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. <u>Title</u>:
The interactive effects of hydrology and fertility on synthesized wetland plant communities

13. <u>Statement of critical regional or State water problem</u>:

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. <u>Statement of results or benefits</u>:

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. <u>Nature, scope, and objectives of the research</u>

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. Methods, procedures, and facilities

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%.

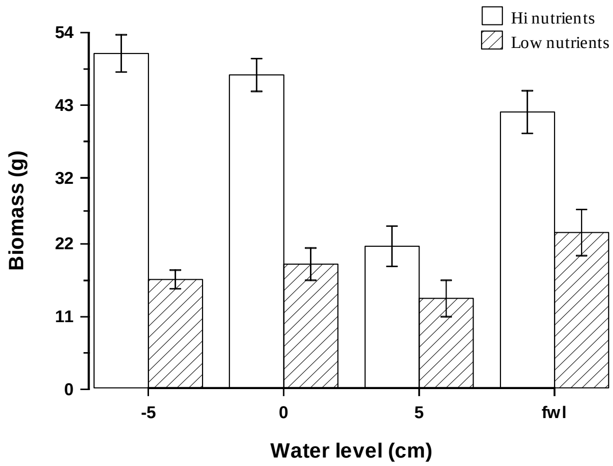
The experiment was initiated March 2001. After 6 months growth, the plants were harvested, oven-dried and individually weighed. It is important to isolate and compare the effect of hydrology on the individual species to better predict how they will respond in the field. By isolating one variable in the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

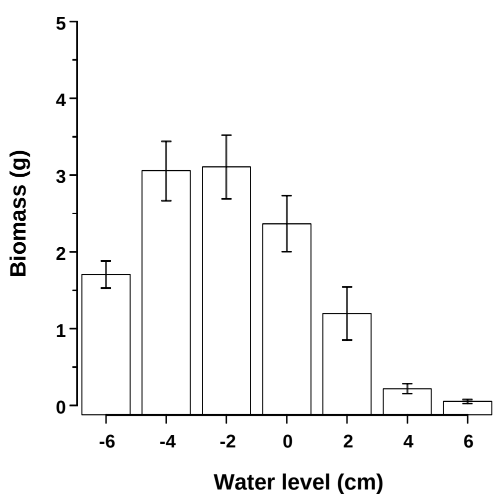
The outdoor microcosm experiment (Experiment 1) was initiated in August 2000 and ended October 2002. Results demonstrate that the treatments had a significant effect (Fig. 1).

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



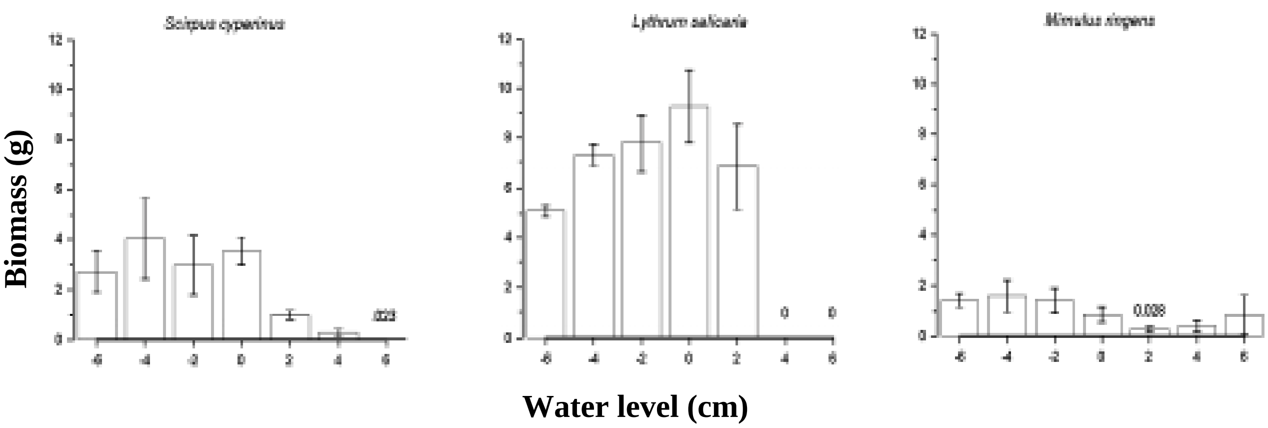
The indoor, laboratory experiment (Experiment 2) allows for the isolation of the hydrologic variable, whereby we can observe how plants will respond individually to fluctuating hydrologic regimes. It serves as a measure to gauge how much of the growth and survival of an individual species is dependent 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



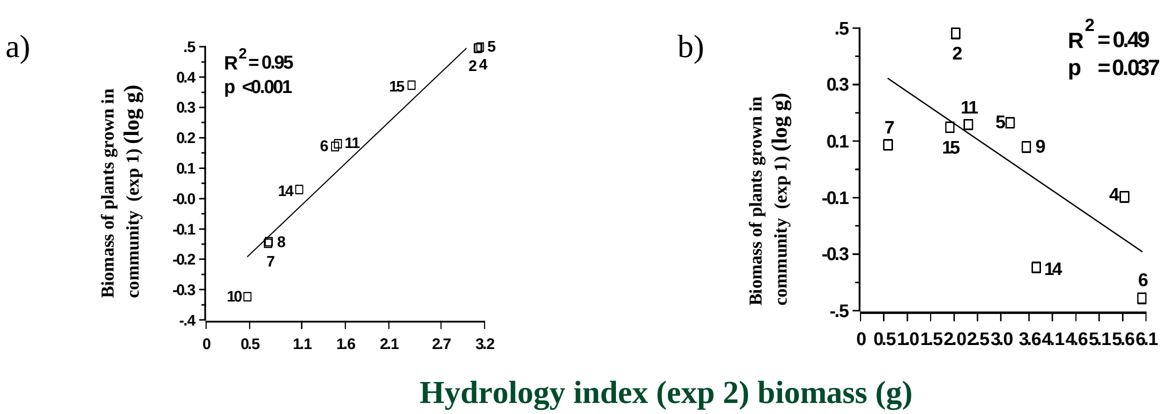
However, we found that plants have a wide range of responses to water levels. Figure 3 demonstrates the variation in species' response to growth at different water levels. Interestingly, *Lythrum salicaria*, an invasive, generally has the greatest biomass at all water levels, except +4 and +6 cm above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

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

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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.

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ACADEMIC HISTORY:

1999-Present	Department of Biology, University of Akron, Assistant Professor
1996-1999	Department of Biology, University of Ottawa, Post-Doctoral Scientist
1993-1996	Department of Animal and Plant Science, University of Sheffield. Ph.D
1990-1993	Department of Botany, University of British Columbia. MSc.
1984-1990	University of British Columbia. BSc.

COURSES TAUGHT

Plant Form and Function, Ecosystem Ecology, Community/Ecosystem Ecology, Wetland Ecology, General Ecology, Field Ecology, Scientific Writing, Topics in Integrative Biology.

FIELDS OF SPECIALIZATION

Wetland Ecology, Plant Community Ecology, Conservation, Plant/Animal Interactions, Trophic Dynamics

AWARDS AND SCHOLARSHIPS:

April 1994:

Runner-up in the national young science writer award held by The Daily Telegraph newspaper and the British Association Promoting Science and Technology.

October 1993:

3-year Post-graduate scholarship at the University of Sheffield.

September 1985:

Academic scholarship at the University of British Columbia.

GRANTS:

April 2003 – April 2004:
U.S. National Park Service, P.I., $91,425, Developing indicators for the assessment of wetland health in the Cuyahoga Valley National Park.

June 2003 – May 2008:
Meulstein Foundation, Senior Scientist, ~$1,500,000.

June 2001 – May 2004:
National Science Foundation, Senior Scientist, $1,169,324, GK-12 Formal Proposal.

June 2001:
University of Akron Research II Initiative, P.I., $7,000, Trophic dynamics in grasslands.

May 2001 – May 2002:
US Geological Survey, P.I., $38,393, Interactive Effects of Hydrology and Fertility on Synthesized Wetland Plant Communities.

July 2000 – June 2003:
U.S. Environmental Protection Agency, co-P.I., $481,730, Evaluation of NPS Built Wetlands as a BMP for Septage and Acid Mine Drainage in Ohio.

September 2000
U.S. Department of Agriculture, co-P.I., $7000, The World's Largest Wetlands.

June 2000 – August 2000:
University of Akron Summer Research Fellowship, P.I., $8000, Building a Plant-Trait Database: Towards a Wetland Restoration Model.

April 2000:
University of Akron Research II Initiative, P.I., $10,000, Plant Growth Chamber.

April 2000:
University of Akron Summer Research Fellowship Research II Initiative Support Funds, P.I., $2000, Building a Plant-Trait Database: Towards a Wetland Restoration Model.

SCIENTIFIC PAPERS

Published and in press:

1. **Fraser, L.H.**, Bradford, M.E. and Steer D.N. (2003) Human appropriation and treatment of fresh water: a global hydrology model incorporating treatment wetlands. International Journal of Environment and Sustainable Development 2: 174-183.
2. Steer, D., Aseltyne, T. and **Fraser, L.H.** (2003) Life-cycle economic model of small treatment wetlands for domestic wastewater disposal. Ecological Economics 44: 359-369.
3. Steer, D., **Fraser, L.H.**, Boddy, J. and Seibert, B. (2002) Efficiency of small constructed wetlands for subsurface treatment of single family domestic effluent. Ecological Engineering 18: 429-440.
4. Keddy, P., **Fraser, L.H.** and Keogh, T.A. (2001) Responses of 21 wetland species to shortages of light, nitrogen and phosphorus. Bulletin of the Geobotanical Institute ETH 67: 13-25.
5. 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.

6. Keddy, P., Gaudet, C., and **Fraser, L.H**. (2000) The effect of nutrients on the competitive hierarchy of 26 shoreline plants. Journal of Ecology 88: 413-423.
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9. Keogh, T.A., Keddy, P. and **Fraser, L.H**. (1999) Patterns of tree species richness in forested wetlands. Wetlands 19: 639-647.
10. **Fraser, L.H.** and Grime, J.P. (1999) Interacting effects of herbivory and fertility on a synthesized plant community. Journal of Ecology 87: 514-525.
11. **Fraser, L.H.** and Grime, J.P. (1999) Experimental tests of trophic dynamics: towards a more penetrating approach. Oecologia 119: 281-284.
12. **Fraser, L.H.** (1999) The use of microcosms as an experimental approach to understanding terrestrial ecosystem functioning. Advances in Space Research 24: 297-302.
13. 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.
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SOCIETY AFFILIATIONS:

British Ecological Society
Ecological Society of America
Society for Ecological Restoration
Society of Wetland Scientists
Society for Conservation Biology
Canadian Botanical Association

G. Budget Summary:

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