Appendix E

New York Great Lakes Protection Fund
Final Report

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Project Name: Lake Ontario's Dynamic Coast: Analyzing Ecosystem History for Sustaining Environmental Health

Report Done By: Nelson G. Hairston, Jr.

1- Summary of Accomplishments:

The objective of this research has been to understand the long-term dynamics of coastal embayments along the shore of Lake Ontario, with the objective of placing current environmental stresses into the context of environmental change over the past several centuries. This perspective is then used in discussions with stakeholders, both local and at the state level, about the nature of the embayment environments. Our approach was to study three embayments, South Sandy Pond (SSP), Juniper Pond (JP) and Little Sodus Bay (LSB), with differing current levels of connectivity to Lake Ontario and different current land use patterns. The basic methodology involved taking sediment cores at each site, and then exploring the following aspects of environmental change using paleolimnological and paleoecological methods: (a) 210-Pb dates and changes in sedimentation rates (all three embayments; Hairston & Engstrom); (b) nutrient (carbon, nitrogen, phosphorus, sulfur) and trace metal (mercury, lead, aluminum, iron manganese, beryllium) concentrations as indicators of embayment trophic conditions and pollutant inputs (all three embayments; Driscoll); (c) diatom microfossils as indicators of both environmental conditions and connection to L. Ontario (all three embayments; Hairston & Wolin); (d) paleomagnetism as indicator of changes sediment origins (SSP only at present; Hairston & Peck); (e) pollen and spore stratigraphy as indicators of broader changes in land use (SSP and JP only,; Peteet); and (f) changes in wetland vegetation (SSP and JP only; Leopold).

Whereas data collection from this project is essentially complete. Data analysis and interpretation continue as do engagement with stakeholders. It is nevertheless exciting to see the different components of this project come together. The PIs remain committed to producing a completed project published in peer-reviewed journals.

Sampling

Triplicate 1-m-long sediment cores ("short cores") were taken by SCUBA in August 2003 at each of the three study embayments. These cores were returned to the laboratory and sliced in 1-cm intervals. The longest core from each site was designated the primary study core, and sediment from each slice was apportioned for delivery to each principal investigator (PI) as well as for radio-isotope dating. One of the other cores was used for preliminary investigation of techniques and subsamples of each slice were made available to all PIs. The slices from third cores were held in case further studies were indicated. These cores were analyzed for sediment chemistry, diatoms, and paleomagneitism

In addition, one 7-meter-long and two 5-meter-long peat cores were taken from the peatland at South Sandy Pond and a 5-meter long core was obtained at the Juniper Pond wetland ("long cores"). These cores were analyzed for pollen, spores and wetland vegetation macrofossils.

Sediment dating

Sediment dating by 210-Pb was completed for the short cores by Daniel Engstrom at the Science Museum of Minnesota. The results indicate steady sedimentation in LSB with a maximum sediment age at the bottom of the core of about 830 AD or 1,173 years before present (YBP). In SSP, the oldest secure dates are from 1545 at 27 cm. Below this there was a major change in sediment lithology (origin of inorganic material) indicating some major perturbation of this embayment system – perhaps a breach in the barrier beach. Extrapolating sediment accumulation rates back to the bottom of the core indicates a very approximate date of 0 AD (2003 YBP). In JP, sediment flux rate was high and varied substantially through time with major peaks in 1995, 1955, and 1890. Further back extrapolated dates suggest that a bottom of the core at 1,460 AD (542 YBP). Thus all cores provide excellent coverage not only for the period of primary interest to us (that following European colonization) but well before. The long cores will be dated by 14-C.

Sediment chemistry, paleomagnetism and diatom stratigraphy

Sediment chemistry, paleomagnetism and diatom stratigraphy

In LSB, there is a marked decline in nutrient and trace metal and diatom concentrations in the late 1800s accompanied by a marked increase in sedimentation rate. There is also a marked decline in the density of pelagic diatoms that began in this period and that persists to the present. All chemical constituents in LSP showed continuous increases in sediment deposition from about 1900 to present. All chemical constituents were strongly correlated with carbon deposition, suggesting that increases in carbon deposition had? been largely responsible for the patterns observed. In SSP, consistent with the 210-Pb dating results, we find major reductions in sediment concentrations of chemical constituents and diatoms at about 1560 AD, and the paleomagnetism data confirm a major change in the origin of inorganic sediment at this time. The diatom community became markedly less benthic in character after (i.e., more recent to) this event. As observed in LSP there have been recent marked increases in the deposition of all chemical constituents studied, nutrients and trace metals. In contrast to the pattern of LSP, chemical deposition has increased exponentially since around 1950. Again, deposition of all chemical constituents is strongly correlated with organic carbon deposition, suggesting that recent increases in the production and deposition of organic matter drives increases in sediment deposition of all chemical constituents. Finally, in JP, small fluctuations in sediment chemical constituents and diatom concentrations appear to relate to changes in sediment flux rate (which is generally high). In contrast to the other two embayments, the deposition of chemical constituents to JP has shown marked variation since 1850. Large peaks in chemical deposition were evident around 1890, 1950 and in recent sediments. Minimum deposition rates were observed around 1920 and

1970. Like the other two embayments, the rates of chemical deposition appear to be strongly controlled by deposition of organic carbon. The diatoms are dominated by benthic taxa throughout.

John Peck's laboratory at the University of Akron carried out paleomagnetic analysis of the SSP sediments, which shows that two distinct zones are present, and these zones correlate with the ragweed/no ragweed horizon (see pollen data section). He suggests that this may be a product of clear cutting and/or farming of the watershed, and this seems indeed to be the case. He has sediment samples from LSB and JP, which he will try to analyze despite small sample sizes.

Diatom microfossil analyses

Juniper Pond is a system dominated by diatom species associated with wetlands and mildly acidic waters. Several major environmental changes are evident in the diatom community shifts throughout the (107cm) core indicated by correspondence analysis (CA). The first major shift in occurs at 87cm and appears to be associated with an erosional event. Diatom deposition and preservation at this level is low, as is diversity (Shannon diversity = 2.2 vs. average 2.8 for all samples). Communities from the 87 cm and 76 cm samples contain the highest percentage of taxa indicative of open water (planktonic) conditions. A rise in *Ambrosia* pollen associated with watershed deforestation occurs between 87 cm and 76 cm indicating that the increase in planktonic taxa is a combined response to increased turbulence from loss of forest cover, nutrient increases, and a potential increase in water level. Diatom taxa found in Lake Ontario assemblages (*Aulacoseira* species) occur at 76 cm but are absent in the rest of the samples. Disturbance events are evident in two other samples in the core. One occurs at 47cm with a corresponding decline in diatom accumulation. Extrapolation of radiometric dates places this event somewhere around 1840. Diatom community shifts occur at this level and are characterized by a decline in the importance of acidic wetland species and an increase in benthic, epiphytic and mesotrophic planktonic forms (*Cocconeis placentula* and *Fragilaria capucina,* respectively). A second disturbance event occurs at 29 cm (ca. 1937) with a shift in diatom assemblages and a decline in diatom accumulation. Timing of this event corresponds with low lake-levels of the mid 1930's and a similar change was reported by Wolin and Stoermer (2005) in a marginal lake in the Lake Michigan basin. Diatom and chrysophyte fossils indicate that Juniper Pond undergoes a fundamental shift after this point. A decline in chrysophyte accumulation is indicative of nutrient enrichment and a corresponding increase is seen in mesotrophic planktonic diatom taxa (*Fragilaria capucina*) and in benthic/epiphytic forms. Correspondence analysis indicates that diatom assemblages above 29cm represent a change in environmental conditions and trajectories from previous samples that continues to the present.

The Little Sodus system is dominated by planktonic diatom taxa, the majority of which require turbulent conditions to keep them in the photic zone (*Aulacoseira* species). Correspondence analysis (CA) of the diatom data indicates several environmental changes occur in the 61 cm core. The first shift in occurs between 51 and 45 cm. It is associated with an increase in diatom deposition and a diversity decline at 51 cm followed by a change in the dominant planktonic species to *Aulacoseira islandica*. This taxon is common in Lake Ontario and may indicate an increased connection between it and Little Sodus. A recovery occurs at 39 cm with a return to previous diatom assemblages but a permanent return to *Aulacoseira islandica* occurs in samples 33 to 21 cm. These levels show and increasing diversity as epiphytic forms and taxa with higher nutrient optima increase. A fundamental shift in assemblages occurs at 13 cm. Dating places this event around 1866 and may indicate a deforestation signal. Diatom diversity increases but diatom and chyrsophyte cyst deposition rates decline. An indication that primary production could be shifting to other algal communities. Benthic diatoms increase in importance and dominate assemblages at 13 and 7 cm. Diatom assemblages in the most recent samples (7, 4 and 2 cm) appear to recover, however they are distinct from previous levels and indicative of increased nutrient conditions in the lake.

South Sandy is dominated by planktonic diatom taxa, that rely on turbulent conditions to keep them in the photic zone (*Aulacoseira* species). Correspondence analysis (CA) of the diatom data show several environmental changes in the 94cm core. The primary signals evident are: pre-settlement water level change and wetland expansion (94 – 39cm), a major erosion disturbance (36-30cm) and nutrient enrichment (26-0cm). The erosional episode causes a fundamental change in the lake ecosystem. Prior to this the lake is dominated by a diverse diatom community indicative of open water and a wetland environment. The average Shannon diversity = 2.7 prior to the event (94-39 cm) and 1.66 afterward (26-0cm). Asssemblages in samples between 87 and 61 cm are dominated by planktonic forms. Subdominants include both planktonic and attached acidophilic taxa associated with wetland ecosystems, though the percentage of plankton is higher. A increase in deposition of benthic and epiphytic forms occurs at 68 cm indicating a possible decrease in lake level in this section. An indication of drier conditions and possible wetland expansion is visible at 94 - 90 cm and 55 - 39cm. The wetland-associated diatom community is dominated by attached forms and benthic diatom deposition increases between 47 and 39cm. Diatom communities above the erosional event cluster together and are again dominated by planktonic taxa. Plankton increase in importance from a pre-event average of 53% to above 90% in recent samples above 20cm. While the total number of taxa decline, an increase in nutrient tolerant plankton and epiphytic forms occurs from 30-0cm. The largest increases in nutrient tolerant taxa occur above 15cm (after 1850) and most probably a response to increased human activity in the watershed.

Pollen and spore analyses

The core from the fen at South Sandy Pond (0-700 cm) provides a general outline of the pollen and spore changes from the base of the section to the surface to the fen initiation. An initial diagram is divided into 4 zones at present. Zone SSF-1 (*Betula-Fagus*-Cyperaceae-Gramineae, 700-650 cm) basal peat is characterized by *Betula* and relatively high charcoal. Increases in *Fagus* (to a maximum of 25%), Cyperaceae, and Gramineae concurrent with a decline in *Betula* and charcoal define the top of the zone. Zone SSF-2 (*Pinus-Alnus*-Cyperaceae-*Cephalanthus-Osmunda*, 650-400 cm) is characterized by increases in local fen species (*Cephalanthus*, Cypereaceae, and *Alnus* followed by invasion of Osmunda and Polypodiaceae fern spores. An increase in *Pinus* and then

Betula toward the top of the zone coincide with a decline in Cyperaceae. Charcoal is relatively low throughout. Zone SSF-3 (*Pinus-Tsuga-Quercus-Betula-Ulmus-Tilia-Carya*-Cyperaceae-Ericaceae, 400-80 cm) is marked by increases in many of the trees as well as increases in Gramineae and Ericaceae as well as Sphagnum. Charcoal reaches very high values but also fluctuates. Zone SSF -4 (*Pinus-Betula-Quercus-Ambrosia-Plantago*, 80-0 cm) shows increases in some trees (*Pinus, Quercus*) but declines in others (*Tsuga, Betula, Fagus, Ulmus, Tilia, Carya*) along with the marked increase in *Ambrosia* and *Plantago*. Charcoal is highest at the top of the core.

The long cores have not yet been dated because we want to complete the pollen and spore counts at higher resolution first, but the pollen zones appear to roughly agree with the plant macrofossil identified by Matt Distle from the Leopold lab. The zones in the pollen and spore stratigraphy appear to represent 4 distinctive intervals thus far and primarily appear to reflect both water level in the fen and possibly climatic shifts on the landscape. The basal sediments show dominance of *Betula* and Matt Distler's macrofossil diagram indicates that the species is *Betula alleghaniensis*. Cyperaceae pollen increases reflect the local wetland community and in zone 2 the increases in *Alnus* and then *Cephalanthus* are very similar to the changes seen in the macrofossils, suggesting a mineral-rich fen community. The upper portion of this zone is dominated by fern spores, both *Osmunda* and Polypodiaceae, making the slides very difficult to count.

Because so much of the pollen is represented by the local plants (ie. *Cephalanthus, Osmunda*, Cyperaceae) the climatic inferences are difficult to make, although compared with the overlying zone, this interval appears possibly to be a cooler climate (less *Quercus, Carya, Ulmus*). The 400 cm depth appears to be a real break from the minerotrophic fen setting to a less mineral rich wetland with increases in Ericaceae and *Sphagnum*, again in agreement with M. Distler's macrofossils. Both macrofossils and pollen and spores have high but fluctuating charcoal in this zone, with possibly a warmer, drier climate as *Quercus, Carya, Ulmus*, and *Tilia* are better represented than in the previous zone. The upper record from about 70 cm depth to the surface shows increases in weedy *Ambrosia* and *Plantago* concurrent with increases in *Pinus*, probably due to anthropogenic impact. These changes in the top zone agree with shifts we see in the more detailed Juniper Pond and S. Sandy pond cores sampled at 2-cm resolution.

Peteet's lab is planning to continue "filling in" their stratigraphy in the SSP Fen core, but the counts are very laborious, taking often 5 or 6 hours to count a single slide. Extensive organic material on the slides makes the location of pollen difficult. Over a dozen of the slides have been reprocessed with the same result. Thus they are not yet ready to write a manuscript, but want to complete the S. Sandy core at 10 cm resolution, and to finish the Juniper Pond core which as yet is also incomplete. In collaboration with Matt Distler, Peteet's group hopes to examine the inference of water table from the mosses and to perhaps examine a new lake sediment core from the region to get an upland comparison in order to better infer climate.

Plant macrofossil analyses

Donald Leopold's lab has analyzed the 7-meter long core representing the deepest area of the wetland at South Sandy Pond, supported by more rapid stratigraphic analysis of two additional (~5-meter) cores from cattail-dominated and forested stands in the same wetland. A 5-meter core from Juniper Pond wetland was also analyzed. The complete core sequence from South Sandy pond shows a progression from mineral-rich forested wetland characterized by yellow birch (*Betula alleghaniensis*) and eastern hemlock (*Tsuga canadensis*), to an alder (*Alnus incana ssp. rugosa*)-dominated community, to a relatively mineral-poor medium fen dominated by sedge (*Carex* spp.), leatherleaf (*Chamaedaphne calyculata*), and sweetgale (*Myrica gale*). Judging by depth of peat accumulation, the fen community has persisted as a fluctuating mosaic of sedges and shrubs for over half of the development of this wetland. Forest and shrub cover appear to have declined over the course of the peatland development, and areas of high and moderate water depth, initially supporting aquatics like pondweed (*Potamogeton* sp.) and buttonbush (*Cephalanthus occidentalis*), were mostly filled by peat. Unexpectedly, fires appear to have been a relatively common disturbance in both study wetlands, especially in the later half of the development of the peatlands. Charred *Chamaedaphne* seeds attest to the presence of fire in the wetlands themselves, and periods of fire correspond with increases in sedge material, a reduction in bryophyte cover, and, in some cases, a decrease in woody material. This pattern suggests that periodic fire has contributed to the persistence of open sedge-fen communities in these wetlands over long periods of time.

There is evidence that extensive, dense cattail (*Typha* x *glauca*) and swamp forest (*Acer rubrum*) communities at South Sandy Pond are novel or at least greatly expanded only in the last century of the wetland's development. Areas that are now dominated by cattail or covered by red-maple swamp appear had been sedge-ericad fen up until the period of European settlement. These data corroborate recent work (USGS 2004, Wilcox et al. 2005) showing that *Typha* stands have spread at the expense of sedge-marsh in Lake Ontario wetlands over the last 50 years since water level regulation began. Furthermore, the work presented here suggests that the recent cattail expansion has been on a scale unprecedented in the long-term development of these wetlands. The replacement of open sedge fen by red maple swamp at South Sandy Pond was preceded by bog-like period characterized by abundant *Sphagnum* moss and tamarack (*Larix laricina*). In the open fen, this short *Sphagnum*/*Larix* period marked the decline of a more diverse fen assemblage followed by dominance of leatherleaf. These changes may represent the hydrologic effects of European land-clearing. Similar changes toward bog-like vegetation have been noted in paleoecological studies of Ontario wetlands as a response to European settlement and land-clearing (Warner et al. 1989). The cessation of periodic fires after European settlement, evidenced by lack of charcoal above the *Ambrosia* rise, may also have played an important part in allowing the unchecked growth of *Sphagnum* and subsequent acidification of the wetland surface.

Juniper Pond, a shrub swamp to the southwest of South Sandy Pond, appears to have developed from a relatively alkaline shrub swamp into a more acidic fen community, probably over 1000 years ago. This successional pathway was interrupted by a hydrological disturbance sometime in the last few centuries, evidenced by deposition of a silt/sand lens at 60 cm depth. After this disturbance, likely a signal of upland erosion from early European land-clearing, the system returned to a more alkaline shrub swamp community similar to that seen today.

Stakeholder engagement

Linda Wagenet's portion of this project is essentially in two parts. First, an overview of landuse history in the area has been undertaken in order to relate findings from the other segments of the research. It is nearly complete. This will provide some historical context for both assimilating the individual research components as well as to inform the outreach portion of the project.

A vital part of this historical review included attending public meetings in New York on the International Lake Ontario-St. Lawrence River Water Level Study, which was completed in 2005. There was not only important historical information included in these meetings, but the public participation provided insight into outreach efforts that need to take place to convey our findings and relate them to current issues and concerns in the area. These meetings were the best mechanism for determining who the key individuals are in terms of land use management and public participation. As well, individual meetings with citizens in the area contribute to this knowledge. There was a strong feeling at the public meetings that the technical people involved were focusing solely on data needs. As one resident stated: "I don't mean looking at it through your eyes. I mean looking at it through the eyes of the people living there." The outreach portion of our project will attempt to capture that sentiment.

For the remainder of the project, Wagenet will develop an outreach program related to the findings of the other investigators. Contact has been made with a variety of individuals in the research locations – these include personnel from the Sea Grant program (affiliated with USDA and Cornell Cooperative Extension), local citizens, and municipal officials. Focus groups will help determine how best to convey our findings and the outlets through which this should occur. These focus groups will take place in late summer or early fall 2007.

Summary

The sediment records for each of these three embayments clearly show distinct patterns of internal and external events of both local and regional origin that have impacted ecological development. The embayments have been dynamic environments with some changes driven by natural processes and others clearly of human origin. Our quantification of these changes, some of which were apparently dramatic, provides a firm foundation against which current anthropogenic environmental changes can be assessed, and a context for future management decisions.

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