Water Resources Center
Annual Technical Report
FY 2002

Introduction

Research Program

Preventing the Initiation of Biofouling of Membrane Bioreactors in Wastewater Treatment t

Basic Information

Title:	Preventing the Initiation of Biofouling of Membrane Bioreactors in Wastewater Treatment t
Project Number:	2002OH11B
Start Date:	3/1/2002
End Date:	11/30/2003
Funding Source:	104B
Congressional District:	2
Research Category:	Engineering
Focus Category:	Treatment, None, None
Descriptors:	MBR, molecular biology, wastewater treatment
Principal Investigators:	Daniel Barton Oerther, Dionysios Dionysiou, George A Sorial

Publication

Project Title. Preventing the Initiation of Biofouling of Membrane Bioreactors in Wastewater Treatment

Project Team.
Daniel B. Oerther, Ph.D., Tenure-track Assistant Professor
Dionysios Dionysiou, Ph.D., Tenure-track Assistant Professor
George A. Sorial, Ph.D., Tenure-track Associate Professor

Department of Civil and Environmental Engineering, University of Cincinnati

Summary of Annual Progress. Membrane bioreactors (MBR) can be expensive to operate because of fouling of the membrane that results in high operating pressures, excessive membrane cleaning, and decreased membrane life. We hypothesize that preventing the initiation of biofilm formation on membrane surfaces is the best approach for eliminating fouling of the membranes in MBR systems. To test this hypothesis, we are investigating the connection between the physiochemical properties of membranes and the ecology of microbial communities inhabiting MBR systems. The specific interdisciplinary aims that are being undertaken in this study include:

a) determining the physicochemical properties of membranes;
b) examining the impact of synthetic pulp and paper wastewater on the physiochemical properties of membranes;
c) determining the biochemical interactions between microorganisms and membranes;
d) examining the impact of synthetic pulp and paper mill wastewater on the microbial community colonizing membranes; and
e) determining the role of microbial ecology in the initiation of biofilm formation on membrane surfaces.

The research team working on this project includes: a tenure-track faculty member with experience in physiochemical properties of membranes (Dionysiou); a tenure-track faculty member with experience in biological treatment of industrial wastewaters (Sorial); a tenure-track faculty member with experience in molecular biology and conventional microbiological analysis of environmental samples (Oerther); and two doctoral students. Milestones for the first year of the project include:

1. Designing, fabricating, and pilot-testing a laboratory-scale membrane reactor system to quantify transmembrane flux (to date, the system has been used to test membranes for a total running time of approximately 80 hours).
2. Designing, fabricating, and operating four laboratory-scale membrane bioreactor systems using activated sludge to treat a synthetic pulp and paper mill wastewater (to date, the reactors have been operated continuously for a period of 120 days).
3. Developing appropriate analytical procedures to characterize the physiochemical properties of membranes including brighfield, phase contrast, and epifluorescence microscopy; transmission electron microscopy; scanning electron microscopy; and FTIR analysis.
4. Developing appropriate analytical procedures to characterize the microbiological community in the various experimental systems including the Full Cycle 16S rRNA Approach and Fluorescence In Situ Hybridization targeting 16S rRNA.
5. Developing and evaluating a mechanistic model that accurately predicts the relationship between loss of transmembrane flux and various aspects of fouling on the surface of a membrane.

In the upcoming year, we plan to complete this project by integrating the separate membrane and bioreactor systems described above. We expect that the results of this project will provide fundamental knowledge that can be used to understand and ultimately to eliminate fouling of the membranes in MBR systems.

Background. The application of membranes to separate particulate and suspended materials from waste streams is an evolving technology. Membrane bioreactors (MBRs) have many advantages as compared to suspended growth wastewater treatment systems that rely upon clarifiers and quiescent settling to remove suspended materials. MBRs:

a) eliminate the problems associated with bulking sludge in conventional activated sludge systems,

b) allow increased biomass concentrations in reactors permitting increased loading rates and promoting higher reaction rates,
c) increase the concentration of extracellular enzymes which improves the kinetics and extent of biodegradation reactions, and
d) permit excessively long sludge ages which promote higher endogenous decay rates, lower excess sludge production, and maintains sludge age sensitive populations including grazing protozoa and higher life forms as well as nitrifiers.

The primary disadvantages of MBRs include capital costs for the membranes and operating costs associated with routine membrane cleaning. Biofouling is a serious problem for the operation of membrane bioreactor systems because it results in decreased transmembrane fluxes. Biofouling involves the synergistic effects of physical, chemical, and biological clogging of membrane pores. Clogged pores result in: (a) reduced transmembrane fluxes, (b) a need for higher operating pressures, and (c) irreversible destruction of the membrane. We hypothesize that preventing the initiation of biofilm formation on membrane surfaces is the best approach for eliminating biofouling of MBRs. To test this hypothesis, we are investigating the fundamental mechanisms of biofilm initiation on membrane surfaces. By understanding the mechanisms of biofilm formation, we expect to provide improvements in MBR technology to eliminate biofouling. If biofouling of MBRs is eliminated, the associated costs should be dramatically reduced. Lower costs for MBR technology should help in the widespread application of this technology for protecting the quality of the water environment in the state of Ohio and the protection of human health.

Nature, Scope, and Objective.

The overall objective of this project is to identify approaches to eliminate fouling of membrane surfaces due to the action of biological components.

To accomplish this objective, our research team is examining the initiation of biofilm formation on membrane surfaces through a synergistic study of the physicochemical properties of select membranes; the impact of synthetic pulp and paper wastewater on the physiochemical properties of select membranes; the impact of synthetic pulp and paper mill wastewater on the microbial community colonizing select membranes; the biochemical interactions between microorganisms and select membranes; and the role of microbial ecology in the initiation of biofilm formation on membrane surfaces.

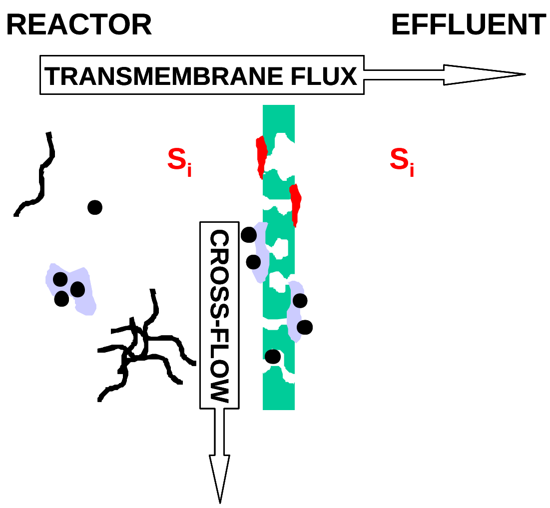


Fig. 1 Schematic of a membrane bioreactor system. Purified water moves from left to right from the reactor to the effluent. The water passes through the membrane (green). Soluble chemical components are indicated in red. Microorganisms are shown in black, and extracellular polysaccharide material is shown in blue.

Figure 1 shows a schematic of a membrane bioreactor system. Wastewater is treated in the reactor system (on the left of the figure). Purified water passes through the membrane (shown in green), and membrane permeate is the effluent from the system. The chemical composition of the wastewater is indicated in red. Microorganisms are shown in black, and extracellular polysaccharides (EPS) are shown in blue. The flux of purified water through the membrane is controlled by the available pore space and the operating pressures across the membrane. Chemical precipitates, EPS material, and microorganisms block available pore space resulting in reduced transmembrane flux at constant operating pressures. In a complex manner, physical, chemical, and biological properties act together to reduce available pore space resulting in reduced transmembrane fluxes.

To study the complex process of biofouling, we are addressing three central questions. Figure 2 shows the three central questions and their relationship to the physical, chemical, and biological principles involved in biofouling. The primary physical question that is being examined in this study is, "Which membrane properties and operating conditions prevent biofouling?" The chemical and biological questions that are being answered are, "Which wastewaters can be treated with membrane bioreactors without biofouling?", and "Which microorganisms are responsible for initiating biofilm formation?", respectively.

For the purposes of our project, we have defined biofouling as the reduction of transmembrane flux through the complex interaction of microorganisms and suspended materials with the surfaces of membranes. Thus, the extent of biofouling is quantified by measuring the loss of transmembrane flux. By relating the definition of biofouling to transmembrane flux, we are reducing the level of complexity of physical principles. For this study, laboratory-scale MBRs are being operated using membranes under a vacuum of less than 5 psi. To reduce the level of complexity of chemical principles, we are using the bioreactors to treat a well-defined synthetic wastewater developed to mimic the waste streams of typical pulp and paper industries. By using a synthetic wastewater, we are able to control the type and levels of suspended materials. In addition, we are able to control the balance of nutrients within the waste stream (i.e., the carbon to nitrogen to phosphorus ratios). By providing experimental control for the levels of suspended materials and nutrients, we expect that we are reducing the levels of physical and biological complexity. To reduce the level of complexity of the biological components, we have initially tested biofilm formation with membrane samples using pure cultures of individual microorganisms and mixtures of pure cultures of individual microorganisms including *Pseudomonas*, *Escherichia*, *Acinetobacter*, *Corneybacterium*, and *Aeromonas*. Recently, we have also begun to use samples of membranes to develop microbial biofilms in the absence of transmembrane flux. Thus, we expect that the simplest example of biofouling – the growth of a biofilm on a membrane surface without transmembrane flux – will provide an appropriate experimental base line for our work.

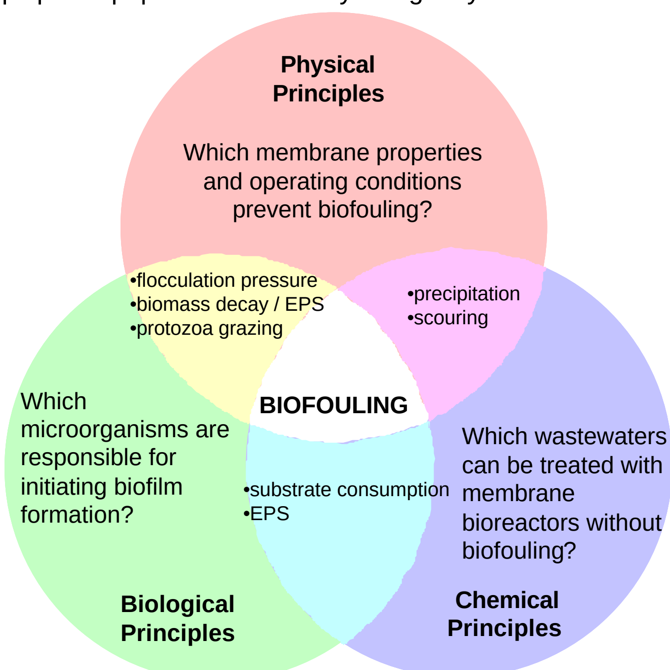


Fig. 2 Relationship among critical research questions and physical, chemical, and biological principles of membrane biofouling.

Methodology for Estimating Total Maximum Daily Load in Watersheds with Considerable Groundwater-Surface Water Interaction

Project 2002OH12G was not funded for FY2002.

Sediment Loads and Conservation Tillage in the Maumee River Watershed

Basic Information

Title:	Sediment Loads and Conservation Tillage in the Maumee River Watershed
Project Number:	2002OH14B
Start Date:	4/1/2001
End Date:	3/31/2002
Funding Source:	104B
Congressional District:	11
Research Category:	Climate and Hydrologic Processes
Focus Category:	Sediments, Non Point Pollution, Models
Descriptors:	
Principal Investigators:	Douglas Moog, Peter John Whiting

Publication

Interactive Effects of Hydrology and Fertility on Synthesized Wetland Plant Communities

Basic Information

Title:	Interactive Effects of Hydrology and Fertility on Synthesized Wetland Plant Communities
Project Number:	2002OH15B
Start Date:	3/1/2001
End Date:	8/31/2002
Funding Source:	104B
Congressional District:	14
Research Category:	Biological Sciences
Focus Category:	Wetlands, Nutrients, None
Descriptors:	wetland ecology, plant diversity, hydrology, restoration
Principal Investigators:	Lauchlan Hugh Fraser

Publication

Research Final Report

1. Title: The interactive effects of hydrology and fertility on synthesized wetland plant communities.

2. Project Type: Research

3. Focus categories: WL, ECL, M&P.

4. Keywords: watershed management, wetland plants, diversity, restoration, conservation.

5. Start Date: 03/01/01

6. End Date: 08/31/02

7. Principal Investigator's Name and University: Dr. Lauchlan H. Fraser, U. of Akron.

8. Congressional district: Summit–14.

9. Abstract:

Approximately 90% of the original wetlands in Ohio have been lost over the last two hundred years, mainly as a direct consequence of human use. There is an urgent need to conserve and restore the remaining wetlands because wetlands serve a very important role in our environment. Wetlands have been described as 'the kidneys of the landscape' and 'biological supermarkets'. They play major roles in the landscape by providing unique habitats for a wide variety of flora and fauna. Acknowledging the importance of wetlands demands conservation and restoration measures.

The objective of this project was to further understand the role of hydrology and nutrients on a wetland ecosystem. These two environmental factors, especially hydrology, have been relatively understudied in wetland ecology. Given these two factors, the morphological variables (height, canopy, rooting depth, biomass) and growth rates, can be compared between treatments. These comparisons will result in a better understanding of the individual and combined roles of hydrology and nutrients on a wetland ecosystem.

The research showed that wetland plant species growth response is very different at different water levels. The average optimal growth was found at approximately +2 to +4 cm above soil level. However, different species responded differently. We were able to apply our hydrology index to predict the performance of individual species within a community, but only at one water level (+5 cm above soil level). It was the goal of both experiments to create usable databases, which can be built upon, to make sound predictions when restoring a wetland community. The data and research sites will also provide a substrate for (1) further studies in wetland ecology, (2) educational programs, and (3) comparative analysis with other wetlands.

10. Budget Breakdown:

	Federal	Non-Federal
1) Salaries a) Principal investigator (LHF) b) Graduate student (J.Karnezis)	 $ 0 $ 8,000	 $ 0 $ 4,500
2) Fringe benefits a) PI (29%) b) Graduate students (0.5%)	 $ 0 $ 40	 $ 22.5
3) Supplies a) Plant presses, sampling containers b) Pentium III computer c) High intensity growth lights (10 at $100 each)	 $ 1,000 $ 0 $ 0	 $ 0 $ 3,000 $ 1,000
4) Equipment	$ 0	$ 0
5) Services or consultants a) 2 undergraduate research assistantships	 $ 2,000	 $ 2,000
6) Travel a) Conferences b) Research van use (5,000 miles at 30 cents/mile)	 $ 250 $ 1000	 $ 750 $ 500
7) Other direct costs a) Publication/offprint costs b) Tuition waiver for 1 student	 $ 250 $ 0	 $ 250 $ 8,300
8) Indirect costs a) Overhead 46% (excluding tuition)	 $ 0	 $ 5,530
9) Total estimated costs	$ 12,540	$ 25,853

11. Budget Justification:

Above is a detailed account of how USGS funds, through the Water Resources Research Institute Program, were spent, as well as the matching costs from the University of Akron. The total budget for this project is $ 38,393.

Mr. Jason Karnezis (MSc candidate) was supported for an entire year (the last year of his degree). Mr. Karnezis was a Research Associate through the summer 2001 and for the fall term. During the spring term Mr. Karnezis was a Teaching Assistant. Two undergraduate students were employed to support the proposed projects. A computer was necessary for the analysis and interpretation of the data collected from this project, as well as follow-up projects that emerge from the results. High intensity lights, containers and nutrients were required to set-up the indoor and outdoor microcosm experiments. The remaining funds were allocated to travel (conferences and the research site) and dissemination costs.

12. Title:

The interactive effects of hydrology and fertility on synthesized wetland plant communities

13. Statement of critical regional or State water problem:

Approximately 90% of the original wetlands in Ohio have been lost over the last two hundred years, mainly as a direct consequence of human use. There is an urgent need to conserve and restore the remaining wetlands because wetlands serve a very important role in our environment. Wetlands have been described as 'the kidneys of the landscape' and 'biological supermarkets'. They play major roles in the landscape by providing unique habitats for a wide variety of flora and fauna. Acknowledging the importance of wetlands demands conservation and restoration measures.

14. Statement of results or benefits:

The main goal of this project was to further understand the role of hydrology and nutrients on a wetland ecosystem. These two environmental factors, especially hydrology, have been relatively understudied in wetland ecology. Given these two factors, the morphological variables (height, canopy, rooting depth, biomass) and growth rates, can be compared between treatments. These comparisons will result in a better understanding of the individual and combined roles of hydrology and nutrients on a wetland ecosystem. The data and research sites will also provide a substrate for (1) further studies in wetland ecology, (2) educational programs, and (3) comparative analysis with other wetlands.

Two experiments were conducted to measure how hydrology affects both the individual growth of a plant, and an entire plant community in combination with a fertility treatment. Measuring the growth rates and morphological variables in both experiments allows for predictive power of the role of hydrology and nutrients on individual wetland plant species and a community of wetland plant species. This data can be applied to a 45-acre site on the Bath Nature Preserve (Bath Township, Ohio) that was formerly a wetland but is currently drained with buried tile, and therefore has good wetland restoration potential. Studying the effects of hydrology on individual plants and then comparing the results when grown in a community allows for (1) the isolation of the role of hydrology on the individual and (2) the effect of an established community on the individual. These results provide insight as to why some wetlands are more diverse or prone to invasiveness. The Bath Nature Preserve (BNP) is virtually surrounded by development and is prone to a high level of disturbance, a factor that has conclusively been linked with invasive establishment in many different ecosystems. Understanding the roles of hydrology and nutrients will provide valuable information on how a wetland community develops and will enable better decisions to be made concerning the restoration of a wetland on the BNP.

15. Nature, scope, and objectives of the research

Wetlands are one of the most productive ecosystems in the world, furthermore they perform many functions that influence the quality of life for people. Wetlands serve as flood and erosion control systems, natural water treatment plants, and as essential habitat for many flora and fauna (Mitch and Gosselink 1993, Kadlec and Knight 1996, Keddy 2000). In Ohio approximately 90 percent of all wetland habitat has been degraded or lost (Mitch and Gosselink 1993). Efforts to restore and preserve remaining wetlands have been fuelled by the passing of the Clean Water Act, 1977. Still, the national trend is averaging annual losses rather than gains in wetland habitat. Further research is required to advance our knowledge of how to better preserve and sufficiently restore wetlands in order to reap their valued benefits.

In 1997 the Bath Township purchased 404 acres of the former Firestone Estate and established it as the Bath Nature Preserve (BNP). The University of Akron has entered into a long-term lease agreement with the township to manage, research, and restore much of the preserve to its original habitat. There are several wetlands in BNP as well as a 45-acre site that was formerly a wetland but is currently drained with buried tile, and therefore has good wetland restoration potential. The BNP is surrounded by development on all sides and therefore serves as a perfect setting to research and restore a natural area within a fragmented landscape.

The importance of wetlands has never been more apparent than today, however we require further study to understand how wetlands function. Gaining insight to these processes is essential for understanding how to reconstruct and preserve wetland habitat. The most important factor in determining how a wetland functions is the hydrology (Mitsch and Gosselink 1993). Much of the current literature in wetland research is focused on how hydrology and nutrients affect the structure and function of a given wetland (Gerritsen and Greening 1989, Owen 1995, Barendregt et. Al 1995). However there is a lack of baseline information as to how hydrological and nutrient regimes affect wetland plant species. Gilvear and Bradley (2000) suggest much of the difficulty in obtaining this information is due to the unique attributes of wetlands such as seasonal variation in size and saturation, and inundation periods, which complicates hydrological monitoring. Additionally, the altering of hydrology and nutrients can lead to the domination of non-native and invasive species, ultimately resulting in decreased diversity and function of a wetland (Weisner 1993). The use of microcosms to control and manipulate these factors can be a powerful tool to study wetland processes under controlled conditions (Fraser and Keddy 1997). For example, we can determine how hydrology and nutrients affect community composition of a wetland using controlled microcosms.

A two-tiered research project is described in this proposal that is designed to examine how different hydrological regimes and nutrient levels affect local wetland species composition.

16. <u>Methods, procedures, and facilities</u>

Experiment 1

The hypothesis for the first experiment was that there will be a difference in community composition across different hydrologic regimes and nutrient levels. The use of microcosms allowed for control of both nutrients and water level to manipulate artificial wetlands.

The experimental design involved four water level treatments: 5 centimeters above the substrate, 5 centimeters below the substrate, at the substrate, and a ‘natural’ water level fluctuation found at the Bath Nature Preserve (BNP). The BNP water level was based on a weekly average of three piezometers installed into the proposed 45-acre wetland restoration site. This data is the beginning of a long-term monitoring process to better understand the hydroperiod of the restoration site. On top of the hydrology treatments there were two separate nutrient levels designated as high and low. The high nutrient regime was a doubling of the concentration of Rorison’s solution (Hendry and Grime 1993) and the low regime was one-tenth the concentration of the solution (Table 1). Each treatment was replicated 12 times resulting in a total of 96 microcosms.

Table 1. A 4 x 2 factorial design produces 8 different sets of microcosms. Twelve replicates of each set will yield 96 total microcosms.

	Hi fertility	Low fertility
H_2O + 5 cm above substrate	1	5
H_2O – 5 cm below substrate	2	6
At the substrate	3	7
BNP H_2O fluctuation	4	8

The microcosms were placed at the BNP, surrounded by fencing and bird netting to exclude as much disturbance as possible. The microcosms were 10 gallon Rubbermaid storage boxes filled with a 3:1 ratio of sand and peat, which provided a relatively neutral substrate to which the nutrient solution could be administered, controlled, and recorded with greater confidence. The microcosms rested on a level surface in three rows in a random blocking pattern to account for sunlight exposure. There was a seed set of 15 wetland plant species added to each microcosm (Table 2). The species were a representative of the local flora present in the other wetlands on the BNP including species such as *Carex lacustris, C. lupulina, Scirpus cyperinus,* and *Eleocharis smallii.* Seeding was done in the early Spring 2001.

Table 2. Plant species in each microcosm.

#	Scientific name	Common Name
1	*Juncus effusus*	Soft Rush
2	*Carex lupulina*	Hop Sedge
3	*Carex lacustris*	Sedge
4	*Carex vulpinoidea*	Fox Sedge
5	*Carex stipata*	Sawbeak Sedge
6	*Carex tribuloides*	Bristlebract Sedge
7	*Elymus virginicus*	Virginia Wildrye
8	*Verbesina alternifolia*	Yellow Ironweed
9	*Scirpus cyperinus*	Woolgrass
10	*Glyceria Canadensis*	Rattlesnake Manna Grass
11	*Rumex orbiculatus*	Great Water Dock
12	*Eleocharis smallii*	Small’s Spikerush
13	*Mimulus ringens*	Monkey Flower
14	*Calamagrostis canadensis*	Bluejoint
15	*Agrostis gigantea*	Redtop

Water levels were manipulated by drilling holes 5 cm above and below the substrate in the respective treatments to allow for drainage during rainy days. An automatic watering unit was designed to administer water four times daily, at half-hour durations. During the summer of 2001, we allowed the communities to establish under the eight different treatments. At the end of the growing season (October), one-third of each treatment (four microcosms per treatment) was harvested: the above-ground biomass was removed, sorted to species, oven-dried and weighed.

The goals of this first experiment are to better understand how the effect of two abiotic factors, hydrology and nutrient levels can influence the community composition of a wetland.

Experiment 2

The focus of the second experiment was solely on the effect of hydrology on the 15 wetland species (Table 2) used in Experiment 1. The hypothesis was that each species will have a unique and differential growth pattern when grown at a range of water levels. Using a laboratory design will allow even greater control over the hydrologic variable to see how plants respond to the different regimes.

The hydrologic treatments constituted a 2 cm incremental range from –4cm to 8cm. All 16 species were tested individually over the 7 water level treatments with 5 replicates in each treatment creating a 16 x 7 x 5 factorial design resulting in a total of 560 units. Each unit contained the same 3:1 sand/peat mixture as described in Experiment 1, and received a weekly regime of nutrients. High-intensity 1000-watt bulbs provided a daily 14-hour photoperiod. Standard temperature was maintained at approximately 22^{o}C and humidity at approximately 65%.

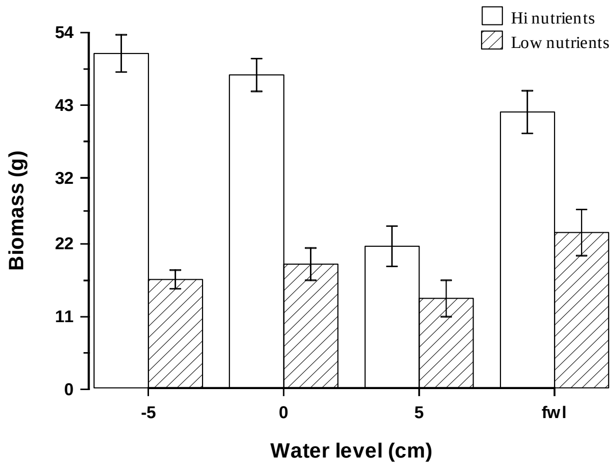
The experiment was initiated March 2001. After 6 months growth, the plants were harvested, oven-dried and individually weighed. It is important to isolate and compare the effect of hydrology on the individual species to better predict how they will respond in the field. By isolating one variable in the experiment it is possible to determine the impact of other variables in the first experiment.

Results and Data Analysis

The above experiments have been designed to test sixteen common wetland species of the Bath Nature Preserve. The preserve is a natural habitat fragment surrounded by development and thus susceptible to human disturbance. The township of Bath is intent on preserving and restoring the BNP as a natural habitat. The University of Akron has the opportunity to conduct research on the BNP to better understand how to restore wetlands.

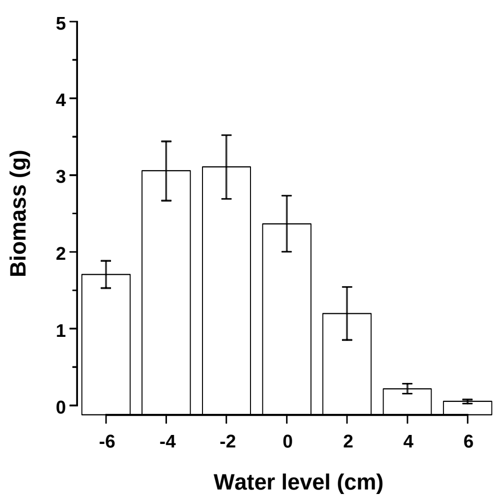
The outdoor microcosm experiment (Experiment 1) was initiated in August 2000 and ended October 2002. Results demonstrate that the treatments had a significant effect (Fig. 1).

Figure 1. Average biomass of each treatment plotted against nutrient and water levels.“fwl” = fluctuating water level.



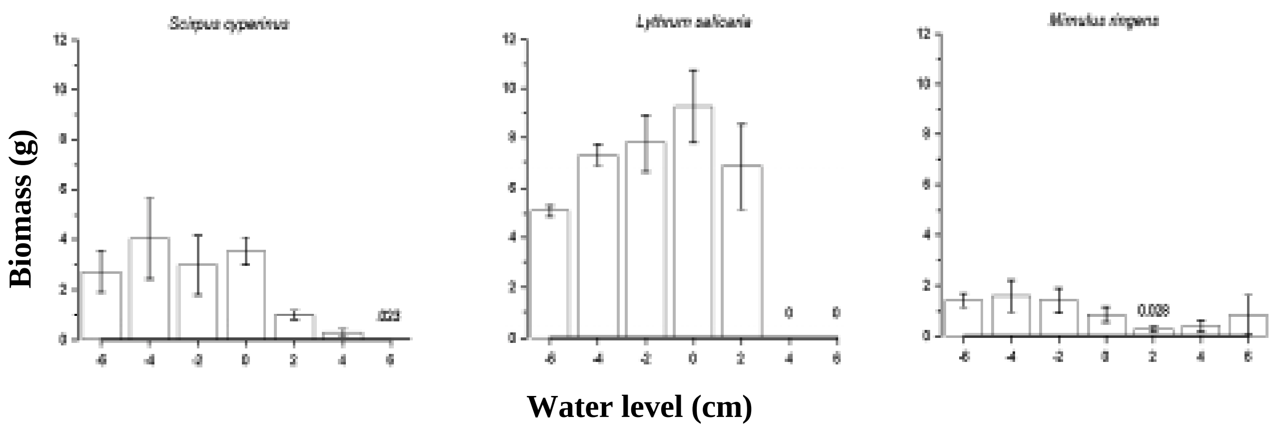
The indoor, laboratory experiment (Experiment 2) allows for the isolation of the hydrologic variable, whereby we can observe how plants will respond individually to fluctuating hydrologic regimes. It serves as a measure to gauge how much of the growth and survival of an individual species is dependent on hydrology given all other conditions as controlled and also sets up a comparative study to predict the effects of competition and nutrient regimes on individual plant growth. An index of performance based on biomass and survival at the different hydrology levels has been developed (Fig. 2). This index can now be used to perform a linear regression on the biomass of those same species sown in the outdoor microcosm experiment. The results will allow for a determination of the relative importance of hydrology as an indicator of plant performance and survival within a multi-species mixture.

Figure 2. Mean growth response (g) of 14 plant species grown under 7 different water level treatments



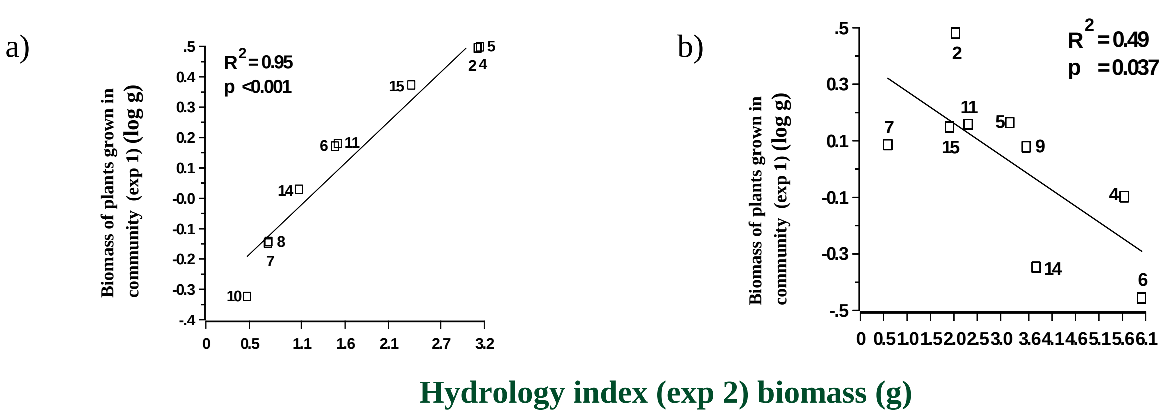
However, we found that plants have a wide range of responses to water levels. Figure 3 demonstrates the variation in species' response to growth at different water levels. Interestingly, *Lythrum salicaria*, an invasive, generally has the greatest biomass at all water levels, except +4 and +6 cm above soil level.

Figure 3. Final biomass (g dry weight) of three wetland species under seven water level treatments (-6 cm to 6 cm relative to soil level). Error bars represent one standard error.



Finally, we can combine the two experiments to employ the hydrology index (experiment 2) as a predictive tool for estimating relative biomass of species in communities at different water levels (experiment 1). Figure 4a shows that when the water level is at –5 cm below soil the hydrology index is a very good predictor of plant's biomass when grown in combination with other plants. A plant that performs well alone at –5 cm, also performs well within a community at –5cm. However, at a water level of 0 cm relative to the soil surface, we see an opposite relationship. This indicates that other factors, such as competition, are important in structuring plant communities.

Figure 4. Prediction of species performance in a community (y-axis) using the hydrology index (x-axis) at (a) –5 cm water level and (b) 0 cm water level. Numbers represent individual species.



The results of both experiments can be applied to wetland restoration techniques. The goal of these two experiments was to observe how two environmental variables, hydrology and fertility, affect both wetland communities and individuals. Based on these observations, predictions have been made as to how species and communities respond and assemble according to these two variables. Additionally, the limitations of each experiment's results speak towards the further research that is necessary for successful conservation and restoration techniques.

The community experiment (experiment 1) demonstrated that wetland community biomass is driven by both hydrology and nutrients. The hydrology index (experiment 2) showed that the growth responses of 14 plants across a range of water levels demonstrating that all species performed relatively poorly across the three, flooded treatments. The comparison of the hydrologic index created from experiment 2 against the plant responses among the community experiment (experiment 1) shows that hydrology cannot always be used to independently predict how species will perform in a natural setting. This supports further investigations to add other variables into the hydrologic index.

Bibliography:

Barendregt, A., Wassen, M.J., Schot, P.P. 1995. Hydrological systems beyond a nature reserve, the major problem in wetland conservation of Naardermeer. *Biological Conservation* 72: 393-405.

Fraser, L.H. and Keddy, P. 1997. The role of experimental microcosms in ecological research. *Trends in Ecology and Evolution* 12: 478-481.

Gerritsen, Jeroen, Greening, Holly S. 1989. Marsh seed banks of the Okefenokee swamp: effects of hydrologic regime and nutrients. *Ecology* 70: 750-763.

Gilvear, D.J., Bradley, C. 2000. Hydrological monitoring and surveillance for wetland conservation and management; a UK perspective. *Physical Chemical Earth Part B* 25: 571-588.

Hendry, G.A.F. and Grime J.P. 1993. Methods in Comparative Plant Ecology: A Laboratory Manual. Chapman & Hall, London.

Kadlec, R.H. and Knight, R.L. 1996. Treatment Wetlands. CRC Press, Boca Raton, FL.

Keddy, P.A. 2000. Wetland Ecology. Cambridge University Press, Cambridge.

Mitsch, W.J. and Gosselink, J.G. 1993. Wetlands, Second Edition. Wiley & Sons, New York.

Owen, Catherine R. 1995. Water budget and flow patterns in an urban wetland. *Journal of Hydrology* 169: 171-187.

Weisner, S.E.B. 1993. Long-term competitive displacement of *Typha latifolia* by *Typha augustifolia* in a eutrophic lake. *Oecologia* 94: 451-456.

17. <u>Related research</u>

The following papers are most closely related to the research I conducted at the Bath Nature Preserve:

1. Keddy, P. and **Fraser, L.H.** (2000) Four general principles for the management and conservation of wetlands in large lakes: the role of water levels, nutrients, competitive hierarchies and centrifugal organization. Lakes and Reservoirs: Research and Management 5: 177-185.
2. Keddy, P., Gaudet, C. and **Fraser, L.H.** (2000) Effects of low and high nutrients on the competitive hierarchy of 26 shoreline plants. Journal of Ecology 88: 413-423.
3. Keddy, P. and **Fraser, L.H**. (1999) On the diversity of land plants. Ecoscience 6: 366-380.
4. Keogh, T.A., Keddy, P. and **Fraser, L.H**. (1999) Patterns of tree species richness in forested wetlands. Wetlands 19: 639-647.
5. Keddy, P., **Fraser, L.H**. and Wisheu, I.C. (1998) A comparative approach to investigate competitive response of 48 wetland plant species. Journal of Vegetation Science 9: 777-786.
6. **Fraser, L.H.** and Keddy, P. (1997) The role of experimental microcosms in ecological research. Trends in Ecology and Evolution 12: 478-481.

18. <u>Training potential</u>

Mr. Jason Karnezis has worked tirelessly on the research discussed in this progress report, and his Masters degree under my supervision at the University of Akron has just recently been conferred.

Ms. Tara Milleti took over Mr. Karnezis' outdoor microcosm experiment. Ms. Milleti was an excellent student with great potential. Ms. Milleti will finish her thesis by end of fall semester 2003.

The following activities have been accomplished with regards to the research conducted with this grant:

MSc Thesis:

1. Karnezis, J.P. 2002. Using the Comparative Screening Approach to Determine the Effect of Hydrology on the Assemblage of Wetland Plants. MSc thesis, University of Akron, Department of Biology, Ohio, USA.

Publications (in prep):

1. Karnezis, J. and Fraser, L.H. Growth response of 14 wetland species at 7 different water levels. Ecology.

Proceedings, Reports, and Abstracts (non-refereed):

1. Miletti, R.E. and Fraser, L.H. 2003 (March). Can wetland be contructed to reseist invasion by non-natives? Oral presentation at the Midwest Ecology and Evolution Conference, Akron, OH.
2. Miletti, T.E. and Fraser, L.H. 2002 (October). Can Wetlands Be Constructed to Resist

Invasion by Non-Natives? Poster at the 2nd annual Woodlake Environmental Conference in the CVNP, OH.
3. Karnezis, J. and Fraser, L.H. 2002 (June). Using the comparative screening approach to determine the effect of hydrology on the assemblage of wetland plants. SWS, Lake Placid, NY.
4. Fraser, L.H., Karnezis, J. and Keddy, P. 2001 (August). Effects of nutrients and hydrology on the assemblage of wetland plants: a comparative approach. Oral presentation at the Ecological Society of America meeting at Madison-Wisconsin.

Presentations:

1. Fraser, L.H. 2003 (March). One step forward, two steps back: testing theory to restore and manage wetlands. Seminar at Kansas State University, KS.
2. Miletti, R.E. and Fraser, L.H. 2003 (March). Can wetland be contructed to reseist invasion by non-natives? Oral presentation at the Midwest Ecology and Evolution Conference, Akron, OH.
3. Fraser, L.H. 2003 (February). One step forward, two steps back: testing theory to restore and manage wetlands. Seminar at Bowling Green State University, OH.
4. Miletti, T.E. and Fraser, L.H. 2002 (October). Can Wetlands Be Constructed to Resist Invasion by Non-Natives? Poster at the 2nd annual Woodlake Environmental Conference in the CVNP, OH.
5. Fraser, L.H. 2002 (June). One step forward, two steps back: testing theory to restore and manage ecosystems. Seminar at the University College of the Cariboo, BC.
6. Karnezis, J. and Fraser, L.H. 2002 (July). Oral presentation at SWS in Lake Placid, NY.
7. Fraser, L.H. 2002 (April). Losing, using, and restoring wetlands: a global perspective. Seminar at Cleveland State University, OH.
8. Karnezis, J. and Fraser, L.H. 2002 (March). The effect of hydrology and fertility on synthesized wetland plant communities. Oral presentation at the MEEC in Bowling Green, OH.
9. Fraser, L.H. 2001 (October). Community assembly rules: towards wetland restoration. Seminar at Cleveland State University, OH.
10. Karnezis, J.P. and Fraser, L.H. 2001 (September). Effect of hydrology and fertility on synthesized wetland plant communities. Oral presentation at the Woodlake Environmental Conference in the CVNP, OH.
11. Fraser, L.H., Karnezis, J. and Keddy, P. 2001 (August). Effects of nutrients and hydrology on the assemblage of wetland plants: a comparative approach. Oral presentation at the Ecological Society of America meeting at Madison-Wisconsin.

19. Investigator's qualifications

Dr. Lauchlan Fraser is an Assistant Professor at the University of Akron. He has a successful record in grant writing and scientific publication. Dr. Fraser co-organised (with Dr. Paul Keddy) a symposium highlighting the ecology and conservation of the largest wetlands of the world, which was held at the Intecol Millennium conference in Quebec City, Aug. 2000. The biography of Dr. Fraser follows.

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

Basic Information

Title:	Hydrological Reconnection of a Coastal Wetland to Lake Erie: Potential for Outwelling of Organic Matter
Project Number:	2002OH16B
Start Date:	3/1/2001
End Date:	6/30/2002
Funding Source:	104B
Congressional District:	15
Research Category:	Biological Sciences
Focus Category:	Wetlands, Ecology, Hydrogeochemistry
Descriptors:	coastal wetland, organic matter, outwelling, stable isotopes
Principal Investigators:	Virginie Bouchard

Publication

1. Bouchard, V. A 40-yr debate: is there outwelling of organic matter from coastal wetlands? Seminar Series of the Department of Biology, Kenyon College, Ohio, USA, March 21, 2002.
2. Bouchard, V. Impact of plant communities on carbon fluxes in coastal wetlands. Seminar Series of the Environmental and Plant Biology Department, Ohio University, Ohio , USA.
3. Bouchard, V. Testing the outwelling concept in a Great Lakes coastal wetland. Society of Wetland Scientists, Lake Placid, NY, USA, June 2-7 2002.
4. Bouchard, V., in preparation. Outwelling of organic matter from a coastal wetland to lake Erie during seiche events. Marine, Coastal and Shelf Science.

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

Project ID: OH2922

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

Focus Categories: Wetlands, Hydrogeochemistry

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

Start Date: 06/01/2001

End Date: 05/31/2002

Federal Funds Requested: $29,224

Non-Federal Matching Funds Requested: $58,882

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.

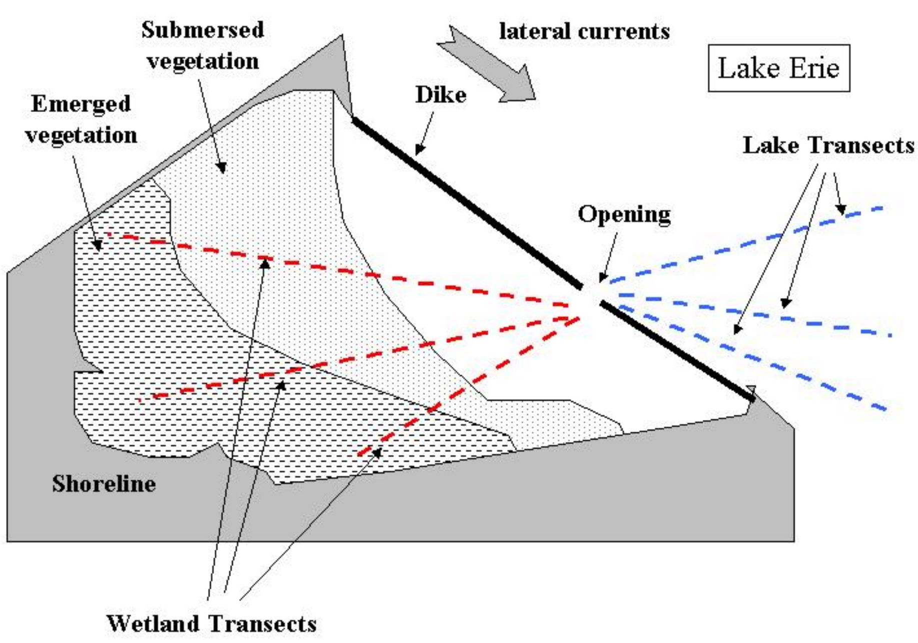


Figure 1. Representation of Metzger Marsh, showing the dike and its 10 m wide opening to Lake Erie. Location of the Wetland and Lake Transects along which water samples were taken.

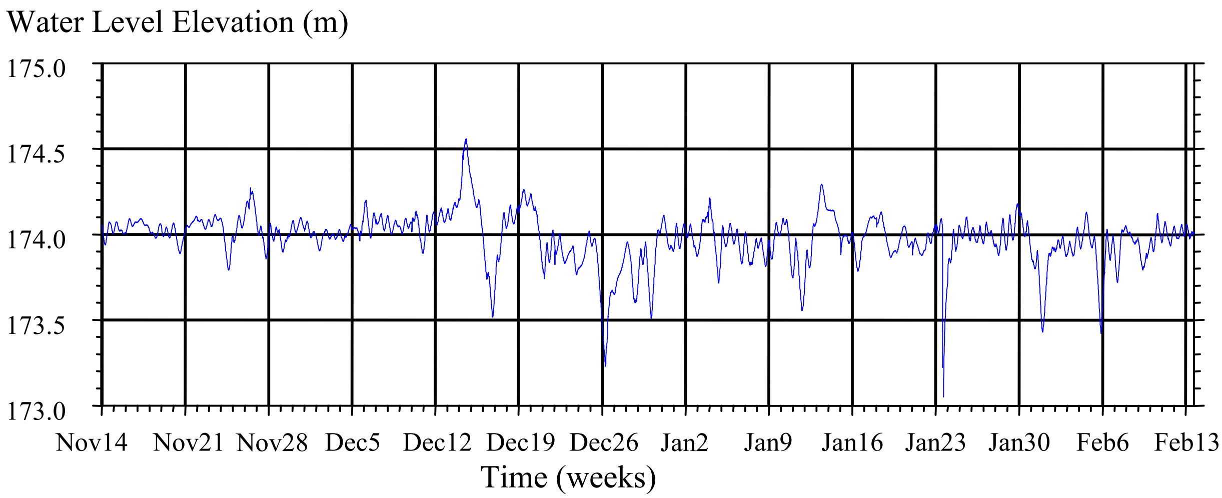


Figure 2. Example of daily water level changes at Metzger Marsh under the influence of seiche events. Seiche periods average 12 to 14 hours at Metzger Marsh. These daily water level changes (~ 0.3m) are superimposed on ~ 0.5 m seasonal changes in lake levels. Short-duration storm surges or "set downs"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

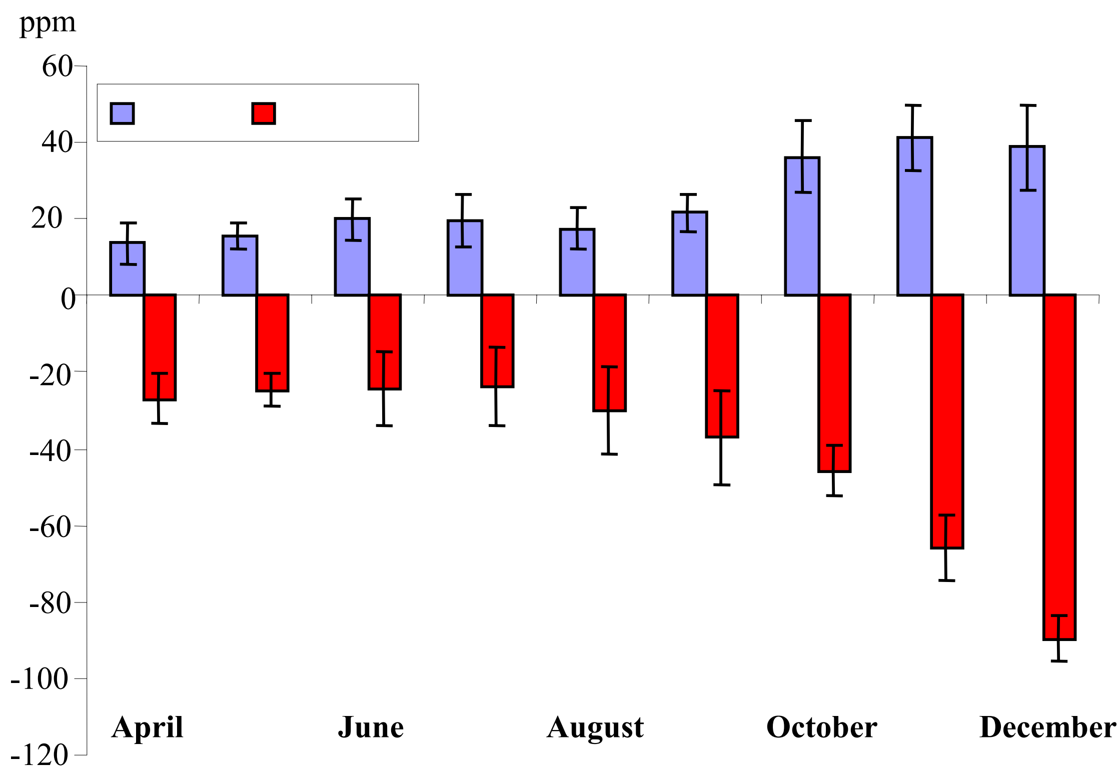


Figure 3. Average concentration (in ppm) of Total Carbon in water flowing inside (i.e., inflow) or outside (i.e., outflow) the marsh during seiche events from April – December 2001.

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).

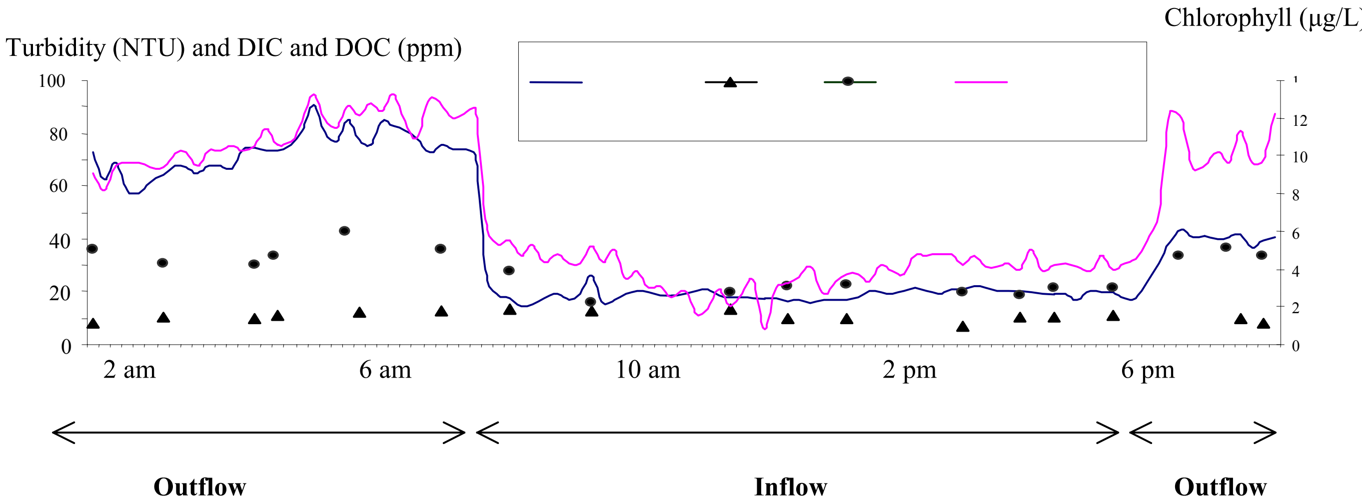


Figure 4. Evolution of the concentration of chlorophyll, turbidity, dissolved inorganic carbon (DIC), and dissolved organic carbon (DOC) during one storm event in September 2001. Chlorophyll and turbidity data were determined at the site every 15 min, while IC and OC were measured in the lab on water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

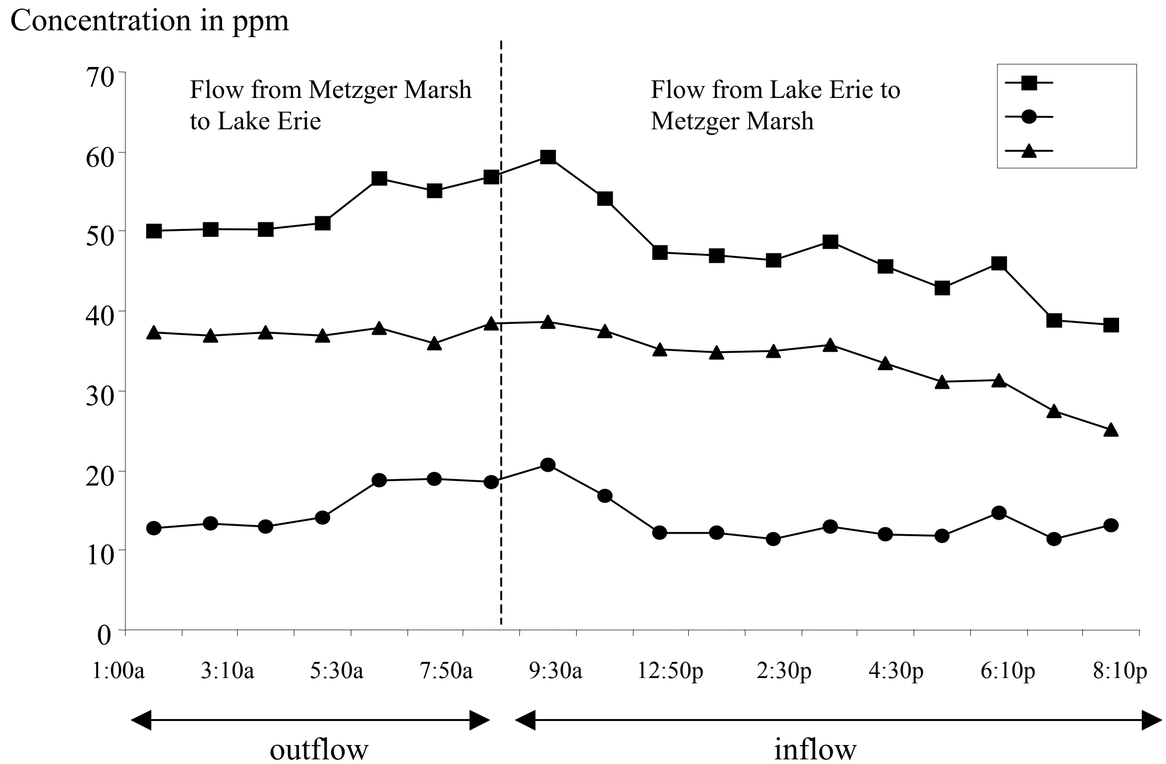


Figure 5. Evolution of the concentration of Total Carbon (TC), Total Inorganic Carbon (TIC), and Total Organic Carbon (TOC) during one seiche event in September 2001. The flow direction is indicated by "inflow" and "outflow" below the X-axis.

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).

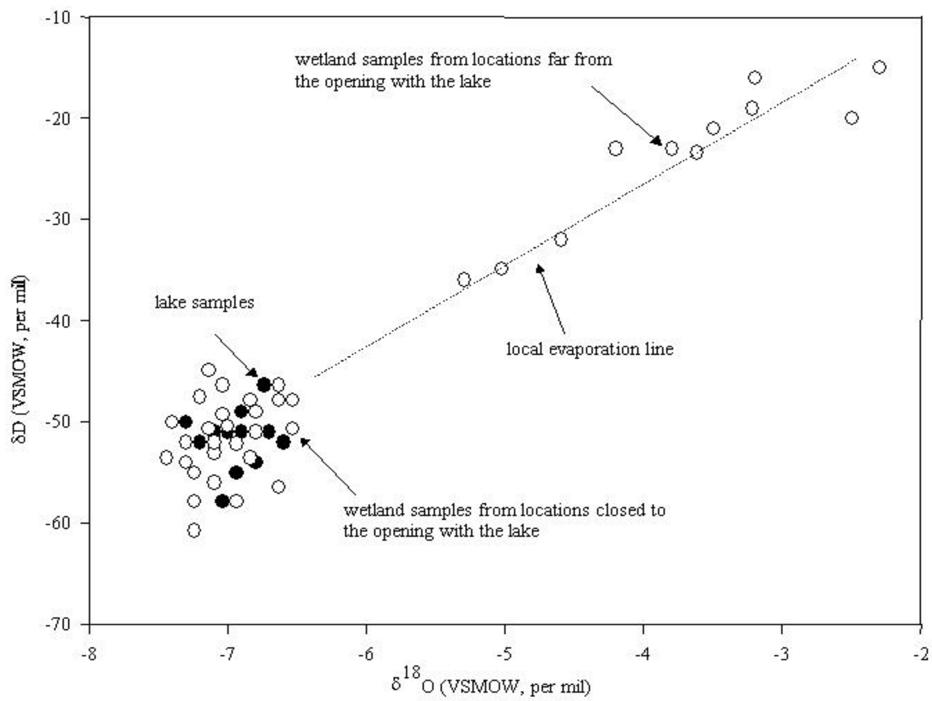


Figure 6. Hydrogen- and oxygen- isotopic compositions of water samples from Lake Erie and Metzger Marsh. The marsh samples taken away from the opening define the evaporation line.

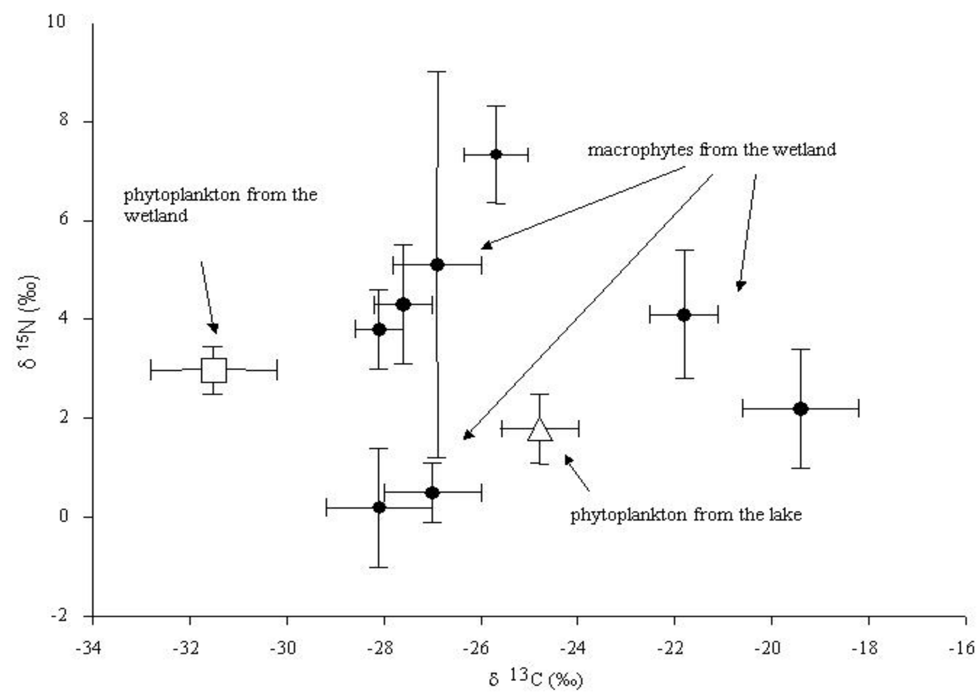


Figure 7. Stable isotope ratios for carbon and nitrogen for primary producers sampled in Metzger Marsh and Lake Erie.

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.

6. References

Bayler, P.B., 1995. Understanding large river – floodplain ecosystems. BioScience, 45: 153-158.

Benke, A.C., Chaubey, I., Milton Ward, G., Lloyd Dunn, E., 2000. Flood pulse dynamics of an unregulated river flooplain in the southeastern U.S. Coastal plain. Ecology, 81(10): 2730-2741.

Brazner, J.C., Beals, E.W., 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Canadian Journal of Fisheries and Aquatic Sciences, 54: 1743-1761.

Bouchard, V., Créach, V., Lefeuvre, J.C., Bertru, G., Mariotti, A., 1998. Fate of plant detritus in a European salt marsh dominated by *Atriplex portulacoides* (L.) Aellen. *Hydrobiologia,* 373/374: 75-87.

Bouchard, V., Lefeuvre, J.C., 2000. Primary production and macro-detritus dynamics in a European salt marsh: carbon and nitrogen budgets. Aquatic Botany, 67: 23-42.

Bookhout, T.A., Bednarik, K.E., Kroll, R.W., 1989. The Great Lakes marshes. In: L.M. Smith, R.L. Pederson and R.M. Kaminski (eds.), Habitat Management for Migrating and Wintering Waterfowl in North America. Texas University Press, Lubock, TX, USA.

Childers, D.L., Jay Jr., J.W., McKellar Jr., H.N., 2000. Twenty more years of marsh and estuarine flux studies: revisiting Nixon (1980). In: M.P. Weinstein and D.A. Kreegers (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, The Netherlands, pp. 389-421.

Clesceri, L.S., Greenberg, A.E., Eaton, A.D. (eds.), 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. United Book Press, Inc., Baltimore, Maryland, USA.
Conservation Foundation, 1998. Protection America's wetlands: an action agenda. The Conservation Foundation, Washington, DC, USA.
Dame, R.F., 1982. The flux of floating macrodetritus in the North Inlet estuarine ecosystem. Mar. Ecol.Prog.Ser., 16 : 161-171.
Dame, R.F., 1989. The importance of *Spartina alterniflora* to Atlantic coast estuaries. Aquatic Sciences, 1 (4): 639-660.
Dame, R.F., Gardner, L.R., 1993. Nutrient processing and the development of tidal creek ecosystems. Marine Chemistry, 43: 175-183.
Dame, R.F., Allen, D.M., 1996. Between estuaries and the sea. Journal of Experimental Marine Biology and Ecology, 200: 169-185.
Fry, B., Sherr, E.B., 1984. $\delta^{13}C$ measurement as indicators of carbon flow in marine and freshwater ecosystems. Contrib. Mar. Sci., 27: 15-47.
Herdendorf, C.E., 1987. The Ecology of the Coastal Marshes of Western Lake Erie: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.9), 171 pp.
Hussey, S.L., 1994. Wetlands reserve program. Fisheries 19 (8): 42-43
Junk, W.J., Bayley, P.B., Sparks, R.E., 1989. The flood pulse concept in river-floodplain systems. In: D.P. Dodge (ed.), Proceedings of the International Large River Symposium Canadian Special Publications Fisheries Aquatic Sciences, 106. Pp. 110-127.
Keough, J.R., Sierszen, M., Hagley, C.A., 1996. Analysis of a Lake Superior coastal food web with stable isotopes techniques. Limnol. Oceanogr., 41: 136-146.
Kowalski, K.P., Wilcox, D.A., 2000. Use of historical and geospatial data to guide the restoration of a Lake Erie coastal marsh. Wetlands, 19: 858-868.
Laffaille. P., Brosse, S., Feunteun, E., Baisez, A., Lefeuvre, J.C., 1998. Role of fish communities in particulate organic matter fluxes between salt marshes and coastal marine waters in the Mont Saint Michel bay. Hydrobiologia, 373/374: 121-133.
Lefeuvre, J.C., Dame, R.F., 1994. Comparative studies of salt marshes processes in the New and Old Worlds: an introduction. In: W.J. Mitsch (ed.), Global Wetlands: Old and New World. Elsevier Science BV, Amsterdam, The Netherlands. pp. 169-179.
Lefeuvre, J.C., Bouchard, V., Feunteun, E., Grare, S., Laffaille, P., Radureau, A., 2000. European salt marshes diversity and functioning: the case study of the Mont Saint-Michel bay, France. Wetland Ecology and Management, 8: 147-161.
Maynard, L., Wilcox, D.A., 1997. Coastal wetlands of the Great Lakes. State of the Lakes Ecosystem Conference '96. Environment Canada and U.S. Environmental Protection Agency, Washington DC, USA. EPA 905-R-97-015b.
Mitsch, W.J., Bouchard, V., 1998. Editorial: enhancing the role of coastal wetlands of the North America Great Lakes. Wetland Ecology and Management, 6(1): 1-3.
Newell, S.Y., Porter, D., 2000. Microbial secondary production from saltmarsh grass shoots, and its known and potential fates. In: M.P. Weinstein and D.A. Kreegers (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, The Netherlands.
Odum, E.P., 1968. A research challenge: evaluating the productivity of coastal and estuarine water. In: Proceedings of the Second Sea Grant Conference, University of Rhode Island, New York, USA. pp. 63-64.
Peterson, B.J., 1999. Stable isotopes as tracers of organic matter input and transfer in benthic food webs: a review. Acta Oecologia, 20(4): 479-487.

Ryan, P.A., Witzel, L.D., Paine, J., Freeman, M., Hardy, M., Scholten, S., Sztramko, L., MacGregor, R., 1999. Recent trends in fish populations in eastern Lake Erie in relation to changing lake trophic state and food web. In: M. Munawar, T. Edsall and I.F. Munawar (eds.),

Teal, J.M., 1962 - Energy flow in the salt marsh ecosystem of Georgia. Ecology, 43 : 614-624.

Teal, J.M., Howes, B.L., 2000. Salt marsh values: retrospection from the end of the century. In: M.P. Weinstein and D.A. Kreegers (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, The Netherlands, pp. 9-19.

USFWS, 1986. North American Waterfowl Management Plan. U.S. Fish and Wildlife Service, Publication Unit, Arlington, VA, USA.

USFWS, 1994. Update to the North American Waterfowl Management Plan, Expanding the Commitment. U.S. Fish and Wildlife Service, Publication Unit, Arlington, VA, USA.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences, 37: 130-137.

Weinstein, M.P., 1981. Plankton productivity and the distribution of fishes on the southeastern U.S. Continental and Shelf Science, 214: 351-352.

Wilcox, D.A., Whillans, T.H., 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. Wetlands, 19(4): 835-858.

Wolff, W.J., van Eeden, M.N., Lammens, E., 1979. Primary production and import of particulate organic matter on a salt marsh in the Netherlands. Neth. J. Sea. Res., 13 : 242-255.

Information Transfer Program

Program Administration Project

Basic Information

Title:	Program Administration Project
Project Number:	2002OH13B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	15
Research Category:	Not Applicable
Focus Category:	, None, None
Descriptors:	
Principal Investigators:	Earl Whitlatch

Publication

A series of tasks were continued, including; the administration of the Water Resources Center at The Ohio State University and activities to transfer and disseminate information and technology developed by researchers affiliated with the WRC to a wide range of state, federal, county, and municipal agencies; to the private sector, academic community, and to private citizens throughout Ohio. Specific tasks were: the initiation and administration of a Special Water and Wastewater Treatment Grants Competition; administration of the 104(B) In-State Competition and the National Competitive Grants Program; assemblage of a directory of college and university water resources research publications and capabilities in Ohio; and continued administrative support for the Water Management Association of Ohio and the Ohio Water Education Program.

Student Support

None

Notable Awards and Achievements

Publications from Prior Projects

None