Hydrological Reconnection of a Coastal Wetland to Lake Erie: Potential for Outwelling of Organic Matter

Basic Information

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Hydrological reconnection of a coastal wetland to Lake Erie: potential for outwelling of organic matter?

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Focus Categories: Wetlands, Hydrogeochemistry

Keywords: coastal wetland, stable isotope, restoration, Lake Erie, outwelling

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Congressional District: 15

Principal Investigator: Virginie Bouchard (Assistant Professor, Ohio State University)

1. Statement of Critical State Water Problem

Lake Erie coastal wetlands have been subject to a wide range of natural (e.g., change in water-level, physical damage with ice and storms; Maynard and Wilcox, 1997) and human-induced stressors (e.g., filling, clearing, excavating; Conservation Foundation, 1988). In the western basin of Lake Erie, an estimated 95 percent of coastal wetlands have been destroyed in the last 200 years (Herdendorf, 1987). In addition, dikes have been built around most of the few remaining wetlands to protect them from annual and daily fluctuations of the lake water level. But if diking is a common management technique to maintain waterfowl habitat, it has had unintended consequences. Because diked coastal wetlands are isolated from the lake, their functions of flood control, water quality improvement and habitat for aquatic species have been lost. Those isolating dikes also remove critical spawning and nursery functions for aquatic species, and fish in particular.

In marine systems, considerable research has demonstrated that tidal events export detrital material produced in salt marshes to marine waters (i.e., Teal, 1962; Odum, 1968; Dame and Gardner, 1993; Lefeuvre and Dame, 1994; Childers et al., 2000). There is strong evidence that this “outwelling” of organic matter consequently supports secondary production in coastal waters, and in particular offshore fisheries production. Despite the fact that coastal wetlands around Lake Erie are also under the influence of regular (in term of frequency) - even if unpredictable (in term of range) - water level fluctuations through seiche events, little or no discussion of the outwelling paradigm has occurred. Lack of such knowledge is a major gap in our understanding of Great Lakes coastal wetlands and, without it, acquiring the ability to properly manage these ecosystems and offshore fisheries is highly unlikely.

Because coastal wetlands have been recognized as highly valuable for the sustainability of the whole Great Lakes system, new management practices are investigated in order to reconnect coastal wetlands with the Great Lakes (Wilcox and Whillans, 1999). Both the governments of the United States and Canada recognized the importance of preserving and restoring wetlands across the continent when they created the North American Waterfowl Management Plan (USFWS, 1986; USFWS, 1994). Locally, environmental agencies are supporting various restoration projects (Wilcox and Whillans, 1999). In Ohio, the US Fish and Wildlife Service and the Ohio Department of Natural Resources are involved together in the restoration of Metzger March, a coastal wetland located on the Ottawa Refuge, 18 km east of Toledo (See Section 3.1 on Site Description). The US Fish and Wildlife Service and the Ohio Department of Natural Resources are looking for data to assist them to decide whether Metzger March should be kept connected or not to Lake Erie. My research was designed to understand if the hydrological connection between the marsh and the lake enhance the ecological integrity of both ecosystems, by allowing the outwelling of organic matter during seiche events. As the restoration at Metzger March is a pilot project, this research – together with those of other scientists involved at the site – will have consequences on future restoration projects of coastal wetlands on Lake Erie.

2. Objective of the Project

Adjacent ecosystems are interconnected through the transfer of energy (i.e., nutrients, organic matter and species) that involves both biological and non-biological mechanisms. This notion of "coupled systems" has been successfully applied to evaluate the exchange of energy between riparian systems and rivers during floods, or between salt marshes and coastal waters during tides. The existence of hydrological interdependence between aquatic systems and their adjacent terrestrial ecosystems is thus known to be one of the most important forcing functions that drives the ecological integrity of both systems. The flood pulse concept (Junk et al., 1989; Bayley, 1995; Benke et al., 2000) describes riparian banks as providers of dissolved and particulate organic matter to watercourses, and in some respect is an extension to the river continuum concept (Vannote et al., 1980) that emphasized longitudinal linkages between downstream and upstream processes but ignored lateral connections. The outwelling concept (Odum, 1968) states that tidal events export detrital material produced in salt marsh to marine water. Strong evidence also indicates that the export of organic matter from terrestrial to aquatic systems consequently supports secondary production. Despite the fact that coastal wetlands of large lakes are also hydrologically connected to lakes through wind-driven seiches (e.g., periodic oscillations with irregular amplitudes of lake water level), little or no information regarding the fluxes of energy between these two systems was available.

The objective of this research was to test the outwelling concept in a coastal wetland hydrologically reconnected to Lake Erie by an opening in the dike. My hypothesis is that seiche events allow detrital material to be quantitatively exported in the water column to the lake. This hypothesis was tested at a site that has a controlled opening between the wetland and the lake.

The objective of the project was achieved by a combination of field sampling at the site during seiche events and lab analysis including carbon species (dissolved, coarse and particulate) and stable isotope ratios.

3. Methods, Procedures and Facilities

3.1. Site Description

Natural coastal wetlands are often semi-isolated from the Great Lakes by a barrier beach (Herdendorf, 1987). Presence of openings in the barrier beach allows hydrologic connections with the adjacent lake. However, most of these marshes have been destroyed by historical high water levels and human disturbances (Herdendorf, 1987; Wilcox and Whillans, 1999). Metzger Marsh is a 300-ha wetland located in an embayment of western Lake Erie. Originally protected from the lake by a barrier beach and connected to Lake Erie by a single opening, the wetland was completely open in 1973 when the beach was decimated by a severe storm (Kowalski and Wilcox, 1999). Records have been examined to understand how Metzger Marsh once functioned and to restore the system to its close natural condition (Kowalski and Wilcox, 1999). Since 1998, the marsh has been separated from the lake by a dike that mimics the protective function of a barrier beach and includes an opening (10 m wide) that allows hydrologic connections (Figure 1). The location and design of the opening has been chosen to mimic the natural opening (Kowalski and Wilcox, 1999; Wilcox and Whillans, 1999). At the site, the seiche averages ~0.3 m on a 10 to 14 h-period (Figure 2). Because of the presence of a controlled opening that allowed us to quantify the fluxes of organic matter, this site is a unique opportunity to test the outwelling theory in Lake Erie.

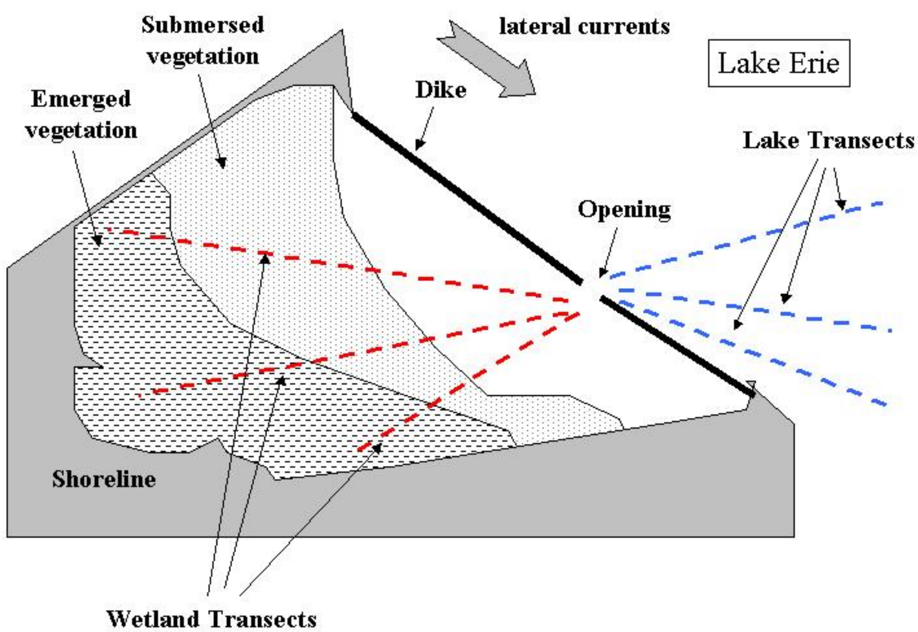

Figure 1. Representation of Metzger Marsh, showing the dike and its 10 m wide opening to Lake Erie. Location of the Wetland and Lake Transects along which water samples were taken.

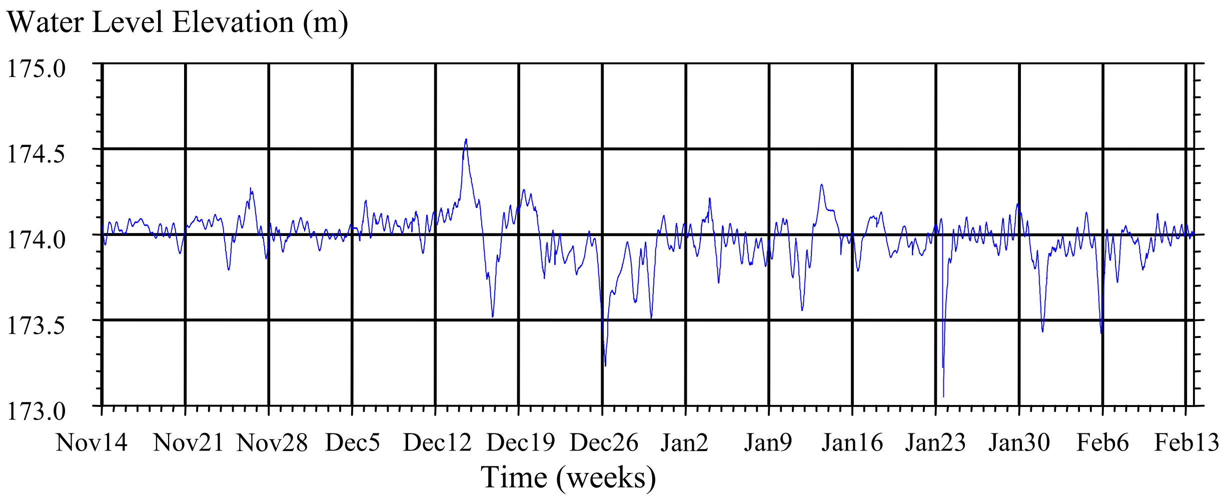

Figure 2. Example of daily water level changes at Metzger Marsh under the influence of seiche events. Seiche periods average 12 to 14 hours at Metzger Marsh. These daily water level changes (~ 0.3m) are superimposed on ~ 0.5 m seasonal changes in lake levels. Short-duration storm surges or "set downs" up to 1.5 meters in magnitude may also occur at these sites.

3.2. Research Methods

Water samples were collected during seiche events, once a week from April to December 2001. We defined a seiche event as a cycle encompassing a period during which the flow enters Metzger marsh, then a short slack period, and finally a period during which the flow leaves the marsh. Seiches last during 6 to 16 hours, with an average of 10-12 hours. Samples were collected while the flow was entering the marsh (i.e., during inflow) and when the flow was leaving the marsh (i.e., during outflow). Samples were taken with auto-samplers. We collected an average of 5-6 samples per flow direction per seiche. During storms events, we collected up to 10-15 samples per flow direction. To ensure the collection of a representative water sample of the entire water column at the opening of the wetland, the auto-sampler was connected to a tube extending from the surface of the water column to the bottom of the opening and perforated every 10 cm. At the opening, the water column depth average 3 m and the entire water column is in motion during inflows and outflows. Water bottles were then brought back to the Aquatic Ecosystem Analytical Laboratory at the Ohio State University for analysis. Half of each sample was filtered over a 0.45-µm Whatman glassfibre filter to separate the dissolved from the particulate fractions. Samples were analyzed for dissolved organic and inorganic carbon (DOC and DIC <0.45µm) and particulate organic and inorganic carbon (POC and PIC, <1mm) with a Total Organic Carbon Analyzer Rosemount Dohrman DC-190.

We measured the stable isotope composition of water ($\delta^{18}O$ and δD) to determine the relative mixing of Lake Erie and Metzger Marsh waters. To identify the origin of the DOC exported and imported from/to the wetland, we analyzed the stable isotope carbon and nitrogen signature of the water. In aquatic systems, natural stable isotope abundance techniques have been successfully applied to investigate the source and pathways of organic matter and to define the functional role of organisms (Fry and Sherr, 1984). The naturally occurring stables isotopes of both carbon (^{12}C and ^{13}C) and nitrogen (^{14}N and ^{15}N) are complementary to the understanding of organic matter fluxes (Peterson, 1999). For isotopic analysis, water samples were collected in the lake and in the wetland, three times during the year (April, June, and October 2001) to account for variability with seasons. In the wetland, we collected 14 water samples along the three Wetland transects (Figure 1). In the lake, we collected 3 samples along the three Lake transects (Figure 1). At each sampling, we collected a 250-ml surface water sample and a 250-ml near-bottom water sample. Then, for each season, two seiches were randomly selected, and three representative samples were analyzed per flow direction. The signature of the water leaving and entering the wetland was then compared to the pool of signature from the water collected around the wetland and the lake in order to identify its origin (i.e., wetland or lake water). On site, each water sample were immediately filtered through Whatmann GF/C filters and preserved with 0.5 ml saturated $HgCl_2$ solution. Stable isotope values were related to primary producers by measurement of the stable isotopic signature of the primary producers following the methods of Keought et al. (1996).

4. Principal Findings

Some export of OC occurred in the spring, but this export significantly increased during the fall (Figure 3).

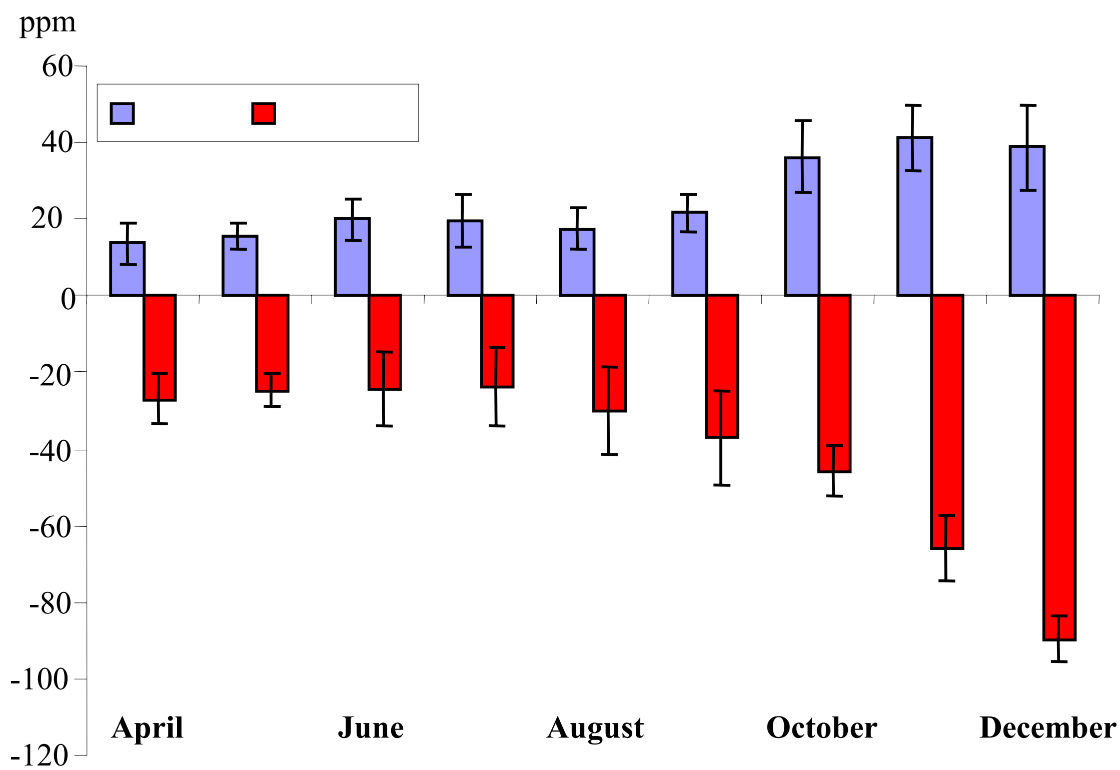

Figure 3. Average concentration (in ppm) of Total Carbon in water flowing inside (i.e., inflow) or outside (i.e., outflow) the marsh during seiche events from April – December 2001.

The average concentration of OC in the water flowing into Metzger Marsh was 18.8 ppm (± 2.1, n = 154) from April to August, and reached 21.4 ppm (± 6.1, n = 161) from September to December. During the first period, the outflow of Metzger Marsh had an OC concentration of 26.4 ppm (± 2.3, n = 126), and increased to 45.2 ppm (± 6.1, n = 131) in the fall. The wetland enriched the lake in OC, particularly during storm events. In September 2001, 53% of the exported OC was exported during a 50-h storm event; in October 2001, 41% of the exported OC was exported during a 42-h storm event; in November 2001, 34% of the exported OC was exported during a 26-h storm event. Finally in December 2001, 52% of the exported OC was exported during 2 storms events accounted 32 hours. During these storms events, we also noted a significant increase of turbidity as demonstrated on Figure 4. However, during regular seiche events, the changes in OC concentration in the inflow and outflow water were insignificant (Figure 5).

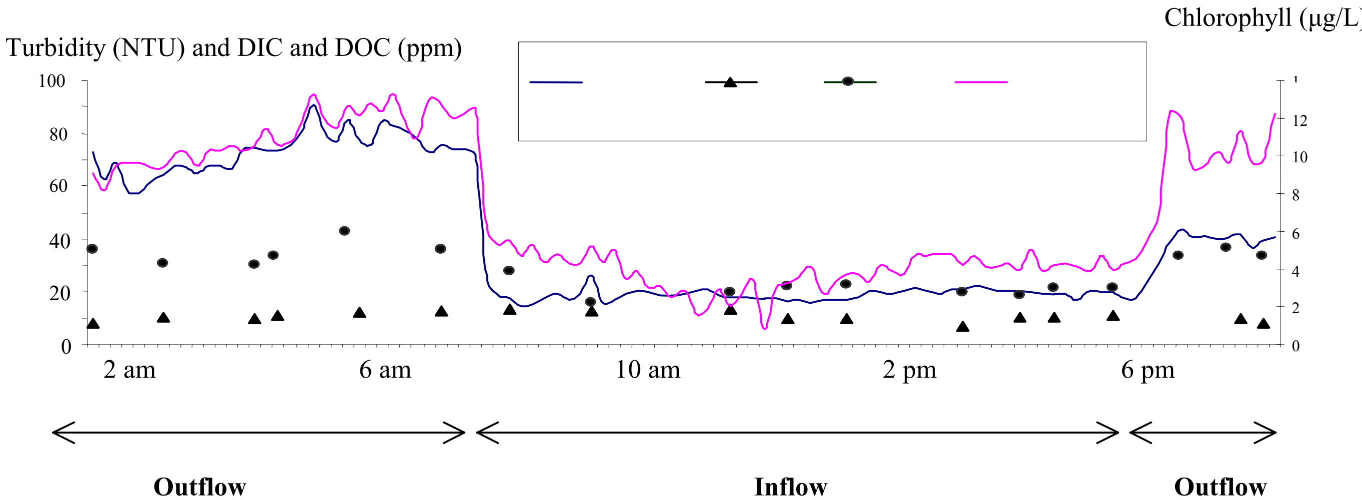

Figure 4. Evolution of the concentration of chlorophyll, turbidity, dissolved inorganic carbon (DIC), and dissolved organic carbon (DOC) during one storm event in September 2001. Chlorophyll and turbidity data were determined at the site every 15 min, while IC and OC were measured in the lab on water samples taken every hour. The flow direction is indicated by "inflow" and "outflow" below the X-axis.

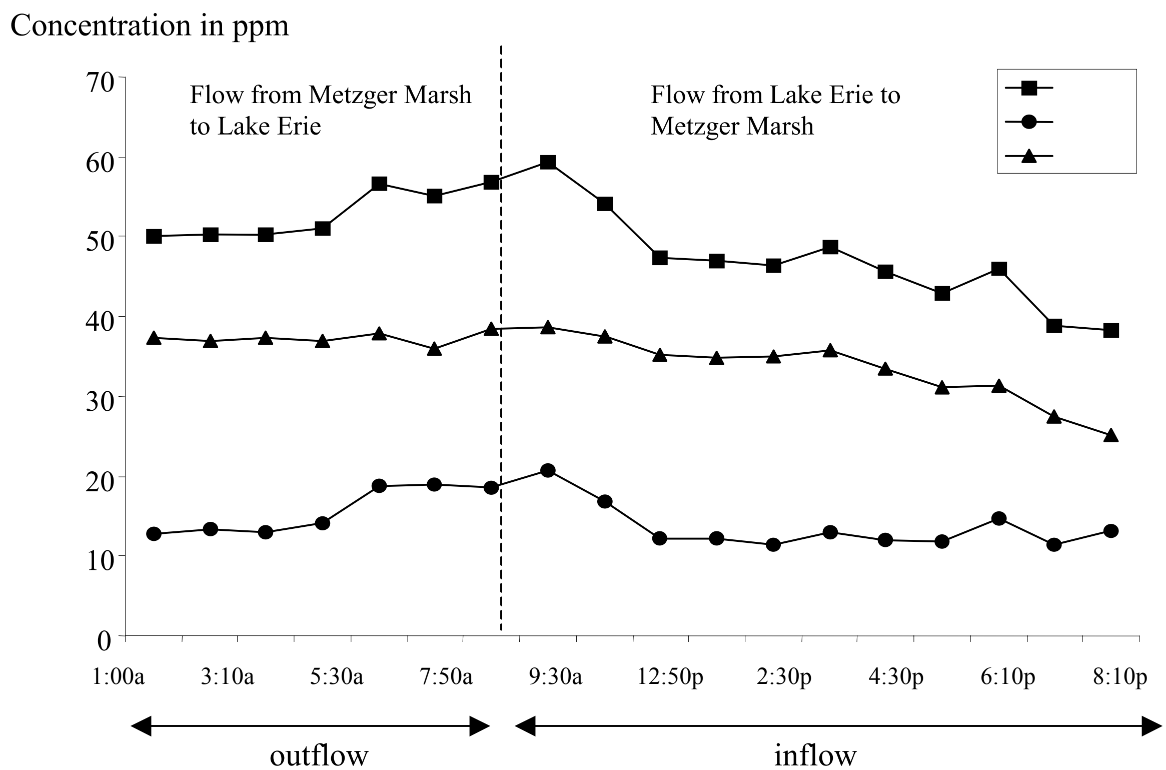

Figure 5. Evolution of the concentration of Total Carbon (TC), Total Inorganic Carbon (TIC), and Total Organic Carbon (TOC) during one seiche event in September 2001. The flow direction is indicated by "inflow" and "outflow" below the X-axis.

The isotopic composition of Lake Erie remained relatively as described by others (e.g., Huddart et al., 1999). The marsh samples were taken at different distances from the opening to the lake. The stable isotope composition of the marsh waters was strongly affected by evaporation and precipitation for the samples taken in the rear of the marsh (Figure 6). But for most of the marsh water samples, the isotopic composition was identical to those from Lake Erie, supporting the concept that there is a significant and well-mixed exchange of water between the two systems (Figure 6).

We measured the isotopic composition of the particulate organic carbon and the dissolved inorganic carbon ($\delta^{13}C_{POC}$ and $\delta^{13}C_{DIC}$) in water samples taken in Lake Erie and Metzger Marsh. The $\delta^{13}C_{DIC}$ values ranged between -12.3 to -5.6‰ (n = 12) in the wetland and between -4.8 and -2.3‰ (n = 4) in Lake Erie, and were comparable to other studies (Keough et al., 1996; Barth et al., 1998). The wetland had a wide range of $\delta^{13}C_{POC}$ values (-36.5 to -17.8‰) depending on time of the year, while $\delta^{13}C_{POC}$ values in the lake were uniformly close to -28‰. Most relevant is the possibility that isotopic composition of DIC and POC can be used to differentiate between waters enriched by carbon from the lake vs. that from the wetland (Figure 7).

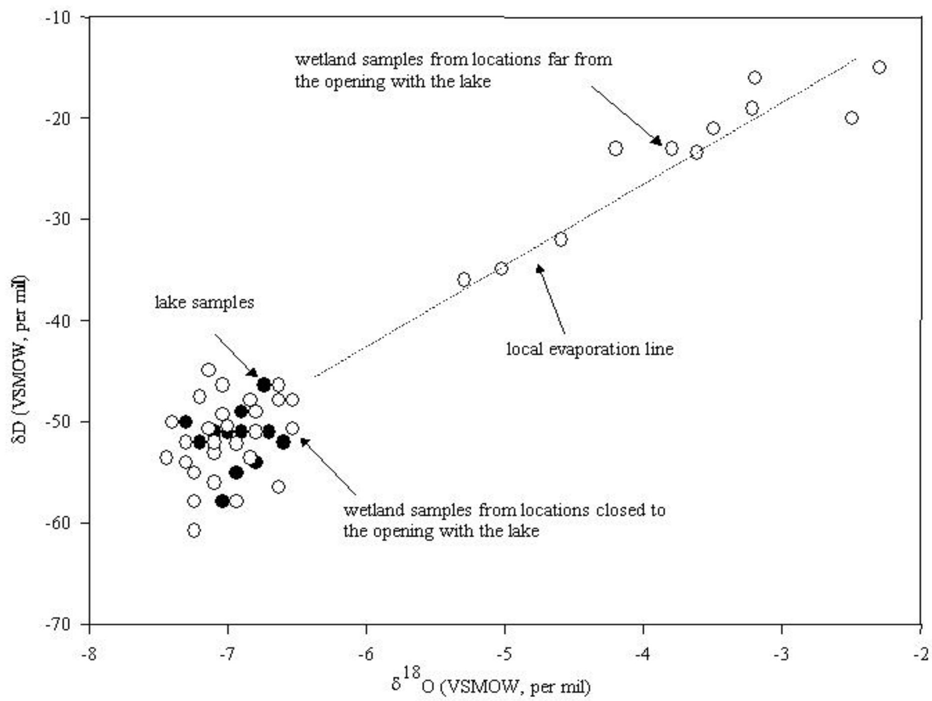

Figure 6. Hydrogen- and oxygen- isotopic compositions of water samples from Lake Erie and Metzger Marsh. The marsh samples taken away from the opening define the evaporation line.

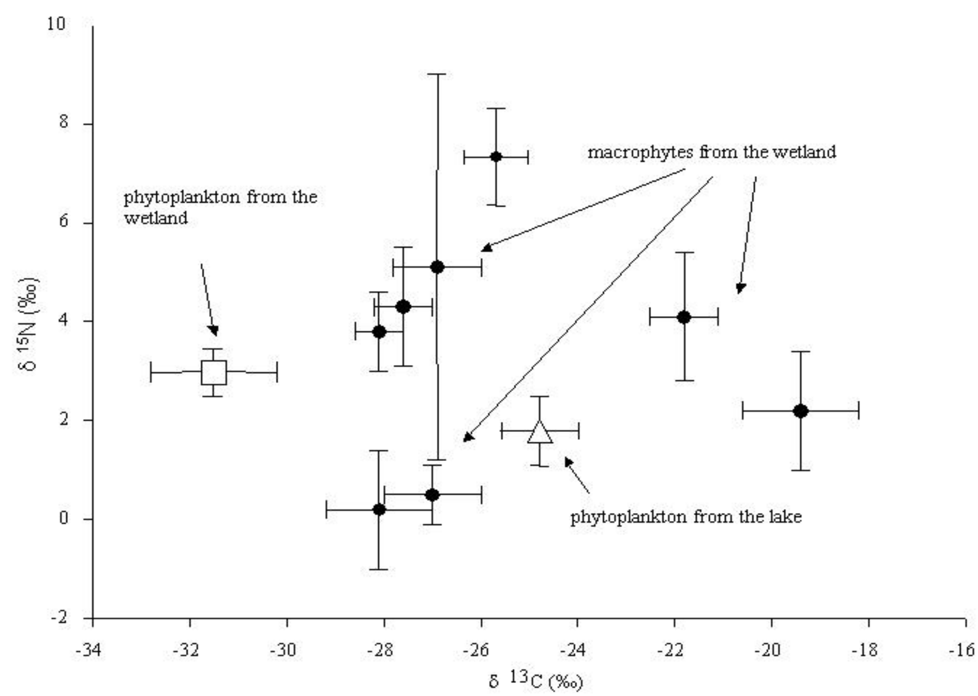

Figure 7. Stable isotope ratios for carbon and nitrogen for primary producers sampled in Metzger Marsh and Lake Erie.

5. Significance of this research

This research is significant in providing critical information that can be applied in rehabilitating or restoring Lake Erie coastal wetlands. This study shed light on the ecological link between two-coupled systems (e.g., lake and coastal wetland) placed under the influence of a physical pulsing event (e.g., seiche). This research may force us to reevaluate our current understanding of the ecology of fresh coastal wetlands, particularly in the Great Lakes. Indeed, in the past 200 years two-thirds of the Great Lakes coastal wetlands have been drained, with most regions having lost more than 90 percent of their wetlands (Herdendorf, 1987). In an effort to provide adequate waterfowl habitat (Bookhout et al., 1989), most of the coastal wetlands along the shore of Lake Erie have been diked to control water levels (Herdendorf, 1987). Because they are artificially isolated from the lake and no longer under the influence of daily water level fluctuations, the contribution of these coastal wetlands to Lake Erie's food web is likely limited, especially for the fish community (Hussey, 1994; Brazner and Beals, 1997; Ryan et al., 1999). Process of outwelling of organic matter during seiche events – similar to that of tidal marshes with tides (Odum, 1968; Childers et al., 2000) – is probably negligible. Metzger March is a pilot project to test the success of such hydrological restoration (Wilcox and Whillans, 1999) and this research will greatly benefit future restoration projects. We demonstrated at that site that the export of organic matter from the coastal wetlands to Lake Erie occurs, mainly during storm events. The next step of this research is now to question whether the organic matter produced in the marsh is used by the Lake food web and indeed enhance the Lake ecological integrity.

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