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Late Holocene paleoenvironmental change in a Great Lakes coastal wetland: integrating pollen and diatom datasets

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Abstract

Multiple proxy indicators are regularly used to present robust arguments for paleoenvironmental change. We use fossil pollen and diatoms from a 495-cm core taken from Cootes Paradise, a coastal wetland in the western end of Lake Ontario, to investigate ecological changes in the late Holocene. We use consensus analysis to demonstrate that pollen diagrams are best zoned after the data have been split into source area, in this case upland and wetland taxa, because each group responds differently to environmental change. We also use consensus analysis to demonstrate the sensitivity of clustering to the distance measure used. The record begins at 2400 ^{14}C years BP, when the wetland was dominated by shallow water emergents and epiphytic diatoms. At 2100 ^{14}C years BP, a decline in the epiphytic diatoms *Epithemia* spp., a rise in Poaceae (cf. *Zizania aquatica*) pollen and a coincident increase in pollen concentration suggest a water level rise at this time. At about 800 ^{14}C years BP, the diatom record shows a pulse in small benthic *Fragilaria* species; shortly after, a shift occurs in the upland tree pollen spectra involving an increase in *Pinus* and a decline in *Fagus*. This shift in upland forest trees has been associated elsewhere with the Little Ice Age and the diatom data present some evidence for impacts of this climatic event on aquatic systems. The diatom and pollen records both indicate large changes associated with the effects of European settlement, including rises in *Ambrosia* as well as *Typha angustifolia* pollen. Planktonic diatoms dominate post-settlement assemblages indicating large-scale hydrological and ecological changes, probably associated with the introduction of carp and alterations to the Iroquois bar which separates the wetland from Lake Ontario. Our work at Cootes Paradise is important for multi-proxy coastal wetland studies in general, in addition to the late Holocene environmental history and prehistory of the Great Lakes region.

Introduction

In paleoecological research, inferences about past environmental conditions are increasingly made using multiple proxy indicators. Arguments for paleoenvironmental change are stronger when two or more indicators give concurrent evidence for the change. In the case of large environmental perturbations such as climatic change, we expect indicators from various parts of the ecosystem to respond contemporaneously. Here, we use pollen and diatoms to investigate late Holocene paleoenvironmental change in a Great Lakes coastal wetland. We are particularly interested in determining if there were concurrent responses in the pollen and diatom records to Little Ice Age cooling and to the onset of European settlement in southern Ontario. To do this, we present techniques to evaluate quantitatively the similarity between the spectra produced from different indicators.

Pollen and diatoms are often used as complementary proxy indicators, yet they are indicative of different aspects of the environment. The pollen record at a given site reflects inputs from local plants, but also includes a regional component of airborne or stream-borne pollen (Bennett and Willis 2001). The diatom record has been widely used to reconstruct local limnological variables (e.g., Brugam et al. 1998; St Jacques et al. 2000). Several studies have shown that climatic changes can affect diatom assemblages through a variety of means such as ice or snow cover or processes mediated by terrestrial ecosystems (e.g., Douglas and Smol 1999). Studying the connections between terrestrial and aquatic responses to climatic changes will give some insight into the feedback mechanisms by which the biosphere responds to climatic changes, and will elucidate more of the linkages between terrestrial and aquatic ecosystems.

In addition to providing the first diatom data, and new pollen data, from this regionally significant wetland, our paper compares dendrograms produced from different paleoecological indicators and from different methods of cluster analysis. Moreover, even though multi-proxy studies are common, there are no standard techniques to integrate independent paleoecological datasets.

Study site

Cootes Paradise Marsh is a 250-hectare coastal wetland located in the western end of Lake Ontario in eastern North America (Figure 1). It has been designated a Provincially Significant Class 1 Wetland, the highest designation under the Government of Ontario's classification scheme. In addition to well preserved and abundant pollen and diatoms in the sediments, the modern environment of Cootes Paradise has been intensely studied (Painter et al. 1989; Chow-Fraser et al. 1996; Davis 2002). The area is also rich archaeologically. A number of Late Woodland Princess Point sites (500–1000 AD) are located around the perimeter of Cootes Paradise and are being actively studied (Smith et al. 1997). This paper will provide an environmental basis against which the archaeological record can be interpreted.

The formation of Cootes Paradise is tightly linked to the post-glacial lake level history of Lake Ontario. At 11,000 years before present, the water level of Lake Ontario was about 90 m below current elevation. The water level then rose at a decelerating rate, driven mainly by the differential isostatic rebound of the eastern portion of the lake basin (Coakley and Karrow 1994). In the middle Holocene, the water level of Lake Ontario was still too low for a wetland to exist at Cootes Paradise (Anderson and Lewis 1985). Cootes Paradise formed when lake water transgressed the western portion of the Lake Ontario basin, perhaps during the Nipissing Highstand. During the last 4000 years in western Lake Ontario, metre-scale fluctuations – likely climatically driven – were superimposed over the gradual trend of isostatically driven water level rise (Flint et al. 1988; McCarthy and McAndrews 1988).

Since the end of the Middle Holocene Hypsithermal 2000 ^{14}C years ago, climate has been relatively stable in southern Ontario (Yu et al. 1997). However, the Little Ice Age, a hemispheric and possibly global event, in which cooler temperatures occurred between the 13th and 19th centuries, had significant effects on forest vegetation. The onset of Little Ice Age cooling corresponds to Ontario regional pollen zone 3d, defined by McAndrews (1981) and McAndrews and Boyko-Diakonow (1989). Around 1400 AD, *Fagus* pollen percentages decline, while *Quercus* increases, followed by a rise in *Pinus*. Campbell and McAndrews (1991) use cluster analysis of 33 Ontario pollen stratigraphies covering the last millennium to show that the decline in *Fagus* pollen followed by an increase in *Pinus*, often with an intervening peak in *Quercus* or *Ulmus*, are the most prevalent trends in the pollen records south of Lake Nipissing for this time period. There has been less work showing the impacts of Little Ice Age cooling on aquatic ecosystems and one of our objectives is to examine the responses of diatoms and wetland macrophytes to the Little Ice Age.

The first paleoecological work at Cootes Paradise was done by Terasmae et al. (1972), who showed that in several short cores, a zone of *Ambrosia* pollen overlies a zone dominated by Poaceae. Since 1996, we have obtained a 125-cm

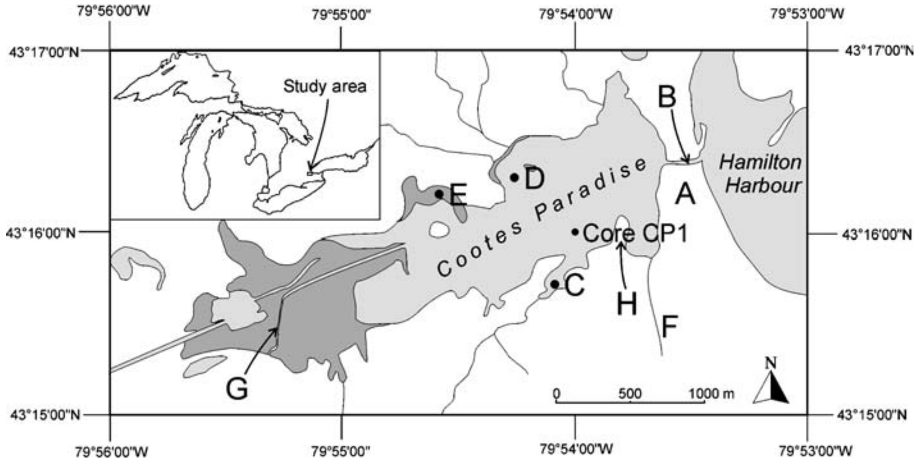

Figure 1. Location of study site at Cootes Paradise and other core sites and place names: (A) Iroquois Bar, (B) Desjardines Canal, (C) Sassafras Point core site, (D) Bull's Point core site, (E) Rat Island core site, (F) Chedoke Creek, (G) Spencer Creek, and (H) Princess Point and location of the Princess Point archaeological site. The light grey represents open water, the dark grey is marsh. Inset shows study area in the Great Lakes region.

core close to Rat Island, a 5-m core from Bull's Point (Smith et al. 1997) and a 6-m core from Sassafras Point, which were all analyzed for pollen (see Figure 1 for locations of cores). These studies show that Poaceae were abundant in Cootes Paradise until at least the time of European settlement. Lee et al. (2004) have confirmed that the pre-industrial Poaceae pollen was predominantly that of *Zizania aquatica* (wild rice).

The history of the wetland from 1793 AD has been historically documented. Surveyors' maps suggest that Cootes Paradise was almost completely vegetated with emergent plants from 1793 to the early 1900s. From 1907 to 1938, 20% of the wetland was open water, with this area increasing throughout the 20th century, attributable in part to the accidental introduction of carp (*Cyprinus carpio*) into Cootes Paradise in 1896 (Painter et al. 1989). Prior to European settlement in 1840, drainage of Cootes Paradise was via Hendrie Valley, a crescent-shaped channel through the Iroquois Bar which separates Cootes Paradise from adjacent Hamilton Harbour. In 1827, a channel was excavated through the Iroquois Bar to form a new outlet, whilst Hendrie Valley was mostly infilled by railway and roadway development for the construction of the Desjardins Canal (Dear et al. 1987). This disturbance may have caused hydrological impacts on the wetland, including a water level rise.

Cootes Paradise is surrounded by a heavily urbanized and industrialized landscape. The remnant vegetation in the uplands is a forest of predominately beech, maple and oak. Today, the wetland is mostly open water, with emergent species accounting for approximately 15% of its surface area. The introduced grass *Glyceria maxima* covers the largest area, followed by *Phragmites australis*, and other taxa such as *Typha* spp. and *Sparganium eurycarpum*. Submerged taxa include *Potamogeton* spp. and *Myriophyllum* spp. Several creeks, including Spencer Creek and Chedoke Creek, drain into Cootes Paradise, with most of the sediment input originating from Spencer Creek (Painter et al. 1989). Cootes Paradise presently drains into Hamilton Harbour, which is connected to Lake Ontario through a breach in the Burlington Bar (Coakley and Karrow 1994). The maximum depth of the Cootes Paradise basin is 180 cm near the Desjardins Canal. The water level in Cootes Paradise fluctuates by ~50 cm annually (Painter et al. 1989).

Methods

Field and laboratory

We took a 495-cm core (CP1) with a modified Livingstone piston corer from near the center of

Cootes Paradise (43°16′00″N, 79°54′00″W) in February 2003 (Figure 1). Coarse sediment was encountered at refusal depth. The core was recovered through 57 cm of ice, which extended right to the sediment surface. The core was labelled and wrapped in plastic for transport and storage at University of Toronto, where the core was logged visually for sediment type. Subsamples were collected every 10 cm to estimate sediment composition by loss-on-ignition (Dean 1974) and for pollen and diatom analysis. Pollen was concentrated by sieving (Cwynar et al. 1979) and treatment with HCl, KOH, HF, glacial acetic acid and acetolysis solution (Bennett and Willis 2001). A known number of exotic *Lycopodium* spores were also added to pollen preparations to determine pollen concentration in grains per millilitre (Stockmarr 1971). Pollen identification was made with reference to McAndrews et al. (1973). Distinctions between *Typha latifolia*, *T. angustifolia*, *T.* x *glauca* and *Sparganium eurycarpum* were made based on Finkelstein (2003); monads larger than 24 μm were classified as *Sparganium.* On average, 570 pollen grains in total were counted per sample, although in some samples with low pollen concentration, the total number of grains counted was 100. To calculate sums, we followed Bennett and Willis (2001); the pollen sum consisted of all terrestrial pollen types. Taxa outside the sum included local wetland plants: emergents, obligate aquatics and ferns. Percentages for taxa outside the sum were calculated on the basis of the total number of pollen grains counted.

Sediments were processed for diatom analysis by overnight soaking in 10% HCl, repeated distilled water washes, and seven days digesting in 30% H_2O_2. After repeated washes with distilled water and centrifugation, diatom slurries of neutral pH were mounted on glass slides using Melt-Mount (refractive index = 1.74) as the mounting medium (Battarbee et al. 2001). Diatoms were examined under a Leica DMRB microscope at 1000× magnification. Identifications followed Krammer and Lange-Bertalot (1986–1991) (most closely) as well as Patrick and Reimer (1966, 1975), Reavie and Smol (1998) and Krammer (1997). At least 300 diatom valves were counted per sample and the data are presented as percentages of the total number counted.

Diatom counts were made on 36 of the samples, and pollen counts on 48. Each sample was spaced at intervals of 10–30 cm in the core. Biostratigraphic diagrams were prepared using Tilia and Tilia-Graph (Grimm 1993). Two samples of organic sediment were sent to Brock University, St Catharines, Ontario, Canada, for conventional radiocarbon dating.

Statistical analyses

The pollen and diatom datasets were each subject to constrained cluster analyses using the incremental sum of squares algorithm in CONISS (Grimm 1987; Legendre and Legendre 1998, pp. 329–333). Prior to calculating the matrix of squared Euclidean distances used for the clustering, we transform the data using four transformation options available in CONISS.

The pollen and diatom datasets were clustered using Orlóci's chord distance, to avoid the paradox that can occur with simple Euclidean distances whereby samples that have few species in common appear more similar than other samples sharing more species (Legendre and Legendre 1998, p. 279). We also zoned the data using the Standardized Euclidean distance for comparative purposes. Next, the pollen data were split into 'wetland' and 'upland' taxa, and each group was clustered using Orlóci's chord distance. This was done to examine how biostratigraphic zones differ between wetland and upland plant communities. Finally, we compared the dendrogram obtained by stratigraphically constrained cluster analysis of the diatom dataset and the dendrogram obtained from the pollen data in order to evaluate the congruity of these two indicators, again using Orlóci's chord distance as the distance measure. Since comparing dendrograms requires the same number of samples, the pollen samples for which no diatom counts existed had to be omitted for this comparison. In all cases, no taxa were excluded from the cluster analyses.

Biostratigraphic zones are defined by imposing a line perpendicular to the branches of the dendrogram generated by CONISS. The line is often placed arbitrarily but the number of zones can also be determined by using a broken stick approach to assess the significance of the variance accounted for by each zone (Bennett 1996).

The dendrograms were compared statistically using consensus trees, which are dendrograms showing similarity between two or more dendrograms (Rohlf 1982; Lapointe and Legendre 1990). A consensus index, quantifying the similarity of the dendrograms, was computed by determining the ratio of the number of common subsets among the dendrograms analyzed to the total number of subsets in one of the dendrograms. This index ranges from 0 to 1, with 1 indicating perfect consensus.

We calculated consensus indices for several combinations of dendrograms produced by CONISS. To do this, each dendrogram was reproduced as a tree matrix in two columns. The first column is the stratigraphic depth of samples in the dendrogram, while the second column contains the distance measurement for the sample, obtained with the program ZONE (Juggins 1991). These measurements can then be manually inputted into a text editor, and imported into NTSYSpc v. 2.0 (Rohlf 1997) for consensus analysis.

Results

Stratigraphy and chronology

Loss-on-ignition (Figure 2) showed that organic matter generally makes up ~20% of the dry mass of the core, with the highest values (~25%) occurring between 50 and 200 cm. Carbonates generally account for ~10% of the mass of the core, with the highest values (~15%) coincident with the section high in organic matter. Silicates constitute the bulk of the core material, ranging from ~70% of dry mass between 50 and 200 cm to ~90% in the top 50 cm and from 300 to 430 cm.

To date, 12 radiocarbon dates have been obtained from Cootes Paradise (Table 1). The boundaries of dated regional pollen zones, their depths in the cores, and their ages in ^{14}C years BP are in Table 2. To determine sedimentation rates for Cootes Paradise, we combined the radiocarbon dates and pollen zone boundary data (Tables 1 and 2). The mean pre-settlement sedimentation rate of the cores from Rat Island, Bull's Point, and Sassafras Point is ~0.22 cm year^{-1}, whereas the mean post-settlement sedimentation rate for the same three cores is ~0.40 cm year^{-1}. For core CP1, the focus of this study, the sedimentation rate between 315 and 485 cm is 0.71 cm year^{-1}. This extremely rapid sedimentation rate (nearly double the post-settlement rate) can be explained in one of two ways: (1) there is a problem with one date, likely 2150 ± 50 ^{14}C years BP, since the date of 2390 ± 50 ^{14}C years by itself gives a pre-Little Ice Age sedimentation rate substantially closer to that of the other cores (0.2 vs. 0.1 cm year^{-1} if 2150 ± 50 ^{14}C years BP is taken); or (2) sedimentation was unusually rapid, possibly due to a drop in water level which resulted in a greater amount of eroded material entering the basin. In the absence of direct evidence with which to reject the date of 2150 ± 50 ^{14}C years BP, we tentatively accept both dates (Figure 2).

Biostratigraphy

For the diatoms, 165 taxa were identified (Figure 3). The first three bifurcations of the dendrogram generated using Orlóci's chord distance delineate four distinctive zones. Zone 1 (205–495 cm) is dominated by epiphytes, especially *Achnanthes lanceolata*, *Cocconeis placentula*, *Gomphonema angustatum* and *Rhopalodia gibba*; benthic taxa are also common. Within Zone 1, there is a pronounced decline in the epiphytes *Epithemia adnata* and *E. turgida* at 310 cm, dated to 2150 ± 50 ^{14}C years BP. Also at a depth of 310 cm, the small benthic *Fragilaria* species that dominate Zone 2 begin to increase.

Zone 2 (105–205 cm) is characterized by a pulse in *Fragilaria* spp. and declines in some of the epiphytes, benthic *Naviula* spp. and *Nitzschia amphibia*, that were dominant in Zone 1. In Zone 3 (25–105 cm), *Fragilaria* spp. begin to decline and the epiphytic and benthic taxa dominant in Zone 1 recover. The eutrophication indicator, *Fragilaria capucina* begins to increase in Zone 3. In Zone 4 (0–25 cm; post-1850 AD), the centric diatoms *Cyclostephanos tholiformis*, *Cyclotella meneghiniana* and*Stephanodiscus parvus* become abundant for the first time.

For the pollen, 37 taxa were identified (Figures 4 and 5). We delineated three zones in the upland pollen diagram using Orlóci's chord distance (Figure 4). Zone 1 (175–495 cm; 2400–800 ^{14}C years BP, see Tables 1 and 2) indicates a mixed forest with some *Pinus* and abundant deciduous species, mainly *Betula*, *Fagus*, *Quercus* and *Ulmus*. At a depth of approximately 310 cm, dated to 2150 ± 50 ^{14}C years BP, the pollen concentration rises considerably, which is a strong indication

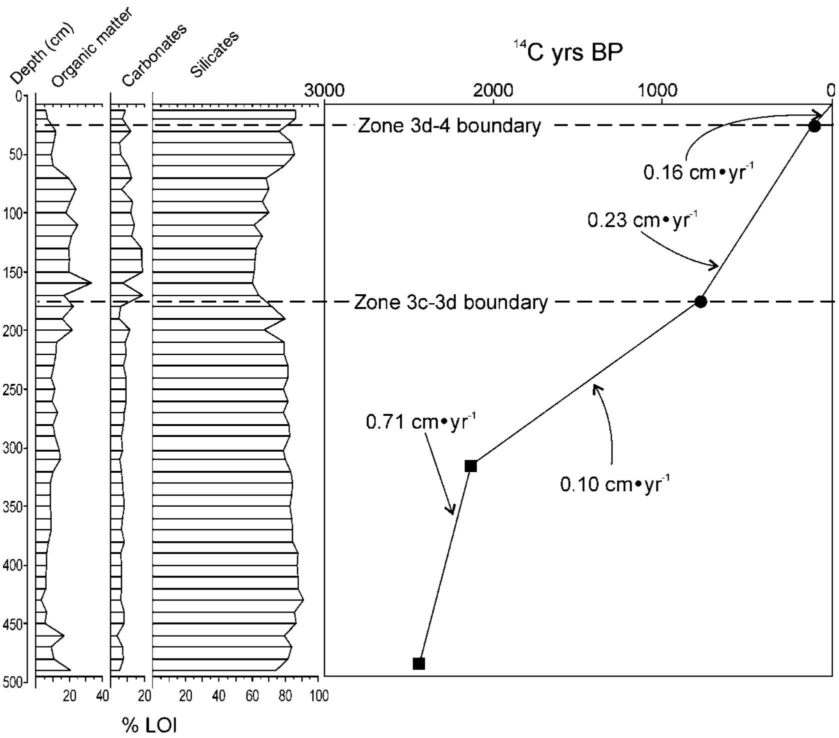

Figure 2. Cootes Paradise loss-on-ignition results and age-depth model for core CP1. Squares are radiocarbon dates and circles are dated regional pollen zones (Tables 1 and 2).

Table 1. Cootes Paradise radiocarbon dates

Location	Depth in core (cm)	Lab number	Uncalibrated ^{14}C years BP	Material	Reference
Northern edge of marsh	~200	BGS-95	11,370 ± 80[a]	Unknown	Karrow (1987)
Northern edge of marsh	~200	BGS-96	11,470 ± 80[a]	Unknown	Karrow (1987)
43°16.2′N 79°55.5′W	1021	GSC-2706	3690 ± 50	Organic silt	Anderson and Lewis (1985); R. McNeely (personal communication 2003)
43°17′20″N 79°53′50″W	1860	WAT-343	4400 ± 50	Wood	Berry and Drimmie (1982)
Rat Island	115–125	Missing	640 ± 50	Peat	This study
Bull's Point	208–220	Beta-106245	840 ± 70	Peat	Smith et al. (1997)
Bull's Point	245–253	Beta-106246	1170 ± 70	Peat	Smith et al. (1997)
Bull's Point	440–450	Beta-114919	1950 ± 80	Gyttja	This study
Sassafras Point	210–220	Beta-114920	1190 ± 70	Peat	This study
Sassafras Point	545–555	Beta-114921	2410 ± 60	Peat	This study
CP1	310–320	BGS-2470	2150 ± 50	Peat	This study
CP1	480–490	BGS-2471	2390 ± 50	Organic silt	This study

All dates obtained by conventional techniques.

[a] These dates seem unreasonably old, given that the material originated from less than 2 m below present water level (Karrow 1987). Unless these dates were made on reworked material, they may represent a depositional environment associated with a stage of glacial Lake Iroquois. Also, H. Melville (personal communication 2003) indicates that these samples received no chemical treatment prior to ^{14}C analysis, suggesting that old carbon contamination may be a factor.

that the sedimentation rate below 310 cm was relatively rapid. The beginning of Zone 2 (25–175 cm; 800–150 ^{14}C years BP) coincides with a rise in *Pinus* and decrease in *Fagus*. *Quercus* increases somewhat in this zone as well. Zone 3 (0–25 cm; post-1850 AD) marks the *Ambrosia* rise.

Table 2. Depths of regional pollen zone horizons, below top of core

Cootes Paradise Core	Zone 3d–4 boundary (depth in cm)	Zone 3c–3d boundary (depth in cm)
CP1 (this study)	25	175
Rat Island (A.M. Davis, unpublished data)	45	Not present (basal date of core is 640 ^{14}C years BP)
Bull's Point (Smith et al. 1997)	50	200
Sassafras Point (A.M. Davis, unpublished data)	60	200

The boundary separating pollen zones 3d and 4 marks the onset of disturbance from European settlement in southern Ontario at 150 years BP, and is principally characterized by an increase in *Ambrosia* pollen. The boundary separating pollen zones 3c and 3d is associated with the onset of Little Ice Age cooling, 800 ^{14}C years BP, and is characterized by an increase in *Pinus* and a decrease in *Fagus* pollen (McAndrews and Boyko-Diakonow 1989).

In the wetland pollen diagram (Figure 5), we also used Orlóci's chord distance to delineate four zones. The three lowermost zones reflect the changing abundances of Poaceae, *Sparganium* and *Typha*. Zone 1 (430–495 cm) is characterized by high Poaceae; Zone 2 (430–405 cm) shows a drop in Poaceae and rise in *Sparganium*, while Zone 3 (405–305 cm) indicates subsequent rises in Poaceae and *Typha latifolia*. Zone 4 (0–305 cm; post-2150 ^{14}C years BP) is a long period of dominance by abundant Poaceae (cf. *Zizania aquatica*).

CONISS output

We clustered the pollen and the diatom data using the two most commonly chosen transformation options: Orlóci's chord distance and the Standardized Euclidean Distance. The consensus index, measuring the similarity between the outputs, was low when we compared the dendrograms resulting from these two options on the same dataset (Table 3).

Consensus analysis confirms that wetland and upland pollen data give dissimilar dendrograms, with only 12% of subsets shared (Table 3). Hence, if the pollen data is clustered as a whole, the result is highly influenced by high pollen producing wetland taxa. The diatom data, when compared with the upland and wetland pollen data, result in similarly low consensus indices of 0.21 and 0.18 respectively (Table 3). Figure 6 permits a visual comparison of the various zonations that result from the cluster analysis of the three datasets.

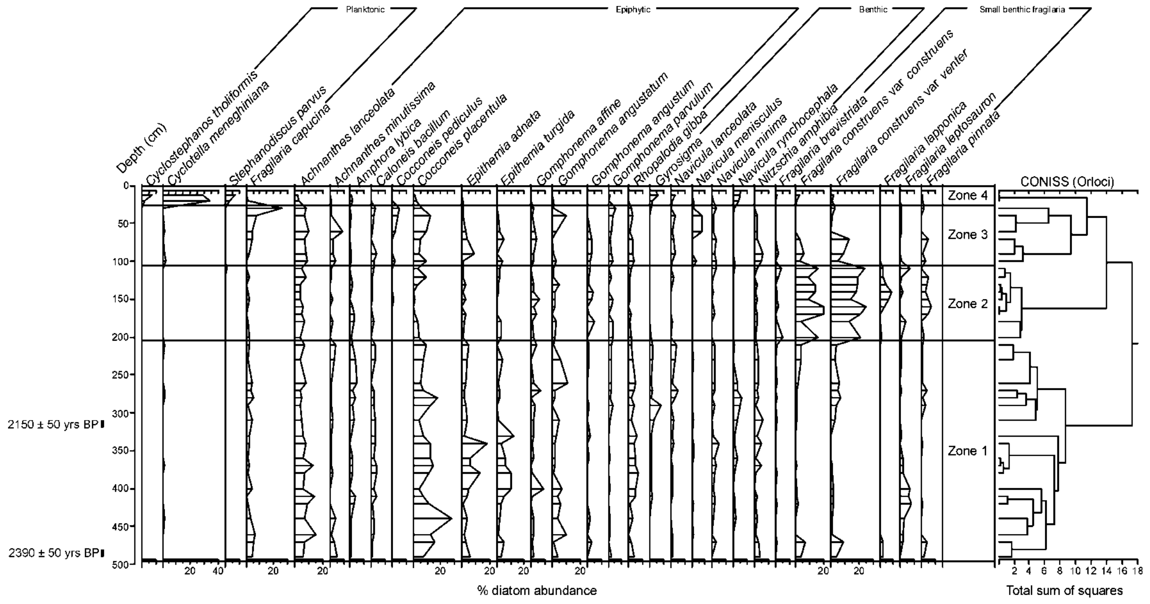

Figure 3. Percentage diatom diagram. All taxa are part of the total sum, but not all are plotted. Cluster analysis was done using Orlóci's chord distance.

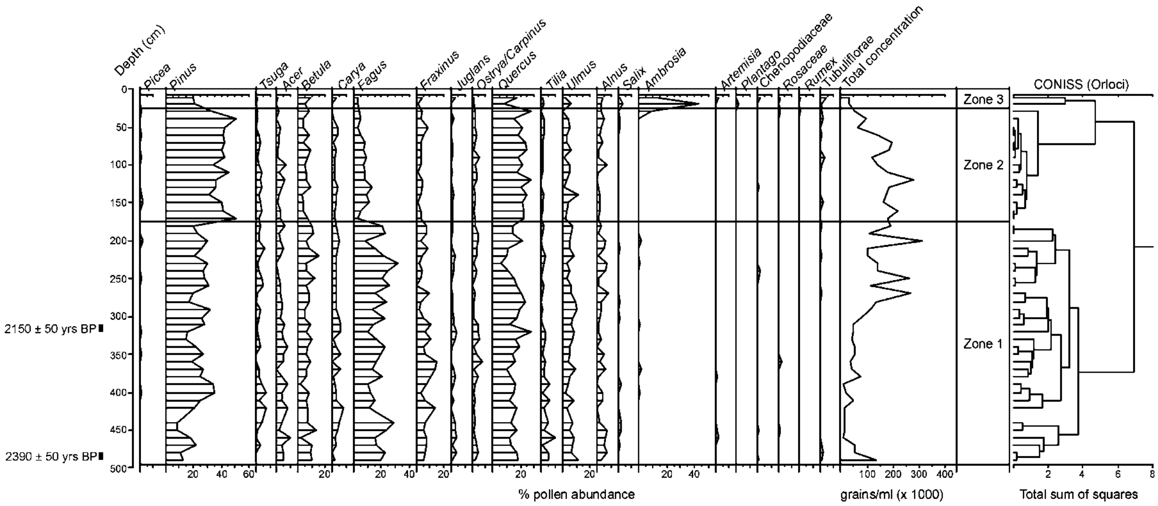

Figure 4. Percentage pollen diagram showing terrestrial taxa. Rare taxa were omitted. The pollen sum includes all terrestrial pollen types. Cluster analysis was done using Orlóci's chord distance.

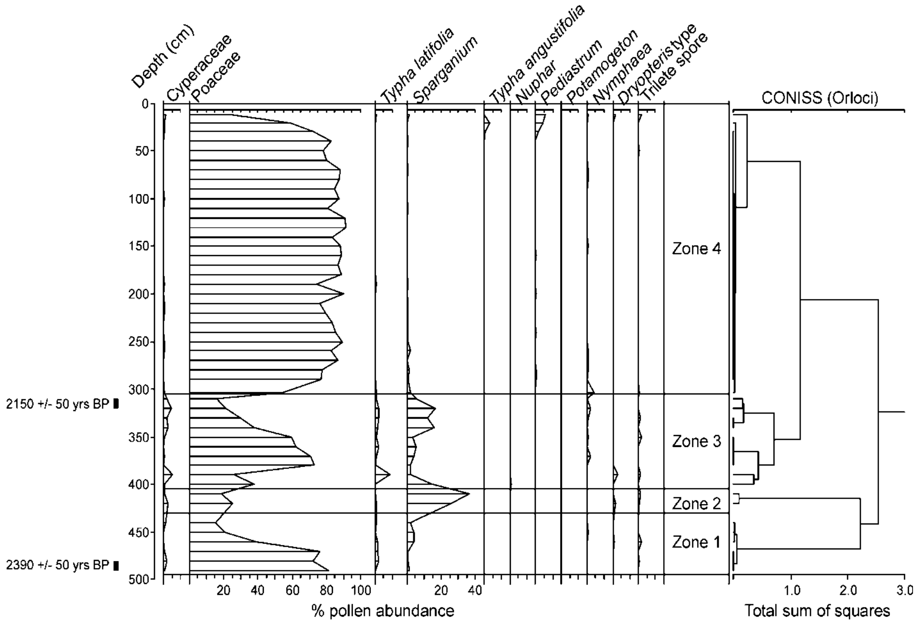

Figure 5. Percentage pollen diagram showing local wetland taxa: emergents, obligate aquatics, ferns and *Pediastrum*. Percentages are based on the terrestrial sum + sum of wetland taxa, equivalent to all pollen types counted. Cluster analysis was done using Orlóci's chord distance.

Discussion

Consensus analyses

Comparing the resulting dendrograms generated from the same data but using different options available in CONISS shows the sensitivity of the results to the dissimilarity measure and implies that the choice of this measure must be justified. This is particularly true when the results of the zonation are the major basis for the paleoenvironmental interpretation. The fact that the agreement between different transformation options for the same dataset was poorer for the diatom data

Table 3. Consensus analysis results

Dendrogram 1	Dendrogram 2	Consensus index (ratio of # of shared subsets to total number of subsets)
Diatom (B)	Diatom (C)	0.26
Pollen (B)	Pollen (C)	0.56
Wetland pollen(B)	Upland pollen (B)	0.12
Diatom (B)	Wetland pollen (B)	0.18
Diatom (B)	Upland pollen (B)	0.21

Letters indicate the CONISS transformation option: (B) Orlóci's chord distance and (C) standardized Euclidean distance.

(Table 3) is a reflection of the species richness of the diatom dataset and the preponderance of rare taxa. This aspect of diatom datasets makes the standardized Euclidean distance particularly problematic due to the large 'double zero' effect (Legendre and Legendre 1998, p. 279).

Separating the pollen data into wetland and upland components prior to clustering and then running consensus analysis on the two resulting dendrograms obtained shows the great dissimilarity between the signals generated from the two pollen sources (Table 3, Figure 6). We suggest that analysts routinely decompose pollen data into source areas prior to running cluster analysis to generate biostratigraphic zones.

Low values for consensus indices in the comparisons between the pollen and diatom datasets indicate little similarity between the spectra (Table 3). However, by examining the zones (Figure 6) and the diagrams, the records suggest points of congruity. The core section below 300 cm is dominated in the pollen record by *Sparganium*, and in the diatom record by epiphytic taxa, notably *Epithemia* spp., which do not reappear significantly later in the core. Finkelstein (unpublished data) found an association between *Sparganium* and *Epithemia* in a study of pollen and diatom assemblages in surface sediments of wetland plant communities at Rondeau Marsh on the northern shore of Lake Erie. The maximum abundance of Poaceae, likely *Zizania aquatica* (Lee et al. 2004), coincides with the peak in *Fragilaria* species occurring between 100 and 200 cm in this core. While it is unlikely that these findings represent specific associations between plants and diatoms, they do suggest correspondence in the two indicators in the signal for water depth. The zonation of the upland pollen record and the diatom record both show changes in assemblages occurring at the time of European settlement and at the time of the Little Ice Age (Figure 6). The low consensus indices calculated for these records is explained partially by a small temporal offset in the response of forest trees and diatoms to environmental change.

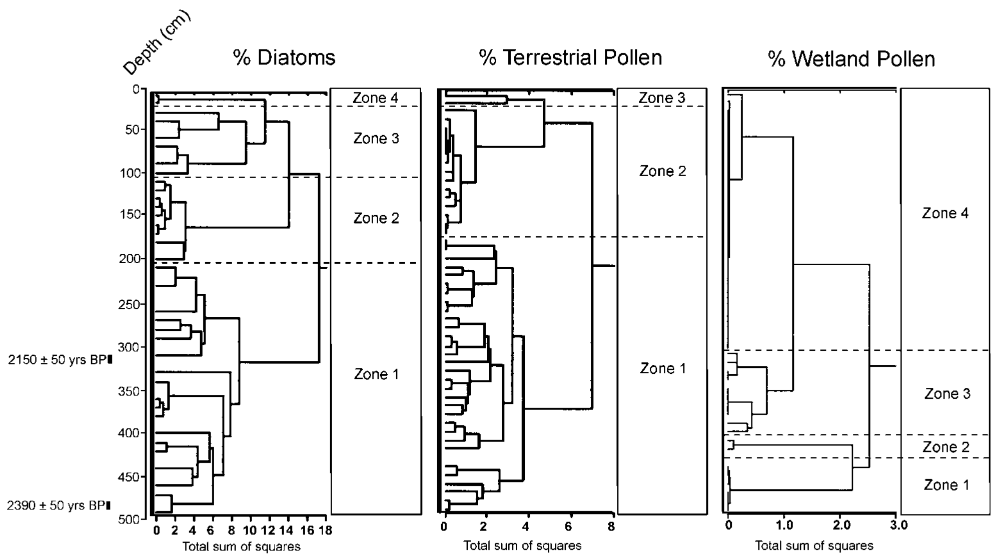

Figure 6. Comparison of the zonation resulting from cluster analysis of diatom data (Figure 3), upland pollen taxa (Figure 4) and wetland pollen taxa (Figure 5).

Cootes Paradise paleoenvironment

Our radiocarbon dates suggest that the Cootes Paradise wetland formed at least 2400 ^{14}C years ago. The dates of 3690 ± 50 ^{14}C years BP (Anderson and Lewis 1985) and 4400 ± 50 ^{14}C years BP (Berry and Drimmie 1982) suggest an older date for the initiation of wetland development (Table 1). Future work will involve vibracoring to obtain a longer sedimentary record, and hopefully older material suitable for radiocarbon dating.

The wetland pollen and diatom data show a shift at 305 cm from a marsh dominated primarily by the emergents *Sparganium* and *Typha*, as well as epiphytic diatoms, to a Poaceae dominated wetland, which most likely consisted of dense stands of wild rice. *Zizania* is more frequently found growing in deeper water than other emergent wetland plants such as *Typha*, *Sparganium* or Cyperaceae (Dore 1969; Newmaster et al. 1997). Above 305 cm, epiphytic diatoms are replaced by benthic, and eventually planktonic taxa. These shifts suggest a water level rise beginning at 2150 ± 50 ^{14}C years BP, which is further supported by the rapid sedimentation rate and low pollen concentration below the depth of 305 cm. Other studies have noted contemporaneous water level rises, at 2100 ^{14}C years BP in Lake Ontario (McCarthy and McAndrews 1988) and at 2170 ± 80 ^{14}C years BP in Lake Erie (Pengelly et al. 1997).

Pollen evidence from this and other cores in the wetland indicate that dense stands of wild rice have persisted here throughout its history. It is assumed that the grain was a valuable resource for indigenous peoples, but there is presently no direct evidence to support this contention. Cootes Paradise is ringed by archaeological sites. Although some are Late Archaic, most are of the Late Woodland Princess Point culture. Sites of this cultural complex have a distinctive location on floodplains and wetland margins (Smith et al. 1997), which suggests that proximity to aquatic resources was an important factor in site selection. Continuing paleoecological and archaeological research will improve our understanding of the role that wild rice played in prehistoric subsistence at Cootes Paradise.

The data suggest that the Little Ice Age had some impact on the wetland. The pulse of small benthic *Fragilaria* species found in this core between 100 and 200 cm has been noted at other coastal wetland sites on Lake Ontario including Second Marsh at Oshawa, Ontario (Earle and Duthie 1984) and East Lake, on the northeastern shore (Yang and Duthie 1994). Stoermer (1993) calls this pulse one of the most striking signals in the pre-European history of the Great Lakes. Small benthic *Fragilaria* spp. are often found in early post-glacial sediments, and still dominate diatom flora in high Arctic environments (Smith 2002), suggesting that their preferred habitat is cold and nutrient poor. The peak noted here is found shortly before the *Pinus* rise and *Fagus* decline, reflecting a more rapid response of algae compared to the longer-lived forest trees.

There are no changes in the wetland pollen record at the time of the Little Ice Age. This may be due to the relatively wide water depth and temperature tolerance ranges for the macrophytes present at the site. Evidence for effects of this climatic event on wetland or aquatic systems are shown here to be better documented in the diatom record. Further investigation into the ecologies of the small benthic *Fragilaria* spp. that dominate diatom assemblages during the Little Ice Age and their detection in other sediment cores in the region spanning this time period will further bolster the conclusion that this peak in *Fragilaria* spp. is a manifestation of Little Ice Age cooling and its impact on aquatic systems.

In the recently deposited sediments spanning the period of heavy human impact, the diatom record indicates a significant increase in water depth, most likely associated with the excavation through the Iroquois Bar. This water level rise cannot be detected in the wetland pollen record due to the confounding effect of introduced carp which have reduced macrophyte cover. The uppermost section of the wetland pollen core shows the recent increase in *Typha angustifolia*, noted for marshes elsewhere (Galatowitsch et al. 1999), and the decline in Poaceae.

The complexity and size of coastal wetlands such as Cootes Paradise precludes generalization about environmental change in the entire wetland on the basis of one core. Future work will focus on integrating paleoecological records from across Cootes Paradise to provide a comprehensive history of the environmental changes in this important wetland.

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