an increase in inorganic sediment presumably due to erosion-driven drought in the estuary, Iona recorded the opposite, presumably due to increased production from the dominance of *Cladium*.

The modern era of the marsh between about 1300 to 2000 CE (Zone I-6) was marked by human influence. This was the only zone with *Phragmites australis*, *Typha* sp., Unknown seed A, Unknown seed B, and very little *Schoenoplectus americanus*, making it feasible that it marked the arrival of Europeans who carried in new species and changed the habitat for old species. 1300 CE is, however, too early for known European arrival on Iona Island, which has been recorded at 1683 CE (NERR 2004). 1300 CE correlates to about 100 cm in the sediment core, which also marks the point when LOI dropped from 73% to 33%. This decline may have been due to Native American disturbance. European arrival has often been recorded in pollen records of the northeastern United States with a rise in *Ambrosia* (ragweed), a weedy species that flourishes as land is deforested (Brugam 1978; Carmichael 1980; Russell et al. 1993;

Pederson et al. 2005). In the pollen diagram for the 00-Iona2 core, the *Ambrosia* rise was seen at 60 cm depth (Figure 7), which was extrapolated on the sedimentation rate graph to roughly equal 1700 CE, making it plausible that European arrival in 1683 increased the abundance of *Ambrosia* at Iona Island marsh. Also at 60 cm on the pollen diagram was the beginning of a large rise in *Typha*, another weedy species that likely benefited from human disturbance. There was a smaller peak in *Typha* previously, which can be attributed to natural variability or to Native American disturbance. The human induced peak reached 50% for *Typha* pollen counts whereas the natural peak reached less than 20%.

The 60 cm rise in Unknown seed A suggests that it is also a weedy species, possibly an invasive introduced from Europe since it was only found in the top meter of the core. Correlative with this increase at 60 cm was *Phragmites australis*, an invasive hybrid of the native *Phragmites* and a species from Europe (Saltonstall 2002). Unknown seed B showed a small rise beginning around 60 cm as well, making it a candidate for a weedy invasive. Finally, the LOI showed a sharp drop at 60 cm from around 45% to about 30% and below. Human activity, especially in terms of clearing, farming, and road building is known to increase inorganic sediments due to increased runoff. The West Shore Railroad, that is still in use across Iona Island today as the Hudson Subdivision of CSX Transportation, was built in 1882 (Stalter 1996), and undoubtedly contributed to the inorganic increase.

Iona Island played a role during the Revolutionary War (1775-1783) as a strategic defense post (Clarke and Rapuano 1976). Vegetation was cleared from shores along the Hudson River for battles during the war and trees were burned to produce charcoal to

make iron (Cronon 1983). The island was purchased by John Beveridge in 1849 and his son-in-law began to cultivate wine grapes on the land (Binnewies 2001). Commercially growing grapes would also involve clearing the land of native species. By the mid 1800s, a large amount of commercially grown fruit was being produced on the island and during the Civil War it was converted to a resort hotel (NERR 2004). The island became a popular day retreat spot for tourists who liked the vineyards, carousel, ferris wheel, and picnic grounds (Dunwell 1991). All of these historical events account for the declines in *Pinus*, *Tsuga*, *Betula*, *Carya*, and *Quercus* pollen in the era after European arrival (Figure 7).

The heavy anthropogenic activity continued in 1899, when the Navy purchased the island and started constructing a munitions depot the next year, which was used in World War I and World War II. Enough naval munitions were stored on Iona Island to supply both the American and British troops in the Atlantic Ocean during World War I, and after World War II, many decommissioned war and merchant ships were anchored in the Hudson River at Jones Point, just south of Iona Island (Binnewies 2001). During the early 1900s, Round Island was attached to the southern end of Iona Island using fill (NERR 2004). The island was bought by the Palisades Interstate Park Commission in 1965. It was connected to the mainland in the 1980s by a two lane auto road making it easier for people to enter as prior to this time the 16 foot wide road that existed was flooded twice daily (Clarke and Rapuano 1976).

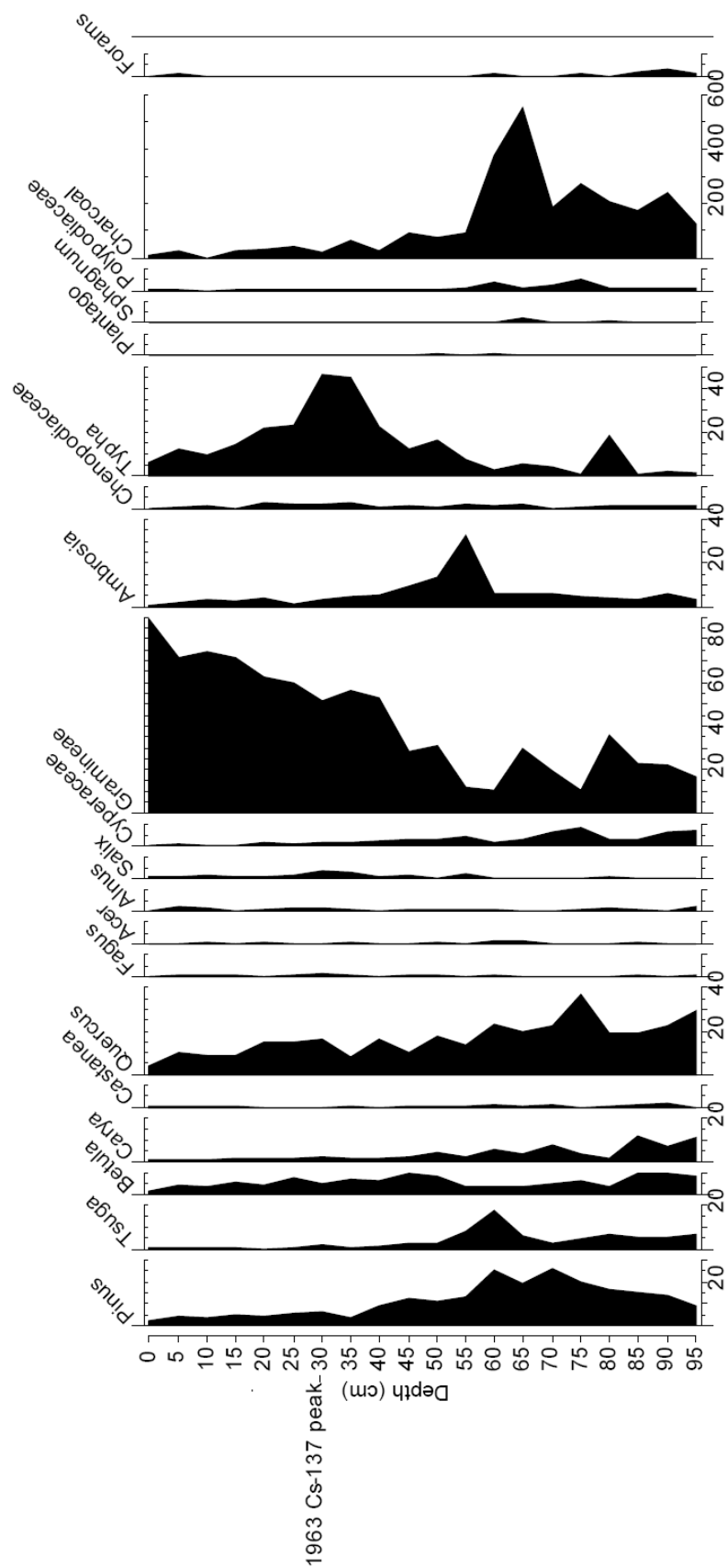


Figure 7. Pollen and spore diagram from 00-Iona2 core, 95-0 cm (Peteet et al. personal communication).

The macrofossil record at the very top of the core (Figure 6) showed a strong domination by *Phragmites australis*, even replacing the *Typha sp.* which had originally expanded under human disturbance at the beginning of Zone I-6. This reflects that out of all the native and introduced species, *Phragmites australis* is most successful in the modern environment of Iona Island marsh, one dominated by human disturbance of the largest scales, ranging from wars, to railroads, to autoroads. Unknown seed A is also thriving at the same level as when it first rose in Zone I-6.

Paleoenvironmental shifts caused by both changes in climate and human activity like those seen thus far in Iona Island Marsh were also seen in Piermont Marsh (Pederson et al. 2005) and the Hackensack Meadowlands (Carmichael 1980). Like the Iona Island record, the Piermont record showed a Medieval Warm Interval, occurring roughly between 800 and 1350 CE. Unlike Iona Island, the percentage of organic sediment was much lower at Piermont during this period. This is most likely due to a difference in species composition. The Piermont pollen record also had a similar *Ambrosia* rise due to European settlement found at about 1687 CE. Finally, the modern zone of the Piermont record showed dominance by *Typha* and *Phragmites*, in the same way these weedy species dominated the modern zone of Iona Island due to human impact.

The Hackensack Meadowlands record nearby also shows patterns of climate change with vegetation shifts between brackish and freshwater environments (Carmichael 1980). The variation in foraminifera species found in the Hackensack sediment core indicates a changing salinity regime throughout the past 2600 years at the marsh as well.

This marsh showed the drastic effects of anthropogenic activity with the great increase of invasive species in the past two centuries.

A possible future study would be to look at the macrofossils in the top meter of Iona Island marsh in a few decades from today. Since Iona Island has been designated a component of the HRNERR, bought by the Palisades Interstate Park Commission, and designated a bird sanctuary with human intrusion limited to the west of the railroad tracks, it is possible that there will be shifts in species composition back to early European disturbance levels, especially with the aid of restoration efforts. The current rapidly changing climate will also undoubtedly play a role in changing species composition.

To build on the data from this project, the ecological implications of the various changes in species composition, LOI, and sedimentation rates throughout the 00-Iona2 sediment core require further investigation. Additional AMS dates and a more detailed record of foraminifera would be helpful in determining salinity.

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