Institute of Water Research
Annual Technical Report
FY 2007
Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU’s efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. (An extended introduction can be found in our FY2001 Annual Technical Report.) We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research data and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute also works closely with the MSU Cooperative Extension Service to conduct outreach and education. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU—WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute's staff works half-time in facilitating MSU—WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute's general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and “intelligent” tools that visualize wise resource management and conservation in a single holistic system are likewise imperative. Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.
Research Program Introduction

Research Program

The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web–based information to aid in the informed decision–making process.

Unique Capabilities: Decision Support Systems as the Nexus

IWR, with its “extended research family,” is exceptionally well–positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water resources, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science–based research produced in these domains.

The Institute's extensive experience in regional and national networking provides exceptional opportunities for assembling multi–agency funding to support interdisciplinary water research projects and multi–university partnerships.

Using A Multi–Disciplinary Framework

Using a multi–disciplinary framework facilitates dynamic applications of information to create geospatial, place–based strategies, including watershed management tools, to optimize economic benefits and assure long–term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real–time environmental datasets make a new “intelligent reality” possible.

Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives.

The ultimate goal of these new imperatives is to secure and protect the future of water quality and supplies in the Great Lakes Basin and across the country and the world—with management strategies based on an understanding of the uniqueness of each watershed.
Grant No. 05HQGR0172 – Strategic Conceptual Plan for Submittal to the Army Corps of Engineers for the 516(e) Great Lakes Tributary Modeling Program

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<td>Principal Investigators:</td>
<td>Jon Bartholic, Jeremiah A Asher, Ouyang Da, Da Ouyang, Saichon Seedang, Yi Shi</td>
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Publication

Title: Grant No. 05HQGR0172 – Strategic Conceptual Plan for Submittal to the Army Corps of Engineers for the 516(e) Great Lakes Tributary Modeling Program
Project Number: 2005MI97S (extended to FY2007)
Start: 09/01/2005 (actual)
End: 08/31/2009 (actual)
Funding Source: USGS (“104B”) Supplemental
Research Category: Water Quality
Congressional District: eighth
Focus Categories: WQL, MOD, SED
Descriptors: Spatial Decision Support System
Primary PI: Jon F. Bartholic, Institute of Water Research, Michigan State University
Project Class: Research

Problem and Research Objectives

A. What is the status of work?

B. What has been completed to date as per identified tasks / deliverables?

C. Where do we go from here / what are your projected future needs?

To date the Corps has funded a total of $225,000 the past three years under three contracts. I have attached each of the three contracts for your reference. In analyzing the contracts, the following major tasks/deliverables are identified:

**Year 1, task 1:** Develop and empower an advisory group.

**Year 1, task 2:** Develop and use simple screening tools to locate potential sediment contributing areas in a watershed.

**Year 1, task 3:** Develop and use watershed-based sediment modeling tools to conduct detailed studies on the high risk areas spotted in Task 2 and test the system on four different 8-digit watersheds.

**Year 1, task 4:** Review economic information of BMPs from landowners and begin to develop policy tools that can be used with sediment risk maps.

**Year 2, task 1:** Continue interactions with the advisory team and provide written summaries of their comments and evaluations.

**Year 2, task 2:** Implement design documents from Year 1 and produce preliminary 3-D visualization and 2-D improved web mapping software.

**Year 2, task 3:** Develop a web-accessible High Impact Tools (HIT) system with reporting functionality plus an assessment of the cookbook and education modules for use in the field.

**Year 2, task 4:** Continue development with a more detailed perspective of integrating BMP utilization, examples of specific zoning ordinances, and an analysis of economic trade-offs.

**Year 2, task 5:** Initiate data gathering for ten watershed studies needed to conduct the analysis of high risk sediment contributing areas and related infrastructure information the Digital Watershed will be acquired.
Year 3, task 1: Continue general development of web-based tools applicable throughout the Great Lakes Basin. Continue development of models for smaller tributaries and sub-watersheds beginning with one tributary in each of four states: MI, WI, OH and NY. Create three general categories of web-based modeling portals targeted for very specific users and/or specific watershed or land-use types. Apply tools to 10 tributaries and evaluate the subwatersheds for erosion potential with some limited consideration of existing BMP utilization. Continue development of a web-based tool for general application in the region, in cooperation with Purdue and other state universities.

Year 3, task 2: Aggressively pursue identifying and assessing trends or issues that may impact overall program objectives.

Year 3, task 3: Maintain and enhance partnerships with regional organizations and programs related to soil conservation and nonpoint source pollution prevention.

Year 3, task 4: Continue interactions with the advisory team enhanced with more region-wide representation. Hold two detailed meetings with the extended advisory team.

Please provide me a status update on the tasks identified in the attached scopes and summarized above. In addition, please let me know your availability the first week of March to meet either in person or via conference call.

Thanks,
-David

David F. Bucaro, P.E.
Planner / Hydraulic Engineer
Environmental Formulation Section, Planning Branch
US Army Corps of Engineers - Chicago District
111 North Canal Street, Suite 600
Chicago, IL 60606-7206

(312) 846-5583
david.f.bucaro@usace.army.mil

The following PowerPoint slides related to the project are available for download in either PowerPoint or PDF format at: http://www.iwr.msu.edu/corp-outreach/powerpoints.htm

It has been an interesting exercise reviewing, developing a status of work with completed steps, and looking into the future of this project. Our cooperative efforts on 516e began in 2001 with a sub-contract from Wade-Trim in which we used the AGNPS model in the Cass River Watershed of the Saginaw Basin. Using AGNPS is very time consuming with a requirement of 22 parameters for each of the potentially thousands of cells. Then, in Spring 2002, Jan Miller asked IWR to "prepare a proposal for a 'big picture' evaluation of sediment loadings from all the tributaries in the Great Lakes as a tool for the 516e program."

To meet this need/opportunity a new approach, the SEDMOD/RUSLE (S/R) system, was developed and evaluated. The program took months to run using a 90m grid for all 8 digit watersheds across the basin. This resulted in a very useful product and published paper with Da Ouyang, Jon Bartholic, and Jim
Selegean. The results were reported at a teleconference meeting in the Detroit, MI Corps office in August of 2003.

Concurrently, the web-accessible and U.S.-wide mapping system Digital Watershed (DW) was developed. With the emergence of these two technologies (S/R and DW), the concept for coupling them for the 516e program evolved and a long range strategic vision resulted.

The FY05, FY06, and FY07-08 work plans all represent steps in bringing the strategic vision into reality. This includes extensive incremental improvements in the modeling and resolution from 90m to 30m and to 10m. Advisory groups including extensive inputs from Conservation Districts have evaluated and influenced new developments. The web-accessible High Impact Targeting (HIT) system is part of this evolution. This system is designed to facilitate land use and BMP selection at the local, county, or watershed level. Intensive work on several Michigan and Ohio watersheds has provided valuable lessons leading to further improvements. The accuracy of the S/R and DW systems in showing high potential sediment contributing sites has been evaluated. Because of the massive analysis required to go basin-wide, extensive efforts have been made to speed up the S/R processing. Additionally, enhancements have been made to improve the user-friendliness of DW.

These improved capabilities and interaction with users have resulted in a system that could serve as a basin-wide web-accessible tool to aid in sediment reduction at the local and watershed levels.

Our next steps will foster expansion and adoption of the system across the basin. This will include partnering with the National Association of Conservation Districts Great Lake's Committee, and other multi-state organizations to jointly select pilot watersheds in each Great Lakes State. The web-based sediment reduction system will be fully implemented on these pilot watersheds. With this experience, the system can then be expanded across the basin as a sustaining tool for sediment reduction at its source.

[The detailed outline below will be presented with slides for discussion during our Friday, March 14, 2008, 9:00-12:00 EST / 8:00-11:00 CST phone conference.]

**Year 1**

Year 1, task 1: Develop and empower an advisory group.

- First meeting of the Advisory team (April 13, 2006).
- Advisory team development
  - [http://www.iwr.msu.edu/corp-outreach/AdvisoryTeamMembers.pdf](http://www.iwr.msu.edu/corp-outreach/AdvisoryTeamMembers.pdf)

Year 1, task 2: Develop and use simple screening tools to locate potential sediment contributing areas in a watershed.

- Tested calculating RUSLE for an entire watershed in a GIS gridded environment.

Year 1, task 3: Develop and use watershed-based sediment modeling tools to conduct detailed studies on the high risk areas spotted in Task 2 and test the system on four different 8-digit watersheds.

- Conducted erosion and sediment analyses for the entire Great Lakes Basin at a 90-meter resolution (30-meter in some areas) using SEDMOD and RUSLE.
• Began 10-meter resolution analyses of four 8-digit watershed watersheds in the Great Lakes Basin: the Lower Maumee (04100009), the Auglaize (04100007), Calumet-Galien (04040001), and the Maple (04050005).

Year 1, task 4: Review economic information of BMPs from landowners and begin to develop policy tools that can be used with sediment risk maps.

• Reviewed conservation programs and existing BMPs implemented at farm level (e.g. several discussions with NRCS staff, advisory team members, conservation district staff, Great Lakes commission staff, etc.).
• Reviewed BMP costs (e.g. EQUIP payment) and BMP effectiveness results from the estimation of previous model simulation scenarios from RUSLE/SEDMOD.

**Year 2**

Year 2, task 1: Continue interactions with the advisory team and provide written summaries of their comments and evaluations.

• Second advisory team meeting (October 16, 2007) provided first-hand demonstration and computer exercise of the web-tool components (e.g. DW, Burn Ditch and Trail Creek decision tool models, and introduction of the HIT web-based system to the advisory team (Ref. http://35.9.116.206/hit/hit.asp).
• Evaluations and summary inputs and outcomes.
  o [http://www.iwr.msu.edu/corp-outreach/RESULTS_ACoE_SurveyOct06.pdf](http://www.iwr.msu.edu/corp-outreach/RESULTS_ACoE_SurveyOct06.pdf)

Year 2, task 2: Implement design documents from Year 1 and produce preliminary 3-D visualization and 2-D improved web mapping software.

• [http://www.iwr.msu.edu/dw](http://www.iwr.msu.edu/dw)
• Developed 3-D DEM visualization for 8 digit watersheds.
• Developed Linkage to Google Maps and Google Earth for 3-D watershed visualization.
• Developed new search entry for 2-D watershed web mapping so users can locate 8-digit watershed by HUC code and name.
• Developed new Google style address search entry for 2-D watershed web mapping.
• Improved 2-D web mapping system stability.

Year 2, task 3: Develop a web-accessible High Impact Tools (HIT) system with reporting functionality plus an assessment of the cookbook and education modules for use in the field.

• Developed on-line HIT system to allow users to analyze sediment and erosion data, and view high-risk areas spatially for selected watersheds.
• System is being utilized by local conservation districts.
• Still refining the system based on user feedback, therefore education modules have not yet been implemented.
Strategic Conceptual Plan for Submittal to the Army Corps of Engineers for the 516(e) Great Lakes Tributary Modeling Program

- Conducted thorough on-the-ground evaluation of system’s prediction of high-risk areas in three watersheds (about 70% success rate).
- Conducted initial comparisons to monitoring data from Heidelberg College (Northwest OH). More detailed comparisons are being conducted in the Kalamazoo River Watershed with Kellogg Biological Station monitoring data.

Year 2, task 4: Continue development with a more detailed perspective of integrating BMP utilization, examples of specific zoning ordinances, and an analysis of economic trade-offs.

- Incorporated selected BMPs and costs to the HIT system and allowed a resource manager to evaluate benefits and costs of selected BMPs for their sediment reduction management.
- Provided guidance and discussion with several soil conservation agencies and local planners (e.g. conservation district staff, drain commissioners, etc.) on how high impact targeting can be incorporated into their local planning in concern areas such as floodplain, wetlands.

Year 2, task 5: Initiate data gathering for ten watershed studies needed to conduct the analysis of high risk sediment contributing areas and related infrastructure.

- Prioritized Great Lakes Basin watersheds by percent agriculture, predicted Phosphorus loading, and percent agriculture on steep slopes using ATtILA (Analytical Tools Interface for Landscape Assessments).
- Prioritized Great Lakes Basin watersheds by predicted upstream accumulated sediment, essentially a potential ranking of harbors by predicted sediment.
- Working with USACE for selection of 10 watersheds.

**Year 3**

Year 3, task 1: Continue general development of web-based tools applicable throughout The Great Lakes Basin. Continue development of models for smaller tributaries and sub-watersheds beginning with one tributary in each of four states: MI, WI, OH and NY. Create three general categories of web-based modeling portals targeted for very specific users and/or specific watershed or land-use types. Apply tools to 10 tributaries and evaluate the sub-watersheds for erosion potential with some limited consideration of existing BMP utilization. Continue development of a web-based tool for general application in the region, in cooperation with Purdue and other state universities.

Year 3, task 2: Aggressively pursue identifying and assessing trends or issues that may impact overall program objectives.

- Research paper (in progress) on applications of web-based sediment modeling tools that can help harbor communities manage their sediment (e.g. governance trading).

Year 3, task 3: Maintain and enhance partnerships with regional organizations and programs related to soil conservation and non-point source pollution prevention.

- Partner with Great Lakes Committee of National Association of Conservation Districts.
- Work with the GLC (in progress).
Year 3, task 4: Continue interactions with the advisory team enhanced with more region-wide representation. Hold two detailed meetings with the extended advisory team.

- Additional discussion/guidance needed.

**Future Goals**

- Continue to pursue goal of implementation of basin-wide sediment analysis system.
- Continue enhancements to SEDMOD and RUSLE.
- Establish baseline analysis for each 8-digit HUC in the Great Lakes Basin.
- Open dialogue and create partnerships with local conservation districts to facilitate use of the system and on-the-ground implementation of conservation practices.
- Explore modeling of additional BMPs in selected locations.
- Continue watershed governance efforts.
Grant No. 07HQGR0003 Developing the Water Withdrawal Assessment Tool

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<td>Jeremiah A Asher</td>
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Publication
Problem and Research Objectives
For the first time in state history, a coherent legal framework has been established to conserve and protect water resources in Michigan. After years of debate, landmark laws protecting Michigan’s water resources were passed by the Legislature and signed into law. The bipartisan package of five bills finally delivers on Michigan’s commitment in 1985 to pass comprehensive legislation that prevents Great Lakes diversions. Institute Director Jon Bartholic provided testimony to the Senate Environment Committee on the current scientific understanding of water resources and at public meetings held around the state. These public meetings helped to open the door to eventual passage of this critical legislation.

Methodology
The process, including model development, an expert panel review, an assessment tool, and a web based interface, was developed through a joint effort with USGS, the Michigan Departments of Natural Resources and Environmental Quality, University of Michigan and Michigan State University. One issue area within the new laws and pending legislation that the Institute of Water Research (IWR) is helping to implement concerns adverse resource impacts of water withdrawals on natural resources. The adverse impacts are now defined by statute as any reduction in flow or lake levels causing functional impairments of characteristic fish populations. To address these potential impacts, legislation called for the development of a water withdrawal assessment process.

Principal Findings/Significance
The IWR has been instrumental in developing the web-based interface and in presenting the evolving tool to the public. In an ongoing process, irrigators, agency personnel, and University researchers and extension educators are conversing with one another, testing the tool and addressing emerging issues such as permitting and registration, protection factors and thresholds, water user responsibilities, the role of water users committees at the local level, return flow, and other sensitive water areas. The IWR is continuing to hold meetings with stakeholders and revise the web-based interface as new information and data becomes available.

Notable Achievements
After years of debate, landmark laws protecting Michigan’s water resources were passed by the Legislature and signed into law. The bipartisan package of five bills finally delivers on Michigan’s commitment in 1985 to pass comprehensive legislation that prevents Great Lakes diversions.
Water Quality Valuation In Michigan’s Inland Lakes Using Hedonic Valuation Methods

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Publication
Title: Water Quality Valuation In Michigan’s Inland Lakes Using Hedonic Valuation Methods  
Project Number: MI101B  
Start: 03/01/07(actual)  
End: 06/30/08 (actual)  
Funding Source: USGS (“104B”)  
Congressional District: eighth  
Research Category: Social Sciences  
Focus Categories: ECON, WQL  
Descriptors: Water quality, economic, hedonic valuation, property values  
Primary PI: Kendra Spence Cheruvelil, Michigan State University  
Other PI: Daniel Boyd Kramer, Michigan State University  
Project Class: Research

Problem and Research Objectives  
Environmental characteristics of lakes and the surrounding landscape play an important role in the economy and ecology of lakes. Lake water clarity, for instance, can be considered “the physical manifestation of eutrophication” (Michael et al. 2000) making it an important and easily observable (Bruhn and Soranno 2005) indicator of lake health that also has a significant effect on the value of lakefront properties (Michael et al. 2000). However, it remains difficult to place monetary values on these types of characteristics. Hedonic valuation is one method used to assign value to non-market goods like environmental amenities. This method views properties as composite goods consisting of a variety of characteristics relating to the structure, location, and environmental amenities connected with the property. An improvement to any one of these characteristics corresponds with an increase in the value of the associated property when compared to a similar property that does not have the same improvement. In this study, we are using hedonic valuation to assess the contribution that lake water clarity makes to lakefront property values in Michigan based on the collective attributes of a residential property. In addition, we are examining the effect of other environmental characteristics on property values to determine if greater proximity to these features has an effect on the price of the property. Michigan is a unique study location due to its large number of lakes (over 11,000 that are 5 acres or larger) and environmental amenities and also because of the state’s appeal to both year-round and seasonal residents (Cheruvelil 2006). Similar to previous hedonic studies in other parts of the country, we have found that lakefront residential property values are positively correlated with lake water clarity. However, ours will be the first published study of its kind in Michigan, in addition to being the first hedonic valuation study to include such a large number of properties and lakes over a broad spatial extent (see below).

Methodology  
We obtained data on 1430 single-family, lakefront residential properties sold from 2001 to 2005 from a real estate database. These data include an assortment of characteristics about each property and the surrounding area (e.g., number of bathrooms, lake frontage feet). The properties are located on 138 lakes that range in surface area from 18 to 4232 acres. Water clarity data, as measured by Secchi disk depth, were collected from six different sources including university researchers (MSU), state agencies (MI-Department of Natural Resources, MI-Natural Features Inventory), and volunteer organizations (Citizen’s Lake Monitoring Program, Tip of the Mitt). These Secchi disk depths were collected during the summer of 2001 to 2006 and range from 0.3 to 6.5 meters.
We are currently analyzing these data using hedonic models to estimate the portion of a lakefront property’s value that is attributed to a variety of lake and landscape environmental characteristics (e.g., lake water clarity, presence of conservation lands, etc.). These models are generally represented by an equation with the price for which the property is sold (P) as a function of structural (S), neighborhood and locational (N), and environmental (E) characteristics:

\[ P = f(S, N, E) \]

We have chosen structural (e.g., square footage and number of bathrooms) and neighborhood characteristics (e.g., distance to the nearest city and housing density along the lake shoreline) to include in these models based on previous studies and their significance in relation to property values. In addition to lake water clarity, other environmental characteristics include distance to conservation lands and public access sites.

**Principal Findings**

Our results thus far indicate that lake water clarity has a significant effect on lakefront property values in Michigan. Structural characteristics, including square footage of the residence and the number of full bathrooms, and other environmental characteristics, including lake area, were also found to significantly affect lakefront property values in preliminary analysis.

We have been advising a graduate student in the Department of Fisheries and Wildlife, Emily Norton, on this project. She is currently analyzing lake and property data while the MSU RS&GIS are quantifying additional neighborhood characteristics (to be completed by the end of June 2008) and drafting a manuscript. She will complete this manuscript during Summer 2008 and has submitted an abstract to present the results orally at the North American Lake Management Society conference during November 2008.

**Significance**

An improvement in water clarity is associated with higher property values and, therefore, higher property taxes which are important to both the local and state economies. In addition, our study is notable for being the first of its kind in Michigan and including a greater number of properties (1430 properties) and lakes (138 lakes) over a greater spatial extent (20 Michigan counties) than previous hedonic valuation studies of lake water quality. Our results will inform policy-makers and lakefront property owners about the value of lake water clarity in Michigan and provide an incentive to protect the state’s lakes from further environmental degradation.

**References Cited**


**Notable Achievements**

n/a

**Publications**

none
Regulation of Large Quantity Water Withdrawal in Michigan: Assessing Alternative Mitigation Options, Economic trade–off, and Impacts of Policy Implementation

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Publication

1. n/a
Title: Regulation of Large Quantity Water Withdrawal in Michigan: Assessing Alternative Mitigation Options, Economic trade-off, and Impacts of Policy Implementation

Project Number: MI102B
Start: 03/01/07 (actual)
End: 02/28/08 (actual)
Funding Source: USGS (“104B”)  
Congressional District: eighth
Research Category: Social Sciences
Focus Categories: ELC, ECON, GW
Descriptors: mitigation offset, economic trade-off, trout habitat, water use efficiency, water conservation, water regulation, groundwater withdrawal
Primary PI: Saichon Seedang, Michigan State University
Other PI: Zhengfei Guan, Michigan State University
Project Class: Research

Problem and Research Objectives
In 2004 a team of researchers lead by Michigan State University (MSU) received funding from the Great Lakes Protection Fund to explore an innovative market-based approach for increasing the value of water in the Great Lakes basin (“Restoring Great Lakes Basin Water Through the use of Conservation Credits and an Integrated Water Balance Analysis System” (herein called the “GLPF project”)). Based on recent water use regulations, as well as political acceptance in Michigan and other Great Lakes states, the GLPF project team designed a “conservation credits offset” trading model to be used within the context of a sensitive watershed groundwater withdrawal permit program where large groundwater withdrawal may cause adverse impacts on aquatic habitat. The project team successfully demonstrated a hypothetical case study in a selected sensitive water area of Southwest Michigan using an integrated hydrologic and ecosystem modeling system and demonstrated how the impacts of withdrawals can be offset by managing recharges through various land uses and covers. However, the system does have its limitations. For example, the offset program does not incorporate economic information into the offset analyses, nor does it investigate existing water users, such as agricultural users, for changes in their water use efficiency.

The intent of this research is to further investigate the use of economic information for policy design, especially the costs of mitigation options for meeting the threshold of resource protection. This research also developed a framework to investigate the possible improvement in water and nutrient use efficiency in the agricultural sector using stochastic frontier approach. The project utilized the results of model scenarios in the GLPF project. The specific objectives are:

1) Review available mitigation options and suggest criteria for selecting potential mitigations

2) Evaluate the economic trade-offs of policy alternatives for protecting ecological resources from large groundwater withdrawal.

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The detailed results and modeling set up can be found in the final project report at http://www.iwr.msu.edu/research/projects.html
3) Examine the impacts of regulations and policies on farm production decisions (e.g., the use of water, chemicals, nutrients, land, etc.) and the environmental impacts of policy on water quantity and quality.

Methodology

We continued our efforts from the GLPF project by investigating how economic information can be integrated with model results to assist in policy decisions for selecting an appropriate offset. This exploratory study supports the implementation of a conservation credit offset system where newly proposed ground pumping would require a permit to offset the withdrawal. Scientific modeling produced a set of mitigations and their effectiveness that can be used for offsetting impacts of withdrawals (final report of the GLPF project), while economic information can help with selecting an appropriate means to achieve policy objectives in both environmental and economic variability.

Three questions for this policy exploratory study are:

1) What mitigations can be used for offsetting withdrawal impacts?

2) Is there economic trade-off when selecting offsetting measures? In other words, how would the decision to select land use combinations (offsetting measures) change when incorporating the offset cost?

3) How are potential actors located to participate in the credit-offset system?

To answer the first question we discuss mitigation options that may have the potential to offset the impact of withdrawals. Mitigation options involve practices that increase recharge values and conservation and/or restoration activities that improve fish habitat.

In the second question, we use the results of three models in the GLPF project. The Soil and Water Assessment Tool (SWAT) model provides the recharge values for different land use types that are used for offsetting withdrawal impacts. The GIS-enabled Interactive Groundwater (IGW) model helps evaluate stream flow impact from groundwater withdrawals and offset analysis from various land use combinations. A stream temperature (STEM) model calculates temperature changes as a result of changes to base flow. An average production value of certain crops per acre in Michigan is used for representing an economic trade-off of various offset options. The primary source of data for crop values (e.g., corn, alfalfa and other hays) is from the National Agricultural Statistics Service (NASS). Forest production value is based on the average timber harvested in state forestland (Kleidon, 2007). Pastureland value is based on the rental rate adapted from the calculation sheet developed by Barry county Michigan extension office. This information is used to represent the trade-off of options for offsetting impacts from withdrawal on stream flow and water temperature at downstream observation points.

For question three, we develop an economic framework to investigate how to locate existing water users in a watershed who have the potential to participate in offset activity. Since the majority of land is agriculture, our focus is on farmers who are not currently using water...
efficiently (e.g., irrigation practices, inputs uses). They represent the group that can provide offsets to reduce impact from downstream withdrawal. In this technical report we are able to develop an economic framework that can be use for conducting a comprehensive study at the farm level.

**Principal Findings**

Potential Mitigation options or “conservation credits”
Within the watershed, the proposed activities that could be eligible for receiving conservation credits may be classified into two groups: (1) conservation practices/activities that directly conserve and reduce surface or ground water use (e.g., implementing efficient irrigation systems, changing crops or other land uses that conserve water, or implementing water conservation best management practices BMPs in urban areas, and (2) conservation practices/activities that do not directly conserve water but instead improve fish habitats (e.g. stream temperature). The first group is required to either return water through recharge or stream flow. In this case offset credit is given to activities related to increasing water (e.g., stream flows, recharge). For example conservation credits are used to offset the pumping of groundwater at the proposed well site through implementation of an efficient irrigation system. In the second group, the offset is allowed to be traded for other habitat improvement measures.

Conservation/restoration activities could help ameliorate potential negative environmental impacts from water withdrawal via activities such as the shading of small streams or the restoration of natural flows through small dam removal. Research clearly shows that flow, water temperature, and other fish habitat components are linked and important for fish survival (Hostetler, 1991; Beschta et al 1987). The review of conservation practices can be found in Appendix G of the GLPF project (Bartholic et al 2007). The review includes conservation or BMPs that can be used in urban and residential areas, agricultural lands, and golf courses. For fish habitat improvement, the review focuses on water temperature improvement such as increased stream shading, removal of small dams, or restoration of river channel and floodplain.

The selection of appropriate actions for mitigation and the granting of conservation credits are determined by the responsible administrative agency. In addition, the ability to quantify and measure the impacts or effectiveness of management actions on flow and fish habitat is crucial in determining the value of a credit offset. Because the hydrologic and bio-ecologic interaction responses to groundwater withdrawals in a watershed are complex, there is a need to develop a method to evaluate the effectiveness of proposed conservation credit actions on offsetting potential negative impacts on fish habitat. The results can be used as a framework for estimating the value of credit offset activities. Potential management actions that can improve temperature and fish habitat might include planting riparian buffers for shading to reduce variation in stream water temperatures (Beschta et al., 1987; Bartholow, 1991). Existing model systems can be used to evaluate these specific management actions. Models such as the CE-QUAL-W2 water temperature model and the Heat Source model already exist and can evaluate shading scenarios (seedang et al 2008).

Several mitigation options were proposed in the GLPF project, including purchasing surplus water withdrawal allowances from current users within the watershed who are not withdrawing their permitted quantities; purchasing conservation credits from landowners who agree to
implement water conservation practices (e.g., a farmer who switches to a more efficient irrigation system to reduce water use earns conservation credits by having surplus allowances); purchasing conservation credits from landowners who agree to change their land use by producing different crops or planting land cover types that require less water (e.g., changing from corn production to brome grass); and relocating wells further from the stream. Figure 1 shows various recharge values (in millimeters per year) from SWAT model results. It was found that perennial grasses such as brome grass produce the highest recharge value to the aquifer, while pervious surfaces in high density populated areas produce the lowest recharge values. For example corn crops could be replaced with alfalfa, brome grass or mixed forest to increase recharge. Although it produces a higher value of recharge than cover crops, in our economic analysis we do not evaluate mitigation for bare soil as an offset since it may introduce the problem of erosion.

**Economic and policy analysis**

1) Potential land use offset scenarios

In the GLPF project case study, the project demonstrated the permitting process through the use of a hypothetically proposed golf course within a medium-density residential resort development in the most sensitive area of the Augusta Creek watershed in Michigan. Large withdrawal from this project (well capacity 700 gallons per minute (gpm) is needed to irrigate the golf course and provide domestic water supplies to resort housing. The selected area to investigate offset and large withdrawal impact has a total acreage of 5,730 (23 km²). The majority of land use is agriculture (62 percent) and corn is the major crop. The remaining land is mixed forest, pasture land and other (Figure 2). Using three existing land uses (corn-forest-pasture) for a baseline recharge, 27 land use combinations were created to investigate potential recharge offsets determined by how these combinations influence downstream flow and water temperature. Note that existing water temperature and flow at the outlet (downstream) of the study site was used as

![Figure 1. Recharge values from various land uses (from SWAT model results)]
the baseline for evaluating the impacts of the proposed withdrawals. This baseline is considered the “minimum standard” to evaluate impacts of withdrawals. Downstream average water temperature and stream flows during August 2006 were 22.6°C and 6.945 cfs respectively. Figure 3 shows that only 12-land use combinations have potential recharge that contribute to increased stream flow and decreased temperature at a downstream location. As expected, the land use combinations of perennial grasses (i.e., broom grass, smooth grass) produces the most offset in terms of lower temperatures and increased stream base flow. Changes of existing land use from mostly pervious (corn, forest, pasture) to impervious surfaces (e.g., urban development) contributes to the greatest reduction in recharge and is unlikely to produce the offset.

Figure 2. Total acreage of existing land use in the study area

Figure 3. Potential land use combinations for offsetting impacts of withdrawals on stream temperature and base flow. For stream temperature, the negative values indicate that recharge of a particular land use combination contributes to reduced stream temperature from the base case. A positive value for base flow indicates an increase in base flow from the base case.
Regulation of Large Quantity Water Withdrawal in Michigan: Assessing Alternative Mitigation Options, Economic trade-off, and Impacts of Policy Implementation

Note: Land use Codes: A-Alfalfa, B-Brome grass, C-Corn, D-Smooth Brome grass, E-Deciduous Forest, F-Mixed Forest, G-Urban High Density, H-Urban Low Density, J-Urban Medium Density, and P-Pasture

2) Potential withdrawal impacts from various well locations
Figure 4 shows well locations in the study site. The Groundwater model predicted downstream withdrawal impacts of 700 gpm on flow and temperature for all 77 well locations in the study site under existing land use patterns. Simulation results reported in the GLPF project show the spatial variation of withdrawal impacts on downstream flow and water temperature. In general, the impact of pumping on downstream base flow and temperature could be mitigated if the wells are moved further away from the point of observation or further from the river or stream.

Downstream impacts of withdrawal from well locations on flow and water temperature was combined with potential offsets of recharge from land use combinations. It was found that to offset (at least) 100 percent of impacts, only 6 land use combinations of replacing corn (other characteristics held constant) with alfalfa, broom grass, smooth grass, and forest are viable (A-F-P, B-F-P, D-F-P and F-F-P). Changing existing land use from forest (other land uses held constant) to broom grass and smooth grass also produce an offset for only a few of the well locations (C-B-P, C-D-P). It is also found that replacing existing corn with perennial grass (B-F-P, D-F-P) contributes to the greatest offset in almost every well location. Replacing the existing major land use (corn) with Alfalfa also has the potential to offset many well location impacts.

3) Economic cost of converting land for offsetting impacts
Seven land use combinations were selected to investigate economic tradeoff for converting land to offset withdrawal impacts on downstream water and flow. Figure 5 showed the economic value of the seven combinations including the base case (Corn-Forest-Pasture). The economic values are determined using the value of cropland production in the study area. It should be noted that this is not the net befit or return to the farmer, and this must be taken into consideration when determining production cost. It was found that the existing land use combination (Corn-Forest-Pasture, C-F-P) has a value of almost 2.3 million dollars. If all corn acreages are converted to alfalfa or other perennial grasses (which produce the highest recharge) to offset impacts, it would produce a net loss of production value from the base case in the range from $357,000-$664,000. However, there is a net gain from converting corn to forest, or converting existing forestland to broom or smooth broom grass, provided that other characteristics do not change.

4) Policy choices
We selected land use combinations that could offset water temperature impacts of pumping at well location 4 (L-4) to investigate the economic tradeoff of how the decision of selecting land-use combination changes when economic information enters into the decision. Table 1 shows a comparison of offsetting percentages and costs of each potential land use combination. When the decision is primarily about protecting water temperature to support stream habitat, the most preferable offset is at 170% with the B-F-P combination, or changing from existing corn to broom grass. However, when considering economic feasibility, selecting C-D-P, or changing existing land use from forest to broom grass, and keeping corn and pastureland as is, would provide an increase in economic production. However, this choice presents some risk to the environment since the offsetting is only 100 percent, allowing no room for uncertainty. Many existing water quality-trading programs require an offset ratio greater than 1:1 or over 100.
Figure 4. Well locations and land uses for model simulation

percent (e.g., 1:2, 1:3) to account for uncertainties, including the effectiveness of practices and/or the relationship between water temperature and flow. In this case, other offset mitigations, such as planting riparian tree for upstream shading, could be used. In addition, the agency may require additional measures such as habitat improvement to overcome uncertainties.
Regulation of Large Quantity Water Withdrawal in Michigan: Assessing Alternative Mitigation Options, Economic trade-off, and Impacts of Policy Implementation

Figure 5. Value of cropland or production values from selected land use combinations. C-F-P is land use base case.
C-F-P=Corn-Forest-Pasture, A-F-P = Alfalfa-Forest-Pasture, B-F-P=Broom grass-Forest-Pasture, D-F-F=Smooth-broom grass-Forest-Pasture, F-F-P=Forest-Forest-Pasture, C-B-P=Forest-Broom grass-Pasture, C-D-P=Corn-Smooth-broom grass-Pasture

Table 1. Percentage of offsets and cost of offsetting the impacts of downstream water temperature (withdrawal at location L-4)

<table>
<thead>
<tr>
<th>Land use combination</th>
<th>Explanation</th>
<th>Offsetting (%)</th>
<th>Net production value change from the base case ($)</th>
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<tr>
<td>C-F-P</td>
<td>Corn-Forest-Pasture (existing land use)</td>
<td>0</td>
<td>0</td>
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<tr>
<td>A-F-P</td>
<td>Change existing land use only from corn to alfalfa (F)</td>
<td>130%</td>
<td>-157,360</td>
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<tr>
<td>B-F-P</td>
<td>Change existing land use only corn to broom grass (B)</td>
<td>170%</td>
<td>-663,648</td>
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<tr>
<td>D-F-P</td>
<td>Change existing land use only corn to smooth grass(D)</td>
<td>160%</td>
<td>-356,800</td>
</tr>
<tr>
<td>F-F-P</td>
<td>Change existing land use only corn to forest (F)</td>
<td>100%</td>
<td>82,064</td>
</tr>
<tr>
<td>C-B-P</td>
<td>Change existing land use only forest to broom grass(B)</td>
<td>110%</td>
<td>304</td>
</tr>
<tr>
<td>C-D-P</td>
<td>Change existing land use only forest to smooth grass(D)</td>
<td>100%</td>
<td>90,862</td>
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Theoretical framework for assessing the efficiency of farm production decisions (e.g., the use of water, chemicals, nutrients, land, etc.) and the environmental impacts of policy on water quantity and quality.

1) Method
Given the low withdrawal cost of ground water, water use efficiency does not play a significant role in agricultural economic decision-making. As water is an un-priced (or under priced) good, water use efficiency is presumably low in agricultural production. In this research, we will study agricultural water use efficiency and analyze the potential for reducing ground water withdrawal. This information will help potential new water users identify the least efficient farms that could become participants in watershed offset trading activity.

Efficiency is an important performance benchmark for decision-making units (DMU) and is widely used in the economic analysis of resource use. In literature, efficiency is generally measured by the distance of each individual DMU from a frontier reflecting best practices. We will use methods developed in literature on the Stochastic Frontier Analysis (SFA). Influential works include Meeusen and van den Broeck (1977), Aigner et al. (1977), Jondrow et al. (1982), and Battese and Coelli (1992). Kumbhakar and Lovell (2000).

Figure 6 illustrates the basic premise behind the methodology in a simplified two-input case. In the figure, farms are producing the same amount of agricultural output with different amounts of inputs, say, fertilizer and water. Firms on frontier points $E_1$ and $E_2$ are using best practices because if they want to continue producing the same amount of output it is not possible for them to lower the use of one input without increasing the use of the other. The frontier curve represents the best performing farms. But farms outside the frontier, at point $Q$, are technically inefficient because it is possible for them to use the same amount of fertilizer, but reduce water use to $E_2$ and still produce the same amount of output. The farther farm $Q$ is away from the frontier, the less efficient it is. Farm efficiency can be measured as the ratio of $OE_1/OQ$, which assumes that the two inputs continue to be used in the same proportion as the frontier is approached. Efficiency can also be measured as the ratio $CE_2/CQ$, which assumes that the
frontier is approached by reducing water use while holding fertilizer use constant (Guan and Oude Lansink, 2003). Recently Guan et al. (2007) proposed a new econometric approach which measures farm efficiency in a single input space (i.e. CE₂/CQ).

The efficiency concept can also be understood from Figure 7. In a one input – one output space where water is used to grow corn, farm Q stays below the frontier and is therefore inefficient. Compared to Farm E on the frontier, Q uses more water to produce the same amount of corn. The water use efficiency of Q could be measured as BE/BQ.

![Figure 7. An alternative way of understanding efficiency](image)

2) Data requirements
The first step in this research is to undertake a comprehensive farm level survey on the types, quantities, and value of inputs used and outputs produced on the farm. The inputs will include, among others, water, fertilizer, pesticides, seeds, land, labor, and capital (fixed assets). Information on farm operator characteristics (education, age, etc.), geographic locations, soil types, level of water tables, and annual precipitation, etc. will also be collected. After the questionnaire is designed, we will have a test run, inviting a small number of farmers to participate, and obtain feedback to improve the questionnaire design. This will improve the response rate in a subsequent mailed survey. To further increase the response rate, we will conduct phone surveys to follow up on non-respondents.

**Significance**
Information on mitigation options, costs, and results of ecological benefits under various offset options will help inform policy decision makers when determining an appropriate policy for protecting water resources and ecological habitats. The significant result from our case study shows that the most preferred choice for environmental protection (e.g., highest offsetting
requirement) contributes to the greatest loss of economic outcome, while lowering environmental standards would also impose risks to the environmental concern. Therefore the appropriate choice for policy is best determined by public preference. Information about the impacts of water use regulations on farmer activities (water use, chemical and nutrient use, crop choices, etc.) can be assembled for developing a more detailed production model for predicting the impacts on agriculture crop production at the farm level. This model can be used to support governmental farm and environmental policies.

**Notable Achievements**

N/A

**Publications**

N/A

**References**


Evaluation of SWAT and HIT Models in the Kalamazoo River Watershed, Michigan

Basic Information

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<td><strong>Principal Investigators:</strong></td>
<td>Steven I Safferman, Dean G Baas, Rosemary Fanelli, Steve Miller, Glenn A O'Neil</td>
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Publication
Title: Evaluation of SWAT and HIT Models in the Kalamazoo River Watershed, Michigan

Project Number: MI103B

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Funding Source: USGS (“104B”)

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Research Category: Water Quality

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Descriptors: Water Quality; Non-point Source Pollution; Monitoring; Modeling; GIS; Watershed Management; Nutrients; Phosphorus; Sediment; Kalamazoo; Michigan

Primary PI: Steve Safferman, Michigan State University

Other PI(s): Steve Miller, Bill Northcott, Dean Baas, and Glenn O’Neil, Michigan State University

Project Class: Research

Problem and Research Objectives

Sediment contribution to lakes and streams is a complex problem that has negative impacts on everything from fish and animal habitat to local and federal economies. While substantial strides have been made in recent decades to reduce point source pollution to our waterways, non-point pollution continues to be a significant source of sediment in lakes and streams and the cause of many water quality issues in the Great Lakes region. Erosion run-off from agricultural areas often carries harmful nutrients, such as phosphorus and nitrogen, which severely damage the macro invertebrate populations in waterways. This in turn disrupts the food chain in our aquatic and terrestrial systems near the waterways. Concentrations of nutrients in lakes can also lead to eutrophication, decimating lake ecosystems. While habitat disruption is one example of the chemical consequences of excessive sediment contribution, the physical space sediments take up within waterways can have significant economic costs. The U.S. Army Corps of Engineers spends over $20 million a year on sediment dredging in the Great Lakes region alone (Ouyang et al., 2005). Furthermore, decreased navigability of streams and lakes hurts everything from international trade via large commercial boats to local recreation revenues via canoes and fishing. As a predominantly agricultural watershed, the Kalamazoo River Watershed in southwest Michigan is susceptible to these challenges and provides an ideal environment to compare and evaluate models designed to quantify these threats.

Multiple models have been developed to quantify nutrient loading, identify particular sub-watersheds that have the highest rates of contribution, and even generate spatially distributed risk maps with farm-level resolution. Two models in particular are SWAT (Soil and Water Assessment Tool) and HIT (High Impact Targeting). SWAT is a spatially-lumped model that can provide predictions of specific nutrient contributions (such as phosphorus and nitrogen) within a watershed. HIT is a spatially-distributed model and can provide-farm level estimates of sediment contributions to a watershed’s stream network. These models can help address the problem of non-point source pollution, but their reliability depends on the availability of monitoring data. SWAT is able to run without monitoring data, but its reliability is significantly enhanced when the monitoring data is used to calibrate the model. HIT, on the other hand, does not incorporate such data, but its reliability has not been fully evaluated due to a lack of monitoring data availability. SWAT and HIT both have unique strengths that could complement each other (the breadth of SWAT’s output and the detailed resolution of HIT), but without
detailed and consistent monitoring and an evaluation of their respective effectiveness their use in tandem would be questionable. (Neitsch et al., 2002)

The primary objective of this project was to evaluate the ability of the HIT and SWAT models to reliably quantify nutrient loading in the Kalamazoo River Watershed by comparing model results to stream monitoring data provided by Michigan State University’s Kellogg Biological Station. The project’s sub-objectives included the following: calibrating each model to reliably predict nutrient loading in the Kalamazoo and topographically similar watersheds; evaluating each model within topographically unique sub-watersheds to determine whether one model is better suited to predict nutrient loading under certain conditions.

Methodology

HIT Modeling

HIT was run for Michigan’s Kalamazoo River Basin (Figure 1), and clipped to basin boundary for where monitoring data present (Figure 2). HIT represents the combination of two models, the Revised Universal Soil Loss Equation (RUSLE) (Renard, et al., 1997) and the Spatially Explicit Delivery Model (SEDMOD) (Fraser, 1999). RUSLE yields an annual estimate of sheet erosion while SEDMOD outputs a delivery ratio indicating the percentage of eroded soil that reaches the stream network. When combined, the two models produce an annual estimate of sediment loading. To calculate RUSLE and SEDMOD for the Kalamazoo, the necessary inputs were gathered (Table 1) and, where necessary, converted to grid datasets to be analyzed in a GIS. The end result was a spatially explicit sediment loading map (Figure 3) where each pixel contained an estimate of annual sediment loading to streams for a given 900 meter² area. This raster was subsequently clipped by the boundaries of the sub-basins output by the SWAT analysis of the Kalamazoo. Total annual sediment loading and sediment loading per acre, as estimated by HIT, were then calculated for each of the sub-basins.
**Table 1. HIT Inputs**

<table>
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<tr>
<th>Dataset</th>
<th>Data Source</th>
<th>Format</th>
<th>RUSLE use</th>
<th>SEDMOD use</th>
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<td>2001 National Land Cover Dataset (mrlc.gov)</td>
<td>Raster</td>
<td>C factor (cover management)</td>
<td>Surface roughness</td>
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<td>CTIC Crop Residue Management Survey</td>
<td>Table</td>
<td>Weight C factors by county-level crop type and tillage practice.</td>
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<td>USDA SSURGO soil surveys</td>
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<td>K factor (soil erodibility)</td>
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<td>Precipitation</td>
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<td>Raster</td>
<td>R factor (rainfall erosivity)</td>
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<td>Streams/Rivers</td>
<td>USGS National Hydrography Dataset (high resolution)</td>
<td>Vector</td>
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<td>Watershed Boundary</td>
<td>NRCS Watershed Boundary Dataset</td>
<td>Vector</td>
<td>Used to clip RUSLE inputs.</td>
<td>Used to clip SEDMOD inputs</td>
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**Figure 2.** Basin (in yellow) captured by the KBS Monitoring.
SWAT Modeling
The Soil and Water Assessment Tool (SWAT) simulation model was developed by the USDA Agricultural Research Service’s Grassland, Soil and Water Research Lab in Temple, Texas. The model was developed for the purpose of assisting water resource managers in predicting and assessing the impact of management on water, sediment, and agricultural chemical yields in large, ungaged watersheds. The hydrologic components of the model have been rigorously tested on watersheds of varying size (Arnold et al., 2000; Srinivasan et al., 1998). The basic model operates on a daily time step and allows continuous simulation over many years. Recent additions allow for simulating surface runoff and infiltration using the Green and Ampt approach using rainfall data of anytime increment and hourly channel routing. The SWAT model has eight major components: hydrology, weather, erosion and sedimentation, soil temperature, plant/crop growth, nutrients, pesticides, and agricultural management.

To simulate the spatial heterogeneity of land cover, topography, soil type and climate, the watershed is subdivided into a number of user-delineated sub-basins. Each sub-basin is then further subdivided into individual Hydrologic Response Units (HRU) which is an individual combination of landuse/cover/management, soil type and meteorological data.

The daily or sub-daily water budget is computed for each HRU in the watershed. Daily surface runoff is calculated using the SCS curve number approach or on an hourly basis using the Green and Ampt method. Peak runoff rate is calculated using a modified rational formula and the routing of in-channel flow between sub-basins is computed with Manning’s equation and the Muskingum or Variable Storage Method.
Several sets of inputs are required to run the model (Table 2). Basic inputs into the model include a 30-m digital elevation model (NED – same as HIT, see Table 1), STATSGO soils coverage, and 2001 Michigan land cover/land use data (NLCD – same as HIT, see Table 1). Observed weather data used in the model was a combination of NOAA cooperative rain gauges used for fallow season simulation and sub-basin averaged NEXRAD derived precipitation estimates for the growing season simulation.

The model was run under two scenarios; 1) using observed weather data during the period of 2003 through 2006 to compare to the observed Phosphorus data and 2) using synthetic weather data over a 20 year period to compare the long term average sediment delivery from SWAT to the HIT model.

To calibrate the SWAT model to the hydrology of the river the USGS stream gaging station on the Kalamazoo River near Battle Creek (Gauge Station 04105500) was used. To calibrate the hydrology portion of the model, the primary variables that were adjusted was the NRCS curve number for the runoff volume and peak flow and the amount of wetlands within the watershed. The Kalamazoo River and many of its tributaries flow through riparian wetlands which have a great buffering capacity for peak flow rates that exceed the capacity of the main channel.

Stream Monitoring
Intensive phosphorus sampling was performed on the Kalamazoo River from 5/10/2005 – 10/4/2006 and 4/4/2006 – 9/27/2006 as part of the Lake Allegan/Kalamazoo River Watershed TMDL project. Weekly water samples were collected from the thalwag portion of the stream using a Van Dorn horizontal sampler at 13 locations in 2005 and 15 locations in 2006. Samples were filtered using a 0.45 µm filter. Unfiltered samples were analyzed for total phosphorus and filtered samples for total dissolved phosphorus. Phosphorus was determined using the persulfate digestion and colorimetric method.

Growing season total and dissolved phosphorus loadings were calculated for the monitored watersheds. Daily discharge for the load calculations were obtained from the SWAT model runs, providing a common discharge basis for comparing actual to modeled phosphorus loading. The availability of daily discharge and weekly phosphorus concentrations presents some challenges in calculating an unbiased estimate of load. The Beale Ratio Estimator which has been used widely in Great Lakes loading calculations, thoroughly discussed in Baun (1982), was used for load calculations. Ratio estimators use the period’s data to calculate a mean daily load, then uses the mean discharge from days lacking concentration data to adjust the mean daily load (Richards, 1998). AutoBeale, a computer implementation of the Beale Ratio Estimator, iteratively seeks out the discharge stratification and minimizes the variance of the load estimate for a given set of data. The AutoBeale program was used for the load calculations for this study.

Calibration of SWAT using Monitoring Data
Multiple iterations of SWAT modeling were conducted in an effort to match SWAT estimates of total phosphorus loading to values estimated by the monitoring data and AutoBeale program. The presence of several significant impoundments, particularly Morrow Lake, within the watershed proved challenging to SWAT. After several unsuccessful attempts to reconcile SWAT’s total phosphorus with the AutoBeale estimates, we chose to move the calibration and
analysis upstream from the problem impoundments (Figure 4). This necessitated a new SWAT run and new study area boundaries, as output by SWAT (Figure 5). HIT could not be directly calibrated to the monitoring data because HIT’s output is total sediment loading to streams and the monitoring data did not measure total suspended sediment. This project sought to evaluate HIT sediment estimates using SWAT’s total sediment and total phosphorus estimates (phosphorus was captured in monitoring data) as a proxy. This assumed a positive direct relationship between in-stream phosphorus and sediment, which previous studies have shown (Varnakovida, et al. 2005; Mau & Christensen 2001).

**Comparison of SWAT and HIT**

Once a SWAT output of total phosphorus was as calibrated with the monitored estimate as could be achieved, the SWAT sediment loading estimate was compared to HIT’s. Sub-basin sediment loading rates in metric tons per hectare were calculated for each sub-basin. Correlations of these rates were analyzed, and a regression analysis was performed to attempt to explain the differences between the models’ rates in terms of land cover class percentages, soil type, topography, sub-basin size, and topography. The Analytical Tools Interface for Landscape Assessments (ATtILA) (http://www.epa.gov/esd/land-sci/attila/index.htm) was utilized to extract, for each sub-basin, land cover class percentages from the NLCD, soil texture from the SSURGO soils dataset, and slope from the DEM.
Principal Findings

*Calibration of SWAT using stream monitoring data*
For the growing seasons of 2005 and 2006 the AutoBeale program estimated annual phosphorus loading at the monitoring station (location 2 in Figure 4) at 4,758 kg and 6,539 kg respectively. SWAT estimates of annual phosphorus location at the same location and for the same time period were 8,319 kg and 11,714 kg respectively. Though these raw numbers are significantly different, the temporal trends they reflect are closely similar. The monitored phosphorus increased from 2005 to 2006 by 37%, while SWAT estimated an increase of 41%. The difference in the raw numbers could have been the result of relatively short time period. A two-year simulation will make SWAT more sensitive to peak events and increase the likelihood of overestimates. Additionally, the differences could have resulted from physical features that were not captured within the SWAT inputs. Best management practices (BMPs) that reduce run-off may have been in place within the study basin, but not reflected in the land cover input (NLCD 2001). SWAT’s accurate representation of the temporal trend in phosphorus loading could imply that its prioritization of sub-basins (by sediment loading rate) is accurate and could be reliably compared to HIT’s. However, until SWAT can be calibrated against a longer record of monitoring data, the use of SWAT’s sediment estimate as a proxy for an evaluation of HIT in this area should be viewed with caution.

*Comparison of SWAT and HIT estimates*
For the entire study basin, SWAT estimated a total annual sediment loading of 33,549 metric tons. This amount represents sediment transport to streams (as calculated by USLE), not to the watershed outlet; therefore it does not reflect the effect of bank erosion or in-stream deposition. HIT’s estimated

---

**Figure 5:** Final SWAT study basins (in yellow) within the original monitoring basin.
47,280 annual metric tons of sediment loading to streams for the study basin, which also does not include bank erosion or in-stream deposition.

Since both SWAT and HIT fundamentally rely on USLE (HIT uses RUSLE) the initial expectation was that the models’ use of different methods for calculating sediment delivery was the primary cause for the difference in annual estimated totals. HIT employs SEDMOD to calculate spatially explicit delivery ratios while SWAT uses the MUSLE equation which is:

\[
\text{Sediment} = 11.8(Q_{\text{surf}} \times q_{\text{peak}} \times \text{Area}_{\text{HRU}}) \times K_{\text{USLE}} \times C_{\text{USLE}} \times P_{\text{USLE}} \times L_{\text{USLE}} \times CFRG
\]

where Sediment is the sediment yield on a given day (metric tons), \( Q_{\text{surf}} \) is the surface runoff volume (mm H2O/ha), \( q_{\text{peak}} \) is the peak runoff rate (m3/s), \( \text{area}_{\text{HRU}} \) is the area of the HRU (ha), \( K_{\text{USLE}} \) is the USLE soil erodibility factor (0.013 metric ton m2 hr/(m3-metric ton cm)), \( C_{\text{USLE}} \) is the USLE cover and management factor, \( P_{\text{USLE}} \) is the USLE support practice factor, \( L_{\text{USLE}} \) is the USLE topographic factor and \( CFRG \) is the coarse fragment factor. USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

One of the primary objectives of this project was to determine if HIT and SWAT similarly prioritize sub-basins in terms of sediment loading, and could therefore potentially be used in tandem. Therefore, a detailed analysis on sediment loading rates for the study area’s 29 sub-basins (Figure 5) was performed. HIT’s sediment loading rates ranged from 0.001 to 0.394 metric tons per hectare, with a mean of 0.209 m.t./ha; SWAT’s rates ranged from 0.023 to 0.297 m.t./ha, with a mean of 0.151 m.t./ha. The rates were significantly positively correlated (r = 0.80). The results were slightly different when the rankings of sub-basins were analyzed. SWAT and HIT rankings were again significantly positively correlated, but at a lesser r = 0.52 (Spearman rank correlation). Sub-basin ranks are important to typical users of SWAT and HIT as sediment loading rates are utilized to prioritize regions for conservation efforts, such as a state agency or local conservation district looking to target nutrient run-off reduction programs. The lower rank correlation implies that, in some areas, SWAT and HIT may send users different messages.

In an effort to explain this variability, differences between SWAT’s and HIT’s sediment loading rates were calculated (HIT rate minus SWAT rate) for each sub-basin. Values ranged from -0.037 to 0.172 m.t./ha, with a mean of 0.058 m.t./ha. These differences were compared against land cover class percentages, soil types, basin size, basin sediment delivery ratio, and topography in a stepwise regression analysis. Regression models were tested utilizing various permutations and transformations of the following terms:

- %agriculture
- %pasture
- %row-crops
- %urban
- %forest
- %wetland
- %sand soils
- %silt soils
The different methods of representing sediment transport in SWAT and HIT proved not to be statistically significant ($r^2 = 0.27$), contrary to initial expectations from the analysis of SWAT and HIT estimates of sediment loading totals. The strongest model was simply a function of row-crop land cover:

$$\text{Sediment Loading Rate Difference (HIT - SWAT)} = -0.0069 + 0.0018 \times \text{Percent Row-crop (2001 NLCD class 82)}$$

$\beta_{\text{Percent Row-crop}}$ and F-statistic are both significant at the 99% confidence interval. $\beta_{\text{Percent Row-crop}}$ adjusted to account for spatial-autocorrelation. 

$R^2 = 0.34$

The model’s $R^2$ is not particularly strong in its own right, but was stronger than the other possible models. The positive sign of $\beta_{\text{Percent Row-crop}}$ indicates that HIT sediment loading rates exceed those of SWAT in areas dominated by row-crop agriculture. Within HIT, such areas receive the highest values for RUSLE’s C factor, and represent areas of decreased surface roughness (facilitating sediment transport to streams). This could imply that there are potentially significant differences between how HIT and SWAT represent C factor, and how land cover factors into sediment transport within each of the models. Additional analyses of HIT and SWAT are needed. Independent comparisons of erosion estimates (USLE and RUSLE, without factoring in sediment transport) and sediment transport (SWAT’S use of MUSLE and HIT’s use of SEDMOD) may illuminate the sources of these differences in rates, and help explain the larger differences in total sediment loading. Additionally, further effort to calibrate SWAT (longer monitoring record, BMP locations) and HIT estimates to in-stream monitoring should yield greater confidence in an analysis of the models’ differences.

**Significance**

This project represented the first concerted effort to compare SWAT and HIT. The two models each have their own strengths. SWAT produces detailed outputs on nutrient loading, while HIT produces spatially explicit maps of sediment loading. The two could potentially be used together to provide a rich product, useful to many in the conservation community. However, if the two models tell different stories regarding sediment loading within a watershed, then a combination of the two could be suspect. This project established a positive correlation between the different models’ prioritization of sub-basins by sediment loading rates, but a weak positive correlation in their rank correlations. Prioritization at the watershed scale is important to managing agencies currently using these tools, such as the Michigan Department of Agriculture and the USDA Natural Resource Conservation Service. This project did show relatively large discrepancies between the models in terms of total estimated sediment loading, and was not able to fully explain the models’ differences in sediment loading rates. This could have been the result of an inability to confidently calibrate the two models and/or the way the two models treat land cover. But this effort served as a solid initial analysis, and identified potential sources of discrepancy between the two models that warrant further analysis.
References


Grant No. 07HQGR0141 Key Indicator Species for Consideration by the International Great Lakes Study and Preliminary Assessment of Rare, Threatened and Endangered Species in the Upper Great Lakes

Basic Information

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<td>Principal Investigators</td>
<td>Jon Bartholic</td>
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Publication

Title: Grant No. 07HQGR0141 Key Indicator Species for Consideration by the International Great Lakes Study and Preliminary Assessment of Rare, Threatened and Endangered Species in the Upper Great Lakes
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Primary PI: Jon F. Bartholic, Institute of Water Research, Michigan State University
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Problem and Research Objectives

A new project has been funded, “Key Indicator Species for Consideration by the International Great Lakes Study (IUGLS) and Preliminary Assessment of Rare, Threatened and Endangered Species in the Upper Great Lakes”. Personnel from the Institute of Water Research and Michigan State University will provide a preliminary assessment, in the form of a Scoping Paper, for the IUGLS on common species plus the rare, threatened and endangered species, which could serve as ‘indicator species’ for determining the effects of lake level regulation, because their life cycles are directly and significantly affected by, or depend on lake level fluctuations. The IUGLS encompasses Lakes Superior, Huron, Michigan, Erie and all the connecting channels and waterways. The purpose of this scoping paper is to assist the IUGLS Study Board and Environmental Technical Working Group in developing a strategy for additional ecological studies and the incorporation of key indicator species in any subsequent decision-modeling framework.


Methodology

The Institute of Water Research (IWR) recently collaborated with Michigan Natural Features Inventory (MNFI) to conduct a preliminary study on lake-level indicator species in the upper Great Lakes Basin. The International Joint Commission (IJC) is re-evaluating the current system of lake-level regulation in the upper Great Lakes (Lakes Erie, St. Clair, Huron, Michigan and Superior, as well as all connecting rivers) to address the changing ecological and economic needs in the Basin. The purpose of this study was to identify both rare and common floral (plant) and faunal (animal) species living in the Great Lakes basin that are sensitive to lake-level fluctuation, which can be used to assess whether changes in lake levels will affect the health of coastal ecosystems.

To initiate this study, IWR and MNFI staff contacted over 340 professional scientists in the Great Lakes Basin with a survey to retrieve information on long-term studies of coastal species that have been previously conducted or are currently underway. These scientists were asked to
provide input on species that were linked to lake-level fluctuation during a portion of their lifecycle. Once the results of the survey were compiled, a thorough literature review was conducted for approximately 24 rare, threatened or endangered species and 22 common species which had been nominated through the survey. These literature reviews were used to identify research studies that illustrate a species’ sensitivity to changes in lake water levels. Approximately 17 common species and 16 rare, threatened or endangered species were recommended to the IJC to be used as lake-level indicator species. Most species that were suggested as indicator species require low-lying coastal habitat for nesting or spawning which can be disturbed if lake levels were uniformly high or low. Perca flavescens (Yellow perch), Esox lucius (Northern pike) and Ondatra zibethicus (Muskrat) were among the common species recommended as indicator species in this report. Charadrius melodus (Piping plover; federally endangered in Canada and the U.S.), Epioblasma torulosa rangiana (Northern riffleshell mussel; federally endangered in Canada and the U.S.) and Cirsium pitcheri (Pitcher’s thistle; federally threatened in Canada and the U.S.) were among the rare, threatened or endangered species recommended as lake-level indicator species. More information on the International Upper Great Lakes Study can be found at: http://www.iugls.org/en/home_accueil.htm
Upper Great Lakes Indicator Species Scoping Project

Final Report
March 2008

Dennis Albert, Ph.D.
Michigan Natural Features Inventory
Michigan State University Extension
Stevens T. Mason Building
PO Box 30444
Lansing, MI 48909-7944

Rosemary Fanelli and Pam Hunt
Institute for Water Research
Michigan State University
101 Manly Miles Building
1405 S. Harrison Rd.
East Lansing, MI 48823
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Executive Summary

The International Upper Great Lakes (IUGLS) Study team provided two draft scopes of work (SOW) for identification of groups of species sensitive to Great Lakes water-level fluctuation (Appendix 1 of this report). A questionnaire, developed to solicit information on species and their sensitivity to lake or water level fluctuations, was sent by email to over 340 individuals representing a diversity of Great Lakes researchers, biologists, conservation organizations, and government agencies. Over 67 individuals responded to the questionnaire. The survey was structured to address two basic categories of species that are explicitly sensitive to lake level fluctuations: common species that may serve as useful indicators or surrogates for guilds; and rare, threatened and endangered species that are affected by direct lake level fluctuations.

Common Species

Through the survey, several individuals and organizations identified common Great Lakes species that seemed to respond to lake-level fluctuations. Only a few of the recommendations were based on long-term studies. Many of the vegetation studies were conducted on both the Great Lakes and connecting rivers. Some of the more systematic, long-term studies were conducted by wildlife and fishery biologists studying waterfowl and fish, although their studies were not specifically aimed at tracking biotic response to lake-level fluctuation.

All of the common species recommended for monitoring lake-level change are associated with Great Lakes coastal wetlands or wetlands that were immediately adjacent to the shoreline, such as interdunal wetlands (pannes or moist sand plain). Species were reviewed for lake-level response from other coastal ecosystems, including bedrock shorelines and sand dunes, but no common species were identified for these habitats, even though rare species have been recommended from both of these habitats. For many of the rare species identified in non-wetland habitat, common species that occupy the same habitat could also be monitored.

Of the common species suggested for indicators of lake level fluctuation in the upper Great Lakes, several did not appear to have adequate linkage to the Great Lakes or that have other biological or distributional characteristics that lent themselves to being treated as indicators of lake level fluctuation. To address this problem, suggested indicators were placed in the following categories: 1) Recommended indicators, 2) Questionable indicators, and 3) Rejected indicators. Annotated bibliographies for each nominated species include justification for recommendation or rejection. Abbreviated summary species reports include literature and reports documenting susceptibility/vulnerability to hydrologic variability and lake level fluctuations, distribution maps for each nominated species, and general information describing habitat and important biological information related to breeding, seed germination, etc.

This report recommends two common fish, three mammals, diatom algae, ten plants, and one plant community, while questionable indicators include one bird, one fish, and two mussels. One bird species was rejected as an indicator species.
Rare, Threatened and Endangered Species

Both U.S. and Canadian definitions of rare, threatened, and endangered species were discussed in the report. All of the Great Lakes states also have their own rare species lists and definitions which are similar, but not necessarily identical with federal categories. Because approximately 130 rare species were recommended as potential indicators of lake-level fluctuation, it was necessary to prioritize the species being recommended as indicators. The first species to be considered are the federally listed species, which comprised 18% of the species recommended for consideration. These species have received the most scrutiny and the data available for these species is typically much more specific and focused. Among the federally listed species are several Great Lakes endemic or near-endemic species, many of which are located in habitats that depend on lake-level fluctuation for successful maintenance.

State-listed species make up 82% of the species recommended and an even larger percentage of the plants. Our recommendation for state-listed species is to identify those that are consistently rare across the range of Great Lakes states, or at least across the lakes that are ecologically similar. Species rare only at the edge of their range are not being recommended for review within the category of rare species, but may be appropriate for inclusion as common species indicators. State listed species with localized distributions were generally not considered appropriate for monitoring the influence of lake-level, as it is difficult to infer ecological relationships on the basis of a small number of sampling sites.

Four other criteria related to the biological characteristics of the species or to characteristics of their habitat were added to assist in reviewing the literature to determine if the survival or viability of either rare or common species were adequately linked to water-level fluctuation. These criteria were 1) rare annual or perennial plants which only appear in direct response to Great Lakes fluctuation events, 2) rare plant species that are linked to sediment changes that occur in response to water level fluctuation, 3) rare animal species of open emergent wetlands that become too densely vegetated without water level fluctuations, or where chemistry of the habitat may become toxic or hostile, and 4) rare animal species whose mating or specific life phases depend on water-level fluctuations.

Appendix 4 summarizes all of the common and rare species that were nominated by biologists and land managers from the Great Lakes, including federal, state, and provincial ranks, habitat comments, publications summarizing research on the species, and the name of the recommending scientist or agency. This list was used to support the recommendation of both common and rare species for further review. Each species chosen from the nominated list of rare, threatened, and endangered species was subject to further research and analysis on their responses to lake level fluctuations and an annotated bibliography is provide. A summary is provided for each rare species.

For rare species suggested for indicators of lake level fluctuation in the upper Great Lakes, we broke the initial list of suggested indicators into 1) Recommended indicators, 2) Questionable indicators, and 3) Rejected indicators. Recommended indicators included four birds, four fish, two mussels, one invertebrate, and five plants. Questionable indicators include one reptile and four plants, while rejected indicators include one reptile and two plants.
I. Development of a questionnaire for Great Lakes agencies and NGOs

A questionnaire was developed to solicit information on species and their sensitivity to lake or water level fluctuations. This questionnaire was sent by email to over 340 individuals representing a diversity of Great Lakes researchers, biologists, conservation organizations, and government agencies directly or indirectly involved in managing, permitting, studying, and monitoring Great Lakes coastal species and their supporting ecosystems. It prompted survey recipients to provide information regarding the habitat of the species, relevant documentation on its response to water level fluctuations and contact information for a researcher who is/was involved in the study of the species. Over 67 individuals have responded to the questionnaire. Some suggested additional biologists to whom follow-up copies of the questionnaire have been sent. The survey is included in Appendix 2.

II. Principal Great Lakes biological/ecological monitoring agencies

The list of individuals who are directly or indirectly associated with biological and ecological monitoring agencies was compiled from numerous resources (Appendix 3). In addition to those who responded to the questionnaire, the Great Lakes Habitat Species Strategy Team established under the Great Lakes Regional Collaboration were automatically added to this list.

III. Common indicator species responsive to lake level fluctuations

Through the survey, several individuals and organizations identified common Great Lakes species that seemed to respond to lake-level fluctuations. Most of these recommendations were not based on long-term studies, but there were also some recommendations that were the result of long-term studies or study of sites that occurred at several year intervals that occurred in years with different lake-level conditions. The majority of these studies were conducted in Michigan, but there were also researchers whose work on common species or co-occurring species in other Great Lakes states. Many of the vegetation studies were conducted on both the Great Lakes and connecting rivers. Some of the more systematic, long-term studies were conducted by wildlife and fishery biologists studying waterfowl and fish, although their studies were not specifically aimed at tracking biotic response to lake-level fluctuation.

All of the common species recommended for monitoring lake-level change are associated with Great Lakes coastal wetlands or wetlands that were immediately adjacent to the shoreline, such as interdunal wetlands (panes or moist sand plain). Species were reviewed for lake-level response from other coastal ecosystems, including bedrock shorelines and sand dunes, but no common species were identified for these habitats, even though rare species have been recommended from both of these habitats. For many of the rare species identified in non-wetland habitat, common species that occupy the same habitat could also be monitored.
IV. Recommended common lake-level indicator species

Table 1 lists common species suggested for indicators of lake level fluctuation in the upper Great Lakes. Several species were recommended that do not appear to have adequate linkage to the Great Lakes or that have other biological or distributional characteristics that do not lend themselves to being treated as indicators of lake level fluctuation. For this reason we are breaking the initial list of suggested indicators into 1) Recommended indicators, 2) Questionable indicators, where the information is very incomplete or where we received conflicting recommendations from researchers, and 3) Rejected indicators, where the linkage of species to lake level fluctuation appears tenuous or where there are too many other factors to allow for effective monitoring. Following the listing of these indicator classes is the summary for each species.

Annotated bibliographies for each of these nominated species include justification for recommendation or rejection (appendix 6). These abbreviated species reports include any available literature and reports documenting their susceptibility/vulnerability to hydrologic variability and lake level fluctuations, as well as distribution maps for each of the nominated species (whenever available). They also include general information provided to describe habitat and important biological information related to breeding, seed germination, etc. A summary of all recommended, questionable and rejected common species is included in Table 1.

SUMMARIES FOR ALL NOMINATED COMMON SPECIES

Anas discors (Blue-winged Teal)

Although there is some evidence that food sources of blue-winged teals may be affected by lake-level regulation, the blue-winged teal may not be an ideal indicator because its reproduction is primarily concentrated in seasonal, inland wetlands, because coastal wetlands warm too slowly in spring and have low invertebrate numbers than nearby inland wetlands. Because of the concentration of this species in inland wetlands, 99% of breeding waterfowl surveys are done in inland wetlands and other statewide breeding bird surveys also have no major coastal wetland component and do not re-survey regularly. Coastal wetlands more important for diving ducks which feed in 6-12 feet of water and are less productive feeders at greater depths (Greg Souliiere, U.S. Fish and Wildlife Service waterfowl specialist, personal communication, with verification by Mike Monfils, Michigan Natural Features Inventory waterfowl specialist).

Anas platyrhynchos (Mallard)

Although there is some evidence that food sources of mallards may be affected by lake-level regulation, mallards may not be an ideal indicator because its reproduction is primarily concentrated in seasonal, inland wetlands, because coastal wetlands warm too slowly in spring and have low invertebrate numbers than nearby inland wetlands. Because of the concentration of this species in inland wetlands, 99% of breeding waterfowl surveys are done in inland wetlands and other statewide breeding bird surveys also have no major coastal wetland component and do not re-survey regularly (Greg
Table 1. List of common species considered for inclusion as lake-level indicator species.

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<th>Scientific name</th>
<th>Common name</th>
<th>Status</th>
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<tr>
<td><em>Esox lucius</em></td>
<td>Northern Pike</td>
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<tr>
<td><em>Perca flavescens</em></td>
<td>Yellow Perch</td>
<td>Common</td>
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<tr>
<td><em>Ondatra zibethicus</em></td>
<td>Muskrat</td>
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<td><em>Microtis pennsylvanicus</em></td>
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<td>Common</td>
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<td><em>Phenacomys intermedius</em></td>
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<tr>
<td><em>Diatom algae</em></td>
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<td></td>
</tr>
<tr>
<td><em>Schoenoplectus canadensis</em></td>
<td>Blue-joint grass</td>
<td>Common</td>
</tr>
<tr>
<td><em>Carex lasiocarpa</em></td>
<td>Wire-grass</td>
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<td><em>Carex stricta</em></td>
<td>Tussock sedge</td>
<td>Common</td>
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<td><em>Lythrum salicaria</em></td>
<td>Purple loosestrife</td>
<td>Common</td>
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<td><em>Phragmites australis</em></td>
<td>Tall reed or common reed</td>
<td>Common</td>
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<td><em>Schoenoplectus acutus</em></td>
<td>Hardstem bulrush</td>
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<td><em>Schoenoplectus pungens</em></td>
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<td><em>Typha angustifolia</em></td>
<td>Narrow-leaved cattail</td>
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<td><em>Typha Xglauca</em></td>
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<td><em>Esox masquinongy</em></td>
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<td><em>Dreissena polymorpha</em></td>
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<td><em>Dreissena bugensis</em></td>
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<td><strong>Rejected</strong></td>
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<tr>
<td><em>Anas discors</em></td>
<td>Blue-winged teal</td>
<td>Common</td>
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Soulliere, U.S. Fish and Wildlife Service waterfowl specialist, personal communication, with verification by Mike Monfils, Michigan Natural Features Inventory waterfowl specialist). There is some difference of opinion here; with data from MI Department of Natural Resources showing spring mallard counts to be strongly associated with Great Lakes water levels (See comment by Dave Luukkonen). Coastal wetlands are more important for diving ducks which feed in 6-12 feet of water and are less productive feeders at greater depths (Soulliere).

**Perca flavescens (Yellow Perch)**

Yellow perch spawn is attached to bulrush stems and other submerged vegetation and structural elements. Since both dominant Great Lakes bulrushes (*Schoenoplectus pungens* and *S. acutus*) have been suggested as potential indicators strongly effected by Great Lakes lake-level fluctuations, yellow perch reproduction is expected to be linked to
these fluctuations as well. In addition to their habitat, a recent study conducted by Environment Canada illustrated that low, regulated lake levels may increase rates of parasitism (eyefluke) in this species and thus, may affect the long-term stability of yellow perch populations. Any study of the effects of lake level on parasitism must also include investigation of distance from alternative hosts to parasites, in this case ring-billed gulls.

**Esox masquinongy (Muskellunge)**

The reproduction of muskellunge is linked to flooding of wet meadow and other nearshore vegetation, where spawning primarily occurs in submersed aquatic vegetation and short emergents along shorelines. Unlike northern pike, which attach spawn to decomposing graminoid vegetation, muskellunge eggs are non-adhesive and often broadcast over the bottom. Bottom sediment conditions may be important for hatching of eggs and survival of larval fish. Prolonged lake level drops may result in greatly decreased availability of breeding habitat. This monitoring could be linked with monitoring of the vegetation and water levels in coastal wetlands where long-term monitoring has been conducted in the past, for example in the Les Cheneaux Islands of northern Michigan.

**Esox lucius (Northern Pike)**

It has been found that water level alterations can shift prime spawning habitat/substrate for the northern pike. The reproduction of northern pike is linked to flooding of wet meadows, where spawn is attached to decomposing graminoid vegetation and larval fish are attached to this vegetation as well, followed by a period of feeding and occupying the low-oxygen environment of the inner marsh. Prolonged lake level drops may result in greatly decreased availability of breeding habitat. This monitoring could be linked with monitoring of the vegetation and water levels in coastal wetlands where long-term monitoring has been conducted in the past, for example in the Les Cheneaux Islands of northern Michigan. Another important research opportunity might be comparing spawning sites on Lake Ontario, where spawning appears to have shifted to deep-water habitat with more stable, flooded conditions, to spawning habitat [sites] in the Upper Great Lakes to document different habitat utilization for spawning.

**Ondatra zibethicus (Muskrat)**

Trapping records of muskrat may provide enough detail to document long-term population trends for muskrat, and the linkage of these trends to water level. The species is also easily monitored by doing seasonally targeted surveys of muskrat lodges. Studies by Farrell, et al. along Lake Ontario can provide protocols for effective use of the indicator in the Upper Great Lakes.

**Microtis pennsylvanicus (Meadow vole) and Phenacomys intermedius (Heather vole)**

Meadow voles occupy the wet meadow zone of Great Lakes coastal wetlands, where they are important prey for raptors, such as northern harrier (Circus cyaneus). Population levels respond to habitat quality, and it is assumed that populations increase during low lake levels. Studies of existing literature could be combined with ongoing field studies. The study of this species could be linked to long-term studies of wet meadow and emergent plants. Heather vole occupies similar habitat to that of Microtis
*pennsylvanicus* (meadow vole), but with a more northerly distribution. Combination of both literature studies with field studies could provide better understanding of the importance of lake level on this species as well, and potentially the population fluctuations of the harrier might show a linkage to water level fluctuations through responses to prey fluctuations.

**Dreissena polymorpha** *(Zebra mussel)* and **Dreissena bugensis** *(Quagga mussel)*

Studies indicate that the recently arrived Dreissena species share habitats and that their habitats continue to shift. Until these species are documented to occupy a well-defined habitat and water depth, it seems that they would not be good candidates for studying or documenting water-level response. Study of these species would be much more relevant if tied to characterizing the algal taxa in relationship to water depth and associated water chemistry.

**Diatom algae**

Water level fluctuations may cause major changes to the algae in the Great Lakes by regulating light and wave disturbance. These effects will vary greatly in open water near-shore habitats and wetlands, and most likely in benthic versus planktonic habitats. Benthic algae are important in food webs of these Great Lakes habitats, and they cause nuisance problems when nutrient concentrations are high. Production by benthic algae, highly regulated by water depth because of light availability and wave disturbance, can constitute greater than 50% of total near-shore algal production during significant proportions of the year. Risks of nuisance benthic algae, such as Cladophora and Spirogyra, could increase with lowered lake levels because light will reach the bottom of more constrained and wave sheltered habitats. These algae alter habitats for fauna and may affect human health by increasing risks to pathogen exposure. Investigations of the ecology of macroalgae and forecasting changes in benthic algal habitats would increase our understanding of algal-related risks resulting from water level fluctuations.

**Schoenoplectus acutus** *(Hardstem bulrush)*, **Schoenoplectus pungens** *(Three-square)*

Hardstem bulrush and three-square are the two aquatic macrophytes most adapted to high-energy wave environments along the Great Lakes, and both are among the commonest dominants along all of the Great Lakes shore (Albert and Minc 2001). Both species are important for multiple reasons, including wave attenuation, sediment accumulation and stabilization, chemical modification of the near-shore environment, and providing structure for invertebrate, fish, and avian habitat (Albert 2004). During high-water conditions, over 250 meters of flooded bulrush bed are found along the fringes of most coastal wetlands, while during the present low-water conditions, less than a fifth of these bulrush beds are flooded and provide habitat or protection from wave erosion. The dewatered portion of these marshes has been subjected to plowing and raking, resulting in the loss of many miles of significant marsh vegetation since the year 2000. In the unplowed marshes, the wave-attenuation and sediment holding functions of these species has been limited by the slow growth rate of both species, which is typically less than 1 ft (30 cm) per year. Further studies of the effect of low water conditions upon the fauna, the reproduction and growth of the bulrush beds, and the physical environment of the outer
marsh are critical to the long-term health of many of our coastal marshes. A further threat to these important species is that they can be rapidly out-competed by *Phragmites australis* (reed) during extended low-water periods, yet upon return to high-water conditions; reed provides little of the sediment-holding and wave-attenuation functions that characterize both of these bulrush species.

**Lythrum salicaria** (Purple loosestrife)

Studies have documented that purple loosestrife expands rapidly as water levels drop in wetlands and expose moist mineral or organic sediments. Existing data sets already document the widespread presence of this species in the southern portions of all of the Great Lakes with the exception of Lake Superior, where the species is less common. Monitoring of previously sampled wetlands and wetland transects in the northern portions of Lakes Michigan and Huron, as well as Lake Superior during the present extended low water conditions could provide a perspective to the continued spread of the species. Most of the largest wetlands along these lakes have been sampled in the late 1980s, and several have been re-sampled in the 1990s and the early 2000s. Release of *Galerucella* beetles as a control for purple loosestrife has reduced coverage values of the plant in many shoreline areas and may complicate research design.

**Wild-rice** (*Zizania aquatica* var. *angustifolia* or *Zizania palustris* var. *palustris*)

Long-term plant sampling and ongoing commercial harvest of wild-rice in northern Wisconsin (Bad River Tribe and James Meeker) provide an opportunity to summarize existing data and potentially supplement that data with additional years of wetland plant data to better understand the relationship of wild-rice to water level fluctuations on the Great Lakes. There are probably important questions related to both extreme low water levels and the more typical shorter-term cyclic fluctuations. Wild-rice is widely enough distributed, ranging from the St. Clair River delta to stream mouths along Lake Superior, to provide for a robust sample size for data analysis.

**Typha angustifolia** (Narrow-leaved cattail) and **Typha Xglauca** (Hybrid cattail)

Both narrow-leaved and hybrid cattails are invasive plants that expand into coastal wetlands during low lake levels. The amount of expansion resulting from recent low lake levels could be documented by comparison to earlier studies during both low and high lake levels. Data has been collected by the same researchers mentioned under *Phragmites australis*. Faunal relationships could potentially be integrated into these studies.

**Phragmites australis** (Reed)

Tall reed is an invasive aquatic macrophyte that occupies the wet meadow and drier inner portion of emergent marsh zones. Recent low water levels have resulted in dramatic expansion into previously flooded wetlands. Once established, they are able to persist in flooded conditions, as long as wave energies are not strong. Previous sampling along transects in areas that contain this species could be combined with ongoing vegetation studies to determine the effect of low lake-level conditions. Studies of the upper Great Lakes could be compared with those of the wetter lower lakes (Lake Ontario and St. Lawrence River); for both areas earlier studies from the 1980s and 1990s could be
combined with future studies to observe differences between different fluctuation regimes. Past vegetation studies that could be incorporated with ongoing studies include work by Dennis Albert, Patricia Chow-Fraser, Greg Grabas, Joel Ingram, Carol Johnston, Jim Meeker, and Doug Wilcox. Studies of reed could also look at purple loosestrife, which responds similarly and is often present in the same marshes that reed occupies.

**Plant species of Interdunal wetland (panne or moist sandplain)**

Interdunal wetlands share several plant species across the Upper Great Lakes. Since some of these species are viewed as rare in states that have only small amounts of Great Lakes shoreline (PA, OH, IN, IL), study of the response of this community across the Upper Great Lakes could help determine if all of these wetlands are responding similarly. Since Pennsylvania has been studying these plants in detail, their protocols and experience could provide useful in states that have not sampled. In Michigan, one of the rare species of these wetlands, Houghton’s goldenrod, has been studied at some sites in detail and may provide a starting point for continued studies.

**Species of wet meadow (Carex stricta, C. lasiocarpa, Calamagrostis canadensis):**

Blue-joint grass, wire-grass, and tussock sedge are all species that occupy wet meadow zones in coastal marshes throughout the Great Lakes. A long-term study (1997 through 2003) along transects in a series of coastal marshes in the Les Cheneaux Islands showed a trend toward changing species densities in these and other aquatic macrophytes, with water level appearing to be the driving factor for these changes. The data collected in this study would benefit from further analysis, and additional sampling could be utilized to document ongoing response to low-water conditions. The first three years of this study were summarized and published by Gathman et al. (2006).

**V. Definitions of rare, threatened and endangered species**

In the United States, the terms of threatened and endangered species are defined by the Endangered Species Act of 1973 (ESA). Section 3 of this Act defines these terms as: (6) The term of "endangered species" means any species which is in danger of extinction throughout all or a significant portion of its range other than a species… and (20) The term "threatened species" means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Species listed as rare are generally defined as a species that is existing in such small numbers throughout all or a significant portion of its range that it may become threatened or endangered if its environment worsens.

In Canada, the Species at Risk Act (SARA), proclaimed in June 2003, utilized the definitions from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). “Threatened” is defined as a species that is likely to become endangered if limiting factors are not reversed. “Endangered” is a species facing imminent extirpation or extinction, with “extirpation” meaning a species that no longer exists in the wild in Canada, but occurring elsewhere, and “extinct” is a species that no longer exists. Also under SARA, the government of Canada will take COSEWIC's designations into consideration when establishing the legal list of species at risk.
In North America, there may be some confusion due to these differences in terminology between Canada and the United States according to the EnviroZone, Environment Canada's Online Newspaper. Similar to Canada's SARA, the United States' ESA designates a different meaning between the terms endangered and threatened. Like COSEWIC definitions, the ESA considers an endangered species (in danger of extinction throughout all or a significant portion of its range) at more of a risk than a threatened species (likely to become endangered within the foreseeable future throughout all or a significant portion of its range). However, unlike its Canadian counterpart, the ESA considers “species at risk” a general term for listed species as well as unlisted ones that are declining in population. Another comparison from the United States Fisheries and Wildlife states that species of concern is an informal term referring to a species that might be in need of conservation action. This may range from a need for periodic monitoring of populations and threats to the species and its habitat, to the necessity for listing as threatened or endangered. Such species receive no legal protection and use of the term does not necessarily imply that a species will eventually be proposed for listing. A similar term is a species at risk, which is a general term for listed species as well as unlisted ones that are declining in population. Canada uses the term in its new SARA. The majority of the species submitted as an indicator species are classified as rare or species of concern/species at risks.

In our tables of rare potential indicator species, we use the labels “E” for endangered species, “T” for threatened, “R” for rare, and “SC” for special concern. For some states, the term “PT” is used for potentially threatened, and for states and provinces who list only “S1”, “S2”, or other similar ranks without using the term endangered, threatened, rare, or special concern, we list the S-rank while awaiting clarification from the agencies responsible for these designations. We also added a category “C” for common, based on herbarium or county distribution records, which are available for Michigan and Wisconsin. We will continue to look for equivalent records that can supplement our understanding of the distribution of species. This distributional information is important, as some species are very common in Ontario, Wisconsin, Minnesota, and Michigan, jurisdictions with extensive areas of Great Lakes shoreline, while these same species may be uncommon in states with either small amounts of Great Lakes shoreline, i.e. Pennsylvania, Illinois, New York (along Lake Erie), and Indiana, or where much of the shoreline has been heavily modified by intensive human management, i.e. Illinois, Indiana, Ohio, New York (along Lake Erie), and Indiana.

VI. Criteria for defining a final subset of rare, threatened, and endangered species whose viability are directly linked to lake level fluctuations

Approximately 130 rare species were recommended as potential indicators of lake-level fluctuation, with the majority of these being plants. Because of the large number of recommendations, it is obviously necessary to prioritize the species being recommended as indicators.

The first category of species to be considered are the federally listed species, which comprise about 18% of the species recommended for consideration. These species have received the most scrutiny and the data available for these species is typically much
more specific and focused. All states track these species to roughly the same level and funds have been available to the states from the federal government to improve the quality of inventory, conduct population studies, and conduct habitat studies. Any federally listed species whose habitat appears to be subjected to lake-level fluctuation are top candidates for inclusion as indicators. Among the federally listed species are several Great Lakes endemic or near-endemic species. These are also good candidates for inclusion as indicators, as many of these species are located in habitats that depend on lake-level fluctuation for successful maintenance.

The state-listed species are a much larger group, making up 82% of the species recommended and an even larger percentage of the plants. Our recommendation for the state-listed species is to identify those that are consistently rare across the range of Great Lakes states, or at least across the lakes that are ecologically similar. Many species are rare at only the edge of their range, but common within the majority of the lake states and Ontario. Such species are not being recommended for review within the category of rare species, but may be appropriate for inclusion among common species being considered as indicators.

Some of the state listed species have only localized distributions with only two or three locations. These species are generally not considered appropriate for monitoring the influence of lake-level, as it is difficult to infer ecological relationships on the basis of a small number of sampling sites. For example, *Panicum tuckermanii* (Tuckerman’s panic grass), is extremely rare along Pennsylvania’s Lake Erie shoreline and therefore cannot provide information that will be either easily or effectively evaluated, nor will it be useful for understanding habitat needs for other portions of the Great Lakes shoreline.

Four other criteria related to the biological characteristics of the species or to characteristics of their habitat were added to assist in reviewing the literature to determine if the survival or viability of either rare or common species were adequately linked to water-level fluctuation. These criteria were:

1. Rare annual or perennial plants which only appear in direct response to Great Lakes fluctuation event. That is, immediately following Great Lakes water level rises or drop (Typically plants of beach or marsh edge).
2. Rare plant species that are linked to sediment changes that occur in response to water level fluctuation. (Example: Sand dune species that require open sand).
3. Rare animal species that nest or feed in open emergent wetlands that become too densely vegetated without water level fluctuations, or where chemistry of the habitat may become toxic or hostile (Birds, invertebrates, fish, mussels).
4. Rare animal species whose mating or specific life phases depend on water-level fluctuations. (Fish and possibly invertebrates and mussels).

VII. List of rare, threatened, and endangered indicator species

Appendix 4 summarizes all of the common and rare, threatened or endangered species that were nominated by biologists and land managers from the Great Lakes research and conservation community. This table contains scientific and common name, federal, state, and provincial ranks, habitat comments, publications summarizing research
on the species, and the name of the recommending scientist or agency. This list was used to support the recommendation of both common and rare species for further review.

VIII. Recommended rare, threatened, and endangered indicator species

The following species were chosen from the list of rare, threatened and endangered species that were initially nominated. These species were subject to further research and analysis on their responses to lake level fluctuations in the upper Great Lakes. An annotated bibliography is provided in appendix 6 for each of these nominated species. These abbreviated species abstracts includes any available literature and reports documenting their susceptibility/vulnerability to hydrologic variability and lake level fluctuations, as well as distribution maps for each of the nominated species. It also includes relevant general information to describe habitat and important biological information related to breeding, seed germination, etc.

Table 2 lists rare species that are suggested for indicators of lake level fluctuation in the upper Great Lakes. Several species were nominated in the questionnaire that do not appear to have adequate linkage to the Great Lakes or that have other biological or distributional characteristics that do not lend themselves to being treated as indicators of lake level fluctuation. For this reason we are breaking the initial list of suggested indicators into 1) Recommended indicators, 2) Questionable indicators, where the information is very incomplete or where we received conflicting recommendations from researchers, and 3) Rejected indicators, where the linkage of species to lake level fluctuation appears tenuous or where there are too many other factors to allow for effective monitoring. A summary of all recommended, questionable and rejected rare, threatened or endangered species are included in table 2.

SUMMARIES FOR ALL NOMINATED RARE SPECIES

*Rallus elegans* (King rail)

**Federally Endangered in Canada**

The King Rail is a species at risk (SAR) in Canada, as well as recognized by the states of Illinois, Michigan, Indiana and Minnesota as endangered. This species require shallow emergent wetlands and marshes with large spans of open water in which to nest/breed. The absence of natural water-level fluctuations and/or artificially high or low water levels may reduce prime breeding habitat for this species in the Great Lakes basin. An inventory was conducted in 1987 high-water level conditions by Mary Rabe at historic sites and where habitat looked appropriate on Lakes Erie, St. Clair, and Saginaw Bay of Lake Huron. These sites could be re-sampled in present low-water conditions to compare population sizes in relationship to water-level fluctuation. Mike Monfils (Michigan State University) has inventoried some sites over the last three years during his dissertation studies.
Table 2: List of threatened and endangered species considered for water-level indicators.

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Status and Jurisdiction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RECOMMENDED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charadrius melodus</td>
<td>Piping plover</td>
<td>Federally Endangered (CN and US)</td>
</tr>
<tr>
<td>Epioblasma torulosa rangiana</td>
<td>Northern riffleshell</td>
<td>Federally Endangered (CN and US)</td>
</tr>
<tr>
<td>Cirsium pitcheri</td>
<td>Pitcher’s thistle</td>
<td>Federally Threatened (CN and US)</td>
</tr>
<tr>
<td>Epioblasma obliquata perobliqua</td>
<td>White catspaw</td>
<td>Federally Endangered (US)</td>
</tr>
<tr>
<td>Somatochlora hineana</td>
<td>Hine's emerald dragonfly</td>
<td>Federally Endangered (US)</td>
</tr>
<tr>
<td>Platanthera leucophaea</td>
<td>Eastern prairie fringed orchid</td>
<td>Federally Endangered (US)</td>
</tr>
<tr>
<td>Rallus elegans</td>
<td>King rail</td>
<td>Federally Endangered (CN)</td>
</tr>
<tr>
<td>Notropis anogenus</td>
<td>Pugnose shiner</td>
<td>Federally Endangered (CN)</td>
</tr>
<tr>
<td>Solidago houghtonii</td>
<td>Houghton’s goldenrod</td>
<td>Federally Threatened (US)</td>
</tr>
<tr>
<td>Ixobrychus exilis</td>
<td>Least bittern</td>
<td>Federally Threatened (CN)</td>
</tr>
<tr>
<td><strong>QUESTIONABLE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Childonias niger</td>
<td>Black tern</td>
<td>State Endangered (IL and NY)</td>
</tr>
<tr>
<td>Acipenser fulvescens</td>
<td>Lake sturgeon</td>
<td>State Endangered (IL and IN)</td>
</tr>
<tr>
<td>Notropis heterolepis</td>
<td>Blacknose shiner</td>
<td>State Endangered (IL and OH)</td>
</tr>
<tr>
<td>Opsopoeodus emiliae emiliae</td>
<td>Pugnose minnow</td>
<td>State Endangered (IL and MI)</td>
</tr>
<tr>
<td>Schoenoplectus smithii</td>
<td>Smith’s bulrush</td>
<td>State Endangered (IN, IL, OH, PA)</td>
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<td>Sagittaria montevidensis</td>
<td>Arrowhead</td>
<td>State Threatened (MI)</td>
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<td>(S. calycina)</td>
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<tr>
<td><strong>REJECTED</strong></td>
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<td>Agalinis gattingeri</td>
<td>Roundstem false foxglove</td>
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<td>Nerodia sipedon insularus</td>
<td>Lake Erie watersnake</td>
<td>Federally Threatened (CN)</td>
</tr>
<tr>
<td>Potamogeton hillii</td>
<td>Hill’s pondweed</td>
<td>State/Provincially Threatened (MI, NY ONT)</td>
</tr>
</tbody>
</table>

**Ixobrychus exilis (Least Bittern)**

**Federally Threatened in Canada**

Least Bitterns use hemi-marshes composed of cattail or bulrush and usually nest very close (within one foot) to standing water levels. As a result, extended extreme high or low conditions are detrimental to either the breeding or foraging habitat. Water level fluctuations are significant to maintaining shallow, open water habitat for least bittern and may highly influence the viability of Least Bittern populations in the Great Lakes region. It is unclear whether the populations of these indicator species will decline with low or high water levels over time or whether the birds will simply redistribute in the marsh if suitable habitat remains. Populations should be modeled in relation to habitat availability and water levels. In a short period of time (e.g., monthly), if there are large water level fluctuations, populations are more likely to be affected due to nest flooding or stranding (Greg Grabas, personal communication).
**Charadrius melodus** (Piping Plover)
**Federally Endangered in Canada and United States**

The Piping Plover is federally endangered in both the United States and in Canada. Its current habitat in the Great Lakes Basin consists of open beach often associated with coastal dunes along lakes Michigan, Huron and Superior. Breeding habitat has been threatened by development and other anthropogenic activities. Plover habitat is also susceptible to fluctuating lake levels. High lake stage has been responsible for flooding Plover nests, while low lake stage may allow plants, including non-native invasive vegetation, to encroach onto the exposed beach, reducing viable nesting habitat for the species. This suggests the piping plover is sensitive to any long-term water level modification and would make an ideal indicator for this study. Studies out of the University of Minnesota have GPS points on nests for the past ten years, which could provide data to document changes in nest location relative to water level changes.

**Chlidonias niger** (Black Tern)
**State Endangered in Illinois and New York**

Although a significant link between black tern population stability/maintenance and water level fluctuations has not yet been established, it has been determined that they utilize wetlands and marshes with emergent vegetation that are susceptible to destruction from prolonged high or low water levels. Black terns are also sensitive to any vegetative shift that may be driven by changes in water level. Black terns nest on floating mats of aquatic vegetation (wrack) and are thus dependent on water levels high enough to flood and erode vegetation. Because black terns are considered a rare species in both Canada and the United States, this species may be an ideal indicator for this scoping project.

**Acipenser fulvescens** (Lake Sturgeon)
**State Endangered in Illinois and Indiana**

Although the major factor impeding lake sturgeon from effectively breeding is the presence of impoundments or other in-stream obstructions inhibiting individuals from migrating upstream, indirect impacts of lake level modification (which can be a general increase or decrease in lake level as well as the removal of any natural seasonal/long term fluctuations that help maintain habitat) may disrupt existing breeding habitat for Lake sturgeon as well. Intentional changes in lake stage may disrupt/change the current flow regime in the connecting channels (St. Mary's, Lake St. Clair), which can bring with it changes in the overall capacity of these rivers to convey their current sediment load. This may lead to a shift in substrate material, from cobble to sand to silt, or vice versa, in these channels (Dennis Albert, Michigan Natural Features Inventory, personal communication).

**Notropis anogenus** (Pugnose shiner)
**Federally Endangered in Canada**

This species is both federally and state/provincially listed as endangered. The Pugnose shiner requires clear, non-turbid, highly vegetated lakes or quiet streams/wetlands as its primary habitat, which may be affected by prolonged high water levels. It has been noted that changes in water levels in shiner habitat may create a shift in
vegetative community, thus increasing competition between this species and other fish for shelter or food sources.

*Opsopoeodus emiliae* (Pugnose minnow)  
**State Endangered in Illinois and Michigan**  
Although there was a general lack of evidence for a definitive link between species success and water level fluctuation, the pugnose minnow requires clear, non-turbid, highly vegetated lakes or quiet streams/wetlands as its primary habitat, which may be affected by prolonged high water levels. It has been noted that changes in water levels in shiner habitat may create a shift in vegetative community, thus increasing competition between this species and other fish for shelter or food sources. This species is also listed as endangered in Illinois and Michigan.

*Notropis heterolepis* (Blacknose shiner)  
**State Endangered in Illinois and Ohio**  
Although there was a general lack of evidence for a definitive link between species success and water level fluctuation, the Blacknose shiner requires clear, cool non-turbid, highly vegetated lakes or quiet streams/wetlands as its primary habitat, which may be affected by prolonged high water levels. This species is also listed as endangered in Illinois and Ohio.

*Epioblasma obliquata perobliqua* (White catspaw)  
**Federally Endangered in United States**  
This species occupies shallow waters in connecting rivers, and may therefore be sensitive to lake-level changes. The species is federally listed and has well studied distributions. Protocols for sampling are well developed and typically involve scuba diving or snorkeling.

*Epioblasma torulosa rangiana* (Northern riffleshell)  
**Federally Endangered in Canada and United States**  
This species occupies shallow waters in connecting rivers, and may therefore be sensitive to lake-level changes. The species is federally listed and has well studied distributions. Protocols for sampling are well developed and typically involve scuba diving or snorkeling.

*Elaphe vulpina gloydi* (Pantherophis gloydi) (Eastern fox snake)  
**Federally Threatened in Canada**  
This species has been the subject of intensive monitoring both in the U.S. and Canada. Its sensitivity to water-level fluctuations is probably greatest during the late fall, winter, and spring during hibernation, when it may be sensitive to water level fluctuations that could result in loss of protection from freezing. It overwinters on the dikes and uplands, and it is assumed that it maintains a position close to the water to achieve protection from the frost, but research has been inadequate to document this.
**Somatochlora hineana** (Hine’s emerald dragonfly)
**Federally Endangered in United States**

The species occupies a habitat that may be very sensitive to lake-level fluctuation, cool carbonate-rich ground-water fed seepages immediately adjacent to the Great Lakes shoreline. These seepage ponds are flooded during high-water periods, but are isolated from the Great Lakes during low-water periods, when all of their water comes from groundwater sources. It is federally listed and has been intensively surveyed for in recent years, providing multiple sites for monitoring and study, including a newly discovered site in Canada. It is dependant on burrowing crayfish that have been documented to require seasonally moving water at the interface with the Great Lakes. The habitat is utilized by another rare dragonfly that could be studied simultaneously.

**Cirsium pitcheri** (Pitcher’s thistle)
**Federally Threatened in Canada and United States**

The KcEachern et al. (1994) article describes the linkage between Great Lakes water-level fluctuations and changing habitat for Pitcher’s thistle, referencing several geological studies of dune process and regional dune history. While several authors describe the habitat conditions required by Pitcher’s thistle to be open, moving sands of dunes and beaches along the Great Lakes shoreline, only one study of the Whitefish Dunes State Park in Wisconsin looks at the linkage between water level fluctuation and plant numbers (Carolyn Rock, email correspondence, 2007). This study shows a strong trend toward decreased numbers of plants along the beach immediately following high-water conditions, but no sampling was conducted during the high water years of either 1986 or 1996-1998. Several researchers have suggested that high lake levels undercut coastal bluffs and stabilized dunes, resulting in increased sand movement and beach ridge and dune migration, conditions that would potentially increase habitat farther inland for Pitcher’s thistle, which requires shallow sand burial for germination. However, deep sand burial eliminates seed germination and can kill established plants, thus indicating that further research would need to be conducted on active parabolic and perched dunes inland from the immediate shore; the Whitefish Dunes State Park study was conducted along the immediate shoreline of Lake Michigan.

**Hymenoxys herbacea** (Lakeside daisy)
**Federally Threatened in Canada and United States**

Lakeside daisy is recognized as requiring habitat that is maintained open by seasonal fluctuations of water table or other types of disturbance that prevent succession to shrubs and trees. Several Canadian populations of lakeside daisy occur along the Great Lakes shoreline on open limestone bedrock. While these Canadian populations were monitored, there are no references to response of these populations to Great Lakes water-level fluctuations, and population comparisons were limited to 1999 and 2000, both low-water years. These Ontario sites, unlike Michigan’s and Ohio’s inland sites, provide an opportunity for long-term monitoring of this species’ response to Great Lakes water level changes.
**Iris lacustris** (Dwarf lake iris)
**Federally Threatened in Canada and United States**
While dwarf lake iris occurs on both sand and limestone bedrock along the Great Lakes shoreline, where it flowers best in open habitat, non-flowering populations can also persist along abandoned shoreline features several miles inland. Water level fluctuations may be no more important than other types of coastal disturbance, such as windstorms or fire for maintaining open habitat for this species. The presence of limestone bedrock at or near the surface may also provide a combination of seasonally wet and dry conditions that maintains open conditions that allow this species to establish and persist. The diversity of habitats and drainage conditions that dwarf Lake Iris thrives within will likely make it a difficult species to evaluate for water-level response.

**Platanthera leucophaea** (Eastern prairie fringed orchid)
**Federally Endangered In United States**
The dependence of Great Lakes populations of eastern prairie fringed-orchid on water level fluctuations is recognized in both the U.S. and Canada. Agricultural development of the upper edge of wet prairies has eliminated the habitat necessary for colonization during high Great Lakes water levels. Biological research resulting from this scoping project will probably be too short-term to document responses of the orchid to water level fluctuation.

**Solidago houghtonii** (Houghton’s goldenrod)
**Federally Threatened in United States**
As both Penskar et al. (1996) and Kristina Makkay (2005) state, three types of habitat are known for this species: rocky and cobble shoreline, interdunal wetlands, and moist beach flats. Water level fluctuations characterize all of these habitats. The author has visited sites in both high-water and low-water conditions and found that the plant was much more wide-spread in low-water conditions, restricted to moist wetland edges during high-water conditions, and expanding across these drying wetlands as water levels dropped. Detailed mapping of stem numbers and locations, along with water depth, over several growing seasons would clarify the degree of flooding tolerated by the plant. Careful examination of rhizomes might also provide us with an understanding of the different levels of bud formation and survival at different moisture levels within natural habitat.

**Potamogeton hillii** (Hill’s pondweed)
**State/Provincially Threatened in Michigan, New York and Ontario**
The distribution of this species is described as centering on the Great Lakes, but ponds and streams appear to be its primary habitat, including ponds and streams close to the Great Lakes shoreline. Information does not appear to indicate that it occupies habitat directly associated with Great Lakes coastal wetlands or that it responds to fluctuations of the Great Lakes water level. For this reason, it does not appear to be a good indicator for Great Lakes water-level fluctuation.
**Sagittaria montevidensis** (Arrowhead)

**State Threatened in Michigan**

The plant is found to respond identically along the Great Lakes shoreline in the three states where it is found (Michigan, Ohio, and Pennsylvania), establishing in large numbers on mud or sand flats immediately following water-level drops. Our studies along western Lake Erie in Michigan indicate that with extended periods of low water the species begins to be outcompeted, and when water levels rise, the species will disappear or become very uncommon until water levels once again drop. These conclusions are based on multiple years of sampling data along a transect at Erie Marsh on Lake Erie.

**Ranunculus cymbalaria** (Seaside crowfoot)

**State Endangered in Illinois and New York**

This plant appears to be strongly associated with saline, muddy sediments along the edge of coastal estuaries, but also in saline habitat in mountains and interior wetland depressions. In Michigan, the locations are in fluctuating muddy wetlands, with no Great Lakes coastal sites. While it may be a local rarity along fluctuating shorelines of coastal Great Lakes wetlands, it appears to be too rare along Great Lakes shorelines to be effectively used as an indicator species.

**Schoenoplectus smithii** (Smith’s bulrush)

**State Endangered in Indiana, Illinois, Ohio and Pennsylvania**

The plant is found to respond identically along the Great Lakes shoreline or the shoreline of small ponds or lakes in the states where it is found, establishing in large numbers on mud or sand flats immediately following water-level drops. The only detailed study tracking this and associated species is that of Dr. James Bissell of the Cleveland Museum of Natural History at Presque Isle State Park along Lake Erie in northwestern Pennsylvania. The plant, in combination with other species of the moist sand plain, could be monitored at this Pennsylvania site, potentially in combination with other exotic species that respond to fluctuating water levels and are in direct competition with this and other similar native plant species.

**Schoenoplectus purshianus** (Weakstem bulrush)

**State/Provincially Endangered in Illinois and Ontario**

This plant is a mudflat annual that germinates on moist sand or organic-rich sediments. It is found at locations along the Great Lakes in Canada, as well as at locations in the southern U.S. The number of known locations along the Great Lakes shoreline is so small that it would appear to be a difficult plant to use effectively as an indicator of water-level fluctuation.

**IX. List of key agencies and NGOs responsible for the protection, restoration and regulation of rare, threatened, and endangered species in the basin**

The primary agencies involved in regulating rare species are the US Fish and Wildlife Service and Environment Canada. State and provincial Heritage programs, often in conjunction with state or provincial departments of natural resources, develop and
maintain databases to track rare species status. Protection is the responsibility of local, state, and federal land managing agencies, as well as land-owning NGOs such as The Nature Conservancy and the Audubon Society. These same land managing agencies and NGOs are often active in habitat restoration for rare species. Appendix 5 lists the agencies and NGOs, along with relevant web sites.

The primary source of information on rare species is Nature Serve and its affiliated Heritage Programs for each state and province in North America. The data from these programs was used extensively in the collection of data on rare species. All of the states and provinces bordering the Great Lakes have collected data on rare species and contributed it to Nature Serve’s global data base. All of the states and provinces began data collection in the 1970s or 1980s, and at that time contributed it to The Nature Conservancy’s (TNC) global database of rare species. In the 1990s Nature Serve was created by TNC to focus on maintenance and continued development of the rare species database, as well as a database on natural communities. Much of the research on federally listed species has been conducted by the U.S. Fish and Wildlife Service, who also funded management plans for many rare species, especially animals.

While lists are available for most rare species, maps tend to be more general in distribution to protect specific sites from destruction or collectors. For many of the federally-listed species, a detailed management plan is available. Many state Heritage programs also have abstracts or brief summaries for all or some of their rare species, and these are often available on the state web sites. Other state agencies and NGO organizations also track and maintain data on rare species, but in a less complete and structured format than Nature Serve, TNC, or the USFWS. While these other sources were queried and used by the authors of this study, they often do not have web sites for broad dispersal of rare species information.

X. Ongoing studies, data collection, and monitoring efforts related to rare, threatened, and endangered lake-level indicator species in the basin

There are surprisingly few long-term studies of rare species response to lake-level changes. The few long-term studies identified are more classic studies of breeding success related to habitat loss or restoration efforts, habitat degradation resulting from human land use, and predation by either natural or introduced predators. For example, ample monitoring efforts have been conducted and a recovery plan has been developed for the federally endangered piping plover (*Charadrius melodus*), whose habitat along the Great Lakes sand dune complexes has been subject to deterioration (USFWS, 2003). Studies such as this one may lend themselves to applying to other species living in a similar habitat, thus providing a surrogate monitoring program for a community of species living alongside a critically impaired population. Although this endangered species has been addressed through monitoring and recovery plans, the population status and distribution of other endangered species in the Great Lakes, such as the White Catspaw pearly mussel (*Epioblasma obliquata perobliqua*), have not been so rigorously pursued (NatureServe 2007).

No responses were received from the municipalities or private sector utility and power companies. Our queries were sent to regulating agencies asking for information
concerning monitoring of rare species populations, but we received no responses providing us information on private sector or municipality permits relating to rare species monitoring. The Institute of Water Research also sent queries to water-shed related organizations and agencies and received no references to monitoring efforts.

One example of long-term monitoring and/or assessment was a study recently conducted by Environment Canada that explored the effects of climate change-induced lake level changes on coastal wetlands (Mortsch et al., 2006). This study assessed the level of vulnerability of wetlands and their inhabitants to changes in lake levels driven by global climate change. Field studies and modeling exercises provided detailed information on species responses to different types of lake level fluctuations in the lower Great Lakes (Ontario and Erie). While no study has been found to date that explicitly focused on the effects of lake-level changes on individual species, other studies that establish the habitat needs and responses to other disturbances (climate change, habitat degradation) might allow for effective re-analysis of data sets with the addition of the lake-level data available from other federal or state agencies.
References


Appendix 1a: Common Lake-level Indicator Species Scope of work

DRAFT (31 Jan, 2007)

Scope of Work
For a “Scoping Paper” on:

Agency and NGO Perspectives on Potential Key Indicator Species for Consideration by the International Upper Great Lakes Study (IUGLS)

OBJECTIVE: Provide a preliminary assessment, in the form of a Scoping Paper, for the International Upper Great Lakes Study (IUGLS) on those key species which could serve as ‘indicator species’ for determining the effects of lake level regulation, because their life cycles are directly and significantly affected by, or depend on lake level fluctuations. (This assessment should not include the formally designated rare, threatened or endangered species, as this work is being conducted under a separate contract). The IUGLS encompasses Lakes Superior, Huron, Michigan, Erie and all the connecting channels and waterways. The purpose of this scoping paper is to assist the IUGLS Study Board and Environmental Technical Working Group (ETWG) in developing a strategy for additional ecological studies and the incorporation of key indicator species in any subsequent decision modeling framework. The Scoping Paper would represent a first order assessment of which species are considered to be candidates for consideration as ‘indicator species’, and would include: (i) the key species in both the US and Canada (identified at the federal, state and provincial levels) that are in some way affected by lake level variability and long-term fluctuations and may serve as practical indicators for subsequent modeling and decision making; (ii) a review of available literature which pertains to the specific issue of lake level variability linked with ecological viability of the selected indicator species; (iii) annotated documentation of specific agency (and related environmental NGO) ongoing studies and related monitoring efforts that are related to the issues; (iv) development of a list of key agencies, relevant departments and personnel who are responsible for protection, regulation and studies for those indicator species in the Great Lakes region.

BACKGROUND: The International Joint Commission (IJC) initiated the IUGLS in December, 2006 in order to: (i) investigate potential improvements of the existing Lake Superior outflow regulation plan; (ii) investigate how hydraulic changes in the St. Clair R. affect lake levels and requirements for changes in the regulation plan; and (iii) investigate impacts of climate variability and climate change on long-term lake level changes and their impacts on the major uses of the lakes. The Plan of Study (POS) highlights a few specific environmental issues, including: (a) peaking and ponding effects on the St. Marys R.; (b) potential ecologic impacts of mitigation/remediation measures that might be proposed for ameliorating the long term effects of dredging and scouring of the St. Clair R.; and (c) the effects of long-term cyclical lowering of water levels in Georgian Bay on wetlands viability. There may be other ecological issues as a consequence of remedial/mitigation actions proposed to alleviate whatever long-term lake level stabilization strategies that emerge during the course of the Study, along with climate variability and climate change. The Study Board and the Public Interest Advisory Group (PIAG) are preparing to undertake numerous studies that are focused on specific physical changes to the hydrology and hydraulics of the upper lakes system that will help to answer many questions and issues raised in the POS. Clearly, the ecological health of the Great Lakes system is a principal concern, to the extent that relatively small anticipated lake level changes may affect the viability (habitat, food web and life cycle requirements) of such species. Although wetlands are not in the RTES category, many RTES species depend on them as habitat for some part of their life cycle. The greatest direct effect of lake level fluctuations, beyond the range experienced historically, would be on unique shoreline habitats which ‘house’ those RTES ( wetlands, sandy shores, embayments, etc.).

TASKS: The analyst will undertake the following specific tasks as part of the scoping paper:
1. Develop a list of the principal Federal, State (Wisconsin, Minnesota, Illinois, Iowa, Michigan, Pennsylvania) and Provincial agencies (with key points of contact), along with the notable NGOs (e.g. Nature Conservancy, Audubon Society, World Wildlife Federation, etc.) that are engaged in studying or monitoring ecosystems and/or species in the Great Lakes region.

2. Develop a questionnaire that would guide the solicitation of information from the identified parties, derived from a combination of telephone interviews, web searches and email contacts with key responsible individuals, scientists and program managers in aforementioned institutions.

3. Contact each agency and respective POC representatives that deal with ongoing monitoring and/or studies of selected species that may be candidates for use as indicator species in the IUGLS. Determine which species have best time series of data; availability of data for use by IUGLS; and which species are most likely to be influenced by lake level regulation changes. Provide whatever documentation is available (agency technical report references, websites, published papers).

4. Discuss which other species (other than rare, threatened or endangered) ought to be considered as indicator species, though little information is available, but for which there is some evidence that lake level fluctuations, or peaking and ponding specifically in the St. Mary’s R., or dredging and erosion in the St. Clair R. are affecting the viability of those species. Provide relevant documentation.

5. Prepare a report nominating no more than 25 key indicators for further use in the investigations that will be performed by the ETWG.

COMPLETION DATE: 31 March, 2007

ESTIMATED LEVEL of EFFORT: 25 days, $10,000
Appendix 1b: Rare Lake-level Indicator Species scope of work

DRAFT (24 Jan 2007)

SCOPING PAPER

Preliminary Assessment of Rare, Threatened and Endangered Species (RTES) in the Upper Great Lakes

OBJECTIVE: Provide a preliminary assessment, in the form of a Scoping Paper, for the International Upper Great Lakes Study (IUGLS) on those rare, threatened and endangered species (RTES) whose life cycles are directly and significantly affected by, or depend on lake level fluctuations. The IUGLS encompasses Lakes Superior, Huron, Michigan, Erie and all the connecting channels and waterways. The purpose of this scoping paper is to assist the IUGLS Study Board and Environmental Technical Working Group (ETWG) in developing a strategy for additional ecological studies and the incorporation of key indicator species in any subsequent decision modeling framework. The Scoping Paper would represent a first order assessment of: (i) the key listed species in both the US and Canada (identified at the federal, state and provincial levels) that are in some way affected by lake level variability; (ii) a review of available literature which pertains to the specific issue of lake level variability linked with listed species viability; (iii) annotated documentation of specific agency (and related environmental NGO) studies and monitoring efforts that are related to the issues; (iv) development of a list of key agencies, relevant departments and personnel who are responsible for protection, regulation and studies of RTES in the Great Lakes region.

BACKGROUND: The International Joint Commission (IJC) initiated the IUGLS in December, 2006 in order to: (i) investigate potential improvements of the existing Lake Superior outflow regulation plan; (ii) investigate how hydraulic changes in the St. Clair R. affect lake levels and requirements for changes in the regulation plan; and (iii) investigate impacts of climate variability and climate change on long-term lake level changes and their impacts on the major uses of the lakes. The Plan of Study (POS) highlights a few specific environmental issues, including: (a) peaking and ponding effects on the St. Marys R.; (b) potential ecologic impacts of mitigation/remediation measures that might be proposed for ameliorating the long term effects of dredging and scouring of the St. Clair R.; and (c) the effects of long-term cyclical lowering of water levels in Georgian Bay on wetlands viability. There may be other ecological issues as a consequence of remedial/mitigation actions proposed to alleviate whatever long-term lake level stabilization strategies that emerge during the course of the Study, along with climate variability and climate change. The Study Board and the Public Interest Advisory Group (PIAG) are preparing to undertake numerous studies that are focused on specific physical changes to the hydrology and hydraulics of the upper lakes system that will help to answer many questions and issues raised in the POS. Clearly, RTES are a principal concern, to the extent that relatively small anticipated lake level changes may affect the viability (habitat, food web and life cycle requirements) of such species. Although wetlands are not in the RTES category, many RTES species depend on them as habitat for some part of their life cycle. The greatest direct effect of lake level fluctuations, beyond the range experienced historically, would be on unique shoreline habitats which ‘house’ those RTES (wetlands, sandy shores, embayments, etc.).

TASKS: The analyst will undertake the following specific tasks as part of the scoping paper:

1. Provide the lists of rare threatened and endangered species, formally recognized as listed species by federal, state and provincial laws, that spend at least some part of their life cycle in the Great Lakes coastal zone, on both the US and Canadian side (lists to be included as appendix).
2. Provide web linkages to agency lists, maps, charts of RTES distributions, locations – to the extent available.
3. Provide definitions of rare, threatened and endangered species, and discuss key differences among the definitions as they relate to the published lists.
4. Develop criteria for defining a final subset of RTES whose viability are directly linked to lake level fluctuations.
5. Select the subset of key RTES which meet the criteria. Develop an annotated bibliography of key literature that exists for those species, organized by species, which support their susceptibility/vulnerability to hydrologic variability and lake level fluctuations.
6. Provide list of key agencies, departments and individuals who are responsible for the protection, restoration and regulation of RTES in the basin (websites, names and telephone numbers) as well as NGOs who are involved in studies and monitoring
7. Provide information on any ongoing studies, data collection and monitoring efforts that are directly related to RTES in the basin, including those of municipalities and private sector utilities and power companies under the auspices of various state and federal licenses and regulatory commissions (e.g. FERC, EPA, State and provincial DEC, etc.).

**SCHEDULE:** A Report is to be submitted by March 31, 2007.

ESTIMATED COST: 25 days @ $400/day = $10,000

**Initial List of U. S. Endangered, Threatened, Candidate, and Special Concern Species:** Lake Erie watersnake, piping plover, common tern, black tern

**Listed in Canada:** Lake Erie watersnake, piping plover, king rail, spotted turtle, least bittern, spiny softshell, Blanding’s turtle, American waterwillow, swamp rosemallow, pugnose minnow, lake sturgeon, deepwater sculpin, silver chub, northern cricket frog
Appendix 2: Questionnaire

The following questionnaire was attached to the emails (Italic added for this report only):

**QUESTIONNAIRE: SPECIES AFFECTED BY GREAT LAKES WATER-LEVEL FLUCTUATIONS**

I have been asked to provide a preliminary assessment for the International Upper Great Lakes Study (IUGLS) to identify key species which could serve as ‘indicator species’ for determining the effects of lake level regulation, because their life cycles are directly and significantly affected by, or depend on lake level fluctuations. Potential indicator species would be separated into two broad classes: 1) Threatened, Endangered, and special concern species, and 2) other, more common or widely distributed species.

To address this task I have provided a brief table and I am seeking the input of researchers who have worked within the Great Lakes. I need species recommendations by March 26, 2007 – I apologize for the extremely short turn-around time. I would appreciate your input and I would also ask that you supply me with the name, email, and phone number of any specialists whose research would allow them to suggest other species of concern. The table is set up for an individual species, but copies could be added if you identify more than one potential indicator species.

The Upper Great Lakes Study encompasses Lakes Superior, Huron, Michigan, Erie and all the connecting channels and waterways. The purpose of this scoping paper is to assist the IUGLS Study Board and Environmental Technical Working Group (ETWG) in developing a strategy for identifying further ecological studies and incorporating key indicator species into the subsequent decision modeling framework.

**The important information needed includes:**

1. Potential indicator species in both the US and Canada that are dependant on lake level variability and long-term fluctuations.
2. Existing literature that links lake level variability to the ecological viability of the indicator species, including on-going research. Identification of existing long-term studies or databases that document the indicators and their habitat relationships are desirable.
3. Documentation of specific agency or environmental NGO, ongoing studies, and related monitoring efforts for the species.

**BACKGROUND:** The International Joint Commission (IJC) initiated the IUGLS in December, 2006 to: (i) investigate potential improvements of the existing Lake Superior outflow regulation plan; (ii) investigate how hydraulic changes in the St. Clair R. affect lake levels and requirements for changes in the regulation plan; and (iii) investigate impacts of climate variability and climate change on long-term lake level changes and their impacts on the major uses of the lakes.
A few specific environmental issues related to Upper Great Lakes water-level fluctuations were identified, including:

1. Peaking and ponding effects on the St. Marys River.
2. Potential ecologic impacts of dredging and scouring of the St. Clair River; and
3. The effects of long-term cyclical lowering of water levels in Georgian Bay on wetland viability.

The following table will assist in directing numerous future studies that are focused on specific physical changes to the hydrology and hydraulics of the upper lakes system. These studies are aimed at understanding the effects of relatively small lake-level changes upon the viability (habitat, food web and life cycle requirements) of any suggested indicator species. It is assumed that the greatest direct effect of Great Lakes lake-level fluctuations, beyond the range experienced historically, would be on shoreline habitats such as wetlands, sandy shores, bays, etc., and the biota of these habitats.

<table>
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<tr>
<th>Taxonomic group (fish, plants, etc.)</th>
<th>Species (or group of related species)</th>
<th>Rare (R) or Common (C) + comments</th>
<th>Habitat (Wetland, open water, dunes, etc.)</th>
<th>Documentation: References, web links, abstracts, etc.</th>
<th>Researcher and contact information: (Phone/email/institution)</th>
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I appreciate your assistance with this scoping project. If you have questions contact me at: albertd@michigan.gov or 541-424-3000.

Thank you,

Dennis Albert, Ecologist
Michigan Natural Features Inventory
Appendix 3. List of contacts associated directly or indirectly with biological and ecological monitoring agencies

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
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<tr>
<td>Steinman, Dr. Alan D.</td>
<td>Annis Water Resources Institute</td>
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<td>Ripple, Paul</td>
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## Appendix 4: Common, rare, threatened and endangered species recommended by survey recipients

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<th>State or Provincial Status</th>
<th>Rare designation from survey</th>
<th>Habitat</th>
<th>Documentation: References, web links, etc.</th>
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<td>Charadrius melodus</td>
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<td>E E E E E E E E</td>
<td>E E E E E E</td>
<td>Endangered</td>
<td>Open sandy beach; Open Beach and Dune</td>
<td>Gerald J. Niemi, Ph.D. Director, Center for Water and the Environment, Natural Resources Research Institute; Professor, Department of Biology, University of Minnesota, Duluth; Dr Francesca Cuttbber University of Minnesota, 612 624-1756, <a href="mailto:cuttbber@umn.edu">cuttbber@umn.edu</a>; Jack Dingledine, US Fish and Wildlife Service; 517 351-6320, <a href="mailto:jack_dingledine@fws.gov">jack_dingledine@fws.gov</a></td>
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<td>E</td>
<td>Threatened</td>
<td>Wetland open water</td>
<td>Susan Doka; <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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<td>Pugnose shiner</td>
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<td>E</td>
<td>Endangered</td>
<td>Wetland open water</td>
<td>Susan Doka; <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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<tr>
<td>Plant</td>
<td>Justicia americana</td>
<td>American water-willow</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>Most of these are not well studied. However, most (perhaps all but Hibiscus moscheutos) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznicek, Sharp, Keddy, and others. Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/ absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat-visit data. “Species at Risk” related field work sometimes provides more frequent updates on population status.</td>
<td>Bill Crins; 705-755-1946; <a href="mailto:bill.crinso@ontario.ca">bill.crinso@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
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</tr>
</tbody>
</table>

**STATE THREATENED AND ENDANGERED SPECIES**

| Bird            | Coturnicops noveboracensis | Yellow rail             | SC            | T                        | SC                         | Rare sedge meadows    | Robert W. Howe Dep’t of Natural and Applied Sciences; University of Wisconsin-Green Bay/Green Bay, WI, 54117-7011; 920-465-2272 |
| Bird            | Rallus limicola       | Virginia Rail              | E             | T                        | T/C                        | Wetland/ open water   | http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm | Michael Penskar, Botanist, Michigan Natural Features Inventory |
| Bird            | Sterna forsteri       | Forster’s Tern             | E             | SC                       | SC                         | Wetland/open water   | http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm | Michael Penskar, Botanist, Michigan Natural Features Inventory |
| Bird            | Xanthocephalus xanthocephalus | Yellow-headed blackbird | E             | E                        | SC                         | Wetland/open water   | http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm | Michael Penskar, Botanist, Michigan Natural Features Inventory |

**Fish**

- Acipenser fulvescens: Lake sturgeon
- Esox niger: Blacknose shiner
- Esox lucius: Lake chubsucker
- Erimyzon oblongus: Creek chubsucker
- Erimyzon sucetta: Lake chubsucker
- Hiodon alosa: Mooneye
- Lepomis gibbosus (Cuvier): Warmouth
- Notropis bifenatus: Blade shiner
- Notropis heterolepis: Blacknose shiner
- Opsopoeus emiliae: Pugnose minnow

**Snake**

- Nerodia sipedon: Insulans Lake Erie watersnake

**Invertebrate**

- Trimerotropis huroniana: Lake Huron locust

**Plant**

- Adlumia fungosa: Climbing fumitory
- Allium schoenoprasum: Wild chives

Page 38
<table>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Species (scientific name)</th>
<th>Species (common name) or community</th>
<th>Federal Status</th>
<th>State or Provincial Status</th>
<th>Rare designation from survey</th>
<th>Habitat</th>
<th>Documentation: References, web links, etc.</th>
<th>Researcher and contact information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>Ammannia robusta</td>
<td>Grand red-stem, sessile tooth-cup</td>
<td>LC E</td>
<td>IL IN MI MN NY OH ONT PA WI</td>
<td>Rare, Ammannia robusta (Endangered) S1</td>
<td>moist bare soil at the edges of Great Lakes marshes after drawdowns; Emergent shorelines, or areas close to water level on shores or in Great Lakes coastal marshes.</td>
<td>G.W. Argus, K.M. Pryer, D.J. White, &amp; C.J. Keddy, eds., 1982-1984 Atlas of the Rare Vascular Plants of Ontario, Four Parts. National Museum of Natural Sciences, Ottawa. Most of these are not well studied. However, most (perhaps all but Helianthus mosquinus) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznick, Sharp, Keddy, and others.</td>
<td>A.A. Reznick (<a href="mailto:Reznick@umich.edu">Reznick@umich.edu</a>) and Bill Crins <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>, Ontario Ministry of Natural Resources, Ontario Parks and</td>
</tr>
<tr>
<td>Plant</td>
<td>Astragalus canadensis</td>
<td>Canadian milk-vetch</td>
<td>T T T</td>
<td>SC E E E</td>
<td>Limestone rock shoreline</td>
<td>MNFI Species summary, [web4.muse.msu.edu/mnfi/data/specialplants.cfm]</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Botrychium acuminatum</td>
<td>Acute-leaved moonwort</td>
<td>E</td>
<td>Open dune</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Botrychium campestris</td>
<td>Prairie moonwort, dune-wort</td>
<td>T E</td>
<td>Open dune</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Botrychium hesperium</td>
<td>Western moonwort</td>
<td>T</td>
<td>Open dune</td>
<td>MNFI, Lansing. 3 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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</tr>
<tr>
<td>Plant</td>
<td>Bromus pumillicanus</td>
<td>Pumpkin's brome grass</td>
<td>T</td>
<td>Open dune</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Cacalia plantaginea</td>
<td>Prairie Indian-plantain</td>
<td>SC PT</td>
<td>Rare</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>A.A. Reznick (<a href="mailto:Reznick@umich.edu">Reznick@umich.edu</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Calylophys serulatus</td>
<td>Toothed evening-primrose</td>
<td>SC</td>
<td>Considered introduced in MI</td>
<td>Dunes</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
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</tr>
<tr>
<td>Plant</td>
<td>Carex nigra</td>
<td>Black sedge</td>
<td>E</td>
<td>Wooded dune and lakes complexes</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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</tr>
<tr>
<td>Plant</td>
<td>Carex richardsonii</td>
<td>Richardson's sedge</td>
<td>T SC X E</td>
<td>Limestone rock shoreline</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<tr>
<td>Plant</td>
<td>Carex scoploidea</td>
<td>burhush sedge</td>
<td>T E</td>
<td>Limestone rock shoreline</td>
<td>MNFI Species summary, [web4.muse.msu.edu/mnfi/data/specialplants.cfm]</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Dactylorhiza scrophularia</td>
<td>Sedge</td>
<td>R SC</td>
<td>Drying lake shore</td>
<td>MNFI, Lansing. 2 pp.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Elodea compressa</td>
<td>Flattened spike-rush</td>
<td>T T E</td>
<td>Limestone rock shoreline</td>
<td>MNFI Species summary, [web4.muse.msu.edu/mnfi/data/specialplants.cfm]</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<td>Habitat</td>
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<tr>
<td>Plant</td>
<td>Eleocharis geniculata</td>
<td>Canada spike-rush</td>
<td></td>
<td></td>
<td>S1</td>
<td>Rare; disjunct to the Great lakes region from farther south</td>
<td>Sandy shores of Lakes Erie and Michigan, rarely inland</td>
<td>G. W. Argus, K. M. Przy, D. J. White, &amp; C. J. Keddy, eds., 1982-1984 Atlas of the Rare Vascular Plants of Ontario, Four Parts. National Museum of Natural Sciences, Ottawa.</td>
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<tr>
<td>Plant</td>
<td>Hedysarum alpinum</td>
<td>Alpine santolin</td>
<td></td>
<td>E</td>
<td></td>
<td>Limestone rock shoreline</td>
<td>MNFI Species summary, <a href="http://web4.msue.msu.edu/mnfi/data/specialplants.cfm">http://web4.msue.msu.edu/mnfi/data/specialplants.cfm</a></td>
<td>Michael Penkar, Botanist, Michigan Natural Features Inventory</td>
</tr>
<tr>
<td>Plant</td>
<td>Hibiscus laevis</td>
<td>Smooth rose mallow</td>
<td>SC</td>
<td></td>
<td>SC</td>
<td>North edge of range in Lake Erie Marsh</td>
<td>Emergent marsh</td>
<td>E. G. Voss, Michigan Flora, volume 2</td>
</tr>
<tr>
<td>Plant</td>
<td>Muhlenbergia richardsonii</td>
<td>Mat muhly</td>
<td>T</td>
<td></td>
<td></td>
<td>Limestone rock shoreline</td>
<td>MNFI, Lansing, MI. 2 pp.</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Panicum tuckermanii</td>
<td>Tuckerman's panic grass</td>
<td>T T T</td>
<td></td>
<td></td>
<td>Great Lakes Palistine Sand Plain Community, low water conditions</td>
<td>NA Natural Heritage Program and 2002 Gulf Pong Rapor from Cleveland Museum of Natural History to Presque Isle State Park, Dr. James K. Bissell, Curator of Botany, Cleveland Museum of Natural History:1-216-231-4600 ext. 3219; best email <a href="mailto:JBissell@cmnh.org">JBissell@cmnh.org</a></td>
<td>Dr. James K. Bissell, Curator of Botany; Cleveland Museum of Natural History:1-216-231-4600 ext. 3219; best email <a href="mailto:JBissell@cmnh.org">JBissell@cmnh.org</a></td>
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<tr>
<td>Plant</td>
<td>Pinguicula vulgaris</td>
<td>Common butterwort</td>
<td>SC T</td>
<td></td>
<td></td>
<td>Clay and marly sand along Great Lakes shoreline, especially common as water levels recede</td>
<td>Clay and marly sand along Great Lakes shoreline, especially common as water levels recede</td>
<td>Michael Penkar, Botanist, Michigan Natural Features Inventory</td>
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<tr>
<td>Plant</td>
<td>Potamogeton hilii</td>
<td>HIH's Pondweed</td>
<td>SC T T T E</td>
<td></td>
<td></td>
<td>Wetland open water</td>
<td>Wetland open water</td>
<td>Greg Grabs, 416 739 4939, Environment Canada – Canadian Wildlife Service</td>
</tr>
<tr>
<td>Plant</td>
<td>Ranunculus spathulatus</td>
<td>Small yellow water crowfoot</td>
<td>E</td>
<td></td>
<td></td>
<td>Emergent marsh</td>
<td>Emergent marsh</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 9037</td>
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<td>Taxonomic group</td>
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<tr>
<td>Plant</td>
<td>Sabatia angularis</td>
<td>Rose-pink</td>
<td></td>
<td></td>
<td>T</td>
<td>MNFI Species summary.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Sagittaria montevideensis (S. calyca)</td>
<td>Arrowhead</td>
<td>T</td>
<td>T</td>
<td>PT</td>
<td>Silty shorelines of Lake Erie immediately following drawdowns</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<td>Plant</td>
<td>Samacenia purpurea</td>
<td>Heterophylla</td>
<td></td>
<td></td>
<td>T</td>
<td>Intertidal wetlands</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Schoenoplectus smithii</td>
<td>Smith’s bulrush</td>
<td></td>
<td></td>
<td>E</td>
<td>Endangered in Ohio and Pennsylvania; present for short period within sandy protected bays and interior ponds, absent during high water stages. Schoenoplectus spp. and Sagittaria cristata are provincially rare. S2</td>
<td>Dr. James K. Bissell, Curator of Botany; Cleveland Museum of Natural History to Presque Isle State Park; Most of these are not well studied. However, most (perhaps all but Hibiscus moscheutos) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznicek, Sharp, Keddy, and others. Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat-visit data. ‘Species at Risk’ related field work sometimes provides more frequent updates on population status.</td>
<td>Bill Crins; 705-755-1946; <a href="mailto:bill.crins@ontario.ca">bill.crins@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
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<tr>
<td>Plant</td>
<td>Scutellaria parvula</td>
<td>Small souciap</td>
<td></td>
<td></td>
<td>T</td>
<td>Limestone rock shoreline</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<tr>
<td>Plant</td>
<td>Senecio congestus</td>
<td>Marsh fleabane</td>
<td>X</td>
<td>SC</td>
<td></td>
<td>MNFI Species summary.</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 108 267 5037; Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<td>Plant</td>
<td>Stellaria longipetala</td>
<td>Stitchwort</td>
<td>SC</td>
<td></td>
<td></td>
<td>MNFI Species summary.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<tr>
<td>Plant</td>
<td>Strophostyles helvula</td>
<td>Amberique-bean, annual wooly-bean, wild bean</td>
<td>SC</td>
<td>SC</td>
<td>Rare</td>
<td>Great Lake beaches and low dunes; often of young areas of sand generated by low water levels.</td>
<td>G.W. Argus, H.M. Pryer, D.J. White, &amp; C.J. Keddy, eds., 1982-1994 Atlas of the Rare Vascular Plants of Ontario, Four Parts. National Museum of Natural Sciences, Ottawa, A.A. Reznicek (<a href="mailto:Reznicek@umich.edu">Reznicek@umich.edu</a>); M.R. Penskar, Botanist, MNFI.</td>
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<tr>
<td>Plant</td>
<td>Triplasis purpurea</td>
<td>Sand grass</td>
<td>SC</td>
<td>E</td>
<td>Open dune</td>
<td>MNFI Species summary.</td>
<td>Michael Penskar, Botanist, Michigan Natural Features Inventory</td>
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<tr>
<td>Taxonomic group</td>
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<tr>
<td>Plant</td>
<td>Utricularia subulata</td>
<td>Zigzag bladderwort</td>
<td>T T X</td>
<td>T</td>
<td>Limeprine rock shoreline</td>
<td>MNFI Species summary</td>
<td>Michael Penasik, Botanist, Michigan Natural Features Inventory</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Viola nova-angliae</td>
<td>New England violet</td>
<td>T</td>
<td>Limeprine rock shoreline</td>
<td>MNFI Species summary</td>
<td>Michael Penasik, Botanist, Michigan Natural Features Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Viola pedatifida</td>
<td>Prairie birdfoot violet</td>
<td>T</td>
<td>Limeprine rock shoreline</td>
<td>MNFI Species summary</td>
<td>Michael Penasik, Botanist, Michigan Natural Features Inventory</td>
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</table>

**COMMON SPECIES (MAY BE RARE IN SOME STATES OR PROVINCES, BUT COMMON IN OTHER GREAT LAKE STATES/PROVINCES)**

- **Algae**
  - Distribution of benthic algae and interaction with plants in nearshore habitats
  - Important elements of coastal zone productivity
  - Nearshore zones of waters and wetlands
  - All aquatic: open water, wetlands, rivers, embayments, etc.

- **Bird**
  - Actitis macularia
  - Spotted Sandpiper
  - There were 11 species identified as highly vulnerable to water level fluctuations in our report (page 91): including Forster’s Tern; Black Tern; Pied-billed Grebe; Ralls; Bitterns

- **SARs**
  - Wetland
  - Wetland Bird Response to Water Level Changes in the Lake Ontario-St Lawrence River Watershed

- **Bird**
  - Marsh Birds (Black Tern, Least Bittern, Virginia Rail)
  - Rare
  - Emergent Wetland
<table>
<thead>
<tr>
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<th>Federal Status</th>
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<th>Documentation: References, web links, etc.</th>
<th>Researcher and contact information</th>
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</thead>
<tbody>
<tr>
<td>Fish</td>
<td>Ameiurus melas</td>
<td>Black bullhead</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
</tr>
<tr>
<td>Fish</td>
<td>Ameiurus natalis</td>
<td>Yellow bullhead</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Ameiurus nebulosus</td>
<td>Brown bullhead</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
</tr>
<tr>
<td>Fish</td>
<td>Esox americanus</td>
<td>Grass pickerel</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
</tr>
<tr>
<td>Fish</td>
<td>Esox lucius</td>
<td>northern pike</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Esox masquinongy</td>
<td>Muskellunge</td>
<td>C</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td>Several indirect studies, linkages to submersed aquatic habitats</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
</tr>
<tr>
<td>Fish</td>
<td>Etheostoma microperca</td>
<td>Least darter</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
</tr>
<tr>
<td>Fish</td>
<td>Fundulus diaphanus</td>
<td>Banded killifish</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Ictiobus cyprinellus</td>
<td>Bigmouth buffalo</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Lepisosteus osseus</td>
<td>Longnose Gar</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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<tr>
<td>Fish</td>
<td>Lepomis cyanellus</td>
<td>Green sunfish</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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<tr>
<td>Fish</td>
<td>LEPOMIS GIBBOSUS</td>
<td>Pumpkinseed</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Lepomis macrochirus</td>
<td>Bluegill</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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<tr>
<td>Fish</td>
<td>Micropterus salmoides</td>
<td>Largemouth bass</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Notemigonus crysoleucas</td>
<td>Golden shiner</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Perca flavescens</td>
<td>yellow perch</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water; specifically Kakagon Wetland Complex, 16,000 acres on Lake Superior; Spawning fish and benthos in littoral areas, emergent aquatic; Declining water levels (especially in the spring) can deny pike the right access to spawning habitat, its generally thought that rising water levels stimulates pike reproduction while declining water levels prevents or minimize pike reproduction. Wetland/open water; Kakagon Wetland Complex, 16,000 acres on Lake Superior; Spawning fish and benthos in littoral areas, emergent aquatic. Extensive, Lake Ontario St. Lawrence River Water Levels Study: All you have to do is open your blanking eyes.</td>
<td>Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada; Tom Doolittle, Bad River NR, Odanah, WI</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Pimephales promelas</td>
<td>Fathead minnow</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Pomoxis annularis</td>
<td>White crappie</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Pomoxis omisculus</td>
<td>Black crappie</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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</tr>
<tr>
<td>Fish</td>
<td>Stizostedion vitreum</td>
<td>walleye</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td>Kakagon Wetland Complex, 16,000 acres on Lake Superior; Spawning fish and benthos in littoral areas, emergent aquatic</td>
<td>Tom Doolittle, Bad River NR, Odanah, WI</td>
</tr>
<tr>
<td>Fish</td>
<td>Umbra limi</td>
<td>Central mudminnow</td>
<td>N/A</td>
<td>CN US IL IN</td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>; Department of Fisheries and Oceans Canada</td>
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**Mammals**

<table>
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<tr>
<th>Species (scientific name)</th>
<th>Species (common name)</th>
<th>State or Provincial Status</th>
<th>Federal Status</th>
<th>Rare designation from survey</th>
<th>Documentation: References, web links, etc.</th>
<th>Researcher and contact information</th>
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<tbody>
<tr>
<td>Ondatra zibethicus</td>
<td>Muskrat</td>
<td>C</td>
<td>CN US IL IN</td>
<td>Wetland Extensive; Final Report Lake Ontario St. Lawrence River Water Levels Study</td>
<td>John M. Farrell; (315) 470-6990; <a href="mailto:jmfarrell@esf.edu">jmfarrell@esf.edu</a>; Susan Doka, <a href="mailto:Dokas@dfo-mpo.gc.ca">Dokas@dfo-mpo.gc.ca</a>, Department of Fisheries and Oceans Canada</td>
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<td>Taxonomic group</td>
<td>Species (scientific name)</td>
<td>Species (common name) or community</td>
<td>Federal Status</td>
<td>State or Provincial Status</td>
<td>Rare designation from survey</td>
<td>Habitat</td>
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<tr>
<td>Plant</td>
<td>Agalinis paupercula</td>
<td>Small-flowered gerardia or smallflower false foxglove</td>
<td>C</td>
<td>E</td>
<td>Great Lakes Palustrine Sand Plain Community within open sands and pond shores; during low lake water levels the sites are covered with Dry Sand Plain</td>
<td>PA Natural Heritage Program and 2002 Gulf Point Report from Cleveland Museum of Natural History to Presque Isle State Park; Dr. James K. Bissell, Curator of Botany, Cleveland Museum of Natural History;1-216-231-4600 ext. 3219; best email <a href="mailto:j24bissell@cmnh.org">j24bissell@cmnh.org</a></td>
</tr>
<tr>
<td>Plant</td>
<td>Bartonia virginica</td>
<td>Screw-stem</td>
<td>C</td>
<td>SC</td>
<td>Shore fan</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
</tr>
<tr>
<td>Plant</td>
<td>Cakile edentula</td>
<td>Sea rocket</td>
<td>C</td>
<td>PT</td>
<td>SC</td>
<td>Dune, sand beach</td>
</tr>
<tr>
<td>Plant</td>
<td>Cakile edentula var. lacustris</td>
<td>Sea rocket</td>
<td>C</td>
<td></td>
<td>dunes</td>
<td>NY Flora Atlas</td>
</tr>
<tr>
<td>Plant</td>
<td>Calamintha arkansana</td>
<td>Low calamint</td>
<td>C</td>
<td>X T C</td>
<td>SC</td>
<td>Marly shoreline or limeona bedrock shoreline</td>
</tr>
<tr>
<td>Plant</td>
<td>Carex crawei</td>
<td>Sedge</td>
<td>C</td>
<td>SC</td>
<td>Sand beach</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
</tr>
<tr>
<td>Plant</td>
<td>Carex diandra</td>
<td>Lesser paniced sedge</td>
<td>C C</td>
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<td><a href="http://www.fes.uwaterloo.ca/research/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/wetlands/index.htm</a></td>
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<tr>
<td>Plant</td>
<td>Carex garberi</td>
<td>Elk sedge</td>
<td>ET C E E E</td>
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<td>Rear dune beach pool</td>
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<td>Plant</td>
<td>Carex isosciarpa</td>
<td>Wire sedge</td>
<td>C</td>
<td></td>
<td>Wetland/open water</td>
<td><a href="http://www.fes.uwaterloo.ca/research/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/wetlands/index.htm</a></td>
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<td>Plant</td>
<td>Carex lentobularis</td>
<td>Sedge</td>
<td>C</td>
<td>T</td>
<td>Sand beach, Lake Superior</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
</tr>
<tr>
<td>Plant</td>
<td>Carex livida var. radiculis</td>
<td>Sedge</td>
<td>E C E T</td>
<td></td>
<td>Bogs and peaty wetlands</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
</tr>
<tr>
<td>Plant</td>
<td>Carex michauxiana</td>
<td>Michaux's sedge</td>
<td>C</td>
<td>T</td>
<td>Bogs and peaty wetlands</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 5037</td>
</tr>
<tr>
<td>Plant</td>
<td>Carex viridula</td>
<td>Little green sedge</td>
<td>T C PT E C</td>
<td></td>
<td>Great Lakes Palustrine Sand Plain Community within open sands and pond shores; during low lake water levels the sites are covered with Dry Sand Plain</td>
<td>PA Natural Heritage Program and 2002 Gulf Point Report from Cleveland Museum of Natural History to Presque Isle State Park; Dr. James K. Bissell, Curator of Botany, Cleveland Museum of Natural History;1-216-231-4600 ext. 3219; best email <a href="mailto:j24bissell@cmnh.org">j24bissell@cmnh.org</a></td>
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<tr>
<td>Plant</td>
<td>Carex viridula</td>
<td>Green sedge</td>
<td>C</td>
<td>PA</td>
<td>Panne, Sand Plain</td>
<td>Great Lakes Palustrine Sand Plain Community within open sands and pond shores; Plants of Concern Project monitors populations at Illinois Beach, IL</td>
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<td>Plant</td>
<td>Chamaesyce polygonifolia</td>
<td>seaside spurge</td>
<td>E C</td>
<td>SC</td>
<td>dunes</td>
<td>NY Flora Atlas</td>
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<td>Plant</td>
<td>Cladium mariscoides</td>
<td>Twig rush</td>
<td>C</td>
<td></td>
<td>Emergent marsh or panne dominant</td>
<td>Plants of Concern Project – monitors populations at Illinois Beach</td>
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<td>Species (common name) or community</td>
<td>Federal Status</td>
<td>State or Provincial Status</td>
<td>Rare designation from survey</td>
<td>Habitat</td>
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<td>Cyperus diandrus</td>
<td>low cyperus, umbrella flat sedge</td>
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<td>C</td>
<td></td>
<td>C</td>
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<td>Plant</td>
<td>Echinocloa watereri</td>
<td>Coast cockspur grass</td>
<td></td>
<td>C</td>
<td>E</td>
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<td>Plant</td>
<td>Elatine minima</td>
<td>Small Waterwort</td>
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<td>C</td>
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<td>C</td>
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<td>Plant</td>
<td>Linum medium var.</td>
<td>Stiff yellow flax</td>
<td></td>
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<td>Plant</td>
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<td>Purple loosestrife</td>
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<td>C</td>
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<td>Plant</td>
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<td>Northern Water Milfoil</td>
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<td>C</td>
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<td>C</td>
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<tr>
<td>Plant</td>
<td>Najas flexilis</td>
<td>Slender Naiad</td>
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<td>C</td>
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<td>Yellow Pond Lily</td>
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<td>Plant</td>
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<td>White Water Lily</td>
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<td>C</td>
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<td>Plant</td>
<td>Phragmites australis</td>
<td>Common or tall reed</td>
<td></td>
<td>C</td>
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<td>C</td>
</tr>
</tbody>
</table>
Most of these are not well studied. However, most (perhaps all but Hibiscus moscheutos) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznicek, Sharp, Keddy, and others. Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat-visit data. “Species at Risk” related field work sometimes provides more frequent updates on population status.

<table>
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<tr>
<th>Taxonomic group</th>
<th>Species (scientific name)</th>
<th>Species (common name) or community</th>
<th>Federal Status</th>
<th>State or Provincial Status</th>
<th>Rare designation from survey</th>
<th>Habitats</th>
<th>Documentation: References, web links, etc.</th>
<th>Researcher and contact information</th>
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<td>Plant</td>
<td>Polygonum ramosissimum</td>
<td>Bushy Knotweed</td>
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<td></td>
<td></td>
<td>Emergent shorelines, or areas close to water level on shores or in Great Lakes coastal marshes.</td>
<td>Most of these are not well studied. However, most (perhaps all but Hibiscus moscheutos) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznicek, Sharp, Keddy, and others. Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat-visit data. “Species at Risk” related field work sometimes provides more frequent updates on population status.</td>
<td>Bill Crins; 705-755-1940; <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
</tr>
<tr>
<td>Plant</td>
<td>Potamogeton pusillus</td>
<td>Slender Pondweed</td>
<td></td>
<td></td>
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<td>Wetland/</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a></td>
<td>Dennis Albert, Curator of Botany, Cleveland Museum of Natural History; 1-216-231-4600 ext. 3219; best email 2(a)<a href="mailto:issel@cmnh.org">issel@cmnh.org</a></td>
</tr>
<tr>
<td>Plant</td>
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<td>Richardson’s Pondweed</td>
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<td></td>
<td></td>
<td>Wetland/</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a></td>
<td>Bill Crins, 705-755-1940; <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
</tr>
<tr>
<td>Plant</td>
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<td>Fern Pondweed</td>
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<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a></td>
<td>Bill Crins, 705-755-1940; <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
</tr>
<tr>
<td>Plant</td>
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<td>Flat-Stemmed Pondweed</td>
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<td></td>
<td>Wetland/</td>
<td><a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a></td>
<td>Bill Crins, 705-755-1940; <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
</tr>
<tr>
<td>Plant</td>
<td>Primula mississippiensis</td>
<td>Bird’s-eye primula</td>
<td>E</td>
<td>C</td>
<td>T</td>
<td>SC</td>
<td>Calcium-rich and limestone bedrock shoreline.</td>
<td>Bill Crins, 705-755-1940; <a href="mailto:bill.crim@ontario.ca">bill.crim@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
</tr>
<tr>
<td>Plant</td>
<td>Sagittaria cristata (S3)</td>
<td>Crested arrowhead</td>
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<td></td>
<td></td>
<td>Emergent shorelines, or areas close to water level on shores or in Great Lakes coastal marshes.</td>
<td>Most of these are not well studied. However, most (perhaps all but Hibiscus moscheutos) rely on water level regimes where there is a slight to moderate reduction in water levels later in the growing season (late July – September). Some of these fit the patterns documented for the Atlantic Coastal Plain flora by Reznicek, Sharp, Keddy, and others. Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat-visit data. “Species at Risk” related field work sometimes provides more frequent updates on population status.</td>
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<tr>
<td>Taxonomic group</td>
<td>Species (scientific name)</td>
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<td>State or Provincial Status</td>
<td>Rare designation from survey</td>
<td>Habitat</td>
<td>Documentation: References, web links, etc.</td>
<td>Researcher and contact information</td>
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<td>Plant</td>
<td>Selaginella selaginoides</td>
<td>Low spikemoss</td>
<td>C</td>
<td>E</td>
<td>Rare; a significant proportion of stations in the Great Lakes region are on sandy calcareous Great Lakes shorelines</td>
<td>A.A. Reznicek (<a href="mailto:reznicok@umich.edu">reznicok@umich.edu</a>)</td>
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<tr>
<td>Plant</td>
<td>Solidago simplex var. gilmahoni</td>
<td>Dune goldenrod</td>
<td>T</td>
<td>T</td>
<td>Sand dunes</td>
<td>Craig J. Anderson, Botanist, Wisconsin Heritage, 608 267 9037</td>
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<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Triglochin maritima</td>
<td>Seaside arrow-grass</td>
<td>T</td>
<td>C</td>
<td>Great Lakes Palustrine Sand Plain Community, low water conditions</td>
<td>Plants of Concern Project – monitors populations at Illinois Beach (no formal study linking population declines with lake levels that I know of); Chicago Botanic Garden – Susanne Masii, Research Botanist; Institute for Plant Conservation; 1000 Lake Cook Road; Glencoe, IL 60022; 847-835-8269 – Phone; 847-835-5484 – FAX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Triglochin palustre</td>
<td>Marsh arrow-grass</td>
<td>T</td>
<td>C</td>
<td>Great Lakes Palustrine Sand Plain Community, low water conditions</td>
<td>Dr. James K. Bissell, Curator of Botany; Cleveland Museum of Natural History;1-216-231-4600 ext. 3219; best email <a href="mailto:jkbissell@cmnh.org">jkbissell@cmnh.org</a>; Bill Crins; 705 755-1946; <a href="mailto:bill.crins@ontario.ca">bill.crins@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Typha angustifolia</td>
<td>Narrow-leaved cattail</td>
<td>C</td>
<td></td>
<td>Wetland/open water</td>
<td>Dr. James K. Bissell, Curator of Botany; Cleveland Museum of Natural History;1-216-231-4600 ext. 3219; best email <a href="mailto:jkbissell@cmnh.org">jkbissell@cmnh.org</a>; Bill Crins; 705 755-1946; <a href="mailto:bill.crins@ontario.ca">bill.crins@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
<td></td>
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<tr>
<td>Plant</td>
<td>Typha latifolia</td>
<td>Broad-leaved cattail</td>
<td>C</td>
<td></td>
<td>Wetland/open water</td>
<td>Dr. James K. Bissell, Curator of Botany; Cleveland Museum of Natural History;1-216-231-4600 ext. 3219; best email <a href="mailto:jkbissell@cmnh.org">jkbissell@cmnh.org</a>; Bill Crins; 705 755-1946; <a href="mailto:bill.crins@ontario.ca">bill.crins@ontario.ca</a>; Ontario Ministry of Natural Resources, Ontario Parks</td>
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<tr>
<td>Plant</td>
<td>Typha x glauca</td>
<td>Hybrid cattail</td>
<td>C</td>
<td></td>
<td>Wetlands, stabilized water levels</td>
<td>Joy Zedler, Doug Wince (<a href="mailto:jzedler@enewc.edu">jzedler@enewc.edu</a>, <a href="mailto:dwince@enewc.gov">dwince@enewc.gov</a>)</td>
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<td>Plant</td>
<td>Utricularia aquatica L.</td>
<td>Wild rice</td>
<td>C</td>
<td></td>
<td>Spawning fish and benthos in littoral zones, emergent aquatics</td>
<td>Organic-rich sediments in emergent marsh, especially where river mouths meet Great Lakes; Kakagon Wetland Complex, 16,000 acres on Lake Superior; <a href="http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm">http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm</a></td>
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Appendix 5. List of key agencies and NGO's for the protection, restoration and regulation of RTES

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<thead>
<tr>
<th>Agency/NGO</th>
<th>Web site with contact information</th>
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<tr>
<td><strong>States</strong></td>
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<tr>
<td>Indiana Department of Natural Resources</td>
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<tr>
<td>Division of Nature Preserves</td>
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<td>Indiana Natural Heritage Data Center</td>
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<td>Michigan Department of Natural Resources -</td>
<td><a href="http://www.michigan.gov/dnr/0,1607,7-153-10370_12141_12168---.00.html">http://www.michigan.gov/dnr/0,1607,7-153-10370_12141_12168---.00.html</a></td>
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<td>Wildlife and Habitat</td>
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<td>Minnesota Department of Natural Resources</td>
<td><a href="http://www.dnr.state.mn.us/ets/index.html">http://www.dnr.state.mn.us/ets/index.html</a></td>
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<td>The Natural Heritage and Nongame Research Program</td>
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<td>Illinois Department of Natural Resources</td>
<td><a href="http://dnr.state.il.us/espb/">http://dnr.state.il.us/espb/</a></td>
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<tr>
<td>The Illinois Wildlife Preservation Fund</td>
<td><a href="http://dnr.state.il.us/orc/wpf/">http://dnr.state.il.us/orc/wpf/</a></td>
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<tr>
<td>Ohio Department of Natural Resources -</td>
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<tr>
<td>Division of Wildlife</td>
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<td>Pennsylvania Department of Conservation and</td>
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<td>Natural Resources - Wild Reseouce Conservation Program</td>
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<td>Wisconsin Department of Natural Resources</td>
<td><a href="http://www.dnr.state.wi.us/org/land/er/wlist/statelisted.asp">http://www.dnr.state.wi.us/org/land/er/wlist/statelisted.asp</a></td>
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<tr>
<td><strong>National</strong></td>
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<tr>
<td>Division, Great Lakes Endangered Species</td>
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<tr>
<td>Species Program</td>
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<tr>
<td>USGS Biological Resources Division</td>
<td><a href="http://biology.usgs.gov/">http://biology.usgs.gov/</a></td>
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<td>Interagency Taxonomic Information System</td>
<td><a href="http://www.itis.usda.gov//">http://www.itis.usda.gov//</a></td>
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<tr>
<td>Northern Prairie Wildlife Research Center, USGS</td>
<td><a href="http://www.npwrc.usgs.gov//">http://www.npwrc.usgs.gov//</a></td>
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<td>U.S. Department of Agriculture (USDA)</td>
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<td>USDA Forest Service</td>
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<td>USDA Plants Database</td>
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<td>National Park Service, Threatened and</td>
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<tr>
<td>Endangered Species in the National Park System</td>
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<tr>
<td>National Oceanic Atmospheric Administration</td>
<td><a href="http://www.noaa.gov/">http://www.noaa.gov/</a></td>
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<tr>
<td>Recover Protected Species</td>
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<tr>
<td>NOAA Fisheries Office of Protected Resources</td>
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<td>Environmental Protection Agency, Ecosystems, Species</td>
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<td><strong>NGO's</strong></td>
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<td>American Forest Foundation -- Forests for Watersheds &amp; Wildlife</td>
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<tr>
<td>American Zoo and Aquarium Association</td>
<td><a href="http://www.aza.org/">http://www.aza.org/</a></td>
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<td>Audubon Society</td>
<td><a href="http://www.audubon.org/">http://www.audubon.org/</a></td>
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<td>Bat Conservation International</td>
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<td>Center for Plant Conservation</td>
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<tr>
<td>National Fish and Wildlife Foundation</td>
<td><a href="http://www.nfwf.org/">http://www.nfwf.org/</a></td>
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<td>The Nature Conservancy</td>
<td><a href="http://www.nature.org/">http://www.nature.org/</a></td>
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<td>NatureServe The largest ongoing effort to collect standardized data on endangered plants, animals and ecosystems.</td>
<td><a href="http://www.natureserve.org/">http://www.natureserve.org/</a></td>
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<tr>
<td>North American Native Fishes Association</td>
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<td>The Peregrine Fund</td>
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<td>Whooping Crane Eastern Partnership</td>
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<tr>
<td><strong>Canada</strong></td>
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<tr>
<td>Committee on the Status of Endangered Wildlife in Canada</td>
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<td><strong>Provincial</strong></td>
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<td>Nature Canada</td>
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</table>
Appendix 6:  
Annotated bibliographies for all nominated indicator species

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  Invertebrates .................................................................................................................145
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COMMON BIRDS

Bird Species: Blue-winged Teal (*Anas discors*)

**Researcher/Contact:** Greg Soulliere (greg_soulliere@fws.gov; U.S. Fish and Wildlife Service), Mike Monfils (monfils@michigan.gov; Michigan Natural Features Inventory), and Dave Luukkonen (luukkond@michigan.gov, Michigan Department of Natural Resources)

**Status:** Common in the Great Lakes basin

**Habitat:** Nesting habitats include slow-moving streams, wetlands, marshes, semi-permanent wetlands and ponds. Nests usually on the ground among tall grasses or sedges, usually near water; seems to prefer to nest in native grass communities in good range condition.

**Distribution:**

![Map of North America showing distribution of Blue-winged Teal](map.jpg)

**Source:**

**Additional literature and resources:**

1. Illinois Natural Resources Information Network (INRIN): Blue-winged Teal webpage
“Species-habitat interrelations: **High water levels are important, causing flooding of small temporary wetlands and of outer sedge zone of larger wetlands, creating territories not available at lower water levels.**”


“When water levels fall as they did on semi-permanent lakes in 1973, a short term increase in invertebrate availability to waterfowl may result due to the shallow water conditions and the concentration of organisms by a reduced water volume. **In the long run, however, if complete drawdown occurs, aquatic invertebrates are eliminated or greatly reduced and food conditions for breeding ducks rapidly deteriorate.** Falling water levels permit the cycle to be completed and provide the conditions that support high invertebrate populations following a subsequent rise in water levels. The effect of the duration and magnitude of a drawdown is not well understood and water level fluctuations can be detrimental to invertebrates that are utilized by waterfowl if they are of short duration (Kadlec 1962).” (pp. 429)


“Semipermanent wetlands with gently sloping basins and both emergent and submergent vegetation provide foraging and brood-rearing sites, and are very important in dry years on the drought-prone prairies. High densities of these wetland types in areas with high-quality nesting cover allow teal to establish nesting territories and avoid long overland brood movements. Restoration of temporary and seasonal wetlands is particularly needed in agricultural landscapes.”


“Management Requirements: Restoration of temporary and seasonal wetlands is particularly needed in agricultural landscapes (Gammonley and Fredrickson 1995). Maintenance of optimal nesting habitat may require active management (allowing dead vegetation to accumulate; periodic burning, mowing, or grazing to prevent it from becoming too dense); disturbance should be performed after the peak hatching period; seeded dense nesting cover used by mallards and gadwalls seems to be less attractive to blue-winged teal (Gammonley and Fredrickson 1995).”

External link: [http://www.natureserve.org/explorer](http://www.natureserve.org/explorer)
Bird Species: Mallard (*Anas platyrhynchos*)

**Status:** Common in the Great Lakes basin

**Habitat:** Primarily shallow waters such as ponds, lakes, marshes, and flooded fields; in migration and in winter mostly in fresh water and cultivated fields. Adapted to dynamic wetland conditions that provide a variety of wetland types in relatively close proximity.

**Distribution:**


**Additional literature and resources:**


“Breeding density (2.3-9.5 birds per sq km) fluctuates with pond abundance in prairie pothole region (Krapu et al. 1983). In Manitoba, nesting home range size averaged 283 hectares (Dzubin 1955). Average breeding home ranges of radio-tagged birds in Minnesota were 210 hectares (12 females) and 240 hectares (12 males); range 66 hectares to 760 hectares (a pair, Gilmer et al. 1975).”
External link: http://www.natureserve.org/explorer


“In summary, the Mallard has several attributes well suited for maximizing reproductive output under variable water conditions in the glaciated prairie region of North America. These attributes include being philopatric to sites where nesting was previously successful; selecting “safe” nesting sites where available, such as islands; pioneering new areas when nesting in old areas was unsuccessful; occupying a large home range that allows food and nesting cover to be widely spaced; tolerating crowding when habitat conditions are favorable at feeding and nesting sites; having the capacity to lay large initial clutches subsidized by lipid reserves carried to the nesting grounds; and having the ability to renest several times, if necessary, when water conditions are favorable. To compensate for occasional prolonged periods of drought or other adverse conditions, the birds are long-lived (Johnsgard 1968).”

3. Dave Luukkonen (luukkond@michigan.gov, Michigan Department of Natural Resources): Personal communication.

Mr. Luukkonen stated that waterfowl biologists felt that there was a link between water level and mallards, and he provided the following table and web links as support.

![Graph showing the relationship between spring mallard abundance and Lake Michigan/Huron water level](http://www.fort.usgs.gov/Products/Publications/10000/)

*Equation: y = 260765x + 419507
R² = 0.6667*

COMMON FISHES

Fish species: Northern Pike (Esox lucius)

Researcher/contact: John Farrell (SUNY-ESF; jmfarrell@esf.edu)

Status: Common in the Great Lakes basin.

Habitat: Freshwater lakes within shallow vegetated areas, marshes, creeks, and small to large rivers. Spawns in shallow flooded marshes associated with lakes or with inlet streams to those lakes (or flooded terrestrial vegetation at reservoir edge); spawning habitat basically a flooded area with emergent vegetation. Young remain in spawning habitat for several weeks after hatching.

Distribution:

Source:

Literature and additional sources:
“Research indicates that springtime water levels that enhance northern pike spawning success were historically important, but today appear to be decoupled from age-0 production and subsequent year-class formation (Farrell 2001). This may be due to current water level management practices preventing access of spawners to preferred habitat types and potentially stranding eggs following spawning. A secondary effect of hydrologic management is long-term habitat changes, including the increase of cattail (Beland 2003; Farrell et al. 2003, Halpern et al. 2003), and the loss of sedge meadow habitats have likely influenced northern pike reproductive success. Post-Seaway year class strength models indicate greater importance for late summer/fall water levels, where low levels promote stronger year-classes, rate of spring warming (days until 8°C is reached), and summer temperatures (#days>20°C or 68°F). These factors are consistent with a post-Seaway habitat change and access scenario for spawning northern pike, and suggest deeper, later spawning and a stronger role of nursery habitat conditions.”

External link:
http://www.losl.org/twg/pi/pi_npike-farrell-e.html


This study assessed reproduction rates and viability of northern pike spawned in artificial wetlands in Conesus Lake, New York. The authors report that “artificial spawning wetlands for northern pike should be designed and managed to promote growth of grasses and sedges and inhibit growth of woody vegetation. They should flood in early spring and dry in late summer or early fall, but water levels should not fluctuate greatly during the spawning and rearing season. Larval and juvenile northern pike should have access to deepwater habitats from hatching until the wetlands dry.”

External link:


“Spawning success has been linked to water-level changes (see review by Inskip 1982). High water levels at time of spawning with stable levels after the incubation period are associated with large year-classes of northern pike (Johnson 1957). High water levels increase nutrient concentrations and primary and secondary production in inundated areas, increasing the amount of available prey for the larval fish, make more spawning habitat accessible, expand the amount of cover, and reduce the potential for predation and cannibalism. This is obvious when new impoundments are flooded and previously unflooded terrestrial vegetation is inundated. Production of young-of-the-year
can be 4–10 times greater the first year after impoundment than in subsequent years (Bodaly and Lysack 1984). Widely fluctuating water levels can inhibit the development of near-shore vegetation; as well, very consistent annual levels are less productive, with low levels being least productive (e.g., Inskip 1982; Gravel and Dubé 1980).


“Abnormally high water levels during spring may have significant effects, such as: (1) shoreline terrestrial vegetation is flooded which initiates dying and decomposition and subsequent release of nutrients, thus increasing the water productivity; (2) fish food organisms such as insects and earthworms are quickly added to the water; (3) new cover and habitat for shoreline fish species is added; and (4) an area of water is created that is sparsely populated with fish, which should stimulate reproduction and growth as fish attempt to fill the 'void'. Certain species of fish, especially largemouth bass, do best when water level increases occur immediately before, during, and for a short time following the spawning and nursery period. Though long-term data on standing stocks of fish in relation to changing water levels are rare, especially in the Great Lakes area, some data from reservoirs appear to show direct benefits of high water levels regarding production of young-of-the-year (YOY) fish. Brief, repetitive water level changes in shoreline wetlands near commercial shipping lanes, influenced by passing ships, have been going on for decades. Recent data show that as much as a 70 cm change in wetland water level may be created by passing vessels in channels. Further, larval fishes and drifting invertebrates may be drawn out of the wetlands during drawdown periods. The effects of these frequent alterations of wetlands on fish communities are not well understood. It is hypothesized that not only high, but stable spring/early summer water levels are important to the Pentwater fish community, as studies from reservoirs have indicated that production of YOY sunfish is negatively affected when water levels fluctuate during the spawning/nursery periods. This should also be true for northern pike, a species spawning in the shallowest, most vegetated portion of the marsh.”


“Although water levels have been controlled in the St. Lawrence River and Lake Ontario system for over 40 years, the effect of habitat change on northern pike reproductive success has only recently been realized. The observed deepwater spawning over submerged macrophyte beds by northern pike is most likely a response to a lack of suitable shallow spawning habitats. In addition, vegetation composition of many coastal wetland areas of the St. Lawrence River has changed and is now predominated by large and dense monotypic areas of Typha, also unsuitable for spawning. Dominance of coastal wetlands by Typha is probably due to changes in the natural flow regime and stabilization of water levels.”
6. Environment Canada project summary webpage on *Effects of Extreme Water Levels on Still-water Spawning Grounds in the Fluvial Section of the St. Lawrence River*

“The year-class strength of Northern Pike is related to several hydrological factors, the most important of which are the water levels in April and during the breeding season, which runs for 28 days after spawning begins. The availability of breeding habitats, expressed as the number of hectares submerged during the spring freshet, is also strongly related to year-class strength. Such breeding habitats are associated with wetlands located in floodplains (i.e. marshes and wet meadows). Lastly, climatic factors, such as the rate of increase in the water temperature, are of some significance, although they play a lesser role in determining the year-class strength of St. Lawrence Northern Pike.”

External link: 
http://www.qc.ec.gc.ca/csl/pro/pro012aa_e.html

7. U. S. Environmental Protection Agency project summary webpage on *Detroit River-Western Lake Erie Basin Indicator Project*

“Changes in both lake level and thermal regime could have significant impacts on the fish community of western Lake Erie and Lake St. Clair. Lower lake levels could potentially affect the amount of habitat available for cold- and cool-water species and limit their production.

If lower lake levels resulted in development of a natural (unhardened) shoreline, this could potentially have a significant positive impact on plant-loving species such as northern pike (Esox lucius), muskellunge (Esox masquinongy), and largemouth bass (Micropterus salmoides), particularly if subsequent submerged vegetation accompanies these changes. The waters of western Lake Erie have become clearer over the last ten years (perhaps due to activities of zebra mussels) and the Lake Erie fish community may currently be responding to these recent changes in habitat (and possibly the warming thermal regime). Western basin bottom trawling has been conducted to track the fish community in Ohio waters of Lake Erie each year since 1969. Bottom trawling programs are not designed to specifically assess the Lake Erie near-shore fish community. However, by-catch information from trawls can tell us about trends in the near-shore fish community. “

External link: 
http://www.epa.gov/med/grosseile_site/indicators/waterlevels.html#contact

Fish Species: Muskellunge (*Esox masquinongy*)

**Researcher/contact:** John Farrell (SUNY-ESF; jmfarrell@esf.edu)

**Status:** Relatively common within the Great Lakes basin (i.e. not federally/ state/ provincially listed as rare). Muskellunge have become locally extirpated or imperiled in many areas of the basin or are supported through stocking efforts (i.e Green Bay, WI). Also due to their susceptibility to a new disease introduction (e.g VHSV) there is heightened concern for this species (John Farrell, SUNY-ESF, pers. comm.)

**Habitat:** Heavily vegetated lakes with lots of tree stumps and bays, as well as streams with long pools (at least 0.2 miles in length) with a minimum depth of at least three to four feet and an abundance of submerged woody structure. In the Great Lakes muskellunge spawning primarily occurs in submerged aquatic vegetation and short emergents along shorelines. Also, Great Lakes muskellunge habitat structure differs from many lakes where literature predominates (e.g Wisconsin). Moderate-depth shoals, rocks, drop-offs and current breaks in large rivers are also important adult habitat features in the basin (John Farrell, SUNY-ESF, pers. comm.)

**Distribution:**

![Map of U.S. States and Canadian Provinces showing conservation status]

**Source:**
**Literature and additional sources:**

1. U. S. Environmental Protection Agency project summary webpage on *Detroit River-Western Lake Erie Basin Indicator Project*

   “Changes in both lake level and thermal regime could have significant impacts on the fish community of western Lake Erie and Lake St. Clair. Lower lake levels could potentially affect the amount of habitat available for cold- and cool-water species and limit their production.”

   “If lower lake levels resulted in development of a natural (unhardened) shoreline, this could potentially have a significant positive impact on plant-loving species such as northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), and largemouth bass (*Micropterus salmoides*), particularly if subsequent submersed vegetation accompanies these changes. The waters of western Lake Erie have become clearer over the last ten years (perhaps due to activities of zebra mussels) and the Lake Erie fish community may currently be responding to these recent changes in habitat (and possibly the warming thermal regime). Western basin bottom trawling has been conducted to track the fish community in Ohio waters of Lake Erie each year since 1969. Bottom trawling programs are not designed to specifically assess the Lake Erie nearshore fish community. However, by-catch information from trawls can tell us about trends in the nearshore fish community.”

   External link: [http://www.epa.gov/med/grosseile_site/indicators/waterlevels.html#contact](http://www.epa.gov/med/grosseile_site/indicators/waterlevels.html#contact)


   “The strong negative relationship observed between northern pike and muskellunge abundance suggests that the success of muskellunge may be linked to the reproductive failure of northern pike at Rose Bay. Northern pike are believed to be a superior competitor over muskellunge, and the greatest potential for esocid interactions occurs during the nursery period (Inskip 1986). A study of natural reproduction in 117 midwestern U.S. lakes associated limited northern pike abundance with muskellunge reproductive success and suggested that water-level modification may affect this relationship (Dombeck et al. 1986). Findings at Rose Bay demonstrated an inverse relationship in relative abundance of age-0 esocids over a 10- year period, suggesting the mechanism of interaction may indeed occur during the nursery period. Other evidence supporting a competitive superiority of northern pike in St. Lawrence River nursery habitats was observed by greater mean daily growth rates of age-0 muskellunge in absence of northern pike and lower survival for stocked muskellunge fry in sites with high pike abundance (Farrell 1998; Farrell and Werner 1999). Water level management influences on the northern pike spawning distribution and subsequent reproductive
success appear to have important indirect effects on muskellunge reproductive success. Interactions between the esocids warrant further investigation.”


“Abnormally high water levels during spring may have significant effects, such as: (1) shoreline terrestrial vegetation is flooded which initiates dying and decomposition and subsequent release of nutrients, thus increasing the water productivity; (2) fish food organisms such as insects and earthworms are quickly added to the water; (3) new cover and habitat for shoreline fish species is added; and (4) an area of water is created that is sparsely populated with fish, which should stimulate reproduction and growth as fish attempt to fill the 'void'. Certain species of fish, especially largemouth bass, do best when water level increases occur immediately before, during, and for a short time following the spawning and nursery period. Though long-term data on standing stocks of fish in relation to changing water levels are rare, especially in the Great Lakes area, some data from reservoirs appear to show direct benefits of high water levels regarding production of young-of-the-year (YOY) fish. Brief, repetitive water level changes in shoreline wetlands near commercial shipping lanes, influenced by passing ships, have been going on for decades. Recent data show that as much as a 70 cm change in wetland water level may be created by passing vessels in channels. Further, larval fishes and drifting invertebrates may be drawn out of the wetlands during drawdown periods. The effects of these frequent alterations of wetlands on fish communities are not well understood. It is hypothesized that not only high, but stable spring/early summer water levels are important to the Pentwater fish community, as studies from reservoirs have indicated that production of YOY sunfish is negatively affected when water levels fluctuate during the spawning/nursery periods. This should also be true for northern pike, a species spawning in the shallowest, most vegetated portion of the marsh.”


“Evidence from lake populations in Wisconsin (Oehmcke 1969) and New York (Bimber and Nicholson 1981) further suggest that even more subtle environmental changes can seriously jeopardize the species' reproductive success. Hatchery experiences imply that early life stages of muskellunge are very sensitive to environmental variables (Hess and Heartwell 1978). In nature, reproductive failure may be associated with the unusual physical properties of muskellunge eggs. Eggs of other esocids are adhesive and cling to vegetation and debris, but those of muskellunge are non-adhesive (Hess and Heartwell 1978) and stay in direct contact with bottom materials throughout embryonic development. Environmental hazards posed to benthic fish embryos and larvae are numerous (Peterka and Kent 1976) and have been implicated as a major ecological factor determining reproductive processes among fishes (Balon 1975). In
lakes, muskellunge eggs are often broadcast over bottoms covered in detritus and silt (Dombeck 1979). In such areas, dissolved oxygen can become depleted at the substrate–water interface (Peterka and Kent 1976).”


Fish Species: Yellow Perch (*Perca flavescens*)

**Status:** Common in the Great Lakes Basin

**Researcher/contact:** Pat Hudson (USGS; phudson@usgs.gov) or Marc Blouin (USGS; mblouin@usgs.gov)

**Distribution:**


**Habitat:** Clear, heavily vegetated still water in shallow lakes and in pools within streams. Yellow perch are most often found within heavy growths of aquatic plants in lakes, spawning over submerged beds of aquatic plants or brush, or over sand, gravel.

**Literature and additional sources:**

1. Environment Canada project website for a study on the Effects of Water Level and Flow Fluctuations in the St. Lawrence River on Fish Health

“Low, regulated water levels contribute to parasitism in certain species of freshwater fish, according to the results of ongoing studies at Environment Canada.”
Results show a higher level of parasitism among Yellow Perch from Lake Saint-François, a regulated aquatic environment (fluctuations of approximately 15cm), than among those from Lake Saint-Pierre, where water levels vary significantly (fluctuations of approximately 2 m).

Furthermore, findings related to the distribution and seasonal fluctuations of the eyeflake (*Diplostomum spp.*) suggest that habitat characteristics significantly affect the abundance of this parasite in fish of the St. Lawrence River. Thus, the average abundance of the eyeflake in Yellow Perch was higher in communities in Lake Saint-Louis, which is close to colonies of Ring-billed Gulls, an important host of the eyeflake.”

External link:  
http://www.qc.ec.gc.ca/csl/pro/pro011dm_e.html


“Yellow perch move from deep water where they overwinter to shallow water spawning areas in the spring. Males arrive on the spawning grounds first. Spawning occurs over sand, gravel, rubble, and vegetation in depths from 0.5 - 8 meters (Craig 1987; Herman 1959). Yellow perch lose their normal diel behavior activity patterns during spawning season.”

External link:  
http://animaldiversity.ummz.umich.edu/site/accounts/information/Perca_flavescens.html
COMMON MAMMALS

Mammal Species: *Ondatra zibethicus* (Musk rat)

**Researcher/contact:** John M. Farrell ([jmfarrell@esf.edu](mailto:jmfarrell@esf.edu)), Jason A. Toner, and Jerry V. Mead.

**Habitat:** Muskrats build their lodge of aquatic vegetation within the wet meadow or emergent marsh along the Great Lakes shoreline. Populations fluctuate due to disease, localized storm events, and possibly water-level fluctuations. In the late 1980s population levels were quite high during high-water periods, followed by dramatic reductions in numbers as water levels dropped (Dennis Albert, personal observations and discussions with MI DNR Wildlife Division staff). A systematic review of trapping records and life-history studies might provide an improved understanding of the relative importance of lake-level fluctuations to population fluctuations (Dennis Albert, MNFI, personal communication).

**Distribution:**

![Map of U.S. States and Canadian Provinces]

**Source:**
Natural stressors to wetland ecosystems include changes in water levels, changes in sediment supply and transport, climate, weather, succession, and biological disturbances. Hydrology is the most important factor in wetland ecosystem maintenance and processes, affecting biogeochemical processes, nutrient cycling and availability, and biological communities (Environment Canada 2002). Addition of sediments to wetlands affects vegetation, water quality, and faunal communities. Transport of sediment along Great Lakes shorelines affects the connectivity of coastal wetlands to direct lake influences. Climate (which is also influenced by anthropogenic activities) affects the floral and faunal communities present in wetlands, as well as water levels. Weather introduces a number of possible disturbance events, such as ice scouring, wave action, and extreme storm events. Succession occurs in wetlands through the accumulation of organic matter, such as peat, and through directional changes in water levels. Several biological stressors may affect wetlands, such as the spread of invasive native plant species (e.g., reed canary grass (*Phalaris arundinacea*)), activities of beaver (*Castor canadensis*), herbivory (e.g., insects, muskrat (*Ondatra zibethica*), moose (*Alces alces*), waterfowl), and disease.


As indicated by the web site Science and Monitoring in Great Lakes Wetlands, <http://www.on.ec.gc.ca/wetlands/sciencemonitoringprojects-e.cfm>, The International Lake Ontario-St. Lawrence River Study Board states that "Water level fluctuations are a natural phenomenon in the Great Lakes due to natural climatic variability. Wetland plant communities, which provide habitat for a multitude of invertebrates, amphibians, reptiles, fish, birds, and mammals, have evolved to adapt to, and in fact depend on, water level changes." Wetland researchers from the U.S. and Canada are conducting a joint study to evaluate the effects of regulation by digitally mapping changes in wetland vegetation using aerial photographs of selected sites across a span of years from pre-regulation to the present. A computer model has been developed that uses historic and current vegetation data, topographic/bathymetric maps of the wetlands, and projected water-levels that would result from proposed new regulation plans to predict the relative area of wetland that will be in each vegetation community type under each new plan. The predictions will be assessed against one another for each of the four wetland geomorphic types and will also be used by researchers studying amphibians, fish, birds, and muskrats to evaluate potential changes in habitat availability."
Vole Species: *Microtis pennsylvanicus* (Meadow vole) and *Phenacomys intermedius* (Heather vole)

**Researcher/Contact:** Joelle L. Gehring, MNFI, Senior Conservation Scientist - Lead Zoologist (517-241-4912; gehringj@michigan.gov)

**Habitat:** Meadow voles occupy the wet meadow zone of Great Lakes coastal wetlands, where they are important prey for raptors, such as northern harrier (*Circus cyaneus*). Population levels respond to habitat quality, and it is assumed that populations increase during low lake levels. Studies of existing literature could be combined with ongoing field studies. The study of this species could be linked to long-term studies of wet meadow and emergent plants. The heather vole occupies similar habitat to that of *Microtis pennsylvanicus* (meadow vole), but with a more northerly distribution. Combination of both literature studies with field studies could provide better understanding of the importance of lake level on this species, and potentially be linked to population fluctuations of the harrier.

**Distribution:** Meadow vole (left) and eastern heather vole (right)

**Source:**

**Literature and additional sources:**
In areas where the meadow vole does not occur, as in Nevada, the mountain vole occurs regularly in wet places (Hall 1946: 542). Furthermore, in areas within the range of both _M. montanus_ and _M. pennsylvanicus_ where the latter is excluded because of altitude, the former also occurs in hydrosere communities. Such a situation may be observed in certain high mountain areas in Colorado (Findley and Negus 1953).

When the above data are analyzed, we emerge with certain tentative conclusions regarding the causes for the relative ecological distribution of these three species of _Microtus_:

1. Where _Microtus pennsylvanicus_ occurs by itself it is capable of occupying most available habitats including both wet and dry grasslands and even the dry sage-grasslands of the northern plains. This is true of both _M. ochrogaster_ and _M. montanus_ except that neither regularly inhabits woodlands.

2. Where the range of the meadow vole overlaps that of _Microtus ochrogaster_, a species seemingly best adapted to dry prairie grasslands, the meadow vole is forced to retreat to its optimum ecological niche, namely moist marshy areas near water.

3. Where the range of _M. pennsylvanicus_ overlaps that of _M. montanus_, a species well-adapted to existence in dry mountain grasslands, the meadow vole is again forced to retreat to its optimum niche, the hydrosere community.

4. The meadow vole may be thought of as typical of the eastern deciduous and northern coniferous forests and their attendant grasslands. As it approaches the southwestern periphery of its range this vole becomes more and more restricted to hydrosere communities. This is
COMMON MUSSELS

Mussel Species: Zebra mussel (*Dreissena polymorpha*) and Quagga mussel (*Dreissena bugensis*)

**Researcher/contact:** Yves de Lafontaine, Environment Canada (Tel.: 1-514-4965025; yves.delafontaine@ec.gc.ca) and G. L. Mackie, University of Guelph, Integrative Biology AXEL (519-824-4120 x53505, gmackie@uoguelph.ca).

**Habitat:** These two invasive mussels are been identified as possible candidates for studying response to lake-level fluctuation by invasive mussels. Further discussions are needed with specialists who have worked with these species to determine if there is any basis for monitoring response to lake-levels for these species.

**Distribution:**

http://nationalatlas.gov/dynamic/dyn_zm.html
http://cars.er.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html

**Literature and additional resources:**


"These results indicate that the recruitment of Zebra Mussels seems to differ according to their location in the fluvial section of the St. Lawrence. The Lake Saint-François sector (sector 1), characterized by weak currents, as well as sectors located between Donnacona and the eastern point of Île d’Orléans (sectors 10, 11 and 12), which are influenced by tidal currents, are more favourable to mussel colonization. Sectors 6 and 7, located between Montreal and Sorel, where currents are stronger and more sustained over time, have a lower rate of colonization."


"Do quagga mussels colonize deeper waters than zebra mussels? D. r. bugensis lacks the keeled shape that allows D. polymorpha to attach so tenaciously to hard substrata; though, D. r. bugensis is able to colonize hard and soft substrata (Mills et al., 1996). The ability to colonize different substratas could suggest that D. r. bugensis is not limited to deeper water habitats and that it may inhabit a wider range of water depths. In the Great Lakes, there are reports that the quagga mussel is colonizing at shallower depths, supporting the idea that the quagga can occupy a wider range of depths (Mills et al., 1996). Quagga and zebra mussels have been found to coexist at lower depths in Lake Ontario, but in Lake Erie as the water depth increased D. r. bugensis outnumbered D. polymorpha 14 to 1, suggesting that this species is a cold-water form of dreissenid (Mills et al., 1996). Dreissena rostriformis bugensis has been found at depths up to 130 m in the Great Lakes, but is only known to exist in its native range from depths 0-28 m and the depths at which both species of Dreissena are found in Lake Ontario are the deepest ever recorded for this genus (Mills et al., 1996; Claxton and Mackie, 1998). The higher abundance of D. r. bugensis in deeper waters in North America is consistent with its native range; however, over time D. r. bugensis began to displace D. polymorpha at all water depths, eventually almost completely taking over in the Dneiper River systems (Mills et al., 1996). Over the past few years, this similar shift in dreissenid dominance has occurred in the Lower Great Lakes, especially in Lake Erie and Lake Ontario, where one study found that a once dominated D. polymorpha shallow area in Lake Erie is now 61% D. r. bugensis (Adrian et al., 1994). Patterns of colonization and population dynamics in Ukraine and North America indicate that D. r. bugensis is not limited to deep-water habitats."
COMMON ALGAE

Diatom Algae

**Researcher/contact:** Dr. R. J. Stevenson, Michigan State University, rjstev@msu.edu

**Literature and additional sources:**

REFERENCE 1: Stevenson, R. J. (Personal communication)

Research on the coastal wetland at the mouth of the Muskegon River, where both long-term and short-term water-level fluctuations cause changes in the water chemistry balance (between riverine and lacustrine water chemistry) that cause changes in both the quantity and species of planktonic and benthic algae present.


"Abstract. We conducted a series of nutrient manipulation experiments over the first 5 y *Dreissena* colonization in Saginaw Bay, Lake Huron, to evaluate benthic algal nutrient limitation and community composition. We placed nutrient-diffusing substrata in the littoral zone of the Bay during 1991 (early *Dreissena* colonization) and from 1992 to 1995 (post-*Dreissena* colonization). The treatments consisted of P, N, and P+N additions, and a control. Chlorophyll *a* decreased through time from 1992 to 1995. Phosphorus limited biovolume only in 1994. Treatments with P additions had significantly more chlorophyll *a* than the controls each year after 1992. This result was consistent with an observed decrease in dissolved P throughout the study. Nitrogen additions had no significant effect throughout the 5-y period. Major shifts in species composition did not result from nutrient additions but rather seemed to be consistent with changes in light penetration and *Dreissena* herbivory. Our data demonstrated that the pre-*Dreissena* benthic algal community was dominated by tychoplanktonic diatoms (i.e., *Aulacoseira granulata* and *Tabellaria fenestrata*), which would be susceptible to filter-feeding *Dreissena*. Early post-invasion conditions were marked by an increase in light penetration, and benthic algae were dominated by filamentous green algae (mostly *Spirogyra* sp.). Late post-invasion conditions were marked by a reduction of light caused by planktonic blooms of *Microcystis* sp., which were resistant to zebra mussel herbivory. The benthic algal dominance shifted to periphytic diatoms (i.e., *Gomphonema clevei*), which were also resistant to zebra mussel filter-feeding. A new equilibrium may be developing where *Dreissena* herbivory limits tychoplanktonic diatoms, which promotes *Microcystis* bloom, which in turn limits *Dreissena* filtering rates."
As water levels have dropped, the amount of algae in shallow coastal waters has increased dramatically, as the water circulation characteristic of high-water levels is absent. The result is high temperatures and massive algal blooms that alter the pH, oxygen availability, and other chemical factors important to fauna using the inner marsh, including fish and aquatic macro-invertebrates.
COMMON PLANTS

Plant Species: Three-square bulrush (*Schoenoplectus pungens*) and hardstem bulrush (*S. acutus*)

Introductory note: *S. pungens* and *S. acutus* are being treated jointly, as they occupy the same high energy, open marsh environment and share some of the same structural and reproductive traits. There has also been little published literature on the direct impact of water level fluctuation on these species.

**Researcher/contact:** Dennis Albert, Michigan Natural Features Inventory (Michigan State University Extension; albertd@michigan.gov)

**Distribution:** Three-square bulrush (left) and hardstem bulrush (right)

Source:

**Literature and additional references:**


Based on notes from Anchor Bay on Lake St. Clair, near New Baltimore, during the summer of 1893, one of the earliest detailed references to coastal marsh encountered.

“In the shallow inlets above mentioned, the flora is mixed. There is a thin growth of *Scirpus pungens* [*Schoenoplectus pungens*] with a few plants of *Sagittaria* and of *Sparganium……..” “*Scirpus pungens* grows in water .5-1 meter in depth, while *Scirpus lacustris* (*S. acutus*) grows in water 1-2 meter deep.” Pieters also mentions that *Sagittaria rigida* and *Pontederia cordata* grow with *S. pungens* and that *Potamogetons* occur in 2-4 meters of water and that *Chara* occurs throughout. *Ceratopyllum* and
*Vallisneria* common. *Chara* common when clay or alluvium sediment, but uncommon if sand substrate. *Najas flexilis* abundant everywhere.

**External link:**
http://books.google.com/books?hl=en&id=XLYGAAAAAMAAJ&dq=the+plants+of+lake+st+clair&printsec=frontcover&source=web&ots=-OR7CMD839&sig=RcupMiIrF4ADWZ68FPC3TICyfxml


Page 8: “Dominance of Bulrush. *Schoenoplectus pungens*, a bulrush commonly known as “three-square”, is one of the most characteristic wetland plants in shallow waters of both Saginaw and Grand Traverse Bays. Along elevational transects, three-square dominated almost all unmanaged and mowed sampling points, typically occurring in over 80 percent of the points along a given transect. Of 24 vegetated transects, only three of were not dominated by three-square, and these were in areas where there was extremely high levels of human management on the beach or where wave energy was high, such as areas on Port Austin Road just north of Sand Point.”

**External link:**


Page 219: *Scirpus acutus* [*Schoenoplectus acutus*] was the most commonly encountered species in Great Lakes emergent coastal wetlands, present in 45% of the sampling points, and *Scirpus americanus* [*Schoenoplectus pungens*] was present in 23.4% of sampling points.


Abstract: “Low seedling survival was attributed to sediment accretion. Seedlings established themselves successfully only on bare patches created by erosion of the micro-bluff separating the lower and the upper marsh.”

**External link:**
http://scholar.google.com/scholar?hl=en&q=author:%22Giroux%22+intitle:%22Seed+production,+germination+rate,+and+seedling+...%22+%26um=1&ie=UTF-8&oi=scholarr
“Propagation from Cuttings: When wild plants are collected under very controlled and specific conditions, no more than a $4 \text{ dm}^2$, 13-15 cm deep [plug] should be removed from any 1 m² area; the hole will fill in within one growing season. Care should be taken not to collect plants from weedy areas as these weeds can be relocated to the transplant site. In addition, the hole left at the collection site may fill in with undesirable species.”

“Planting plugs (either from the greenhouse or wild transplants) is the surest way to establish a new stand of this species. Plug spacing of 30-45 cm will fill in within one growing season. Soil should be kept saturated. Basket grass can tolerate 5-8 cm of standing water during the first growing season. Fluctuate the water levels during the establishment period to increase the rate of spread. Water levels can be managed to both enhance expansion of the clone and to control weeds.”

“Basket grass can tolerate up to 30-45 cm of standing water if the water level is fluctuated during the growing season. This species can tolerate periods of drought and total inundation. This subspecies grows in the high salt marsh, and can tolerate both brackish water and diurnal tidal inundation. In non-tidal situations, water levels can be managed to either enhance or reduce spread as well as to control terrestrial weeds.”

“Propagation by Seed: Germination of this species is difficult. Seeds ripen from late July through August. Seeds are held in the seed head for a couple of months, if not disturbed by high winds, high tides, or inundation. Seeds may be collected by hand stripping them from the plant or by clipping the seed heads with a pair of hand shears. A power seed harvester may also be used.”

External link:


“The high energy wetland supports a very depauperate emergent flora, with only one species, hardstem bulrush (*Schoenoplectus pungens*). The second lowest FQI score is for Thomas Road, another high-energy wetland with only nine species present, eight of which are native.”

External link:


For example, *Sarcocornia pacifica* had the most widespread elevational distribution, with a number of species occurring at slightly lower elevations, including *Spartina foliosa,*
Typha angustifolia, Bolboschoenus maritimus, and Schoenoplectus acutus. There was substantial overlap and spatial variability in distributions relative to both elevation and inundation patterns for some dominant species. We found little evidence for critical thresholds for plant distributions across all wetlands, although, there is evidence that plants respond to minor changes in elevation and inundation.

**External link:** http://eco.confex.com/eco/2007/techprogram/P7005.HTM


Abstract: “Where many different plant species occupy an environmental gradient, the responses of their offspring to that gradient could show one of two patterns. All species could have similar requirements for maximum recruitment, in which case all would show maximum germination and emergence in the same regions of the gradient ("shared responses"). Alternatively, each species could have different requirements for recruitment and therefore would show maximum recruitment in different regions of the gradient ("distinct responses"). The objective of this study was to test between these two alternatives in plants occurring along a water level gradient. Seeds of 11 wetland species were allowed to germinate in sand along a gradient of water depth, ranging from 10 cm above to 5 cm below the substrate surface. Scirpus americanus [Schoenoplectus pungens], S. validus, Sagittaria latifolia, Typha angustifolia, and Lythrum salicaria showed no significant response to this gradient, while Spartina pectinata, Polygonum punctatum, Bidens cernua, Acorus calamus, Alisma plantago-aquatica, and Eupatorium perforliatum did.”

**External link:**
Plant Species: Purple loosestrife (Lythrum salicaria)

Researcher/contact: Dennis Albert, Michigan Natural Features Inventory (Michigan State University Extension; albertd@michigan.gov)

Distribution:


Literature and additional sources:


Abstract: The effects of a 1-m drop in average water levels in 1999 on species composition and biomass were documented for a St. Lawrence River wetland and compared with a similar episode in 1931. These observations highlight the manifold effects of past and future water level fluctuations on St. Lawrence River wetlands and faunal habitats, resulting from natural hydrologic variability, climate change, and (or) human intervention. In 1931 and 1999, waters were 2–3 °C warmer than the previous 10-year average. Low water levels markedly altered wetland vegetation: various Gramineae (including Phalaris arundinacea and Phragmites australis) and facultative annual species invaded previously marshy areas. Submerged species previously found in shallow waters.
were replaced on dry ground by annual terrestrial plants; *Alisma gramineum* colonized emergent waterlogged mudflats. The low water levels of 1999 induced a spatially discontinuous plant biomass that was richer in terrestrial material than in previous years (1993–1994). In comparison with the 1930s, recent surveys indicate a decline of assemblages dominated by *Equisetum* spp. and *Najas flexilis* and a rise of those dominated by *Lythrum salicaria*, *Potamogeton* spp., and filamentous algae. These shifts reveal the additional effects of nutrient enrichment, alien species, and shoreline alteration accompanying a change from a mostly agricultural to a mostly urbanized and industrialized landscape.

**Page 604**: “Although the 1996 image was taken when the water level was 33 cm lower than when the 1931 image was taken and when the emergent vegetation was well developed (early fall), the proliferation of dense *Typha angustifolia* and of *Phragmites australis* (since 1980, C. Hudon, unpublished data) across the upstream half of the channel is an additional indication of its progressive clogging.”

**Pages 607-608**: “Wetland plant composition and biomass. Records of species composition during the low-level years of 1931 and 1999 were compared with each other and with those of previous years. The wetland was divided into five elevation zones (strata) corresponding to different immersion regimes. Under average water level conditions, these elevations coincided with the sequence of wet meadow, marsh, and increasingly deep open water; under low water levels (1931 and 1999), the same elevation sequence coincided with dry meadow, wet meadow, a dry/waterlogged barren mud zone, and shallow open water. In the dry 1999 summer, the two uppermost strata were flooded only in the spring. The low water levels experienced in 1931 and 1999 brought about a marked, similar change in the species composition of all strata, except the upper shrubby zone. Meadows and marshy areas were invaded by *Phalaris arundinacea*, various grasses, and other facultative annual wetland plant species. Very shallow open waters previously colonized by submerged species became a dry, barren zone colonized by annual terrestrial plants (*Impatiens capensis* and *Polygonum* spp.), whereas waterlogged mudflats allowed for the germination and extensive flowering of *Alisma gramineum*. If the species mentioned by Marie-Victorin (1943) are taken as commonly occurring, the comparison of major species composition between 1931 and 1999 reveals the lesser abundance of *Equisetum* spp., *Strophostyles helveola*, *Najas flexilis*, and *Callitriche hermaphroditica* and the increased occurrence of *Phragmites australis*, *Potamogeton crispus*, *Potamogeton richardsonii*, and *Stuckenia pectinata*, as well as filamentous algae, in the 1990s. The similarities between our results and the general pattern observed in 1931 suggest that a closer examination of the overall zonation of wetland plant biomass and of its short-term seasonal changes would yield general information and allow the testing of hypotheses on the response mechanisms of this community under changing water levels.

**Page 610**: “**Deep marsh turned into wet meadow (6.06–5.56 m)**”……“In 1999, the 1-m drop in water level pushed the water’s edge about 70 m horizontally. Emergent and aquatic vegetation thus grew under mostly dry, sometimes waterlogged conditions, with brief periods of shallow water (2 cm) incursions during the summer of 1999 (Fig. 4b).” ………. “Submerged plants disappeared and the abundance of previously dominant obligate plants decreased, whereas several grass (*Phalaris arundinacea*, *Phragmites australis*, and *Leerzia oryzoides*) and annual (*Impatiens capensis*, *Polygonum* spp.,
Ranunculus trychophyllum, Sonchus oleraceus, and Hypericum spp.) wetland species proliferated (Table 5).” …..

“Taxa occurring the most frequently under dry conditions were Polygonum spp. (62% of 47 samples), Typha angustifolia (55%), and Bolboschoenus fluviatilis (30%); Lythrum salicaria (either small germlings or adult plants) was observed in 9% of samples. Lythrum salicaria seedlings were especially numerous just above the water line (5.56–6.06 m) where open, dry ground was available for colonization in between shoots of obligatory emergent wetland species.”


“We have excavated purple loosestrife root crowns in many parts of its range in the United States and Canada, but have found no evidence of spread by rhizomes.”

“….mean number of seeds produced per plant was estimated at 2,700,000. Capsules from early flowers produced ripe seed while the plants were still green.” ….” Ridley (1930) noted that L. salicaria seeds sink upon being thrown into water, but rise to the surface following germination. He considered seed dispersal to be largely by means of floating seedlings. We agree with his conclusion on mode of dispersal, but find that not all seeds sink upon falling on water; some dispersal could be by floating, ungerminated seeds. Although Ridley did not include L. salicaria among plants whose seeds were dispersed by wind, Shamsi and Whitehead (1974a) declared that L. salicaria has wind-dispersed seeds. Nilsson and Nilsson (1978) used Sernander's (1901) work to classify L. salicaria as a species that was dispersed by wind over snow and ice. Surely the seeds are light enough (0.5-0.6 mg) to be carried by a strong wind, but we have observed that the densities of seedlings fall off sharply within the first 10 m from the parent plant, suggesting a very limited role for wind dispersal.” ….

“Seedling Establishment. Floating seeds or propagules must fall or lodge against moist soil to begin a successful establishment. Bodmer (1928) reported that a 3-day-old seedling was about 3 mm long from the tip of the cotyledon to the extremity of the root. By 10 days, the seedling was about 6 mm long, with most of the growth in the primary root. By 20 days, the seedling was about 40 mm; the first true leaves appeared, and lateral and secondary roots had developed. By 25 days, stem elongation began with a 1-2-mm growth of the epicotyl; true leaves and vascular tissue were well developed.” …

“Optimum substrates for the growth of L. salicaria are moist soils of neutral to slightly acid pH. Nevertheless, we have found the plant growing in such a wide range of soil textures and types as to suggest that moisture is the most important factor for growth and reproduction. Parent materials invaded by purple loosestrife in North America varied from rock crevasses to gravel, sand, clay, and organic soils.” ……. “L. salicaria’s affinity for wetland habitats in Europe is closely reflected in its invasion of North American sites. Freshwater marshes, open stream margins, and
alluvial floodplains are its optimum habitats in the northeastern and north-central United States and adjacent Provinces in Canada.” … “In North America, L. salicaria has shown a sharply different pattern of community dynamics in relation to many of its mixed-species associates in Europe. In the late 1950's, a large percentage of 23 small wetland impoundments that had been created in the lower Hudson area of New York had become almost pure stands of purple loosestrife (McKeon 1959). As of 1980, these monospecies stands were still more or less unchanged (G. Cole, personal communication).” … “Several characteristics of the ecology and distribution of L. salicaria in Europe favored an early immigration to North America. It was present in most of the marine estuaries of northern Europe that were the export centers to North America.” …


REFERENCE 3:  Personal communication with Robert Humphries, MI DNR Wildlife biologists.

Robert Humphries observed the establishment of purple loosestrife during low-water years. Humphries observed the expansion in the 1970s on Pt. Mouillee. He noticed that drawdowns of the diked wetlands often resulted in dense monocultures of this species establishing.
Plant Species: Wild-rice (*Zizania aquatica* var. *angustifolia* or *Zizania palustris* var. *palustris*)

**Researcher/contact:** James E. Meeker, Northland College, Ashland, WI 54806  
(JMeeker@northland.edu)

**Distribution:** Both *Zizania aquatica* and *Zizania palustris*

Source:  

**Literature and additional resources:**


From the abstract, page 219: …“Higher sedimentation rates took place closest to the vegetation- open water interface (deep zones). However, in shallow zones, a significant proportion of the annual sedimentation took place during the submersed and floating leaf stages [of wild-rice], showing the importance of these time periods for providing an annual input of sediment to large areas of riverine habitat. Of nutrients tested, both TKN and NO3-N had lower concentrations in the period following wild-rice stem elongation. These data suggest that the early growth habit of wild-rice (submersed and floating stages) promotes pulses of nutrient-rich sediment, which are necessary for the later nutrient-demanding stages of stem elongation and grain formation.”

Page 230: “For example, how important is the seiche activity that operates in this coastal wetland in influencing these results? The upstream flow characteristics of a seiche logically increase the retention time of inputs to a lotic system and presumably increase
both sedimentation rates and nutrient availability.” …… “As an annual plant, the greatest sedimentation-related threat to wild-rice’s survival would likely be excess seed burial that could reduce seedling emergence.” …… “In experiments conducted concurrently with the research presented here, I have shown that while 4 cm of sediment and no sediment (a planted control) did not reduce wild-rice emergence and final stem density, placing an 8-cm-thick layer of sediment (of similar density and texture to that which accrued in the study) reduced wild-rice seedling emergence and final density to very low levels.”

**External link:**

**REFERENCE 2:** Dennis Albert, personal communication.

Transect sampling of a marsh on Dickinson Island in the St. Clair River delta showed major differences in quantities of wild rice in different years (the species occurred in protected marsh with little wave action). In 1988, immediately after extreme high water, there were low levels of rice in 45 cm of water. In 1994, with water levels of 45-75 cm in the same area, rice was quite abundant. In 1999, with water levels at 17-20 cm, intermediate levels of rice were present. In 2005, with water levels of 5-15 cm, Phragmites australis had established and there was no wild-rice observed. These data show no easily interpreted relationship between water level and wild-rice, but do demonstrate that extreme low-water can result in conversion of wild-rice beds to exotic plants.

**External link:** None
Plant Species: Narrow-leaved cattail (*Typha angustifolia*) and Hybrid cattail (*Typha xglauca*)

Note: These two species are treated jointly as they share the same habitat and are often found growing together. Common cattail (*Typha latifolia*) may also grow nearby, but it tends to be a much less common or aggressive species along Great Lakes coastal shorelines.

**Researcher/contact:** Dennis Albert, Michigan Natural Features Inventory (Michigan State University Extension; albertd@michigan.gov)

**Distribution:** Narrow-leaved cattail


**Literature and additional sources:**


Page 232, from Abstract: “In wetlands designed to improve water quality, nutrient-rich water and highly variable water levels often favor aggressive, flood-tolerant plants, such as Typha × glauca (hybrid cattail). At Des Plaines River Wetlands Demonstration Site (Lake Co., IL), we assessed T. × glauca dominance and plant community composition under varying hydroperiods in a complex of eight constructed wetlands. Plots flooded for more than 5 weeks during the growing season tended to be dominated by T. × glauca, while plots flooded fewer days did not. Plots with high cover of T. × glauca had low species richness (negative correlation, $R^2 = 0.72$, $p < 0.001$). However, overall species richness of the wetland complex was high (94 species), indicating that wetlands in urbanizing landscapes can support many plant species where T. × glauca is not dominant. T. × glauca-dominated areas resisted the establishment of a native plant community.”

External link: http://linkinghub.elsevier.com/retrieve/pii/S0925857406000838


“Examining the plant taxa lists did not show a pattern that either submergent or emergent plant communities were different between open lacustrine or protected embayment wetlands. Although plant diversity was high in most wetlands, invasive plants were abundant [along Lake Erie] in most wetlands. For example, emergent plant communities were generally dominated by either Typha angustifolia and T. glauca or Phragmites australis that are not native in Lake Erie coastal wetlands.”

External link-2: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VFB-44VDTHB-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ff98431baefd6dccb0bc6728a450a47d


Page 16: Figures document decrease in meadow-marsh vegetation and increase in cattail dominance in Eel Bay of Lake Ontario following regulation of lake level [which increased the water level and reduced the amount of lake level fluctuation].

Page 19: “Before regulation, the range of fluctuations [in Lake Ontario] during the 20th century was about 6.5 ft (fig. 6). ………… Regulation reduced the range to about 4.4 ft in the years after 1973. The lack of alternating flooded and dewatered conditions,
especially the lack of low lake levels, resulted in establishment of extensive stands of cattail at the expense of other plant community types, mostly the sedge/grass community at upper elevations in the wetlands (fig. 14) (Wilcox and Meeker, 1995; Wilcox and others, 2005).”

**External link:** http://www.usgs.gov/pubprod

**REFERENCE 5:** Albert, Dennis. Comments based on state-wide marsh research in 1987-1989 and in the late 1990s and early 2000s.

Hybrid and narrow-leaved cattails were encountered along the Munuscong River delta and in nearby coastal marshes along the St. Marys River, which connects Lakes Superior to Lake Erie during the high-water conditions of 1987. At both sites the extensive cattail beds were being heavily eroded by wave action, resulting in significant amounts of cattail stems and rhizomes being piled up in low ridges along the shoreline. As water levels dropped, the cattail beds in both beds recovered and began to extend lakeward on the moist substrate or into the shallow marsh.

Sampling of narrow-leaved cattail beds at Pinconning County Park on Saginaw Bay, Lake Huron demonstrated that this species formed thick, almost monocultural stands in protected sites during mid to high water levels in the late 1990s. However, as water levels dropped and left the cattails growing on non-flooded substrate, density of the plants declined significantly, allowing other herbs and shrubs to invade the cattail beds.

Sampling within diked wetlands on Lake St. Clair and Saginaw Bay, Lake Huron indicated that hybrid cattail and narrow-leaved cattail formed dense monocultures in shallow (<18 inches (45 cm)) flooded wetlands that were protected from direct wave action.


Abstract, page 115: “The vegetation of the 80.7 hectare Cowles Bog Wetland Complex has been altered from its historic mixed sedge-grass domination (Carex stricta, Calamagrostis canadensis) in lower areas and woody growth in slightly elevated areas, as based on archival aerial photographs from 1983-1982 and recent field data. Cattails (Typha spp.) were present in 1983 and made minor gains in cover through 1970. However, the major invasion of cattails appears to be associated with stabilized, increased water levels caused by seepage from diked ponds constructed upgradient from the wetland in the early 1970s. The water level increases are assumed to have been of a magnitude which adversely affected the sedge-grass community but did not preclude cattail growth. The cattail vegetation type increased in cover from 2.0 ha in 1938 to 9.7 ha in 1970 to 37.5 ha in 1982. The sedge-grass vegetation type correspondingly decreased from 56.4 ha to 43.0 ha to 5.7 ha. Cattail invasion appears to have occurred through establishment of disjunct colonies by seed reproduction, followed by vegetative expansion and merging of the colonies.”
External link:
Plant Species: Reed (*Phragmites australis*)

**Researcher/contact:** Dennis Albert, Michigan Natural Features Inventory (Michigan State University Extension; albertd@michigan.gov)

**Distribution:**

Source:

**Literature and additional sources:**


**Abstract:** The effects of a 1-m drop in average water levels in 1999 on species composition and biomass were documented for a St. Lawrence River wetland and compared with a similar episode in 1931. These observations highlight the manifold effects of past and future water level fluctuations on St. Lawrence River wetlands and faunal habitats, resulting from natural hydrologic variability, climate change, and (or) human intervention. In 1931 and 1999, waters were 2–3 °C warmer than the previous 10-year average. Low water levels markedly altered wetland vegetation: various Graminea (including *Phalaris arundinacea* and *Phragmites australis*) and facultative
annual species invaded previously marshy areas. Submerged species previously found in shallow waters were replaced on dry ground by annual terrestrial plants; *Alisma gramineum* colonized emergent waterlogged mudflats. The low water levels of 1999 induced a spatially discontinuous plant biomass that was richer in terrestrial material than in previous years (1993–1994). In comparison with the 1930s, recent surveys indicate a decline of assemblages dominated by *Equisetum* spp. and *Najas flexilis* and a rise of those dominated by *Lythrum salicaria*, *Potamogeton* spp., and filamentous algae. These shifts reveal the additional effects of nutrient enrichment, alien species, and shoreline alteration accompanying a change from a mostly agricultural to a mostly urbanized and industrialized landscape.

Page 604: “Although the 1996 image was taken when the water level was 33 cm lower than when the 1931 image was taken and when the emergent vegetation was well developed (early fall), the proliferation of dense *Typha angustifolia* and of *Phragmites australis* (since 1980, C. Hudon, unpublished data) across the upstream half of the channel is an additional indication of its progressive clogging.”

Pages 607-608: “Wetland plant composition and biomass Records of species composition during the low-level years of 1931 and 1999 were compared with each other and with those of previous years. The wetland was divided into five elevation zones (strata) corresponding to different immersion regimes. Under average water level conditions, these elevations coincided with the sequence of wet meadow, marsh, and increasingly deep open water; under low water levels (1931 and 1999), the same elevation sequence coincided with dry meadow, wet meadow, a dry/waterlogged barren mud zone, and shallow open water. In the dry 1999 summer, the two uppermost strata were flooded only in the spring. The low water levels experienced in 1931 and 1999 brought about a marked, similar change in the species composition of all strata, except the upper shrubby zone. Meadows and marshy areas were invaded by *Phalaris arundinacea*, various grasses, and other facultative annual wetland plant species. Very shallow open waters previously colonized by submerged species became a dry, barren zone colonized by annual terrestrial plants (*Impatiens capensis* and *Polygonum* spp.), whereas waterlogged mudflats allowed for the germination and extensive flowering of *Alisma gramineum*. If the species mentioned by Marie-Victorin (1943) are taken as commonly occurring, the comparison of major species composition between 1931 and 1999 reveals the lesser abundance of *Equisetum* spp., *Strophostyles helveola*, *Najas flexilis*, and *Callitriche hermaphroditica* and the increased occurrence of *Phragmites australis*, *Potamogeton crispus*, *Potamogeton richardsonii*, and *Stuckenia pectinata*, as well as filamentous algae, in the 1990s. The similarities between our results and the general pattern observed in 1931 suggest that a closer examination of the overall zonation of wetland plant biomass and of its short-term seasonal changes would yield general information and allow the testing of hypotheses on the response mechanisms of this community under changing water levels.

Page 610: “Deep marsh turned into wet meadow (6.06–5.56 m)”…….“In 1999, the 1-m drop in water level pushed the water’s edge about 70 m horizontally. Emergent and aquatic vegetation thus grew under mostly dry, sometimes waterlogged conditions, with brief periods of shallow water (2 cm) incursions during the summer of 1999 (Fig. 4b). As was observed in the previous elevation stratum, belowground and litter biomass increased
significantly in 1999 (Table 3). Although total aboveground biomass did not differ significantly (Table 3), significant changes in the proportions of submerged and emergent wetland plants were observed (Table 4). **Submerged plants disappeared and the abundance of previously dominant obligatory plants decreased, whereas several grass (Phalaris arundinacea, Phragmites australis, and Leerzia oryzoides) and annual (Impatiens capensis, Polygonum spp., Ranunculus trichophyllum, Sonchus oleraceus, and Hypericum spp.) wetland species proliferated (Table 5).”


Abstract, pg 127: “……. When grown in deep (70 or 75 cm), compared to shallow (20 or 5 cm) water, plants allocated proportionally less to below-ground weight, made proportionally fewer but taller stems, and had rhizomes that were situated more superficially in the substrate. ………. In an additional field study, the rhizomes were situated superficially in the sediment in deep, compared to shallow water.”

External link: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T4F-42RMMDG-4&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&acct=C000050221&version=1&_urlVersion=0&_userid=10&md5=85669907c5d59952ec0079255493e5aa


Abstract, Page147: “Colonisation by reed seedlings, Pragmites australis (Cav.) Trin. Ex Steud. is rare and usually occurs after drawdown and when shallow water prevails. P. australis seeds have high rate of germination but successful colonization is dependant upon subsequent water depths.” … Young P. australis plants require shallow water levels without long lasting submergence to grow and survive. Tolerance to submergence increases with age.”

External link: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T4F-42RMMDG-5&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&acct=C000050221&version=1&_urlVersion=0&_userid=10&md5=5de57ffe14221f1d7708e109e28dd607

Abstract, page 639: … “The preservation of stable water levels favored colonization by vegetative growth. The experimental spring drawdown led to a 25% increase in reed area with up to 40 m progressions. Such rare events with low water levels in spring favor sexual colonization. Sexual reproduction plays an important role in the pioneer stage of reed beds, allowing both fast progression and establishment of genetically diverse stands.”


REFERENCE 5: Personal communication with Robert Humphries and Ernie Kafkas, MI DNR Wildlife biologists.

Both Robert Humphries and Ernie Kafkas observed the establishment of Phragmites during low-water years. Humphries observed the expansion in the 1970s on Pt. Mouillee, while Ernie Kafkas observed the changes following the drop of water levels along Lake St. Clair in 1999, which has persisted through 2007. My vegetation sampling at Dickinson Island in the St. Clair River delta documents the change between samples with low levels of Phragmites in 1988, 1994, 1999, followed by over 60% dominance in 2005 sampling of the same kilometer-long transect.

External link: None.
Plant Species: Species of Interdunal wetland (panne or moist sandplain)

Note: Because there is a large number of species that characterize this plant community, the entire plant community is being recommended for monitoring. No references for specific species are being provided, although Schoenoplectus smithii and Solidago houghtonii are two rare species of this community being recommended as indicators.

Researcher/contact: James K. Bissell, The Cleveland Museum of Natural History (j24bissell@adelphia.net) and Debra Nelson, Natural Heritage Biologist, District 8 (Debra.Nelson@Illinois.gov).

Literature and additional references:


Page 6: “Palustrine types: Calcareous Moist Sandplain: A total of 25 Plants of Special Concern in Pennsylvania have been found within the Palustrine Sand Plain Community on Gull Point since 1985, twenty-four POSCIP species and one hybrid: Agalinis paupercula (Endangered), Aster dumosus (Tentatively Undetermined), Carex bebbii (Endangered), Carex garberi (Endangered), Carex viridula (Endangered), Cyperus diandrus (Endangered), Eleocharis caribaea (Endangered), Eleocharis elliptica (Endangered), Eleocharis pauciflora (Endangered), Eleocharis quadrangulata (Endangered), Equisetum x.ferrissii (Endangered), Equisetum variegatum (Endangered), Lipocarpha micrantha (Endangered), Hypericum majus (Threatened), Juncus alpinus (Threatened), Juncus arcticus (Rare), Juncus biflorus (Tentatively Undetermined), Juncus brachycephalus (Rare), Juncus torreyi (Endangered), Lathyrus palustris (Tentatively Undetermined), Lobelia kalmii (Endangered), Parnassia glauca (Endangered), Potentilla anserina (Threatened), Potentilla paradoxa (Endangered), Schoenoplectus smithii (Endangered).

Page 8: “The greatest changes in natural communities that have occurred on Gull Point from 1987 to 2003 are due to the higher levels of Lake Erie in 1987 and 1997 compared to the lower levels of 1992 and 2002. Lake Erie levels in 1997 were more than a foot higher in 1997 than in 1987.”

Page 11: “Large Palustrine Sand Plain on Gull Point Threatened. One of the largest and most diverse Palustrine Sand Plain Communities mapped on Presque Isle in 1987 is a large area west of Pond 16. During the relatively high Lake Erie levels of 1987 and the high level of 1997, the flats west of Pond 16 were covered with Palustrine Sand Plain community containing more than a dozen Plants of Special Concern in Pennsylvania. This historical large Palustrine Sand Plain was located west of Sites “J” and “k” on the 2002 Palustrine Sand Plain Sites Map. More than half of the area where the 1987 Palustrine Sand Plain community was mapped had eroded away in 1997. Since 1997, several Beach Grass Dunes have developed and buried much of the sand plain. The very important Palustrine Sand Plain labeled Site “I” on the 1997 Palustrine Sand Plain Map remained intact in 2002. The only Presque Isle population of variegated horsetail is still
present at this site. The site is also an important seed bank for several other rare plants including Kalrn’s lobelia (Lobelia kalmii), Garber’s sedge (Carex garberi), small-flowered false foxglove (Agalinis paupercula) and slender spike-rush (Eleocharis elliptica). No populations of slender spike-rush, Kalrn’s lobelia, small-flowered false foxglove or Garber’s sedge were found on Gull Point in 2002.”

External link: none.

REFERENCE 2: Debra Nelson (email response)

“Triglochin maritima and other panne plant species such as Carex viridula, Juncus alpinus, Cladium mariscoides This community type and plant association in extremely rare in Illinois. Plants of Concern Project – monitors populations at Illinois Beach (no formal study linking population declines with lake levels that I know of)”
“…..we have seen huge populations (500+) of Triglochin maritima disappear in pannes near the lake where the water table is determined by lake levels, while those populations farther west where we think the water table is more related to water from the upper watersheds are still doing fine. We have not formally connected the declines to lower lake levels, but we suspect so. These populations have been monitored for the last 3 years by the Plants of Concern Program administered by Susanne Masi of the Chicago Botanic Garden. Given that water levels have been low in Lake Michigan for longer than 3 years, it’s difficult to draw conclusions based on such a short period of time with total confidence, but I suspect other species indicative of lakeshore panne communities may also be affected (see attached survey).”

REFERENCE 3: Michigan Natural Features Inventory (community abstract – Author: Dennis Albert)

“Interdunal wetland is a rush, sedge, and shrub dominated wetland situated in depressions within open dunes or between beach ridges along the Great Lakes and possibly other large freshwater lakes. Also called pannes in Ontario.

Range: Interdunal wetland is associated with portions of the shoreline of all of the Great Lakes, from eastern Lake Ontario to western Lake Superior and southwestern Lake Michigan. Interdunal wetlands can occur wherever there are large coastal parabolic or perched dunes, or where narrow swales, pannes, or troughs occur behind a water- or wind-formed sand beach ridge.”

“Landscape context: Interdunal wetlands occur in the open swales or pannes between beach ridges, in wind-formed depressions in dune fields, and in abandoned river channels that once flowed parallel to the lakeshore behind a foredune. Interdunal wetlands occur near the shoreline of all of the Laurentian Great Lakes.”

“Natural processes: Water-level fluctuations of the adjacent Great Lakes are important for maintaining open interdunal wetlands. Interdunal wetlands are formed when water levels of the Great Lakes drop, creating a swale or linear depression between an existing, more inland foredune (beach ridge) and the newly formed foredune along the water’s edge. Rising Great Lakes water levels or storm waves can result in interdunal wetlands being partially or completely buried by sand (Albert 2004, Hiebert et al. 1986). Water level fluctuations are similarly important for destabilizing parabolic or perched dunes, producing interdunal wetlands at the bases of blowouts. Studies by several researchers

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have documented the long-term water level changes and dynamics of both the parallel coastal beach ridges and the parabolic and perched dune fields with their associated interdunal wetlands (Dorr and Eschman 1984, Lichtner 1998, Loope and Arbogast 2000, Thompson 1992).” 

**“Vegetation description:** The data used for this abstract is almost exclusively from narrow interdunal wetlands along the Great Lakes shoreline, with little data from hollows or depressions in dune fields and no data from large inland lakes. Dominant plants include Baltic rush (*Juncus balticus*) and twig rush (*Cladium marisoides*), both species able to survive sand burial and water level fluctuations. Some other common plants are bog lobelia (*Lobelia kalmii*), horned bladderwort (*Utricularia cornuta*), common bog arrow-grass (*Triglochin maritimum*), Kalm’s St. John’s-wort (*Hypericum kalmianum*), false asphodel (*Tofieldia glutinosa*), golden-seeded spike-rush (*Eleocharis elliptica*), grass-leaved goldenrod (*Euthamia graminifolia*), shrubby cinquefoil (*Potentilla fruticosa*), three square (*Schoenoplectus pungens*), northern white-cedar (*Thuja occidentalis*), blue joint grass (*Calamagrostis canadensis*), and beak-rush (*Rhynchospora capillacea*).

**Characteristic plants:** Other typical species include several sedges (*Carex aquatilis, C. garberi, C. viridula, C. lasiocarpa*), small-fringed gentian (*Gentianopsis procera*), blue-leaf willow (*Salix myricoides*), geocaulon (*Geocaulon lividum*), purple gerardia (*Agalinis purpurea*), balsam ragwort (*Senecio pauperculus*), Houghton’s goldenrod (*Solidago houghtonii*), Ohio goldenrod (*Solidago ohioensis*), silverweed (*Potentilla anserina*), grass-of-Parnassus (*Parnassia glauca*), scouring rush (*Equisetum variegatum*), sweet gale (*Myrica gale*), tamarack (*Larix laricina*), spike rush (*Eleocharis quinqueflora*), hardstem bulrush (*Schoenoplectus acutus*), pitcher-plant (*Sarracenia purpurea*), sand dune willow (*Salix cordata*), Indian paintbrush (*Castilleja coccinea*), dwarf Canada primrose (*Primula mistassinica*), smooth scouring rush (*Equisetum laevigatum*), red osier (*Cornus stolonifera*), low calamint (*Calaminta arkansana*), tag alder (*Alnus rugosa*), ticklegrass (*Agrostis hyemalis*), marsh cinquefoil (*Potentilla palustris*), rose pogonia (*Pogonia ophioglossoides*), jack pine (*Pinus banksiana*), marsh pea (*Lathyrus palustris*), hair grass (*Deschampsia cespitosa*), slender bog arrow-grass (*Triglochin palustris*), panic grass (*Panicum lindheimeri*), and marsh bellflower (*Campanula aparinoides*). Most of the common and characteristic plant species of the interdunal wetland tolerate or require the carbonate-rich conditions of the Great Lakes shoreline. The majority of plants are perennial herbs with strongly developed rhizomes. Unlike the interdunal wetlands of the lower Great Lakes, those along the shores of Lake Superior are not buffered by calcium carbonate, and as a result they often become acidic and support a flora with more acid-tolerant shrubs and small trees, including leatherleaf (*Chamaedaphne calyculata*), black chokeberry (*Aronia prunifolia*), bog rosemary (*Andromeda glaucophylla*), Labrador tea (*Ledum groenlandicum*), and black spruce (*Picea mariana*), along with more acid-tolerant sedges, like *Carex paupercula*. *Sphagnum* mosses are a major component in some Lake Superior interdunal wetlands.” 

**“Michigan indicator species:** Baltic rush (*Juncus balticus*), twig rush (*Cladium marisoides*), bog lobelia (*Lobelia kalmii*), horned bladderwort (*Utricularia cornuta*), common bog arrow-grass (*Triglochin maritimum*), Kalm’s St. John’s-wort (*Hypericum kalmianum*), false asphodel (*Tofieldia glutinosa*), golden-seeded spike-rush (*Eleocharis elliptica*), grass-leaved goldenrod (*Euthamia graminifolia*), shrubby cinquefoil
(Potentilla fruticosa), three square (Schoenoplectus pungens), beak-rush (Rhynchospora capillacea), and seedlings of northern white-cedar (Thuja occidentalis).”

“Research needs: …………… Studying the dynamics of interdunal swales over multiple years would also be a significant contribution to understanding their ecology. Documenting the response of the rare species to water fluctuations may be important, as the relatively small size of the individual interdunal wetlands may increase the susceptibility of their rare species to local extinction. Houghton’s goldenrod populations have been observed to increase greatly when water levels are low and decrease greatly with high water levels.”

Plant Species: Species of wet meadow
(*Carex stricta, C. lasiocarpa, Calamagrostis canadensis*)

Note: Because there is three major species that characterize this plant community, all three species are being recommended for monitoring.

**Researcher/contact:** Dennis Albert, Michigan Natural Features Inventory (Michigan State University Extension; albertd@michigan.gov)

**Literature and additional sources:**


**Page 91:** “Abstract” The loss of *Carex* dominated meadows due to agricultural drainage in the previously glaciated midcontinent of North America has been extensive. The lack of natural *Carex* recruitment in wetland restorations and the failures of revegetation attempts underscore the need for information on the establishment requirements of wetland sedges. In this study, seedlings of *Carex stricta* Lam. were planted in three experimental wetlands in east-central Minnesota, USA to investigate the biotic and abiotic environmental limitations to establishment. Seedlings were planted along an elevational water depth gradient to assess the effects of water depth and water level fluctuation on seedling survival and growth. A different water level fluctuation regime was assigned to each of the experimental wetlands to assess seedling tolerance for seasonal water level changes. The effects of seedling planting density and the presence or absence of non-sedge colonizers on seedling survival and growth were also studied. The experiment was followed for three growing seasons. **The results of this study indicate that C. stricta seedlings were sensitive to the timing and duration of inundation during the first growing season. Once established, plants tolerated a broad range of seasonal drying and flooding conditions.** Seedling and juvenile growth was slowed by non-sedge colonizers during the first two growing seasons, but by the third growing season, *C. stricta* was able to out-grow all annual and perennial weeds, except the aggressive perennial, *Phalaris arundinacea* L. The rapid growth of *C. stricta* plants, once established, indicates that the use of seedlings is a successful method for (re) introducing this tussock sedge into wetland restorations under a variety of environmental conditions. Comparison with other studies performed under similar conditions suggests that planting of seedlings is a more appropriate method of establishing this species than the use of transplanted rhizomes.”

External link: [http://www.springerlink.com/content/g622551x454j6j15/](http://www.springerlink.com/content/g622551x454j6j15/)

Page 255: “Abstract: A seedling and sporeling emergence assay was conducted on 50 soil cores taken from within Carex stricta tussocks (intra-tussock) and from paired, adjacent inter-tussock areas in the Hawkins Conservation Area, South Hadley, Massachusetts, USA, to test the hypothesis that local heterogeneity in water levels alters seed bank composition and subsequent seedling emergence patterns. Soil cores were sliced into 2.5-cm-thick sections and split into flooded and drawn-down treatments. Germination of buried seeds and spores was assessed in these treatments under greenhouse conditions for 6 months. Eighteen species emerged from both treatments combined: 17 from inter-tussock samples and 12 from intra-tussock samples. Pooled across sample depths and watering treatments, more species of grasses, forbs (exclusive of Impatiens capensis), and woody plants germinated from intra-tussock samples, while more pteridophytes germinated from the inter-tussock samples. Emergence of pteridophytes, grasses, and forbs was associated significantly with sample depth. More pteridophytes germinated from samples close to the swamp surface, while grasses and forbs were most abundant in samples 10-20 cm below the surface. In the drawn-down treatment, pteridophyte and forb seedlings were more plentiful from inter-tussock samples. In contrast, more forb seedlings emerged from intra-tussock samples in the flooded treatment. This variation in forb emergence seems to reflect differences in species composition within and between tussocks. Twenty-two species occurred in the standing vegetation of the study area, but only nine of these also occurred in the seed bank. The composition of standing vegetation atop and between tussocks did not differ significantly. Grasses, which dominated the seed bank, were absent from standing vegetation. Grasses clearly represent a persistent population of seeds in the seed bank, while forbs are more transient within the seed bank. The depth-stratified species composition of the seed bank also suggests patterns of temporal succession in the aboveground vegetation of this New England tussock swamp.”


Page 159: “Abstract: The water depth in marshes occurring along Lake Michigan is largely controlled by fluctuations of the Lake Michigan water level. The role of water level in controlling the distribution and cycling of N and P in emergent (Sparganium eurycarpum, Scirpus validus, and Typha latifolia) and wet meadow (Calamagrostis canadensis, Carex stricta, and Carex aquatilis) communities of a Lake Michigan river mouth marsh was studied. Nutrient uptake was determined from biomass sampling and tissue analysis. Community distribution at various lake stages was determined from aerial photographs.”

Abstract, page 115: “The vegetation of the 80.7 hectare Cowles Bog Wetland Complex has been altered from its historic mixed sedge-grass domination (Carex stricta, Calamagrostis canadensis) in lower areas and woody growth in slightly elevated areas, as based on archival aerial photographs from 1983-1982 and recent field data. Cattails (Typha spp.) were present in 1983 and made minor gains in cover through 1970. However, the major invasion of cattails appears to be associated with stabilized, increased water levels caused by seepage from diked ponds constructed upgradient from the wetland in the early 1970s. The water level increases are assumed to have been of a magnitude which adversely affected the sedge-grass community but did not preclude cattail growth. The cattail vegetation type increased in cover from 2.0 ha in 1938 to 9.7 ha in 1970 to 37.5 ha in 1982. The sedge-grass vegetation type correspondingly decreased from 56.4 ha to 43.0 ha to 5.7 ha. Cattail invasion appears to have occurred through establishment of disjunct colonies by seed reproduction, followed by vegetative expansion and merging of the colonies.”

RARE BIRDS

Bird species: Piping Plover (Charadrius melodus)

Researcher/contact: Dr. Francesca Cuthbert University of Minnesota (cuthb001@umn.edu), Jack Dingledine, US Fish and Wildlife Service (jack_dingledine@fws.gov) and Jennifer Stucker, US Geological Survey (jstucker@usgs.gov)

Status: Federally listed as endangered (U.S., Canada); State listed endangered (New York, Ohio, Minnesota, Illinois, Indiana, Wisconsin, Michigan)

Designation history: In 2001, the species was split into two sub-species (Charadrius melodus melodus and Charadrius melodus circumcinctu) in Canada. Only subspecies circumcinctus occurs in Ontario.

Habitat: Open, exposed beach with a mix of sand and cobble and sparse vegetation; often associated with coastal dunes within the Great Lakes basin. Often nests are located near the mouth of streams or rivers.

“Habitat change and loss is an additional concern. Rising lake levels in the Great Lakes narrowed beaches and may have caused habitat loss (Bradstreet et al. 1977). (not sure where this came from; he has not worked in the the Great Lakes; but, it is true) Hay and Lingle (1981) discuss destruction of nests due to flooding. In the Great Plains, lowering of the water table due to irrigation projects and strip mines is a growing concern (Kantrud 1979, Dinsmore 1981, USFWS 1988). On the Canadian Prairies, reservoir water management is a major concern; water is impounded in the spring, causing levels to rise throughout the breeding season, flooding nests and reducing brood rearing habitat (Boyne 2000). Woody species encroachment of lake shorelines and riverbanks may be responsible for habitat loss (Dinsmore 1981, Haig 1983, Hay and Lingle 1981, USFWS 1988; Lingle, pers. comm.). Invasion of sites by Marram Grass (Ammophila breviligulata), Bayberry (Myrica pensylvanica), and even spruces (Picea sp.) is a problem on the east coast; areas may need to be weeded (Haig 1992, Master, pers. comm.). Plans for dredging and recreational developmen along the Gulf of Mexico coast, particularly on Laguna Madre in Texas, pose a serious threat (USFWS 1994).” In the Great Lakes, lower than average lake levels and reduction in ice cover limits ice-scouring and substrate movement of shoreline during the non-breeding season. Under these conditions, plover habitat becomes stable vs dynamic and vegetation encroaches rendering the site unsuitable (Cuthbert pers. observ.).

Source: Natureserve.org
http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Charadrius+Melodus

Distribution: In the U.S.: Northwest Michigan, along the coast of Lake Michigan during summer breeding season.
Charadrius melodus

total range area = 1,552,665 km²

Distribution
- Known
- Projected
- Possible
- Historical

Source: World Conservation Union (IUCN)
External link:

Literature recommended by nominators:


This account summarizes all know research, conservation and management documents written about Piping Plovers in North America. It is the best source of information on the biology and conservation of this species at date of publication.

This document outlined the recovery and management plan of current and future Piping Plover populations, as well as identified critical areas that will be targeted/ designated as potential Piping Plover habitat. In the process of identifying key areas that could support future Piping Plover populations in the Great Lakes basin, the authors considered many physical factors, including lake level fluctuations:

“Site suitability was also ranked based on additional data on human disturbance, accessibility, predator levels, adjacent land use, vulnerability to rising lake levels, and patterns of habitat use and reproduction by piping plovers.” (pp. 16)

“Depending on lake levels, an additional 5-25 km (3-15 mi) of Lake Erie shoreline on Long Point, Ontario is physically suitable nesting habitat for a potential 15-20 breeding pairs, but efforts are needed to control very high predator activity if piping plovers attempt to nest at this site (J. McCracken, Program Manager, Bird Studies Canada, Long Point Observatory, Port Rowan, Ontario, pers. comm., 1999).” (pp. 108)

External link: www.fws.gov/midwest/Endangered/birds/index.html#piping

3. Great Lakes Waterbird Research Program:

This University of Minnesota based program works with US Fish and Wildlife Service and Michigan Department of Natural Resources to coordinate research, outreach and public participation in the management and monitoring of Piping Plover populations. One of their management techniques is to move nests that are in danger of inundation. They have been recording nest site locations (using GPS) for about 10 years for the Great Lakes population. They do not have a specific study using these data but plan to related nest site location to water levels (Francie Cuthbert, University of Minnesota, personal communication).

“In 1999, several nests occurring in low-lying areas were at risk of inundation. These nests were elevated up to 30 cm in height by augmenting existing locations with mounds of gravel and sand. This technique was successful and prevented inundation and nest washout. Each of these nests hatched and fledged offspring.”

External link: www.waterbirds.umn.edu/Piping_Plovers/piping1.htm

Additional literature/resources:

1. Ruling for Endangered and Threatened Wildlife and Plants; Final Determination of Critical Habitat for the Great Lakes Breeding Population of the Piping Plover
“The dynamic ecological processes that create and maintain piping plover habitat are also important primary constituent elements. These geologically dynamic lakeside regions are controlled by processes of erosion, accretion, plant succession, and lake-level fluctuations. The integrity of the habitat depends upon regular sediment transport processes, as well as episodic, high magnitude storm events. By their nature, Great Lakes shorelines are in a constant state of change; habitat features may disappear, or be created nearby. The critical habitat boundaries reflect these natural processes and the dynamic character of Great Lakes shorelines.”


“In Michigan, piping plovers prefer fairly wide, sandy, open beaches along the Great Lakes with sparse vegetation and scattered cobble for nesting (Lambert and Ratcliffe 1981, Powell and Cuthbert 1992). Nesting may occur on the open beach near the edge of the foredune or in the cobble pan behind the primary dune. Territories often include rivers, lagoons, channels, or interdunal wetlands that provide additional food sources for chicks. Nests consist of a shallow scrape in the sand that are sometimes lined or surrounded with fragments of shells, driftwood or small pebbles (Haig 1992).”


“Using 1992 and 1993 nest site elevations and reproductive data, we developed a simulation model to assess the effects of flooding on piping plover reproductive success over the last 30 yr. Our model shows that fledging success at Lake Diefenbaker has been below the level recommended for sustainability of the species, in 24 of the last 30 yr. To maximize reproductive success at this location, we recommend that lake levels be managed to prevent or reduce flooding during the breeding season.”

“Fluctuating water levels prevent colonisation of beaches by plants, thus maintaining their suitability for plovers over the long-term (Cairns and McLaren, 1980; Burger, 1987; Prindiville Gaines and Ryan, 1988; Espie et al., 1996). Vegetation encroachment is reduced at many other prairie basins by high salinity and occasional flooding (Prindiville Gaines and Ryan, 1988).”

“Piping Plover populations at LOTW have gradually declined from peak levels during 1982-1985, despite rather intensive management efforts, particularly since 1990. There does not appear to be any single cause for this decline at the local level. Instead, Piping Plovers face a variety of problems (e.g., predators, fluctuating lake levels, weather, habitat degradation and loss, competition with gulls for nesting areas) and a unique mix of circumstances each year. For example, in 1988 water levels were very low, creating excellent habitat conditions, but the failure to trap one mink (four others were removed) and the subsequent predation on plover eggs and chicks (likely by this mink), led to lowered reproductive success. In contrast, 1989 had very high water levels, leading to poor habitat conditions and extensive erosion. Predators had less of an impact, but half the plover nests were washed away, beach habitat was greatly reduced, and only one chick fledged.” (pp. 479)

External link:
http://www.jstor.org/view/15244695/ap050004/05a00160/0
Bird species: King Rail (*Rallus elegans*)

**Researcher/contact:** Greg Grabas and Shawn Meyer, Environment Canada, Canadian Wildlife Service (Greg.Grabas@ec.gc.ca)

**Status:** Nationally listed as endangered (Canada), state/provincially listed as endangered (Illinois, Indiana, Michigan, Minnesota, Ontario)

**Habitat:** Freshwater marshes within the Great Lakes basin, emergent coastal marshes with hummocky topography within the open water.

**Distribution:**

![Map of U.S. States and Canadian Provinces showing the distribution of the King Rail](image)

**Source:**

**Literature and additional resources:**

“Since the availability of suitable habitat is a major limiting factor, protection of occupied habitats is needed as well as artificial manipulation to enhance areas for migrating and nesting rails. Hummocky topography and natural swales should be maintained for nesting and foraging. Artificial land leveling should be discouraged. Beds of perennial vegetation should be encouraged where water depths are moist to 10 inches. In a continuum of preferred water depths for inland-breeding rallids, king rails nest in the most shallow water areas. These shallow, seasonally flooded sites are most easily drained and impacted by agriculture, especially in the Great Lakes Region when water levels are low.” (p. 4)


2. Environment Canada Species at Risk (SAR) database:

“King Rails are found in a variety of freshwater marshes and marsh-shrub swamp habitats. The species occurs in areas where wild rice grows but also in sedge and cattail marshes. Most importantly, the species requires large marshes with open shallow water that merges with shrubby areas. In fact, birds only return in successive years to large marshes that are not overgrown with cattails. Originally, the best habitat for King Rails was in southwestern Ontario, but most of these wetlands have since been eliminated. Only 10% of the original pre-European settlement marshes remain in the one area of Ontario where the largest component of the species occurs. The quality of the remaining habitat is also deteriorating.”

External link: http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=24


“Currently, COSEWIC (2003) has identified Least Bittern and King Rail as threatened and endangered species, respectively, because of their small population sizes. In addition, Marsh Monitoring Program survey results suggest that many other populations of marsh bird species, such as Black Tern, Common Moorhen, Pied-billed Grebe, and Sora are declining within selected areas of Great Lakes coastal wetlands (Timmermans 2001). Consequently, modification of the hydrological regime, due to climate change, may affect the Great Lakes populations of Least Bittern, King Rail, Black Tern, Common Moorhen, Pied-billed Grebe, Sora, and other small, or declining, coastal marsh bird populations more than populations that are increasing or stable (e.g. Canada Goose and Common Grackle). This may result in reduced distribution and numbers of some marsh bird populations and loss of some species completely.” Page 85.
“Climate change has the potential to alter wetland habitat along the Great Lakes shoreline if water levels change. Habitats for many marsh birds, particularly marsh nesting obligate birds (i.e. birds that nest exclusively in marshes with rare exceptions) will be affected. These birds have several breeding requirements that are vulnerable to any change in habitat. Many marsh nesting obligate birds breed in Great Lakes coastal marshes including, Pied-billed Grebe (*Podilymbus podiceps*), American Bittern (*Botaurus lentiginosus*), Least Bittern (*Ixobrychus exilis*), Yellow Rail (*Coturnicops noveboracensis*), **King Rail** (*Rallus elegans*), Virginia Rail (*Rallus limicola*), Sora (*Porzana carolina*), Common Moorhen (*Gallinula chloropus*), American Coot (*Fulica americana*), Forster’s Tern (*Sterna forsteri*), Black Tern (*Chlidonias niger*), Marsh Wren (*Cistothorus palustris*), and Swamp Sparrow (*Melospiza georgiana*) (Peck and James 1983; Timmermans 2001; Tozer 2003).”

External link: 
http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm

4. King Rail - preferred breeding habitat coverage (Lake Ontario) Performance Indicator (PI) Summary (LOSLR Study Environmental Technical Working Group)

“Water level regulation could change the availability of preferred breeding habitat in open and protected embayments. Predictions of this PI are generated from the wetland plant model developed by Wilcox and Ingram. Wetland plant community evolution is strongly dependent on the hydroperiod (i.e., flooding and dewatering history) at a particular elevation.”

External link: 
http://www.losl.org/twg/pi/pi_kingrail-e.html

4. Wisconsin “Species of Greatest Conservation Need” Summary for King Rail

“Threats and Issues: Disruption of hydrology can impact wetland quality and extent. King Rails often use adjacent grasslands and shallow, dry marshes, thus unusually high water levels can negatively impact this species.”

External link: 
http://dnr.wi.gov/org/land/er/wwap/plan/pdfs/Birds_KingRail.pdf


“Management Requirements: Eddleman et al. (1988) provided the following information on managing waterfowl areas in a way that is compatible with the conservation of inland rails. Wetlands of the greatest importance to rallids (other than gallinules and coots) are shallower and have greater percentage cover by emergent vegetation than those typically managed for waterfowl. Dewatering in northern breeding areas should occur before April 15 to avoid disruption of rail nest initiation. Gradual dewatering (and presumably
presence of topographic diversity) provides the maximum amount of favorable foraging area (edge between moist soil and marsh). Amount of nesting cover (emergent perennial vegetation) should be maximized. To provide rail habitat every year, different impoundments should be flooded in different years.

For autumn migration, shallow flooding should commence in late summer in middle latitudes (vs. late autumn or winter for waterfowl), and habitat should include various shallow water depths, robust cover, and short-stemmed seed-producing plants. Flooding too deeply and too early, and deep winter flooding, lead to loss of robust plant cover.

In spring, areas that have annual grasses and smartweeds should be shallowly flooded (<15 cm), with some areas flooded to depth of up to 50 cm. Drawdowns are most favorable when they concentrate invertebrate prey. These conditions also provide excellent habitat for dabbling ducks such as blue-winged teal and northern shoveler. Land leveling, which reduces topographic diversity and favorable rail foraging habitat (edge) should be avoided.”

External link:
http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Rallus+elegans
Bird species: Black Tern (*Chlidonias niger*)

**Nominated by:** Krista Holmes, CWS-Ontario Region (email: Krista.Holmes@ec.gc.ca) and David J. Adams, Waterbird Specialist Non-game and Habitat (Phone: 518-402-8902; email: djadams@gw.dec.state.ny.us).

**Status:** State listed as endangered (Illinois, New York); State/provincially listed as a special concern (Ontario, Michigan).

**Habitat:** freshwater wetlands along lake coasts in the Great Lakes basin; marshes with emergent vegetation.

**Distribution:**


**Literature and additional sources:**

“Diversity of wetland bird communities is widely considered to be associated with the diversity of wetland flora, as well as spatial complexity of their juxtaposition with one another on the landscape (Gibbs et al. 1991). Consequently, any ecological processes that tend to simplify or homogenize wetland habitats will likely do so to the detriment of wetland-associated bird communities. Stabilizing water levels or managing them outside the range of historic fluctuations eliminates the dynamic patterns that allow a diversity of wetland species and communities to thrive (Bedford 1990). Such is the case in the Great Lakes region, where one consequence of decades of water-level management on Lake Ontario has been a tendency for fringing wetlands to become more densely vegetated and dominated by cattail (Typha spp.) and invasive species such as purple loosestrife, (Lythrum salicaria L.) and/or common reed, (Phragmites australis (Cav.) Trin. ex Steud., (Wilcox 1990, Wilcox 1993, Wilcox et al. 1993, Hudon 1997, Beland 2003, Farrell et al. 2004), a tendency that runs counter to the maintenance of “hemi-marsh” situations that benefit most wetland birds species (Gibbs et al. 1991). Water-level management in Lake Ontario, initiated with operation of the St. Lawrence Seaways, has reduced water-level fluctuations from about 2 m to approximately 0.9 m since 1976 (Wilcox 1993) and has eliminated year-to-year variation (Wilcox and Whillans 1999). Artificially minimizing water-level fluctuations may negatively affect wetland bird populations adapted to aquatic microhabitats. This would likely be achieved through direct loss of microhabitats most closely associated with wetlands, such as submergent vegetation.”

2. Michigan Natural Features Inventory species abstract:

“An estimated 50% of Michigan’s original wetlands have been drained, filled or altered and 70% of coastal wetlands have been lost throughout Michigan since European settlement (Cwikiel 1996). Similar situations have occurred in Canada. Compounding the problem, very little information concerning black tern winter ecology or the limiting factors on the wintering grounds is available. In addition to outright habitat loss are the corollary problems of habitat degradation, water and food quality and successional change. If pollutants, disturbance, or exotic invasion has changed the character of a wetland, it may become unsuitable for nesting black terns.” (pp.2)

External source:

3. Illinois Natural Resources Information Network (INRIN):

“Black tern populations in the Great Lakes appear to remain stable from year to year as long as marsh habitats are protected. High water levels have destroyed much of this habitat, therefore the populations may be expected to decline. Mortality and survival rates and sex ratio unavailable. Majority of mortality occurs at the egg stage (Bergman et al. (1970) Reported 29% nesting success.”

“Black Tern[s] construct nests on floating vegetation in emergent marsh vegetation, and require marsh habitat that is flooded for nesting and feeding. Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, and the rate of water level change (rapid rise > 20cm) are also important annual hydrologic factors. **During the nesting period, water levels increases can drown eggs and chicks, and water level decreases, increase ground predator access to nests.**” (pp. 3)

“**Black Tern PI is retained as a Key PI because it clearly shows an important vulnerability and sensitivity to alternations in water levels and flows,** and as such it should be used to evaluate potential environmental responses to alternative water regulation plans.” (pp.4)


“Black Terns nest in freshwater wetlands that are prone to substantial water level fluctuations (Bergman et al. 1970; Bailey 1977; Mosher 1986), and they typically construct nests only a few centimeters above the water surface (Bergman et al. 1970; Dunn 1979; Davis and Ackerman 1985). Consequently, flooding from rain events is a major source of nest losses (Cuthbert 1954; Bergman et al. 1970; Bailey 1977; Dunn 1979; Macikunas 1993; Hickey 1997; Mazzocchi et al. 1997). Mosher (1986) observed four consecutive years of nest losses (14-27% of nests) from weather in British Columbia, and Macikunas (1993) reported annual nest losses due to flooding of 15-30% over a 7-year period in Lithuania. Hickey (1997) reported the highest annual loss (40%), but loss rates associated with individual storms were undoubtedly greater. **These and other accounts (Dunn and Agro 1995) indicate that water level dynamics are an important aspect of Black Tern ecology; however, analyses of long-term patterns in nest losses to flooding have not been made.**”

“Lake Ontario survey routes contained reduced species occurrence (diversity) and abundance (density) and were, on average, lower than those at routes within the other Great Lakes. These results indicate that natural cycling of Great Lakes water levels are necessary for maintaining habitat quantity and diversity to support healthy and diverse marsh bird communities. Overall, marsh species benefit from natural high and low water events through time. Marsh bird species have evolved to persist during periodically unfavourable hydrologic conditions. This cycling provides a diversity of habitat for many species, therefore any measure that reduces this variability and disrupts the nature of these processes, has the potential to affect the ecological integrity of freshwater coastal wetlands and their biotic communities.”


“When there were rapid or moderate increases in water levels, observed breeding populations of Black Tern, Marsh Wren, Common Moorhen, and American Bittern were reduced by 84% or more.” (pp. 344)

“The Black Tern is experiencing regional population declines (Ontario and New York State) and the North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes/St. Lawrence Plain Bird Conservation Region 13 (BCR 13) critical to its regional population integrity (Milko et al., 2003). The Black Tern PI is also a surrogate species for Pied-billed Grebe (Podilymbus podiceps) and Common Moorhen and several wildfowl species that use deep emergent marshes as feeding and rearing habitats. Black Tern and Pied-billed Grebe are listed by the New York State Department of Conservation as Endangered and Threatened respectively. The Black Tern is also listed as vulnerable by the Ontario Ministry of Natural Resources.” (p. 354)


“Habitat measurements taken at Perch River WMA in 1995 and 1996 support that Black Terns select nest sites within an approximate 50:50 vegetation cover to open water ratio (Weller and Spatcher 1965, Tilghman 1980, Chapman Mosher 1986, Hickey 1997a). Structural features appeared more important to nest site selection than specific plant species. However, differences in dominant vegetation between 1995 and 1996 may have been related to water level differences. In 1996, when the mean water level at nests was
<50 cm, cattail was the dominant plant accounting for a greater number of nests in taller vegetation.”
Bird species: Least Bittern (*Ixobrychus exilis*)

**Researcher/contact:** Greg Grabas, Environmental Canada (Greg.Grabas@ec.gc.ca) and Robert W. Howe, University of Wisconsin-Green Bay (hower@uwgb.edu)

**Status:** Nationally listed as threatened (Canada); State/provincially listed as threatened (Michigan, Illinois, Ontario); State listed as endangered (Indiana).

**Habitat:** Wetlands or open water marshes where there area of open water roughly equals the area of vegetation (i.e. hemi marshes).

**Distribution:**

Source:

**Literature recommended by nominators:**

“Expansion of monotypic vegetation, such as cattail or common reed, because of lower water levels associated with climate change (see Chapter 3), may affect aquatic plant diversity and wetland habitat interspersion. This expansion may also displace some marsh birds as open emergent marsh and meadow marsh are replaced by monotypic stands of tall, dense vegetation. Pied-billed Grebe, Least Bittern, Black Tern, American Coot, and Mallard (Anas plathrynchos) (Gibbs et al. 1992b; Dunn and Agro 1995; Brisbin and Mowbray 2002; Drilling et al. 2002) depend on open emergent marsh within coastal wetlands for breeding habitat, whereas Northern Harrier, Eastern Kingbird, Swamp Sparrow, Le Conte’s Sparrow (Ammodramus leconteii), and Sedge Wren (Cistothorus platensis) (Gibbs et al. 1991; MacWhirter and Bildstein 1996; Riffell et al. 2001) rely primarily on meadow marsh. These marsh birds may be replaced by marsh birds that use robust emergent vegetation (e.g. Virginia Rail, Sora, Marsh Wren, Red-winged Blackbird, Common Grackle, and Common Yellowthroat) as cattail and common reed expand (Conway 1995; Yasukawa and Searcy 1995; Melvin and Gibbs 1996; Kroodsman and Verner 1997; Peer and Bollinger 1997; Meyer 2003).”


Additional literature and resources:


“In evaluating how temporal patterns of marsh bird species abundance indices at coastal marshes related to temporal patterns of hydrology in the Great Lakes basin, it was found that nine marsh dependent bird species indices were positively correlated with Great Lakes water level variability during the critical breeding period. Of these species, American Coot (Sutherland and Maher 1987), Forster’s Tern (McNicholl et al. 2001), Least Bittern (Rodgers and Schwikert 1999), Marsh Wren (Verner 1965), Pied-billed Grebe (Muller and Storer 1999), Sora (Melvin and Gibbs 1996) and Virginia Rail (Conway 1995), often nest less than 1 meter above and forage exclusively in standing water in marshes. Subsequently, these wetland dependent bird species were expected to relate most directly to temporal water level changes.” pp 14.


“Least Bittern usually construct nests in emergent vegetation 20 cm (7.87 in) to 80 cm (31.5 in) above to water surface, and require marsh habitat that is flooded for nesting and feeding. Nests are typically located in emergent marsh with water depths ranging from 10 cm (3.94 in) to 100 cm (39.37 in). Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, flood amplitude, recurrence and duration, as well as the rate of water level change (rapid rise or drop > 20 cm or 7.87 in) are also important hydrologic factors. During the nesting period, water level increases can drown eggs and chicks, and water level decreases, increase ground predator access to nests.”

External link:


A growing-season drawdown has been proposed for Reelfoot Lake to consolidate substrates and improve sport fish spawning habitat (USFWS 1989, USACE 1999). A drawdown during the growing season will affect the vegetation and Least Bitterns on Reelfoot Lake. Giant cutgrass germinates on dry-to-moist mudflats, whereas swamp loosestrife germinates under moist-to-flooded conditions. Both species also reproduce vegetatively. Since a 1–2 m band of giant cutgrass occupies many Reelfoot Lake marsh edges, any exposed mudflats during a drawdown will likely be seeded and vegetated with giant cutgrass as during a previous drawdown in 1985 (J. W. Henson, University of Tennessee, Martin, personal communication). This would have a positive effect on Least Bitterns; however, the drawdown will increase tree germination in the standing swamp loosestrife marshes, ultimately reducing Least Bittern habitat.

External link:


“Weller (1961) found least bittern nests in the north-central states most often associated with marshes dominated by cattail and/or bulrush. When compared to the American bittern, the least bittern is more prevalent in deeper water marshes (Weller 1961, Weller and Spatcher 1965). In their study of Iowa marshes, Weller and Spatcher (1965) recorded the species in the greatest abundance during years when ratios of emergent vegetation to open water were approximately equal (the hemi-marsh stage), and the species was not observed in areas of dense vegetation until opened up by muskrats. Brown and Dinsmore (1986) found that least bitterns were observed more often on Iowa wetlands larger than 12 acres (5 ha), suggesting that the species may be area
sensitive. While Bogner and Baldassarre (2002) observed a mean home range size of 9.7 ha (11.4 ha for females, 8.1 for males) in their study in western New York, they suggested that vegetation type and cover ratios are likely more important than marsh size to least bittern populations.”

External link:

5. Environment Canada Species at Risk Website

“The main factor for the decline in the numbers of Least Bitterns is loss of habitat due to the drainage of wetlands. Natural succession, the natural filling in of wetlands by woody vegetation, has also been a cause of habitat loss. In southwestern Ontario, more than 90% of the original marshes are gone. Human disturbance during the nesting period is a second important limiting factor. For example, recreational water boats which create high waves can adversely affect the reproductive success of Least Bitterns. Since Least Bitterns are partially nocturnal and tend to fly very low, they are sometimes killed by cars or by collisions with hydro lines or buildings.”

External source:
http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=51


“Least Bittern usually construct nests in emergent vegetation 20 cm (7.87 in) to 80 cm (31.5 in) above to water surface, and require marsh habitat that is flooded for nesting and feeding. Nests are typically located in emergent marsh with water depths ranging from 10 cm (3.94 in) to 100 cm (39.37 in). Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, flood amplitude, recurrence and duration, as well as the rate of water level change (rapid rise or drop > 20 cm or 7.87 in) are also important hydrologic factors. During the nesting period, water levels increases can drown eggs and chicks, and water level decreases, increase ground predator access to nests.” (pp.2)

External link:


“Diversity of wetland bird communities is widely considered to be associated with the diversity of wetland flora, as well as spatial complexity of their juxtaposition with one another on the landscape (Gibbs et al. 1991). Consequently, any ecological processes that
tend to simplify or homogenize wetland habitats will likely do so to the detriment of wetland-associated bird communities. Stabilizing water levels or managing them outside the range of historic fluctuations eliminates the dynamic patterns that allow a diversity of wetland species and communities to thrive (Bedford 1990). Such is the case in the Great Lakes region, where one consequence of decades of water-level management on Lake Ontario has been a tendency for fringing wetlands to become more densely vegetated and dominated by cattail (Typha spp.) and invasive species such as purple loosestrife, (Lythrum salicaria L.) and/or common reed, (Phragmites australis (Cav.) Trin. ex Steud., (Wilcox 1990, Wilcox 1993, Wilcox et al. 1993, Hudon 1997, Beland 2003, Farrell et al. 2004), a tendency that runs counter to the maintenance of “hemi-marsh” situations that benefit most wetland birds species (Gibbs et al. 1991). Water-level management in Lake Ontario, initiated with operation of the St. Lawrence Seaways, has reduced water-level fluctuations from about 2 m to approximately 0.9 m since 1976 (Wilcox 1993) and has eliminated year-to-year variation (Wilcox and Whillans 1999). Artificially minimizing water-level fluctuations may negatively affect wetland bird populations adapted to aquatic microhabitats. This would likely be achieved through direct loss of microhabitats most closely associated with wetlands, such as submergent vegetation.”
RARE FISHES

Fish species: Lake Sturgeon (*Acipenser fulvescens*)

**Researcher/contact:** Contacts from the Essex-Erie Recovery Team in Canada: Matthew Child - Chair - Conservation organization (NGO) 519-776-5209; Shawn Staton - Chair - Fisheries and Oceans Canada 905-336-4864

**Status:** Nationally listed as threatened (Canada); State listed as Endangered (Illinois); State/provincially listed as threatened (Michigan, Ontario, Ohio, New York); State listed as Special Concern (Minnesota).

**Habitat:** Bottom of large shallow lakes, clear large, shallow rivers, within run-pool sequences.

**Distribution:**

Literature and additional sources:

1. New York State Department of Environmental Conservation species summary:

“Lake sturgeon are primarily found in freshwater lakes and large rivers, but can also
occur in brackish waters. In New York, lake sturgeon have been collected in Lake
Ontario, Lake Erie, the St. Lawrence River, Niagara River, Oneida and Cayuga Lakes,
Lake Champlain, the Oswegatchie River, Grasse River and Black Lake. However, their
current numbers in these waters are a mere shadow of what they once were. Since 1995,
sturgeon populations in five Northern New York waters have been supplemented through
the stocking of some hatchery-raised fish. The American Fisheries Society lists lake
sturgeon as threatened in all the states where they occur. **Reasons for their population
decline are attributed to: overexploitation due to high demand for caviar and
smoked flesh; construction of dams that cut off spawning and nursery areas; and
some pollution and degradation of habitat.**”

External link:
http://www.dec.ny.gov/animals/7008.html

River near Port Huron, Michigan.; US Fish and Wildlife Service. National Fish
and Wildlife Foundation Project no. 2001-005-008 Alpena, Michigan.

“Canada has listed lake sturgeon as a protected species. Within Michigan, lake sturgeon
are currently listed as a state threatened species, and a controlled harvest is allowed only
in a limited number of locations where the population is able to sustain itself (e.g. Lake
St. Clair, Black Lake, and the Menominee River). Throughout other locations in the state
fishing for sturgeon is illegal.”

**“Sturgeon utilized areas of reduced water flow while at the spawning site.”** Within 1
km upriver from the spawning reef were four large underwater obstructions (three
shipwrecks and a large debris field approximately 0.2 km wide by 0.7 km long). In
addition, there was also a shipwreck adjacent to the spawning site that provided refuge
from the current. Results from the telemetry data indicated that sturgeon could be
consistently found at refuge locations before and after the peak spawn.”


“Lake sturgeon populations have diminished over much of their historic range. While
over-fishing and water quality declines have been significant factors in this decline, dam
construction may be the most important. **Dams have both blocked migratory pathways
and inundated critical spawning habitat.** Traditional fish ladders were rarely designed
to accommodate or effectively pass sturgeon. **While dam removal is the best solution to
sturgeon passage, nature-like passage may be the next best alternative.** This
presentation will discuss by-pass fishways and conversion of low-head dams to rapids that both pass fish and provide potential spawning habitat.

Lake sturgeon were once historically abundant throughout their range but have experienced dramatic declines in population numbers and abundance due to overharvest, destruction of spawning habitats and barriers to migration. Management activities have resulted in some improvements to spawning habitats and restoring natural flow regimes. However, many extant populations continue to show little evidence of natural recruitment. High rates of predation on eggs could be one explanation for the low rates of recruitment. Lake sturgeon may also be subject to an Allee effect, where low recruitment is attributed to low fertilization rates due low spawner numbers. We currently lack quantitative information on factors that may be barriers to natural recruitment in lake sturgeon. The objectives of this study were to 1) estimate fertilization rate as a function of spawner number and sex ratio, 2) characterize the water velocity, depth and substrate size where lake sturgeon eggs are naturally deposited and 3) determine the sources and magnitude of egg predation prior to larval emergence at several different spawning sites and stream habitats. Results over two field seasons revealed a large amount of heterogeneity in egg deposition, high invertebrate predation, and inter-annual variability in post-emergent recruitment to the larval stage. Quantification of the relative importance of factors affecting recruitment is vital to the recovery of this species.”

External link:


The Black Sturgeon River is one of Lake Superior’s largest north shore tributaries. The majority of the river alternates between slow moving water with deep channels of silt and sand and riffle-pool areas containing large amounts of cobble and gravel. The Camp 43 dam, also known as the Twin Rapids dam, is located approximately 16.3 km above the river mouth. The dam has fragmented this population into an isolated land locked stock and Lake Superior stock. Access to spawning, nursery and foraging habitat in the upper Black Sturgeon River is therefore, no longer available

External link:
http://www.fws.gov/midwest/sturgeon/omnrls-02assmts.htm

5. Wisconsin Department of Natural Resources study on the Manitowish River/Rest Lake Dam Issue (summary website):

“The lake sturgeon population (on Wisconsin's watch species list) in the Turtle Flambeau Flowage appears to be reduced to relatively low numbers of large old fish, with no evidence of natural recruitment documented in the system (Roth, 2002). Radio-tagged fish from the flowage apparently run up the Manitowish River above Benson Lake in Vilas County to spawn. This is also based on observations of other sturgeon in the Benson Lake area. The Turtle Flambeau Flowage Master Plan (WDNR, 1995) states that
the reasons for the lack of reproduction are not understood at this time, but this population may eventually disappear if rehabilitation efforts are not successful. Short-term rehabilitation strategies have been implemented. Fingerling sturgeon have been stocked using an egg source from within the same drainage in 1994 and 1998. The department has documented good survival of these fish stocked in 1994 and 1998 (Roth, 2002)."

“There are many suspected reasons why spawning success is a continued failure in the Turtle Flambeau and Manitowish River. For one, the sturgeon in the Manitowish River have spawned as late as the first two weeks of June. Typical sturgeon spawning takes place (Wolf and Wisconsin Rivers) in late April. Why spawning occurs so late is a mystery, but it could be water flow or temperature related. Attraction flows have been shown to be important in triggering Lake Sturgeon spawning migrations at other locations (Martini, personal communication, 2002). Low flows (< 50 cfs) in April, May, and June would likely inhibit spawning activity and contribute to reproductive failure. The water temperature may be too warm for proper egg development, hatching and embryo survival. Lack of water or fluctuation water levels in the Manitowish River at the time sturgeon spawn could be another factor. The rusty crayfish also inhabits the Manitowish River. They could be feeding on sturgeon eggs. Another unique situation that could be limiting recruitment is predation by redhorse suckers. As indicated earlier, the sturgeon spawn later than usual and at the same time as the redhorse are spawning.”

External link:
http://dnr.wi.gov/org/gmu/upwis/restlakedam/issuepaper.htm


“Before the enhanced flow regime began in 1991, highly variable water releases created periods of low velocity and shallow shoreline habitats. These areas were sparsely occupied by a few macrohabitat generalist fishes, and empty microhabitats were very common. At the downstream site, fish were more abundant and assemblage composition was more diverse, with both macrohabitat generalists and fluvial specialists present. One year after the enhanced flow regime was implemented, shoreline microhabitats at the upstream site had constantly flowing water which was often deeper than before. The fish assemblage also shifted, with about twice as many species, five times the number of fish, a greater frequency of samples containing fish, and a major complement of fluvial specialist species. As expected, changes in the fish assemblage and habitat were less pronounced at the downstream site, but species composition did shift to one dominated by fluvial specialists. Overall, our results indicated that the enhanced flow regime provided conditions that support a diverse fish assemblage more reflective of a riverine system, particularly at the upstream site.”

“The importance of habitat loss to lake sturgeon populations is not well documented; the loss of habitat was considered far less important than overfishing in their decline. In fact, many of the populations were reduced to remnant populations prior to major environmental perturbations affecting lake sturgeon habitat. Since these historic population crashes, prairie river systems have undergone extensive habitat degradation due to decreased flows and water quality as a result of irrigation and the construction of dams. Fluctuating flow in the Cumberland delta, resulting from the construction of a dam on the Saskatchewan River, has negatively impacted lake sturgeon populations downstream of the dam. “

“Generally, impoundments have altered flows and limited pristine habitat (Figure 13). Studies on the Winnipeg River indicate lake sturgeon distribution, especially of juveniles, is positively correlated with unaltered river habitat (Dick 2004).”

External source: http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Facipenser%5Ffulvescens%5Fe%2Epdf

8. Michigan Natural Features Inventory species abstract:

“In lakes, habitat use varies and depends on the habitats available. Gravelly tributary streams of rivers and lakes serve as spawning habitat, although rocky, wave-swept areas near lake shores and islands serve as spawning habitat when preferred habitats are unavailable.”

“Lake sturgeon apparently do not feed during the spawning period. Spawning occurs at temperatures between 13°C and 18°C (Scott and Crossman 1973, Basset 1982) over clean, rocky substrates in two to 15 ft of water in swift currents. Great Lakes populations are known to spawn in wave action over rocky areas or ledges along shorelines and islands (Scott and Crossman 1973).”

External link: http://web4.msue.msu.edu/mnfi/abstracts/aquatics/Acipenser_fulvescens.pdf
Fish species: Pugnose shiner (Notropis anogenus)

Researcher/contact: Susan Doka, Department of Fisheries and Oceans Canada (Dokas@dfo-mpo.gc.ca)

Status: Federally listed as Endangered (Canada); State/provincially listed as a Special Concern (MN, MI), Threatened (WI), and Endangered (New York, Ontario)

Habitat: Wetland and open water; clear lakes and streams of very low gradient, free of suspended sediment.

Distribution:

Source:

Literature and additional sources:
“Vulnerability indices were developed to assess the current sensitivity of Great Lakes coastal wetland vegetation and wetland-dependent breeding birds to hydrologic changes, and fishes to hydrologic and thermal changes. Scores for vulnerability factors were used to categorize species into low, moderate, and high risk groups. Wetland plant species with limited drought-tolerance and modes of colonization were identified as the most vulnerable. As a result, diversity, particularly among submerged aquatic and floating leaved plants, could suffer. Plant species identified as highly vulnerable included wild rice (Zizania palustris) and Hill’s pondweed (Potamogeton hillii). Least vulnerable were several invasive species such as purple loosestrife (Lythrum salicaria) and common reed (Phragmites australis). Obligate wetland breeding bird species with nesting and foraging preferences that require specific hydrologic conditions were identified as most vulnerable with the requirement for prolonged, relatively stable water levels during the breeding season being a key factor (e.g. Forster’s Tern (Sterna forsteri), Black Tern (Chlidonias niger), Pied-billed Grebe (Podilymbus podiceps), rails, and bitterns). Many of the high risk bird species are considered at-risk species within the Great Lakes, or have declining population trends, indicating existing stresses that may be exacerbated further by climate change. High-risk lacustrine, native fishes that were most sensitive to coastal changes included cool to warmwater species with limited geographic distributions, spring and shallow-water spawning, and a preference for vegetated habitat in all life stages (e.g. pugnose minnow (Opsopoedus emiliae), spotted gar (Lepisosteus oculatus), and muskellunge (Esox masquinongy)).” (pp. vii)

External link:
http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm

2. Environment Canada Species at Risk database:

“Declines of the Pugnose Shiner have been attributed to increases in turbidity of the water, destruction of large aquatic plants near the shore, and loss of habitat. Parks on Point Pelee and Rondeau Bay, that would presumably offer protection from habitat deterioration, have failed to prevent the decline or extirpation of the Pugnose Shiner. Potential limiting factors could include habitat changes caused by the introduced Eurasian watermilfoil (Myriophyllum spicatum), and an increase in the number and diversity of predators.”

External link:
http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=108#description

“Another factor that could have played a role in the decline or extirpation of the Pugnose Shiner at Point Pelee was an increase in competition for resources with species such as the Bluegill (*Lepomis macrochirus*), juvenile Black Crappie, and Brook Silverside (*Labidesthes sicculus*). These species feed heavily on cladocerans and to some extent on plant material and did not appear in collections until 1958. However, Brook Silversides and juveniles of Bluegill and Black Crappie occurred together with Pugnose Shiners in 1999 collections at Walpole Island (ROM unpublished data) Most of the Canadian habitat of this species has been affected by the introduced zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena bugensis*). Their effect on the Pugnose Shiner is unknown, but it is possible that the increased water clarity and macrophyte proliferation associated with these invasive species may benefit this species. 

**Changes in the aquatic plant community on which the species depends could also have played a role.** The extirpation of the Pugnose Shiner and seven other fish species in one lake in Wisconsin was associated with the introduction and explosive increase of Eurasian Water Milfoil, *Myriophyllum spicatum* (Lyons 1989).” (pp. 9)

External link: 
[http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Fpugnose%5Fshiner%5Fe%2Epdf](http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Fpugnose%5Fshiner%5Fe%2Epdf)

4. Michigan Natural Features Inventory species abstract:

“Conservation and management: The pugnose shiner is naturally rare throughout its range (Parker et al. 1987). **This species is susceptible to turbidity and any practice that removes or decrease macrophyte abundance or changes sediment transport such as herbicides and shoreline or riparian modifications can impact this species.** Their habitats tend to be difficult to sample effectively which may present an inadequate picture of their population status.

Research needs: There is a paucity of information on this species and hence studies on their life history are needed. Targeted sampling efforts are needed to determine the true status of the pugnose shiner in Michigan due to the difficulty in sampling their habitats. Studies to examine whether blackchin shiners are good indicators for pugnose shiner habitats in Michigan, could prove to be helpful for identifying new areas to survey for the pugnose shiner.”

External link: 

5. Wisconsin Department of Natural Resources website

“[Pugnose Shiners] **Prefer clear, weedy shoals of glacial lakes and streams of low gradient over sand, mud, gravel or marl.** Characteristic vegetation includes pondweed, water milfoil, elodea, eelgrass, coontail, bullrush and filamentous algae.”

External link:  
[http://dnr.wi.gov/org/land/er/factsheets/fish/Pugshn.htm](http://dnr.wi.gov/org/land/er/factsheets/fish/Pugshn.htm)
6. New York State Department of Environmental Conservation:

“The pugnose shiner prefers clear, slow water areas of large streams and lakes with plenty of vegetation. It is restricted in range to the Great Lakes Drainage basin and has been captured in New York, Ohio, Michigan, Indiana, Illinois, Wisconsin, Minnesota, North Dakota, and Canada. In New York State, this rare minnow has been found in Cayuga Lake, Montezuma, Irondequoit Bay, Little Sodus Bay, French Creek (Jefferson County), Sodus Bay, and the St. Lawrence River (near Alexandria Bay). Currently, it inhabits the last two areas.”

External link:
http://www.dec.ny.gov/animals/26022.html

Fish species: Blacknose shiner (*Notropis heterolepis*)

**Researcher/contact:** Susan Doka, Department of Fisheries and Oceans Canada

**Status:** State listed as Endangered (Illinois, Ohio)

**Habitat:** Species is usually found in cool, clear, heavily vegetated creeks, small rivers, and lakes. Very sensitive to low dissolved oxygen levels.

**Distribution:**

Source:

**Literature and additional sources:**
“Management implications and summary.—*Notropis heterolepis* has an ‘‘opportunistic’’ life history strategy (sensu Winemiller and Rose, 1992) in that it is a short-lived species that likely does not exhibit parental care and its reproductive effort is expended over a protracted period through multiple spanning bouts. Therefore, reproductive success in populations of *N. heterolepis* should be resilient to minor, short-term disturbances (e.g., pulse disturbances such as flood events). However, reproductive success of *N. heterolepis* is likely vulnerable to chronic disturbances that persist throughout the reproductive season, especially those that reduce or eliminate the presence of aquatic vegetation that is also important to the species as a foraging and nursery habitat (e.g., sedimentation). Further, because all or most propagules are produced by the age 1 year class, population abundance and persistence of *N. heterolepis* should be greatly influenced by annual reproductive success and year class survival. Chronic disturbances to lake and stream systems, such as sedimentation and eutrophication, are prevalent throughout the Midwest and are likely linked to population declines reported for *N. heterolepis* and other cyprinid fishes (e.g., Taylor and Miller, 1990; Schrank et al., 2001). Conservation and management efforts for remaining populations of *N. heterolepis* in the region should focus on maintaining clear water habitats with well vegetated littoral zones and abundant crustacean zooplankton communities, and minimizing chronic disturbances that adversely affect any of these habitat components.”
Fish species: Pugnose minnow (*Opsopoeodus emiliae*)

**Researcher/contact:** Susan Doka, Department of Fisheries and Oceans Canada (Dokas@dfo-mpo.gc.ca)

**Status:** Nationally listed as a Special Concern (CAN), state listed as Endangered (IL, MI), state/provincially listed as a Special Concern (Ontario and Wisconsin)

**Habitat:** Clear shallow lakes, non-turbid streams; Specifically prefers quiet, weedy lakes, sloughs, and low-gradient rivers over bottoms of mud, sand, rubble, silt, clay, or gravel (Wisconsin Department of Natural Resources)

**Distribution:**

![Map of U.S. and Canadian Provinces showing distribution of Pugnose Minnow]

**Source:**

**Literature and additional sources:**

1. Canada Species at Risk website:

“The Pugnose Minnow may be limited by siltation or water turbidity and removal of aquatic plants, conditions which are prevalent throughout its Canadian range. Although the species can occur in turbid environments, these are believed to be marginal habitats.
The siltation of rivers and streams, caused by urbanization and agricultural practices, is believed to be the main reason for the small size of Pugnose Minnow populations in Canada. Wetlands that provide ideal habitat for Pugnose Minnows have been steadily declining in the species' range. The Pugnose Minnow is protected under the federal *Species at Risk Act (SARA).*

External link:
[http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=107#limits](http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=107#limits)


“The pugnose minnow occurs in rivers and shallow regions of lakes. It prefers slow, clear water and is found in greatest abundance in weedy areas. The pugnose minnow is found most often over sand or organic substrate. In several areas, including the Huron River, the pugnose minnow has been found in turbid areas lacking submergent vegetation. It is assumed that these occurrences in submarginal conditions are the result of changing habitats and remnant fish populations (Trautman 1981).”

External link:


“Vulnerability indices were developed to assess the current sensitivity of Great Lakes coastal wetland vegetation and wetland-dependent breeding birds to hydrologic changes, and fishes to hydrologic and thermal changes. Scores for vulnerability factors were used to categorize species into low, moderate, and high risk groups. Wetland plant species with limited drought-tolerance and modes of colonization were identified as the most vulnerable. As a result, diversity, particularly among submerged aquatic and floating leaved plants, could suffer. Plant species identified as highly vulnerable included wild rice (*Zizania palustris*) and Hill’s pondweed (*Potamogeton hillii*). Least vulnerable were several invasive species such as purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*). Obligate wetland breeding bird species with nesting and foraging preferences that require specific hydrologic conditions were identified as most vulnerable with the requirement for prolonged, relatively stable water levels during the breeding season being a key factor (e.g. Forster’s Tern (*Sterna forsteri*), Black Tern (*Chlidonias niger*), Pied-billed Grebe (*Podilymbus podiceps*), rails, and bitterns). Many of the high risk bird species are considered at-risk species within the Great Lakes, or have declining population trends, indicating existing stresses that may be exacerbated further by climate change. **High-risk lacustrine, native fishes that were most sensitive to coastal changes included cool to warmwater species with limited geographic**
distributions, spring and shallow-water spawning, and a preference for vegetated habitat in all life stages (e.g. pugnose minnow (*Opsopoedus emiliae*), spotted gar (*Lepisosteus oculatus*), and muskellunge (*Esox masquinongy*)).” (pp. vii)

External link:
http://www.fes.uwaterloo.ca/research/aird/wetlands/index.htm
RARE MUSSELS

Mussel Species: White catspaw (*Epioblasma obliquata perobliqua*)

**Researcher/contact:** Peter J. Badra, Conservation Scientist - Aquatic Ecology
(517-241-4179; badrap@michigan.gov)

**Habitat:** "Because the White catspaw is so rare, little is known of their required habitat. In Fish Creek where the only extant population exists, the species has been found in riffles or runs of high gradient streams. Coarse, stable substrates, such as gravel and pebble, are preferred. While the species has been found on the surface of the substrate (Clark 1977), the lack of marl or algae on freshly dead shells indicates that the white catspaw is typically buried in the substrate (USFWS1990). In Michigan, the White catspaw also has been collected in large rivers, such as the Detroit River, and in the nearshore areas of Lake Erie. Specific Habitat Needs: Gravel, pebble substrate needed in headwater stream (1st-2nd order), riffle, headwater stream (1st-2nd order), run."

From Michigan Natural Features Inventory
http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=12362

**Distribution:**

http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=12362
http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Epioblasma+Obliquata+Perobliqua

Literature and additional sources:


"Extinction of North American unionoid bivalves can be traced to impoundment and inundation of riffle habitat in major rivers such as the Ohio, Tennessee and Cumberland and Mobile Bay Basin. Damming resulted in the local loss of the bivalves' host fish. This loss of the obligate host fish, coupled with increased siltation, and various types of industrial and domestic pollution have resulted in the rapid decline in the unionoid bivalve fauna in North America."

External link: none.

2. Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application).

"Management - Maintain high water quality and protect the host fish fauna. Like all filter-feeding mussels, the white catspaw is sensitive to siltation, and efforts should be made to decrease surface run-off. Changes in river hydrology and morphology can also harm this riffle-dwelling species, and dredging, channelization and damming projects should be avoided. Maintenance or establishment of vegetated riparian buffers can help protect mussel habitats from many of their threats. Control of zebra mussels is critical to preserving native mussels. And as with all mussels, protection of their hosts habitat is also crucial."

Survey References:
- Technical References

External link: http://web4.msue.msu.edu/mnfi/explorer

"Changes in river hydrology and morphology can also harm this riffle-dwelling species, and dredging, channelization and damming projects should be avoided."

**External link:**
http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Epioblasma+Obliquata+Perobliqua
Mussel Species: Northern riffleshell (*Epioblasma torulosa rangiana*)

**Researcher/contact information:** Peter J. Badra, Michigan State Conservation Scientist - Aquatic Ecology (517-241-4179 badrap@michigan.gov), Bill Tolin, U.S. Fish and Wildlife Service West Virginia Field Office (304-636-658) and G. Thomas Watters, Division of Wildlife, Ohio Department of Natural Resources, Columbus, Ohio. Also:

Ausable River, Canada Recovery Team
- Shawn Staton - Chair - Fisheries and Oceans Canada (905-336-4864)
- Mari Veliz - Chair - Conservation organization (NGO) (519-235-2610)

Ontario Freshwater Mussel Recovery Team
- Todd Morris - Chair - Fisheries and Oceans Canada (905-336-4734)

Sydenham River Recovery Team
- Muriel Andreae, Chair - Conservation organization (NGO) (519-245-3710)
- Shawn Staton - Chair - Fisheries and Oceans Canada (905-336-4864)

Walpole Island Ecosystem Recovery Team
- Madeline Austen - Chair - Environment Canada (416-739-4214)

**Habitat:** "The mussel lives mainly in highly oxygenated riffle areas of rivers or streams of various sizes. It once inhabited shoals in western Lake Erie and Lake St. Clair, where wave action was sufficient to produce continuously moving water. Preferred substrates range from rocky, sandy bottoms, to firmly packed sand and fine to coarse gravel." (Source: Canada species at risk (SAR) website)

**Distribution:** From Morris and Burridge, 2006 (left); state/federal distribution (right)

Source:
**Literature and additional sources:**


Selected References:

**External link:** [http://web4.msue.msu.edu/mnfi](http://web4.msue.msu.edu/mnfi)

2. Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application)

"The future of the Northern riffleshell depends on the protection and preservation of habitat and host fish. Siltation and run-off must be reduced to facilitate the recovery of this species. Damming and dredging of rivers have had a negative effect on the riffleshell, altering fast flowing, clear water habitats and making them unsuitable for sustaining riffleshell populations."

Survey References:
  Technical References

External link: http://web4.msue.msu.edu/mnfi/explorer


“Summary of Progress to Date

In 2002 the Ausable River Recovery Team was formed to develop an ecosystem-based recovery strategy for the watershed. The team synthesized existing information on four factors: species at risk (population trends, habitat needs and limiting factors), land use, water quality, and stream channel structure. This overview of the river’s health and threats provided a basis for the recovery strategy (draft available at www.abca.on.ca). The strategy identifies a high priority conservation zone, part of the watershed that contains the full range of all endangered and threatened species. It also recommends implementation of agricultural best management practices and improvements to wastewater treatment plants to reduce suspended sediment and nutrient loadings, which represent the most significant threats for the majority of species at risk.

Summary of Research/Monitoring Activities

Basin-wide surveys to assess the distribution of fish and mussel species at risk were conducted during the summer of 2002, resulting in the first records of Bigmouth Buffalo and Black Redhorse in the basin. Surveys of dragonflies, damselflies and reptiles along the Ausable River were conducted during July 2003. Additional surveys for fish, mussel, and reptiles were conducted in 2004 to help establish a more complete assessment of the current status of all aquatic species at risk in the basin. These surveys provide baseline data against which future population monitoring can be compared to track recovery progress.

Additional research is planned to inventory aquatic habitat and further clarify threats to species at risk. The goal is to assess the relative significance of identified threats and then implement mitigation measures.

Summary of Recovery Activities

The Ausable River Recovery Team has used several strategies to increase public awareness about species at risk in the river, including the distribution of brochures, installation of signs at local Conservation Areas and development of a website (see species at risk at www.abca.on.ca). Landowners have also received grants to complete stewardship activities that improve water quality and habitat for species at risk (e.g., excluding livestock from watercourses; planting buffer strip/riparian vegetation; modifying farm equipment to aid in efficient manure spreading, thereby reducing water pollution; and conservation tillage, which reduces soil erosion).
Because most of the land along the Ausable River is private farmland, landowner stewardship is critical to improving the health of the river and its species. The recovery team hopes to facilitate agricultural best management practices through more public outreach and landowner grants.

**Summary of Progress to Date**

The Sydenham River watershed is being addressed under an aquatic ecosystem-based recovery plan because it contains numerous species at risk (fishes, mussels, reptiles) that face similar threats which are related to land use throughout the watershed.

In advance of developing a recovery strategy, the recovery team synthesized existing information on four key factors: species at risk (trends over space and time, habitat needs, and limiting factors), land use, water quality, and stream channel structure. These reports and the synthesis report are available on-line at [www.sydenhamriver.on.ca](http://www.sydenhamriver.on.ca). The team found that the primary threat for most species at risk is siltation and associated turbidity from suspended solids, with nutrient loads, toxic compounds, thermal effects and exotic species as additional stressors.

The recovery team aims to maintain existing populations of aquatic species at risk and restore each species to areas of the river where they formerly occurred. Meeting this goal will require reducing sediment and nutrient loading and chemical inputs to the river. In order to track the effectiveness of the recovery program, the team is establishing a broad-based monitoring program that tracks the physical, chemical, and biological characteristics of the system. As well, research projects are being conducted to address knowledge gaps. The majority of the land in the Sydenham watershed is private; therefore, the team is endeavoring to improve land stewardship practices by encouraging a sense of public ownership and involvement among landowners, those working in the watershed, and other interested citizens.

**Summary of Research/Monitoring Activities**

A water quality monitoring program for the Sydenham re-instated in 2001 indicates that phosphate levels are high throughout the watershed and heavy metals are a concern in some locations.

Invertebrates in river bottom sediments are also being monitored because their diversity and abundance (e.g. crayfish, mayfly larvae, and dragonfly nymphs) is an excellent indicator of a river’s health.

Mussel species have been surveyed in order to determine each species’ distribution, and a monitoring protocol for periodic mussel surveys has been established. Surveys suggest that the Wavy-rayed Lampmussel has been extirpated from the Sydenham River, however populations of other species such as the Northern Riffleshell and Snuffbox are actively reproducing.

Extensive fish surveys have been conducted to identify the species occurring in the Sydenham River and determine their current distribution. Periodic surveys will be conducted to monitor fish species at risk.
Mussels spend part of their life cycle living as parasites on the gills or fins of fish. Researchers have been working to identify the fish hosts for several endangered mussels in the Sydenham and other Ontario rivers. Several of the Rayed Bean’s hosts have been identified: the Greenside Darter (also a species of concern), Rainbow Darter, Largemouth Bass, and Mottled Sculpin.

The Mudpuppy Mussel actually parasitizes mudpuppies (salamanders) instead of fish. Mudpuppy surveys have been conducted to determine the salamander’s population size and status in the Sydenham River.

Some of the endangered mussels, including the Northern Riffleshell and Rayed Bean, also have populations in the United States. Researchers are studying the genetic relationship between Canadian and American populations in order to determine if they are similar enough that healthier American populations could be used to restock extirpated Canadian populations.

Surface runoff from agricultural land is a significant source of sediment and nutrients. Tile drainage, in which tiles are placed underground to divert excess water from agricultural lands, also contributes sediment and nutrients, but the full impact of tile drainage was not known. Therefore, researchers measured the underground movement of sediment through tiles; preliminary results indicate that sediment input from tile drainage is much less than from surface runoff. If this is correct, reductions in surface runoff should remain the priority for recovery action. However, some tile drainage systems have surface inlets (e.g. catch basins), where surface runoff goes underground, and researchers are currently examining these systems to determine if surface inlets increase sediment inputs.

**Summary of Recovery Activities**

Several stewardship activities have been undertaken to reduce sediment and nutrient pollution in the Sydenham River. Riparian vegetation significantly reduces streamside erosion and sediment inputs and has been planted at many sites. In some cases, stream banks have been stabilized to reduce erosion. Buffer strips have been created on farms and riparian zones have been fenced to exclude cattle from streams. Building covers for manure storage sites eliminates runoff from manure stacks, thus protecting nearby watercourses. Sediment ponds or sediment traps also have been built to divert sediment flow away from the river.

Most of the land adjacent to the Sydenham River is privately owned. The recovery team facilitates stewardship through outreach (e.g., direct landowner contact, public meetings, website) and demonstration projects that profile several pasturing options designed to keep cattle out of streams (e.g., solar-powered water pumps for pasture cattle, rotational grazing, low level stream crossings). Furthermore, provincial and federal grants have been used to help farmers undertake stewardship activities that protect water quality. Since 2002, over 400 stewardship projects were undertaken with the support of such grants.

An education program on species at risk is offered, free of charge, for school-aged children and a presentation and display on the Sydenham Recovery program is available for watershed community events. Annually, a “Sydenham River Aquatic Species at Risk” newsletter is distributed through all watershed newspapers, describing recent research, stewardship, outreach and education activities.

External link:
http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=582
RARE SNAKES

Snake Species: Eastern fox snake
(Pantherophis gloydi) (Elaphe vulpina gloydi)

Researcher/contact: Yu Man Lee, Conservation Scientist, Michigan Natural Features Inventory (517-373-3751 leeyu@michigan.gov). See also:

Recovery Team for Eastern Foxsnake
Gary Allen - Chair - Government of Ontario (705-725-7517)
Angela McConnell - Chair - Environment Canada (416-739-5715)
Brian Hutchinson - Chair - Parks Canada (613-998-9880)

Walpole Island Ecosystem Recovery Team
Madeline Austen - Chair - Environment Canada (416-739-4214)

Habitat: The habitat used by Eastern Foxsnakes is mainly unforest, terrestrial shoreline ecosystems adjacent to marshes. Early successional stages (beaches, sandspits, and exposed rock) and intermediate seres (fields and marsh shorelines) are important habitats for the subspecies.

Source: http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=587

Distribution:

Left: Canadian Distribution of the Eastern Foxsnake (shown in red) ¹,²
¹Author: Canadian Wildlife Service, 2004;
²Data Sources: The main source of information and data is the COSEWIC Status Report. In many cases additional data sources were used; a complete list will be available in the future.


The distribution of the Eastern Foxsnake overlaps with a region of North America characterized by particularly high-density human populations, intensive urban and agricultural development, and high levels of industrial pollution. Present threats to the subspecies’ persistence in Ontario include: habitat loss and fragmentation (e.g.,
alteration and draining of wetlands, shoreline development), incidental mortality on roads, and human persecution. Illegal collecting and environmental pollution may also negatively affect local populations of the snake.

From: http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=587

**Monitoring:** SARA Public Registry Notice of Permit

**Purpose:** Scientific research for the conservation of the species

**Description:** Monitoring of Northern Map Turtle, Eastern Spiny Softshell Turtle, Eastern Fox Snake, Queen Snake and Butler's Garter Snake. Specimens live captured, examined, & released.

**Start:** 2006-05-25  **End:** 2006-08-15  **Contact:** Andrew Taylor andrew.taylor@ec.gc.ca

**Purpose:** Scientific research for the conservation of the species

**Description:** A population survey for the Eastern Fox snake on Middle Island at Point Pelee NP of Canada. Survey includes measuring, weighing and sexing captured Eastern Fox snakes. Passive Integrated Transponder (PIT) tags implanted. **Start:** 2005-05-05  **End:** 2008-05-04

**Issuing Authority:** Parks Canada Agency  **Contact:** Ms. Vicki McKay vicki.mckay@pc.gc.ca

**Purpose:** Other type of activity necessary or beneficial to the species

**Description:** To educate Point Pelee National Park visitors about the importance of all species, and in particular. Eastern Foxsnake and occasionally Stinkpot turtles are the Schedule 1 Species at Risk that are used as part of the "Creature Feature" program. **Start:** 2005-06-24  **End:** 2007-08-07.  **Issuing Authority:** Parks Canada.  **Contact:** Ms. Vicki McKay  vicki.mckay@pc.gc.ca

**Purpose:** Scientific research for the conservation of the species

**Description:** Hand capture of Eastern Fox snakes in order to sex, measure, weigh, and record UTM location.  **Start:** 2007-04-10  **End:** 2009-10-31.  **Issuing Authority:** Environment Canada  **Contact:** Andrew Taylor andrew.taylor@ec.gc.ca

**Summary of Research/Monitoring Activities**

from http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=587:

- Eastern Foxsnake habitat and hibernation sites are periodically monitored to ensure that restoration and recovery practices are improving.
- Gene flow and genetic population structure of the Eastern Foxsnake are being examined in the Georgian Bay and south-western Ontario, with the goal of identifying and minimizing loss of genetic diversity. A long-term monitoring strategy is underway in this area to identify population trends (survival and recruitment rate, the ratio between males and females, and age structure) and to develop growth models to determine key life history traits, such as age of maturity and maximum life span.
- The Ontario Natural Heritage Information Centre (NHIC) maintains a database that has compiled all known records of Eastern Foxsnake in Ontario, including
hibernation data where possible. The database is continually updated as new information is obtained. The Georgian Bay Reptile Awareness Program collects records of species at risk in the Georgian Bay area, which are forwarded to NHIC.

Radio telemetry studies at many locations on Georgian Bay have provided data on movement patterns, habitat use, hibernation locations, mating behaviour, egg laying sites, population characteristics, etc. Communal hibernacula at some of these locations have been monitored. A radio telemetry study is underway at Ojibway Prairie Nature Reserve and another telemetry study is planned for Long Point Provincial Park.

Radio telemetry studies have been conducted as well at Point Pelee National Park, Pelee Island, and in Norfolk County. Compilation of records including measurements and passive integrated transponder tagging (for identification) is ongoing at Point Pelee National Park, Georgian Bay Islands National Park of Canada, Rondeau Provincial Park, East Sister Island, Killbear Provincial Park, and Ojibway Prairie Nature Reserve.

Blood samples have been collected from several sites for DNA analysis by Queens University researchers. Samples from Long Point area snakes have been sent to Carlton University for study.

**Literature:**


Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application). Available online at http://web4.msue.msu.edu/mnfi/explorer

Natural Heritage Center, Ontario Ministry of Natural Resources

Royal Ontario Museum and the Ontario Ministry of Natural Resources Fact Sheet
http://www.rom.on.ca/ontario/risk.php?doc_type=fact&lang=&id=146
RARE INVERTEBRATES

Invertebrate species: Hine’s emerald dragonfly (*Somatochlora hineana*)

**Researcher/contact:** Dave Cuthrell, Michigan Natural Features Inventory ([cuthreld@michigan.gov](mailto:cuthreld@michigan.gov)), Mark O’Brien -- Michigan Odonata Survey Coordinator, Museum of Zoology, University of Michigan ([mfobrien@umich.edu](mailto:mfobrien@umich.edu); (734) 647-2199) Tim Cashatt, Dept. of Entomology, Illinois State Museum ([cashatt@museum.state.il.us](mailto:cashatt@museum.state.il.us)) Bob Glotzhober, Ohio Historical Society ([bglotzhober@ohiohistory.org](mailto:bglotzhober@ohiohistory.org))

**Habitat:** “…graminoid dominated wetlands which contain seeps, or slow moving rivulets; cool, shallow water slowly flowing through vegetation; and open areas in close proximity to forest edge (Zercher 1999). The shallow, flowing, cool water provides important larval habitat and the open areas with adjacent woodland edge provide adult hunting and roosting habitat. Michigan Hine’s emerald dragonfly sites could be classified as calcareous wetlands or northern fens with an underlining layer of shallow dolomite. One site in Mackinac County has been described as thinly treed, alkaline peatlands (Penskar and Albert 1988). Dominant vegetation in northern fens include sedges (*Carex aquatilis, C. lasiocarpa, C. limosa*, etc.).”


**Distribution:**

![Distribution Map](map.jpg)

Literature and additional sources:


   Selected references from Cuthrell, 1999:


   “Abstract: The federally endangered Hine’s Emerald Dragonfly is known only from a handful of sites where cool groundwater-fed wetlands occur in proximity to surface exposures of dolomite bedrock. Breeding occurs in small slowly flowing rivulets or in muck within sedge meadow/fen complexes with groundwater at or just below the surface.”

   Contact Information: Kenneth S. Mierzwa, Earth Tech, P.O. Box 1125, Ferndale CA 95536, USA, Phone: 312-420-3394, Fax: 312-777-5501, Email: ken.mierzwa@earthtech.com

"Larvae may take 2 to 4 years to fully mature, depending upon food resources, water levels, and temperature".


“Larvae for this species appear to have narrow habitat requirements (Vogt and Cashatt 1994, Cashatt and Vogt 2001, U. S. Fish and Wildlife Service 2001). Larval habitat for *Somatochlora hineana* was described by Cashatt and Vogt (2001) as follows: “Most of the known sites have some notable unifying features. These include: shallow, organic soils (usually muck) overlying dolomitic bedrock; calcareous water from intermittent seeps; shallow, small channels and/or sheetflow. These seepage wetlands often dry out for a few weeks during the summer, but otherwise have thermal regimes that are relatively moderate (warmer in winter and cooler in summer) compared to nearby sites without groundwater influence. Vegetation is predominantly herbaceous; natural communities include marshes, sedge meadows, and fens. These communities usually are dominated by graminoid plants such as cattails (*Typha* spp.) and sweetflag (*Acorus calamus*) in marshes or by sedges (*Carex* spp.) in sedge meadows and fens. Larvae are found in cool, shallow, slow moving (sometimes barely detectible) water flowing between hummocks of sedges or in shallow streamlets in spring-fed cattail marshes. The microhabitat usually contains decaying vegetation, such as cattail or sedge leaves.”

**Literature cited by Vogt and Cashatt, 2007:**


6. ORILLIA NATURALISTS' CLUB

**External link:**
http://www.couchconservancy.ca/ONCWebsite/htm/Find%20of%20the%20Month.htm
RARE PLANTS

Plant Species: Pitcher’s thistle (Cirsium pitcheri)

Researcher/contact: Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov) and Craig Anderson, Wisconsin Department of Natural Resources (craig.anderson@wisconsin.gov).

Distribution:

Source:

Literature and additional sources:


Page 196-197: “There are at least two disturbance regimes that affect the availability of open habitats that can be colonized by C. pitcheri (Fig. 8.2). One is the stochastic
occurrence of severe storms that erode beaches and open inland blowouts. The other is a nested cycle of dune system response to annual and longer-term climate changes. Shorelines characteristically recede during fall and winter periods of storm erosion and rebuild during spring and summer. **They also undergo more severe erosion and accretion cycles as lake levels fluctuate in response to climate shifts.** Lake Michigan levels fluctuate on approximately 30-year cycles nested within 100-year and 300-year cycles (Olson 1958b, Larsen 1985, Thompson 1987). Lakes Superior and Huron undergo similar fluctuations, but have slightly different cycle periods and magnitudes of change (Farrand and Drexler 1985).

Lake level fluctuations cause dune habitats to shift differently in space over time, depending upon their locations. For example, during high lake levels, beaches and foredunes erode and shift inland, while more inland dunes may remain stable or lose sand on their windward faces.” ……

**External link:**
http://books.google.com/books?hl=en&lr=&id=iOdN_SZC40QC&oi=fnd&pg=PR9&dq=.pitcher%27s+thistle&ots=vDJz2gzio0&sig=q_1mux03b2-1NxMnlWyjrIloRsQ

Note: this link provides only some brief excerpts from the book. The above quote was taken directly from the book itself.

**REFERENCE 2:** Carolyn Rock, Natural Resource Educator, Whitefish Dunes State Park. phone: 920 823-2400, fax: 920 823-2640, e-mail: carolyn.rock@wisconsin.gov

Email comments: “All the sampling was total plant counts. We go out and grid off the beach and then count all the thistles found within each of the grid segments.”

“I have seen thistle approach the water's edge but not more than 5 to 10 feet away. We have heavy beach walkers and I think that effects their growth. They do take advantage of openings within the dune and new beach area quite quickly. It is good to see them in larger numbers.”

Carolyn Rock’s data from Whitefish Dunes State Park shows a trend from immediately post-high-water conditions in 1989, when the population was 208 plants, to 2006 low water conditions, with a population of 12,382 plants. During the brief high water conditions in 1993 to 1995 populations did not show strong response, and there was unfortunately no data collected in the high water years of 1996 through 1998. Based on this partial data set it appears that Pitcher’s thistle increases dramatically on the beach when water levels are low, resulting in more habitat for Pitcher’s thistle on open, exposed sand.

**REFERENCE 3:** Higman, P.J. and M.R. Penskar. 1999. Special plant abstract for *Cirsium pitcheri*. Michigan Natural Features Inventory, Lansing, MI. 3 pp. Excerpts follow:
**Distribution:** The range of this Great Lakes endemic falls primarily within Michigan’s borders, occurring along the entire shoreline of Lake Michigan, with localities along the more limited dunes of Lake Huron and a few sites along the extensive Grand Sable dunes of the Lake Superior shore. In Canada this species occurs in northern Lake Huron and at least one site on the north shore of Lake Superior. Several scattered sites occur along Lake Michigan in Wisconsin, and populations remain extant in Indiana within Indiana Dunes National Lakeshore. Historically, Pitcher’s thistle was known from several localities in Illinois, where it was subsequently extirpated, but is now being reintroduced as part of the Federal Recovery Plan for the species.

**Habitat:** Pitcher’s thistle typically grows on open sand dunes and occasionally on lag gravel associated with shoreline dunes. All of its habitats are along the Great Lakes shores, or in very close proximity.

**Biology:** Seeds are dispersed individually by wind or as entire flower heads blown across the sand, or possibly transported by water.

**Literature:**

Wisconsin Endangered and Nongame Species Handbook. Wisconsin DNR.

**External link:**


“This monocarpic herb is an obligate colonizer of >70% open sand habitat in early- to mid-successional vegetation maintained by intermediate levels of disturbance or created by stochastic disturbance events.” ….. “The habitat requirements of Pitcher's thistle have made it extremely vulnerable to shoreline erosion, development, and recreational use. It is federally listed as threatened and state listed as endangered or threatened throughout its range in the United States. In Illinois, Pitcher's thistle was collected at least twelve times from the Lake Michigan shoreline between 1862 and 1919; it then apparently disappeared, probably as a result of the combined effects of increasing human activity, lake level fluctuations, collecting, and other chance events.” … "Ordination and cluster analysis demonstrated strong similarities between upper beach, foredune, secondary dune, and dunefield habitat in Illinois and similar thistle-occupied habitats in Indiana and Wisconsin. However, at Illinois Beach State Park only the secondary dune habitat appeared to be free from shoreline erosion and recreational impacts. Propagated plants from Indiana and Wisconsin seed sources were introduced into this habitat in 1991, with greater survivorship among the Indiana plants. Experimental establishment of additional cohorts from seeds and propagated material is
needed to further identify appropriate microhabitat, while shoreline protection, control of recreation, and periodic reintroduction may be required to maintain a metapopulation at Illinois Beach.”

**External link:**


“Although burial is required for germination, only 8% of seedlings emerged from a depth of 8 cm…..”

“Seeds of Pitcher's thistle can remain viable 1–2 y in the laboratory, suggesting this species can maintain a seed bank, although it is ephemeral. Seeds and seedlings of *Cirsium pitcheri* successfully exploit the dynamic nature of their dune habitats. Our results suggest that conservation efforts must consider seed storage conditions, genetic source of seeds and seed size, as well as maintenance of natural sand erosion and accretion regimes for preservation and restoration of this taxon.”

**External link:**


This reference contains general discussion of Pitcher’s thistles habitat, Great Lakes coastal dunes, but does not link the species to water-level fluctuation.

**External link:**


The population was decimated by the bursting of a beaver dam in 1986. ….. “Mosquin (1990) suggests that the species is an early successor into sandy environments, and that periodic disturbance is vital to its survival.”
Promaine suggests that populations dropped substantially due to reduced periodic disturbances following the bursting of the beaver dam and the rerouting of the stream along which the dam was located, but cooler and moister climatic conditions actually resulted in increased seedling establishment. No mention is made to relationships of thistle populations to Great Lakes water level.

External link: None.


“Pitcher’s Thistle (*Cirsium pitcheri*), Asteraceae, is endemic to the shoreline beaches and sand dunes of the Great Lakes. It is a disturbance-dependent rare species adapted to live in dynamic and often stochastic sand dune habitats.” ……

“Populations of *C. pitcheri* are found in sandy habitats on the high beach, foredunes, blowouts and dune ridges. The plants prefer sandy soils with texture of 39.4 to 76.7 % fine sand (<0.250 mm) and 19.7 to 56.2 % medium-grained sand (0.25-0.50 mm). In slacks the species can also grow in sandy soils with very coarse texture.”

“At the Pinery, *Calamovilfa longifolia* and *Andropogon scoparius* were the most abundant grasses with low coverage of *Ammophila breviligulata* on the first dune ridge and occasional shoots on the second dune ridge (Table 1). *Cirsium pitcheri* occurred most frequently in blowouts and within *C. longifolia* populations on the second dune ridge that were receiving about 2-3 cm of sand deposition annually. The species requires a moderate amount of sand movement and open bare areas among the vegetation. Mean percent bare sandy area at the Pinery ranged from 65.1 % on dune ridges to about 80 % in slacks (D.Ulisse and Maun 1996). The plants also occupied blowouts with 100 % bare area.”

**Burial of seeds and germination:** The percent seed germination and emergence of seedlings from 2, 4, 6, 8, 10 and 12 cm burial depths were negatively correlated with depth (Chen and Maun 1999). Seedling emergence occurred from a maximum depth of 6 cm with most seedlings emerging from 2 cm depth. Thus excessive burial is detrimental to the emergence of seedlings.”

**Anthropogenic Impact:** Recreational use of sand dunes affects populations in three ways. First, trampling kills plants directly (Fig. 2c). Second, trampling creates paths which enlarge over time because of erosion of sand thus exposing the roots of *C. pitcheri* and killing them. Third, the eroded sand is transported over the dune ridges and deposited on plants on the leeward sides of ridges which leads to excessive burial and eventual death of plants. Excessive burial in sand increases the vulnerability of the species at three stages of growth: seeds, seedlings, and adult plants. Deeply buried seeds either do not germinate or if they do the seedlings are unable to emerge from the soil. The ungerminated seeds may either decay in the soil or undergo enforced dormancy. After emergence the *C. pitcheri* seedlings may also be buried by sand to varying degrees in
different microhabitats (Maun et al. 1996). Seedlings can survive up to 75% burial in sand but complete burial of seedlings is fatal. In vegetative juvenile plants the probability of dying was greater in the smaller size classes owing to lower energy reserves. Large vegetative plants die when the sand deposition exceeds 25 cm (Rowland 1999).”

External link:  


Research by Anderson and Loope indicates that sand erosion rates increase during high-water periods, resulting in the activation of coastal sand dunes.

External link:  None.
Plant Species: Lakeside daisy (*Hymenoxys herbacea*)

**Researcher/contact:** Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov) and Laura Haynes, NRCS/USDA (laura.haynes@wdc.usda.gov).

**Literature and additional sources:**


“**Total range:** Lakeside daisy is an endemic restricted to the Great Lakes area, within which it is one of the region’s rarest plants. In the United States it is known only from the Marblehead Peninsula area in northern Ohio, three restored populations in northern Illinois (where it was known historically from two sites), and a single, extremely small colony in Michigan’s Upper Peninsula. In Ontario, Canada, where Lakeside daisy is most abundant, it occurs along much of the southern coast of Manitoulin Island and in several restricted areas near the tip of the Bruce Peninsula.”

“**Habitat:** In the main portion of its range, such as Manitoulin Island in northern Lake Huron, lakeside daisy occurs primarily in the limestone pavement community known widely as alvar, although it also inhabits limestone or dolomite cliffs near the Lake Huron shore. Spring flooding in many sites is followed by summer drought, which impedes woody plant establishment and succession. Fire may also play a role in these systems.”

**Literature:**


**External link:**


“**Global Range:** *Hymenoxys herbacea* is endemic to the Great Lakes region (Morton and Venn, 2000).”

“**HABITAT: Habitat Requirements**
*Hymenoxys herbacea* is largely confined to the grassland and pavement alvars or lakeshores in the Great Lakes regions. These habitats are characteristically flat, thin-soiled areas with prevalent dolomite and limestone rocks, sand and gravel that are
sparsely vegetated (De Mauro, 1993; Voss, 1996; Wunderlin, 1971). The habitats are open, with little tree cover, and receive large amounts of sunlight. The limestone pavement that is prevalent in the area allows for good drainage. The plants primarily grow in the cracks of the limestone pavements or on tufts of low-growing vegetation (i.e. mosses).”

“Specific Habitat: Hymenoxys herbacea occurs in one of three specific types of alvar habitat as defined by Reschke et al. (1999). A shortened description of each habitat type is given below; for a more detailed description see Reschke et al. (1999).

Grassland alvars have been classified by the Alvar Working Group of The Nature Conservancy (Reschke et al., 1999) as a ‘Little bluestem alvar grassland’. This community has a global rank of G2 (imperiled globally with usually 6 to 20 global occurrences) and is recognized by: open canopy, few shrubs over 0.5 m tall, many dwarf shrubs under 0.5 m tall, less than 50% of the ground surface is exposed and is dominated by grasses and sedges, loam soils are shallow over flat limestone dolostone bedrock, soils are often seasonally wet (saturated) and very dry (Reschke et al., 1999). Non-vascular pavement alvars have a global rank of G2 and are defined as having: open canopy, few shrubs, ground layer is primarily exposed limestone or dolostone bedrock covered with lichens and mosses, and the little soil present is restricted to rock crevices (grikes), or underneath a mossy mat (Reschke et al., 1999). Great Lakes limestone alvars are sparsely vegetated lakeshores found along the Great Lakes shorelines of Ontario and have exposed flat limestone or dolostone bedrock (about 20% vegetative cover). The surface of the bedrock has numerous cracks and crevices where most of the plants are rooted (Reschke et al., 1999).”

“Trends: Some shoreline habitat is degrading rapidly, particularly where pedestrian traffic is high within Bruce Peninsula National Park. These areas have been trampled consistently for a number of years as the Bruce Trail and National Park trails make use of the open spaces typical of the lakeshore habitat of the plant. Likewise, alvar habitats, with their open spaces, are being converted into camping areas although at a much slower pace than the shoreline habitat.”

External link:


External link:
http://books.google.com/books?hl=en&lr=&id=iOdN_SZC40QC&oi=fnd&pg=PR9&dq=pitcher%27s+thistle&ots=vDJz2gzio0&sig=q_1mux03b2-1NxMnlWyjrIlRoRsQ

Note: this link provides only some brief excerpts from the book. The above quote was taken directly from the book itself.

HABITAT: In full sun in xeric, calcareous sites; limestone and dolomite quarries and exposures; dry prairies.

HAZARDS: Overgrowth by woody species through succession; trampling and soil compaction; over-collecting; raiding of wild populations for gardens.

External link:
http://www.dnr.state.oh.us/dnap/Abstracts/h/hymeherb/tabid/1316/Default.aspx
**Plant Species: Dwarf Lake Iris (Iris lacustris)**

**Researcher/contact:** Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov) and Craig J. Anderson, Wisconsin DNR (Craig.Anderson@Wisconsin.gov)


“**Total range:** Iris lacustris is endemic to the northern shores of Lakes Michigan and Huron, growing nowhere else in the world. Its distribution centers around the Mackinac Straits region, with outliers extending to Wisconsin’s Door Peninsula and Ontario’s Bruce Peninsula. The distribution in the Great Lakes follows the geological feature known as the Niagara Escarpment, a limestone formation extending from the Door Peninsula through Michigan and Ontario to New York.”

“**Habitat:** Dwarf lake iris usually occurs in close proximity to Great Lakes shores on sand or in thin soils over calcareous gravel or bedrock (alvar). It tolerates full sun to nearly complete shade, but appears to flower best in semi-open edge or ecotonal habitats, typically amongst scattered trees or on shoreline forest margins where it usually occurs with northern white cedar (Thuja occidentalis) and balsam fir (Abies balsamea).”

**External link:** http://web4.msue.msu.edu/mnfi/abstracts/botany/Iris_lacustris.pdf


“**Species information:** …….. The plant spreads vegetatively by rhizomes, and can form very large colonies of interconnected stems.”

“**Habitat requirements:** Dwarf lake iris grows along lakeshores on sandy or gravelly beach ridges in shallow calcareous soils at the beach-forest edge, where there are numerous small gaps in the forest canopy (Van Kley and Wujek, 1993).” …….. “It usually grows within close proximity to the Lake Huron shoreline, although it can be found inland on the shores of small lakes, ponds or wetlands several hundred metres from the Lake Huron shoreline (Van Kley and Wujek, 1993). These populations are possibly remnants from former glacial-lake shorelines. Most sites in Ontario were located within 500 metres of the Lake Huron shore. The exception is the site found at Highway 6 and Dorcas Bay Road, Bruce Peninsula. The species can tolerate a wide range of microclimate types, soil types, and pH range (Van Kley and Wujek, 1993), but grows and reproduces optimally on thin, well-drained soils that are semi-shaded, a habitat also favoured by bearberry (Arctostaphylos uva-ursi). Light intensity appears to have the strongest effect on dwarf lake iris, with bloom to shoot ratio being highest at approximately 40900 Lux (3800 foot-candles). There is also a lower bloom to shoot ratio where the water table is within 25 cm of the surface (Van Kley and Wujek, 1993).” ….
“At several of the sites where field observations were made, a cool fine mist could be seen blowing off Lake Huron by prevailing westerly winds. The author hypothesizes that this mist might be a component of dwarf lake iris habitat.”

“Reproduction: Dwarf lake iris mainly reproduces vegetatively with new plants being established from rhizomes resulting in colonies of genetically identical individuals. Natural fruit and seed set are low, and seeds only germinate sporadically after long periods of dormancy (Hannan and Orick, 2000; Makholm, 1986).”

“Movements/dispersal: Dwarf lake iris seeds are ant-dispersed. ……… Plants generally are not near the water’s edge so it is unlikely that seeds could float to Ontario shores from the limited sites in the USA; few seeds are produced by the plants and their longevity in water is unknown.”

External link:
Plant Species: Eastern prairie fringed orchid (*Platanthera leucophaea*)

**Researcher/contact:** Michael Penskar Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov) and Laura Haynes, NRCS/USDA (laura.haynes@wdc.usda.gov)

**Distribution:**

Source:

**Literature and additional sources:**


**Total range:** “Centered about the Great Lakes, *P. leucophaea* occurs east to Virginia and along the St. Lawrence drainage to Maine, ranging west into the Great Plains to the Dakotas and Iowa, and south in the Mississippi drainage to Missouri and Oklahoma. Now near extinction throughout much of its range, most populations are concentrated in the southern Great Lakes region, occurring primarily in southern Wisconsin, Illinois, Ohio, and southern Lower Michigan. This species is considered rare in Illinois, Iowa, Maine, Missouri, Ohio, Oklahoma, Virginia, Wisconsin, and Ontario. It is considered extirpated...
in Indiana, New Jersey, and Pennsylvania, and is known only from historical records in New York and South Dakota.”

**Habitat:** “*Platanthera leucophaea* occurs in two distinct habitats in Michigan--wet prairies and bogs. It thrives best in the lakeplain wet or wet-mesic prairies that border Saginaw Bay and Lake Erie. These communities have relatively alkaline, lacustrine soils, and are dominated by *Carex aquaticis*, *C. stricta*, and *Calamagrostis canadensis*, as well as several prairie grasses and forbs. **Prairie fringed-orchid frequently persists in degraded prairie remnants, and will frequently colonize ditches, railroad rights-of-way, fallow agricultural fields, and similar habitats where artificial disturbance creates a moist mineral surface conducive to germination.** Open or semi-open bog mats of *Sphagnum* and *Carex*, with slightly acidic, neutral, or somewhat alkaline lake water also support small populations of this orchid.”

**Biology:** ……… “Plants do not flower every year, frequently producing only a single leaf above ground (M. Bowles, pers. comm) and possibly even becoming dormant when conditions are unsuitable, such as the onset of drought. Fire is thought to help break dormancy and stimulate flowering (Sheviak 1974), although its role in Michigan *Platanthera* sites is highly uncertain and controversial among some botanists.”

**Conservation/management:** Competitive encroachment by native shrubs, especially dogwoods and willows, and pernicious exotics such as *Lythrum salicaria* (purple loosestrife) pose one of the greatest threats to Michigan’s remaining prairie fringed orchids. The large-scale destruction of lakeplain prairie habitat, primarily through alteration by ditching and diking, the conversion of areas for agricultural use, and other land settlement activities have rendered this species particularly vulnerable to extinction. **In its last remaining viable sites, eastern prairie fringed orchid is best protected by maintaining the natural hydrological cycles of the lakeplain wet prairies.** Protection can only be adequately afforded when sufficient refugia are available during periods of high lake levels. Unfortunately, few natural areas are left that provide the necessary landward habitat. Where refugia are available, this species is able to seed inland during high water cycles, advancing shoreward again as lake levels recede (Case 1987). This natural fluctuation along the Great Lakes shores maintains the necessary open, wet prairie habitat, preventing closure and shading by highly competitive woody plants such as dogwoods (*Cornus* spp).”

**External link:**
http://web4.msue.msu.edu/mnfi/abstracts/botany/Platanthera_leucophaea.pdf


**“Global Range.** The Eastern Prairie Fringed-orchid once occurred from Maine west to southern Ontario and Michigan, southern Wisconsin, southeastern Iowa and south to Oklahoma, Louisiana and Arkansas (Sheviak 1987), east to central Virginia and Pennsylvania with a higher concentration of occurrences (many extirpated) in the area of the southern Great Lakes (particularly the prairie peninsula). It has been reliably reported from 13 states and 1 province (Sheviak and Bowles 1986, Bowles 1991).”…..
“Habitat. Eastern Prairie Fringed-orchid occurs in six types of habitat in Ontario some
of which may be considered more important than others because they last longer and are
more difficult to create and manage. The habitat types (particularly graminoid and shrub
fen) may intergrade, but still provide a useful distinction when looking at the total range
of habitat occupied by the species.

1. Fens dominated by the sedge Carex lasiocarpa (e.g., sites 31, 24, 30, 10, 33). The
latter 4 sites have been known for at least 35 years and are considered viable. These
fens are often rather shrubby, with shrubs most commonly occurring on hummocks. The
orchid is then usually found in the sedge-dominated hollows.

2. Fens dominated by common reed grass (Phragmites australis) and sedges (e.g.,
sites 31 and 12).

3. Boggy mats around lakes with sphagnum moss, heaths and cranberry, but not
strongly acid and somewhat marly below the raised acid hummocks. Only one site (22)
and possibly not long-lasting due to limited area.

4. Cobble limestone shore. Only one site known (1) on Bruce Peninsula which has
a long history. The lake has a broad, shallow shoreline which, depending upon beaver
activity, is exposed annually.

5. Wet mesic prairie with bluestems and other grasses and a high diversity of
plants. The mesic and wet mesic prairie communities are largely confined to
Lambton County and the St. Clair delta area and to the more limited area at
Windsor (site 8). A description of these habitats is available in Faber-Langendendoen and
Maycock (1994). Brown (1985) lists plants associated with P. leucophaea at a site in
Lambton County. These are long-lasting gradient habitats.

6. Old fields with Poa compressa, Carex lanuginosa, Juncus spp., and early
development of Cornus shrubs (e.g., sites 2, 3, 22). These habitats last for approximately
10 years before loss to succession.”

“The Eastern Prairie Fringed-orchid is adapted to water level fluctuations. It
may remain dormant or vegetative in areas that are either too wet or too dry along a
gradient with fluctuating water levels. The problem now is that during periods of
low water levels (particularly in the Great Lakes), agricultural cultivation extends
further into the lower ground thus eliminating populations in the upper part of the
gradient. Wet years result in flooding of cropland, rather than flooding of a natural
habitat (see also Case 1987 p. 20).”

“In fens where water levels fluctuate the succession is interrupted and restarted
when shrubs are flooded out or die due to drying out or are burned. Rhizomes of these
perennial orchids may survive these events below ground so that the populations do not
actually disappear but only vary in their above ground appearance. The same is true of
some prairie sites where either drought or high water prevent succession to shrub cover
or domination by a few species, thus perpetuating an intermediate successional stage
where the orchids can survive. Some of the sites in fens (e.g., site 31) or lake margins
(site 1) fluctuate from hundreds or even thousands to none from year to year.”
BIOLOGY. …… “Platanthera leucophaea exhibits adaptations to catastrophic events such as periodic drought and may exist in subterranean, dormant or mycotrophic state for one or more years, but proof that flowering plants revert to subterranean existence is lacking. Vegetative plants, however, have been found in many places where flowering plants previously occurred. The plants are noted for dramatic, massflowerings following several-year periods of apparent absence. This behaviour appears to be linked to fire-stimulated growth and flowering, although other factors, such as rainfall and soil moisture levels, are likely involved as well (Sheviak and Bowles 1986). Population maintenance is dependent on long-term survival of adults and reproduction by seeds.”

External link:
Plant Species: Hill’s pondweed (Potamogeton hillii)

Researcher/contact: Greg Grabas, Environment Canada, Canadian Wildlife Service
(416-739-4939 Greg.Grabas@ec.gc.ca)

Distribution:

Source:

Literature and additional sources:


“Reason for designation An inconspicuous, rooted, aquatic plant currently known from fewer than 20 Canadian populations and occupying a very small total area of habitat. No imminent limiting factors have been identified that would have significant impacts on this globally rare species, but invasive exotic plants may be impacting some populations.”

“Species information Hill’s pondweed (Potamogeton hillii) is an entirely submerged pondweed, 30-60 cm long with narrow, linear, bristle-tipped leaves 2-6 cm long and 1-
2.5 mm wide. Fruit is brown, up to 4 mm long, and borne on a recurved stalk. Its overall appearance is similar to other linear-leaved pondweeds.”

**Habitat**

Hill’s pondweed is found in cold, clear, calcareous streams, ponds and ditches with an alkalinity of 53.0 to 316.7 mg/l HCO₃, usually where there is dolomitic limestone.”

**Biology**

Reproduction occurs both by seed and vegetatively by winter buds. Flowering occurs in July, and seed set occurs August to September. Seeds are water or waterfowl dispersed.”

**External link:**

**REFERENCE 2:**

“**Canadian range:**  Given its unremarkable appearance, it is likely that Hill’s pondweed has been long overlooked, and could be more widespread than is currently reported. It is associated with dolomitic limestone (Hellquist, 1984) so potential habitat might be found along the Niagara Escarpment and the Precambrian contact line (Brownell, 1986).”

Both inland and Great Lakes coastal sites identified.

“**Habitat requirements**  Hill’s pondweed is found in cold, clear, slow-moving, calcareous streams, ditches, and ponds with a muddy substrate. Rarely is it in turbid or polluted waters, in open lakes (Hellquist, 1984), or fast moving streams (personal observation by the report writer)”.  

“It was typically observed during field visits in shallow channels in open marshes dominated by grasses or sedges (most often Phalaris arundinacea).”

Note: No long-term monitoring has been conducted.

**External link:**

**REFERENCE 3:**
Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application). Available online [Accessed Nov 8, 2007]

“**Key Characteristics**

Aquatic plant of cool northern Michigan ponds; stem slender and branched; leaves alternate, submerged, and narrow (1-2 mm), with three parallel veins.”

**External link:**
http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=15819
Plant Species: Seaside crowfoot (*Ranunculus cymbalaria*)

NOTE: Several references to seaside crowfoot indicate that it is found on exposed saline muds, primarily in coastal estuaries, rather than in freshwater marshes.

**Researcher/contact:** Craig Anderson, Wisconsin Department of Natural Resources ([craig.anderson@wisconsin.gov](mailto:craig.anderson@wisconsin.gov))

**Distribution:**

![Map of U.S. States and Canadian Provinces](image)

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**Literature and additional sources:**

**REFERENCE 1:** Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application).

“**Habitat** This species is known from damp shores of meadows, marshes, and streams and moist, boggy lakeshores. **Natural Community Types** Intermittent wetland [boggy seepage wetland]”

**External link:** [http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=14632](http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=14632)

“... Primary colonizers of estuarine brackish soft sediments are Hippuris tetraphylla, Hippuris vulgaris, *Ranunculus cymbalaria* and Myriophyllum exalbescens. ...”


“... flats whose saline nature was indicated by the presence of such plants as sea milkwort (Glaux maritima), seaside crowfoot (*Ranunculus cymbalaria*), the tiny star ...”

External link: http://links.jstor.org/sici?sici=0004-8038(194304)60%3A2%3C171%3ANHOTYR%3E2.0.CO%3B2-O


“... *P. trivialis*, *Ranunculus cymbalaria* and Spergularia rubra, did oc- cur in the seed bank but were not found in the estab- lished vegetation of the transects. ..”

External link: http://links.jstor.org/sici?sici=1100-9233(199806)9%3A3%3C395%3ASBOGAU%3E2.0.CO%3B2-0
Plant Species: Arrowhead (Sagittaria montevidensis)

**Researcher/contact:** Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov) and James K. Bissell, the Cleveland Museum of Natural History (j24bissell@roadrunner.com)

**Literature and additional references:**

**REFERENCE 1.** Michigan Natural Features Inventory. 2007. Rare Species Explorer (Web Application)

“Status and Rank:
State Status: T - Threatened (legally protected)
State Rank: S1S2 - Rank is uncertain, ranging from critically imperiled to imperiled
Global Rank: G4G5 - Rank is uncertain, ranging from apparently secure to secure

Habitat: Broad-leaved arrowhead is found in wet to shallowly inundated mud flats and banks, lagoons, and estuaries.

Management To protect this species, maintain hydrological cycles, including periodic natural drawdowns necessary for replenishment of seed bank. Control of invasive species like purple loosestrife and Phragmites may also be necessary at some locations.”

**External link:** [http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=15095](http://web4.msue.msu.edu/mnfi/explorer/species.cfm?id=15095)

**REFERENCE 2:** Dr. James Bissell’s email comment:

“In response to your reference to Sagittaria montevidensis, I checked to see whether I sent you the info on Sagittaria montevidensis (syn.=S. calycina).” ……… “This plant had not previously been reported for Presque Isle even though it is common within the Palustrine Sand Plain Communities on Lake Erie east of Sandusky. I first found the Sagittaria calycina at Presque Isle during the low lake levels of 1999, 2000, 2001. Close to a thousand plants appeared on newly exposed sandy flats within the area locals call Leo Boat Livery. There were at least a thousand Schoenoplectus smithii growing with the Sagittaria calycina.”

**External link:** None.
Plant Species: Weakstem bulrush (Schoenoplectus purshianus)

**Researcher/contact:** Bill Crins, Ontario Ministry of Natural Resources, Ontario Parks. (bill.crins@ontario.ca)

**Literature and additional references:**


Page 109 (abstract): “Seeds buried in either flooded or nonflooded soil and exposed to natural seasonal temperature changes for 32 months exhibited an annual dormancy/nondormancy cycle each year when tested in light under either flooded or nonflooded conditions. That is, seeds came out of dormancy during autumn and winter and could germinate to high percentages in spring. Burial prevented seeds from germinating ….”

Page 110: “*This annual sedge (Strong, 1994) grows on muddy or sandy shores of lakes and ponds, especially after water levels have receded (Voss, 1972; Strong, 1994).*”

Page 114: “In Illinois, USA, where *S. purshianus* is state-endangered…” …. “In summers with low rainfall, the depressions are dry enough to be ploughed and sown with crops. **However, in wet summers the depressions become filled with water, and seeds of *S. purshianus* germinate at the edge of the ponds.**”

Page 115: “The soil depressions in Illinois were filled with water in 1974 and 1993, and the occurrence of *S. purshianus* at the site in 1993 suggested that the species has a persistent soil seed bank that lasts for at least 20 years (McClain et al., 1997).”

**External link:** none.


“... can germinate under water, at relatively low oxygen concentrations, similar to those of the mudflat summer annual *Schoenoplectus purshianus* (Fern.) Strong ...”

**External link:**

**REFERENCE 3:** Bill Crins, email response to questionnaire:

Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay cast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular
monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat visit data. ‘Species at Risk’ related field work sometimes provides more frequent updates on population status.
Plant Species: Smith’s bulrush (*Schoenoplectus smithii*)

**Researcher/contact:** Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov), James K. Bissell, The Cleveland Museum of Natural History ([j24bissell@adelphia.net](mailto:j24bissell@adelphia.net)) and Bill Crins, Ontario Ministry of Natural Resources, Ontario Parks ([bill.crins@ontario.ca](mailto:bill.crins@ontario.ca))

**Literature and additional references:**

**REFERENCE 1: Dr. James Bissell’s email comment:**
“In response to your reference to Sagittaria montevidensis, I checked to see whether I sent you the info on Sagittaria montevidensis (syn.=S. calycina).” ......... “This plant had not previously been reported for Presque Isle even though it is common within the Palustrine Sand Plain Communities on Lake Erie east of Sandusky. I first found the *Sagittaria calycina* at Presque Isle during the low lake levels of 1999, 2000, 2001. Close to a thousand plants appeared on newly exposed sandy flats within the area locals call Leo Boat Livery. There were at least a thousand *Schoenoplectus smithii* growing with the *Sagittaria calycina*.”

**External link:** none.


Page 2: “The major changes in natural communities that have occurred on Gull Point between 1987 and 2002 are due to rises and falls in the level of Lake Erie and rapid encroachment of two invasive species, reed grass (Phragmites australis) and narrow-leaf cattail (Typha angustifolia).” ......... “Wherever reed grass or narrow-leaf cattail is absent from pond and bay shores, the Palustrine Sand Plain Community establishes on newly exposed wet sand flats on inland pond and protected bay shores during low levels of Lake Erie such as those in 1992 and 2002. Where pond shores and protected bay shores have native emergent marsh species such as greater bur-reed (Sparganium eurycarpum) and blue-joint reed grass (Calamagrostis canadensis), the native marsh species die back when the level of Lake Erie rises. **When the lake levels fall again, the Palustrine Sand Plain Community will establish on the open wet sands formerly occupied by the marsh species.”**

Page 5-6: “In 2002, the following rare species previously reported from Presque Isle outside the Gull Point Peninsula were discovered on Gull Point:

- *Ptelea trifoliata*
- *Rosa setigera*
- *Schoenoplectus smithii*.“

...................................... “1. Palustrine sand plain
The palustrine sand plain is a moist sparsely vegetated sandy flat. Standing water is often present in the spring. The water table often drops below the surface during the summer. Typical sand plain species include: Juncus articulatus, Juncus arcticus, Juncus alpinus, Cyperus bipartitis, Cyperus flavescens, Agalinis paupercula, Carex viridula, Schoenoplectus americanus and Hypericum majus.

A total of 25 Plants of Special Concern in Pennsylvania have been found within the Palustrine Sand Plain Community on Gull Point since 1985, twenty-four POSCIP species and one hybrid.

Agalinis paupercula  Endangered
Aster dumosus  Tentatively Undetermined
Carex bebbii  Endangered
Carex garberi  Endangered
Carex viridula  Endangered
Cyperus diandrus  Endangered
Eleocharis caribaea  Endangered
Eleocharis elliptica  Endangered
Eleocharis pauciflora  Endangered
Eleocharis quadrangulata  Endangered
Equisetum x. ferrissii  Endangered
Equisetum variegatum  Endangered
Lipocarpha micrantha  Endangered
Hypericum majus  Threatened
Juncus alpinus  Threatened
Juncus arcticus  Rare
Juncus biflorus  Tentatively Undetermined
Juncus brachycephalus  Rare
Juncus torreyi  Endangered
Lathyrus palustris  Tentatively Undetermined
Lobelia kalmii  Endangered
Parnassia glauca  Endangered
Potentilla anserina  Threatened
Potentilla paradoxa  Endangered
Schoenoplectus smithii  Endangered”

Page 9: “Ten POSCIP [Pennsylvania rare] plants returned from the seed bank where park staff removed reed grass on the shoreline of the West Inlet. The ten species found within the restored community include Smith’s bulrush (Schoenoplectus smithii), Tuckerman’s panic grass (Panicum tuckermanii), bushy cinquefoil (Potentilla paradoxa), green sedge (Carex viridula), dwarf bulrush (Lipocarpha micrantha), umbrella flatsedge (Cyperus diandrus), Torrey’s rush (Juncus torreyi), larger Canada St. John’s-wort (Hypericum majus), alpine rush (Juncus alpinarticulatus), small-headed rush (Juncus brachycephalus), Baltic rush (Juncus arcticus) and four-angled spike-rush (Eleocharis quadrangulata).”
Page 2: “During 1985-86 and 1996-97, the highest levels of Lake Erie, no Palustrine Sand Plain Community was found along the north central and northwest shore of Thompson Bay on Gull Point. **However, the lower level of Lake Erie in 1992 exposed moist sandy flats that supported high-quality Palustrine Sand Plain and many rare plants including Carex viridula, Lippocarpha micrantha, Juncus alpinus, Juncus brachycephalus, Juncus arcticus, Potentilla paradoxa, Potentilla anserina, and Hypericum majus.** In 1997, the 1992 Palustrine Sand Plain flats were again under the waters of Lake Erie. Due to the lower level of Lake Erie in 2002, the flats of 1992 were again exposed that were covered in 1997 and Tuckerman’s panic grass (Panicum tuckermanii), not observed on Gull Point in 1997, was observed again on many of the same flats where it was observed in 1992. Several high quality Palustrine Sand Plains that were mapped in 1992 were not present in 2002 because phragmites has since crowded them out.”

**External link:** none.

**REFERENCE 3:** Bill Crins, email response to questionnaire:

Little active monitoring is occurring for these species anywhere in Ontario. Occasional inventories in protected areas along the Georgian Bay coast document presence/absence in particular years, and sometimes abundance, providing intermittent and irregular monitoring information. Parks such as Georgian Bay Islands National Park have some limited monitoring data on some of these species. Other coastal protected areas generally have species inventories, but few or no repeat visit data.; ‘Species at Risk’ related field work sometimes provides more frequent updates on population status.

**External link:** none.
Plant Species: Houghton’s goldenrod (*Solidago houghtonii*)

**Researcher/contact:** A.A. Reznicek, University of Michigan Herbarium (Reznicek@umich.edu) and Michael Penskar, Michigan Natural Features Inventory (Michigan State University Extension; penskarm@michigan.gov)

**Literature and additional references:**


“The greatest concentrations of *S. houghtonii* lie in Chippewa, western Mackinac, northern Emmet, Cheboygan, and northern Presque Isle counties. Each of these areas has large populations extending over at least a mile of shoreline, as well as several scattered smaller populations. About 60 occurrences are known overall. **Habitat:** *Solidago houghtonii* occurs primarily along the northern shores of Lakes Huron and Michigan, restricted to calcareous beach sands, rocky and cobbly shores, beach flats, and **most commonly the shallow, trough-like interdunal wetlands that parallel shoreline areas.** This species also occurs on seasonally wet limestone pavement, its more typical habitat in the eastern portion of its range, primarily in Ontario (Morton 1979; Semple and Ringius 1983). **Biology:** Houghton’s goldenrod is a perennial, frequently forming small clumps (clones) produced vegetatively by means of relatively short rhizomes (underground stem)”……

**External link:** [http://web4.msue.msu.edu/mnfi/abstracts/botany/Solidago_houghtonii.pdf](http://web4.msue.msu.edu/mnfi/abstracts/botany/Solidago_houghtonii.pdf)


Exerpts from report:

“**Habitat** Houghton’s goldenrod grows on seasonally wet limestone pavements (alvars), calcareous beach sands, or interdunal wetlands along the Great Lakes shoreline. The Ontario population is primarily found on alvars. There is little information regarding microclimate requirements.” …

“**Biology**”……. “Flowering occurs in approximately 6 to 31% of shoots. Flowers are insect pollinated and appear to be incapable of self-pollination. Fruit set and germinability are low. *Solidago houghtonii* can also reproduce vegetatively by means of underground rhizomes.” ………

“**Limiting factors and threats** Houghton’s goldenrod is restricted to alvars and interdunal wetlands. The main threats to the species are drought, heavy recreational use, and quarry operations. There may also be some threat from floods, invasive species, and residential development.” ………
“Habitat requirements: Houghton’s goldenrod is closely associated with the Great Lakes shorelines, particularly Lake Huron and Lake Michigan. The continental climate of the area is moderated by the effect of Lake Huron. Both Manitoulin Island and the Bruce Peninsula have milder winters and cooler summers than areas of similar latitude in Ontario. Average January temperature is -10.0°C, average July temperature is 19.1°C, and the area receives 808.9 mm of precipitation each year (Environment Canada climate data for Gore Bay). Houghton’s goldenrod is found on calcareous beach sands, interdunal wetlands, or seasonally wet limestone pavements (Morton, 1979). The latter kind of habitat, also known as alvar, is by far the most common habitat for Houghton’s goldenrod growing in Ontario. Over 86% of Ontario’s known populations of Houghton’s goldenrod occur on alvars (Catling, 1995). This is in contrast to Michigan, where the species is mostly associated with dunes (Morton, pers. comm.) but perhaps more specifically in interdunal wet meadows (Penskar, 1997).”

“Little else is known about particular microclimate requirements, but the persistence of Houghton’s goldenrod in alvars indicates it is likely to be drought-resistant (Penskar, 1997). It is also limited to calcareous areas, suggesting that the species may have a high calcium requirement.”

“General Houghton’s goldenrod is a perennial herb that reproduces asexually by rhizomes and sexually. It grows on alvar substrates where plants are subjected to flooding and dessication.”

“Reproduction” “Solidago houghtonii can also reproduce vegetatively by means of underground rhizomes. Plants have between 2 to 12 ramets that rapidly disarticulate and become established as independent plants (Penskar, 1997). Basal rosettes live 1-6 years without flowering and often persist vegetatively after successfully flowering and fruiting (Penskar, 1997).”

“Behaviour/adaptability There is little information about the adaptability of this species to stress or disturbance. Its presence in alvar habitat indicates that it is likely to be tolerant of droughts and floods, and a poor competitor, though no studies have been published that test these.”


REFERENCE 3: The author (Dennis Albert) has collected this species at least three miles (5 km) inland from the present Great Lakes shoreline in seepages along the glacial Lake Algonquin shoreline of the Great Lakes, created approximately 11,000 years ago. The habitat is open, wet, and calcareous, very similar to the plant’s habitat along the present Great Lakes shoreline.
Natural Resources Integrated Information System

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Publication

Institute of Water Research
Annual Technical Report
FY 2007

Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU’s efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. (An extended introduction can be found in our FY2001 Annual Technical Report.) We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research data and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute also works closely with the MSU Cooperative Extension Service to conduct outreach and education. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU-WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute’s staff works half-time in facilitating MSU-WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute’s general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and “intelligent” tools that visualize wise resource management and conservation in a single holistic system are likewise imperative.
Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.

**Research Program**

The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web-based information to aid in the informed decision-making process.

**Unique Capabilities: Decision Support Systems as the Nexus**

IWR, with its “extended research family,” is exceptionally well-positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water resources, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science-based research produced in these domains. A special emphasis is being placed on facilitation of science-based natural resource state and national policy evolution.

The Institute’s extensive experience in regional and national networking provides exceptional opportunities for assembling multi-agency funding to support interdisciplinary water research projects and multi-university partnerships.

**Using A Multi-Disciplinary Framework**

Using a multi-disciplinary framework facilitates dynamic applications of information to create geospatial, place-based strategies, including watershed management tools, to optimize economic benefits and assure long-term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real-time environmental datasets make a new “intelligent reality” possible.

Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives.

The ultimate goal of these new imperatives is to secure and protect the future of water quality and supplies in the Great Lakes Basin and across the country and the world—with management strategies based on an understanding of the uniqueness of each watershed.
Title: Natural Resources Integrated Information System

Project Number: MI99B

Start: 03/01/07 (actual)
End: 02/28/08 (actual)

Funding Source: USGS (“104B”)

Congressional District: eighth

Research Category: Water Quality

Focus Categories: M & P, WQL, MOD

Descriptors: Data Analysis, Data Storage and Retrieval, Information Dissemination, System Analysis, Geographic Information Systems, Water Quality Management, Watershed Management

Primary PI: Jon F. Bartholic, Institute of Water Research, Michigan State University

Project Class: Research

Problem and Research Objectives

To protect and restore the nation’s waters, federal and state agencies are increasingly utilizing a watershed approach to examine and address water resources problems. The overall goal of this approach is the restoration, maintenance and protection of water resources across the country. The Institute of Water Research at Michigan State University is also looking at water resources on a watershed basis and is working to develop programs and partnerships within a watershed framework. Because of our Institute's long-term position relative to national and state water programs, we function as a coordinator to assist with linkages, support education, research, and outreach with and among agencies in the broad water arena. Accordingly, we are in a unique position to facilitate watershed policy, planning, and management using a multi-disciplinary perspective.

Methodology

Our proposed efforts include three major thrusts. The first is the enhancement of integrated watershed systems including both surface and groundwater that can be used for analysis of various management options. The second is extended education where the internet and advanced computer systems as well as traditional conferences and training workshops are used to extend new knowledge to agencies, organizations, and local level watershed and land use groups. The third involves developing a networking infrastructure to facilitate cooperation among partners such as the USDA, Natural Resource Conservation Service, USEPA, Army Corp of Engineers, the Great Lakes Commission, state Departments of Natural Resources, Environmental Quality, and Agriculture, township associations and county organizations.

Principle Findings and Significance

Extensive investigation and research is needed to achieve effective coupling of human management needs with geospatial databases and decision support systems to assist better decision-making. Multiple research funding opportunities exist to support linking understanding of various phases of the hydrologic cycle with impacts on water use, management, and conservation. As a result, outstanding opportunities to develop scientific water management skills and techniques for the 21st Century are clearly within reach.
Development of geospatial decision support systems complement and build on the extensive scientific knowledge of the role of the hydrologic balance in the functioning of dynamic ecosystems. Based on current development of geospatial databases and modeling systems, a model of the hydrologic balance for the state can be developed to assist water management and conservation. By incorporating extensive geospatial data with the analytical capacity of decision support systems, university researchers are providing decision-makers and managers with a more refined understanding of the hydrologic cycle and water balance functions at watershed and statewide scales.

Our USGS investments over the past two years led to a two-year $540,000 grant from the Great Lakes Protection Fund awarded to Michigan State University and the Institute of Water Research (IWR) for a project entitled “Restoring Great Lakes Basin Waters Through the Use of Conservation Credits and an Integrated Water Balance Analysis System.” The IWR is responsible for coordinating and collaborating multidisciplinary teams from various organizations including the World Resources Institute, Institute for Fisheries Research of the Michigan Department of Natural Resources, Public Sector Consultants of Lansing, US Geological Survey District Office, and MSU Departments of Agricultural Economics, Biosystems and Agricultural Engineering; Geography, Civil and Environmental Engineering; and the Community, Agriculture, Recreation and Resource Studies (CARRS). The website for this just completed grant is: http://www.iwr.msu.edu/research/projects.html

The bottom line shows a unique convergence of our NIWR/USGS and the Great Lakes Protection Fund project with the implementation of recently-enacted state legislation and with the next phase of state policy making. As prescribed in recent legislation, a set of policy recommendations addressing the sustainability of groundwater will be submitted by the Groundwater Conservation Advisory Council (GCAC) July 1, 2007 and the GCAC process needs to be informed by hard science and knowledge of state water resources and watershed management. In addition, the Groundwater Conservation Advisory Council is responsible for guiding the overall implementation of the legislative mandates for related water policy development as well designing the water withdrawal assessment tool. As some members of our project Advisory Committee serve on the Groundwater Conservation Advisory Council, a robust linkage provides an important mechanism for the Institute’s role in developing the assessment tool and assisting in conflict resolution processes. See report 2006MI114S Grant No. 07HQGR0003 Developing the Water Withdrawal Assessment Tool.
Web-based Offerings

Our web-based offerings continue to expand. A Nation-Wide Digital Watershed web site (Figure 1) has been developed to allow individuals from across the United States locate themselves by using their address, watershed, or by regional areas established by the EPA. The illustration shows the software developed in the IWR that can be applied to a national situation. The data used in the system was acquired from EPA Basin data via the web. The site for Michigan allows users to zero-in on the eight-digit watersheds and then down to the 12-digit watershed system known as “Know Your Watershed.”

USDA Awards $600,000 Conservation Innovation Grant to Michigan Department of Agriculture for MSU Institute of Water Research Project (CIG-MDA)

The Institute of Water Research at Michigan State University and the Michigan Department of Agriculture (MDA) have teamed up to land a $600,000 Conservation Innovation Grant (CIG) to improve and protect water quality in three state watersheds.

The grant, awarded by the USDA Natural Resources Conservation Service (NRCS), funds implementation of the Institute’s new GIS-based High-Impact Targeting (HIT) program in three Michigan watersheds. NRCS funds will be distributed by the MDA as incentives to qualified farmers for supporting the implementation of conservation best management practices (BMPs).
Figure 2. Conservation Innovation Grant (CIG). http://www.iwr.msu.edu/CIG-MDA/

“The HIT program (Figure 2) will help protect water quality in rural areas through the targeted application of appropriate conservation BMPs,” said Jon Bartholic, director of the Institute of Water Research.

The Institute will work closely with MDA and soil conservation district staff to implement the HIT approach in three watersheds: the Maple River, Saginaw Bay, and the River Raisin. The HIT program complements the USDA-funded Conservation Reserve Enhancement Program and Conservation Security Program implemented by the MDA in those watersheds.

The HIT program targets installation of conservation BMPs on high-risk erosion areas with the greatest potential to contribute sedimentation and associated loadings to state waterways. The Institute has developed this new technology with Geographic Information Systems (GIS) capacity to increase the efficiency of federal and state conservation programs delivery.
“The CIG is a wonderful opportunity that will allow farmers and landowners to improve water quality, prevent soil erosion, and enhance wildlife habitat through a targeted approach,” said Mitch Irwin, MDA Director.

“Michigan’s conservation districts will benefit from using this new technology to target their conservation work to areas in critical watersheds to greatly improve water quality and wildlife habitat,” said Gordon Wenk, MDA Environmental Stewardship Division director.

“We’re enthusiastic about this collaborative project, which builds on our long and successful relationship with the Michigan Department of Agriculture,” Bartholic said. “We look forward to using our research and outreach capacity in cooperation with the MDA to deliver this new HIT technology in watersheds where it can best be used to improve water quality and prevent soil erosion.”

The project team is made up of the NRCS, the USDA’s Farm Services Agency, the Michigan Departments of Environmental Quality, Natural Resources, and Agriculture as well as the MSU Institute of Water Research and Huron, Lenawee, and Clinton County soil conservation districts. Visit: http://www.iwr.msu.edu/CIG-MDA/ for more information.

Watershed Comprehensive Assessment Tool (Watershed CAT)

The need for accurate geospatial data to develop effective watershed management plans has been well known to watershed managers, environmental government agencies and non-governmental organizations (NGOs) that specialize in restoring or maintaining the quality of water resources.
Many online data sources offer web-services that freely distribute these data. However, it is difficult for a user to access, view and analyze watershed-scale, geospatial data without extensive GIS capabilities, even though it is a vital step to identify critical areas or pollution sources in a watershed. The Watershed Comprehensive Assessment Tool (Watershed CAT) Figure 3 fills this gap in watershed management by assembling a variety of data layers into one data viewer and coupling the viewer with a number of web-based tools. This allows users to analyze watershed data more efficiently and with more detail, and ultimately leads to developing highly effective management plans.

The primary objective of this project is to develop an online system to house a data viewer, data analysis tools and decision support tools. Using the primary data viewer (Digital Watershed), data layers from a variety of sources can be assimilated together to observe physical and hydrological spatial trends within the watershed. Using the numerous analytical tools, such as Analytical Tools Interface for Landscape Assessment (ATtILA), Regional Vulnerability Assessment (ReVA), Online access to Long-Term Hydrologic Impact Assessment (L-THIA) and the High Impact Targeting (HIT) system contained in the Watershed CAT, users will be able to identify landscape stressors, calculate the amount of impervious surfaces, identify areas of high erosion, etc. Finally, using decision support tools provided by the Watershed CAT, users will be able to compare and the cost effectiveness of numerous sediment erosion management practices.

The U.S. Environmental Protection Agency (EPA) has developed an extensive manual documenting the watershed management plan process, and is commonly referred to as the EPA Watershed Handbook. This guide highlights every step in the process of developing a watershed management plan, and many of those steps require substantial data collection and analysis. Many of these data-intensive steps are also necessary to be completed in order for the plan to be considered for funding under section 319 of the Clean Water Act. These requirements include creating a watershed data inventory, identifying causes of impairment and pollutant sources, and descriptions of the non-point source management measures to be taken to reduce pollutant loadings. The Watershed CAT system will provide a large majority of data necessary for the inventory, as well as several modeling options that can facilitate the completion of these funding requirements by watershed organizations.

Local watershed management forms the basis for continued economic development and environmental improvement in the United States. Success depends on an integrated approach that brings together scientific, education and training advances made across many individual disciplines and modified to fit the needs of the individuals and groups, who must write, implement, evaluate, and adjust their watershed management plans.

New and Future Development for Digital Watershed

As a key technical component of Midwest Spatial Decision Support System Partnership, the Institute of Water Research’s Digital Watershed (DW) website has been recognized by EPA Office of Research and Development as an important environmental computing portal for a suite of EPA’s environmental decision support tools. Funding is underway to support the future development of DW to achieve this goal. The first step is to integrate EPA's ATtILA (Analytical Tools Interface for Landscape Assessments) tool into DW and provide watershed comparison function at 8-digit watershed level. This work will lay a solid foundation for the integration of
other EPA decision support tools such as Regional Vulnerability Assessment Program's EDT (Environmental Decision Toolkit).

The Institute of Water Research was also awarded a grant by the US Army Corps of Engineers Chicago District to create a tool that integrates a GIS-based sediment runoff predictive tool, MUSLE (Modified Universal Soil Loss Equation), into Digital Watershed (DW) and the Long-Term Hydrologic Impact Assessment (L-THIA) system and its associated EQIP tools. The resulting modeling and decision support tool will be easily accessed and used by a wide variety of expertise levels in determining the effects of development and different agricultural practices to the sediment loadings within two tributaries to Lake Michigan in Northwest Indiana; Burns Ditch/Little Calumet East Branch and Trail Creek. We've recently completed EQIP and the preliminary MUSLE integration on the project. In the near future, users will be able to model different BMP scenarios using this online tool.

Another new function that's already up and operational on Digital Watershed is the Google Map and Google Earth interoperability capability. Users can explore their own watersheds on Google Maps or Google Earth by simply click a button on Digital Watershed interface. We've received a lot of positive feedbacks on this new development.

**Virtual Watershed Management Courses**

The web-available Mapping is used extensively in IWRs Virtual Watershed Management courses (Figure 4). This past year we offered all four 3-credit modules of Watershed
Management each semester in the series for Certification. There are now over 120 students registered per year in these courses.

Related Research
We continue to obtain synergistic impacts by closely aligning our efforts with support from such organizations as the Corps of Engineers, USDA, US Forest Service and numerous other agencies and NGO’s. This past year we received a grant from the Corps of Engineers for $75,000 which involves estimating sediment delivery from each of the eight-digit watersheds within the entire U.S. side of the Great Lakes Basin. This database is not only of value to the Corps in prioritizing their efforts but also provides us with a broad set of additional information that we can use in other programs, and for assisting with the prioritization of high risk areas for erosion throughout the region. USDA funds involve a coordinating effort of outreach and research among all states within the EPA Region V. IWR personnel are partially funded through this regional project which coordinates and facilitates the communication of research methodologies, approaches, and results from our research and aides with region-wide outreach programming.

Training Potential
New graduates and graduate training continue to be a high priority of IWR. Unfortunately, graduate stipends have increased to the extent that a 1/2 time graduate student with fringe benefits, requires from $35,000-$45,000 (per year). We will make every effort to continue incorporating graduate students but with the high cost, it is increasingly difficult to employ more than a few students at any given time. As part of our partnership philosophy, we have jointly supported numerous graduate students with other departments and units on campus.

Notable Achievements
Title: Restoring Great Lakes Basin Waters Through the Use of Conservation Credits and Integrated Water Balance Analysis System
Brief: A two–year, $540,000 project funded by the Great Lakes Protection fund has been concluded this year by the Institute of Water Research, Michigan State University (MSU). This innovative market–based approach to groundwater management, using an integrated model with a system of conservation credits trading was developed through the collaborative efforts Michigan State University, the University of Michigan, the World Resource Institute, the U.S. Geological Survey, and Public Sector Consultants. The Integrated Watershed Balance Analysis model is the first–of–its–kind in assessing the impacts of groundwater withdrawals. The innovative Integrated Watershed Balance Analysis model uses the health of a cold–water trout stream and fish populations as an indicator and measure of the ecological impact of proposed groundwater withdrawals. The model integrates three major components. First, the Soil and Water Assessment Tool (SWAT) estimates stream recharge rates and the long–term water balance. Second, a groundwater aquifer model provides data connecting the impacts of changes in local groundwater resources on ecological values associated with water resources in that area as evidenced by trout populations. Third, an aquatic ecosystem model measures the changes in trout populations resulting from the changes in the groundwater resources. To provide water users with convenient access to the system, the team designed a User Assisted Interface (UAI) with a Web portal linked to the hypothetical groundwater withdrawal permit and conservation credit system. The portal linked the modeling results from an integrated model consisting of surface, ground water, and ecological models to assist users in identifying groundwater–sensitive areas and estimates of associated conservation credits within the case study area. The final project report was submitted to the Great Lakes Protection Fund in early May 2007, and can be found at http://www.iwr.msu.edu/research/projects.html
**Notable Achievement:** The Project Team designed a groundwater permitting system that could be hypothetically used for ecologically-sensitive watersheds in which connections between groundwater and stream flow exist and large withdrawals might cause adverse impacts on trout populations and related habitats. Stream flows in Michigan streams depend on groundwater supply for over half of their volume, on average, 60%. The model is used to determine the rates of groundwater recharge and the ecological impacts of groundwater withdrawals.

**Funding Agency:** Great Lakes Protection Fund

**Title:** Water Withdrawal Assessment Project

**Brief:** For the first time in state history, a coherent legal framework has been established to conserve and protect water resources in Michigan. After years of debate, landmark laws protecting Michigan’s water resources were passed by the Legislature and signed into law. The bi-partisan package of five bills finally delivers on Michigan’s commitment in 1985 to pass comprehensive legislation that prevents Great Lakes diversions. Institute Director Jon Bartholic provided testimony to the Senate Environment Committee on the current scientific understanding of water resources and at public meetings held around the state. These public meetings helped to open the door to eventual passage of this critical legislation.

**Notable Achievement:** One issue area within the new laws and pending legislation that the Institute of Water Research (IWR) is helping to implement concerns adverse resource impacts of water withdrawals on natural resources. The adverse impacts are now defined by statute as any reduction in flow or lake levels causing functional impairments of characteristic fish populations. To address these potential impacts, legislation called for the development of a water withdrawal assessment process. The process, including model development, an expert panel review, an assessment tool, and a web-based interface, was developed through a joint effort with USGS, the Michigan Departments of Natural Resources and Environmental Quality, University of Michigan and Michigan State University. The IWR has been instrumental in developing the web-based interface and in presenting the evolving tool to the public. In an ongoing process, irrigators, agency personnel, and University researchers and extension educators are conversing with one another, testing the tool and addressing emerging issues such as permitting and registration, protection factors and thresholds, water user responsibilities, the role of water users committees at the local level, return flow, and other sensitive water areas. The IWR is continuing to hold meetings with stakeholders and revise the web-based interface as new information and data becomes available.

**Funding Agency:** Michigan Department of Environmental Quality

**Publications**

Information Transfer Program Introduction

Since the Institute of Water Research Information Dissemination and Technology Transfer Training Program began in the early 1970s, the program has been responsive to the informational needs of a wide variety of user groups. Many modes of information exchange have been used to further this program and provide the latest research information to user groups, including conferences, training workshops, exhibits, publications, email exchanges, and other printed materials. Audiences include agency personnel, watershed organizations, riparian owners, farmers, local governmental agencies, students, and University faculty. Evaluations of programs are included to assess the merit of the programs and help prioritize issue areas and programming/training needs.
Information Dissemination and Technology Transfer Training Programs

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Publication

Introduction
Since the Institute of Water Research Information Dissemination and Technology Transfer Training Program began in the early 1970s, the program has been responsive to the informational needs of a wide variety of user groups. Many modes of information exchange have been used to further this program and provide the latest research information to user groups, including conferences, training workshops, exhibits, publications, email exchanges, and other printed materials. Audiences include agency personnel, watershed organizations, riparian owners, farmers, local governmental agencies, students, and University faculty. Evaluations of programs are included to assess the merit of the programs and help prioritize issue areas and programming/training needs.

Information Transfer Activities
Research Program
The following programs were coordinated, developed and delivered for fiscal year 2007-2008.

Training Workshops
A water withdrawal assessment screening tool that could be used to protect and conserve the waters of the state and assess the impact of large capacity water withdrawals on local water resources and associated ecosystems was jointly developed by a legislatively-appointed Groundwater Advisory Council, the US Geological Survey, Michigan Departments of Natural Resources and Environmental Quality, and the Institute of Water Research at MSU. The tool was designed to be used by individuals preparing a new or increased water withdrawal. Staff members of the Institute were responsible for developing the web based system and for the “roll out” and training on the use of the tool. Two training workshops were held in 2007 and 2008 for Extension personnel, agency representatives, and farmers who may be using the Tool. IWR staff also convened an Expert Review Panel to assess the water withdrawal assessment tool and organized a 2-day workshop to critique the models and tool. Until new legislation is passed that would require users to register their withdrawal through the web based system, the system is being demonstrated but not available online.

The Lake and Stream Leader’s Institute convened the Class of 2007. The goals of the program included developing local water/land resource leaders and educating participants on a variety of lake and stream issues ranging from ecology to local government to mediation. Staff members
of the IWR have been involved in both the development and implementation of this program and worked with several colleagues. One IWR staff member led hands-on session in lake and stream management and provided advisory and logistical support while another provided a step-by-step approach to developing a watershed management plan.

An IWR staff member led several sessions on lake and stream ecology during The Conservation Stewards Program, a comprehensive eight week program to assist local decision makers, agency personnel, and interested citizens with tools and information concerning land and water ecosystems. The 10-hour session, co-led by IWR staff and divided into two days, consisted of lectures, interactive sessions, and hands-on lake and stream ecology. Approximately 33 attendees took part in the class.

IWR Staff led an evening training workshop for Michigan Sea Grant’s Clean Boats, Clean Water Program. The session focused on exotic species and biological control strategies and IPM measures to prevent these species from entering inland lakes throughout the state.

A class directed towards undergraduate students was offered as a one-week class through the Department of Fisheries and Wildlife. With funding from another source, the class, Development of a Natural Resources Field Institute: Shaping Future Professionals through Experiential Learning and Teaching, provided opportunities for students to take part in hands-on field work, develop projects, and present their results. IWR staff lends support for this course by helping to teach two days of the class focusing on lake and stream ecology and management.

Conferences
An annual conference is convened on current and emerging issues related to the Great Lakes. This year the IWR co-sponsored its 17th Great Lakes conference, titled: The Great Lakes: Opportunities and Challenges. Co-sponsored by several MSU departments as well of the Office of the Great Lakes, Michigan Department of Environmental Quality, the conference focused on nuisance exotic species and restoration efforts. Presentations were given on VHS, Exotic Threats at Sleeping Bear Dunes National Lakeshore, Hydrilla, Phragmites, and Sea Lamprey. Restoration talks focused on Lake Sturgeon Recovery and Great Lakes Restoration Efforts. Approximately 175 people attended the conference representing state and local agency personnel, researchers, educators, environmental organizations, and interested citizens.

IWR staff members also co-coordinated a workshop covering two topics: Harmful Algal Blooms and Alum Treatment in Lakes. In coordination with the Michigan Chapter, North American Lake Management Society, the meeting focused on current research efforts in these two topic areas. Approximately 55 people attended the meeting.

Events
The Institute offers its expertise and knowledge by lending support to a variety of MSU sponsored events. In FY 2007-08, the following programs and/or exhibits were led and taught by IWR staff: Ag Expo, an agricultural exhibition that attracts over 35,000 visitors annually; Wetlands Tour and Demonstration, a tour of a Wetland Restoration Project at the University; Michigan Science Olympiad – State Finals for the event on Awesome Aquifers; Grandparents
University focusing on the river that runs through the campus and its water quality; and the Children’s Water Festival featuring river inhabitants as indicators of water quality.

Internet-Based Decision Support System
IWR staff members continually work to populate and improve its decision support system development. One program, Digital Watershed (www.iwr.msu.edu/dw) has expanded nationally, and has now linked to Google Earth, several models, and a number of water-related data bases. Users can type in an address or county anywhere in the continental United States and obtain information for the surrounding area. The IWR also continues to publish its bi-monthly on-line newsletter, The Watershed Post to provide current information on Institute activities as well as general articles of interest. Contributions are generally made by IWR staff, but submissions are also received from grantees on USGS grants.

Lectures and Seminars
The Institute staff give many presentations on and off-campus, and in FY07-08 focused on several topic areas including wetlands, E. coli monitoring and sampling, high impact targeting for reducing soil erosion, wellhead protection, exotic species, water withdrawals, and watershed management. Audience participants included legislators, community personnel, watershed managers, college students, K-12, and interested citizens. Staff also gave class lectures in the Departments of Fisheries and Wildlife, Community, Agriculture, Recreation and Resources, Journalism, and the Honors College.

Personnel and Facilities
The Institute of Water Research maintains a variety of computer workstations and servers for its growing web based decision support systems. In addition to computer-related supplies and equipment, the IWR also has video editing and photographic equipment, color printers, and field supplies for its Information Dissemination Program. The Institute's technology transfer program is under the direction of Principal Investigator Dr. Lois Wolfson, with several Institute personnel contributing to the project, including Dr. Jon Bartholic, Ruth Kline-Robach, Rosemary Finnelli, and Jeremiah Asher.

Notable Achievements
The Institute was involved with a project that focused on E. coli monitoring in streams by volunteers and assessing testing methods. Although the project was funded through another agency, IWR staff shared the results of the project with other campus specialists, and gave the workshop at a Michigan Clean Water Corps workshop. The project received the 2008 USDA CSREES Water Resources Team Award for Outstanding Extension Program and the 2006 Gold Award for Team Projects through the Agriculture and Natural Resources Professionals Association.

Professional Development
IWR Staff participated in professional development activities offered through the MSU Extension Water Area of Expertise program. The activities focused on alternative waste treatment systems for small communities, and on low impact development alternatives.
Publications


## Student Support

<table>
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<tr>
<th>Category</th>
<th>Section 104 Base Grant</th>
<th>Section 104 NCGP Award</th>
<th>NIWR–USGS Internship</th>
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Notable Awards and Achievements

Title: Restoring Great Lakes Basin Waters Through the Use of Conservation Credits and Integrated Water Balance Analysis System Brief: A two-year, $540,000 project funded by the Great Lakes Protection Fund has been concluded this year by the Institute of Water Research, Michigan State University (MSU). This innovative market-based approach to groundwater management, using an integrated model with a system of conservation credits trading was developed through the collaborative efforts Michigan State University, the University of Michigan, the World Resource Institute, the U.S. Geological Survey, and Public Sector Consultants. The Integrated Watershed Balance Analysis model is the first of its kind in assessing the impacts of groundwater withdrawals. The innovative Integrated Watershed Balance Analysis model uses the health of a coldwater trout stream and fish populations as an indicator and measure of the ecological impact of proposed groundwater withdrawals. The model integrates three major components. First, the Soil and Water Assessment Tool (SWAT) estimates stream recharge rates and the long-term water balance. Second, a groundwater aquifer model provides data connecting the impacts of changes in local groundwater resources on ecological values associated with water resources in that area as evidenced by trout populations. Third, an aquatic ecosystem model measures the changes in trout populations resulting from the changes in the groundwater resources. To provide water users with convenient access to the system, the team designed a User Assisted Interface (UAI) with a Web portal linked to the hypothetical groundwater withdrawal permit and conservation credit system. The portal linked the modeling results from an integrated model consisting of surface, ground water, and ecological models to assist users in identifying groundwatersensitive areas and estimates of associated conservation credits within the case study area. The final project report was submitted to the Great Lakes Protection Fund in early May 2007, and can be found at http://www.iwr.msu.edu/research/projects.html

Notable Achievement: The Project Team designed a groundwater permitting system that could be hypothetically used for ecologically sensitive watersheds in which connections between groundwater and stream flow exist and large withdrawals might cause adverse impacts on trout populations and related habitats. Stream flows in Michigan streams depend on groundwater supply for over half of their volume, on average, 60%. The model is used to determine the rates of groundwater recharge and the ecological impacts of groundwater withdrawals. Funding Agency: Great Lakes Protection Fund Title: Water Withdrawal Assessment Project Brief: For the first time in state history, a coherent legal framework has been established to conserve and protect water resources in Michigan. After years of debate, landmark laws protecting Michigan's water resources were passed by the Legislature and signed into law. The bipartisan package of five bills finally delivers on Michigan's commitment in 1985 to pass comprehensive legislation that prevents Great Lakes diversions. Institute Director Jon Bartholic provided testimony to the Senate Environment Committee on the current scientific understanding of water resources and at public meetings held around the state. These public meetings helped to open the door to eventual passage of this critical legislation.

Notable Achievement: One issue area within the new laws and pending legislation that the Institute of Water Research (IWR) is helping to implement concerns adverse resource impacts of water withdrawals on natural resources. The adverse impacts are now defined by statute as any reduction in flow or lake levels causing functional impairments of characteristic fish populations. To address these potential impacts, legislation called for the development of a water withdrawal assessment process. The process, including model development, an expert panel review, an assessment tool, and a web-based interface, was developed through a joint effort with USGS, the Michigan Departments of Natural Resources and Environmental Quality, University of Michigan and Michigan State University. The IWR has been instrumental in developing the web-based interface and in presenting the evolving tool to the public. In an ongoing process, irrigators, agency personnel, and University researchers and extension educators are conversing with one another, testing the tool and addressing emerging issues such as permitting and registration, protection factors and thresholds, water user responsibilities, the role of water users committees at the local level, return flow, and other sensitive water areas. The IWR is
continuing to hold meetings with stakeholders and revise the webbased interface as new information and data becomes available. Funding Agency: Michigan Department of Environmental Quality
Publications from Prior Years


