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Aquatic Studies in National Parks of the Upper Great Lakes States: Past Efforts and Future Directions

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Aquatic Studies in National Parks of the Upper Great Lakes States: Past Efforts and Future Directions

U.S. Department of Interior
National Park Service

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EXECUTIVE SUMMARY

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Great Lakes Inventory and Monitoring Network (GLKN) parks are situated in one of the most water rich locations in the world, and aquatic habitats in the parks are substantial in area and diversity. The GLKN includes portions of three major watersheds (Great Lakes, Mississippi River, and Hudson Bay), and consists of nine parks. Lake Superior parks include Apostle Islands National Lakeshore (APIS), Grand Portage National Monument (GRPO), Pictured Rocks National Lakeshore (PIRO) and Isle Royale National Park (ISRO), and Lake Michigan parks include Indiana Dunes National Lakeshore (INDU) and Sleeping Bear Dunes National Lakeshore (SLBE). Other GLKN parks include St. Croix National Scenic Riverway (SACN), located along the border of Wisconsin and Minnesota, Mississippi National River and Recreation Area (MISS), located near the Minneapolis/St. Paul area, and Voyageurs National Park (VOYA), located in northern Minnesota adjoining the border with Canada.

From bogs and wetlands, to small streams and large rivers, to inland lakes or the waters of Lake Michigan and Lake Superior, GLKN parks hold an impressive variety of aquatic habitats and biota inhabiting them. Parks contain nearly 1,000 km (over 600 miles) of Great Lakes coastline and over 183,000 ha (450,000 acres) of Great Lakes surface area. In addition to areas along the Mississippi, St. Croix, and Namekagon Rivers, over 110 other named streams exist in the Great Lakes parks, amounting to 1,272 km (790 miles) of perennial streams and 234 km (146 miles) of intermittent streams. The parks also host 129 named lakes, totaling nearly 41,000 ha (101,000 acres).

This aquatic synthesis is an attempt to compile information from water-related studies and investigations that have occurred within the GLKN parks. In our review of aquatic research conducted in the parks, we collected more than 600 pertinent studies and reports. Total numbers of aquatic studies varied among parks but were generally related to the prominence of the park's water resources. Accordingly, parks with the highest numbers of studies included SACN, VOYA, and ISRO, which are dominated by aquatic habitats. GRPO, on the other hand, has very few water resources, and has not been as frequently studied. Studies in these parks have been as varied as the aquatic habitats found there, with investigations ranging from small streams to large rivers and from splash pools to Lake Superior. They have addressed diverse aspects of water resources, including water quality, aquatic biota (fish, plankton, mussels, macroinvertebrates, wildlife, and aquatic vegetation), contaminants, hydrology, groundwater, and physical processes. Of these, fisheries, water quality, and basic limnological studies have received by far the greatest emphasis Network-wide. Many studies have also provided information on contaminants and hydrology, but fewer studies have addressed wetlands and aquatic vegetation. Only a small number of studies have addressed aquatic wildlife, amphibians and reptiles, groundwater, or physical processes.

Although the breadth of aquatic research in Great Lakes area parks is impressive, until recently there has been no coordinated effort to synthesize the available information for use in management or to help guide future research and monitoring. Much of the existing research in Great Lakes area parks has consisted of short-term projects conducted by many different people without common methods or objectives. Previous attempts to synthesize existing water resource information have focused primarily on individual park units or particular long-term research projects. Because GLKN parks exist in a common environmental and historical context and share similar water resource issues, valuable insights may be gained from a comprehensive, network-wide analysis of the available information.

We undertook a wide-ranging synthesis of aquatic studies and investigations in GLKN parks in order to 1) summarize existing aquatic resource information; 2) identify aquatic resource issues, themes, and information needs in GLKN parks; 3) provide considerations pertinent to the development of long-term monitoring strategies; and 4) elevate the profile of aquatic resources in GLKN parks and encourage involvement from partner agencies, organizations and institutions in addressing information needs.

Form and function of the document

This report is composed of three principal sections. The first section summarizes water-related studies and investigations and their recommendations on a park by park basis. The second section provides a brief synthesis of water-related issues common to multiple parks across the GLKN. Finally, the appendices provide an annotated summary of the over 600 existing studies and investigations identified, including information on individual study approaches, sampling designs, and findings. We include recommendations taken directly from the reviewed literature as well as our own considerations for future monitoring and research.

The raw materials for this aquatic synthesis were derived from an extensive literature search. We reviewed natural resource files and library materials at each park, and discussed research and monitoring activities with natural resources staff. In addition to these internal searches, we conducted online literature searches using each park's name or portions of each park's name as keywords.
We performed cursory reviews of the literature as it was acquired from parks or other sources. In order to maximize the accessibility and usefulness of the document to individual parks, we kept the literature grouped by park. Literature cited at the end of each park's section includes those studies referenced within the text, as well as those studies annotated in Appendix B. Within each park, we assigned each piece of literature to a category. Categories were selected based on natural groupings found across all of the compiled research, and included general resource documents and plans, water quality, biology and ecology, fish, aquatic wildlife, amphibians and reptiles, wetlands and aquatic vegetation, contaminants, hydrology, groundwater, and physical structure and processes.

Past and ongoing water resource efforts

As expected, the individual parks each have their own specific resource issues and concerns, along with specific research and monitoring needs. Proximity to population centers or relative remoteness usually played a role in resource issues and the research that has occurred at the parks. . Mississippi National River and Recreation Area and INDU, for example, are in areas that are much more urbanized and industrialized than the other parks and impacts to resources reflect this. . Isle Royale National Park, however, is less affected by direct impacts because of the remote location of the island.

The composition of research differed among GLKN parks, often reflecting critical resource issues or local interests at individual parks. Research at APIS, for example, has included a strong emphasis on fisheries and more studies of amphibians and reptiles than other parks. Other APIS research has been spread fairly evenly across categories, with a number of water quality, biology, and aquatic wildlife studies represented. Few water resource studies have been conducted at GRPO; studies noted in this synthesis focused on fisheries, water quality, and contaminant issues. . Indiana Dunes National Lakeshore had one of the higher numbers of water quality studies among the Great Lakes parks, many of which focused on fecal indicator bacteria. Additionally, several wetland and aquatic vegetation studies have been conducted at INDU due to the significance of the Lakeshore’s large marshes, interdunal ponds, and bog habitats. Because of ISRO’s remote location, more studies of long-range contaminant transport have been conducted there than at any other park. . Isle Royale National Park files also contained more fisheries-related studies than other parks, Studies of potential impacts of contaminants on ISRO biota have focused primarily on sport fisheries of Lake Superior and in inland lakes. Other strong points of ISRO’s research history include wide-ranging aquatic biology and ecology studies and more than 20 years of long-term research in the Wallace Creek watershed.

Research at MISS has been conducted almost exclusively by other agencies and has focused heavily on water quality, contaminants, fisheries, hydrology, and groundwater. More studies of groundwater resources have been conducted at MISS than at any other park, primarily because of groundwater extraction issues in the Twin Cities metropolitan area. Aquatic research studies at PIRO have been primarily broad-based limnological or ecological projects addressing water quality along with some biological components. A high proportion of PIRO studies have also emphasized fishery resources. . St. Croix National Scenic Riverway has hosted a great deal of aquatic research, much of which has focused on requirements of endangered mussels and issues of nutrient and sediment loading. . St. Croix National Scenic Riverway research also features a series of shoreline studies that provide more extensive information on physical processes than is available for most GLKN parks. Research at SLBE has focused strongly on basic limnology, with particular emphasis on water quality issues in the Glen Lake and Platte River watersheds. The research program at VOYA has touched on nearly every component of aquatic ecosystems, and often with respect to the issue of lake level regulation. Aquatic wildlife studies (addressing beaver, muskrat, and common loon) are better represented at VOYA than at most other GLKN parks, and fisheries studies are also prominent. Due to the program objectives of the Upper Mississippi River Basin National Water Quality Assessment (UMIS), these studies have primarily targeted surface and groundwater water quality issues (particularly contaminants) and have contributed greatly to the knowledge base at MISS and SACN. Unlike research at most parks, UMIS studies have rarely addressed biological attributes.

Strengths, needs, and future considerations

Of the research categories identified in this document, the strongest knowledge base is available for fisheries, water quality, and general aquatic biology. While we have identified many remaining needs for future research and monitoring in these categories, requirements for basic data are fulfilled at most GLKN parks. Other categories, however, have received comparatively little attention (e.g., wetlands, amphibians, hydrology, and groundwater) or are in need of further study in the future (e.g., contaminants). Wetlands and aquatic vegetation remain relatively unexplored at most parks and baseline inventories and assessments are needed. Amphibians are a taxonomic group of global conservation concern, but data on their distribution, abundance, species composition and habitat requirements are unavailable or unquantified for most GLKN parks. Hydrologic information is critical for understanding water quality and biological data in GLKN parks, and installation of gages in key locations and support for existing U.S. Geological Survey gaging stations is essential for acquiring and maintaining this database. Groundwater-surface water interactions are important issues, particularly at some of the southern GLKN parks (MISS, INDU, and SLBE). These will require greater attention as population growth and development place increased pressure on groundwater resources. Contaminant studies have taken place in many GLKN parks, and represent a continuing water resource concern. While some contaminant issues are gradually diminishing in importance due to air quality regulations and manufacturing bans, others (such as leakage from industrial landfills, urban runoff, mercury bioaccumulation, and boat-related pollution) are ongoing, and others (newer pesticides, pharmaceuticals, and personal care products) have received increased attention in recent years.

Several regional or even global issues affect all GLKN parks and would benefit from increased and more coordinated monitoring, research, and management attention on a regional scale. **Aquatic nuisance species** represent perhaps the most significant and imminent biological threat to GLKN aquatic resources, and their effective prevention and management will require stronger National Park Service involvement in the future. **Contaminants**, from sources ranging from direct point source discharges to long-range atmospheric transport and deposition, constitute a long-standing and continuing concern for all GLKN parks. **Landscape changes** related to resource extraction, urban development, agricultural activities and natural processes (e.g., windthrow, fire, and beaver dam construction) affect water resources Network-wide; these stressors should be monitored and managed in a regional context where appropriate. **Climate change** is a growing concern expected to greatly affect GLKN parks through changes in seasonal precipitation patterns, increased intensity and length of precipitation events, alterations in surface and groundwater hydrology, changes in the thermal qualities of aquatic habitats, and changes in watershed biogeochemistry. Monitoring strategies should target these likely changes. **Fisheries management** issues in GLKN parks are complex and include effects of stocking non-indigenous species, establishment of aquatic nuisance species, and related losses of native fish stocks and genetic diversity. Because GLKN parks are linked strongly to surrounding landscapes and other management entities, active coordination will be critical in addressing these issues. In particular, a need exists for increased coordination with the States on fisheries management issues; with other federal agencies, the states, and local organizations on monitoring strategies; with science institutions on research and development needs; and with regional policy makers on policy issues pertaining to the Great Lakes and Upper Mississippi River Basins.

In addition to these broader resource issues affecting all GLKN parks, several subsets of parks share similar aquatic habitats or resource issues that present additional opportunities for multi-park research and monitoring. Similarities in aquatic habitats are found at SLBE and INDU in dune-swale topography featuring interdunal ponds and wetlands. Bar lakes and lagoon-type ecosystems are present at both APIS and SLBE. Inland northern or boreal lakes at ISRO and VOYA present an opportunity for comparative or island biogeographical studies. . Mississippi National River and Recreation Area and SACN share similarities in terms of large river qualities, backwater habitats, and tributary streams. Sandy shoreline features and processes along the Great Lakes are common to APIS, INDU, PIRO, and SLBE. Shared aquatic resource issues at parks include bacterial contamination and beach closure concerns at INDU and SLBE; urban development concerns related to waste disposal, urban wastewater, and groundwater withdrawal at INDU, MISS, and the southern part of SACN; fuel or oil spill concerns in parks situated immediately adjacent to or in Lakes Michigan and Superior; Lake Superior fisheries concerns at several northern parks (APIS, GRPO, ISRO, and PIRO); and imminent aquatic nuisance species concerns at parks located closest to invaded Great Lakes waters. These and other parallels in aquatic habitats and water resource issues provide opportunities to share knowledge among parks, increase management efficiency, and broaden the ecological insights gained from research and monitoring efforts.

In addition to providing the Great Lakes Network with background information useful for understanding aquatic resource information needs and developing monitoring strategies, we envision that this aquatic synthesis will serve other groups and purposes as well. For example, park planning processes and assessments (e.g., Resource Stewardship Plans, Water Resources Management Plans, Fisheries Management Plans, and upcoming Watershed Condition Assessments) may benefit from the summary of existing information provided here. Park-specific and Network-wide considerations for future research may be used to stimulate discussion of research priorities within and among parks, communicate research needs to cooperators, and develop research proposals for internal and external funding calls. Finally, this synthesis represents a common, current reference document that can be consulted as needed by park resource managers and shared with interested partners into the future.

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INTRODUCTION

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The Great Lakes feature prominently on the map of North America, spanning almost 250,000 square kilometers (almost 100,000 square miles) and containing a full 18% of the world's supply of fresh water (Wetzel 2001). The Great Lakes also represent an important part of the region's natural and cultural heritage. Originally used by native peoples for hunting and fishing, the lands and waters of the Great Lakes Basin are now home to over 33 million people who use the lakes for water supply, fishing, transportation, power generation, recreation, and other activities (Fuller and Shear 1995). The Great Lakes Basin is characterized by a strong gradient in land cover, climate, and soil characteristics from the northwest to southeast. Northwestern parts of the Basin feature cooler climates, granite bedrock, and northern coniferous forests, whereas southern parts of the Basin experience a milder climate and have deeper, more fertile soils suitable for agriculture (Fuller and Shear 1995). Many lands of the Great Lakes Basin were logged and converted to agricultural, urban and industrial uses following European settlement, and the Basin remains a center of agricultural and industrial activity for both the United States and Canada.

The northwestern reaches of the Great Lakes Basin have undergone comparatively little development. Human population in the Lake Superior drainage, for example, comprises less than 2% of the total population in the Great Lakes Basin, and population in the Lake Michigan drainage (excluding the Chicago area) comprises around 8% (derived from Fuller and Shear 1995). As a result, these areas have retained some notable natural features such as large sand dunes, pristine shorelines, undeveloped islands, coastal wetlands, waterfalls, and diverse inland waters and wetlands. These resources have become increasingly valued, and over the last century the U.S. Congress has elected to preserve several of the most outstanding areas as units of the National Park System. The current list of National Park units in the western Great Lakes region includes one National Park, four National Lakeshores, and one National Monument. An additional National Park and two riverine park units, located outside the Great Lakes Basin but nested within its cultural and historical context, were also established.

Freshwater resources are critical components of each of these park units (Route and Elias 2003). Several parks are located in or along Lake Superior (i.e., Grand Portage National Monument, Apostle Islands National Lakeshore, Isle Royale National Park, and Pictured Rocks National Lakeshore) or Lake Michigan (i.e., Sleeping Bear Dunes and Indiana Dunes National Lakeshores). In addition to coastal resources, each of these parks features valuable inland water resources including streams, lakes, lagoons, and wetlands. Area parks located inland from the Great Lakes are also water-based. Voyageurs National Park is situated along the watery United States-Canada borderlands in northern Minnesota, and nearly half of its area consists of aquatic and wetland habitats. The two riverine park units consist almost entirely of water resources. St. Croix National Scenic Riverway protects 420 km (261 miles) of the St. Croix and Namekagon Rivers in Minnesota and Wisconsin, and the Mississippi National River and Recreation Area protects a 123 km (77 mile) stretch of the upper Mississippi River in the Twin Cities area. All together, Great Lakes area parks protect an impressive 987 km (613 miles) of Great Lakes coastline, 183,010 ha (452,225 acres) of Great Lakes waters, 1,272 km (790 miles) of perennial streams, 40,905 ha (101,078 acres) of named lakes, and 43,141 ha (106,603 acres) of wetlands (Table 1).

Some Great Lakes area park units are situated in remote locations, removed from direct effects of urban development or other anthropogenic stressors. Even those parks located in urban and industrial areas (e.g., Indiana Dunes National Lakeshore, Mississippi National River and Recreation Area) are afforded greater protection than nearby non-National Park Service lands. Because of their protected status and unique natural features, National Parks are increasingly recognized for their usefulness as natural laboratories in scientific investigations (National Park Service 2001). Many aquatic resource studies have been conducted in Great Lakes area park units, particularly over the past several decades. Researchers have explored the chemical and hydrologic attributes of the area's diverse aquatic habitats, studied aquatic biota ranging from microbes to moose, and addressed a variety of pressing water resource concerns.

Table 1. Water resource statistics for Great Lakes Network parks, derived primarily from the National Hydrography Dataset. km=kilometers, ha=hectares, and #=number. See Appendix A for a detailed description of the methods used to derive these statistics. APIS=Apostle Islands National Lakeshore, GRPO=Grand Portage National Monument, INDU=Indiana Dunes National Lakeshore, ISRO=Isle Royale National Park, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks National Lakeshore, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes National Lakeshore, VOYA=Voyageurs National Park.

			Park									
	Feature	**Unit**	**APIS**	**GRPO**	**INDU**	**ISRO**	**MISS**	**PIRO**	**SACN**	**SLBE**	**VOYA**	**Total**
Great Lakes	Coastline Length	km	258	1	19	543	0	62	0	105	0	987
		miles	160	1	12	338	0	38	0	65	0	613
	Great Lakes Area	ha	10,899	0	241	165,182	0	2,438	0	4,249	0	183,010
		acres	26,932	0	596	408,172	0	6,025	0	10,501	0	452,225
Streams	Named Streams	#	2	1	4	8	12	19	54	5	10	115
	Intermittent Streams Length	km	62	0	5	45	34	20	53	11	5	234
		miles	38	0	3	28	21	12	33	7	3	146
	Perennial Streams Length	km	20	3	12	233	160	114	517	20	192	1,272
		miles	12	2	8	145	100	71	322	12	119	790
	Mississippi River Length	km	0	0	0	0	123	0	0	0	0	123
		miles	0	0	0	0	77	0	0	0	0	77
	St. Croix River Length	km	0	0	0	0	0	0	248	0	0	248
		miles	0	0	0	0	0	0	154	0	0	154
	Namekagon River Length	km	0	0	0	0	0	0	172	0	0	172
		miles	0	0	0	0	0	0	107	0	0	107
	Ditches Length	km	0	0	19	0	0	0	0	0	0	19
		miles	0	0	12	0	0	0	0	0	0	12
Inland Lakes	Named Lakes	#	0	0	2	42	13	14	11	18	29	129
	Un-named Lakes	#	11	0	12	45	64	10	27	7	275	451
	Named Lakes Area	ha	0	0	32	3,435	3,613	744	3,566	425	29,090	40,905
		acres	0	0	80	8,488	8,927	1,839	8,811	1,051	71,882	101,078
	Un-named Lakes Area	ha	43	1	34	104	291	25	129	16	970	1,612
		acres	106	2	84	257	719	61	319	39	2,397	3,984
Wetlands	Total Wetland Area	ha	951	8	505	7,030	10,518	1,805	9,248	559	12,517	43,141
		acres	2,350	20	1,247	17,372	25,990	4,461	22,853	1,381	30,930	106,603

Although the breadth of aquatic research in Great Lakes area parks is impressive, until recently there has been no coordinated effort to synthesize the available information for use in management or to help guide future research and monitoring. Much of the existing research in Great Lakes area parks has consisted of short-term projects conducted by many different people without common methods or objectives. Previous attempts to synthesize existing water resource information have been intensive but primarily focused on individual park units (e.g., Holmberg et al. 1997, Vana-Miller 2002, Kallemeyn et al. 2003) or particular long-term research projects (e.g., Stottlemyer et al. 1998, Kallemeyn 2002). Because these parks exist in a common environmental and historical context and share similar water resource issues, valuable insights may be gained from a comprehensive, regional analysis of the available information.

Objectives

We undertook a wide-ranging synthesis of aquatic research in Great Lakes area parks in order to serve that need. We had four main objectives:

1. Summarize existing aquatic resource information;
2. Identify aquatic resource issues, themes, and information needs in GLKN parks;
3. Provide considerations pertinent to the development of long-term monitoring strategies; and
4. Elevate the profile of aquatic resources in GLKN parks and encourage involvement from partner agencies, organizations, and institutions in addressing information needs.

Study area and context

The study area for this synthesis encompasses all nine parks in the western Great Lakes area (Figure 1). These parks, not coincidentally, are also the nine components of the National Park Service's Great Lakes Inventory and Monitoring Network (GLKN). Such networks have recently been established as part of a nationwide effort to provide natural resource expertise and monitoring resources to groups of parks with common geography and resource issues (Route and Elias 2003). The inventory and monitoring program was funded as part of a larger initiative, known as the Natural Resource Challenge, designed to encourage science-based natural resource management in the national parks.

Established in 1999, GLKN's activities to date have included large scale biological inventory, data cataloging, and information synthesis efforts. . The Great Lakes Network has populated NPSpecies and NatureBib, two large databases that house species lists, biological inventory data, and bibliographical entries for each park. Ledder (2003) summarized past water quality monitoring in GLKN parks, noting patterns of water quality exceedences for each park, using the Baseline Water Quality Data Inventory and Analysis reports. . The Great Lakes Network has also compiled information on existing monitoring programs in the region, funded the analysis of existing water quality datasets, developed conceptual models for major aquatic ecosystem types, and begun planning its long-term monitoring program.

The long-term monitoring program is intended to identify and track a subset of park resources and processes known as “vital signs” over time. To help identify good indicators for water resource monitoring, GLKN held an aquatic vital signs meeting with subject matter experts in February 2004. This aquatic synthesis document aims to complement the Network’s efforts by providing a thorough review of previous aquatic studies and addressing implications for long-term monitoring and research.

Methods

Literature search

The raw materials for this aquatic synthesis were derived from an extensive literature search. We reviewed natural resource files and library materials at each park, and discussed research and monitoring activities with natural resources staff. We also visited the Midwest Regional Office in Omaha, Nebraska, and reviewed regional natural resource files for relevant materials. In addition to these internal searches, we conducted online literature searches using each park's name or portions of each park's name as keywords. Online

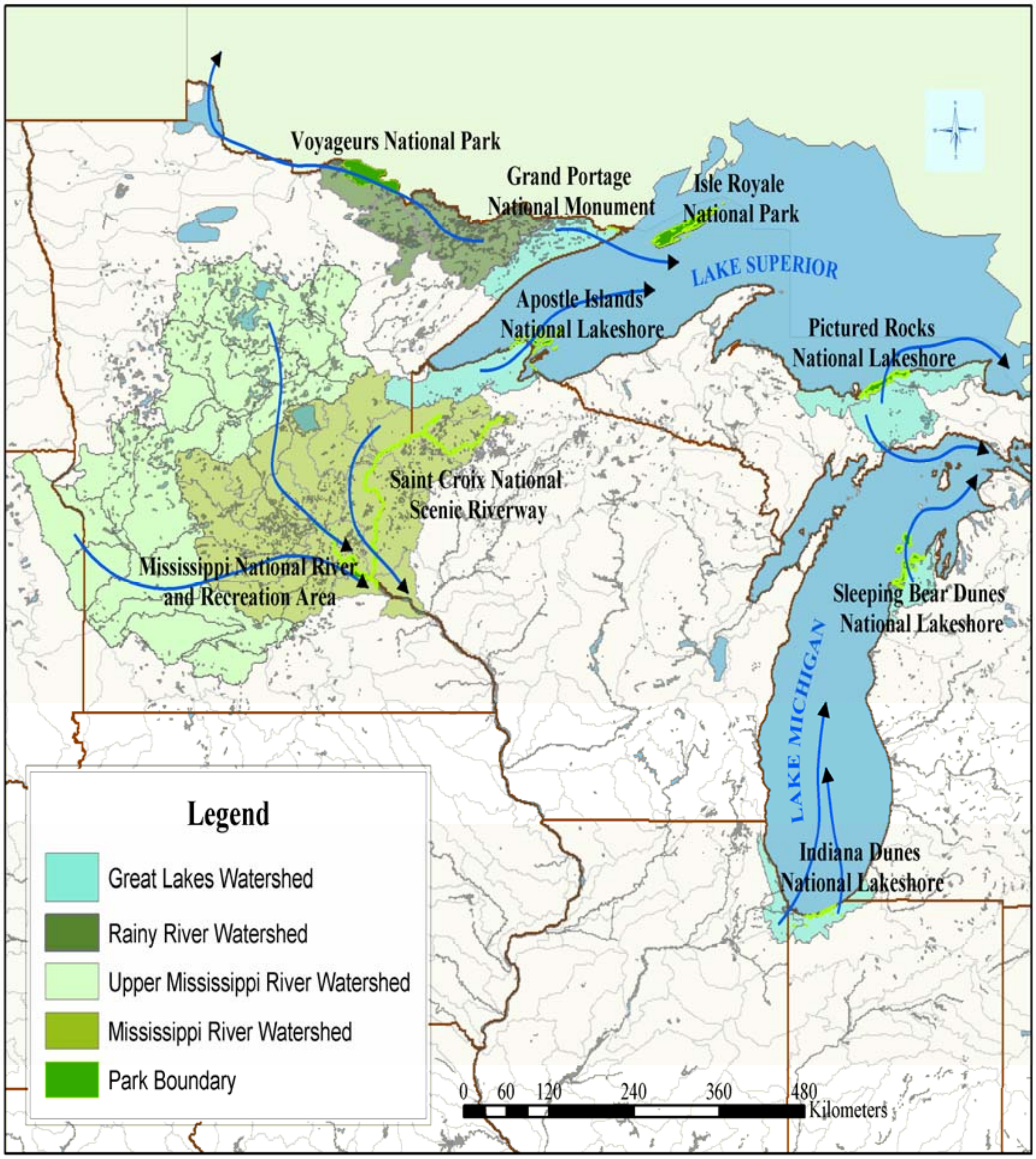

Figure 1. Map of the regional distribution of Great Lakes Network parks, showing state boundaries, National boundaries, park locations, park boundaries, and major watersheds.

databases searched included Biological Abstracts, Cambridge Abstracts of Biology, and Web of Science. Literature found during these searches was downloaded from electronic journals, copied from library journals at the St. Croix Watershed Research Station, or requested via interlibrary loan.

The above efforts produced a significant amount of literature for most parks, but very little for two Minnesota parks (Grand Portage National Monument and Mississippi National River and Recreation Area). To overcome this shortfall, we conducted a more intensive search of literature available through U.S. Geological Survey's Minnesota District office. Finally, because two of the Great Lakes area parks are located within a study unit of the National Water Quality Assessment program (NAWQA), we acquired copies of recent studies from the Upper

Mississippi River Basin NAWQA unit. The NAWQA collection is for the most part treated individually in this document because it pertains to both St. Croix National Scenic Riverway and Mississippi National River and Recreation Area.

To the extent that monitoring activities were described in a report or manuscript and were accessible via the above search techniques, they were included in our synthesis. The Baseline Water Quality Data Inventory and Analysis reports are perhaps the most extensive of these, and merit special mention. Compiled for each park by the National Park Service Water Resources Division in the mid- to late-1990s, these reports summarized water quality data from six of the Environmental Protection Agency's national databases, including, most notably, the water quality Storage and Retrieval database (STORET). In this document we provide a brief encapsulation of these reports in each park-specific chapter, including information on water quality monitoring stations, monitoring parameters, and exceedences (based on screening criteria related to Environmental Protection Agency water quality criteria as well as screening levels identified by the Water Resources Division).

Finally, park files contained a number of documents and reports from state resource agencies that contributed greatly to our efforts. We did not specifically search files from state resource agencies, because locating pertinent reports from all state resource offices represented a task well beyond the scope of our investigation. We acknowledge that this reduces the overall number of relevant documents reported in this synthesis and that some categories such as fisheries and aquatic wildlife may appear to be under-reported in certain parks where States have been actively involved with research and management. These types of reports do, however, provide important and useful information for the parks, and parks should attempt to acquire all relevant reports for park files.

Literature review and organization

We performed cursory reviews of the literature as it was acquired. In order to maximize the accessibility and usefulness of the synthesis to individual parks, literature was first grouped by park. Within each park, we assigned each piece of literature to a research category. Categories were selected based on natural groupings found across all of the compiled research, and included: general resource documents and plans; water quality; biology and ecology; fish; aquatic wildlife; amphibians and reptiles; wetlands and aquatic vegetation; contaminants; hydrology; groundwater; and physical structure and processes. Many of these categories are intuitive, but we have formulated some clarifying definitions (Table 2). We acknowledge that the categories are artificial and may seem restrictive for the more comprehensive ecological studies. They do, however, provide needed structure for the analysis and our discussion of research strengths and information gaps. Additionally, studies addressing more than one category are represented in multiple categories in the network-wide synthesis, discussed below.

Water resource statistics

To provide geographical and hydrological context for this synthesis, we have included maps of each park along with basic water resource statistics. The water resource statistics were primarily derived from the National Hydrography Dataset (NHD), which provides nationwide hydrography delineated by eight-digit hydrologic unit code boundaries (HUCs). National Wetland Inventory data were used for those units that did not include wetland data. The NHD datasets were downloaded by HUC boundary into ArcGIS, and after considerable manipulation, length (of streams, rivers, and shoreline) and area (of Great Lakes, inland lakes, and wetlands) measurements were calculated. See Appendix A for a detailed description of the methods used to derive these calculations.

Data recording

We recorded the data from individual studies or pieces of literature in a detailed Summary Table (Appendix B), organized by park, research theme, chronology, and author. Data recorded for each study included the author(s), date of publication, methods and approach, results, and conclusions or recommendations. Conclusions and recommendations may have been directly presented in the study, or may be derived from the studies' findings and presented by the

Table 2. Descriptions of research categories identified in a review of literature from Great Lakes Network Parks. These categories provided a framework for our analysis of past aquatic research efforts and future research and monitoring needs in the Great Lakes Network.

Research Category	Definition
General resource documents and plans	Park planning documents or background documents providing basic information on aquatic resources.
Water quality	Studies that focus primarily on water chemistry and quality, with little or no attention to aquatic biology or ecology. Bacteria studies are also included here.
Biology and ecology	A catch-all category that includes: 1) studies that emphasize biological, limnological or ecological aspects of aquatic systems, or 2) studies that focus on a particular biological attribute not addressed in another category (e.g., plankton or invertebrates).
Fish	Studies that emphasize any aspect of fish or fisheries resources.
Aquatic wildlife	Studies that focus on aquatic or semi-aquatic birds and mammals (e.g., common loon, beaver, muskrat, moose).
Amphibians and reptiles	Studies that involve amphibians (larval or adult) and reptiles.
Wetlands and aquatic vegetation	Studies that address wetland structure and function or involve riparian and/or littoral zone macrophytes.
Contaminants	Studies that emphasize presence or effects of contaminants on aquatic ecosystems or biota (e.g., mercury, acid deposition, PAHs, pesticides).
Hydrology	Studies that address hydrologic aspects of ecosystems (e.g., stream flow, lake level fluctuations).
Groundwater	Studies that focus on groundwater resources, including groundwater supply and quality or interactions with surface water.
Physical structure and processes	Studies addressing habitat structure or physical processes affecting aquatic habitat, including erosion, mass wasting and dredging, shoreline trampling, landscape changes, and recreational impacts.

synthesis authors (Brenda Moraska Lafrancois and Jay Glase). The information recorded in this table provided a template for the more generalized exploration and synthesis presented in the text of this document. The most pertinent considerations were incorporated into the park-by-park summaries, with the source specified (i.e., directly from studies, or derived by the synthesis authors).

Occasionally we included information from emails, letters or memoranda that were found in park files and contained what we considered important information about specific subjects. Generally these were included in the summary table as a single listing referring to multiple documents by various authors spanning a range of dates. Because this information often included several emails, letters, or memoranda, these are not listed in the park-specific literature cited sections.

Data processing and analysis

We conducted two levels of summary and synthesis. The first level involved park-by-park summaries of aquatic resources and research. We provided maps, basic water resource statistics, and a general discussion of previous research for each park. We relied upon information in the detailed summary table (Summary Table, Appendix B) to analyze dominant research themes, identify strengths and needs, and provide considerations for future monitoring and research specific to each park. We presented these considerations at the end of each park section, noting which came directly from the documents and which we derived during our literature review. We have presented these considerations as bulleted lists divided into research and monitoring categories. Only those considerations we deemed most pertinent to the individual parks were included. Ultimately, park managers will decide which research and monitoring needs are most critical; our considerations may help inform those decisions.

The second level of synthesis involved a network-wide review of the existing research, with an emphasis on common information needs among parks and considerations for future GLKN or multi-park monitoring and research efforts. We created a list of considerations in similar fashion to those mentioned above for the park by park sections. These network-wide and multi-park considerations are listed for each of the subject categories. To help synthesize information at the network scale we drew upon insights from the park-by-park summaries, but also created a more general summary table for each park (SuperSummary Table, Appendix C). In these tables we recorded *all* of the studies that contained information pertinent to a particular research theme. The water quality category, for example, contains water quality studies but may also contain studies that focused on fish but provided useful water quality information. SuperSummary tables for St. Croix National Scenic Riverway and Mississippi National River and Recreation Area also included references from the Upper Mississippi River NAWQA studies (Appendix C). We counted the number of studies addressing each research category and graphed the results on a Network-wide and park-by-park basis. This more inclusive approach enabled us to better evaluate relative strengths and needs among parks.

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PARK-BY-PARK SYNTHESES

APOSTLE ISLANDS NATIONAL LAKESHORE

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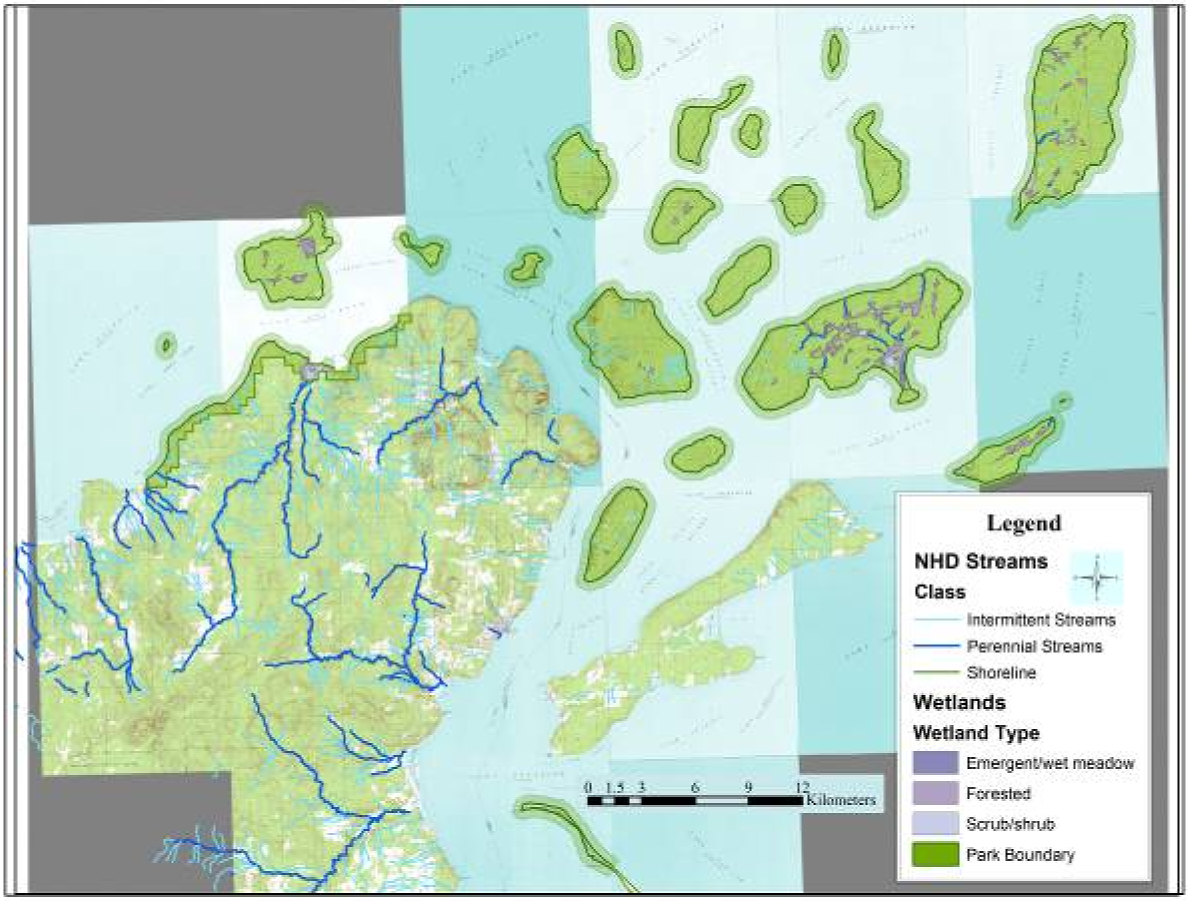
Photographs from top to bottom: Apostle Islands from above (Erickson Post Cards & Souvenirs), Oak Island stream (B.M. Lafrancois), and Stockton Island Lagoon outlet (J. Van Stappen).



Apostle Islands National Lakeshore and surrounding area, showing streams and wetlands derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 5, for the regional context of the park.

APOSTLE ISLANDS NATIONAL LAKESHORE

Apostle Islands National Lakeshore (APIS), established in 1970, is an island archipelago consisting of 21 islands located off northern Wisconsin's Bayfield Peninsula in Lake Superior. The Lakeshore also features a 19 km (12 mile) mainland unit along Lake Superior. Together, the islands and mainland unit protect 257 km (160 miles) of Lake Superior shoreline (Table 1, pg. 2). . Apostle Islands National Lakeshore jurisdiction in Lake Superior waters near the islands is limited to the meniscus; that is, jurisdiction does not extend below the surface through the water column, but the surface area under Park jurisdiction covers nearly 11,000 ha (27,000 acres) (Table 1, pg. 2). The mainland unit and several islands contain notable inland water resources that have received some attention over the past several decades. The Sand River runs through the mainland unit, and small perennial and intermittent streams are found on several of the islands. Unlike other parks, APIS features very few named streams and lakes. However, it features more kilometers of intermittent streams than any other Great Lakes area park (Table 1, pg. 2). Unique lagoon ecosystems are found on the mainland unit as well as Stockton, Outer, and Michigan Islands. Bogs, beaver ponds, and wetlands occur on many of the islands.

Summary of existing aquatic research

General resource documents and plans

In addition to general biological inventories for particular islands or sets of islands (Stadnyk et al. 1974, Anderson et al. 1979, 1980, 1982, 1983, Brander and Bailey 1983), APIS also has assembled plans for wildlife management and natural resource monitoring. Anderson and Stowell (1985) presented a management plan for select habitats and species, with specific reference to intact spruce bog habitats and amphibians and reptiles. Van Stappen (1999) provided the most current review of the monitoring program to date, which included many aquatic or semi-aquatic components. Relevant monitoring efforts by partners and cooperators were also provided in Van Stappen (1999), along with recommendations for future inventory and monitoring. No official Fisheries Management Plan has been written for the Apostle Islands. Although there are some documents that describe fisheries management plans for specific Wisconsin Department of Natural Resources management zones, a plan for the entire area is lacking. This may be due to the fact that most of the fisheries resources are found in Lake Superior, and the State of Wisconsin has management jurisdiction for those waters. A coordinated management plan authored and agreed upon by the National Park Service, Wisconsin Department of Natural Resources, area tribes, and other resource management agencies would be useful as a guidance document for all parties.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for APIS was reviewed for insights on past water quality monitoring in and near the Lakeshore (National Park Service 1999, Table 3). Of the 222 monitoring stations identified in the study area, only 44 were located within the Lakeshore boundaries. Monitoring sites were located mainly in coastal lagoons and Oak Island streams, and records for most sites represented either one-time or intensive short-term sampling efforts. One active and one inactive U.S. Geological Survey stream gage were identified in the study area, but none are presently operating within the Lakeshore. Based on the data compiled for this report, surface waters within the study area generally appeared to be of good quality. Nonetheless, six parameters exceeded screening criteria at least once in the study area (dissolved oxygen, pH, turbidity, fecal coliform, copper, and alkalinity), and two parameters (dissolved oxygen and pH) exceeded screening criteria within the Lakeshore boundaries. Dissolved oxygen and pH were routinely lower than the Environmental Protection Agency criteria for the protection of freshwater aquatic life in the naturally acidic waters of Stockton, Michigan, and Outer Island Lagoons, and pH was lower than this criterion for stream sites on Oak Island for 50-100% of the observations. Potential sources of contaminants identified by the authors included natural spring runoff erosion, as well as nearby municipal and industrial wastewater discharges, quarrying operations, agricultural and forestry operations, marine water traffic, atmospheric deposition, and recreational use.

In addition to water quality monitoring activities, several intensive water quality studies have been conducted at APIS (U.S. Geological Survey 1980a, Rose 1988, Balcer and McCauley 1989, Lake Superior Ecosystem Research Center 1997). These studies included portions of nearshore Lake Superior waters and bays, coastal lagoons, streams on Oak and Stockton Islands, and the Sand River, Raspberry River, and Red Cliff Creek on the mainland unit. They addressed water quality parameters ranging from hydrology and basic water chemistry constituents to bacteria and nutrients. Limited benthic biological sampling was also conducted. In general, these studies suggested that many island streams were intermittent and that most were quite dilute. Baseflow conditions were strongly influenced by groundwater on Oak Island and seepage from wetlands and beaver ponds on Stockton Island. Mainland streams had more stable hydrographs, and the highest constituent concentrations were found at base flow. Loads of sediment and nutrients, however, were positively related to flow. Lagoon water chemistry was relatively dilute and linked to the presence of nearby bogs and hydrologic interactions with Lake Superior. Water quality in Lake Superior was also dilute, with low nutrient and contaminant levels in the water column. Contaminant levels in Lake Superior sediments were higher.

Biology and ecology

A series of basic inventories addressed the Lakeshore's aquatic resources in a general sense. Some of these inventories were largely reviews of existing information (Stadnyk et al. 1974, Anderson et al. 1983, Brander and Bailey 1983), whereas others included additional water

Table 3. Summary of information derived from National Park Service Baseline Water Quality Data Inventory and Analysis reports for the nine Great Lakes Network parks. Table includes data from water quality monitoring sites within each park's study area (generally up to three miles beyond actual park boundaries) and data derived by Great Lakes Network office staff for only those sites within the park boundaries. "Observations" refers to the total number of water quality records found within the study area, and "Parameters" refers to the total number of water quality attributes measured in the study area. "Monitoring stations" refers to the total number of monitoring stations; this number is noted for sites found within the study area, sites found within the park, and sites found within the park that have recorded water quality exceedences. "Parameter exceedences" denotes the number of parameters that exceeded screening criteria at least once within the study area and park, respectively. "Stream gages" denotes the total number of active or inactive U.S. Geological Survey, U.S. Army Corps of Engineers, or U.S. National Weather Service gaging stations (may include streams, lakes, wells, and climate) found in the study area, and the number of active U.S. Geological Survey stream gages found within the park, respectively. "Dischargers" denotes the number of industrial dischargers present in the study area, and "Drinking water intakes" refers to the number of intakes in the study area. APIS=Apostle Islands National Lakeshore, GRPO=Grand Portage National Monument, INDU=Indiana Dunes National Lakeshore, ISRO=Isle Royale National Park, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks National Lakeshore, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes National Lakeshore, VOYA=Voyageurs National Park.

		APIS	**GRPO**	**INDU**	**ISRO**	**MISS**	**PIRO**	**SACN**	**SLBE**	**VOYA**
Observations	study area	20,681	2,578	165,608	9,248	273,531	7,466	113,022	51,317	17,935
Parameters	study area	479	173	743	366	803	237	628	294	316
Monitoring stations	study area	222	28	337	26	541	76	469	149	98
	park	44	7	50	15	184	35	107	76	72
	park exceedence	34	0	41	1	58	5	10	27	33
Parameter exceedences	study area	6	6	23	7	24	4	19	8	9
	park	2	0	12	7	22	3	14	4	8
Stream gages	study area	2	2	9	3	43	0	47	4	1
	park	0	0	3	1	4	0	2	1	1
Dischargers	study area	6	1	46	0	98	0	41	3	0
Drinking water intakes	study area	0	0	3	0	7	0	0	0	0

quality and biological sampling (Anderson et al. 1979, Anderson et al. 1980). Common components of these inventories were vegetation maps (including aquatic vegetation), amphibian and reptile surveys, and bird and mammal surveys (including some aquatic or semi-aquatic animals). Inventories featuring more intensive sampling also included water quality, plankton, benthic invertebrate, and fish samples. These documents were broad in scope and focused on generating basic information for management purposes.

Several studies, however, addressed more specific ecological features at APIS, such as the mollusk (Stern 1979, Doolittle 1991) and non-mollusk (Hiltunen 1969, Winter 1971, Montz 1986) benthic macroinvertebrate fauna, as well as plankton (Winter 1971). Six species of unionid mussels were found in a survey of APIS lagoons and Lake Superior bays (Doolittle 1991). Several of these species were noted as suitable bioindicators due to their abundance, longevity, and role as contaminant bioaccumulators. Stern (1979) sampled invertebrates in streams, beaver ponds, lagoons and Lake Superior shorelines. He noted high abundances of gastropods, but only two species of unionid mussels. Sphaeriid mollusks predominated. Other benthic invertebrate investigations have focused on Lake Superior benthic habitats. Dredge samples of bottom substrates were dominated by the amphipod *Pontoporeia affinis,* with oligochaetes, dipterans, flatworms and the mayfly *Hexagenia* also found (Hiltunen 1969, Winter 1971). Similar species assemblages were found in a more recent survey (Lake Superior Ecosystem Research Center (1997). Montz (1986) conducted depth transects and found two major invertebrate community types: rock-rubble communities with sparse, lotic taxa and soft substrate communities with higher densities and mostly lentic taxa.

<u>*Fish*</u>

There have been several investigations on life history characteristics of Lake Superior fish species that are found near or within the Apostle Islands National Lakeshore boundaries. Investigations have focused on age and growth, bathymetric distribution, relative abundance and other life history characteristics. Most of the reports available are for common sport or commercial species such as lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), and whitefish (*Coregonus clupeaformis*); however there are some reports such as McCauley et al. (1989) and National Biological Survey (1995) that provide information on several species. The reports are not necessarily Lakeshore-specific, but may be used by resource managers to understand the status of species within Lake Superior waters near or adjacent to the islands. However, many of these types of surveys need to be updated. There has been some fisheries work in waters of the islands within the Lakeshore boundaries, but these are somewhat limited. Much of the research has been conducted by other agencies such as U.S. Fish and Wildlife Service, U.S. Geological Survey, or local tribes, but there have been internal documents as well.

Inland waterbody fish surveys and investigations

There is limited inland water on the islands suitable for fish habitation, although there are small streams and wetland areas as well as some small lagoons created by barrier beaches. Two documents found in Lakeshore files provide limited fisheries information on inland waterbodies; Dean (1980) investigated the mouth of the Sand River on the mainland in 1979 and captured 11 species of fish. A small, un-named, permanent stream on Oak Island was also sampled and was classified as a class II trout stream; brook trout (*Salvelinus fontinalis*) and sculpin (*Cottus sp.*) were collected. The Outer Island lagoon was also sampled where one small northern pike (*Esox lucius*) was collected, although anglers at the site had three northern pike ranging from 16 to 20 inches.

Slade (1994) surveyed two streams on Oak Island and collected brook trout at both streams and slimy sculpin in one stream. The brook trout were all juvenile fish and were assumed to potentially be part of a coaster brook trout population since no adults were found in the streams and adult instream habitat was apparently lacking. This would indicate that spawning may occur in the streams and juvenile rearing does occur – two signs that coaster populations may be using the streams.

Lake Superior fish surveys and investigations

Lake Superior surveys around the Apostle Islands have been conducted since at least the mid 20th century. In addition to the area immediately adjacent to the islands, the Chequamegon Bay area to the south of APIS is an important area for fisheries and other aquatic studies. Although there have undoubtedly been a multitude of studies in this bay, many of those may not be in Lakeshore files if they are not specifically related to investigations of the Lakeshore or the immediate adjacent area. Those investigations from Chequamegon Bay that were not found in Lakeshore files are therefore not included in this synthesis. Acquiring these types of studies for APIS files is recommended as many probably pertain to species that use the area around APIS for at least part of their life or at certain times of the year. Several investigations of species life history characteristics were conducted between the 1950s and early 1970s in areas in or near the Lakeshore; these included investigations of sport and commercially important species as well as non-game fish (Bailey 1964, Dryer 1964). Eschmeyer and Bailey (1954) and Bailey (1963, 1969, 1972) in particular reported on often neglected but otherwise interesting species such as the pygmy whitefish (*Coregonus coulteri*), round whitefish (*Prosopium cylindraceum*), longnose sucker (*Catostomus catostomus*), and burbot (*Lota lota*). There have also been several assessments of tribal fisheries for species such as walleye and lake trout that have been harvested around the Apostle Islands area for several years (Busiahn 1982a, 1982b, 1982c, 1983a, 1983b, 1983c; Bronte and Gurnoe 1983; Bronte et al. 1986). These types of investigations and assessments should be continued and updated, as most investigations have not been conducted since the 1980s or the information is not yet in Lakeshore files. The National Biological Survey (now the U.S. Geological Survey-Biological Resources Division) provided a more comprehensive summary of historic fish abundance data for several species (National Biological Survey 1995). McCauly et al. (1989) reported on distribution and abundance of 17 forage species in five locations around the islands.

Lake trout and lake trout restoration efforts have been a popular subject around the Apostle Islands and the species is well represented in research and monitoring reports. Work from the Wisconsin Department of Natural Resources, U.S. Fish and Wildlife Service, and others covers a variety of subjects including density independent survival, predator prey relations, and spawning habitat assessments (Horal et al. 1980, U.S. Fish and Wildlife Service 1983, Wisconsin Department of Natural Resources 1983 and 1984, Bronte et al. 1995, Hudson et al. 1995). The U.S. Geological Survey began conducting a nearshore fishery survey for the Lakeshore in the summer of 2003; results are expected by 2005.

Aquatic wildlife

Aquatic wildlife studies at APIS have focused on beaver (*Castor canadensis*) and semi-aquatic birds. Beaver ecology is likely a key factor shaping aquatic habitats at APIS, particularly on Stockton and Outer Islands where beaver activity is highest (Smith and Peterson 1991). Research indicated that APIS beaver population dynamics are shifting toward fewer, more entrenched family colonies (Smith and Jenkins 1994), and that APIS beaver populations were affected by low fecundity, poor food resources, variable water levels, site instability, and susceptibility to bear predation.

Herring gull (*Larus argentatus*) populations at APIS increased from 1974 to 1979, and ring-billed gull (*Larus delawarensis*) and common tern (*Sterna hirundo*) breeding activity was noted (Matteson 1979). Tern reproductive success was low and habitat improvements and minimization of human disturbance were recommended. The Gull Island double crested cormorant (*Phalacrocorax auritus*) colony increased substantially in size from 1978-1984, causing conflicts with fisherman (Craven et al. 1984). Cormorants adjusted readily to all abatement devices.

Amphibians and reptiles

Herptile inventories and surveys are well represented at APIS. The most comprehensive of these surveys is also the most current, and took place Lakeshore-wide (Casper 2001). Most studies have involved call surveys as well as direct observations (Patzoldt and Brown 1977, Patzoldt 1978, Ludwig 1993, Ernst 1998, Krenz 1998), and some have also included funnel traps, hand capture, frog loggers, and dip net sampling for larvae and egg masses (Rogers et al. 1995, Casper 2001). A total of 16 amphibian species were encountered in Casper's Lakeshore-wide survey; most species were terrestrial forest species dependent upon shallow fishless wetlands for breeding. Breeding sites were mapped; deformities were rare (Casper 2001).

Wetlands and aquatic vegetation

Aside from vegetation information supplied in early survey and inventory reports, there are three primary sources of information on APIS aquatic vegetation. Judziewicz and Koch (1993) described the vegetation and flora of APIS after a series of visits to each island. They provided vegetation lists for coastal and perched bogs as well as alder (*Alnus*) thickets and beaver flowages. Meeker (1998) surveyed and mapped the wetlands of Long Island. He identified nine wetland types based on vegetation characteristics and provided detailed recommendations for future monitoring. Meeker (2000) extended this work to establish permanent vegetation transects in several APIS lagoons and bogs. Vegetation types included two main groups associated with peat versus inorganic substrates. Meeker urged development of consistent monitoring guidelines and protocols for all of the monitored wetlands.

Contaminants

Research on contaminants at APIS is limited to a pair of older reports on polychlorinated biphenyls (PCBs) and organochlorine pesticides in nearby Lake Superior waters, sediments, and fish. The studies concluded that APIS fish had high levels of PCBs and dieldrin relative to other Lake Superior sites, but that these concentrations were low relative to fish from Lake Michigan (Wisconsin Department of Natural Resources 1977, Strachan and Glass 1978).

Hydrology

Information on stream and lagoon hydrology is provided in the water quality reports cited above.

Groundwater

Groundwater information is limited to a single data report on well depths, water levels, drawdowns and pumping rates for Presque Isle Point, Quarry Bay, Rocky Island, Little Sand Bay, and Sand Island (U.S. Geological Survey 1980b).

Physical Processes

Two studies addressed bank erosion and shoreline processes at APIS. A 1987 report by Milfred showed bank edge retreat over a two year period at Presque Isle campground on Stockton Island, and a report by Green and Dunning (1992) provided insights on developing a long-term monitoring program for Long Island's shoreline.

Strengths and needs

An array of basic water resource information is available through general resource documents and basic water quality and biological assessments. In general, however, the aquatic work at APIS has favored breadth over depth, so insights about water quality and aquatic biology are based on relatively few studies with relatively few data points. Additionally, with the exception of the Lakeshore-wide amphibian survey (Casper 2001) and the Long Island wetland survey (Meeker 1998) many of the most comprehensive studies are now becoming dated. Fish species assemblage work should be updated and the surveys of the nearshore waters around the islands in 2003 will help meet that need. Results from this work are expected by 2005. Topical, issue-based aquatic research at APIS has been very limited. Important stressors to consider in the future are aquatic invasive species, contaminant bioaccumulation, recreational effects, and climate change and lake level variation.

Considerations for monitoring

Directly from the literature

- Doolittle (1991) identified several mussel taxa as potentially useful bioindicators: *Elliptio complanata, Anodonta g.* form *grandis,* and *Lampsilis radiate siliquoidea*. *Elliptio complanata* may be especially useful for contaminants.
- Smith and Peterson (1991) recommended aerial surveys of beaver colonies every 1-3 years and transect or beaver cutting surveys every 3-5 years.
- Craven et al. (1984) recommended annual surveys of Gull Island cormorant colony, and Matteson (1979) recommended a repeat gull and tern survey every five years.
- Krenz (1998) and Ernst (1998) noted that the use of multiple methods (auditory surveys and hand captures) improved the species list for amphibians.
- Casper (2001) provided detailed methodological recommendations for monitoring amphibians.
- Meeker (1998) outlined a detailed monitoring regime for Long Island wetlands and established monitoring transects for wetlands on several other islands.

Derived from the literature by the synthesis authors

- Current water quality monitoring at APIS is limited to Lake Superior open waters. Inclusion of nearshore sites and lagoon sites is desirable.
- Invasive species monitoring should occur in wetlands, lagoons, and Lake Superior. Monitoring to detect presence of zebra mussels (*Dreissena polymorpha*) in APIS nearshore waters is of particular importance given their presence in nearby Ashland harbor.
- Consistent monitoring of Lake Superior fish species assemblages should occur at least every decade, but preferably every 5 years. The trawl surveys conducted by U.S. Geological Survey in 2003 are a start, although there may be a need for assessments that incorporate several types of collection methods.
- In light of the interest in coaster brook trout and the potential for rehabilitating populations in the APIS area, stream monitoring and Lake Superior monitoring of existing brook trout populations will be an important component to these efforts.
- Lake trout harvest information should be updated regularly.
- Changes in shoreline habitat for piping plover (*Charadrius melodus*) and other shore-adapted flora and fauna should be monitored, with attention to erosion and recreational disturbance.
- Several studies noted the significant effects of beaver on stream drainage patterns, especially at Outer Island (see Anderson et al. 1979). Given the effects of beaver on hydrology, biogeochemical processes and mercury transport, such landscape changes should be monitored over time.

Considerations for research

Directly from the literature

- Effects of the ruffe invasion on fish and other attributes of the Sand River should be investigated (see PMIS #73658).
- Further research into the effects of human activities on gull and tern breeding ecology has been suggested (Matteson 1979).

Derived from the literature by the synthesis authors

- Investigations into the presence and abundance of aquatic nuisance species could potentially lead to research in the area of impacts to food web dynamics from non-native aquatic species. *Bythotrephes* (spiny water flea) investigations will occur in Lake Superior National Park Service units by 2008. Research related to impacts from this species will be critical in understanding potential changes in aquatic community structure and function.

- Intermittent streams at APIS have unique hydrologic regimes; they may serve as refugia for rare invertebrates and fish, and may be home to organisms with novel physiological adaptations that have not been investigated. These systems may be of interest to physiological ecologists, natural historians and systematists.
- Lagoons at APIS differ with respect to the presence or absence of fish. Related differences in food web structure have implications for the effects of biological invasions by non-native fish and invertebrates. Thorough baseline ecological data on the lagoons would be useful.
- Brook trout rehabilitation efforts are occurring at Whittlesey Creek National Wildlife Refuge and in other areas on the mainland near APIS. Genetic investigations of brook trout stocks of the area may have occurred prior to this effort, but there is likely a need for further work investigating stocks around the islands, especially since Isle Royale brood stock were used for the Whittlesey Creek effort. . Apostle Islands National Lakeshore should coordinate with other entities involved in coaster rehabilitation efforts to determine if a locally developed brood stock would be feasible or more appropriate for stocking efforts.
- Several potential contaminant issues are poorly understood at present: mercury bioaccumulation in lagoons and nearshore Lake Superior fish, declines in pesticide burdens in fish tissues (see Strachan and Glass 1978), and polycyclic aromatic hydrocarbon (PAH) contamination in boat docking areas/marinas. Existing data from other agencies should be consulted to address the issue of mercury and organochlorine contamination of fish tissues in Lake Superior fish.
- Effects of recreation on shoreline habitat and shoreline processes should be addressed at heavily visited sites.

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GRAND PORTAGE NATIONAL MONUMENT

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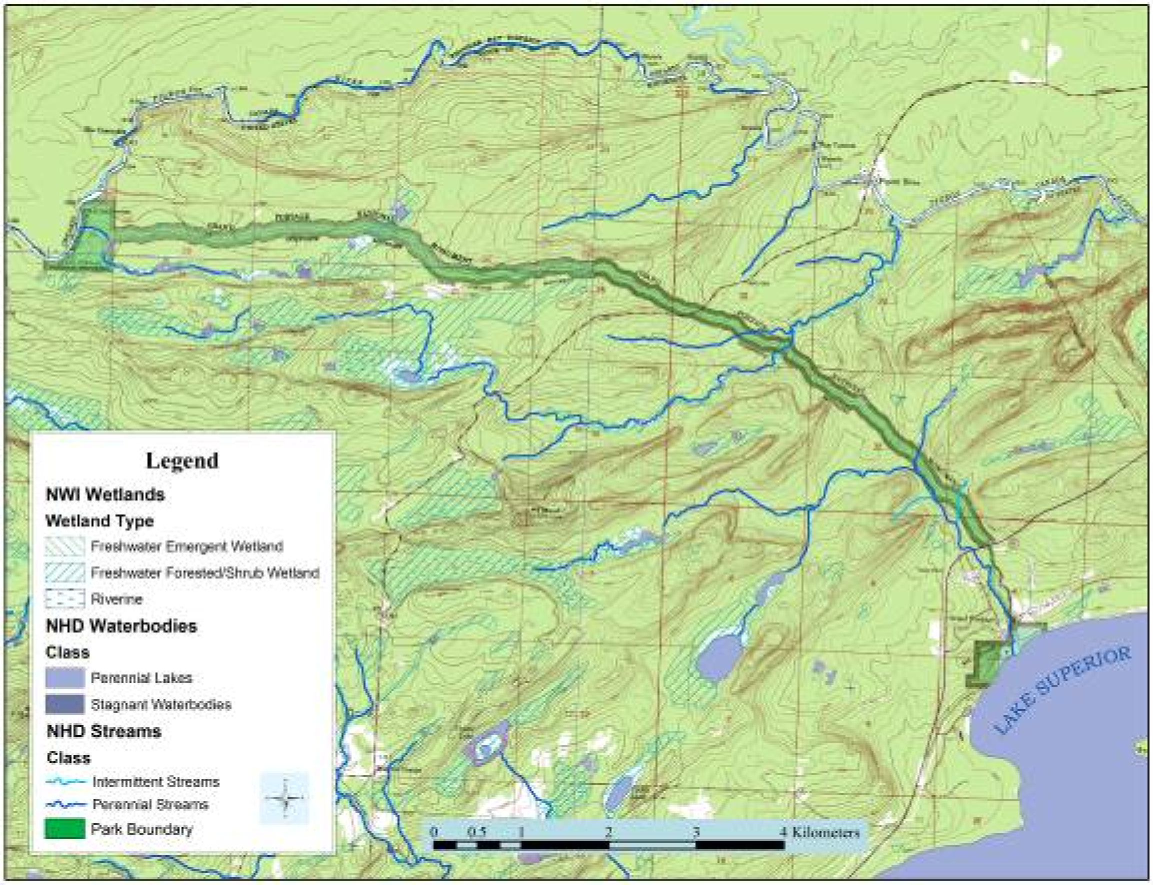
Photographs from top to bottom: Grand Portage National Monument from Mt. Rose (S. Gucciardo), Grand Portage Creek near Grand Portage National Monument (S. Gucciardo), and beaver pond (S. Gucciardo).



Grand Portage National Monument and surrounding area, showing streams and water bodies derived from the National Hydrography Dataset (NHD), and wetlands derived from the National Wetland Inventory (NWI). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

GRAND PORTAGE NATIONAL MONUMENT

Grand Portage National Monument (GRPO) was designated in 1951 as Grand Portage National Historic Site and re-designated a national monument in 1958. Situated just south of the Canadian border along Grand Portage Bay of Lake Superior, GRPO lies entirely within the Grand Portage Band of Minnesota Chippewa Reservation. It remains chiefly a historical monument, preserving a vital center of centuries-old fur trade activity and Anishinaabeg (Ojibwe) heritage. Unlike other Great Lakes area parks, GRPO contains very few water resources (Table 1, pg. 2). Lake Superior and the Pigeon River are the most prominent water resources in the area, but these are beyond GRPO jurisdiction. Local parts of Lake Superior are managed jointly by the Grand Portage Band of Minnesota Chippewa Reservation and the Minnesota Pollution Control Agency, in keeping with a novel cooperative agreement approved by the Environmental Protection Agency in 1996. . Grand Portage National Monument's 14 km (8.5 mile) portage corridor between Lake Superior and Fort Charlotte intersects the watersheds of three streams, namely Grand Portage Creek, Poplar Creek, and Snow Creek. All three drain portions of the rugged Grand Portage Highlands.

Summary of existing aquatic research

<u>*General resource documents and plans*</u>

The Grand Portage Band of Minnesota Chippewa, in cooperation with the U.S. Geological Survey, assembled a proposed environmental monitoring program that would address several aspects of Reservation water resources (Goldstein 2000). The proposed sites include two streams that cross the Grand Portage corridor, Poplar and Grand Portage Creeks, as well as several stations in Grand Portage Bay. The protocols recommend sampling water chemistry, sediment chemistry, fish, benthic invertebrates, and algae in the streams; and water chemistry, depth profiles, and phytoplankton in Grand Portage Bay. The proposed activities are quite comprehensive and should be coordinated with any GLKN monitoring efforts at GRPO. Due to the limited fisheries resources found at the Monument, a fisheries management plan would not appear to be necessary. However, some sort of management plan should be a part of the ongoing coaster brook trout (*Salvelinus fontinalis*) rehabilitation efforts at Grand Portage Creek, and may include coordination with the U.S. Fish and Wildlife Service and/or Grand Portage Band.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for GRPO was reviewed for insights on past water quality monitoring in and near the Monument (National Park Service 1999, Table 3, pg. 14). Of the 28 monitoring stations identified in the data retrieval, only seven were within the Monument boundaries, and more than half the observations were derived from two stations on the Pigeon River at Middle Falls, outside the Monument. A total of 2,578 observations were recorded, covering 173 parameters. One active and one inactive U.S. Geological Survey stream gage were identified in the study area; no active gages are currently found within the Monument. Based on the data compiled for this report, surface water resources within the study area appeared to be of good quality. Six parameters, including several metals, exceeded screening criteria at least once within the study area, but there were no exceedences within the Monument boundaries. Turbidity exceeded the screening criterion only once, on the Pigeon River in 1974, and total coliform and fecal coliform concentrations exceeded the bathing water screening criterion three times and once, respectively. Copper and zinc concentrations exceeded their acute freshwater criteria approximately 30 times each, all on the Pigeon River from 1968 to 1976. Lead concentrations exceeded drinking water criteria 31 times, also on the Pigeon River between 1968 and 1976. The authors identified potential sources of these contaminants to be municipal wastewater discharges, stormwater runoff, mining operations, recreational use, logging activities, and atmospheric deposition.

In addition to the above monitoring records, data concerning water resources in and near GRPO are available in several recent reports. Water quality of Grand Portage Bay was assessed during the summers of 1994-1996 (Ruhl 1997). In general, concentrations of phosphorus, trace metals, and bacteria were low. Nitrate concentrations were relatively high (0.4 mg/L N), and atrazine was detected in water column samples. Lakes, streams, and wetlands of Grand Portage Band of Minnesota Chippewa Reservation were surveyed for water chemistry in 1997 and 1998 by U.S. Geological Survey (Winterstein 2000). While none of these sites were within GRPO boundaries, the data provide a useful context. Water quality and drainage characteristics were evaluated for four GRPO stream sites, including sites on Grand Portage Creek, Poplar Creek, and Snow Creek, during summer 2000 (Grand Portage National Monument 2000). Grand Portage and Poplar Creeks are higher gradient streams than Snow Creek, which drains a wetland complex and has higher chlorophyll *a* concentrations. The streams were seasonally coherent with one another with respect to water chemistry. There was no evidence of excess nutrients or fecal coliform, nor of mercury or polychlorinated biphenyl (PCB) contamination.

Biology and ecology

Aquatic biological work at GRPO is limited to a report on benthic invertebrates in Poplar and Grand Portage Creeks (Boyle and Richmond 1997). All sites were dominated by small boulders with some smaller particles also present. The invertebrate fauna was represented by 140 taxa, with highest densities encountered in late summer and fall. Particle size, nutrient, and temperature monitoring was recommended for all sites, particularly on the Grand Portage Creek tributary, where construction of a small dam has been proposed.

Fish

There are limited aquatic and fisheries resources at GRPO, but relatively healthy aquatic habitat. Grand Portage Creek flows through sections of the Monument; the northwest section of the Monument at the Fort Charlotte site borders a section of the Pigeon River and a small tributary that flows into the Pigeon River. A short section of Poplar Creek also flows through the Monument on its way to the Pigeon River. There are also beaver (*Castor canadensis*) ponds that create areas of aquatic habitat that are important for some species that may not occupy stream habitats of GRPO.

Fish of inland lakes or streams

There are limited aquatic and fisheries resources at GRPO, which is reflected in the very limited amount of fisheries information available. Documents that provide specific fisheries information include reports on coaster brook trout from the Grand Portage Band and U.S. Fish and Wildlife Service, and a report from Boyle and Richmond (1997) that provides qualitative and quantitative habitat information. Boyle and Richmond (1997) also discussed plans by the Grand Portage Band and the U.S. Fish and Wildlife Service to construct a dam on a tributary to Grand Portage Creek, in order to decrease water temperatures for brook trout rehabilitation efforts. There have been efforts to rehabilitate coaster populations since 1991 in Grand Portage Creek, which flows partly through the Monument and enters Lake Superior at the stockade (Newman 1993, Newman and Johnson 1996). Recent information from the U.S. Fish and Wildlife Service in Ashland, Wisconsin indicates that rehabilitation efforts at Grand Portage were successful in establishing naturally reproducing coaster populations. If monitoring continues to indicate that these efforts were successful, the methods used at Grand Portage could be applicable to rehabilitation efforts in other areas of the Lake Superior shore of Minnesota. The Monument is currently conducting a fish species inventory, which will provide information on resident species as well as those species that move into and out of Grand Portage Creek and the Pigeon River.

Groundwater and hydrology

Groundwater resources were assessed for Grand Portage Reservation in 1992, focusing on stream flow in the Pigeon, Reservation, and Grand Portage Rivers, as well as aquifer storage coefficients, transmissivity, and yields (Ruhl 1994). Groundwater quality was described based on well data. As with Isle Royale streams, peak stream flows occurred in April-May, with secondary peaks in October and November. Groundwater was supplied mainly by bedrock rather than sand-gravel aquifers. Well data indicated somewhat high dissolved solids, chloride, and iron in several wells, and toluene was detected at a well downstream of an abandoned landfill.

Strengths and needs

GRPO water resource information is limited, but the extent of water resources within Monument boundaries is also limited.The information that does exist is fairly current and thorough. Research and monitoring at GRPO has been basic and descriptive in nature. To date, there has been no research on aquatic vegetation, aquatic wildlife, or amphibians and reptiles. Possible stressors to consider are invasive species (especially *Dreissena polymorpha,* the zebra mussel, and *Bythotrephes longimanus,* the spiny water flea), land use changes in the watersheds of the streams, low-head dam construction on tributaries, contaminant bioaccumulation in Grand Portage Bay, and increased nitrogen deposition.

Considerations for monitoring

Directly from the literature

- Relevant stream monitoring parameters would include thermal regimes, nutrients, and sediment loads in creeks (Boyle and Richmond 1997).

Derived from the literature by the synthesis authors

- Seasonal coherence in water quality in the three streams suggests that monitoring only one stream may suffice (Grand Portage National Monument 2000).
- Status of brook trout in Grand Portage Creek should be assessed, as well as species assemblages in other water bodies of the Monument. Spawning season surveys of Grand Portage creek would require fairly minimal effort and could be conducted annually. Information obtained from this effort would be invaluable in determining long-term success of rehabilitation efforts or if populations are increasing or decreasing.
- Water resource monitoring at GRPO should be coordinated with the Grand Portage Reservation monitoring program proposed above (i.e., sampling sites could be co-located and similar sampling methods and parameters used).

Considerations for research

Derived from the literature by the synthesis authors

- Boyle and Richmond (1997) noted that construction of a proposed low-head dam on a Grand Portage Creek tributary may affect stream nutrient and sediment characteristics. Some follow-up work may be useful if dam construction is still under consideration.
- Boyle and Richmond (1997) found that stream nutrient ratios suggested nitrogen limitation of algal growth. . Grand Portage National Monument is located in a region with changing nitrogen deposition patterns, and potential effects of increased nitrogen on algal growth should be monitored.
- If it is not known, it is important to determine whether or not zebra mussels have become established in Grand Portage Bay. If they have become established, the potential for transport to inland waters near GRPO or to Isle Royale (via pleasure boat traffic and summer ferries) should be addressed. If they are not present, existing water quality data should be used to determine if local water quality conditions (e.g., calcium concentrations, water temperature) could support their establishment in the future.

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INDIANA DUNES NATIONAL LAKESHORE

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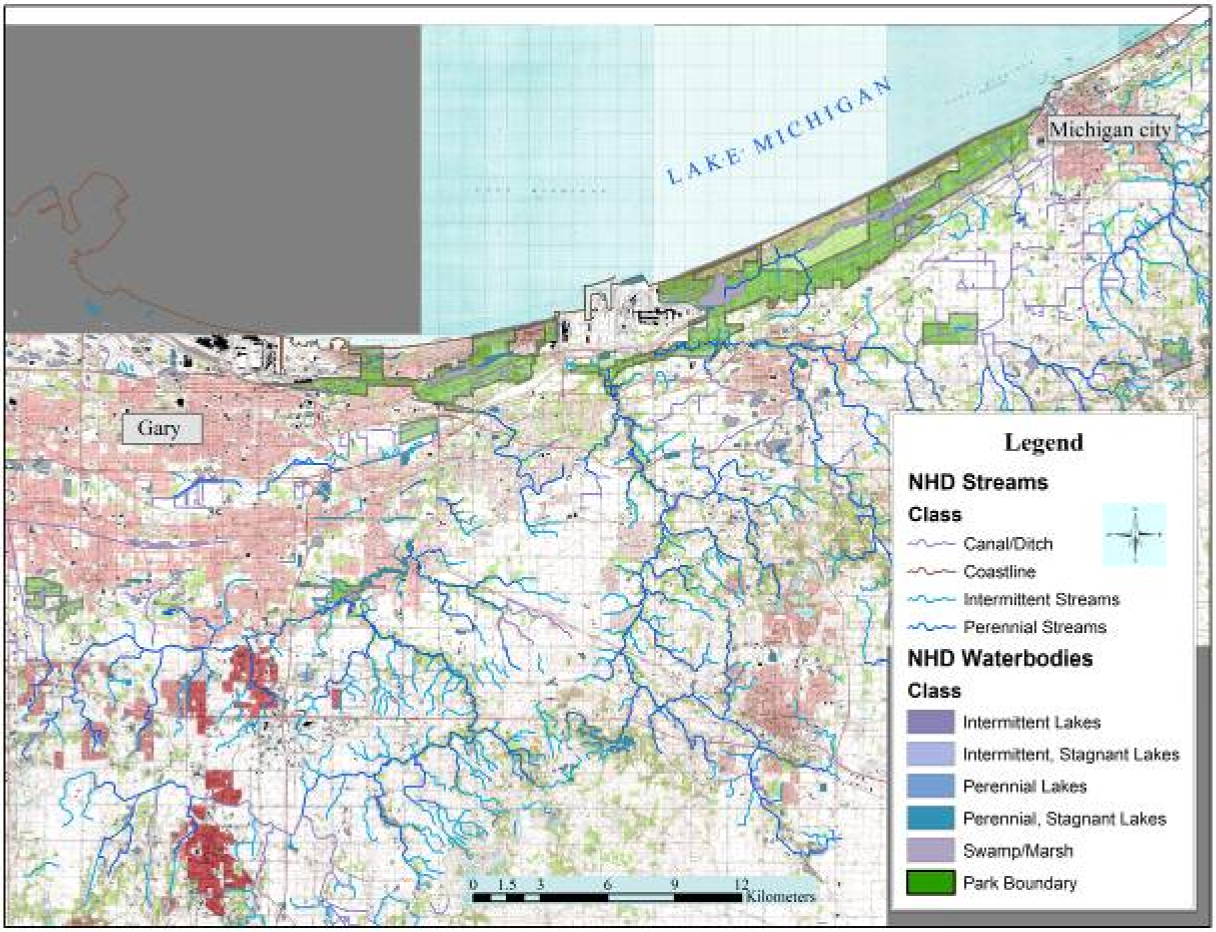
Photographs from top to bottom: Lake Michigan shoreline, Little Calumet River, Great Marsh, and Pinhook Bog. All images courtesy of Indiana Dunes National Lakeshore photograph files.



Indiana Dunes National Lakeshore and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

INDIANA DUNES NATIONAL LAKESHORE

Indiana Dunes National Lakeshore (INDU) was designated in 1966 and protects 19 km (12 miles) of Lake Michigan shoreline between Gary, Indiana and Michigan City, Indiana. Prominent aquatic resources include Lake Michigan, 241 ha (596 acres) of which are under INDU jurisdiction, extensive emergent wetlands, forested wetlands, and bogs, the Grand Calumet Lagoons, and streams. In addition to natural streams, INDU also features 19 km (12 miles) of ditched streams (Table 1, pg. 2), some of which have been named and studied intensively. Lentic water resources are not strongly represented at INDU, with only two named lakes (Lake George and Long Lake) and one named bog (Pinhook Bog) noted in our analysis (Table 1, pg. 2). . Indiana Dunes National Lakeshore water resources are exposed to a complex mixture of adjacent land uses, ranging from heavily industrial to residential and agricultural.

Summary of existing aquatic research

General resource documents and plans

INDU's water resources management document (Dolak 1985) provided a good overview of water resources and related hydrogeologic processes, issues, knowledge gaps, legal mandates, and management options. This is a valuable document but is in need of an update. Garza et al. (2002) and Whitman et al. (2002) offered descriptive ecological information about Long Lake and restoration in the Grand Calumet River Basin, respectively. Whitman et al. (2002) featured a synthesis chapter which recommends possible management actions related to the restoration effort.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for INDU was reviewed for insights on past water quality monitoring in and near the Lakeshore (National Park Service 1994, Table 3, pg. 14). Of the 337 monitoring stations identified in the data retrieval, 50 were located within the Lakeshore boundaries, and 41 of those sites within the Lakeshore boundaries had recorded water quality exceedences. Sites with the longest records included several in Kintzele Ditch, the Little Calumet River, Pinhook Bog, Cowles Bog, and Interdunal Pond C. Nine active or inactive U.S. Geological Survey stream gages were identified in the study area, with three gages currently active within the Lakeshore. A total of 165,608 water quality observations and 46 industrial dischargers were identified in the data retrieval, second among the Great Lakes parks only to Mississippi National River and Recreation Area, for which 273,531 observations and 98 dischargers were recorded. The data covered 743 parameters, 23 of which exceeded the screening criteria at least once within the study area, and 12 of which exceeded screening criteria within the Lakeshore. Within the Lakeshore boundaries, dissolved oxygen, pH, chloride, sulfate, and several heavy metals (lead, zinc, copper, cadmium, and nickel) exceeded their respective drinking water criteria or Environmental Protection Agency criteria for the protection of aquatic life. Indicator bacteria (total and fecal coliform) concentrations and turbidity frequently exceeded screening limits for primary body contact recreation and aquatic life, respectively. The authors noted that water quality at INDU is typical of that found in highly developed areas, and has been affected by industrial and sewage effluents, stormwater runoff from roads and parking lots, and atmospheric deposition of sulfur and nitrogen oxides.

As may be expected given the history of indicator bacteria exceedences, a sizeable amount of work has been dedicated to investigations of bacterial contamination of INDU waters over the past decade, including Lake Michigan beaches as well as local ditches and streams. Whitman and others have examined the use of coliform bacteria as indicators of human sewage contamination. Their work has examined the likely sources of indicator bacteria (Whitman et al. 1995); identified high variability in the dispersal and deposition of indicator bacteria in streams (Whitman et al. 1999); documented the interaction of factors such as rainfall, wind direction, and water temperature with bacteria concentrations (Whitman et al. 1999); and examined the association of indicator bacteria with stream water, sediments, soils, and even the alga *Cladophora* (Byappanhali et al. 2003a, 2003b, Whitman and Nevers 2003, Whitman et al. 2003). The authors concluded that traditional bacterial indicator species may not be adequate predictors of human sewage contamination, that current beach monitoring/closure protocols are not effectively predicting harmful bacteria levels, that *E. coli* can persist and multiply in both nearshore sand substrates and *Cladophora,* and that ditching and wetland loss may contribute to chronically high *E. coli* concentrations at INDU.

Several spatially extensive water quality studies have been conducted at INDU. Arihood (1975) examined INDU's geohydrology and surveyed precipitation chemistry and ground and surface water quality around the time of the Lakeshore's establishment. . Indiana Dunes National Lakeshore geology consisted mainly of unconsolidated lake and glacial deposits, with sandy units providing the highest groundwater yield. Groundwater quality was quite hard and varied with depth and location but not over time. Precipitation chemistry was influenced by lead and zinc deposition. Most surface water sites showed circumneutral to slightly basic pH levels, calcium-bicarbonate chemistries, and dissolved oxygen levels near saturation. The chemistry of marsh and bog sites was distinct, with low pH, conductance, and dissolved oxygen levels. Several sites showed evidence of fecal contamination, trace metal contamination, and pesticide pollution.

Hardy (1983) conducted a comprehensive water quality study at INDU, surveying 52 sites in the Grand Calumet Lagoons, the Little Calumet drainage basin, and in Dunes Creek, Derby Ditch, and Kintzele Ditch. Basic water quality characteristics, fecal coliform and streptococci, benthic invertebrates, and streambed trace elements and chlorinated hydrocarbons were sampled during high and low flows for several summers. As suggested in Arihood (1975), water and sediment quality was related to urban, residential, and industrial discharges.

Consequently, many sites showed elevated concentrations of nutrients in the water column and elevated concentrations of lead, zinc, dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs) in the sedimentts. Wetlands and agriculture had localized effects on concentrations of organic materials, nutrients, sulfates, iron, and sediments in parts of Kintzele Ditch, Derby Ditch, and Dunes Creek. Hardy's (1983) and Arihood's (1975) studies both highlighted the variety of stressors affecting INDU water resources.

Simon et al. (1997) surveyed four shallow lakes at INDU for morphometric and water chemistry characteristics. The lakes tended to be shallow, well-mixed depressions with depths generally less than 3 m. The lakes did not stratify or become anoxic, resulting in little recycling of nutrients and metals from the lake sediments. Conductivity in the lakes ranged widely, but pH was consistently neutral to slightly alkaline. The authors noted that nitrogen levels were comparable to other mesoeutrophic lakes in the area, but phosphorus levels were an order of magnitude higher.

Biology and ecology

Benthic meio- and macro-invertebrates have been examined in a variety of studies at INDU. These studies include an analysis of beach nourishment impacts on nearshore Lake Michigan invertebrates (Whitman and Garza 2002), documentation of the presence of an exotic crustacean in nearshore Lake Michigan sands (Horvath et al. 2001), and a study of the composition and distribution of interstitial meiofauna in Lake Michigan nearshore sands (Whitman et al. 1994). Lake Michigan nearshore benthic invertebrate communities varied with depth, with fauna at shallow sites (<3 m, 9.8 feet) adapted to wave and sediment disturbance, fauna at deeper sites more diverse and stable, and fauna showing some decrease in densities downdrift of beach nourishment activities (Whitman and Garza 2002). Aquatic invertebrates extended as far as 30 m (98 feet) landward and 2 m (6.5 feet) below the sand surface of the open beach in interstitial waters, and consisted mainly of oligochaetes, nematodes, and the crustacean *Parastenocaris* spp. (Whitman et al. 1994). Two non-native harpacticoid crustaceans (*Schizopera borutzkyi* and *Heteropsyllus* sp.) were documented in nearshore sands and found to be numerically dominant (Horvath et al. 2001).

Some inland ecological studies included relationships of stream biota to factors such as land use, habitat, and water quality in Dunes Creek and Derby and Kintzele Ditches (Stewart et al. 1997, Stewart et al. 2000). Macroinvertebrate and aquatic macrophyte patterns were more closely tied to local abiotic factors than to catchment-wide characteristics or land use qualities. In general, structural and functional biotic metrics best distinguished among-site differences, and macroinvertebrate metrics suggested degraded stream and wetland conditions.

Other work in inland waters included ecological assessments of the Miller Woods interdunal ponds (Whitman et al. 1988, Whitman et al. 1991), with documentation of pond morphometry, determination of aquatic plant distribution and relative abundance, and analysis of phytoplankton, zooplankton, and benthic invertebrate communities. The Miller Woods ponds tended to be shallow and fishless. Vernal ponds were found to have higher phytoplankton densities than the larger, dredged, permanent ponds. Variation among ponds was linked to extensiveness of littoral areas, varying water levels, fish presence/absence, and dredging activities. Phytoplankton and water quality were also examined in Long Lake over the course of two summers (Nevers and Whitman 2004). Phytoplankton communities in Long Lake were dominated by euglenoid taxa and differed from those of lakes in northern Great Lakes area parks (i.e., Pictured Rocks National Lakeshore, Isle Royale National Park, and Voyageurs National Park).

Fish

Various investigations have been conducted by U.S. Geological Survey and academic researchers on subjects ranging from fish assemblages within the Lakeshore to studies of recruitment in Lake Michigan. There are also research progress reports or updates of ongoing research from Illinois-Indiana Sea Grant including, among other subjects, examinations of larval yellow perch (*Perca flavescens*) early life history in Lake Michigan and creation of transgenic fish for aquaculture purposes. Aquatic nuisance species in Lake Michigan and their effects on native fish are also well covered by Indiana-Illinois Sea Grant. Other aquatic investigations that are not specifically related to fish may provide information on factors affecting fish populations (see other sections). Some survey work has been conducted within the boundaries of the Lakeshore, but because fisheries habitat is limited at Indiana Dunes, investigations have been few. Investigations outside of Indana Dunes, while not specific to the Lakeshore, provide useful information about regional changes in fish populations and habitat. The description of fish assemblages in the Valparaiso Chain of Lakes (Simon et al. 2004a) is one example. The authors described declines in species diversity and biological condition due to multiple anthropogenic disturbances. From this we may presume similar declines at INDU since the area has been subjected to the same disturbances. The primary waters in the Lakeshore boundaries that have fish populations or fisheries habitat with potential to support populations are the Little and Grand Calumet Rivers, Dunes Creek, Kinzele and Derby Ditches, Long Lake, and ponds within the Miller Woods area.

Inland waterbody fish surveys and investigations

The most recent, and perhaps only, comprehensive investigation of fish populations in the Lakeshore area was conducted by Spacie (1988) who investigated populations in all the major watersheds of the Lakeshore, including the Kinzele and Derby ditch systems. Although 22 species were detected, she also found indicators of poor water quality such as high proportions of species that are highly tolerant of poor conditions. She indicated fish were present in the ponds of Miller Woods, although a report by Whitman et al. (1988) stated no fish were present in their investigations of the Miller Woods ponds. No other comprehensive fisheries investigation was found in Lakeshore files, nor was there a reference to earlier comprehensive surveys in Spacie's 1988 report.

Garza et al. (2002) examined the ecological characterizations of Long Lake. Information regarding fisheries was limited and primarily referenced Spacie (1988) and Brenan (1923 as referenced in Garza et al. (2002)). The latter referenced document from Brenan was not found in our search of the Lakeshore files. The report from Garza stated that yellow perch had not been identified in Long Lake since 1990, when a fish kill occurred.

The Little and Grand Calumet Rivers have been the subject of fisheries monitoring and research including investigations of past and present assemblages in the Grand Calumet River (Simon and Moy 1999) and surveys in the Little Calumet River by the Indiana Department of Natural Resources as referenced in Spacie (1988). Rivers of the Lakeshore are subject to invasion by exotic species that occur in Lake Michigan as documented by Simon et al. (1998). During the period from 1992 to 1998 they documented six new species in the Grand Calumet and Little Calumet Rivers that were either from Europe and Asia or were non-native North American species. Ironically, they suggested that efforts to restore Great Lakes harbors, declines in toxic sediments, and chemical load reductions in tributaries have allowed habitation by non-natives in previously toxic areas. Simon et al. (2004b) also reported on a potentially positive effect of having an intentionally introduced exotic species, the Chinook salmon (*Oncorhynchus tshawytscha*) in the Calumet basin. They suggested that the presence of Chinook salmon in the Grand Calumet River could possibly force changes in designated uses to more conservative standards that are more protective of coldwater fish. These potential changes could ultimately lead to pollution reductions in the basin.

Simon (1992) also reported new ichthyofaunal records of some indigenous species for rivers of the region, including the Calumet basin. He documented populations of native fish either previously not reported in the area or that have not been documented in several years. The bluntnose darter (*Etheostoma chlorosoma*) for example, had not been recorded in the Calumet basin in 80 years prior to this investigation. The American brook lamprey (*Lampetra appendix*) had previously not been recorded from any Lake Michigan tributaries in Indiana, but it, too, was documented in the Calumet basin.

Lake Michigan fish surveys and investigations

Simon and Stewart's (1999) investigation of fish communities of the southern Lake Michigan basin is a valuable resource for understanding the history of impacts to aquatic habitats in and near INDU, and the potential for rehabilitation efforts. Most other Lake Michigan studies have been or will probably be conducted by the State of Indiana, federal agencies other than the National Park Service or academic researchers. There may be studies available from these organizations not found in Lakeshore files that would add to the overall understanding of past and current status of species found in the southern Lake Michigan area. Though an inventory of those reports is beyond the scope of this document, investigations of nearshore waters adjacent to the Lakeshore boundary would be of particular interest and these reports should be sought by INDU for their files.

Amphibians and reptiles

INDU herpetofauna have been investigated on several occasions using opportunistic collecting techniques, drift fences, and artificial cover objects at various sites (Resetar 1985, 1992, 1994, Glowacki and Grundel 2005). Historical distribution and ecology of northwestern Indiana herpetofauna were treated in Resetar (1992), and comprehensive species lists and location data were provided. Combined amphibian and reptile species richness at INDU appears to be greater than 24. Cited management concerns included forest fragmentation, domestic cat predation, poaching (box turtles, *Terrapene carolina*), and increased shading of turtle nests sites due to increased tree cover (Resetar 1994). In 2002-2003, Glowacki and Grundel (2005) used a variety of survey techniques to determine whether or not the wetland-loving massasauga rattlesnake (*Sistrurus catenatus catenatus*), a candidate for federal listing as a threatened or endangered distinct population segment, still existed within INDU. In addition to one confirmed capture of a massasauga rattlesnake and several likely sightings, the authors also documented 23 species of amphibians and reptiles, including nine frog and toad, five salamander, two turtle, one lizard, and six snake species.

Wetlands and aquatic vegetation

Wetland research at INDU has focused on three main study areas, the Cowles Bog wetland complex, Pinhook Bog, and the Miller Woods interdunal ponds. Hydrology, water chemistry, and cattail invasions of sedge meadows have been investigated at Cowles Bog. Vegetation shifts toward cattail (*Typha* sp.) dominance began in the mid-1960s at the Cowles Bog wetland complex, likely due to the higher, more stable water levels induced by seepage from nearby diked ponds (Wilcox et al. 1984). Several vegetation types were correlated with water level fluctuations (Wilcox et al. 1986) and possibly water chemistry (Stewart et al. 1993). Simon et al. (2001) developed multimetric indices of biotic integrity for wetland communities in the Great Marsh and Grand Calumet Lagoons. These indices showed promise in distinguishing reference sites from impacted sites, and could be useful in prioritizing high quality wetland patches for further protection.

At Pinhook Bog, stratigraphy and developmental history has been investigated (Wilcox and Simonin 1988), along with effects of deicing salts on water chemistry and aquatic vegetation. Portions of Pinhook Bog were affected by highway runoff and showed elevated interstitial salt concentrations and altered bog vegetation (Wilcox 1986a, 1986b). Management actions to reduce road salt inputs resulted in improved chemical conditions and recovery of some bog plants (Wilcox 1986b).

In addition to the ecological studies of the Miller Woods interdunal ponds described earlier (Whitman et al. 1988, 1991), investigators also examined aquatic plant types, water chemistry and sediment chemistry to determine the chronosequence of dune/swale pond rows (Wilcox and Simonin 1987). Pond rows formed sequentially beginning about 3,000 years before present. Sediments in older pond rows had higher amounts of organic matter, but water chemistry was similar across ponds. Both Wilcox and Simonin (1987) and Hiebert et al. (1986) noted that the interdunal ponds harbored unique flora and that plant species composition tended to vary with water depth and water level fluctuation. Simon et al. (2000) recently examined 62 wetlands in the Miller Woods area and developed a multi-group, multi-metric index of biotic integrity. The authors noted that incorporating multiple taxonomic groups into their index improved its ability to distinguish reference sites from disturbed ones.

A joint study at INDU and Sleeping Bear Dunes National Lakeshore (SLBE) addressed purple loosestrife (*Lythrum salicaria*) life histories, relationships to gradients in soil chemistry and hydrologic regime, and competition with other plants (Edwards 1995). Investigators found that factors affecting purple loosestrife success differed for INDU and SLBE, with INDU populations affected by small-scale differences in hydrology and nutrients and SLBE populations affected more by large scale climatic factors and the density of other plants. They concluded that a single purple loosestrife control method is not likely to be successful in all situations.

Contaminants

Many contaminant studies at INDU have focused on industrial contamination of the Grand Calumet River and Indiana Harbor Canal Area of Concern. Stewart et al. (1999, 2003) and Simon and Stewart (1998) investigated a suite of chemical and biological features in the Grand Calumet Lagoons in order to develop biological impairment indicators. Water quality, sediment chemistry, and metrics for periphytic algae, aquatic plants, and fish were all indicative of contamination in the West Lagoon at sites nearest an industrial landfill. Toxicity tests with fathead minnows (*Pimephales promelas*), an amphipod (*Hyalella azteca*), and an oligochaete (*Lumbriculus variegatus*) provided further evidence of the extreme toxicity of sediments in the West Lagoon (Stewart et al. 1999) and throughout the Grand Calumet River and Indiana Harbor Canal (Ingersoll et al. 2002). MacDonald et al. (2002a, 2002b) summarized information on the chemical composition and toxicity of sediments and biological tissues in the Grand Calumet River and Indiana Harbor Canal, noting that multiple lines of evidence pointed toward injury of fish and sediment-dwelling organisms due to a range of contaminants. Results of these studies linked a source of contamination with biological impairment and emphasized the usefulness of weight-of-evidence approaches in developing impairment metrics.

Additional studies at INDU focused on heavy metal contamination due to coal fly ash ponds and atmospheric deposition. Wilcox and Hardy (circa 1982) examined the effects of coal fly-ash disposal on water chemistry in Blag Slough, noting that seepage from the ponds increased concentrations of many ions and metals in downgradient waters, and that soils in the dewatered wetland basin contained potentially phytotoxic concentrations of aluminum, boron, manganese, and zinc. Cole et al. (1990) and Perkins et al. (2000) analyzed historic trends in atmospheric deposition of toxic metals using sediment cores from Cowles Bog and elsewhere in the Lakeshore. Both noted that metal concentrations (particularly zinc, lead, and manganese) were currently much higher than pre-European settlement levels and that they were highest at sites closest to anthropogenic sources. Accumulation rates of most metals had, however, declined since the 1970s due to emission controls. Importantly, Perkins et al. (2000) found that hydrologic factors, such as the duration or frequency of flooding, influenced the mobility of some metals and had implications for current wetland restoration projects.

Groundwater

Interactions between ground and surface water have been investigated in several INDU studies. Meyer and Tucci (1979) constructed a digital groundwater flow model and determined that seepage from coal fly ash settling ponds averaged two million gallons per day and had already raised groundwater levels by four feet in the Cowle's Unit. Construction dewatering was predicted to decrease groundwater levels by three to five feet. Shedlock and Harkness (1984) examined the effects of potential ditch dredging on groundwater flow and the drainage characteristics of Brown Ditch. They concluded that dredging Brown Ditch to a uniform gradient would decrease the water table in the Town of Pines, whereas dredging in the upstream arm of Brown Ditch would lower the water table in INDU by nearly a foot. Isiorho et al. (1996) found that water seepage out of Long Lake accounted for >50% of the groundwater recharge for the lake's basin. In general, INDU studies have identified strong surface water-groundwater linkages in the area, and suggested that groundwater quality may be vulnerable to contamination from aerial or surface water pollutants. Further, groundwater levels and wetland hydrology may be very responsive to dredging, ditching, and industrial ponding activities in the area.

Physical processes

An intensive three-year study addressed shoreline processes and characteristics at INDU (Great Lakes Coastal Research Laboratory 1986). It provided maps of wave, current, and erosion patterns and offered site-specific recommendations for shoreline protection decision-making.

Strengths and needs

INDU water resources work has been extensive, covering many aquatic habitat types, including ditches, creeks, lagoons, large wetland complexes, interdunal ponds, and bogs. The research program, aided by scientists at the co-located U.S. Geological Survey Lake Michigan Ecological Research Station, has been strong. Research on bacteria monitoring, wetlands ecology, and industrial contaminants is well represented in INDU's research history, and such studies are ongoing. Contaminant studies from the Grand Calumet Lagoons and Indiana Harbor Area of Concern are particularly well represented. Additionally, scientists at the Lake Michigan Ecological Research Station and elsewhere have significant experience and expertise in developing bioassessment metrics, using biological groups ranging from aquatic vegetation to invertebrates and fish. Future biological monitoring efforts at INDU and throughout the Great Lakes Network could benefit from this park-based expertise. Although INDU has supported basic water quality monitoring of inland waters for the past decade, this monitoring has not included Lake Michigan (except for bacteria). Given the strong surface water-groundwater interactions noted in several studies, more information is needed on the potential for contamination of surface waters by groundwater and vice versa. Aside from the information on groundwater and surface water physical/chemical connectivity, relatively little information is available on the ecological connections between Lake Michigan and the inland aquatic habitats, or how the biota of inland habitats may be impacted by interactions with Lake Michigan.

Considerations for monitoring

Directly from the literature

- Several water quality and ecological studies noted high variability among sites within a given lagoon or drainage system. This particularly large influence of local or site-specific factors on chemistry and communities at INDU should be accounted for in future monitoring designs.
- Plans for biological monitoring at INDU should consider the biotic assessment work that Stewart et al. (1997, 1999, 2000, 2003) have done with INDU streams, and that Simon et al. (1998, 2000, 2001) have done with INDU wetlands and lagoon sites. The authors generally favored the use of weight of evidence approaches that incorporated more than one biological group.
- Meiofauna may be sensitive indicators of silt and organic matter loading; they reflect conditions of both surface and interstitial water (Whitman et al. 1994).
- In their recent survey of amphibians and reptiles, Glowacki and Grundel (2005) noted that drift fences were the most successful suvey method, with visual searches unsuccessful in summer conditions of heavy vegetation, and cover boards attracting few amphibians or reptiles.

Derived from the literature by the synthesis authors

- Both INDU and SLBE spend considerable time and resources on bacteria monitoring. A review and synthesis of existing information on indicator bacteria, covering both Lakeshores and addressing recent studies and advances in rapid testing techniques, would be valuable.
- With the exception of bacteria, INDU's water quality monitoring program currently does not address Lake Michigan nearshore waters. Incorporating Lake Michigan nearshore sites into its usual monitoring program (or coordinating with other agencies to make this kind of data regularly available) would be useful.
- The status and trends of all aquatic nuisance species should be determined with consistent monitoring, preferably every 2-3 years or more frequently.
- Interdunal ponds were not easily categorized based on their biological composition (Whitman et al. 1988). If these are to be included in future monitoring, site selection should be based on other factors.

- More consistent assessment schedules to determine status and changes in fish assemblages in various aquatic habitats are needed – e.g., repeat Spacie (1988) and Simon and Stewart (1999) work more frequently.
- Because of the interest in yellow perch life history and the importance of the species in Southern Lake Michigan, potential habitat and productivity in Lake Michigan nearshore waters around the Lakeshore should be investigated. Monitoring could be conducted here in coordination with ongoing efforts of Seagrant and other researchers.

Considerations for research

Derived from the literature by the synthesis authors

- Whitman et al. (2003) indicated that current beach monitoring and beach closure protocols are inadequate and that other ambient variables should be used as predictors. The refinement of such predictive tools for INDU and SLBE would be very useful.
- Potential occurrence of aquatic nuisance species movement from Lake Michigan nearshore environments into other aquatic habitats within the Lakeshore (and the likely magnitude of impacts) should be investigated.
- Nearshore Lake Michigan benthic communities have received little attention and are in need of further research, with attention to the presence and effects of non-native benthic species (Horvath et al. 2001, Whitman and Garza 2002). To date, work on exotic invertebrates in the Great Lakes has focused on pelagic species, but the ecological importance of benthic organisms and processes is increasingly recognized.
- Glowacki and Grundel (2005) noted that potential habitat for the threatened massasauga rattlesnake should be incorporated into Lakeshore management plans, and urged further research into the rattlesnake's status and habitat use.
- INDU streams, ditches and lagoons are exposed to an extensive suite of anthropogenic stressors, including seepage from industrial and municipal landfills, agricultural runoff, highway runoff, hydrologic alterations, and atmospheric contaminant deposition. These waters would be good candidates for multiple stressor and contaminants research.
- Atmospheric deposition levels at INDU are among the highest in the National Atmospheric Deposition Program for a variety of contaminants. Deposition of mercury and nitrogen is substantial and potential effects on water chemistry, aquatic ecology, and the invasibility (nitrogen-induced) of INDU wetlands could be addressed.
- Groundwater-surface water interactions and effects of industrial practices like settling ponds need more investigation, especially given the prominence of INDU wetlands and their sensitivity to water level changes.
- Similarities between INDU and SLBE water resources provide unique opportunities for comparative studies and for research streamlining. Both Lakeshores devote significant time and effort to the bacteria issue, both have unique interdunal wetland systems, and both are faced with invasive wetland species such as the common reed, *Phragmites australis*. Simultaneous research on the above issues at INDU and SLBE might prove beneficial.

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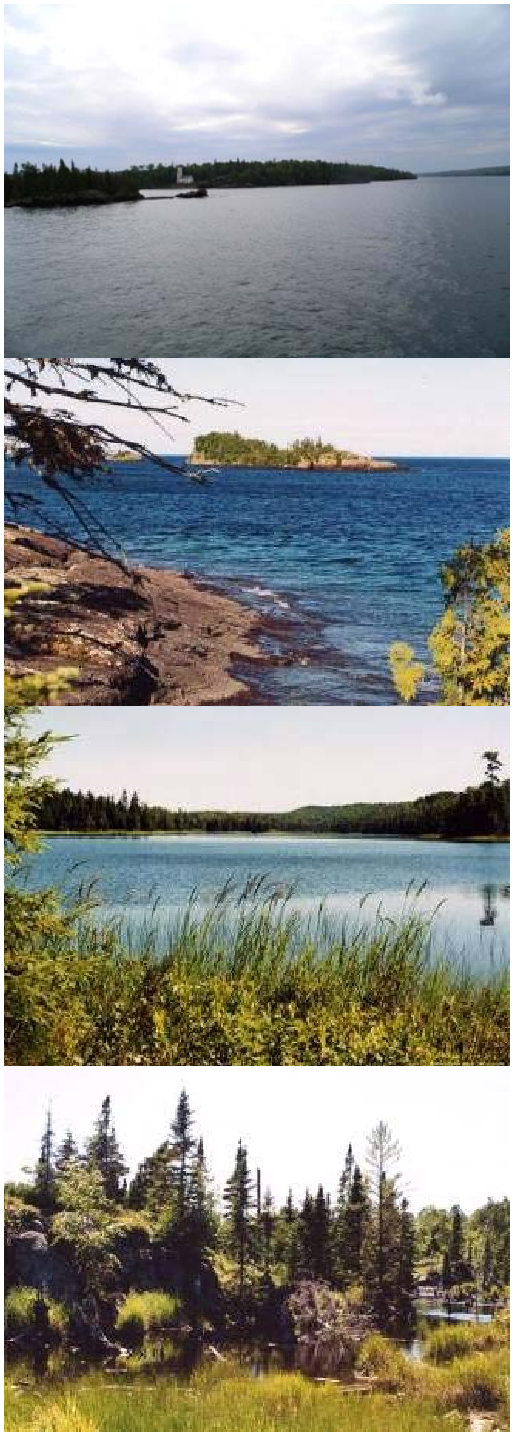
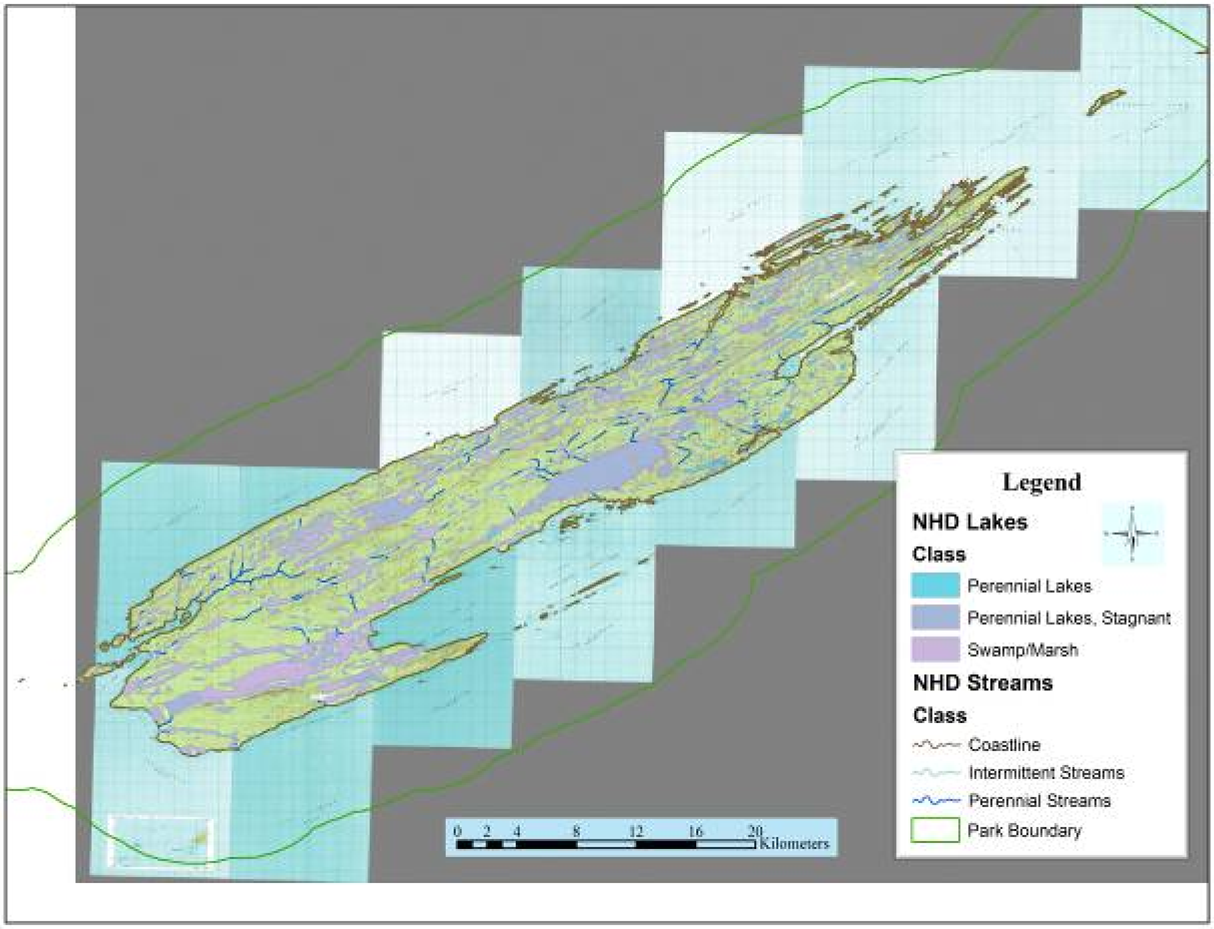


Photographs from top to bottom: Isle Royale lighthouse (J. Glase), Lake Superior shoreline (B.M. Lafrancois), Lake Livermore (B.M. Lafrancois), and an interior wetland (B.M. Lafrancois).



Isle Royale National Park, showing streams and lakes derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

ISLE ROYALE NATIONAL PARK

Isle Royale National Park (ISRO) is a remote island archipelago situated in the northwestern portion of Lake Superior. . Isle Royale National Park was designated in 1931 and preserves a total land area of over 220,000 ha (965 square miles), including submerged land, which extends four and a half miles out into Lake Superior. The Park consists of one large island surrounded by about 400 smaller barrier islands, which together protect 543 km (338 miles) of coastline, more than any other Great Lakes park (Table 1, pg. 2). Much of the Park was designated as Wilderness in 1976, and its relatively pristine condition has made it an ideal natural laboratory and a United Nations Biosphere Reserve. Prominent water resources include Lake Superior, including an expansive 165,182 ha (408,173 acres) of bays, nearshore waters, and offshore waters (Table 1, pg. 2). Additionally, ISRO features more named inland lakes than any other Great Lakes area park, several perennial streams (e.g., Washington, Grace, and Tobin Creeks, and Big Siskiwit, Little Siskiwit, and Siskiwit Rivers), many kilometers of un-named perennial and intermittent streams, and many inland wetlands associated with lake littoral zones, beaver activity, and the pronounced ridge-valley topography (Table 1, pg. 2).

Summary of existing aquatic research

General resource documents and plans

There have been two waves of water resource planning at ISRO. The first of these occurred in the 1960s. A natural sciences research plan by Linn et al. (1966) addressed some aspects of water resources, providing descriptions of bogs, swamps, beaver ponds, lakes, fish, invasive species, and aquatic vegetation and its relationship with moose. Linn et al. also described aquatic research needs in detail, some of which have yet to be addressed. A long-range aquatic resources management plan by Wallis (1966) addressed aquatic resource characteristics in addition to fishing-related issues. Bick et al. (1985) served as a general reference document with information on physical, chemical, and biological properties of ISRO aquatic ecosystems. Each of these documents, long-range though they may have been, are now quite dated.

Two aquatic resource plans are currently underway. The Isle Royale Water Resources Management Plan will characterize water resource conditions, provide a prioritized list of aquatic resource needs, and offer recommendations about future water resources management at ISRO (expected 2005). A fisheries management plan for Isle Royale is also currently being written with assistance from several organizations. This document will provide management recommendations primarily for inland lakes and streams – those water bodies for which the National Park Service has management jurisdiction. However, recommendations for nearshore Lake Superior waters and management of the species found there will also be a component of this document. Completion of the Isle Royale Fisheries Management Plan is expected in 2005.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for ISRO was reviewed for insights on past water quality monitoring in and near the Park (National Park Service 1995, Table 3, pg. 14). Of the 26 monitoring stations identified in the data retrieval, 15 were located within the Park boundaries, with others located in nearby Lake Superior waters. A total of 9,248 water quality observations and 336 parameters were recorded in the study area. Three active or inactive gages were found within the study area; a long-standing U.S. Geological Survey gage on Washington Creek (1964-2003) was recently deactivated. Only one site within the Park (Washington Creek at Windigo) yielded multiple observations or recorded any water quality exceedences. At this site, seven parameters exceeded the screening criteria at least once over the period of record. There was one record of pH below 6.3, the Environmental Protection Agency chronic criterion for freshwater life. Total and fecal coliform concentrations exceeded the criterion of 200 colony forming units per 100 mL in 10-20% of observations. Occasional exceedences of the Environmental Protection Agency acute freshwater criteria were observed for cadmium, copper, and zinc. Lead exceeded the proposed drinking water criterion at this site on a number of occasions from 1968-1991. The authors indicated that surface waters at ISRO were of very good quality due to the Park's remote location and Wilderness designation. Small effects of human activities on indicator bacteria concentrations were noted in summer and early fall.

ISRO benefits greatly from two long-term water quality monitoring programs. Activities associated with these programs include nearly four decades of water quality monitoring from the Washington Creek Hydrologic Benchmark Network site, described above, and over two decades of intensive watershed investigations in the Wallace Creek Watershed. An analysis of long-term data from the Washington Creek site (Mast and Turk 1999) showed that Washington Creek had intermediate conductance and was generally well buffered. Most weathering-derived constituents had strong inverse correlations with discharge, due to dilution. In addition to the long-term monitoring at Washington Creek, nine sites in the Washington Creek watershed were sampled during a U.S. Geological Survey synoptic study in September 1992 (Mast and Turk 1999). Chemical composition of tributary streams was similar to the main stem Washington Creek site, although sulfate concentrations and organic acid content were higher in some tributaries.

In preparation for long-term watershed studies, Stottlemyer et al. (1998) sampled 26 stream sites at ISRO. These data, along with twenty years of intensive stream and watershed research in the Wallace Lake watershed, were compiled and summarized. This summary described how initial concerns about acid deposition and surface water acidification (Stottlemyer 1981, 1984) gradually diminished as sulfur oxide deposition declined following the Clean Air Act. Additionally, research results showed that ISRO streams were surprisingly well buffered (Stottlemyer et al. 1998) and could neutralize acid additions over short temporal and spatial scales (Stottlemyer 1982a, 1989). Subsequent studies also showed how incoming precipitation was modified by processes in winter snowpacks, forests, and soils before reaching surface waters (Stottlemyer 1982b, 1997, Stottlemyer et al. 1998, Stottlemyer and Toczydlowski 1999). Research has now shifted to the effects of climate change and nitrogen deposition on watershed processes. The Wallace Lake watershed currently has high nitrogen retention (Stottlemyer and Toczydlowski 1999), but recent work indicates that soil nitrogen mineralization and soil and root respiration are positively linked to temperature, such that future climate warming could alter export of nitrogen and carbon to surface waters (Herrmann et al. 2000, Stottlemyer et al. 2002), and potentially influence the transport of mercury to surface waters as well.

Aside from these long-term monitoring projects, stream water quality research is limited to a thesis study of chemistry and invertebrates in Grace and Washington Creeks and the Little Siskiwit River (Bowden 1981). Both upstream and downstream sampling locations were represented for each stream; discharge rates and water quality varied upstream to downstream. Most cations (calcium, magnesium, and sodium) showed inverse relationships to discharge, consistent with the long-term Washington Creek data.

Water quality in ISRO's inland lakes has been investigated on several occasions (Toczydlowski et al. 1978, Stottlemyer et al. 1998, Kallemeyn 2000). The most comprehensive and recent of these was Kallemeyn (2000). Toczydlowski et al. (1978) and Kallemeyn (2000) both noted that thermal stratification was common but not universal among ISRO lakes. Conductivities were generally moderate (Stottlemyer et al. 1998, Kallemeyn 2000) and alkalinities were low (Kallemeyn 2000). Dissolved organic carbon concentrations varied from 5.0 mg/L in Siskiwit Lake to 15.2 mg/L in Mason Lake (Kallemeyn 2000). Total phosphorus concentrations and chlorophyll *a* were variable across the study lakes, but indicated low to intermediate productivity levels (Kallemeyn 2000). Using the Carlson Trophic State Index, most ISRO lakes could be considered mesotrophic or oligotrophic, with few to no eutrophic lakes (Kallemeyn 2000). Few discernable changes in water quality parameters have occurred over the past two decades (1980-81 vs. 1995-97), but sulfate concentrations were substantially lower in the more recent survey (Kallemeyn 2000).

Finally, several years of monitoring related to bacterial contamination of ISRO waters took place in the mid-1980s (Meldrum 1987). Sampling sites included dock areas in harbors and coves, campground areas near lakes and bays, the sewage outflow area in Rock Harbor, and open Lake Superior. In general, fecal coliform to fecal streptococcus (FC:FS) ratios were indicative of non-human bacterial sources. However, higher FC:FS ratios were noted occasionally at Chickenbone West, Moskey Basin, and McCargo Cove, and Rock Harbor sample sites generally had higher bacteria levels than Lake Superior control sites. These data are now quite dated, and, given changes in vistor use, some additional work on bacterial contamination may be needed to evaluate potential problems.

Biology and ecology

A variety of studies have investigated benthic invertebrate communities in ISRO streams, lakes, and Lake Superior shoreline splash pools. Bowden (1981) collected hydrologic and chemical data on ISRO streams, and noted longitudinal gradients in invertebrate composition coincident with gradients in substrate types and water chemistry. Peak invertebrate densities were found in July, and there was no evidence that invertebrate composition was directly affected by low pH or alkalinity in upstream reaches. Johnson (1980) analyzed invertebrate fauna collected from 31 diverse sites along the Siskiwit River and identified 64 taxa. Plankton and other organic matter from the Siskiwit Lake outlet appeared to influence benthic invertebrate composition in upstream reaches, and substrate, current, and water depth influenced composition in the marsh sites. Toczydlowski et al. (1978) sampled benthic invertebrates in both lakes and streams of ISRO; most sampling was conducted in stream habitats, although the sampling strategy does not appear to have been systematic. The survey generated a list of invertebrate genera and a categorical measure of their relative abundance.

Van Buskirk (1992a) assembled a species list of Isle Royale dragonflies from splash pools as well as lakes, ponds, and wetlands, and documented eight species not recorded in early 20th century surveys. Among these was *Aeshna juncea*, an arctic disjunct found in shoreline splash pools. Detailed study of this dragonfly provided evidence of density dependence among *A. juncea* larvae, with different feeding habits and behavior noted in adjacent age classes (Van Buskirk 1992b). *Aeshna juncea* diet analysis revealed prey items such as midges (Chironomidae), ostracods (Ostracoda), water boatmen (Corixidae), water fleas (Cladocera), mites (Hydracarina), water striders (Gerridae), other *Aeshna*, and terrestrial invertebrates (Van Buskirk 1992b, 1993).

Population structure and status of ISRO's unionid mussel fauna were recently investigated in McCargoe Cove and ISRO inland lakes (Nichols et al. 2001). Two species of *Lampsilis* and three species of *Pyganodon* were identified. Mussels were found above the thermocline in deeper lakes, and were distributed in substrate-related patches in shallow lakes. No exotic mussels were encountered. . Isle Royale National Park streams lacked mussel populations, likely due to winterfreeze and lack of suitable substrates. Where encountered, mussel populations appeared healthy and stable, with relatively high densities and multiple year classes. Organic and metal contaminants were below consensus deleterious levels for all specimens measured. In addition to the mussels, abundant assemblages of tall freshwater sponges were also noted in several ISRO lakes (Nichols et al. 2001).

Larson et al. (2000) analyzed zooplankton samples collected from 36 lakes during the Kallemeyn (2000) fish survey. Despite substantial variation among lakes in terms of morphometry, chemistry, fish communities, and food web characteristics, zooplankton assemblages were fairly similar among lakes. Rotifers dominated in terms of density and species richness, and *Bosmina longirostris* was the dominant crustacean. Exotic zooplankters such as the spiny water flea (*Bythotrephes longimanus*) and the fishhook water flea (*Cercopagis pengoi*), now present in Great Lakes waters, were not encountered.

A series of surveys addressed ISRO phytoplankton in the mid-1900s. Taylor (1935) provided an early account of Isle Royale phytoplankton based on net phytoplankton samples from two inland lakes and ten sites nearshore and offshore on Lake Superior. Taylor reported phytoplankton results by species, and noted their relative abundance and distribution. In the late 1930s, Prescott used the same set of phytoplankton samples to construct more detailed notes on Isle Royale's desmid flora (Prescott 1936, 1937, 1939, 1940). Several of the 221 recorded species and varieties were new records for the State of Michigan. No further phytoplankton work was conducted until the late 1970s (Toczydlowski et al. 1978). Of the surveyed lakes, Feldtmann Lake had the most distinct phytoplankton composition, with few diatom representatives and abundant *Gloeocapsa* (a blue-green alga) and *Scenedesmus* (a green alga). About half of the phytoplankton found in each of the lakes was recorded as unidentified flagellates. Lastly, phytoplankton and water quality were monitored over the course of two summers in Sargent and Siskiwit Lakes (Nevers and Whitman 2004). Phytoplankton communities in these lakes consisted of a mixed assemblage of green algae, diatoms, and chrysophytes, similar to the lakes at Voyageurs National Park.

Fish

Fish population assessments have been conducted since the early 20th century at ISRO, but only two were comprehensive surveys (Koelz 1929, Kallemeyn 2000). Research by other agencies and academia has focused on Lake Superior fish populations or effects of contaminants on fish from inland lakes. Other investigations included studies of lake trout (*Salvelinus namaycush*) genetics in Lake Superior, coaster brook trout (*Salvelinus fontinalis*) genetics and population assessments in harbors and streams, and sea lamprey (*Petromyzon marinus*) surveys in island streams. A fishery survey of the nearshore waters of Lake Superior was conducted by U.S. Geological Survey in 2003 and 2004. This is the first thorough fisheries investigation of the nearshore waters at ISRO; results are expected in 2005. A Fisheries Management Plan is in preparation and is expected in 2005. Fisheries resources at Isle Royale are unique among the GLKN parks in that inland lake populations had been genetically isolated from outside influences for thousands of years when the island first emerged from Lake Superior. Because of this isolation, fisheries investigations have included analysis and research regarding genetic "distancing" from mainland populations of the same species. Early investigations by

Koelz (1929) included subspecies determinations for populations in several lakes. Later investigations by Hubbs and Lagler (1949) supported the sub-species categorization, but these were refuted by Bailey and Smith (1981). More recent investigations by Kallemeyn (2000) followed the premise of Bailey and Smith and did not recognize several of the subspecies categories. However, the question of species distancing remains and there are current investigations of cyprinid populations and proposals to investigate genetics of northern pike (*Esox lucius*) populations.

Native Americans that used the resources of the island for subsistence have likely exploited the fisheries of the island since pre-historic times. Commercial fishing also occurred since at least the early 19th century. A fairly extensive commercial fishery for lake trout and some coregonids existed in Lake Superior waters of the Park until the mid 20th century. At that time, lakewide impacts from sea lamprey invasions and overharvest caused a collapse of most Lake Superior lake trout fisheries. Isle Royale was not immune to these effects, although the impacts at the island were much less than at other locations around the lake. Commercial harvest was, however, greatly curtailed, and today exists only in a remnant and demonstration form at the island. Sport fisheries have been popular since the 19th century in the Lake Superior waters of the Park, and some early documents from the late 1800s indicate that widely renowned fisheries existed for brook trout and lake trout.

Inland waterbody or riverine fish surveys and investigations

Surveys by Ruthven (1909) of the cold-blooded vertebrates of Isle Royale were the first documented scientific investigations that included fish of the inland lakes of the island, but the fisheries component of this investigation was limited. Koelz (1929) provided the first comprehensive look at fish of the inland lakes of the island, and he categorized some as new species or subspecies. Koelz's report included descriptive text of each of the surveyed lakes along with current conditions of inlet and outlet tributaries for several of the lakes. General geomorphology, bathymetry, and aquatic and terrestrial plant life were described. Depth and temperature data were taken at each lake. A total of over 3,600 depth soundings were taken; the number at each lake was dependent on degree of regularity of contour lines. Temperatures were taken at various depths, locations, and times of day, and there appeared to be no consistency of time of day for temperature readings among lakes.

Koelz provided some incidental information on aquatic insects from fish stomach investigations and other observations, as well as descriptions of mussels or "clams" in the lakes. Descriptions of beaver (*Castor canadensis*) activity and its effect on various lakes were also included. Koelz occasionally referred to fires and certain tree species that escaped recent conflagrations and to vegetation consumption by moose (*Alces alces*). He stated that "eradication by the moose of the higher aquatic plants has undoubtedly had serious consequences for the fish" and suggested that fish productivity was likely reduced in some lakes due to a decrease in food and shelter.

Koelz reported a total of 30 species of fish in the inland lakes. Two subspecies of herring (previously *Leucichthys,* currently *Coregonus artedi*) were listed as *Leucichthys artedi sargenti* and *L.a. huronicus*. He also listed two subspecies of whitefish - *Coregonus clupeaformis dustini* and *C. c. neo-hantoniensis*. Hubbs (1932) also described several taxa as subspecies: the fathead minnow in Lake Harvey was classified as *Pimephales promelas harveyensis*, the Lake Harvey race of pearl dace as *Margariscus margarita koelzi*, and the stripenosed shiner in Lake Harvey as *Notropis atrocaudalis regalis.*

Hubbs and Lagler (1949) investigated the island's fisheries in the late 1940s and referred to the works of both Koelz and Ruthven in compiling a list of 49 kinds of fish representing 41 species, 31 genera, and 14 families. This list includes some Lake Superior species as well as inland lake species. Sharp and Nord (1960) investigated some of the inland lakes and made recommendations for managing northern pike by increasing the size limit from 14 to 20 inches. Although ISRO may develop park-specific fisheries regulations, it has generally followed those of the Michigan Department of Natural Resources; the legal size limit for northern pike is currently 24 inches.

Kallemeyn's (2000) work provided the first thorough fisheries survey of the inland lakes in nearly 70 years. Kallemeyn provided a much more detailed account of physical/chemical characteristics than any previous fisheries report. He included information on lake trophic levels and biological characteristics such as mercury and selenium levels in fish tissue and age/growth analysis of fish. He also provided descriptions and references regarding theories of the origin of various species at Isle Royale. Kallemeyn surveyed 32 lakes in the summers of 1995 and 1996. He returned in 1997, repeating sampling for four water chemistry parameters on all 32 lakes. Nine lakes were also resampled in 1997 to collect fish species reported by Hubbs and Lagler in 1949, but not found in the 1995 or 1996 surveys. Kallemeyn did not recognize the subspecies from Koelz or those listed by Hubbs and Lagler (1949). The two subspecies of herring were therefore reported as a single species, *Coregonus artedi*; the two whitefish as *Coregonus clupeaformis*; the fathead minnow as *Pimephales promelas*; and the pearl dace as *Margariscus margarita*. Kallemeyn described the stripenosed shiner of Koelz as the blacknose shiner *Notropis heterolepsis*.

Kallemeyn's sampling detected 28 of the 30 species observed by Koelz; no additional species were collected. Two species sampled by Koelz that were not sampled by Kallemeyn were brook trout and mottled sculpin (*Cottus bairdi*). Kallemeyn noted that "observed changes in the fish communities included no change (14 lakes), additional species (11 lakes), and undetected species (12 lakes). In five lakes, both species gains and losses were observed." He also suggested that species gains are likely attributable to upstream migrations from other inland lakes or Lake Superior.

Kallemeyn grouped lakes into five different types based on fish species assemblages. The most widespread species were northern pike and yellow perch (*Perca flavescens*), occurring in 26 and 30 lakes, respectively. Carlisle (2002a) analyzed some results from Kallemeyn's report and grouped lakes into four types based on water quality and habitat parameters. These included: 1) shallow lakes with high dissolved organic carbon, 2) large, deep lakes with low dissolved organic carbon, 3) lakes with hard water and higher algal biomass, and 4) softwater lakes high in total phosphorus. Unique fish assemblages were associated with three of these categories. Data on mercury in fish tissue (Kallemyen 2000) led to investigations to determine the factors that affect mercury bioaccumulation. Gorski et al. (2003) investigated Sargent Lake and Lake Richie and found significantly higher levels of mercury in Sargent Lake northern pike than in Lake Richie pike. They suggested the differences between pelagic and benthic based food webs led to different levels of bioaccumulation of methyl mercury, although their study was not specifically designed to address issues of energy flows through food webs.

While direct comparisons of populations cannot be made between Koelz and Kallemeyn, future surveys will be able to repeat Kallemeyn's efforts and be comparable. Kallemeyn indicated that fish communities of Isle Royale have changed little since 1929, especially when compared with mainland lakes and Lake Superior. Future monitoring and continued conservation of these communities will therefore be useful for understanding issues such as dispersal, isolation, and speciation.

There is limited stream habitat on the island compared to lentic habitat, and the number of stream fisheries investigations has been few. Studies of fisheries populations of the streams of Isle Royale have been limited to sea lamprey investigations, surveys related to brook trout restoration activities (Slade 1994, 1995a, Quinlan 1999), and a survey of six streams of the island conducted in 1993 (Slade and Olson 1994). Surveys for coaster brook trout continue to be conducted by the U.S. Fish and Wildlife Service at the Big and Little Siskiwit Rivers and the Siskiwit River flowing from Siskiwit Lake to estimate success of coaster rehabilitation efforts around the island.

In addition to general fisheries population investigations, there is a wealth of information on contaminants testing and monitoring that includes some inland lake populations on the island. Siskiwit Lake has been monitored since the mid-1970s for accumulation of contaminants in fish tissue (Swain 1978, Swain et al. 1986, Swackhamer and Hites 1988, Baker and Hites 2000) (see also "contaminants" section). Originally intended as a control lake for comparing relatively pristine waters of an island lake with Lake Superior, Swain (1978) discovered that chlorinated organic residues affected Siskiwit Lake as much or more than Lake Superior. These early investigations noted that some Siskiwit Lake fish actually had higher amounts of some contaminants from airborne deposition than did Lake Superior fish.

Lake Superior fish investigations

The majority of the fisheries work in Lake Superior has focused on popular sport and commercial species, even though Isle Royale bays and nearshore waters provide habitat for a variety of species. Hubbs and Lagler's work (1949) provided some of the most comprehensive work on nearshore Lake Superior species assemblages. They indicated 20 common species found in waters 15 m (50 feet) deep or less during the summer months at the island. In addition to the more common species, they suggested that other species such as some of the deepwater coregonids may enter nearshore habitat during spawning periods. They also described assemblages found in fairly specific regions such as near stream mouths and exposed shoreline. The U.S. Geological Survey Lake Superior Biological Station (formerly the U.S. Fish and Wildlife Service Lake Superior Biological Station) conducted summer assessments in deeper waters near the island from 1958 through 1997 with concurrence from the Michigan Department of Natural Resources. Assessments consisted of gill net surveys with nets set at several locations around the island in depths from 20 to 100 m (66 to 328 feet). The Isle Royale Fish Management Plan stated that these assessments were sometimes conducted concurrent with assessments along the Minnesota north shore. Resulting data were then sent to either the Minnesota or Michigan Departments of Natural Resources. However, no formal review or analysis of this data has been conducted and no report has been written (Quinlan et al. In preparation). The data from these assessments included information on lake trout, cisco (*Coregonus artedi*), the *Coregonus* complex known as chubs (*C. hoyi, C. kiyi, C. zenithicus*), lake whitefish (*Coregonus clupeaformis*), and burbot (*Lota lota*).

More recently, Lake Superior fisheries work at ISRO has included studies of lake trout populations and genetics, coaster brook trout genetics and population estimates, fisheries contaminants, and creel survey data that provided information primarily on lake trout and other salmonids captured in Lake Superior waters. Curtis et al. (1998) reported on the decline and recovery of lake trout near Isle Royale by analyzing data from 1929 through 1990. Hansen et al. (1995) also analyzed historic data and reported on restoration of lake trout from 1959 through 1993. Peck (1998) compared commercial catches from the Sivertson fishery at the island with information from nearshore mainland stocks. He found nearly 98% wild lake trout in the Sivertson fishery from the ISRO area. Lake trout genetics has been a popular area of study throughout the Great Lakes, including ISRO stocks, in part because these fish were possibly less impacted by the rapid population declines following sea lamprey invasion and subsequent restocking efforts in the mid 20th century. Burnham-Curtis and Smith (1994) investigated Isle Royale stocks and found that although there were only three morphotypes remaining in Lake Superior, ISRO stocks had maintained some genetic diversity found in historic populations. Guinand et al. (2003) also examined remnant and extinct stocks of lake trout throughout the upper Great Lakes and concluded that ISRO stocks had been impacted by hatchery stocks but not to the extent of most other stocks in the upper Great Lakes.

A creel survey conducted in Lake Superior waters of the island in 1998 (Lockwood et al. 2001) provided an indication of fishing pressure and harvest of species around the island. The species of interest for investigators were lake trout and brook trout. The primary species targeted by anglers was lake trout and no brook trout were recorded captured in the survey. Other species caught in low numbers included:

northern pike, *Esox lucius;*
coho salmon, *Oncorhynchus kisutch;*
rainbow trout, *O. mykiss;*
Chinook salmon, *O. tshawytscha;*
splake, *Salvelinus naymaycush x fontinalis;*
lake whitefish, *Coregonus clupeaformis;*
rock bass, *Ambloplites rupestris;*
walleye, *Sander vitreus;*
brown trout, *Salmo trutta.*

Lake trout made up 96% of catch and 94% of harvest in the non-charter fishery. Non-charter anglers fished 62,232 $\pm$ 17,731 hours and harvested 9,612 $\pm$ 2,622 lake trout. In addition to those fish that were harvested, 10,760$\pm$3,075 lake trout were caught and released by noncharter anglers. In the charter boat fishery, lake trout made up 90% of harvest; catch and release information was not available. Charter boat anglers fished 3,148 hours, and harvested 871 lake trout.

The brook trout has been a popular species for anglers at ISRO since the 19th century. Raymond (1897) provided anecdotal information on the popularity and abundance of this fish in his account of a fishing trip to the island when he and three other “gentlemen” harvested several large fish from the Tobin Harbor area. Brook trout have been the subject of population and genetics investigations (Slade 1994, Quinlan 1999) and rehabilitation efforts (Slade 1995a, Newman and Bast 1996, Newman et al. 1999). Brood stocks developed from Tobin Harbor and Siskiwit Bay brook trout have been used for rehabilitation efforts at the island and other locations in Lake Superior.

The first thorough survey of the nearshore Lake Superior waters was conducted by U.S. Geological Survey in 2003 and 2004. This effort attempted to identify species present in waters from one to 15 m (49 feet) deep at several locations around the island. Results of the survey are expected in 2005.

Aquatic wildlife

In addition to ongoing loon (*Gavia immer*) and beaver monitoring activities, several more intensive studies of aquatic wildlife have been conducted at ISRO. Egan and Oelfke (2000) surveyed 47 interior lakes and 45 areas along the Lake Superior shoreline for common loons. They confirmed the presence of 98 loon territories, of which 63 were found on inland lakes. Loon productivity (0.3 young per territory) and breeding pair success rates (30-50%) were average when compared with loons elsewhere. Smith and Shelton (2002) conducted the island’s fifteenth aerial survey and census of ISRO beaver colonies and evaluated beaver food quality at documented sites. They found evidence of continued declines in beaver colonies since the mid-1980s, and predicted further declines due to reductions in beaver habitat quality, increased wolf (*Canis lupus*) predation, and drought. They noted that aerial survey methods likely underestimated the actual number of beaver colonies by 20% or more.

Several ISRO moose studies are relevant to aquatic resources at ISRO. Over the past 75 years, moose populations, their summer aquatic feeding ecology, and their effects on aquatic vegetation have been investigated. Peterson and Vucetich (2004) summarized the results of the most recent in a long list of moose-wolf surveys on ISRO, noting that moose populations on the island have declined rapidly since 1998, perhaps due to climate- and parasite-induced increases in their vulnerability to wolf predation. Koelz (1929) first observed moose feeding on aquatic vegetation on ISRO during his fish survey, noting that moose activity resulted in trampling and destruction of the vegetation. Murie (1934) later made similar notes, and suggested that through the destruction of aquatic vegetation moose were likely affecting other parts of the aquatic ecosystem, such as fish habitat. Moose-macrophyte relationships became the subject of more intensive investigations in the 1970s. Jordan and Aho (1978) and Aho and Jordan (1979) conducted exclosure experiments in two ISRO beaver ponds. These experiments indicated that moose influenced macrophyte production directly by grazing, as well as indirectly by increasing turbidity and reducing light availability through browsing and trampling. Jordan (1978) speculated that moose consumption of submerged aquatic vegetation during summer was driven by a need to supplement the sodium levels in their otherwise terrestrial diet.

Amphibians and reptiles

Aside from recent park-wide amphibian inventory work (conducted by herpetology experts from the Milwaukee Public Museum and supported by the Great Lakes Inventory and Monitoring Network), the majority of herptile work at ISRO has focused on shoreline splash pools on the northeastern end of the island. Several studies have addressed ecological interactions within and among populations of frogs and salamanders in these pools. Smith (1983) observed the highest chorus frog (*Pseudacris triseriata*) densities in permanent pools situated at intermediate levels up the shoreline. Chorus frog densities appeared to be constrained on the one hand by pool permanence, due to disturbance by Lake Superior splashover, and on the other hand by predation risk, due to the presence of predaceous dragonfly larvae in pools closer to the forest edge. In intermediate-level pools, chorus frog densities were constrained by competition among individuals. Smith also examined effects of body size and date at metamorphosis on chorus frog survivorship to maturity, but did not find a strong relationship (Smith 1987). More recently, Smith and Van Buskirk (1995) examined ecological performance and phenotypic plasticity in tadpoles of two species, the spring peeper (*Pseudacris crucifer*) and the chorus frog. Their results showed how phenotypic traits exhibited by each species enhanced their ecological performance in their respective habitats. Van Buskirk and Smith (1991) also explored blue-spotted salamander (*Ambystoma laterale*) populations in the splash pools and found that density dependence was a strong regulator of salamander numbers.

In addition to the shoreline splash pool work, ISRO has conducted several amphibian monitoring surveys since 1996. A report from the 2000 survey (Milanowski et al. 2000), which included ten call survey points along each of four transects near Park trails, indicated that five of six species were heard each year since 1996, and that all six species were recorded during the 2000 survey. The authors noted that beaver ponds appeared to support the highest abundance of anurans. Additionally, they noted that more information was needed on how rainfall, temperature, and humidity affected their estimates of population size.

Wetlands and aquatic vegetation

A recent report on ISRO flora noted that the status and distribution of aquatic and wetland plants remained largely unexplored (Judziewicz 1999). However, previous studies have offered some insights about aquatic vegetation for a subset of ISRO lakes and streams. Toczydlowski added several macrophyte and bryophyte taxa to existing species lists and conducted a percent cover study of aquatic vegetation at Wallace Lake (Toczydlowski et al. 1978). Cluster analysis identified five general vegetation zones in Wallace Lake (emergent shoreline, emergent littoral, beaver dam, floating mat, and patchy deep). Additionally, Park vegetation types, including wetlands, were recently mapped as part of a sophisticated U.S. Geological Survey-National Park Service mapping program (U.S. Geological Survey circa 2000). Aquatic or semi-aquatic vegetation classes at ISRO included black ash (white cedar) mixed hardwoods swamp complex, northern tamarack rich swamp, red maple-ash-birch swamp forest, sedge/sphagnum meadow complex, sedge meadow complex, speckled alder swamp, and wooded peatland complex. Finally, a project funded through the Great Lakes Inventory and Monitoring Network for fiscal years 2003-05 will investigate aquatic vegetation on a park-wide basis (Principal Investigators James Meeker, Northland College; Emmet Judziewicz, UW-Stevens Point; and Allan Harris, Northern Bioscience).

Contaminants

Isle Royale's remote location separates it from most direct sources of contaminants, making it an ideal place to study long-range transport and deposition of atmospheric contaminants like mercury and persistent organic pollutants (POPs). Swackhamer and Hornbuckle (2004) provided the most recent and thorough review of atmospheric contaminant issues for both ISRO and Voyageurs National Park (VOYA). They provided detailed recommendations for improved monitoring and research on atmospheric contaminants at these parks, emphasizing the need for a trends monitoring program for biota, research addressing mercury cycling through ecosystems, research addressing the ecological risks associated with bioaccumulated toxins, and efforts to understand emissions and bioaccumulation of organic contaminants from snowmobiles and motorboats.

Mercury on Isle Royale is primarily atmospheric in origin, and its bioaccumulation has been investigated in Lake Superior and inland lakes across a range of biota (Gostomski 2002). Kelly et al. (1975) provided a historical look at mercury accumulation in fish, using walleye from museum collections (1929) and recent collections (1971). They noted high levels of mercury in fish, but no significant change over time. Later studies showed that 20% of fish from 32 inland lakes had mercury concentrations exceeding the 500 ng/g State of Michigan fish consumption advisory level (Kallemeyn 2000). Fish mercury concentrations varied among lakes and with fish size and trophic position, with the highest concentrations found in piscivorous fish of low-pH lakes (Kallemeyn 2000). Processes affecting fish mercury concentrations, including invertebrate mercury burdens and characteristics of the food web and surrounding drainage basin, were investigated in two lakes with comparable morphometry and watershed areas (Gorski et al. 2001, 2003). Differences in northern pike mercury concentrations in the two study lakes were attributed to food web differences: the Sargent Lake food web was pelagic-based, with higher zooplankton mercury concentrations and higher bioaccumulation in fish, whereas the Lake Richie food web was more benthic. Mercury concentrations in mussel tissues were generally low and well below toxic effects levels, even in lakes known to have high fish mercury concentrations. However, due to relatively high mussel densities, the total amount of mercury bound in all mussel tissues was quite high when estimated on a whole-lake basis (Nichols et al. 2001).

Mercury burdens in common loons have been investigated for Sargent Lake and Lake Superior. Ten percent of adult loons were found to have feather mercury concentrations at or above the suggested toxic effects threshold for common loon (Kaplan and Tischler 2000). Loon mercury burdens tended to vary with loon sex, age, and location. Generally concentrations were highest for older male loons in low-pH lakes (Evers et al. 1998).

Since the 1970s, a surprising variety of POPs have been measured in ISRO's waters, particularly in nearshore Lake Superior waters and in Siskiwit Lake. Most of these POPs arrive via atmospheric deposition following long-range atmospheric transport.

Two studies have compared levels of organic residues in lake trout from Lake Superior and Siskiwit Lake at ISRO. Early work by Swain (1978) documented elevated levels of organic residues in lean lake trout (*Salvelinus namaycush*) and fat lake trout (*Salvelinus namaycush siscowet*) in Lake Superior waters near ISRO, and even greater levels in fish from Siskiwit Lake. Swackhamer and Hites (1988), on the other hand, suggested that organochlorine concentrations were similar in lake trout from Siskiwit Lake and Lake Superior, and that levels generally decreased between 1975 and 1983.

Several studies addressed organochlorine contamination across Lake Superior and made reference to sites near ISRO. Strachan (1983) found measureable amounts of some organic compounds and noted that concentrations were twice as high on the west side of Lake Superior (near ISRO) as they were on the east side. Strachan and Glass (1978) summarized existing organochlorine data relating to Lake Superior water, sediments, and fish, and noted that polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) in fish routinely exceeded policy objectives at sites near ISRO. Eisenreich et al. (1979, 1980) noted a zone of high sediment PCB accumulation stretching from Thunder Bay, Ontario, past ISRO to the Keweenaw Peninsula, Michigan. Frank et al. (1980) explored PCB and organochlorine insecticide contamination on a Lake Superior-wide scale, and noted zones of high DDE (1,1-dichloro-2,2bis (P-chlorophenyl) ethylene) and PCB contamination in areas close to ISRO.

Czuczwa et al. (1984) noted that polychlorinated dibenzo-*p*-dioxins and dibenzofuran (toxins produced from the incineration of chlorinated waste) were present in Siskiwit Lake sediments. Using sediment cores from Siskiwit Lake, Baker and Hites (2000) later showed that atmospheric deposition of these chemicals peaked in the 1970s.

In recent decades, new toxins have been transported to ISRO via atmospheric deposition and discovered in ISRO's surface waters. Thurman and Cromwell (2000) documented the presence of triazine herbicides and their degradation products at several ISRO sites. Atrazine was found in ISRO surface waters, with concentrations generally higher in shallow, well mixed lakes than in deeper lakes. A recent study addressed the distribution of polychlorinated napthalenes (PCNs) in fishes of Michigan waters including Siskiwit Lake (Kurunthachalam et al. 2000). The investigators detected PCNs in Siskiwit Lake lake trout, and fish from both Siskiwit Lake and nearby Lake Superior sites contained greater proportions of highly bioaccumulative PCN congeners than fish from other sites.

Polycyclic aromatic hydrocarbons (PAHs) can be transported to ISRO via atmospheric deposition, but are also associated with heavy boat traffic or fuel spills. McVeety (1986) and McVeety and Hites (1988) constructed a mass balance of PAHs in Siskiwit Lake, and found that atmospheric dry deposition of PAHs was the primary input to the lake and that peak deposition occurred around 1950. Similarly, Gschwend and Hites (1981) noted that PAH flux to sediments at Isle Royale and other northeastern U.S. sites has diminished in the last several decades.

With respect to local, non-atmospheric hydrocarbon sources, Carlisle (2002b) evaluated ecological recovery from a 1999 diesel fuel spill near Washington Creek, noting that two years after the spill, water chemistry and decomposition rates had recovered but abundance of sensitive invertebrates remained low. Potential PAH contamination of ISRO harbors from local boat traffic and fueling operations is also being studied (Cox and Clements 2004). Preliminary results showed that total PAH concentrations exceeded sediment quality guidelines at sites near marinas, and densities of some invertebrate taxa (amphipods) were depressed at these sites.

Hydrology

Hydrological processes at ISRO have been examined from both historical and modern perspectives. Raymond et al. (1975) described historic ISRO hydrologic processes affecting ISRO, and addressed previous Lake Superior water level stages and implications for ISRO inland lakes. Deep sediment core analysis showed that some inland lakes at ISRO had been underwater during historic lake level stages of Lakes Minong and Nipissing. More contemporary hydrologic processes have been investigated during long-term monitoring projects at Washington Creek and the Wallace Creek watershed. Both monitoring efforts have shown that peak annual stream flows generally occur in April, with secondary peaks in October and November (Bowden 1981, Stottlemyer et al. 1998, Mast and Turk 1999). Additionally, strong links between surface water hydrology and chemistry were commonly observed in Stottlemyer's work (e.g., Sottlemyer et al. 1998).

Groundwater

Groundwater investigations at ISRO are limited to a single study in 1981, which described geologic formations relevant to ISRO and investigated well output from test holes (Granneman and Twenter 1982). The study indicated that the potential for development of groundwater resources was limited at ISRO, and that scarce glacial deposits were most productive.

Strengths and needs

Isle Royale offers a rare opportunity to study natural systems and processes at sites removed from direct anthropogenic stresses. Its remote location has helped inspire valuable long-term watershed studies and long-range contaminant research on the island. The watershed research program at Wallace Lake is unique among Great Lakes parks and has provided important information for understanding ISRO hydrology and biogeochemistry. This valuable information base should be used to formulate future research questions. Unique stocks of lake trout and brook trout have been the subject of several studies and have been utilized as brood stock for rehabilitation efforts elsewhere. Isolation of inland water bodies creates unique opportunities for investigations into the effects of this isolation on speciation and fish genetics. . Isle Royale National Park has also hosted a large number of contaminant studies and represents an ideal site for continued work on long-range contaminant transport. While previous contaminant studies provide evidence of contaminant deposition at ISRO, the effects of these contaminants on ISRO aquatic biota and ecological processes remains unclear and should be addressed in the future. Finally, nearshore and offshore environments under ISRO's jurisdiction remain largely unstudied, but represent important habitat for a variety of organisms and are vulnerable to fuel spills and invasion by non-native species.

Considerations for monitoring

Directly from the literature

- Given the large influence of the snowmelt season on stream chemistry at ISRO, Bowden (1981) recommended year-round water quality monitoring.
- Stottlemyer's body of work at ISRO, Pictured Rocks National Lakeshore, and elsewhere underscores the usefulness of the watershed approach in monitoring and interpreting long-term water quality changes (see Stottlemyer et al. 1998).

- Johnson (1980) noted that diversity indices were not useful for differentiating benthic community types among sites within the Siskiwit River, but may be useful for long-term, within-site invertebrate monitoring.
- Larson et al. (2000) recommended long-term monitoring to better understand interannual variation in zooplankton assemblages and zooplankton distribution across ISRO lakes, and suggested that selection of monitoring lakes may be based on a cluster analysis using lake chemical and morphometric parameters. This would ensure that representative lakes "types" are monitored.
- Given ISRO's unique biological resources and the threat posed by various non-native species already in Lake Superior, frequent invasive species monitoring of nearshore waters, bays, and inland waters is needed (Kallemeyn 2000).
- Milanowski et al. (2000) recommended increasing the seasonal frequency of amphibian call surveys to more than three times per season, in order to ensure that peak calling times were captured. Additionally, they cautioned that amphibian populations and their calling intensities were strongly affected by rainfall, temperature, and humidity.
- Loon surveys and monitoring activities, as described in Egan and Oelfke (2000), should be continued in order to evaluate long-term trends in loon densities and reproductive success.
- The long-term moose population monitoring record is of tremendous value and continued monitoring should be supported.
- Swackhamer and Hites (1988) noted that lake trout and whitefish readily accumulated chlorinated organic compounds, making them suitable organisms for monitoring these contaminants.
- Kaplan and Tischler (2000) recommended the use of juvenile flight feathers as indicators of loon mercury exposure in specific water bodies. Juvenile flight feathers develop completely on natal territories and thus reflect the mercury concentrations therein. Evers et al. (1998) noted that assessments of mercury exposure in loons must account for sex, age, tissue type, and geographic distribution.
- Kurunthachalam et al. (2000) noted that polychlorinated napthalenes were detected in all sampled fishes, which should facilitate future monitoring.
- Thurman and Cromwell (2000) recommend monitoring triazine herbicide presence in ISRO waters every five to ten years in order to detect possible future increases.
- Swackhamer and Hornbuckle (2004) recommended implementing trend monitoring programs for contaminants in both deposition and biota, with particular emphasis on persistent, bioaccumulative toxins such as mercury and polychlorinated biphenyls.

Derived from the literature by the synthesis authors

- The Washington Creek monitoring site has a long record of water quality and hydrologic monitoring data, making this an ideal site for continued research and monitoring. Gage monitoring by U.S. Geological Survey has recently been discontinued and continued gage operation and data collection may require National Park Service support.
- Inclusion of biological parameters in the Wallace Creek watershed monitoring project would be beneficial, given that biota and ecological functions will likely be sensitive to projected changes in climate and watershed biogeochemistry.
- Inland lake fish assessments should be conducted on a regular basis. Every ten years may be feasible and appropriate if fishing pressure remains relatively light, but every 5 years would be desirable. Kallemeyn (personal communication 2005) suggested this may be important for observing population changes potentially related to climate change. He cited Lake Desor as a good example, where continued warming may cause extinction of coregonids, similar to the disappearance of brook trout from inland lakes.
- A nearshore fisheries survey was conducted by U.S. Geological Survey in 2003 and 2004, and should be a regular part of fisheries monitoring at the island.
- Creel surveys of both Lake Superior and inland lakes should occur regularly; more frequently for Lake Superior, and relatively soon for sensitive species such as coaster brook trout.
- The lake trout is targeted by anglers more than any other fish at the island. Because of this popularity, lake trout stocks at the island should be monitored on a regular basis, either with creel

surveys, suveys conducted by state or federal fisheries agencies, or both. Survey protocol should be developed by both National Park Service and other management agencies so that the National Park Service can aquire specific, desired information for this species.

Considerations for research

Directly from the literature

- Nichols et al. (2001) emphasized the rarity and value of ISRO's stable, abundant mussel resource, and provided detailed recommendations for further research and management.
- Swackhamer and Hornbuckle (2004) recommended research to evaluate the relative impact of local versus regional or global sources of atmospheric contaminants at ISRO and VOYA; noted a need for more process-oriented research on mercury deposition, cycling, and bioaccumulation; and suggested that ecological risks associated with contaminant bioaccumulation should be explored.
- Carlisle (2002b) cited a need for baseline data on aquatic resources near fuel handling and potential fuel spill sites.
- Kaplan and Tischler (2000) recommended that future research address possible effects of mercury on loon productivity at ISRO.

Derived from the literature by the synthesis authors

- Stottlemyer's work in ISRO watersheds showed that climate warming may significantly affect dissolved nitrogen and carbon inputs to ISRO surface waters, both directly through increased mineralization and respiration, and indirectly through changes in vegetation. Continued support of this work is needed, with particular attention to how climate warming may affect the cycling of nutrients and organic carbon in ISRO watersheds, and, consequently, the transport of mercury to surface waters.
- Shoreline splash pools support a hardy and regionally unique biota, including boreal chorus frog tadpoles. These habitats are exposed to Lake Superior and are vulnerable to fuel or oil spills from shipping traffic. The pools are also small, have variable hydroperiods and permanence, and would be sensitive to climate change or changes in Lake Superior lake levels. An inventory of these habitats with attention to distribution, hydroperiod, and resident biota would provide useful baseline information.
- The potential for zebra mussel colonization of Lake Superior bays and coves and subsequent dispersal from nearshore waters to inland lakes via stream channels should be explored.
- ISRO has jurisdiction over Lake Superior waters up to 4.5 miles (7.2 km) from shore, but little work has been done on these nearshore and offshore waters. Bathymetric assessments, habitat mapping, and biological inventories are needed.
- Further genetics investigations of lake trout are necessary to determine if there are different stocks around the island and if potential over-exploitation could be possible due to low numbers of some stocks.
- Genetics investigations of inland lake species should be conducted to determine genetic distancing of northern pike and possibly some of the cyprinids and coregonids that have previously been assumed to be subspecies.
- Investigations of brook trout in streams of Isle Royale as they potentially relate to coaster brook trout populations will be important. Measures to protect coaster brook trout will likely be effected in the near future. Investigations that help provide a thorough understanding of which inland water bodies (such as the Siskiwit Rivers and Washington Creek) are inhabited by brook trout and if these could potentially harbor coasters, or contribute to coaster populations, will be helpful in determining the necessary extent of special regulations.
- Early lake surveys and more recent studies have shown that moose browsing can affect lake macrophyte biomass and compromise fish habitat. Further work could examine how these relationships have changed over time with moose density and distribution, and what the specific effects of moose browsing are on lake and pond ecology. Lake sediment core records could be

compared with moose density records to investigate historic and current effects of moose on endpoints like primary productivity, nutrients, and food web structure.

- Future contaminant research should focus on the effects of ambient concentrations of mercury and persistent organic pollutants on particular aquatic biota, populations, or ecosystem functions.

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MISSISSIPPI NATIONAL RIVER AND RECREATION AREA

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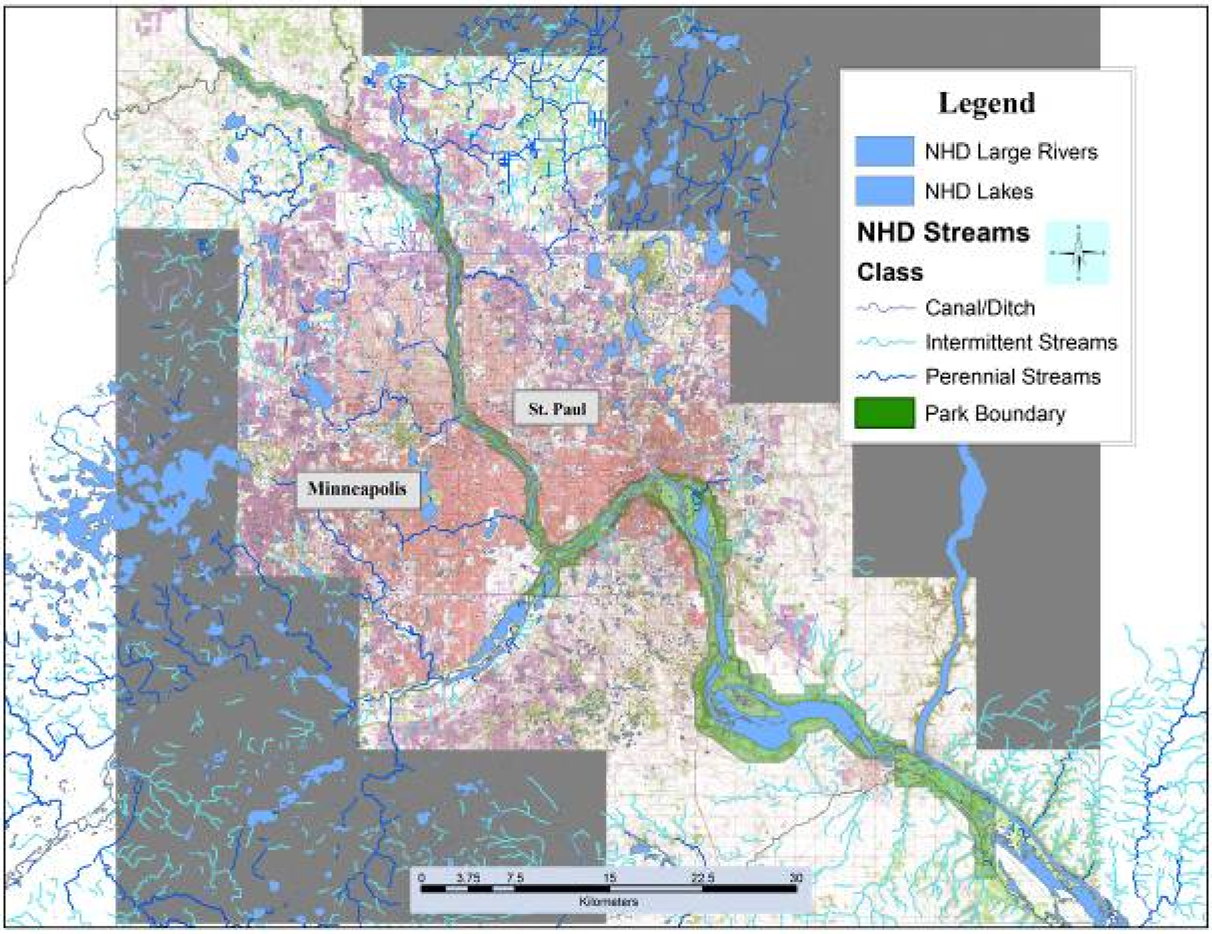
Photographs from top to bottom: main channel Mississippi River, Crosby Farm backwater area, side channel Mississippi River, and Minnehaha Creek. All images courtesy of Mississippi National River and Recreation Area photograph files.



Mississippi National River and Recreation Area and surrounding area, showing streams, rivers, and lakes derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

MISSISSIPPI NATIONAL RIVER AND RECREATION AREA

Mississippi National River and Recreation Area (MISS) comprises a 123 km (77 mile) stretch of the Mississippi River that passes through the Minneapolis - St. Paul Metropolitan area. Lands held by the National Park Service are limited to a handful of floodplain islands in the Mississippi River, but MISS boundaries encompass a complex mix of privately owned lands and public lands administered by local governments, organizations, and state and federal agencies. The primary role of MISS is to support and coordinate activities that protect natural and cultural resources, provide diverse recreational opportunities, and contribute to the economy. Primary water resources include parts of the Mississippi, Minnesota, and Vermillion Rivers, a number of perennial and intermittent tributary streams, and significant floodplain wetlands and standing backwaters (Table 1, pg. 2). Water resource information pertinent to MISS is available from a variety of sources. The Metropolitan Council and U.S. Geological Survey represent two primary sources for information cited in this document. Information collected by the U.S. Army Corps of Engineers, the Minnesota Department of Natural Resources, and local parks may be available at the respective agency offices, but is not presented here.

Summary of existing aquatic research

General resource documents and plans

Several documents address water resources at MISS in a general way. Winterstein (1982) compiled an annotated bibliography for the Mississippi and Minnesota Rivers in the Twin Cities area, including citations for reports, computer models, and raw data. This document is dated but quite comprehensive. It contains references to many reports of potential interest to MISS. The Metropolitan Council recently completed a water resources management policy plan (Metropolitan Council Environmental Services 1998) which reviewed water resources in the Twin Cities area and addressed the roles and goals of Metropolitan Council. Minnesota Department of Natural Resources (1999) recently completed a survey of Mississippi River islands owned by the MISS. Physical habitat assessments and basic inventories of vegetation, wildlife, threatened and endangered species, and exotic species were provided for each island. Most aspects of this report are terrestrial, but insights on adjacent jurisdictions, vegetation types, and recreational use are worthy considerations for aquatic resource management as well. Finally, Kloiber (2003) conducted an aquatic resource assessment for the Twin Cities area, with references to both the Mississippi and St. Croix Rivers. The Mississippi River was noted for its recreational uses, its ecological value, and its importance as a water supply source for the Twin Cities.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for MISS was reviewed for insights on past water quality monitoring in and near the Park (National Park Service 1995, Table 3, pg. 14). A total of 541 monitoring stations were identified in the data retrieval, more than for any other Great Lakes Network Park. Of these, 184 were located within the Park's boundaries, 58 of which recorded at least one water quality exceedence. Records of 43 active or inactive stream gages were found within the study area, and four active U.S. Geological Survey stream gages are currently found within the Park boundaries. Within the MISS study area, 273,531 water quality observations were recorded and 803 water quality parameters were measured, the highest of all Great Lakes Network parks. Water quality exceedences were recorded at least once for 24 different parameters within the study area; 22 of these occurred within the MISS boundaries. Dissolved oxygen, pH, cyanide, chloride, cadmium, copper, lead, mercury, selenium, silver, and zinc exceeded their respective Environmental Protection Agency criteria for protection of freshwater aquatic life. Nitrite, nitrate, nitrite plus nitrate, cyanide, chloride, sulfate, arsenic beryllium, cadmium, chromium, lead, mercury, nickel, and zinc exceeded Environmental Protection Agency drinking water criteria. Concentrations of turbidity and fecal indicator bacteria (total and fecal coliform) exceeded screening criteria for aquatic life and bathing, respectively. The authors concluded that surface waters within the study area were heavily influenced by human activities as a result of the Park's urban/suburban setting. Potential contaminant sources included industrial and municipal wastewater dischargers (of which 98 were noted in the study area), stormwater runoff, and urban/suburban development.

In addition to the water quality records noted in National Park Service (1995) and the Upper Mississippi River Basin National Water Quality Assessment studies discussed in a later section of this document, several other water quality studies have taken place in and around MISS. These studies have addressed spatial patterns as well as temporal trends in water quality. Have (1991) investigated large-scale variation in water quality throughout the upper Mississippi River basin, using existing data compiled from area agencies. Water quality differed among sub-basins according to the dominant land use, with high dissolved solids and nitrates found in row-cropped sub-basins, and increasing conductivity and decreasing dissolved oxygen found in the Mississippi River below the Metropolitan sewage treatment facility and the confluence of the Minnesota River. Larson et al. (1976) investigated spatial variation on a finer scale in the Mississippi River using a time-space contouring technique. Larson suggested that maps derived from this work could serve to identify problem areas for key water quality variables, both within the river channel and over time, and help guide site selection for more intensive monitoring.

Trends in water quality at MISS have also been examined. Larson et al. (1976) offered an initial analysis of water quality at five long-term monitoring stations. Results of this analysis indicated that dissolved oxygen concentrations had changed little in 40 years, but that biological oxygen demand and coliform bacteria had both increased at most sites due to increasing population in the Twin Cities area. Kloiber (2004) provided a more recent analysis of water quality trends in the Twin Cities area, using data collected by Metropolitan Council Environmental Services from 1976 to 2000. Trends for the Mississippi River at Anoka included declines in biological oxygen demand, ammonium, total phosphorus, total suspended solids, and turbidity. Nitrate concentrations, on the other hand, had increased over the period of record. Loads of nutrients and sediments in the Mississippi River were strongly influenced by contributions from the Minnesota River.

In addition to the mainstem Mississippi River and major tributaries, small urban streams tributary to the Mississippi have also been investigated. Payne et al. (1982) studied water quality in runoff from rural and urban watersheds in the Twin Cities area. Ayers et al. (1985) analyzed this data set in greater detail, noting that rainfall was the most significant factor controlling runoff and constituent loads in storm-sewered watersheds. In rural watersheds, however, runoff and constituent loads were greatest during snowmelt and were less closely tied to seasonal rainfall patterns.

Biology and ecology

Much of the biological work at MISS has focused on freshwater mussels, particularly the federally endangered Higgins' eye mussel (*Lampsilis higginsi*) which has been collected at MISS as empty shells. Stern et al. (1982) developed a recovery plan for the Higgins' eye, identifying recovery criteria and essential habitat areas. The plan recommended monitoring the mussel populations in essential habitats and developing techniques for relocation and artificial propagation. Hornbach et al. (1998) issued a revision of the original recovery plan in response to the zebra mussel (*Dreissena polymorpha*) invasion and the flood of 1993. The revised plan recommended greater emphasis on immediate needs to limit zebra mussel impacts, requiring the use of double hull barges, and developing uniform protocols for data collection. Continued monitoring and re-assessment of essential habitat areas were also recommended. The U.S. Fish and Wildlife Service (2004) recently issued a second revision of the Higgins' eye recovery plan. The zebra mussel threat was re-emphasized, and recommendations were made to monitor the distribution and density of zebra mussels, particularly in critical habitat areas, to relocate adult Higgins' eye mussels from heavily infested locations, and to clean infested Higgins' eye mussels manually. Responses to other threats, including construction activities, contaminants, and poor water quality, were also outlined.

In addition to this work on the Higgins' eye mussel, mussel work at MISS has included studies of trends in fingernail clam densities and a large-scale mussel inventory. Wilson et al. (1995) evaluated trends in fingernail clam (Sphaeriidae) populations from historic and new survey data on the Upper Mississippi River from navigation pools 2 to 19. They noted statistically significant population declines at most sites, including Pool 2 at MISS. Declines were attributed to toxic conditions at the water-sediment interface due to point source pollution (metals and ammonia), although no toxicity tests were conducted. A recent mussel inventory was conducted along the entire MISS corridor at 138 sites (Kelner and Davis 2002). Empty shells of two federally endangered mussels were collected (the Higgins' eye and the winged mapleleaf, *Quadrula fragosa*), along with 28 species of live mussels. Fortunately, the survey provided no evidence of zebra mussels above Lock and Dam 1 and only low densities in Pools 2 and 3. Additionally, recent and ongoing recruitment was verified for most species, indicating stable population age structure.

Fish

The Mississippi River is undoubtedly one of the most studied single bodies of water in the country, and there have been several fisheries studies in the upper Mississippi, some of them in the MISS area. There is also a wealth of information from various agencies in areas outside of the Park that may include species or environmental variables that are common to the MISS area. Investigations have been conducted by various agencies prior to and since the Park's inception. Studies range from effects of barge traffic on fish to habitat associations of certain species of fish. Fisheries community investigations on common species found in the upper Mississippi have been conducted since the early 20th century and offer baseline information on community structure that are invaluable to researchers in understanding changes that may have occurred over time. Eddy et al. (1963), for example, is an excellent reference for historic species composition in the Mississippi above and below St. Anthony's Falls – the only natural falls on the Mississippi.

Not surprisingly, the effect of industrialized society and urbanization on fisheries and aquatic biota is an area that has received a fair bit of attention on the upper Mississippi. Water quality and physical habitat in the Twin Cities metropolitan area and the associated impacts on fish species assemblages was the subject of investigations by Talmage et al. (1999). They found high percentages of omnivores and tolerant species with few intolerant species in fish communities of thirteen streams in the area. Index of Biotic Integrity scores were also low, ranging from fair to very poor for most sample areas. Lee et al. (2000) used biological characteristics of common carp (*Cyprinus carpio*) to examine potential impacts from wastewater treatment plants around the State of Minnesota, including sections of the Mississippi within MISS. They found that effluent from wastewater treatment plants was a potential source of hormonally active agents in surface water, and that sites draining primarily agricultural areas also showed indications of hormonally active agents. Lee and Anderson (1998) summarized 20 years of spatial and temporal information on polychlorinated biphenyl (PCB) levels in common carp and walleye (*Sander vitreus*). They found that levels of the contaminant were generally highest in fish from the Mississippi River in the Twin Cities area. The good news is that PCBs declined in most areas by as much as 80% between the 1975-79 and 1988-95 time periods that were examined. Holland (1986) assessed the impacts of commercial vessel passage on various fish life stages by monitoring mortality and changes in species distribution before and after barge passage in the Mississippi. She found significant short term changes in distribution of eggs and larvae following passage, but no consistent effect on catch of age-0 or small adult fish. Information from studies such as these can be invaluable in helping persuade communities to strive towards healthier aquatic systems, especially when impacts from contaminants and habitat loss are obvious in popular visitor use areas such as MISS.

Species assemblages, spatial variation and abundance patterns as they relate to habitat have also been well studied (Holland-Bartels and Duval 1988, Johnson and Jennings 1998, Koel 2004). Several studies are also presented in the annual Proceedings of the Mississippi River Research Consortium and offer an indication of what types of intentional or unintentional habitat modifications may or may not be beneficial to populations (e.g., Hausler et al. 1995, Metz and Frie 1995, Mundahl et al. 1995,).

Amphibians and reptiles

No formal studies of amphibians or reptiles were found in our literature review. The Great Lakes Network office has recently contracted with herpetology experts from the Milwaukee Public Museum to conduct a Park-wide amphibian inventory.

Contaminants

The Upper Mississippi Basin National Water Quality Assessment program, described later in this document, has conducted a variety of studies related to contaminants in the ground and surface waters of the Twin Cities area. In addition to these studies are several other reports related to contaminants at MISS. Brown (1984) investigated the contribution of atmospheric deposition to nonpoint source runoff in the Twin Cities. Local sources of atmospheric pollutants influenced the magnitude of deposition at highly urban sites such as Shingle Creek, and contributed as much as 84% of the nitrate and lead runoff in the area. Anderson and Perry (1999) addressed 10-year trends in PCB and trace element concentrations in Pool 2 of the Mississippi River, noting that trace element concentrations had declined in water and bed sediments since 1985, but had not changed in fish tissue. PCBs in water declined from 1985-1995 at the Metropolitan wastewater treatment plant. Lee et al. (2000) investigated the potential use of characteristics of common carp to indicate exposure to hormonally active agents. Biological characteristics of common carp collected above and below discharges from wastewater treatment plants suggested that wastewater was a potential source of hormonally active agents. Evidence of hormonally active agents was also found at upstream sites draining agricultural and forested lands, perhaps as a result of pesticide use.

Hydrology

Long-term gaging sites have helped provide a good understanding of surface water hydrology at MISS. Schoenberg and Mitton (1990) summarized some of the long-term hydrologic monitoring data relevant to MISS and St. Croix National Scenic Riverway (SACN) and provided monthly mean discharges for ten different gaging stations. Mitton (2002) provided an analysis of hydrologic data from 44 gages in the upper Mississippi River basin during the season of the 2001 flood. Record flows were recorded at nine gaging stations throughout the basin, including the Mississippi River gage at St. Paul and the St. Croix River gage at St. Croix Falls, each of which recorded a 50-100 year flood in 2001.

Groundwater

Because MISS is located in an expanding metropolitan area, the use, chemical properties, and availability of the area's groundwater have received considerable attention. Early studies characterized the quality of area groundwater in a general sense or examined past groundwater usage and availability from water supply and planning perspectives. Maderak (1965) identified several aquifers yielding calcium-bicarbonate type groundwater and noted a gradient in dissolved solids concentrations from the northeastern to the southwestern reaches of the study area. Maderak's investigation indicated that few changes in groundwater chemistry had occurred between 1899 and 1963, but that nitrate contamination was apparent in some shallow aquifers. Horn (1983) examined groundwater use trends in the Twin Cities over the last century, finding that 80% of groundwater withdrawals came from the Prairie du Chien-Jordan aquifer and that most of this was used for self-supplied industry. Groundwater use increased from 1880 until the 1970s when groundwater conservation measures began to be implemented. Horn (1984) provided a more recent review of groundwater use trends from 1971-1980, noting that most groundwater continued to be withdrawn from the Prairie du Chien-Jordan aquifer for both industrial and public supplies. Schoenberg (1984) examined a similar dataset and found that water levels in the Mount Simon-Hinckley aquifer had increased nearly 18 m (60 feet) in response to reductions in pumping during 1970-1979. Water levels in the Prairie du Chien-Jordan aquifer varied by up to 7.6 m (25 feet) in response to local water pumping or recharge activities.

In addition to studies of past and current groundwater conditions and use patterns, several studies have addressed the potential effects of increased groundwater withdrawals in the region. Norvitch et al. (1973) analyzed available groundwater information and found that surface water resources of the Twin Cities area were not sufficient to meet all needs during a severe drought. Additionally, aquifers were already experiencing cones of depression during maximum withdrawals in summer months. Metropolitan Council (2004) more recently reviewed groundwater demand and supply for future planning in the Twin Cities area. Their analysis showed that groundwater was the primary source of water for a large component of the metropolitan area's population, but cited limitations to future development of the region's groundwater supply, including lack of access to the Prairie du Chien-Jordan aquifer and the adverse impacts of withdrawals and contamination. Other studies have examined future water use trajectories through detailed research and modeling. Lindgren (1990) and Schoenberg (1990) simulated groundwater flow in the major aquifers of the area using a three-dimensional groundwater flow model. Both studies projected substantial drops in the hydraulic heads of these aquifers if pumping were to increase by 125-200% over 1980 levels.

Groundwater-surface water interactions have also received attention at MISS. Ruhl et al. (2002) estimated recharge to unconfined aquifers and leakage to confined aquifers in the Twin Cities Area in order to assist water managers with their concerns about long-term groundwater depletion. Ruhl et al. (2002) noted that impervious land areas in the metro areas had little or no recharge potential, whereas surficial sand and gravel areas (e.g., Washington County near the St. Croix River) had great recharge potential. Schoenberg (1989, 1994) and Payne (1995) estimated contributions of groundwater to flows in the Mississippi and Minnesota Rivers, finding that seepage from bedrock aquifers affected flow particularly during dry years. Payne (1995) also noted locations where groundwater emerged from beneath river beds and along river margins.

Physical processes

A recent study by the U.S. Army Corps of Engineers (Hendrickson 2003) addressed sediment loading and bed material in the Mississippi River from Anoka to Guttenburg. Hendrickson developed a bed material sediment budget for the entire reach, noting three distinct reaches upstream, in, and below Lake Pepin. The Minnesota River was a key sediment contributor to the Mississippi River above Lake Pepin.

Strengths and needs

The reach of the Mississippi River protected by MISS is of significant public interest and its water resources have been the topic of diverse research projects. In general, MISS has access to excellent long-term hydrologic and water quality monitoring records from other agencies, and has much more comprehensive information on groundwater availability, quality, and contributions to surface water than is available for most GLKN parks. Additionally, many studies at MISS have addressed water resource issues in a basin-wide context, which provide a useful perspective for managing main stem Mississippi River resources. In terms of water resource information needs, few studies have addressed aquatic biota such as fish, benthic invertebrates, aquatic wildlife, or aquatic vegetation. There is, however, some coverage of the impacts of industrialization and urbanization on aquatic biota, as affected by habitat and water quality degradation. Inventories, assessments, and monitoring of aquatic biota would be of interest to both scientists and the public, especially given that this reach of river was severely impaired in its recent history. In the same vein, ecosystem functions and processes (such as nutrient and contaminant cycling) are of great interest in the greater Upper Mississippi River Basin, but have received little attention within MISS. . Mississippi National River and Recreation Area would also benefit from Park-specific analysis of existing regional and local datasets. Continued coordination with area agencies on issues of urban development and water supply will be needed to protect MISS resources from degradation.

Considerations for monitoring

Directly from the literature

- Kloiber (2004) evaluated water quality trends in the Mississippi River since 1976; continued monitoring is needed, particularly given the rapid growth of the Twin Cities metropolitan area.
- Have (1991) noted that that Mississippi River water quality was strongly affected by inputs from the Metropolitan sewage treatment plant and the Minnesota River. As a result, water quality in the Mississippi River at Hastings was not representative of the entire study unit. Multiple monitoring stations will be needed to understand water quality at MISS.
- Both Ayers et al. (1985) and Have (1991) noted the strong influence of large precipitation events on water quality, particularly in urban streams of the area. They recommended that monitoring should occur on both a regular and event-based schedule.
- Larson et al. (1976) provided time space contour figures in their analysis. Though dated now, a similar technique could prove useful in selecting water quality sites for future monitoring.
- Anderson and Perry (1999) reviewed water quality data and concluded that increased coordination, quality assurance, and metadata collection were needed in future monitoring efforts.
- Follow-up studies of freshwater mussel communities are needed at MISS, including monitoring of recruitment and recovery and an evaluation of the zebra mussel threat (Kelner and Davis 2002).
- Wilson et al. (1995) suggested that fingernail clam densities were responding to gradients in water and sediment quality. These organisms are important components of the food web and their densities may be useful indicators of point source pollution at MISS.

Derived from the literature by the synthesis authors

- Kloiber (2004) noted that in contrast to most other water quality constituents, nitrate concentrations were increasing. Future work should address the potential causes of this increase and how these increases contribute to total nitrate loads carried by the Mississippi River to the Gulf of Mexico.
- Several studies indicated that percent impervious land surface affected stream water quality and groundwater recharge potential in the area. Land cover attributes should be closely monitored at MISS, with attention to where modifications could be made to improve infiltration and reduce nutrient and contaminant loading to MISS.
- Fish species assemblages should be monitored more frequently, especially in areas where anthropogenic changes may occur, whether it is habitat rehabilitation or degradation.
- Monitoring of trends in contaminant levels in biota, especially consumables such as fish, should continue.
- There were no records of monitoring for aquatic wildlife or herpetofauna found in Park files, and monitoring records for fish and other aspects of aquatic biology were under-represented. Attempts to incorporate biological monitoring efforts from other agencies into MISS files and resource management are needed.

Considerations for research

Directly from the literature

- Brown (1984) recommended that future investigations of nonpoint source runoff account for the substantial inputs of nitrates and lead from atmospheric deposition.
- Kelner and Davis (2002) recommended exploring the potential for re-establishing mussel species previously inhabiting the area. They also noted that MISS could potentially serve as a refuge for mussels imperiled in other parts of the river. These possibilities should be further investigated.
- Lee et al. (2000) recommended controlled studies to confirm the effects of hormonally active agents on fish reproduction and population structure.
- Schoenberg (1989) recommended further work on groundwater-surface water interactions and seasonal changes in aquifer and river chemistry.

Derived from the literature by the synthesis authors

- MISS has experienced considerable point source pollution. Sediments remain contaminated in Pool 2, making conditions unsuitable for some benthic biota (e.g., Wilson et al. 1995). Lingering biological impairment related to this history of contaminant loading should be better evaluated.
- Several studies noted the strong influence of nutrient, sediment, and pesticide inputs from the Minnesota River basin on MISS water quality. Close cooperation with managers and scientists in the Minnesota River basin is needed to ensure protection and improvement of aquatic resource conditions at MISS.
- The Metropolitan Wastewater Treatment Plant processes large volumes of wastewater from the Twin Cities metropolitan area. Technological advances at the treatment plant have been repeatedly overwhelmed by population growth in the metro area. Because the Mississippi River is the receiving water for this effluent, MISS should have a role in future decisions about wastewater treatment.
- Effects of future groundwater withdrawals at locations near MISS should be investigated in greater detail. Such research should focus on how those withdrawals may affect hydraulic heads and groundwater interactions with the Mississippi River, particularly in low flow years and heavy pumping months.
- No aquatic wildlife or herpetofauna studies were found in Park files, and studies of fish and other aspects of aquatic biology were under-represented. Attempts to incorporate biological research efforts from other agencies into MISS files and resource management are needed.

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PICTURED ROCKS NATIONAL LAKESHORE

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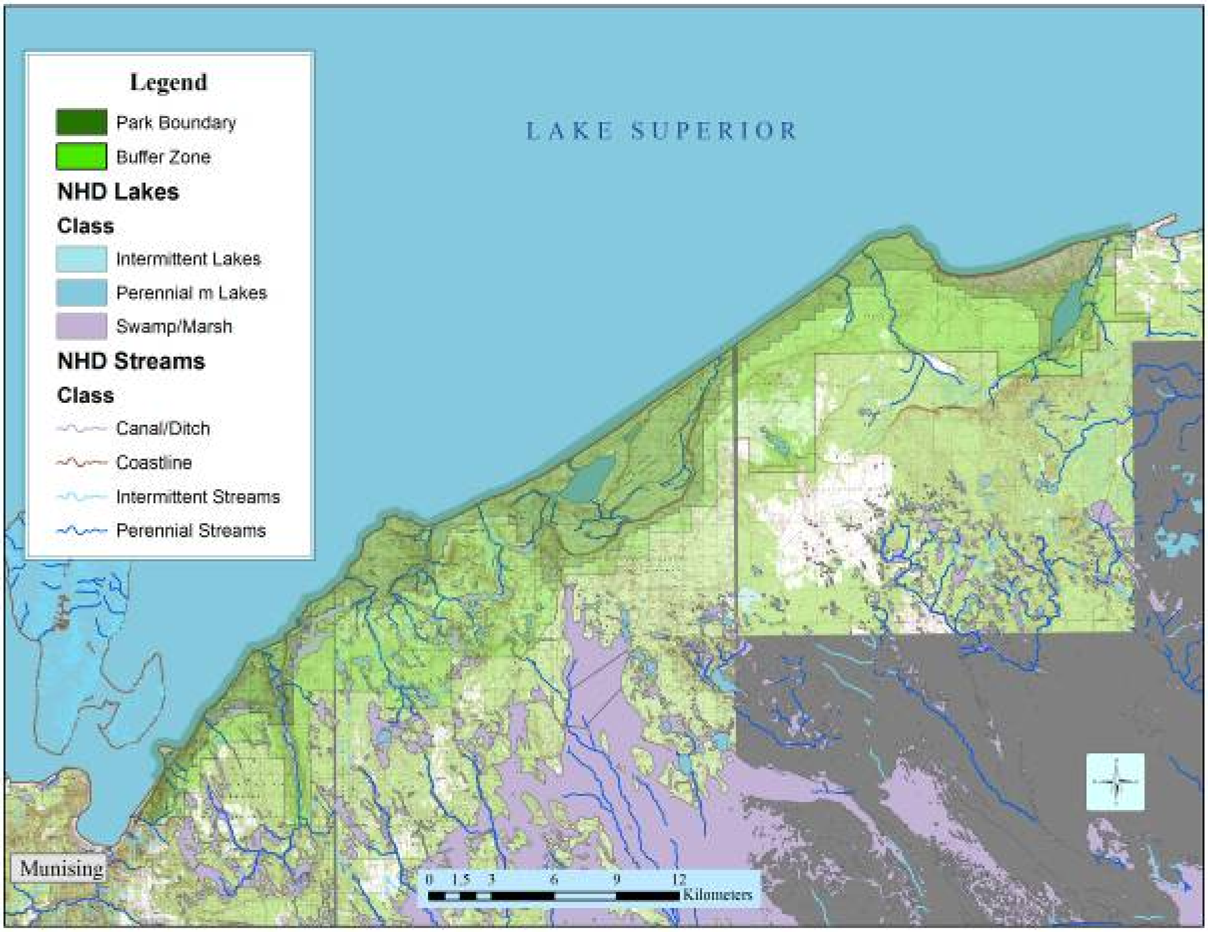
Photographs from top to bottom: Pictured Rocks from across Munising Bay (J. Glase), Sable Falls (B.M. Lafrancois), Miners River outlet (B.M. Lafrancois), and Miners Lake (J. Glase).



Pictured Rocks National Lakeshore and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

PICTURED ROCKS NATIONAL LAKESHORE

Pictured Rocks National Lakeshore (PIRO) preserves 62 km (39 miles) of Lake Superior shoreline in Michigan's Upper Peninsula. The Lakeshore's namesakes are the colorful sandstone cliffs extending along the shoreline, but the Lakeshore also protects a variety of aquatic resources. Lentic water resources include extensive coastal habitats, over 2,400 ha (6,000 acres) of Lake Superior surface waters, 14 named inland lakes, and several beaver ponds and wetlands (Table 1, pg. 2). Prominent inland lakes include Grand Sable, Beaver, Little Beaver, Chapel, Little Chapel, Miners, Trappers, Legion, Kingston, and the Shoe Lakes. Lotic water resources at PIRO are unique and more plentiful than at many Great Lakes area parks (excluding the river parks) (Table 1, pg. 2). .

Pictured Rocks National Lakeshore features 19 named streams, of which Miner's River is the longest and largest. In general, PIRO streams are short and drain directly to Lake Superior. Two PIRO streams (Beaver and Grand Sable Creeks) originate in lakes, although the lakes themselves have tributary streams. In addition to the federally-owned shoreline zone, PIRO also includes a second layer of protection via the non-federally-owned Inland Buffer Zone (IBZ), consisting of state forest land, private commercial forests, and small private holdings. At one time, the IBZ also contained national forest land but this land was turned over to Lakeshore ownership several years ago. The designation of the IBZ acknowledged the importance of watershed processes to the protection of PIRO's inland waters.

Summary of existing aquatic research

General resource documents and plans

Several PIRO documents provide basic information on the Lakeshore's natural resources along with guidelines for management and monitoring. Michigan Technological University (circa 1980) provided an early overview of PIRO ecosystems, describing geology, soils, watersheds, climate, and vegetation and wildlife patterns. A cooperative, draft fisheries management plan developed in the early 1980s by Michigan Department of Natural Resources with input from PIRO provided recommendations characteristic of fish management methods practiced by many states at that time (Michigan Department of Natural Resources 1981). This plan offered one or two paragraph recommendations for several waterbodies in the Lakeshore, and made suggestions such as removal of fallen trees from streams, stocking plans, and management for Pacific salmonids in certain streams. Another brief cooperative Fisheries Management Plan was completed by PIRO in coordination with Michigan Department of Natural Resources (Pictured Rocks National Lakeshore and Michigan Department of Natural Resources 1995). The plan provided management recommendations for 14 streams, ten lakes, and two pond systems; identified the need for a review of historic and current fisheries management in the Lakeshore; and recommended increased use of science and increased information on pre-European water resource conditions. An updated plan that incorporates National Park Service fisheries management policy is needed. Loope (2001a) began work on a monitoring plan for aquatic resources at PIRO, noting a need to address stressors such as exotic species, atmospheric contaminants, climate change, stream sedimentation, bacterial contamination, emissions from personal watercraft, and watershed disturbances.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for PIRO was reviewed for insights on past water quality monitoring in and near the Lakeshore (National Park Service 1995, Table 3, pg. 14). A total of 76 monitoring stations were identified in the data retrieval, representing 7,466 observations and covering 237 water quality parameters. Within the Lakeshore boundaries, 35 monitoring stations were found, of which five recorded water quality exceedences. No active or inactive gages were encountered within the Lakeshore boundaries or the greater study area. Water quality exceedences were noted at least once for only four water quality parameters. Exceedences for three of these parameters (pH, cadmium, and lead) occurred within the Lakeshore boundaries during short-term sampling efforts at Spray Creek, Chapel Creek, or the Mosquito River. Cadmium and pH exceeded Environmental Protection Agency acute or chronic criteria for the protection of aquatic life, and cadmium and lead exceeded their respective drinking water criteria. The authors concluded that surfaces waters in the PIRO area appeared to be of generally good quality, attributing the water quality exceedences to local development.

In general, water quality information at PIRO has come in the form of basic water quality surveys (Handy and Twenter 1985) and more comprehensive limnological studies (see the "biology and ecology" section below). Handy and Twenter (1985) provided a general characterization of water resources in PIRO lakes and streams, indicating that PIRO waters were highly colored, due to high dissolved organic carbon (DOC), but suitable for aquatic life according to Environmental Protection Agency criteria. Differences in stream chemistry above and below Miner's Lake were noted.

Issue-specific water quality research at PIRO has focused on atmospheric deposition, acidification mechanisms in Legion Lake, and logging. Atmospheric deposition research at PIRO was often conducted in conjunction with watershed studies on Isle Royale and the Keweenaw Peninsula of Michigan. Studies in the Little Beaver drainage at PIRO showed acidic precipitation, high seasonal variability in stream water chemistry, and spring reductions in stream pH (Stottlemyer 1982a, 1982b). As with Isle Royale National Park (ISRO), however, forest canopy and soil types modified precipitation inputs to PIRO streams (Stottlemyer 1982b, Stottlemyer 1989). Additionally, PIRO streams had even higher buffering capacity than ISRO streams, and headwater streams in PIRO's Little Beaver Creek watershed were able to neutralize experimental additions of acid readily (Stottlemyer 1982a).

Legion Lake is a unique, highly acidic, clear water lake at PIRO and has been the subject of substantial speculation and some investigation. Stottlemyer (1989) examined lake sediment cores from Legion, Upper Shoe, and Lower Shoe Lakes, and found that Legion Lake was largely disconnected from watershed processes and groundwater and is one of the most naturally acidic clear water lakes in the nation. Further results of the Legion Lake study were reported in Lewin (1991), who provided additional evidence that Legion Lake was naturally acidic due to minimal groundwater seepage.

Effects of timber harvest practices on PIRO streams were investigated in the 1980s (Mullen 1988). Three stations on the Mosquito River were monitored for stream flow and water quality throughout the winters for two years. The study provided little evidence of harvest-related changes in stream flow, water quality or soil quality, and the authors concluded that small winter harvests (<15% cover removed) would likely have negligible effects on PIRO waters. However, effects of more substantial harvests conducted during the summer growing season were not investigated, and would likely result in more significant effects on PIRO streams.

Biology and ecology

Several basic limnological studies have been conducted in PIRO waters (Limnetics, Inc. 1970, Doepke 1972, Kamke 1987, Loope 1998a). Sampling sites for these studies have included inland lakes and streams as well as Lake Superior, and study parameters have ranged from water and sediment quality to plankton, macroinvertebrates, and macrophytes. The studies have generally shown PIRO waters to be highly colored and relatively productive, although watershed and morphometric characteristics varied among lakes. Trophic status also varied among lakes, ranging from eutrophic (Miners Lake) to oligotrophic (Grand Sable). Most lakes were dimictic, but due to unique basin morphometry, Chapel Lake appeared to be meromictic, with a permanent chemocline present. Loope (1998a) provided the most recent limnological summary for PIRO, and documented the presence of the non-native spiny water flea (*Bythotrephes longimanus*) in Beaver Lake in 1998 (Loope 1998b). It has since been documented in Grand Sable Lake as well. Phytoplankton communities in two of PIRO's lakes (Beaver and Grand Sable) received specific attention over the course of two summers (Nevers and Whitman 2004). Phytoplankton composition in these lakes was generally dominated by diatoms and chrysophytes, and was more similar to that of other northern lakes (Isle Royale National Park and Voyageurs National Park) than to lakes at Sleeping Bear Dunes National Lakeshore or Indiana Dunes National Lakeshore.

Benthic invertebrate collections and biological assessments have been conducted on two occasions (Boyle et al. 1999, Michigan Department of Environmental Quality 2000) and both studies have emphasized the influence of stream bed and substrate characteristics on benthic invertebrate assemblages. Boyle et al. (1999) collected invertebrates and water quality samples from several lakes and streams in the mid 1990s. Lakes appeared mainly mesotrophic and strong links were noted between substrate size and benthic invertebrate community composition in the streams. These linkages are significant, because substrate size is likely affected by local factors such as dune processes, timber harvest, and gravel road erosion. In addition to Boyle's work, the Michigan Department of Environmental Quality (2000) conducted a basic habitat and biological assessment in Sable Creek and other nearby Lake Superior tributaries. High levels of sedimentation were noted, due to inputs from the Sable Dunes and other sources.

Nichols et al. (2001) recently conducted a survey of unionid mussels in PIRO lakes and rivers. They found that Chapel Creek and most PIRO lakes supported unionids; absence of unionids in other PIRO streams was attributed to winterfreeze and unsuitable bedrock substrates. Densities were variable among lakes but consistent recruitment was apparent in all lakes but Grand Sable. Nichols suggested that unstable populations in Grand Sable may be related to human harvest or declines in the host fish, yellow perch. As at Isle Royale National Park, organic contaminants in mussel tissues were below consensus deleterious levels.

Fish

The Pictured Rocks area has had a varied history of fishery management efforts. This area was historically, and continues to be, a popular fishing area; some lakes were managed for desired sport fish by the State of Michigan's Department of Natural Resources prior to the area's designation as a National Lakeshore.

Inland waterbody or riverine fish surveys and investigations

The Michigan Department of Natural Resources has conducted assessments and surveys in some of the lakes and streams of the Lakeshore for many years. Most are population studies with information on species present, age and growth statistics, and relative abundance (Doepke 1972, Gruhn 1976, Grim 1990a, 1990b). Others have provided a more comprehensive coverage and reported on species assemblages in several streams and lakes. Gerovac and Whitman (1995) investigated nine streams, a channel connecting Beaver and Little Beaver lakes, and four lakes within the Lakeshore boundaries; they compiled a list of 19 fish species collected. They also referred to previous Michigan Department of Natural Resources surveys that listed ten additional species at PIRO. The only method Gerovac and Whitman used was seine netting in streams and lakes, so this should not be considered a comprehensive survey since seining cannot be used in deep water. Boyle et al. (1999) reported eleven species of fish in five streams in the Lakeshore using electro-shocking techniques. Vogel (1999) conducted a thorough literature review and conducted interviews of long time residents to get some telling anecdotal information on historic changes in the fisheries of the area. Some information on stocking and species presence was also presented in this report.

An exciting effort to restore grayling (*Thymallus arcticus*) populations in PIRO waters was presented by Loope (1986) and Loope and Scott (1987). Unfortunately, efforts to restore this species to the area were unsuccessful. Grayling were introduced very soon (about a week) following treatment with Rotenone, which is known to kill most stream macroinvertebrates. It is possible that the stocked grayling had little food base. Another reason this effort was unsuccessful may be that habitat conditions in most of upper Michigan are not yet conducive to restoration of this species.

Coaster brook trout (*Salvelinus fontinalis*) research and rehabilitation is a popular area of study at PIRO, as it is in many areas of Lake Superior, and efforts to rehabilitate populations there have occurred since 1997. Most of the coaster investigations have not been in Lake Superior proper, but rather in the streams of the Lakeshore that are tributary to the big lake. There have been cooperative efforts with U.S. Fish and Wildlife Service and Michigan Department of Natural Resources to determine the status of coasters (Baker et al. 1999) as well as migration studies by researchers from Northern Michigan University (Armichardy and Leonard 2003). During one of these investigations, Armichardy and Leonard (2003) caught or observed 25 species, including the first documentation at PIRO of the native American brook lamprey (*Lampetra appendix*).

Lake Superior fish surveys and investigations

Fisheries investigations of the nearshore waters of Lake Superior at PIRO are limited. The most recent survey was conducted in 2002 by the U.S. Fish and Wildlife Service to determine species presence and relative abundance along the shoreline area (Newman 2003). Newman found 29 species present, although references in his report suggest that up to 73 species could be present in the area. He concluded that habitat was not diverse enough to hold all species suggested in other documents, or that some species may only use the area for short periods. One discouraging statistic in the report that does not bode well for ongoing brook trout rehabilitation efforts was that the number of non-native steelhead (*Onchorhynchus mykiss*) captured was 210 while only one native brook trout was captured. However, this survey was conducted over short time periods in spring, summer, and fall during only one year. Brook trout can be very difficult to capture in open water and it is possible that some brook trout could have been missed during these efforts. Additional surveys targeted specifically at brook trout that include additional nocturnal sampling and more sampling periods should be conducted before any conclusive results can be offered regarding brook trout populations in the area. Edsall (1960) provided some information on age and growth of whitefish in Munising Bay. While Munising Bay is not within the Lakeshore boundaries, information from these nearby waters can be useful for PIRO managers in understanding the potential influence that species found there may have on efforts such as coaster brook trout rehabilitation.

Aquatic wildlife

Factors affecting breeding success of bald eagles (*Haliaeetus leucocephalus*) were assessed throughout the Hiawatha National Forest, including a site near PIRO (Bowerman 1991). Probable reasons for low bald eagle productivity included low abundance of prey fish as well as pesticide and polychlorinated biphenyl (PCB) contamination.

A study of furbearers at PIRO documented information on beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) colony density as determined by aerial surveys (Daues 1991). Aerial surveys were conducted in late October of 1989 and 1990 by flying over stream courses and inland lake perimeters to search for browse piles and lodges. Beaver colony density was 0.21/km^2 (0.54/mi^2) a figure that Daues reported was at the low end of average for colony density in North America (0.15-4.6 colonies/km^2, or 0.39-11.9 colonies/mi^2). Beaver populations in the Lakeshore in the autumns of 1989 and 1990 were estimated at 121 and 160, respectively.

Amphibians and reptiles

Site-specific herpetofaunal surveys were conducted in the Sand Point and Rim Road areas of PIRO (Werner 1989, Premo and Davis 1990). In both cases amphibians and reptiles were recorded and identified using vocal calls and collected by hand, dip nets, minnow traps, and fyke nets. At Sand Point, relatively low densities and species richness were attributed to reductions in aquatic vegetation and invertebrates, along with increases in turbidity and siltation caused by beaver activity (Werner 1989). Along the Rim Road, researchers encountered higher species richness (12 amphibians and 7 reptiles), but cited habitat destruction and traffic-induced mortality as potential stressors (Premo and Davis 1990). In addition to these studies, the Great Lakes Network office has recently contracted with herpetology experts from the Milwaukee Public Museum to conduct a Lakeshore-wide amphibian inventory.

Wetlands and aquatic vegetation

Information on aquatic vegetation at PIRO is limited. Crispin et al. (1984) reviewed past records and conducted a survey of threatened and endangered plant resources at PIRO. Two aquatic species of special concern (the water starwort, *Callitriche hermaphroditica* and the alternate flower water milfoil, *Myriophyllum alterniflorum*) and one state threatened species (Farwell's milfoil, *Myriophyllum farwellii*) had previously been documented in inland lakes but were not encountered by Crispin et al. (1984). Similarly, the northern wet meadow species bog aster (*Aster nemoralis*) had been found previously. The authors recommended more intensive vegetation surveys of inland lakes by boat. Kamke (1987) provided basic survey notes on aquatic macrophyte presence and composition in four PIRO lakes, and Loope (2001b) compiled a list of basic wetland types featured at PIRO. Loope (2001b) noted that even basic biological inventories for these habitats were lacking. Prominent wetland types included wet meadow marshes found in headwater zones and near beaver ponds, northern bogs found near Legion Lake and the Shoe Lakes, vernal pools found throughout the Lakeshore in deciduous forests, and cedar swamps found in several locations. In a recent vegetation survey, MacKinnon (2004) noted several wetland and aquatic species not previously documented from PIRO.

Contaminants

The Michigan Department of Natural Resources has evaluated contaminant concentrations in Grand Sable Lake's biota and sediments on two occasions as part of larger studies (Michigan Department of Natural Resources 1989, 1991, 1992). In the late 1980s, a sediment core was collected from Grand Sable Lake and analyzed for percent solids, dry weight, metals, and nutrients. Concurrent with the sediment core work, benthic invertebrates from bottom sediments were collected and identified, and mercury was analyzed in sediments, fish, and bald eagle feathers. Mercury concentrations were highest in surficial sediments, as were other metals and nutrients (Michigan Department of Natural Resources 1989, 1991). Neither fish mercury concentrations nor benthic invertebrate densities were related to surface sediment mercury concentrations, but most lakes (including PIRO's Grand Sable Lake) had fish with total mercury concentrations exceeding the State of Michigan consumption advisory level of 500 ng/g (Michigan Department of Natural Resources 1991). Further fish sampling in Grand Sable Lake confirmed the relatively high concentrations of mercury in lake trout and northern pike, and also noted measurable amounts of chlordane, dichlorodiphenyltrichloroethane (DDT), and DDT degradation products (Michigan Department of Natural Resources 1992).

Hydrology

Little information on PIRO hydrology or hydrologic processes exists. In one study, however, deep cores from PIRO's Beaver Lake were used to investigate Lake Superior's lake level fluctuation history (Fisher and Whitman 1999). Deglaciation dates and past depositional environments were apparent in the sediment record.

Physical processes

Physical and geomorphic processes have been evaluated at PIRO from long-term (i.e., Holocene and glacial), historic (i.e., since European settlement), and modern (i.e., recent decades) perspectives. Blewett (1994) addressed the phases of deglaciation at PIRO, emphasizing the role of spatial and temporal variations in glacial processes in shaping modern surficial geology. Loope et al. (2004) conducted a novel investigation of the historic geomorphic processes affecting Grand Sable Lake. The authors noted that the lake was formed during multiple episodes of sand deposition and damming of ancestral Sable creek. These episodes were influenced by changes in lake levels on Lake Superior.

Other studies have focused on residual effects of post-European land use change in the area. Boyle et al. (1999) conducted a risk analysis of the aquatic resources of the Lakeshore that featured the application of the Universal Soil Loss Equation to predict areas with the greatest potential for stream sedimentation. Their methods included physical stream habitat descriptions (channel classification, substrate type, quantification of large woody debris, and discharge). Loope and Holman (1991) assessed stream bank and streambed characteristics for ten PIRO streams to evaluate possible effects of historic logging activities. Pictured Rocks National Lakeshore streams, however, had surprisingly high bank stability and no excessive sand bed load. The authors concluded that the high gradient of PIRO streams had discouraged the accumulation of sand and sediment mobilized in the logging era, and that future research on the topic should focus on lower gradient reaches in the inland buffer zone. Loope (1993), on the other hand, described lingering effects of a turn-of-the-century logging dam on Beaver Creek and Beaver Lake. These effects included narrow terraces above current water levels in Beaver Creek and the Beaver Lakes (indicating previous high water marks due to damming), evidence of sedimentation and substrate homogenization in the littoral zones of the Beaver Lakes, low density and species-poor flora and fauna in the littoral zones of the Beaver Lakes, and alder establishment on the exposed terraces in Beaver Creek. A series of studies explored possible effects of the Beaver Lake logging dam by conducting substrate surveys (Hoff 1996), evaluating surface sediment characteristics (Gerovac et al. 1996), and examining littoral zone sediment cores (Fisher and Whitman 1998). In general, these studies indicated that Beaver Lake substrates had been sandy throughout the post-glacial history of the lake, and that the Beaver Lake logging dam had not resulted in burial of coarse substrates suitable for walleye spawning.

Finally, two studies have focused primarily on modern geomorphic processes and issues. The first of these documented erosion-related changes at Sand Point, Chapel Beach, and Beaver Creek Campground using erosion pins and aerial photographs (Farrell and Hughes 1984). The authors determined that Sand Point was rapidly growing out from the mainland. Additionally, wave erosion and mass wasting were common, but effects of human trampling-induced mass wasting events were difficult to distinguish from naturally occurring processes. Loope (1992) placed recent shoreline changes and issues in a long-term context, noting that shifts in shoreline features at PIRO are inevitable and strongly influenced by natural water level fluctuations on Lake Superior. The author discouraged the use of artificial shoreline protection and emphasized the protection of natural geomorphic processes.

Strengths and needs

Aquatic research at PIRO has addressed a broad range of topics and supplied a good deal of general information on aquatic resources. Several solid limnological studies have been conducted but are now quite dated (1980s), and differences in methods and sampling sites complicate comparisons among water bodies and over time. To date, wetland resources at PIRO have escaped attention despite their prevalence and diversity in the Lakeshore. A limited amount of issue-specific research has addressed the effects of logging and atmospheric contaminants (acid and mercury deposition), but additional investigations may be necessary. A number of studies have addressed geomorphic changes and processes at PIRO, often placing modern geomorphic issues within a long-term context. . Pictured Rocks National Lakeshore's location makes it vulnerable to both climate change and invasive species stressors; future monitoring and research efforts should devote increased attention to these emerging concerns. Pictured Rocks National Lakeshore has moved toward restoration and more natural management of native fish species assemblages by implementing National Park Service management policies. These efforts should be continued and expanded, and an updated fisheries management plan that incorporates National Park Service policy into management recommendations should be completed. Removal of non-native species should be considered, where feasible, to aid in recovering native species assemblages.

Considerations for monitoring

Directly from the literature

- Standard indices of trophic status were not effective monitoring tools at PIRO because color confounded the measurement of Secchi depth and water clarity (Kamke 1987).
- The presence of several exotic species in Lake Superior and the recent establishment of the spiny water flea (*Bythotrephes longimanus*) in two PIRO lakes make invasive species monitoring a high priority for PIRO. Invasion of other lakes at PIRO by *Bythotrephes* and other aquatic invasives should be monitored (Loope 1998b, Nichols et al. 2001).
- Nichols et al. (2001) provided recommendations for future monitoring of unionid mussels, including PIRO-wide surveys every ten years and more intensive studies in Grand Sable Lake.

Derived from the literature by the synthesis authors

- Several studies (e.g., Limnetics, Inc. 1970, Doepke 1972) noted the potential for nutrient enrichment of PIRO waters. . Pictured Rocks National Lakeshore lakes may make good core sampling sites for analysis of historic changes in nutrient concentrations, and should be monitored closely for future changes.
- Despite several limnological investigations at PIRO, seasonal variability in lake water quality and biology has not been addressed in previous reports. This dimension should be explored through future monitoring.
- The brown color and high DOC content of PIRO waters is stressed repeatedly in the literature. DOC concentrations are closely linked to climate fluctuations and play an important role in light attenuation, microbial activity, and ecosystem function in northern lakes. This variable should be closely monitored for any future changes related to climate warming.
- Information on fish species assemblages should be updated in as many water bodies as possible by conducting regular, consistent assessments.
- Lake Superior fish surveys should occur more regularly, especially to determine the status of coaster brook trout and to monitor abundance of potentially competitive salmonids such as steelhead, coho salmon (*Oncorhynchus kisutch*), and splake. These surveys would also provide basic information on which species may use the area, even on an occasional basis.

Considerations for research

Directly from the literature

- Handy and Twenter (1985) recommended further research to explore how lake processes mediate the impacts of watershed activities (i.e., logging, atmospheric deposition) on water quality in streams like Miners and Grand Sable.
- Nichols et al. (2001) recommended further investigation into the cause of the low mussel recruitment in Grand Sable Lake.
- Mullen (1988) suggested that small winter harvests were not likely to have adverse effects on PIRO streams; however, whether or not this is the case for larger harvests in different seasons is unclear. Effects of other logging practices on other endpoints such as sediment loading and biological structure and function merit further investigation. Boyle (1999), for example, noted strong relationships between benthic communities and substrate type and size.
- MacKinnon (2004) noted that vegetation in open peatlands near Lower Shoe Lake were examined too late in the season and should be re-visited earlier in the the growing season in future years to document additional plant species.

Derived from the literature by the synthesis authors

- Because PIRO drainages are small, short and steep, there should be measurable effects of local land uses on sediment loads, stream organic matter, nutrient concentrations, and benthic invertebrate communities. . Pictured Rocks National Lakeshore streams are good candidates for investigating land-water interactions and watershed processes on a small, easily understandable scale.
- While the presence of the spiny water flea (*Bythtrephes longimanus*) in Beaver and Grand Sable Lakes for several years is well documented, it is unclear how large the populations are or how they are affecting native aquatic biota (e.g., zooplankton, young perch) and ecological processes (e.g., grazing, mussel-host fish interactions) in these lakes. A project funded in fiscal years 2008-2010 will investigate these effects in greater detail (PMIS #105200).
- Coaster brook trout rehabilitation efforts may benefit from a better understanding of genetics of local stocks and potential implications of stocking Tobin Harbor strain fish at PIRO. More specific genetic investigations of coaster brook trout in the area should be conducted. Northern Michigan University's research on growth and movement should be continued concurrent with genetics investigations.
- The history of fish stocking in PIRO waters should be reviewed, in a manner similar to Vogel's (1999) effort, to determine composition of historic assemblages for future inland lake and stream rehabilitation efforts.

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ST. CROIX NATIONAL SCENIC RIVERWAY

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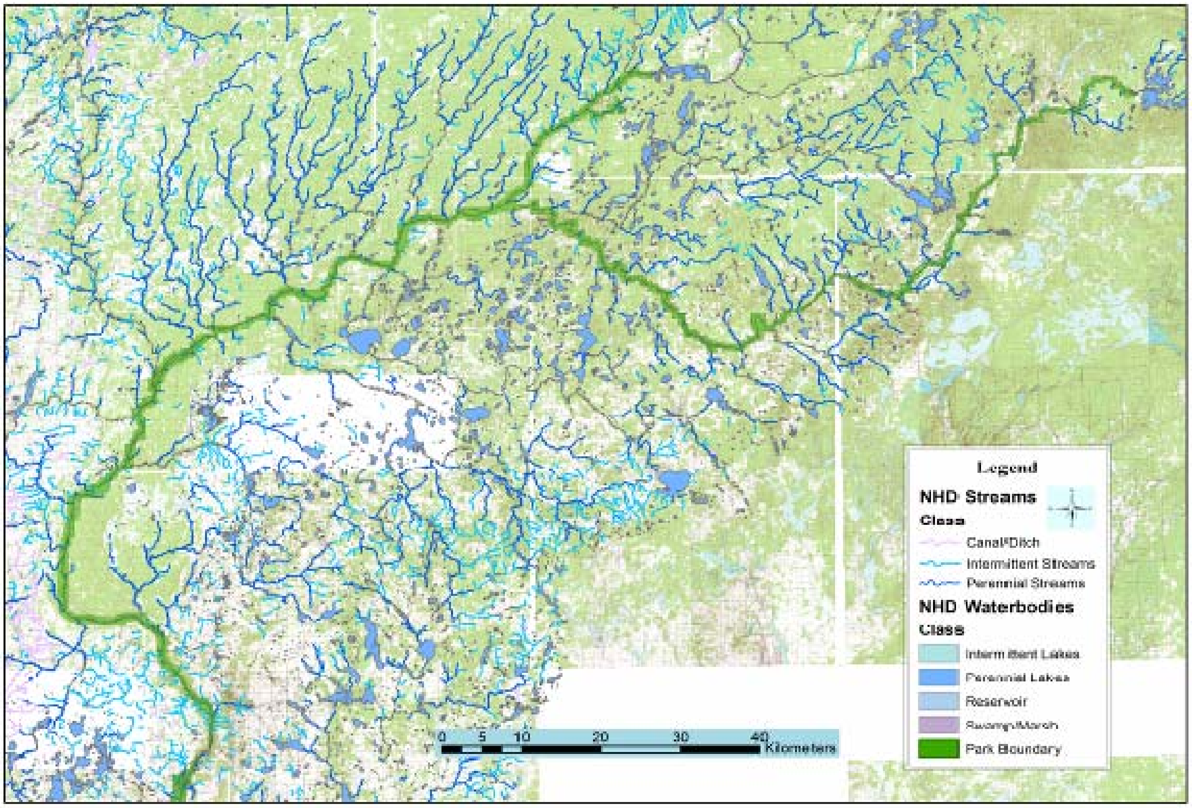
Photographs from top to bottom: Namekagon River (R. Ferrin), Pacwawong Flowage on Namekagon River (R. Ferrin), St. Croix River near Marine on St. Croix (J. Hoffman), and Lake St. Croix (courtesy of St. Croix National Scenic Riverway photograph files).



Northern portion of the St. Croix National Scenic Riverway, and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD), and wetlands derived from the National Wetland Inventory (NWI). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

Southern portion of the St. Croix National Scenic Riverway, and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD), and wetlands derived from the National Wetland Inventory (NWI). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

ST. CROIX NATIONAL SCENIC RIVERWAY

One of eight rivers granted protection under the original Wild and Scenic Rivers Act, St. Croix National Scenic Riverway (SACN) was designated in 1968, with the Lower Riverway designated in 1972. The Riverway stretches 420 km (261 miles) from the forested headwaters of the St. Croix and Namekagon Rivers in northern Wisconsin to the confluence of the St. Croix with the Mississippi River near the Twin Cities Metropolitan Area. The Riverway is recognized for its outstanding scenic qualities and its diverse and rare biological resources. It is home to over 100 species of fish and 40 species of unionid mussels, two of which are federally endangered. Upper reaches of the Riverway flow through forests, marshes, and peatlands. At

Taylors Falls, Minnesota, the river passes through a hydroelectric impoundment and a deep gorge. The river below the dam is characterized by islands, sandbars, and sloughs, and becomes lake-like for its final 41 km (26 miles), due to its impoundment by a 9,500 year-old delta of the Mississippi River. Various aquatic habitats can be found within and along the Riverway, including tributary streams, wetlands, floodplain forests, backwaters, ponds, and spring and cliff seeps (Table 1, pg. 2). Due to the nature of the Park, more kilometers of perennial and intermittent streams are found at SACN than at any other Great Lakes area park (Table 1, pg. 2). Since the federal designation affords only a thin corridor of protection to the St. Croix River, SACN resource managers coordinate their activities with those of other resource management agencies throughout the watershed. This cooperation is facilitated by the St. Croix Basin Water Resources Planning Team (hereafter referred to as the Basin Team), created in 1994 via an interagency memorandum of understanding.

Summary of existing aquatic research

General resource documents and plans

SACN completed a Water Resources Management Plan in 1997 (Holmberg et al. 1997). The plan summarized previous aquatic research efforts and described existing conditions for water quality and aquatic biology. The plan also outlined key water resource issues at SACN and recommended future studies of nutrient and sediment loading issues. A cooperative Fisheries Management Plan was completed in 1999 with efforts from the National Park Service and Minnesota and Wisconsin Departments of Natural Resources (Ferrin et al. 1999.) One of the most thorough documents for fisheries information on the river, this plan included information for warmwater, coolwater, and coldwater zones of the Riverway. Past and present management approaches were discussed, and plan implementation included a list of several meaningful project statements that would benefit the resources. Additional SACN planning documents include a St. Croix basin water quality management plan assembled by the Wisconsin Department of Natural Resources (Malischke et al. 1994), a St. Croix River monitoring plan prepared by the Nutrient Technical Subcommitee of the Basin Team (St. Croix Basin Team Nutrient Technical Subcommittee 1998), and a basin-wide planning status report prepared by Basin Team coordinator Pam Davis (Davis 2003). Malischke et al. (1994) addressed agency activities and management efforts throughout the basin and noted the need for interstate consistency, a common database, and coordinated water quality monitoring. The St. Croix Basin Team Nutrient Technical Subcommittee (1998) addressed some of these needs by preparing a plan for coordinated nutrient monitoring and modeling in the St. Croix River and its tributaries. Davis (2003) described the considerable progress made on nutrient studies and other activities, and outlined the future direction of the Basin Team.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for SACN was reviewed for insights on past water quality monitoring in and near the Riverway (National Park Service 1995, Table 3, pg. 14). A total of 469 monitoring stations were identified in the data retrieval, representing 113,022 observations and covering 628 water quality parameters. A total of 107 monitoring stations were located within the Riverway boundaries; of these, only 10 recorded water quality exceedences (two on the Namekagon River, five on the St. Croix River, and three in Lake St. Croix). A total of 47 active or inactive gages were encountered within the study area, with two active U.S. Geological Survey gages currently operating within the Riverway boundaries, at Danbury, Wisconsin and at Taylors Falls, Minnesota. Water quality exceedences were recorded at least once for 19 different parameters in the study area. Of these, 14 parameters exceeded screening criteria within the Riverway boundary, including pH, cyanide, cadmium, copper, lead, mercury, and zinc, which exceeded their respective Environmental Protection Agency acute or chronic criteria for the protection of freshwater aquatic life, and cyanide, fluoride, beryllium, cadmium, lead, mercury, and nickel, which exceeded their respective drinking water criteria. Bacteria concentrations (total and fecal coliform) and turbidity exceeded the screening limits for bathing water and aquatic life, respectively. Three industrial dischargers were documented within the study area. The authors concluded that water quality in SACN has been affected by human activities, including industrial and municipal wastewater discharges, stormwater runoff, and land uses such as agriculture, forestry, and urban and residential development.

Issues of nutrient and sediment loading have been a water quality focal point at SACN. Several studies have reported on historical (Troelstrup et al. 1993a, Edlund and Engstrom 2001, Triplett et al. 2003) and recent (Graczyk 1985, Meyer et al. 1999, Lenz et al. 2001, Kloiber 2004, Lenz 2004) trends in nutrients and sediments. Other work has explored nutrient status and sources in Lake St. Croix (Environmental Protection Agency 1975), nutrient and organic waste loading from point sources basin-wide (McKersie et al. 1972, Edlund 2004), and nutrient loading from tributaries throughout the St. Croix basin (Lenz et al. 2001). An intensive modeling study was used to examine future nutrient trajectories for SACN (Robertson and Lenz 2002). The National Water Quality Assessment (Upper Mississippi River study unit) has also targeted these issues on the St. Croix River; its efforts are described later in this document.

Historic trends, reconstructed from sediment cores taken at Lake St. Croix and the impoundment at St. Croix Falls, indicated increased sediment accumulation rates following European settlement, with peaks in the 1950s-1970s. Marked increases in phosphorus loading and chlorophyll *a* concentrations have occurred since 1950 (Troelstrup et al. 1993a, Edlund and Engstrom 2001, Triplett et al. 2003). These patterns have been accompanied by increases in diatom productivity, shifts in diatom composition from benthic to planktonic species dominance, and shifts in chironomid composition toward those tolerant of low oxygen conditions (Troelstrup et al. 1993a, Edlund and Engstrom 2001).

More recent trends in water quality have been examined using existing monitoring data sets. These trends suggest modest water quality improvements since the 1970s. Graczyk (1985) examined water quality at ten sites throughout SACN from 1975-1983, and noted declines in suspended sediment and organic carbon concentrations. Meyer et al. (1999) explored an extensive set of monitoring data collected by Metropolitan Council Environmental Services (MCES), and showed that total phosphorus and suspended solid concentrations declined in Lake St. Croix over the period of record (1976-1996). Similarly, using MCES data from 1976-2002 in a recent investigation of Twin Cities rivers, Kloiber (2004) found declines in suspended solids, turbidity, total Kjeldahl nitrogen, ammonium, biological oxygen demand, and fecal coliform bacteria in Lake St. Croix; he noted increasing trends for nitrate nitrogen. Finally, Lenz (2004) explored water quality and stream flow records from Danbury and St. Croix Falls, Wisconsin. Stream flow appeared to have increased over the past century, but water quality, collected during shorter-term bouts over the past three decades, showed no sign of a change over time.

Several studies have explored nutrient status and sources in the St. Croix basin. McKersie et al. (1972) investigated point source loading to the St. Croix River, noting that water quality was generally good but that three municipalities still lacked secondary treatment. They provided recommendations for improved wastewater treatment at several sites, including the fish hatchery at St. Croix Falls. Edlund (2004) provided recently analyzed point source loading in an historic context, noting that untreated sewage was discharged in the early part of the 1900s, with secondary treatment available at most facilities by the 1960s-1970s, and tertiary treatment currently in place at most facilities. Present day point source phosphorus discharges were estimated to account for 13% of the total phosphorus loading to the St. Croix River. The Environmental Protection Agency (1975) monitored Lake St. Croix during the summer of 1972 as part of the National Eutrophication Survey and examined nutrient concentrations and loadings from tributaries and municipal wastewater plants. This study estimated that nonpoint sources contributed 88% of the large total phosphorus load, with most phosphorus entering Lake St. Croix via the Kinnickinnic and St. Croix Rivers. Troelstrup et al. (1993b) reviewed spatial patterns in water quality and biology in the lower St. Croix River. Lenz et al. (2001) investigated nutrient loading from St. Croix tributaries. Precipitation amounts and intensity greatly affected tributary loading, but the Sunrise River appeared to be a major nutrient and sediment contributor during both base flow and high flow events. Benthic invertebrate data, collected simultaneously, did not help identify which tributaries were the most affected by nutrients and sediments.

Robertson and Lenz (2002) used the BATHTUB model to explore water quality responses to future increases or reductions in phosphorus loading in Lake St. Croix. Results from their study showed that linear increases in phosphorus loading would result in non-linear increases in algal biomass, increases in algal bloom frequency, and marginally reduced water clarity. Effects of increased phosphorus would be exacerbated in dry years.

In general, SACN nutrient studies suggest that despite some recent improvements, the Riverway has undergone significant changes (including cultural eutrophication) since European settlement. Nutrient concentrations and sediment accumulation rates remain significantly higher than pre-European settlement levels, algal species composition remains altered, and modeling results suggest that Lake St. Croix remains sensitive to future increases in phosphorus inputs.

In addition to an intensive nutrient and sediment research program at SACN, a variety of short-term water quality studies have also been undertaken to examine water quality spatial patterns (Troelstrup and Foley 1993 and Payne et al. 2002) and fecal bacteria issues (Kroening 2000). Troelstrup and Foley (1993) used growth and shell chemistry of the threeridge mussel (*Amblema plicata*) to examine water quality patterns in the Lower Riverway, and found that mussel morphology and growth rates in downstream reaches reflected poorer water quality and a shift from riverine to lacustrine habitats. Element groups in the shells were useful in identifying soil disturbance, fertilizer use, and urban inputs. Payne et al. (2002) conducted a synoptic study of water chemistry, physical habitat, and characteristics of fish and benthic macroinvertebrate assemblages at 14 sites on the St. Croix River. Concentrations of most water chemistry variables increased gradually downstream, but all sites showed low dissolved phosphorus concentrations and biological measures were indicative of good water quality. Kroening (2000) conducted a study of fecal coliform and *Escherichia coli* for SACN, noting that bacteria counts were below federal standards for all sites, did not show consistent seasonal patterns, and did not appear related to discharge.

Biology and ecology

Aquatic biological work at SACN has focused heavily on unionid mussels and other benthic invertebrates. Freshwater unionids are globally threatened organisms and the St. Croix River is home to an extraordinary mussel fauna that includes two federally endangered species. Mussel research on the river has included small and large-scale mussel surveys, studies of the distribution, life history and habitat requirements of endangered mussel species, mussel relocation experiments, and investigations into the effects of stressors such as dams and ammonia levels.

Mussels

General mussel surveys –
Several site-specific surveys have been conducted. Stern (1983) conducted SCUBA dives along transects in the St. Croix at St. Croix Falls, and provided a species list along with depth distribution information. Havlik (1987) conducted SCUBA and wading surveys at seven proposed bridge/tunnel sites on the Lower St. Croix and provided recommendations for preferred bridge crossing and mussel relocation sites. Helms & Associates (1994) found eleven mussel taxa at sites near Stillwater, but found no evidence of zebra mussels (*Dreissena polymorpha*), Asian clams (*Corbicula fluminea*), or threatened or endangered species at those sites. A group from Grantsburg High School surveyed mussels on the Upper St. Croix River, noting 17 species of mussels and normal age distributions and recruitment (Grantsburg High School 2001). Hove and Hornbach (2000) investigated mussel community characteristics downstream of the St. Croix Falls hydropower dam.

Other mussel surveys have addressed the St. Croix River more comprehensively. Heath and Rasmussen (1990) surveyed five study areas of the St. Croix in order to establish a baseline for long-term mussel monitoring. In addition to baseline information, the authors provided detailed monitoring recommendations including the estimated number of quadrats needed to determine a given percent change in mussel populations. Troelstrup et al. (1993d) examined longitudinal patterns in elemental accumulation in mussel tissues in the Lower St. Croix. Many elements were detected, and several were correlated with boat traffic and land use characteristics, suggesting that mussels may be useful biomonitoring tools for the St. Croix. Doolittle and Heath (1997) re-visited sites sampled in Heath and Rasmussen (1990), and found that mussel densities had declined since

1987 at two sites, Marine 2 and the Narrows. These sites also had a high proportion of dead shells and showed declining recruitment across taxa. Hove and Hornbach (2002) surveyed mussel communities at four St. Croix River sites and compared results with earlier survey work. Their results indicated recent declines in mussel diversity and density, and a shift in sediment composition toward finer particles.

Research at SACN has also addressed the effects of habitat characteristics on mussel density, diversity, and composition. In an extensive mussel research review for the Water Resources Management Plan, Hornbach (1996) noted differences in mussel composition above and below the dam at St. Croix Falls (which prevents host fish passage) and found that physical habitat characteristics explained little of the variation in mussel density or species richness. Hornbach et al. (1997) investigated juvenile and adult mussel habitat patterns at Interstate Park, noting that small juveniles were common in deep side channels and adults were rare where frequent dewatering occurred due to dam operation. Macrohabitat factors affecting mussel distributions in the St. Croix were investigated by Hornbach (2001), who noted significant spatial variation and distinct effects of the dam at St. Croix Falls on mussel composition, with lampsilines dominant in the upper reaches of the river and amblemines more common in the lower reaches.

Endangered mussels –
The distribution, ecological requirements, and life histories of SACN's two federally endangered mussel species have received substantial attention since their initial listing. Recovery plans have been developed for both the Higgins' eye pearlymussel (*Lampsilis higginsi*) and the winged mapleleaf mussel (*Quadrula fragosa*) (Stern et al. 1982 and Vaughan 1997, respectively). Hornbach et al. (1998b) issued a revision of the original Higgins' eye recovery plan in response to the zebra mussel invasion and the flood of 1993. The U.S. Fish and Wildlifle Service (2004) recently issued a second revision, re-emphasizing the zebra mussel threat and outlining recommendations for monitoring the distribution and density of zebra mussels, particularly in critical habitat areas, relocating adult Higgins' eye mussels from heavily infested locations, and cleaning infested Higgins' eye mussels manually. At the time of publication, the Interstate Park site was the only critical habitat area for Higgins' eye mussels not currently invaded by zebra mussels. Management and responses to these and other threats, including construction activities, contaminants, and poor water quality, were outlined. Recommendations outlined in these recovery plans continue to guide mussel research activities at SACN.

Busacker (1989) examined the potential effects of replacing the Stillwater river crossing on the Higgins' eye pearlymussel, noted several recently occupied Higgins' eye shells in the study area, and concluded that live Higgins' eye were likely present. Hornbach et al. (1995) investigated the abundance and distribution of Higgins' eye at several sites in the Lower St. Croix. Significant Higgins' eye populations were found only at the Lakeland and Prescott sites, with dead or scarce Higgins' eye noted at other sites. The authors noted that Higgins' eye was present in the slower-moving parts of the river that were most threatened by zebra mussels.

Ecological characteristics and distribution of the winged mapleleaf were investigated at Interstate Park (Hornbach 1992, 1996, Hay et al. 1995, Hornbach et al. 1996) and throughout the Lower St. Croix River (Troelstrup and Hornbach 1994). In each of these studies, winged mapleleaf was associated with dense and species-rich mussel communities, particularly the monkeyface (*Quadrula metanerva*), the deertoe (*Truncilla truncata*), and the fawnsfoot (*T. donaciformis*), and densities were highest in water depths of 2 m (6.5 feet) or more. Because the winged mapleleaf was generally found in areas with other healthy mussel populations, the authors surmised that management benefiting the mussel community as a whole should also benefit winged mapleleaf mussels. The authors recommended increased efforts to identify host fishes and to determine their distribution, habitat, and water quality requirements (Troelstrup and Hornbach 1994).

Two studies addressed reproductive characteristics of the winged mapleleaf mussel. Hornbach et al. (1998a) investigated morphometric and genetic techniques for identifying winged mapleleaf glochidia, and showed that DNA and polymerase chain reaction techniques could be used to distinguish winged mapleleaf from other species of *Quadrula.* Heath et al. (2000) noted that winged mapleleaf mussels brooded later in the season

(September-October) and for a shorter period of time than other mussels. Its brooding season was similar to that of the mapleleaf (*Quadrula quadrula*) and was linked to water temperature. Hove et al. (2000a, 2000b) used 35 potential host fish species to test host fish suitability for the winged mapleleaf, and found channel catfish (*Ictalurus punctatus*) to be the most likely hosts.

A detailed and valuable sampling strategy for monitoring winged mapleleaf population trends in the future was assembled by Hornbach et al. (2000) following a related workshop.

Mussel relocation and refugia –
Two studies have evaluated the potential for mussel relocations into and within the St. Croix River. The first of these studies involved moving mussels from the proposed Stillwater bridge site to a site just upstream (Ecological Specialists, Inc. 1997). Recovery rates were high and no mortality was observed in the larger sample grids. A second relocation project, conducted by Bartsch et al. (2000), involved moving individuals of several species (including the Higgins' eye) from near Lakeland upstream to Franconia. Both recovery and survival rates were high, suggesting that relocations to *in situ* refugia in the St. Croix may be a viable tool for preserving threatened mussel fauna in the future.

Specific mussel stressors –
The effects of two specific stressors have been investigated with respect to SACN mussel fauna. These include effects of the hydrodam operation at St. Croix Falls and effects of high pore water ammonia levels. Investigations into the effects of the hydrodam were motivated by concerns over the fluctuations in water depth just downstream of the dam, where the only known population of the winged mapleleaf is found. Johnson (1995a) and Hornbach (1995a, 1995b) used the PHABSIM model to assess instream flow requirements of the mussels. This analysis showed that the most suitable mussel substrate was gravel and that moderate velocities were preferred. Mussel density was highest at intermediate and deep sites, and habitat diversity and availability were limited at high and low flows. The authors noted that higher discharges were needed to protect mussel habitat. Hanson and Leonard (1995) provided a critical review of this work and suggested that more evidence was needed to determine whether or not flow modifications would improve habitat conditions. Additional analyses provided support for the results of the original PHABSIM simulations (Johnson 1995b).

Newton et al. (2003) evaluated potential ammonia toxicity on unionid mussels using juvenile plain pocket book mussels (*Lampsilis cardium*). The studies involved sediment toxicity tests, *in situ* experiments across an ammonia gradient in the St. Croix River, and mollusk surveys at previously unsampled sites. Toxicity tests showed that lethal concentrations were much lower than the acute national water quality criterion for ammonia, and that sublethal effects may occur at still lower concentrations. Juvenile mussel survival in *in situ* experiments was variable and not strongly related to ammonia concentration gradients.

Benthic macroininvertebrates

Non-mussel work on invertebrates at SACN has included general benthic invertebrate surveys and ecological studies, an investigation into the effects of dams on invertebrate fauna, intensive studies of particular invertebrate species or groups, and a series of studies on invertebrate distribution and drift in Valley Creek, a tributary to the Lower St. Croix River.

General macroinvertebrate surveys –
Troelstrup et al. (1993b) provided a general review of existing information on water quality, benthic invertebrates, unionid mussels, and fish, noting water quality trends over time and providing species lists. Other invertebrate studies have focused on relationships between macroinvertebrate assemblages and drainage characteristics, water quality, and habitat. In general, these studies have noted that macroinvertebrate density and composition varies substantially throughout the river and its tributaries. Tributary inputs, watershed characteristics, flow, geomorphometry, and small scale habitat features were all cited as factors influencing variation in invertebrate assemblages.

Boyle et al. (1992) found that macroinvertebrate density and species richness declined downstream along the St. Croix River, with marked reductions below St. Croix Falls, and high proportions of grazers below tributary inputs. In a follow-up report, Boyle and Strand (2001) provided a more detailed multivariate analysis of this data set, showing that sampling date, temperature, drainage area, and substrate type explained significant variation in benthic invertebrate assemblages among sites. In a study of invertebrates associated with large woody debris, Davis (1998) noted that invertebrate density was most affected by the surface area of the debris, but that invertebrate richness and diversity were influenced by qualities like age of large woody debris, water depth, and water velocity. Macbeth et al. (1999) provided an understanding of large- and small-scale spatial variability in the Riverway and noted implications for benthic invertebrates on the Upper St. Croix River. Major segments were classified by basin-level properties, minor segments were classified using channel gradient measures, and reaches were classified using local geomorphic features. Low gradient segments were less easily classified and less tightly linked to benthic invertebrate composition. Westrick (2000) collected macroinvertebrates from third order streams throughout the upper St. Croix basin and successfully constructed a model to predict approximate benthic invertebrate composition using measurements of discharge, stream length, conductivity, and percent gravel.

Effects of dams on macroinvertebrates – Several dams are present on the Namekagon and St. Croix River and their tributaries. At SACN, two studies have examined the effects of dams on benthic invertebrates. Boyle and Beeson (circa 1990) investigated the effects of the Pacwawong and Phipps flowages on benthic invertebrate assemblages of the Namekagon River. They found increased density, richness, and diversity, and altered functional group composition downstream of both flowages, and suggested that the dams were affecting benthic invertebrates via changes in organic matter and substrate characteristics. MacKay and Waters (1986) investigated the effects of a small Valley Creek impoundment (tributary to the Lower St. Croix) on hydropsychid caddisflies. Their work showed that hydropsychid production was higher downstream of the dam due to increased abundance and quality of seston and more abundant periphyton.

Individually studied macroinvertebrate taxa – Both the mayfly group and the St. Croix snaketail dragonfly (*Ophiogomphus susbecha*) have received individual attention at SACN. Rare and endangered mayflies were surveyed from sand-bottomed areas of the St. Croix and other Wisconsin rivers (Lillie 1995). The St. Croix had the second highest number of mayfly taxa and the highest number of unique taxa of all the sampled rivers. Vogt and Smith (1993) described the first record of the St. Croix snaketail dragonfly in the north central United States, and noted that this species is known only from large rapid rivers with relatively pristine water quality.

Valley Creek macroinvertebrate studies – One St. Croix tributary, Valley Creek, has been used extensively as a study site for stream invertebrate work. Many of these studies have focused on invertebrate drift, with studies addressing seasonal and diurnal drift patterns, as well as the effects of light, population density, and predation pressure on drifting organisms (Waters 1961, 1962, 1965, 1966, 1981, Holt and Waters 1967, Newman and Waters 1984, and Shiozawa 1986).

Fish

According to the Fisheries Management Plan for SACN, fish species other than “sport fish” have received little attention by management agencies in the St. Croix and Namekagon Rivers (Ferrin et al. 1999). The plan attributed this lack to difficult sampling logistics, inconsistent management practices, and the perception that non-sport species are of lesser value than sport fish. The plan addressed reports from management agencies and academia that include aquatic resource assessments, investigations of relative abundance, and sport fish creel surveys. This plan also provided authoritative guidance for future management direction, and will be useful for developing fisheries research ideas for SACN.

In addition to the Fisheries Management Plan, a 1997 creel survey conducted by the Minnesota and Wisconsin Departments of Natural Resources provided very useful information on species targeted by anglers in the St. Croix (Sewell and Morse 1998). Angling pressure, total catch and harvest, and other aspects of the fishery were estimated. Some non-angling recreational use, such as canoeing and houseboating activity, was also estimated. Total fishing pressure for the period between May 3 and October 31, 1997 was estimated at 74,854 hours. Smallmouth bass (*Micropterus dolomieu*) and walleye (*Sander vitreus*) were the two most sought species. Smallmouth bass were the most captured fish, while walleye were harvested more. There were a total of 44,761 fish caught, but only 4,648 fish were harvested, indicating a release rate of nearly 90%.

The physical extent of the Riverway and the habitat and species diversity of the St. Croix basin create a challenge when it comes to fisheries investigations. Much of the past fisheries work has been conducted by different agencies and entities, with little consistency in sampling effort among the agencies, making analysis of information difficult. However, comprehensive surveys have been conducted that provide a wealth of information on species assemblages and distribution. Some of the most comprehensive survey work was conducted by the Wisconsin Department of Natural Resources (Fago 1986 as referenced in Holmberg et al. 1997). Samples were taken at 940 stations throughout the entire basin and a total of 93 species were collected. Fago described accounts of species such as the crystal darter (*Crystallaria asprella*), listed as endangered by the State of Wisconsin, and eight other species in the basin that are considered threatened in Wisconsin. The paddlefish (*Polyodon spathula*), considered threatened in Minnesota, was also documented. Fago and Hatch (1993) also provided a thorough summary of fisheries information in a broader document that reports on the aquatic resources of the basin. This report included a list of all fish species found in the basin, listed by major sub-basins, from 1889 to 1990. They also included a list of species that have not been collected in the basin since 1974. Montz et al. (1989) surveyed sections of the St. Croix that had been previously surveyed in 1959 and found 68 species representing 15 families. More recent investigations by Benike and Michalek (2001) covered only the lower St. Croix River, but provided a good update of species present in that part of the basin. The State of Wisconsin produced a recent report on the state of the St. Croix basin (Wisconsin Department of Natural Resources 2002) which included references to previous fisheries investigations. A few reports provided guidance on use of an Index of Biotic Integrity (IBI), or described relative habitat quality through a modification of the IBI for the St. Croix (Fausch 1987, Simon 1988, Goldstein et al. 1999, Niemela and Feist 2000).

More specific investigations have reported on certain species or groups of fish found in the basin; the potential diversity of the species in the basin is hinted at by some of these reports. Hatch (1986) gave an account of the growth, reproduction, habitat, and food utilization of the various darters of the basin. Johannes (1980) analyzed information from lake sturgeon tagging efforts conducted in 1960 in several tributaries of the St. Croix. Tagged fish were recaptured up to 15 years later. He suggested that the population was self-sustaining based on age classes present in the population and assumed this was due to low fishing pressure at the time. Damman (1993) compared lake sturgeon surveys from 1988 and 1989 with historic information from 1959. He reported a 50 to 98% reduction in sturgeon numbers since 1959 and suggested past over-harvest was the primary reason for the decline. Pratt (1982) reported on trout populations and trout habitat with a comprehensive survey of three sections of the Namekagon River. Brown (*Salmo trutta*), rainbow (*Oncorhynchus mykiss*), brook (*Salvelinus fontinalis*), and even tiger trout, a brown trout / brook trout hybrid, were documented in his investigations. A creel survey conducted as part of these investigations indicated that brown trout made up the majority of angler harvest, followed by rainbow trout and brook trout. He also evaluated special regulations for trout in one of these sections ten years later, reporting that regulations achieved the goals of redistributing anglers and increasing catch and release angling (Pratt 1992). Cochran (1987) described collecting a non-parasitic form of lamprey (*Ichthyomyzon* sp.) in the Namekagon River that was indistinguishable from the southern brook lamprey (*I. gagei*) previously only described in southern Missouri. He theorized that this could also be an independently evolved satellite of the chestnut lamprey (*I. castaneus*).

Many past surveys have focused on very specific areas, such as the various flowages or sections of tributaries. Population assessments span several decades for game species found in these various sections of the river. Johannes (1984) reported on walleye recruitment and muskellunge (*Esox masquinongy*) fingerling survival in the Trego Flowage of the Namekagon River. In addition to information for these two species, he provided statistics for several species collected during surveys. Additional assessment work that provides useful species assemblage information has been conducted in the Trego Flowage (McComas 1990), Namekagon Lake (Rieckhoff 1977), Lake Hayward (Pratt 1993), and the impoundment at Taylor's Falls (Peterson 1964).

One of the more thoroughly studied groups of organisms in the St. Croix has been the mussels found in the basin. Determining fish hosts for glochidia has been an important area of research and has been well studied, as indicated previously in this section (Waller and Holland Bartels 1988, Hove and Kapuscinski 1996, 1997, Hove et al. 2000a, b).

Amphibians and reptiles

In addition to ongoing amphibian work through the U.S. Geological Survey's Amphibian Research and Monitoring Initiative (http://armi.usgs.gov/2002_report_NC.asp), studies of SACN herpetofauna have included field surveys along the middle and lower sections of the Riverway, a wood turtle (*Clemmys insculpta*) survey on the Namekagon River, and a detailed analysis of turtle assemblages along the St. Croix River. DonnerWright (1994, 1996) and Probst et al. (1991) provided summary accounts and species lists from their field investigations using pitfall traps, time searches, and turtle traps. They concluded that time searches were useful but that abundance estimates were improved by the use of pitfall traps. Savage (1993) reported the results of an on-the-water survey of a reach of the Namekagon River, noting that spiny soft shell (*Apalone spinifera*) and painted turtles (*Chrysemys picta bellii*) were most common. Each of these surveys provided species lists and useful baseline information for the study sites. DonnerWright et al. (1999), however, explored the turtle datasets in greater detail. She found that most of the variation in turtle species abundance was accounted for by channel morphology and river physical characteristics, and was able to relate the occurrence of several turtle species to characteristics such as water depth, velocity, and substrate type. She noted that geomorphic differences along the river and geomorphic changes over time were important considerations in future efforts to monitor and preserve SACN turtle assemblages.

Wetlands and aquatic vegetation

Several aquatic vegetation surveys have taken place on the St. Croix River, and a macrophyte study was conducted for Trego Flowage on the Namekagon River. Glenn-Lewin (1988) and Glenn-Lewin et al. (1991, 1992) evaluated several wetland sites on the lower St. Croix River, and categorized wetland types based on the vegetation present. Degree of hydrologic connectivity with the St. Croix and presence of flowing water strongly affected vegetation types. This work suggested that temporary or long-term changes in flow regimes could have significant effects on aquatic vegetation in wetlands connected to the St. Croix. Konkel (2000) conducted an additional study of aquatic vegetation at three 1.6 km (1 mile) stretches on the lower St. Croix River. Study results indicated that most plants were found in the 0 to 0.5 m (0 to 1.5 foot) depth zone, but that plant growth did occur at depths of up to 1 to 2 m (3 to 6 feet). Factors that may limit plant growth at these sites included low water clarity, soft water, dominance of sand and rock substrates, and fluctuations in water levels and velocities. Barr Engineering Company (1994) conducted a macrophyte survey on the upper one-third of Trego Flowage, noting 27 species, including the non-native curly pondweed (*Potamogeton crispus*), and macrophyte growth up to the six foot depth contour. Several localized management scenarios were evaluated to facilitate open water recreation.

Contaminants

In addition to a series of Upper Mississippi Basin National Water Quality Assessment (UMIS) studies addressing contaminants in the St. Croix (see UMIS section, below), several studies particular to SACN have been completed in recent years. Stewart and Butcher (1999) investigated effects of cranberry operations on water quality and macroinvertebrates in the St. Croix River. The authors found no apparent effects of the cranberry operations on nutrient concentrations or macroinvertebrate biological indices; however, the pesticide azinphosmethyl was found in high concentrations at one site. Conclusions of the study were limited by high detection limits and infrequent sampling. Lee et al. (2000) investigated the potential use of characteristics of common carp (*Cyprinus carpio*) to indicate exposure to hormonally active agents. Biological characteristics of common carp collected above and below discharges from wastewater treatment plants suggested that wastewater was a potential source of hormonally active agents. Evidence of hormonally active agents was also found at upstream sites draining agricultural and forested lands, perhaps as a result of pesticide use. Elemental chemistry in streambed sediments was evaluated at 30 sites in the St. Croix River and tributaries (Brigham 2002). Results indicated that trace metal concentrations in the St. Croix Basin were low relative to concentrations in urbanized streams, and that the primary sources of trace elements were geological. Payne and Hansen (2003) recently completed a reconnaissance survey of mercury and methylmercury concentrations in the St. Croix River and tributaries. The highest methylmercury yields were found in tributaries whose watersheds were dominated by wetlands and forests.

Hydrology

Long-term gaging sites have helped provide a good understanding of surface water hydrology at SACN. Schoenberg and Mitton (1990) summarized some of the long-term hydrologic monitoring data relevant to Mississippi National River and Recreation Area (MISS) and SACN, and provided monthly mean discharges for ten different gaging stations. Mitton (2002) provided an analysis of hydrologic data from 44 gages in the upper Mississippi River basin during the season of the 2001 flood. Record flows were recorded at nine gaging stations throughout the basin, including the Mississippi River gage at St. Paul, Minnesota, and the St. Croix River gage at St. Croix Falls, Minnesota, which recorded floods of 50- and 100-year magnitudes, respectively, in 2001. Lenz (2004) analyzed long-term hydrologic and water chemistry data from gaging sites at Danbury and St. Croix Falls, Wisconsin, noting evidence of increasing stream flow at these sites over the past century.

Groundwater

Several studies have addressed the potential effects of increased groundwater withdrawals in the region encompassing MISS and the lower St. Croix River. Norvitch et al. (1973) analyzed available groundwater information and found that surface water resources of the Twin Cities area were not sufficient to meet all needs during a severe drought. Additionally, aquifers were already experiencing cones of depression during maximum withdrawals in summer months. Ruhl et al. (2002) estimated recharge to unconfined aquifers and leakage to confined aquifers in the Twin Cities Area in order to assist water managers with their concerns about long-term groundwater depletion. Recharge estimates indicated that impervious land areas in the metro areas had little or no recharge potential, whereas surficial sand and gravel areas (e.g., in Washington County near the St. Croix River) had great recharge potential. Metropolitan Council (2004) more recently reviewed groundwater demand and supply for future planning in the Twin Cities area. Their analysis showed that groundwater was the primary source of water for a large component of the metropolitan area's population, but cited limitations to future development of the region's groundwater supply, including lack of access to the Prairie du Chien-Jordan aquifer and the adverse impacts of withdrawals and contamination.

Physical processes

A series of studies related to shoreline erosion, island geomorphology, and recreational use was completed and compiled for the Lower St. Croix River in the late 1990s. Several studies specifically addressed shoreline erosion issues. Ferrin et al. (1998) categorized and mapped shoreline erosion, and found that nearly 25% of shorelines, mostly in the main navigation channel, were in the moderate erosion category. Griffin et al. (2000) quantitatively surveyed shoreline profiles and found that sites with no wave action or trampling showed net sediment deposition over the study period, whereas boat trampling and boat waves increased island erosion. Johnson (1999a, b, c, d) investigated effects of wind- and boat-generated waves on shoreline erosion and deposition. These studies indicated that wind-related erosion was low relative to boat-related erosion and that runabouts and cruisers were associated with higher wave heights and greater erosion. Island geomorphology investigations were conducted by Pitt et al. (1999), who examined aerial photographs (1969 and 1991) and noted that forested islands were becoming smaller and more fragmented below the Arcola Sandbar and larger and more agglomerated above. Recreational use and effects were evaluated in studies of recreational boat use and shoreline vegetation. Johnson (2000) used aerial photography to monitor boat use patterns, and showed that average densities of moving water craft exceeded the 10 acres/craft (0.4 ha/craft) action point set by the Lower St. Croix Management Commission. Konkel's (1999) survey of shoreline vegetation indicated significant trampling and bare soil at sites with substantial recreational use. In general, these studies suggested that heavy recreational use occurring in the Lower Riverway influenced erosion and sedimentation processes as well as island geomorphology.

In a study not related to shoreline erosion, Troelstrup et al. (1993c) investigated large woody debris accumulations in the Lower Riverway, noting recent increases in snag accumulation due to increased urbanization and recreation.

Strengths and needs

Highly constructive relationships with other resource management agencies, the Minnesota District of the U.S. Geological Survey, and universities and colleges in the St. Croix Basin are an important asset for SACN. These relationships continue to support management activities and guide research and monitoring throughout the basin. . St. Croix National Scenic Riverway also benefits from its inclusion in the Upper Mississippi River Basin National Water Quality Assessment unit; research conducted under this program also addresses MISS and is covered in a separate section. Strong points of SACN's research program include the extensive body of work addressing water quality (particularly nutrients and sediments) and freshwater mussels (particularly the federally endangered Higgins' eye and winged mapleleaf mussels). Long-term monitoring and paleolimnological studies have provided important historical perspectives on water quality in the St. Croix Basin. Despite the considerable breadth and depth of existing aquatic research at SACN, certain habitats and issues will continue to require attention. Basic data on backwater habitats are lacking. Additional work on nonpoint source nutrient loading and endangered mussel ecology will be needed. Integrative ecological studies addressing how water quality trends and patterns affect aquatic biota, how mussel and host fish distribution interact, and how changes in river geomorphology and habitat affect aquatic vegetation and wildlife are also needed. Consistency in data collection is lacking in certain subject areas (i.e., water quality, fish) due to the various methods used over time and by different agencies and researchers.

Considerations for monitoring

Directly from the literature

- Newton et al. (2003) noted that episodic ammonia toxicity may occur in St. Croix sediments. Monitoring of water column and sediment pore water ammonia concentrations was recommended.
- Diatom abundance and composition were sensitive indicators of past environmental change in the St. Croix Basin and would make good bioindicators for future monitoring (Edlund and Engstrom 2001, Triplett et al. 2003).
- Continued monitoring of St. Croix mussel communities is needed (Hove and Hornbach 2002), and should follow existing monitoring protocols (Heath and Rasmussen 1990, Doolittle and Heath 1997, Hornbach et al. 1998b, 2000) with attention to longitudinal variation in mussel composition throughout the river (Hornbach 2001).
- Boyle and Strand (2001) noted that benthic invertebrate patterns were strongly affected by seasonal variability, and that multiple samplings per growing season were needed for analysis of species-environment relationships. Future monitoring protocols must account for such seasonal variation.
- Benthic invertebrate community metrics were not sensitive indicators of nutrient and sediment problems in St. Croix tributaries (Lenz et al. 2001), and may not make reliable metrics for biomonitoring. Benthic invertebrate data, analyzed in other ways, may prove more useful.
- The habitat classification findings of Macbeth et al. (1999) should provide a framework for future study design and monitoring activities on the St. Croix.
- Wetland types identified by Glenn-Lewin (1988) and Glenn-Lewin et al. (1991, 1992) should be considered in future wetland monitoring at SACN.

Derived from the literature by the synthesis authors

- Important hydrologic and water quality insights have been gained from previous long-term monitoring at sites in SACN (Meyer et al. 1999, Lenz 2004, Kloiber 2004). Future monitoring activities should seek to support and augment existing datasets and data collection efforts.
- Maintenance of sufficient flows below the St. Croix Falls dam is needed to support the resident winged mapleleaf population. Regular stage readings or flow monitoring should occur at this site, with emphasis on habitat implications of flow fluctuations (e.g., Johnson 1995a, b).
- Changes in temperature and residence time affect responses of Lake St. Croix to increased phosphorus loading (Robertson and Lenz 2002). Additionally, breeding habits of many organisms, including the endangered winged mapleleaf, are influenced by water temperature (Heath et al. 2000), and distribution of aquatic plants is influenced by flow (Glenn-Lewin 1988, Glenn-Lewin et al. 1991, 1992). Water temperature, flow, and residence time will be important monitoring parameters at SACN.
- St. Croix has an excellent fisheries management plan, although the document may need to be reviewed and updated within the next few years. Several fisheries monitoring examples can be found in this plan (Ferrin et al. 1999). Some suggested monitoring has begun. Monitoring that emphasizes species of concern or understudied species should be prioritized.
- The influence of river geomorphology on turtle and benthic invertebrate assemblages was noted in DonnerWright et al. (1999) and Macbeth et al. (1999). Changes in river geomorphology have implications for other organisms' habitat as well. St. Croix geomorphology should be monitored, perhaps via remote sensing.

Considerations for research

Directly from the literature

- Reasons for the decline in the endangered Higgins' eye pearly mussel mussel at upstream sites should be further investigated (Hornbach et al. 1995).
- Hornbach (2001) and Doolittle and Heath (1997) note that more research is needed to understand host fish distribution and its effects on mussel distribution in the St. Croix.
- Doolittle and Heath (1997) noted that further study of mussel fauna on the Namekagon River was needed.
- Habitat conditions, water quality characteristics, and other biota associated with winged mapleleaf mussels have been investigated on several occasions. Additional work is needed to address winged mapleleaf food quality, potential effects of dam operations on the winged mapleleaf, and life history and ecology of those taxa co-occuring with the winged mapleleaf.
- Lee et al. (2000) recommended controlled studies to confirm the effects of hormonally active agents on fish reproduction and population structure.

Derived from the literature by the synthesis authors

- Nitrate concentrations have been increasing at long-term monitoring sites on the lower St. Croix (Kloiber 2004), which has implications for St. Croix biota as well as nitrogen transport to the Mississippi River and contribution to the Gulf of Mexico hypoxia problem. Future research should aim to identify nitrate sources on the St. Croix, perhaps via nitrogen and oxygen stable isotope analysis.
- Several studies suggest that the Sunrise River is a significant nutrient and sediment contributor to the St. Croix River (e.g., Payne et al. 2002). More detailed study of nutrient dynamics in the Sunrise River is needed. Upcoming watershed modeling work on the Sunrise River should fulfill this need (PMIS # 84757).
- Troelstrup et al. (1993a) noted the possibility of hypolimnetic oxygen depletion in Lake St. Croix. Given the importance of benthic resources to SACN and their vulnerability to low oxygen conditions, this possibility should be investigated further. An upcoming study using fossil chironomids from sediment cores will address this problem (PMIS # 103664).

- Point source discharges currently account for a relatively small proportion of the total phosphorus load (Edlund 2004), but this proportion is more bioavailable. Future research should address how increases in point source versus nonpoint source phosphorus may affect algal growth.
- Fossil diatom assemblages indicated shifts in primary production from benthic to pelagic habitats in recent decades (Edlund and Engstrom 2001, Triplett et al. 2003), but it is not known whether or how this has affected benthic fauna. Future research should target food web implications of this shift in primary producers.
- Ferrin et al. (1999) recommended studies of artificial barriers and potential remediation at these areas. The potential for rehabilitation of native fish species assemblages in conjunction with any remediation should be a priority where feasible.
- Although there has been thorough research on mussel glochidia use of fish hosts, what knowledge is there of whether these are mutual or commensal symbiotic relationships? Studies of the potential impacts to fish species when mussels are extirpated from certain areas could be useful.
- Mussels are long-lived, relatively sessile, and can be used as site-specific environmental integrators. In Troelstrup and Foley (1993), mussel shell chemistry proved useful for identifying locations where urban versus agricultural inputs predominated. Because mussels are less mobile than fish, mussel tissues may also prove a useful complement to fish tissues in studies of contaminant distribution riverwide.
- Cumulative effects of backwater areas, wetlands, and reservoirs on mercury methylation and nutrient and sediment loading throughout the St. Croix Basin should be investigated.

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SLEEPING BEAR DUNES NATIONAL LAKESHORE

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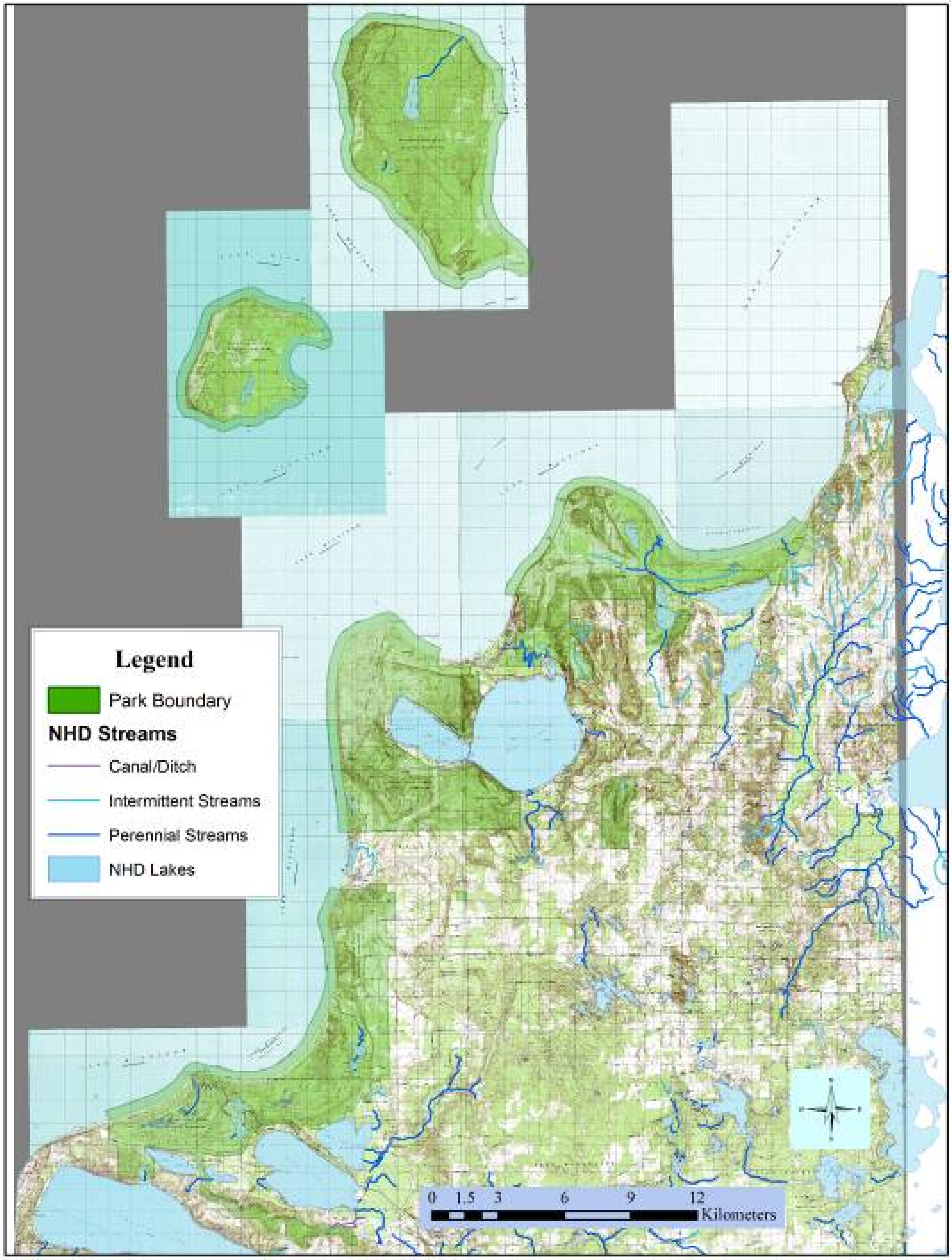
Photographs from top to bottom: Lake Michigan shoreline (P. Murphy), Lake Manitou (P. Murphy), Crystal River (P. Murphy), and Aral Marl Springs (P. Murphy).



Sleeping Bear Dunes National Lakeshore, and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

SLEEPING BEAR DUNES NATIONAL LAKESHORE

Sleeping Bear Dunes National Lakeshore (SLBE) was established in 1970 and preserves over 105 km (65 miles) of Lake Michigan shoreline, including the 120 m (400 feet) tall Sleeping Bear Dunes and the Manitou Islands. In addition to these unique scenic qualities, SLBE also protects a variety of water resources, all of which have been designated outstanding state resource waters (OSRW) by the State of Michigan. . Sleeping Bear Dunes National Lakeshore waters include 18 named inland lakes of varying size and character, four sizable streams (all of Otter Creek and parts of the Platte River, Crystal River, and Shalda Creek), and many bogs, springs, and interdunal wetlands (Table 1, pg. 2). In general, SLBE surface waters are characterized by significant groundwater contributions and feature relatively stable hydrographs.

Summary of existing aquatic research

General resource documents and plans

Two recently developed management plans address water resources at SLBE. The first of these is the Water Resources Management Plan (Vana-Miller 2002), which described existing resource conditions and outlined water resource planning issues. High priority issues identified in the plan included hiring a full-time water resource professional, conducting a wetland inventory, conducting amphibian and reptile inventories and monitoring, developing a water quality monitoring plan, conducting more detailed bacterial investigations, investigating Crystal River flows during drought, and examining recreational stream use. Heiman and Woller (2003) addressed management issues specific to the Glen Lake/Crystal River watershed. This management plan described relevant governmental jurisdictions and existing resource conditions with respect to groundwater recharge, water quality, and biology. Critical areas noted for protection included Hatlems Creek and the Crystal River, both of which support rare plant species. Key stressors in the watershed were identified, and included nutrient enrichment, exotic species, habitat loss, bacterial and thermal pollution, and contaminants.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for SLBE was reviewed for insights on past water quality monitoring in and near the Lakeshore (National Park Service 1997, Table 3, pg. 14). A total of 149 monitoring stations were identified in the data retrieval, representing 51,317 water quality observations and covering 294 water quality parameters. A total of 76 monitoring stations were located within the Lakeshore boundaries, and 27 of these recorded water quality exceedences. Four active or inactive stream gages were encountered within the study area; currently one active U.S. Geological Survey stream gage exists within the Lakeshore on the Crystal River. Water quality exceedences were recorded at least once for eight different parameters in the study area. Four parameters (dissolved oxygen, pH, cadmium, and total coliform) exceeded the screening criteria within the Lakeshore boundary. Dissolved oxygen was frequently below and pH was frequently above the Environmental Protection Agency criteria for protection of aquatic life in SLBE's inland lakes. Total coliform concentrations exceeded the bathing water criterion at sites on the Platte River and Lake Michigan. Cadmium concentrations exceeding the acute freshwater and drinking water criteria were documented on one occasion in the Platte River at the M-22 Bridge. The authors noted effects of human activities on surface waters, including industrial and municipal wastewater effluent, septic leakage, stormwater runoff, and recreational use.

Much of the water quality research at SLBE has been conducted as part of the limnological and ecological studies addressed in following sections. In addition to these, however, are a series of intensive water quality studies in the Platte Lake-Platte River and Glen Lake-Crystal River watersheds. The Platte River watershed studies have been strongly driven by concerns about nutrient inputs from the upstream Platte River fish hatchery and the decay of returning salmon. A history of the issue, from a legal perspective, was provided in Fuss (1998). Related research has included an analysis of existing monitoring data (Walker 1998a), a modeling exercise evaluating the effects of alternative phosphorus loading scenarios (Walker 1998b), and a comparative study examining phosphorus concentrations in surface sediment in Platte Lake and other area lakes (Canale 1998). At the court's order, the hatchery has taken several actions to reduce phosphorus inputs to the watershed, including low-phosphorus fish diets, reduced lake flow volumes, and phosphorus removal processes. Fuss (1998) suggested that the issue would continue to require attention, including oversight of monitoring efforts, critical review of Walker's work, awareness of the Platte Lake Improvement Association's efforts to contest the NPDES (National Pollutant Discharge Elimination Program) permit, and investigation into the increasing phosphorus loads found in the Platte River.

Several Glen Lake-Crystal River watershed studies were conducted in response to concerns about declining water quality in Glen Lake (Environmental Protection Agency 1992). The Michigan Department of Natural Resources, the Glen Lake Association, and the Environmental Protection agency all contributed to the data collection. The final Phase I Report was supported by research projects investigating historical trends in water quality (Fritz and Engstrom 1992), hypolimnetic anoxia and internal phosphorus loading (Nürnberg 1992), and the ability of soils to remove phosphorus from septic systems around Glen Lake (Ellis 1991). In general, these studies indicated that Glen Lake was oligo-mesotrophic and fed primarily by groundwater and precipitation. Phosphorus inputs to the lake were largely accounted for by direct precipitation on the lake surface. Algal communities reflected oligotrophic conditions and algal growth was limited by phosphorus. Concentrations of organic contaminants and mercury in fish were similar to those found in other nearby lakes. Despite the elevated sediment accumulation and diatom production rates in Glen Lake (Fritz and Engstrom 1992), the results of these studies underscored the high quality of Glen Lake water resources, the strength of groundwater contributions to surface waters in the Glen Lake watershed, and the need to manage anthropogenic phosphorus inputs along the lake.

Other water quality studies include two summary reports by SLBE natural resources staff, a study of variation in water quality among inland lakes, and a bacteria study. Murphy (2001, 2002) conducted frequent monitoring of SLBE lakes and rivers and provided detailed data and graphics for each lake, noting that most lakes could be classified as mesotrophic and dimictic. Murphy also noted likely groundwater inputs to several lakes during a wet period, and made recommendations for future monitoring. Last et al. (1995) investigated limnological variation in 12 SLBE lakes over two summers, noting thermal stratification in over half the lakes, hypolimnetic oxygen depletion in Loon and Narada Lakes, and evidence of groundwater inputs in several lakes. In general, SLBE lakes were considered meso-oligotrophic with respect to nutrients and chlorophyll *a*. In a study of nearshore waters at Indiana Dunes National Lakeshore and SLBE, Whitman et al. (2003) explored relationships between *Escherichia coli,* enterococci, and the alga *Cladophora.* The authors showed that both of the bacteria could survive for over six months in sun-dried *Cladophora* mats stored at low temperatures, and suggested that *Cladophora* itself may support the growth of indicator bacteria.

<u>*Biology and ecology*</u>

Several limnological and ecological studies have been conducted on the inland lakes and streams of SLBE. In general, these studies characterize SLBE waters as being relatively nutrient-poor, alkaline, and strongly influenced by groundwater. Many of these studies provided detailed species lists for biological components such as phytoplankton, zooplankton, and benthic invertebrates, but provided little analysis of species composition or relationships with water quality. Other studies have been more explicitly biological, and have focused on benthic invertebrates or made use of zooplankton and benthic invertebrates for biomonitoring or bioassessment purposes. A single study specifically addressed phytoplankton communities for three SLBE lakes.

General limnological work

Curry (1973) conducted a baseline survey of the Crystal River drainage basin. Waters in this drainage basin had high pH and dissolved oxygen as well as elevated bacteria concentrations at some shallow shoreline sites. Species lists for phytoplankton, zooplankton, and benthic fauna were provided. Stockwell and Gannon (1974 and 1975) conducted similar investigations of water quality and biology in the Platte River system and Florence Lake, and likewise provided zooplankton and benthic invertebrate species lists. Nutrient concentrations in the Platte River system suggested that lakes were serving as overall nutrient sinks. In a baseline limnological study of Florence Lake, Gannon and Stockwell (1978) provided morphometric maps and data on water quality, zooplankton, phytoplankton, macroinvertebrates, and fish composition. Unique among SLBE lakes, Florence Lake was noted for its relatively soft water and lower pH, its strong groundwater contributions, and its possible sensitivity to increased nutrient inputs.

Benthic invertebrate studies

Invertebrate studies at SLBE have included intensive work on chironomid communities (Curry 1977), invertebrate habitat analysis (Linton 1987), ecological analysis (White 1987, Boyle and Hoefs 1993, Whitman et al. 1994), and bioassessment (Flower and Walker 1999a, 1999b, Whitman et al. 2002). Curry (1977) investigated chironomid communities throughout the Crystal River basin. Lentic communities were less variable than lotic ones, and the most complex community types were found in impounded stream sites and in aquatic vegetation along lake margins. Linton (1987) identified invertebrate habitat types in SLBE streams; the most common included lotic depositional runs and marshes. White (1987) and Boyle and Hoefs (1993) surveyed invertebrates and water quality in SLBE streams and found that fine particulates dominated organic matter in all streams, and filtering and gathering invertebrates were dominant at stream sites near lake outflows. Whitman et al. (1994) surveyed invertebrates in SLBE streams as well as lakes, finding high variability in macroinvertebrate density and richness measures but generally higher values at upstream sites.

A series of studies made use of benthic invertebrates or zooplankton for bioassessment and monitoring. Flower and Walker (1999a, 1999b) used the State of Michigan's rapid bioassessment procedure to evaluate conditions in the Crystal and Platte River systems. The Platte River had low nutrient and metal concentrations and did not show clear signs of impacts from the upstream fish hatchery. Poor culvert design contributed to sluggish flows, erosion, altered channel morphology, and some biological impairment in both rivers. Heuschele (2000) provided a summary of biomonitoring recommendations based on White (1987), and Boyle and Hoefs (1993) encouraged the development of a long-term monitoring program. Finally, Whitman et al. (2002) investigated the potential use of zooplankton as a bioassessment tool for SLBE inland lakes. While zooplankton proved to be capable indicators of lake trophic status, the costs of zooplankton taxonomic work will likely limit their use in future monitoring.

Plankton studies

In addition to limited plankton data reported from earlier limnological surveys, plankton assemblages have received specific attention on two occasions. Stevenson (1992) collected plankton from sites in Big and Little Glen Lakes. Phytoplankton species composition differed between the two lake basins, but was dominated by low densities of diatoms and chrysophytes. Zooplankton densities were quite low, but increased in response to periods of high phytoplankton densities. More recently, phytoplankton communities in three other SLBE lakes (Round, Loon, and North Bar) were investigated over the course of two summers (Nevers and Whitman 2004). Phytoplankton composition in all three of these lakes was dominated (>90%) by green algae.

Invasive species studies

Two studies in or near SLBE have specifically addressed the effects of recent zebra mussel (*Dreissena polymorpha*) invasions. Lowe and Carter (2004) investigated how zebra mussels affected nearshore Lake Michigan habitats, noting that zebra mussel filtration increased light penetration and increased the flow of organic matter and energy to the benthic zone. This in turn enhanced the growth of the filamentous alga *Cladophora,* which expanded the benthic surface area available for periphyton growth and led to increased densities of amphipods, isopods, decopods, snails, and chironomids. The authors suggested that this shift toward the benthos could have profound effects on higher trophic levels. Wearly et al. (2004) explored the effects of zebra mussel invasions on algal communities in Leelanau Lake near SLBE. They found differences in phytoplankton community composition along a gradient of zebra mussel density, with higher proportions of cyanobacteria found in areas of high zebra mussel density.

Fish

As at PIRO, the State of Michigan has performed assessment and surveys in some of the lakes and streams of SLBE for many years. Exotic species, both intentionally and accidentally introduced, and their effects on native species create ample opportunities for research projects at SLBE. The Platte River, which flows through the Lakeshore, was the site of the first intentional Pacific salmon introductions in United States waters of the Great Lakes. This river continues to be a site of research in the area of fisheries and water quality. Studies by outside agencies, academia, and internal Lakeshore reports have included species composition surveys, natural history surveys, and water quality and aquatic ecology reports that include fisheries information. A Water Resources Management Plan completed in 2002 includes species lists for many of the waters in the Lakeshore and information on past fisheries investigations (Vana-Miller 2002). With assistance from the Grand Traverse Band of Ottawa and Chippewa Indians, SLBE is completing a comprehensive fisheries survey of its inland waters in 2003 and 2004.

Inland waterbody or riverine fish surveys and investigations

Kelly and Price (1979) conducted the first comprehensive fisheries surveys of the inland waters of SLBE. They examined the four major watersheds within Lakeshore boundaries as well as the nearshore waters of Lake Michigan. They documented 76 species within the Lakeshore, with ten exotic species present. Of the ten exotic species, eight were intentionally introduced. Alewife (*Alosa pseudoharengus*) and sea lamprey (*Petromyzon marinus*) were two unintentional introductions. The lakes of the Manitou Islands have also been studied for limnological characteristics and fish populations (Gannon and Stockwell 1978, Michigan Department of Natural Resources 1987) but limited fisheries information is presented in those additional reports, and non-game fish are not well represented in these surveys. Information obtained from surveys and angler reports has resulted in special regulations that restrict harvest of bass to one fish over 46 cm (18 inches) in lakes of the Manitou Islands. An update of the effects of this regulation would be useful. Other historic information usually covers specific bodies of water or gives generalized information within a much broader report (Scott 1920, Michigan Department of Natural Resources 1987, 1990).

The Platte River has received the most attention of any single body of water in the Lakeshore with regard to fisheries investigations. Taube (1974) provided a historical account of the limnological characteristics of the Platte River, along with past sport fishing information. The report focused on the salmonid fisheries, however, so information about many native species and non-game fish is lacking. Taube documented 20 species in the mainstem Platte River during his investigations but the most abundant species were all non-native salmonids: coho salmon (*Oncorhynchus kisutch*), steelhead (*Onchorhynchus mykiss*), and brown trout (*Salmo trutta*). A biological survey of the Platte River system in 1998 (Michigan Department of Environmental Quality 1999) referenced only four coldwater species of fish; three of these were the non-native salmonids mentioned above. A much more thorough accounting of species present in the Platte River and the rest of the basin (including lakes and tributaries) was presented by Kelly and Price (1979); 53 species were documented in the basin during their investigations.

Lake Michigan fish surveys

Information about fisheries of Lake Michigan waters within the Lakeshore boundary is sparse. Kelly and Price (1979) reported on nearshore species. They referred to other reports and stated that 34 species have been documented in nearshore waters around SLBE; however, they captured only seven species during their seining efforts at five locations. Organ et al. (1979) reported on past and presently known spawning areas of Michigan coastal waters of the Great Lakes. Only the cover page for this document was found during our review of Lakeshore files, but based on the report's title, it may contain useful information on species found in nearshore waters around SLBE and the entire report should be sought.

Aquatic wildlife

Research on aquatic-based wildlife at SLBE has included a single study on the Manitou gull colonies (Patton 1978). Ring-billed gull (*Larus delawarensis*) and herring gull (*Larus argentatus*) nests were identified, counted, and monitored daily for disturbances from humans, red fox (*Vulpes vulpes*), and avian predators. Mortality was related to predation, gunshots, fishing lures, and unknown causes. The author recommended continued monitoring of the gull colony, accompanied by fox radio telemetry, to determine effects of fox on gull reproduction.

Amphibians and reptiles

Information on SLBE amphibians and reptiles is limited to a survey of herpetofauna on the Manitou Islands and incidental information included in a list of SLBE terrestrial vertebrates. Linton and Kats (1987) surveyed herpetofauna on the islands by direct observation and hand capture. Similar numbers of species were found on each island. McCann (1975) provided an annotated list of 17 amphibians and 16 reptiles likely to be present at SLBE. Although past amphibian studies at SLBE have been limited, the Great Lakes Network office has recently contracted with herpetology experts from the Milwaukee Public Museum to conduct a Lakeshore-wide amphibian inventory.

Wetlands and aquatic vegetation

Two studies have addressed the aquatic vegetation of SLBE lakes, streams, and wetlands (Hazlett 1989, Albert 1992); one study has addressed vegetation in two un-named bogs (Wilcox 1982), and one study has addressed purple loosestrife (*Lythrum salicaria*) population constraints (Edwards 1995). Both Hazlett (1989) and Albert (1992) investigated aquatic vegetation in multiple habitats, described plant species composition and community types, and provided recommendations for further research. They noted that bog and sedge (*Carex* sp.) mats were sensitive to degradation due to visitor impacts and that dune swale wetland hydrology was linked to substrate and drainage characteristics rather than Lake Michigan water levels. Albert (1992) noted a gradient in vegetation from Lake Michigan inland, with wet meadows and emergent macrophytes near the shoreline and shrub or swamp vegetation common farther inland. Wilcox (1982) investigated chemistry and vegetation composition in two bogs. The two bogs were both fed by precipitation rather than groundwater but differed in terms of vegetative structure and diversity. Edwards (1995) investigated factors constraining purple loosestrife at both Indiana Dunes National Lakeshore (INDU) and SLBE, concluding that site-specific conditions influenced which factors were most important and that restoration of native vegetation may be the most effective control mechanism.

Contaminants

Aside from the State of Michigan monitoring of metal and polychlorinated biphenyl (PCB) concentrations in fish tissues, contaminant issues have received little attention at SLBE, despite the location of an Integrated Atmospheric Deposition Network (IADN) master site at the Lakeshore. Cline and Chambers (1977) investigated the distribution of heavy metals in lake sediments near Sleeping Bear Point in Lake Michigan. They found strong relationships between sediment grain size and heavy metal concentrations, and suggested that accumulation of heavy metals in upper strata may be more the result of natural geochemical and physical factors than cultural loading. Hoefs (1993) conducted an ecological assessment using benthic invertebrates at several sites above, at, and below the site of a spill on the M-22 Bridge. Spatial and temporal variability were high, but some differences in the densities of oligochaetes, mollusks, and Ephemeroptera-Plecoptera-Trichoptera taxa were detected immediately adjacent to the spill site. The study results underscored the need for adequate pre-spill baseline data in assessing ecological damage following spills.

Hydrology

Albright et al. (2002) assembled existing hydrologic information from the Glen Lake-Crystal River watershed, and used a computer model to understand relationships between river depth and flow. They concluded that flows of 30 cubic feet per second were required for navigation, and that small changes in discharge to the Crystal River would have negligible effects on lake levels in Glen Lake.

Groundwater

Despite many references to groundwater inputs to streams and lakes, few studies have specifically addressed groundwater resources at SLBE. The exception is found in Handy and Stark (1984), who offered a preliminary examination of groundwater in SLBE wells and springs. In addition to basic geologic information, their report provided data indicating that water quantity was sufficient for current needs and uses. No pesticides were found, and trace metal concentrations were low.

Physical processes

Environmental Resources Management (1985) conducted a study related to dredging operations on the lower Platte River. Physical processes occurring at the river mouth were described in detail, in addition to effects of dredging activities on turbidity, macroinvertebrates, and sand spit morphology. Recreational effects on Platte River shorelines and substrates were also evaluated. The authors encouraged future monitoring of shoreline processes and recreational impacts. Kemezis (1983) conducted a visitor use survey, noting that motorboats conflicted with other recreational uses by creating large wakes. Such boat activity likely continues to affect shoreline resources.

Strengths and needs

Water quality and ecology of SLBE's inland lakes and streams have been regularly investigated and monitored, providing a good working knowledge of these ecosystems and their basic components. Water quality conditions, particularly with respect to nutrients, have been well studied in two lakes in or near the Lakeshore (Platte Lake and Glen Lake). Seasonal variation in the water quality of SLBE's waters, however, has received comparatively little attention. A series of aquatic studies addressing benthic invertebrates has helped document their distribution in lakes and streams and their potential use in bioassessment and monitoring activities. Distribution and ecology of amphibians, reptiles and other aquatic wildlife at SLBE are less well understood. Additionally, the influence of groundwater-surface water interactions is frequently noted, but there have been few attempts to study this phenomenon or its effects on stream hydrographs, lake levels, or water chemistry. In order to respond to increasing population and groundwater demands in the vicinity, more information on SLBE groundwater resources is needed. No Fish Management Plan currently exists for SLBE, which creates a large gap in important fisheries information. Past fisheries management concerns, current management practices within SLBE boundaries and differences between National Park Service and Michigan Department of Natural Resources management policies may make a coordinated Fish Management Plan difficult to complete, but the possibility of a cooperative effort between National Park Service, Michigan Department of Natural Resources, and potentially other interested organizations should nevertheless be explored. Finally, SLBE inland waters have undergone recent invasions by zebra mussels and rusty crayfish, and efforts to investigate and mitigate the ecological effects of these invasions are needed. The recent Water Resources Management Plan (Vana-Miller 2002) suggested additional areas for future work.

Considerations for monitoring

Directly from the literature

- Boyle and Hoefs (1993) included several monitoring insights. They suggest that Secchi depth was generally a good indicator of algal growth and productivity, that benthic invertebrate assemblages below lake outfalls may make good indicators of changes in lake productivity, and that qualitative sampling provided a more complete inventory of stream invertebrate communities than quantitative methods.
- Whitman et al. (2002) noted characteristically high temporal variation in zooplankton composition and density, and recommended a biweekly sampling regime for future studies or monitoring.
- Patton (1978) recommended continued monitoring of ring-billed gull colonies.
- Hazlett (1989) recommended monitoring the state threatened water parsnip (*Berula erecta*), monitoring and preventing purple loosestrife spread, and using aquatic vegetation composition as an indicator of water quality in lakes.

Derived from the literature by the synthesis authors

- Previous studies and monitoring activities have noted that Florence Lake was different from other SLBE lakes in terms of drainage characteristics and water quality. This lake should not be considered representative of SLBE waters in future monitoring designs, but should be monitored individually as a locally unique aquatic ecosystem.
- SLBE is rapidly undergoing aquatic species invasions, with zebra mussels, rusty crayfish and several invasive plants already found in Lakeshore waters. High levels of visitor use and close proximity to Lake Michigan make continued monitoring for invasive species a significant priority. Future monitoring activities should focus on the spatial extent of shoreline biofouling by zebra mussel-*Cladophora* complexes, and effects of zebra mussels on inland lake biota and ecology.
- Past studies using benthic macroinvertebrates as bioassessment tools or ecological indicators (White 1987, Boyle and Hoefs 1993, Hoefs 1993, Flower and Walker 1999a, 1999b, Heuschele 2000) should help guide biomonitoring protocol development for the Lakeshore.
- Curry (1977) provided a solid baseline for chironomids of the Crystal River drainage basin. This baseline could be useful in future biological monitoring or paleolimnological reconstructions using chironomids.
- Comprehensive fisheries surveys that include all watersheds in the Lakeshore (similar to Kelly and Price, 1979) should be conducted on a regular basis.

Considerations for research

Directly from the literature

- Linton and Kats (1987) recommended additional investigations of amphibians and reptiles.
- Albright et al. (2002) noted a need for more consistent discharge measurements and field quantification of instream flow needs for recreational and biological uses on the Crystal River. A funded project (PMIS #74101) and coordinated monitoring efforts will help address these needs.

Derived from the literature by the synthesis authors

- Research to determine effects of zebra mussels, rusty crayfish, and exotic plants on Lake Michigan nearshore waters and invaded inland lakes at SLBE is critically needed. This will help predict the response of uninvaded lakes to future invasions and may help mobilize public support for invasion prevention and management strategies.
- The unique Aral Springs area of the Lakeshore should be investigated to determine biotic composition. Some species of fish use the network of connected surface and subsurface waters. A determination of fish and other aquatic species that use this area and how they access the springs would be helpful in understanding how much and what type of protection this unique area should have.
- Several studies noted the importance of groundwater-surface water interactions in SLBE waters. Future research should investigate the effects of groundwater inputs on stream hydrographs, lake levels, and water chemistry.

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VOYAGEURS NATIONAL PARK

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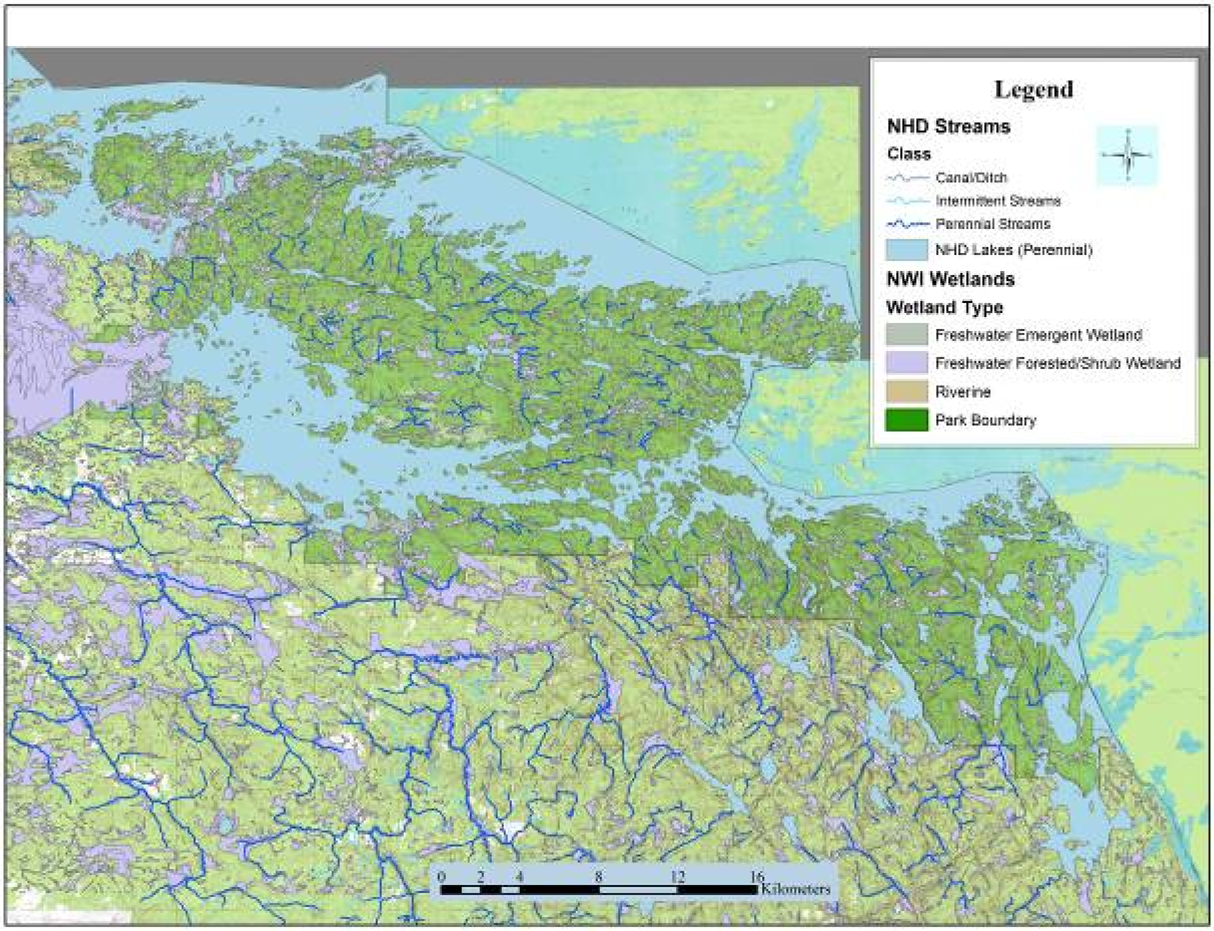
Photo credits from top to bottom: Voyageurs National Park from air (Voyageurs National Park photograph files), Jorgens Lake (Voyageurs National Park photograph files), Anderson Bay (L. Grim), and beaver pond (D. Szymanski).



Voyageurs National Park, and surrounding area, showing streams and waterbodies derived from the National Hydrography Dataset (NHD), and wetlands derived from the National Wetland Inventory (NWI). See the map of the Great Lakes Network parks, page 4, for the regional context of the park.

VOYAGEURS NATIONAL PARK

Voyageurs National Park (VOYA) protects over 88,000 ha (217,000 acres) of the watery U.S.-Canada borderlands in northern Minnesota (Table 1, pg. 2). The Park is situated along the southern reaches of the Canadian Shield and is characterized by Precambrian granite bedrock geology and expansive boreal forests. . Voyageurs National Park is the only Great Lakes Network park within the Hudson Bay drainage basin. Water is central to the Park's history and its present day ecology, and aquatic habitats cover nearly half of the Park's area. These aquatic habitats include four large lakes (Rainy, Namakan, Kabetogama, and Sand Point), 29 named interior lakes, and countless wetlands and beaver ponds (Table 1, pg. 2). Relative to its lentic water resources, VOYA features relatively few kilometers of perennial and intermittent streams. It does, however, contain a greater area of wetlands and inland lakes than any other Great Lakes Network park, including some 275 un-named lakes (Table 1, pg. 2). Lake levels in the Park's large lakes have been regulated by a hydroelectric dam on Rainy Lake and regulatory dams on Namakan Lake since the early 1900s. Because these waters are shared by the United States and Canada, the International Joint Commission oversees water level management in the area. Reservoir operations were modified in 2000 to more closely approximate natural water level fluctuations in the large lakes at VOYA.

Summary of existing aquatic research

General resource documents and plans

Several documents provide useful background information and descriptions of VOYA water resources and issues. The Bureau of Sport Fisheries and Wildlife (1969) provided general information on fisheries and aquatic-based wildlife at Voyageurs, and assessed the potential benefits the National Park designation would provide for those resources. They concluded that the formation of VOYA would benefit otter, muskrat, and moose populations; provide a sanctuary for eagle and osprey; improve waterfowl breeding populations; and help sustain a good fishery. Weeks and Andrascik (1998) assembled a water resources scoping report addressing existing water resource conditions, relevant legislation, and water resource issues. Key issues included aquatic ecological responses to regulated lake levels, mercury in fish and sediments, invasive species, and wastewater and hydrocarbon pollution from boats. A Water Resources Management Plan for VOYA is also nearing completion.

By far the most complete and current synthesis of aquatic research available to any of the Great Lakes Network parks was provided by Kallemeyn et al. (2003). The synthesis describes the state of the knowledge on climatic, geologic, hydrologic, physical, chemical, and biological attributes of VOYA aquatic ecosystems, with references to previous research and recommendations for future research and monitoring. This document is an excellent resource and its recommendations are supported by decades of research and professional experience at VOYA. It should be consulted in place of this network-wide synthesis for Park-specific applications.

Water quality

The Baseline Water Quality Data Inventory and Analysis report for VOYA was reviewed for insights on past water quality monitoring in and near the Park (National Park Service 1995, Table 3, pg. 14). Some 98 monitoring stations were identified in the data retrieval, representing 17,395 water quality observations and covering 316 water quality parameters. Many of these monitoring stations (n=72) were located within the Park, and nearly half of these (n=33) recorded water quality exceedences. Sites with the longest water quality records occurred on the large lakes (mainly Rainy and Kabetogama). Currently one active U.S. Geological Survey stream gage exists within the Park, at the Gold Portage outlet of Lake Kabetogama. Water quality exceedences were recorded at least once for nine parameters within the study area, and eight parameters within the Park. Dissolved oxygen, pH, alkalinity, copper, lead, and zinc exceeded their respective Environmental Protection Agency acute or chronic criteria for the protection of aquatic life, and cadmium, nickel, and lead exceeded drinking water criteria. Exceedences for pH were due to low pH values (<6.5) at most sites, but sites on Lake Kabetogama registered exceedences for pH values >9. Alkalinity exceedences were due to low alkalinity levels in some interior lakes (Jorgens, Wier, Cruiser, Shoepack, McDivitt, Loiten, and Locator). The authors concluded that surface waters at VOYA were of generally good quality, with some impacts from anthropogenic stressors, such as atmospheric deposition.

Several intensive water quality investigations have been undertaken at VOYA over the past three decades (Payne 1979, 1991, 2000, Kepner and Stottlemyer 1988, Christensen et al. 2004). Payne (1979) included 11 near-shore and mid-bay sites on the large lakes, and Payne (2000) re-sampled a subset of seven of these. Payne (1991) sampled VOYA's waters more comprehensively, with 41 sites on the large lakes as well as 19 interior lakes and two rivers. A suite of water quality parameters was measured, including major ions and nutrients (all studies), phytoplankton composition and abundance (Payne 1979, 1991), phytoplankton chlorophyll *a* (Kepner and Stottlemyer 1988, Christensen et al. 2004), bacteria concentrations (Payne 2000), and bottom sediment carbon and nitrogen concentrations (Payne 1979). In general, the large lakes were low in conductivity, with moderate alkalinity and variable nutrient concentrations. Sites with calcareous drift rather than Precambrian bedrock watersheds had higher nutrient concentrations and exhibited blue-green algal blooms. There were few significant changes in water quality variables over time (Payne 2000, Christensen et al. 2004), but nitrate, phosphorus, and chlorophyll *a* concentrations appeared to have declined somewhat since the earlier samplings (Payne 2000), and chlorophyll-based trophic state indices had shifted from eutrophic to mesotrophic in Kabetogama Lake and Black Bay of Rainy Lake following the change in lake level regulation in 2000.

The Minnesota Department of Natural Resources has conducted standardized lake surveys routinely for VOYA's 26 interior lakes. Measured water quality parameters generally have included temperature, dissolved oxygen, transparency, and major ions. Complete surveys of all the interior lakes were first conducted in the 1970s, with 14 of the lakes surveyed for a second time in 1983, two more sampled for a second time in 1996 and 1999, and nine lakes surveyed for a third time between 1995 and 2003. In a separate study, Payne (1991) found that most interior lakes were thermally stratified and had low nutrients, alkalinity, and conductivity. Water quality in the Ash River had higher nutrient and sediment concentrations than the Namakan River (Payne 1991). Several interior lakes (Cruiser, Locator, Loiten, and Shoepack) were also the subject of long-term acid deposition and water chemistry research, discussed later (Webster et al. 1993, Webster and Brezonik 1995).

<u>*Biology and ecology*</u>

Ecological studies at VOYA have focused heavily on the issue of lake level fluctuations on the large lakes. Some of these studies are addressed in this section; others are treated separately under fisheries, aquatic wildlife, or aquatic vegetation. Ecological effects of lake level fluctuations at VOYA were first reported in Sharp (1941), who estimated the area of lake bottom exposed during winter drawdowns, provided striking photographs of the drawdown conditions, and noted negative effects on fish, waterfowl, aquatic plants, muskrat (*Ondatra zibethicus*), and benthic fauna. He noted that pickerel (referring to northern pike, *Esox lucius*), tullibee (previously *Leucicthys tullibee*, currently *Coregonus artedi*), and whitefish (*Coregonus clupeaformis*) spawning was reduced, minnows and benthic fauna became stranded or frozen, and waterfowl and muskrat habitat was altered.

A suite of studies was conducted in the 1980s in response to this issue. Kraft (1988) examined effects of altered lake levels on benthic macroinvertebrates in Namakan Reservoir and Rainy Lake. Invertebrates were found dead or stranded during drawdown periods, and species composition and density varied with depth in the more widely fluctuating Namakan Lake. Invertebrate densities in Namakan Lake were negatively correlated with the magnitude of fluctuations. Kallemeyn (1990a, 1992) and Kallemeyn et al. (1993) reviewed the findings of several lake level research studies undertaken in the 1980s, including studies of water quality, aquatic macrophytes, benthic invertebrates, fish, and aquatic birds and mammals. Kallemeyn et al. (1993) also presented an alternative rule curve, or hydrologic regime, for the large lake system, and concluded that under the proposed rule curve, affected aquatic biota would recover and phosphorus concentrations would likely decline.

In addition to lake level related research, some attention has also been given to plankton assemblages and zebra mussel (*Dreissena polymorpha*) monitoring. Hargis (1981) collected samples for water quality, chlorophyll *a,* and zooplankton on 20 interior lakes and 13 stations on the large lakes. His report included a taxa list, a photographic identification file, and an analysis of how zooplankton assemblages related to water quality across lakes. Hargis noted that few unusual species were encountered and that water clarity was negatively linked to chlorophyll *a* and zooplankton production across lakes. Hargis (1981) also offered recommendations for future zooplankton monitoring. Mayasich (1981) conducted field bioassays to evaluate the response of phytoplankton communities to acidification. Acidification to pH 3.8 and 5.0 resulted in altered phytoplankton composition and declines in diatom abundance; however, the high level of acid stress and the short duration of the experiments make results difficult to interpret. Finally, phytoplankton communities in two VOYA lakes (Locator and Mukooda) were recently monitored over the course of two summers (Nevers and Whitman 2004). Phytoplankton composition in these lakes was a mix of green algae, diatoms, and chrysophytes, and was similar to that of Siskiwit and Sarget Lakes at Isle Royale National Park (ISRO).

Hoven (1998) described zebra mussel monitoring activities at VOYA, which included placing substrate samplers and conducting plankton tows near visitor centers. Plankton tows were inspected for zebra mussel veligers. There was no evidence of zebra mussel presence at these sites, but continued monitoring for these and other aquatic nuisance species was recommended.

Fish

There have been investigations ranging from life history characteristics of individual species to species interrelationships within various aquatic types within the Park. Much of the fisheries investigation work has been performed by Minnesota Department of Natural Resources, along with personnel from the National Park Service and U.S. Geological Survey. A U.S. Geological Survey fishery biologist stationed at this park has provided numerous reports covering subjects within and outside of the Park ranging from species specific investigations to broad studies of aquatic ecology.

In the large lakes at VOYA, the Minnesota Department of Natural Resources, and VOYA and U.S. Geological Survey personnel conduct fisheries assessment activities on the Minnesota portions of the lakes. The Minnesota Department of Natural Resources Large Lake Assessment Program, which was designed to standardize sampling on Minnesota's largest, most conspicuous walleye (*Sander vitreus*) lakes, is used on Rainy and Kabetogama lakes, with some aspects of the program also being used on Namakan and Sand Point Lakes. Sampling has been conducted annually since 1983 using standardized equipment and procedures. Experimental gill netting is done at fixed stations at the same time each year. Other sampling equipment used includes small-mesh gill nets, seines, trap nets, and an electrofishing boat.

Minnesota Department of Natural Resources has also surveyed fish in a variety of interior lakes on several occasions since the 1970s. Complete surveys of all 26 of the interior lakes were first conducted in the 1970s. In 1983, 14 of the lakes were resurveyed, with two more sampled for the second time in 1996 and 1999. Nine lakes were subsequently surveyed for a third time between 1995 and 2003. Fish were generally sampled using experimental gill nets, trap nets, and seines. Additionally, fish population assessments have been done more frequently on the some of the more popular interior fishing lakes.

Investigations have primarily focused on popular game species according to Kalleymeyn et al. (2003), and the majority of the investigations have occurred in three large lakes of the Park (Rainy, Namakan, and Kabetogama). The emphasis on game species is not surprising, as Voyageurs undoubtedly has the highest level of angler use of fisheries resources of any of the Great Lakes Network parks. Anglers expend nearly 760,000 hours of effort annually during the summer on the large lakes of the Park. Angler effort through creel surveys is, therefore, well documented and related reports provide useful information for making management decisions regarding fisheries regulations (Kallemeyn 1985, 1987, 1990b).

In addition to creel surveys, there have also been assessments and syntheses of past data to determine species assemblages and general population statistics for both adult and juvenile fish in Park waters. These investigations provided information on year class strength, potential recruitment, and relative health of populations that is useful for managers of the fisheries resources in the Park (Cohen et al. 1993, Kallemeyn 1985).

Studies by Kallemeyn (1989, 1990c) on walleye in Kabetogama Lake also help determine the status and behavior of this popular game species so that appropriate harvest levels can be established. Duffy et al. (1994) considered the potential impacts of introduced rainbow smelt (*Osmerus mordax*) and made several recommendations for monitoring this species to understand how it may affect other species. Sorensen et al. (2001) followed up on at least one of the recommendations from Duffy et al. (1994) and investigated effects of smelt on nutrient and trophic pathways and mercury bioaccumulation in Rainy and Namakan Lakes. They determined that smelt comprised a relatively small component of the diets of walleye and northern pike based on carbon and nitrogen isotope investigations. The Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources have monitored the large lakes of the Park for many years. Investigations have included species-specific work such as McLeod's (1999) assessment of lake sturgeon, general fish population assessments (McLeod 2002), and broad scale cooperative ventures such as the Minnesota-Ontario boundary waters fisheries atlas (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources 1998).

There are 26 other "interior" lakes in the Park, but much less effort has been expended in those areas, due to the popularity of the larger lakes with anglers and other Park users. The work that has been done in the interior lakes, however, gives some insight into the diversity of the area and the potential for important research in the various waters of the Park. Radomski (1990) found that largemouth bass (*Micropterus salmoides*) populations in Loiten Lake could be over-exploited by anglers due to increased vulnerability during spawning periods. Soupir (1998) and Soupir et al. (2000) examined potential implications of interactions between exotic largemouth bass and native northern pike by studying allopatric and sympatric populations in several inland lakes. They determined that there was some diet overlap between the species, but bass had little trophic restructuring effect on pike in sympatric populations. Stomach samples indicated that largemouth bass probably did not prey on northern pike. Northern pike did prey on bass, though, and the authors suggested that this predation, combined with competition for food at times when resources are limited, may place largemouth bass at an ecological disadvantage. Kallemeyn and Warner (1995) investigated the potential for restoring northern pike in Beast Lake, a lake that had been managed for non-native species since the 1960s. They determined that restoration was feasible and might be achieved through various reintroduction strategies.

The effect of lake level fluctuations on the biotic communities in the reservoirs of the Park has received considerable attention. Rule curves that prescribe how lake levels are regulated were first established by the International Joint Commission in 1949 and modified in 1957, again in 1970, and most recently in 2000 (Kalleymeyn et al. 2003). Kallemeyn (1983) began researching the effects of fluctuating lake levels in the Park and describing possible alternatives to flow regimes through the reservoirs. Kallemeyn (1985) summarized several previous studies investigating effects of lake level fluctuation on various biota in the Park. He also evaluated specific impacts to northern pike and found reservoir fluctuations affected reproduction by altering the timing of natural flooding of vegetation in northern pike spawning areas (Kallemeyn 1987). Cole (1986) and Kallemeyn and Cole (1988) recommended alternatives to restore more natural conditions on Namakan Reservoir in order to reduce biological impacts from reservoir fluctuation. Cohen and Radomski (1993) evaluated commercial fisheries catch data, water level fluctuations in the reservoirs since 1911, and water levels in an unregulated lake. They identified a clear link between changes in the yearly range of reservoir levels and changes in commercial fish catches.

Effects of water level regimes on beaver pond fish assemblages were investigated by Schlosser and Kallemeyn (2000). They suggested that changes in hydrology were mediated by beaver activity rather than by hydrodam management. Kallemeyn and Schlosser found that fish abundance and species richness varied according to beaver pond succession within drainages. Abundance was highest in upland ponds and species richness highest in collapsed ponds and streams. They noted that assuring diverse and productive fish assemblages requires preservation of many successional habitat stages related to beaver activity.

Aquatic wildlife

Park staff have conducted observations of aquatic-based bird populations at VOYA for many years, but no formal reports have been written. Research on aquatic wildlife at VOYA, however, has considerable breadth and falls into three general categories. The first of these addresses effects of lake level fluctuations on aquatic birds, beaver (*Castor canadensis*), muskrat, and river otter (*Lutra canadensis*). The studies of Reiser (1988) evaluated effects of lake level fluctuations on the reproductive success, distribution, and abundance of common loons (*Gavia immer*) and red-necked grebes (*Podiceps grisegena*) on the four large lakes. On Namakan Reservoir, which experienced the largest fluctuations, loon and grebe reproductive success was affected by nest flooding during rising water levels. Route and Peterson (1988) suggested that shifts in otter home ranges occurred due to reduced habitat during winter drawdowns, and that shifts in otter diets occurred due to summer drawdowns that exposed sediments and made crayfish more available. Smith and Peterson (1988) examined effects of lake level fluctuations on beaver, noting drying and freezing of lodges and food caches, as well as changes in beaver foraging behavior. Drawdowns also appeared to reduce family size and kit production. Thurber and Peterson (1988) reported similar results from their study of muskrat, noting higher muskrat densities in areas experiencing minimal winter drawdowns, and reduced overwinter survival during winter drawdowns and habitat freezing. All three of these studies concluded that a more natural hydrologic regime would benefit aquatic wildlife on VOYA's large lakes.

The second group of aquatic wildlife studies at VOYA addressed beaver populations and related landscape changes. Basic population biology and breeding in beaver was investigated on two occasions. Smith (1994) implanted transmitters in 34 beaver and surveyed habitat in active beaver colonies and inactive ponds. Only a subset of the collared beaver dispersed. Smith and Jenkins (1994) conducted intensive beaver population studies at VOYA and Aposle Islands National Lakeshore (APIS), noting differences in age structure and number of kits per family between the parks. They also noted relationships between resource availability and recruitment and sex ratios.

Additional beaver studies addressed landscape-level effects of beaver at VOYA. Naiman et al. (1988) published a review paper on alteration of North American streams by beaver, including a history of beaver in North America and their effects on stream channels, riparian zones, and landscape attributes. Naiman's review paper also provided a conceptual model of how beaver affect landscape on VOYA's Kabetogama Peninsula. Johnston and Naiman (1990a, b) used aerial photographs and a geographic information system to evaluate beaver-related changes in the VOYA landscape from 1940-1986. They found increased beaver population density and an increase in total impounded area, much of which occurred before 1970. Simultaneous analysis of sediment cores from nine beaver-impounded areas indicated that nitrogen concentrations had also increased from 1940-1986. The authors predicted that beaver populations peaked in 1981 and that establishment of new ponds would begin to decline, restricting beaver to already disturbed areas.

Amphibians and reptiles

Aside from ongoing amphibian work at VOYA through the U.S. Geological Survey's Amphibian Research and Monitoring Initiative (http://armi.usgs.gov/2002_report_NC.asp), we found only one study of VOYA herpetofauna. Palmer (1989) collected reptiles and amphibians using pitfall traps, dip nets, and opportunistic trap net and seine searches. Ten species were positively identified, eight species were likely present, and five additional species were possibly present but rare. Additional amphibian work on interior aquatic habitats is needed.

Wetlands and aquatic vegetation

In addition to studies addressing lake level fluctuations, invasive species, and the basic biology of northern wetlands, the U.S. Geological Survey has recently completed a sophisticated vegetation mapping effort in the Park (Hop et al. 2001), including extensive field work, review of aerial and ground photographs, and detailed vegetation classification. Many aquatic or wetland vegetation classes were identified and outstanding mapping products were generated. Additionally, the Minnesota Department of Natural Resources has surveyed aquatic vegetation in many interior lakes since the 1970s. Complete surveys of all 26 of the interior lakes were first conducted in the 1970s. In 1983, 14 of the lakes were resurveyed, with two more sampled for the second time in 1996 and 1999. Nine lakes were subsequently surveyed for a third time between 1995 and 2003.

Many aquatic vegetation studies at VOYA have focused on the issue of lake level fluctuation. Monson (1986) analyzed effects of water level fluctuation on littoral zone macrophytes in the large lakes. Biomass of floating leaf macrophytes was lower in some areas experiencing water level fluctuations, and wild rice populations were likely affected. Wilcox and Meeker (1991, 1992) provided more convincing evidence of lake level effects by examining aquatic vegetation in lakes with varying water level fluctuations. Lac La Croix, not in the Park, is not regulated by a dam and was used as a control. Plant communities in Lac La Croix were structurally diverse at all depths and showed greater species diversity and complexity than communities at Rainy Lake or Namakan Reservoir. Namakan Reservoir, which experienced the most dramatic fluctuations, was dominated by rosette and mat-forming species which provided poorer quality habitat for invertebrates and fish (Wilcox and Meeker 1992).

Two documents have reported on purple loosestrife (*Lythrum salicaria*) control and management at VOYA. Benedict and Grim (1989) described management alternatives and environmental consequences, and acknowledged a need for increased purple loosestrife monitoring and research. Grim and Leland (1998) reported on management techniques employed from 1992-1997 and expressed an interest in alternative management methods such as biological control.

Several studies addressed northern wetlands at VOYA. Pastor et al. (1996) examined grass and sedge communities in four beaver meadows and determined species-area relationships for both vegetation types. Updegraff et al. (1995) and Bridgham et al. (1995) investigated wetland biogeochemistry. Updegraff et al. (1995) collected cores from an abandoned beaver pond and a *Sphagnum* bog and measured carbon and nitrogen mineralization and carbon partitioning into carbon dioxide and methane. Carbon and nitrogen mineralization rates were highly variable, and were affected strongly by wetland type and substrate quality. Bridgham et al. (1995) drew upon previous work on landscape changes, and determined how these changes affected methane production over time. Increased coverage by pond and marsh wetland types between 1940 and 1986 corresponded with an estimated 3.7-fold increase in methane production; the authors concluded that landscape changes could significantly affect wetland biogeochemistry.

<u>Contaminants</u>

Atmospheric contaminants and their effects on water quality and biota at VOYA have received considerable attention over the past three decades, with the focus on acid and mercury deposition. Swackhamer and Hornbuckle (2004) provided the most recent and thorough review of atmospheric contaminant issues for both ISRO and VOYA. They provided detailed recommendations for improved monitoring and research on atmospheric contaminants at these parks, emphasizing the need for a trends monitoring program for biota, research addressing mercury cycling through ecosystems, research addressing the ecological risks associated with bioaccumulated toxins, and efforts to understand emissions and bioaccumulation of organic contaminants from snowmobiles and motorboats.

Concern over acid deposition was related to the low buffering capacity of VOYA waters as well as the wealth of acid precipitation studies occurring in forested regions of Europe, Canada, and the northeastern United States at the time. Rapp et al. (1985) conducted a survey of 267 northeastern Minnesota lakes (including several at VOYA) and found that the lakes did not respond uniformly to acid deposition. Effects of acid deposition varied within and among watersheds, and the relationship between atmospheric deposition and water chemistry was stronger in headwater lakes (particularly for sulfate concentrations and alkalinity) than in other lakes. Webster et al. (1993) examined water chemistry trends in four low-alkalinity lakes at VOYA (Cruiser, Locator, Loiten, and Shoepack) and found that surface water sulfate concentrations declined from 1983-1989, but that recovery of acid neutralizing capacity and pH was lagging. Webster and Brezonik (1995) suggested that recovery of pH and acid neutralizing capacity may be hindered by a trend toward warmer, drier climatic conditions and related declines in groundwater inputs of calcium and magnesium, particularly in other northern Wisconsin and Michigan lakes. Tighter restrictions on sulfur emissions have resulted in declines in sulfate deposition and reduced research interest in acid deposition issues, although deposition of nitrogen oxides and effects of climate warming on acidification recovery remain a concern.

Mercury studies at VOYA have addressed historic mercury trends, deposition, concentrations in water, and bioaccumulation. The Minnesota Department of Natural Resources has monitored mercury levels in the gamefish of VOYA lakes regularly since the 1970s. Engstrom et al. (1999) conducted an extensive paleolimnological study of mercury in 50 Minnesota lakes, including four at VOYA. Their results indicated that mercury accumulation rates were highest in lakes of the Twin Cities metropolitan area, but that methylated mercury concentrations were highest (and increasing) in lakes of northeastern Minnesota, in or near VOYA. The authors suggested that elevated methylmercury concentrations were due to deposition of sulfate and nitrate and related increases in mercury methylation. Two studies addressed trends and patterns of wet mercury deposition in the region. Sorensen et al. (1994) found that the amount of mercury deposition was related to precipitation across the region. Glass and Sorensen (1999) described trends in mercury deposition, noting that annual mercury deposition varied greatly among sites and increased slightly from 1990-1995. Methylmercury comprised only 1.5% of total mercury in precipitation. Despite the low percentage of methylmercury in precipitation, mercury concentrations in VOYA's aquatic biota and sediment (Engstrom et al. 1999) are routinely high. Sorensen et al. (1990) investigated how mercury deposition and watershed characteristics affected mercury concentrations in water, sediments, and biota of northern Minnesota lakes. Across the study area, mercury concentrations in lakes and their biota were negatively correlated with pH and alkalinity and positively correlated with total organic carbon. Similar findings were later reported by Goldstein et al. (2003) in a survey of 20 interior VOYA lakes.

Several studies have explicitly addressed mercury accumulation in VOYA biota. Lafrancois and Carlisle (2004) investigated mercury burdens in native crayfish (*Orconectes virilis*), a key food web component of VOYA's interior lakes. Crayfish mercury burdens were positively related to water column organic carbon concentrations across lakes, but did not exceed concentrations considered toxic or lethal to wildlife predators like mink and otter. Sorensen et al. (2001) examined the effects of exotic rainbow smelt invasions on trophic pathways and mercury uptake in VOYA's large lakes and eight interior lakes. Fish mercury burdens were correlated with trophic position, and mercury in northern pike was twice as high in interior lakes as in the large lakes of VOYA. Ongoing mercury studies aim to understand mercury bioaccumulation in interior lake food webs (Brent Knights, U.S. Geological Survey, and Jim Wiener, University of Wisconsin-La Crosse, personal communication) and relationships between lake level fluctuations and bioaccumulation in game fish (PMIS #103152). Two studies have examined mercury concentrations in common loons at VOYA (Ensor et al. 1992, Evers et al. 1998), including measurements of mercury in loon livers, blood, and feathers. The authors found that many loons had liver mercury levels indicating potential reproductive impairment. Older individuals and those breeding on low pH lakes had the highest mercury burdens. The authors noted that mercury concentrations in loon blood and feathers were correlated within individuals, suggesting feather mercury concentrations may prove useful as monitoring endpoints. Ensor et al. (1992) also examined lead poisoning in loons, and found it was occasionally the cause of death in adult loons. Route and Peterson (1988) measured mercury concentrations in fur samples from several otter, one of which represented the highest otter mercury burden then recorded in North America.

<u>*Hydrology*</u>

Water level regulation on VOYA's large lakes has been consistently noted as a key water resource issue for the Park. In addition to the body of research addressing ecological effects of water level fluctuations (see previous sections) several studies have fulfilled more basic information needs related to large lake hydrology. Flug (1986 a, b) and Kallemeyn and Cole (1988) constructed models of the Rainy Lake-Namakan Reservoir system and simulated the effects of alternate hydrologic regimes on aquatic habitat and resources. The model was used to find the optimal rule curve compromise; model results suggested a more natural hydrologic regime was the best option. The authors noted that extreme hydrologic conditions (e.g., drought, floods) would make strict compliance with the proposed rule curves difficult. Kallemeyn (2002) reported on the findings of an international, interagency workshop designed to evaluate effects of the new, more natural rule curve implemented in 2000. Kallemeyn urged development of a long-term monitoring program that effectively evaluates effects of the new rule curve, accounts for multiple species, and acknowledges social concerns.

Strengths and needs

The aquatic research program at VOYA has benefited greatly from the co-located U.S. Geological Survey International Falls Biological Station and the experience and expertise of its lead aquatic research biologist, Larry Kallemeyn. Lake level fluctuations and related ecological effects have been the subject of intense binational research and planning efforts. These efforts have provided a good framework for evaluating the success of the new rule curve, implemented in 2000. A multi-component, three-year monitoring program addressing hypothesized ecological responses to the new rule curve began during summer 2004. In addition to lake level studies, research at VOYA has also targeted a major landscape driver (beaver activity) and a significant ecological stressor (mercury contamination). Long-term monitoring of beaver-induced landscape change and continued investigations into the drivers and biological effects of mercury bioaccumulation should be conducted. Angling is one of the primary attractions for many Park visitors and the fisheries resource of the Park is a major feature of the aquatic biota. However, there is not a specific fisheries management plan for the Park. A coordinated plan with input from National Park Service, Minnesota Department of Natural Resources, and Ontario Ministry of Natural Resources could provide helpful management guidance and should be a priority for the Park. Amphibian research has been very limited to date, but VOYA was recently selected as a study site for the U.S. Geological Survey Amphibian Research and Monitoring Initiative (http://armi.usgs.gov/2002_report_NC.asp). Related studies will greatly improve the information base on VOYA herpetofauna. Identified but relatively unstudied stressors include invasive species (both established and future) and wastewater release from houseboats on VOYA's large lakes.

Considerations for monitoring

Directly from the literature

- Christensen et al. (2004) noted that future monitoring on the large lakes at VOYA should include total phosphorus and chlorophyll *a,* because of their relationship to lake level fluctuations and their strong record of previous sampling.
- Payne (1979) recommended a future focus on nutrient enrichment, an increased number of sampling sites in the large lakes, and more frequent sampling if short-lived bioindicators like phytoplankton are used.
- Monitoring for zebra mussels, purple loosestrife, rusty crayfish, and other aquatic nuisance species should be continued (Benedict and Grim 1989, Hoven 1998).
- Hargis (1981) recommended sampling zooplankton in mid-July if sampling can only be conducted once. The cladoceran fauna was fully developed by then.
- For interior lakes, a single zooplankton sampling site for each lake should be representative; for the large lakes many sampling sites are needed (Hargis 1981).
- Route and Peterson (1988) recommended further investigation of otter mercury burdens, and suggested that crayfish may be useful mercury biomonitoring tools because they are easily captured and represent a key part of otter diets.
- Ensor et al. (1992) and Evers et al. (1998) noted that future mercury monitoring in loons should account for variation in age, sex, and tissue type.
- Evers et al. (1998) noted that blood and feather mercury concentrations were related, and Ensor et al. (1992) noted that juvenile feathers would be useful for monitoring long-term regional trends in loon mercury burdens.
- Swackhamer and Hornbuckle (2004) recommended implementing trend monitoring programs for contaminants in both deposition and biota, with particular emphasis on persistent, bioaccumulative toxins such as mercury and polychlorinated biphenyls.

Derived from the literature by the synthesis authors

- Better understanding of behavior of fish stocks that may move between U.S. and Canadian waters of the Park combined with cooperative U.S and Canadian creel surveys would be helpful in determining management strategies for the species harvested by anglers in the Park.
- Fisheries assessments of the interior lakes, with surveys occurring at least every five years, would create a long-term database for evaluating population changes that may occur following certain management actions per National Park Service policy.

- Johnston and Naiman (1990a, 1990b) were able to track changes in landscape and beaver populations over time using aerial photographs (1940-1986). If new photographs have become available since 1986, additional analysis of landscape changes over the past 15-20 years would be useful.

Considerations for research

Directly from the literature

- Sorensen et al. (2001) recommended further studies to determine how the rainbow smelt invasion may affect game fish trophic position and mercury burdens over time.
- Schlosser and Kallemeyn (2000) categorized beaver ponds based on successional age; these categories may provide a useful framework for site selection in future studies.
- Swackhamer and Hornbuckle (2004) recommended research to evaluate the relative impact of local versus regional or global sources of atmospheric contaminants at ISRO and VOYA; noted a need for more process-oriented research on mercury deposition, cycling, and bioaccumulation; and suggested that ecological risks associated with contaminant bioaccumulation should be explored. They also recommended further investigations into the impact and bioaccumulation of organic contaminants from snowmobile and motorboat emissions.
- Ensor et al. (1992) recommended linking loon population size to mercury burdens by comparing loon populations in lakes with high and low mercury contamination, and collecting dead or dying loons for necroscopies.

Derived from the literature by the synthesis authors

- VOYA's large lakes are expansive, and water quality investigations would benefit from greater spatial coverage of sampling sites. Current volunteer monitoring work aims to fulfill this need.
- An analysis that addresses the likelihood of invasion by various Great Lakes or Upper Mississippi River Basin aquatic nuisance species should be conducted, with attention to the origin, arrival vector, and existing geographic extent of these species.
- Engstrom et al. (1999) suggested that the high proportions of methylmercury found in sediments of northeastern Minnesota lakes may be related to elevated levels of sulfate and nitrate deposition. Given the unregulated nature of nitrogen oxide emissions and the potential for power plant construction and expansion in the region, this hypothesis should be further explored.
- Mercury research at VOYA and elsewhere has linked mercury concentrations in water and biota with total and dissolved organic carbon and sulfate concentrations. A better understanding of the watershed and in-lake processes (including lake level fluctuations) affecting concentrations of those variables is needed.

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UPPER MISSISSIPPI RIVER NATIONAL WATER QUALITY ASSESSMENT

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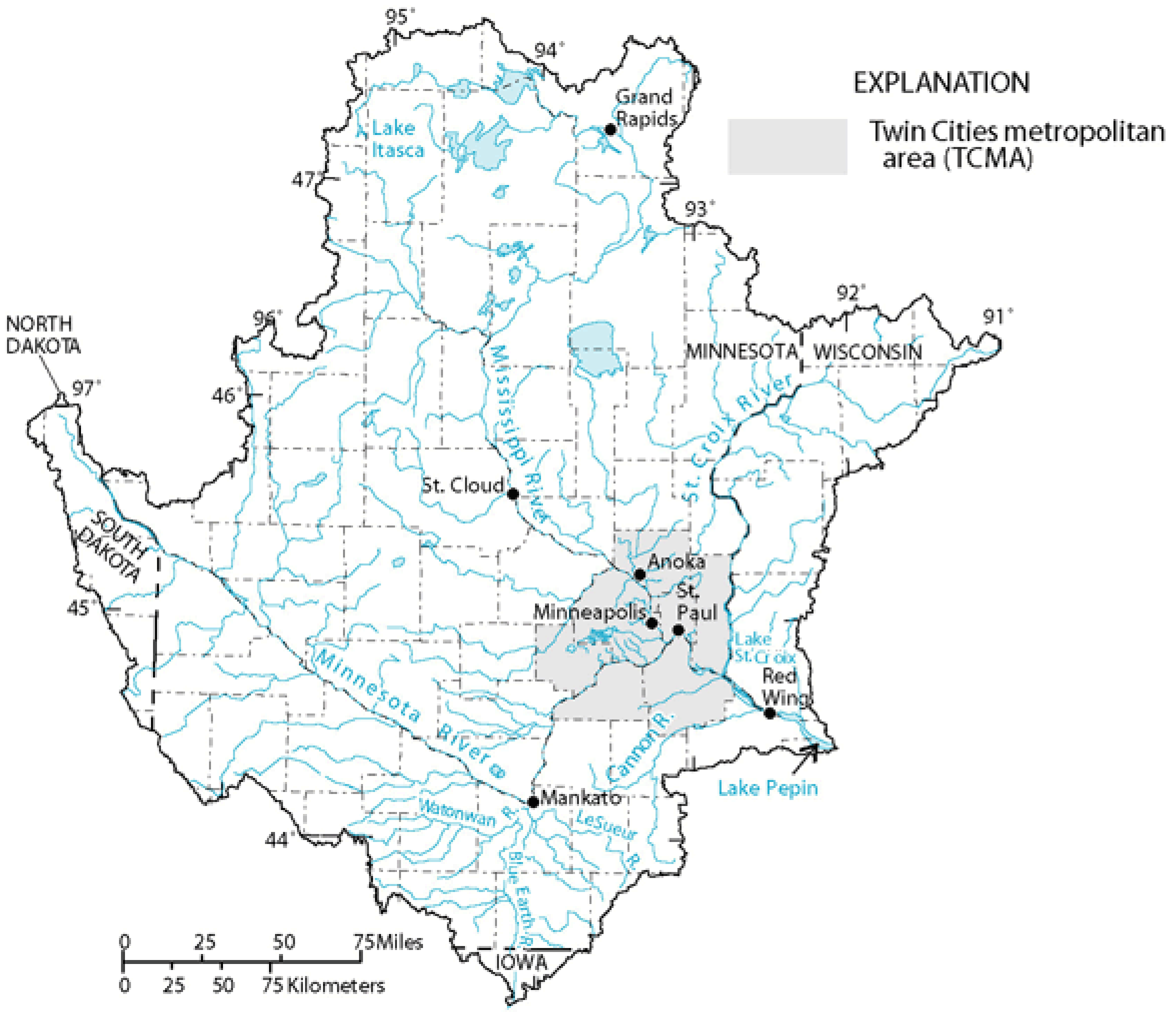
Photo credits from top to bottom: North Fork Crow River above Paynesville, MN, Minnesota River near Jordan, MN, Mississippi River at Red Wing, MN, and Namekagon River at Leonards, WI. All images courtesy of the Upper Mississippi Study Unit, National Water-Quality Assessment Program (http://mn.water.usgs.gov/umis/bio_bfs.html).



Upper Mississippi River National Water Quality Assessment study unit, showing major streams and waterbodies. See the map of the Great Lakes Network parks, page 4, for regional context.

UPPER MISSISSIPPI RIVER NATIONAL WATER QUALITY ASSESSMENT

The Upper Mississippi River Basin (UMIS) is a study unit of the National Water Quality Assessment, a nationwide effort to describe status and trends in water quality. It was selected for study because Mississippi River water quality is of national concern and because the area contains significant agricultural and urban areas. The UMIS study unit consistsofthree major drainage basins: the Mississippi, Minnesota, and St. Croix Rivers. Because it contains two National Park units, St. Croix National Scenic Riverway (SACN) and Mississippi National River and Recreation Area (MISS), research derived from UMIS is presented individually in this document.

The Mississippi River is joined by the Minnesota River in the Twin Cities and by the St. Croix River just downstream of the Twin Cities. A strong gradient in land cover exists within the study unit, with forests and wetlands predominating in the north, and urban and agricultural uses more common in the south and west, respectively. Seventy-five percent of the study unit's human population lives in the Twin Cities Metropolitan Area, which is rapidly expanding in size. The initial six-year phase of UMIS studies (1994-1999) focused on data collection and analysis in a 50,500 km^2 (19,500 miles^2) area including the Twin Cities

Metropolitan Area. Effects of the Twin Cities on water quality and aquatic ecology were of primary interest.

Summary of existing aquatic research

General resource documents and plans

Stark et al. (1996) and Andrews et al. (1996) conducted extensive literature reviews for the study area, described general environmental context, and presented the study design for future UMIS studies. The documents provided a good deal of basic information about the upper Mississippi River basin and past research activities. Surface water, groundwater, and aquatic biology and ecology studies were all treated in the literature review, which covered over 2,000 citations.

Water quality

A series of studies have addressed surface water quality, with nutrients and sediments as a primary focus. Stark et al. (2000) provided a summary of UMIS activities and research findings to date, with emphasis on spatial patterns of nutrients and sediments in UMIS surface waters. Kroening (1998) addressed sources of nutrients to UMIS and its subbasins, noting that nonpoint nutrient sources (fertilizer and manure) predominated in all subbasins. Total nutrient inputs to the St. Croix basin were lower than inputs to the Minnesota and Mississippi River, but inputs from atmospheric deposition were proportionally higher in the St. Croix basin.

Variation in water quality among subbasins and over time has been investigated. Stark (1997) and Kroening et al. (2002) examined causes of spatial variability in water quality and found that the considerable gradient in land cover explained much of the variation. They concluded that land use patterns have accentuated natural differences in water quality throughout the basin. The St. Croix basin generally had the lowest nutrient loads and alkalinity; much higher nutrient and sediment loads were found below the confluence of the Minnesota and Mississippi Rivers. Minnesota and Mississippi River sites also had the highest chlorophyll concentrations and algal abundances, with some evidence of blue-green algal dominance. Fecal bacteria concentrations occasionally exceeded standards in the Minnesota and Mississippi Rivers, and heavy metal concentrations were greatest in the Mississippi River downstream of the Twin Cities.

Temporal variation in water quality has been assessed in several studies. Kroening and Stark (1997) and Kroening and Andrews (1997) investigated seasonal and long-term trends in UMIS water quality from 1984-1993. They found that water chemistry varied seasonally in streams, with agricultural streams showing peaks in nitrogen during spring and summer, and forested streams showing nitrogen peaks during winter. Total phosphorus concentrations were greatest in spring and summer for all monitored streams. No significant water quality trends were noted for sites outside the Twin Cities area from 1984-1993, but within the Twin Cities area ammonia-N declined and nitrate-N increased, perhaps reflecting changes in wastewater treatment practices.

Loading of nutrients to the St. Croix River from snowmelt runoff was investigated by Fallon and McNellis (2000). Streams draining agricultural areas transported many times more nitrogen and phosphorus during snowmelt than streams in forested and urban areas. Nitrogen in snowmelt runoff from forested streams was primarily in particulate and dissolved organic forms, whereas agricultural and urban streams were dominated by nitrate. In general, suspended sediment concentrations were highest in agricultural streams. High suspended sediment loads in some forested streams were attributed to characteristics of their surficial geology.

Biology and ecology

Biological work in UMIS has been limited, but ZumBerge et al. (2003) recently published a report relating periphyton and benthic invertebrate communities to environmental factors and land use throughout the basin. Sites included both small streams and mainstem sites on large rivers. Of the small streams sampled, periphyton densities were lowest on the Namekagon River in the St. Croix River basin and highest in the North Fork Crow River in the Minnesota River basin. Periphyton growth and composition in small streams were not consistently related to nutrient patterns, suggesting other factors such as light, temperature, and substrate were also important. In the Mississippi and St. Croix Rivers, periphyton densities generally increased from upstream to downstream, with lower relative abundance of diatom taxa at downstream sites. Benthic invertebrate composition in small streams was related to land cover type (forested versus agricultural). In the Mississippi and St. Croix Rivers, benthic invertebrate diversity and richness decreased from upstream to downstream.

Fish

Two studies addressed fish assemblages in the UMIS study unit. Talmage et al. (1999) investigated how fish community composition relates to water quality and habitat factors in streams of the Twin Cities area. Stream sites were selected to cover a gradient of population density and urban development. Nutrient concentrations were generally low, but very high fecal bacteria concentrations were detected at some sites and atrazine was detected in all of the sampled streams. Fish habitat was described as poor, with little woody debris or cobble. Most fish species were tolerant omnivores. The authors concluded that urban land use, percent impervious surface, water chemistry, temperature, geomorphology, substrate, habitat, and migration barriers were all important factors affecting fish community composition in these sterams.

Goldstein et al. (1999) described broader-scale patterns in fish community composition in UMIS streams and rivers. They found that fish species composition differed among small streams according to land use. Agricultural streams were affected by nutrients from fertilizers, increased temperature from loss of shade, habitat modifications due to channelization, and hydrologic modifications from dams and drain tiles. Fish species in agricultural streams generally required some cobble and gravel and were mainly invertivorous. Forested streams contained fewer species, mainly invertivores and carnivores requiring cold clear water and cobble or boulder substrates. Urban streams contained many lentic species tolerant of silt, low dissolved oxygen, and marginal habitats. Large river fish composition was affected by dispersal barriers, dams, and the Twin Cities Metropolitan Area. Fish in the Twin Cities area of the Mississippi River were generally lentic, planktivorous species with higher thermal tolerances.

Contaminants

UMIS studies have addressed a variety of contaminants in surface water, groundwater, streambeds, and fish tissues. Two wide-ranging studies of volatile organic carbons (VOCs) have been conducted in the study unit. Andrews et al. (1995) reviewed existing VOC data and found that trace amounts of VOCs had been detected previously in all rivers and some water supply lakes. The highest groundwater concentrations were found in shallow wells from sand and gravel aquifers. The most commonly detected VOC was trichloroethene, a degreasing agent. In a follow-up study of rivers and groundwater, Andrews (1996) noted very few VOC detections in St. Croix and Mississippi River sites, but frequent detections in wells. The highest well concentrations were found near spills, leaks, and landfills, and most Environmental Protection Agency exceedences were found at sites within the Twin Cities metropolitan area.

Two studies have investigated pesticide presence in surface waters and bed sediments. Pesticide use and detections in surface water were reviewed by Fallon et al. (1997), who found that detection of herbicides was widespread, with the highest incidences of detection in row cropped areas. Atrazine was the herbicide most commonly detected in surface water, and concentrations were generally highest in July. Persistent organochlorine pesticides, however, were more common in streambed sediments, particularly in the Twin Cities area. Fallon (2000) analyzed pesticide concentrations in relation to land use, noting that herbicides were more commonly detected in stream water, particularly in agricultural areas. In general, concentrations were below levels considered harmful to humans and aquatic life.

Two studies have investigated organochlorine contaminants in fish tissues. Lee and Anderson (1998) analyzed existing data on polychlorinated biphenyls (PCBs) in carp (*Cyprinus carpio*) and walleye (*Sander vitreus*) from UMIS. Declines in PCBs averaged 80% across sites since the late 1970s, with sites in the Twin Cities area showing the most marked declines. McNellis et al. (2000) investigated organochlorine compounds in bed sediments and fish of the St. Croix basin. The types and concentrations of organochlorines found in sediments and fish tissues varied according to land use, with forested sites featuring the lowest concentrations. High levels of PCBs were found in fish tissues from the St. Croix River at Hudson and the Mississippi River downstream of the Twin Cities area.

Kroening et al. (2000) investigated trace elements in streambed sediments and fish livers at sites throughout the UMIS study unit. The occurrence and distribution of these elements was related to surface geology and land use, with the highest concentrations found in urban sites. Sediment concentrations of cadmium were highest downstream of the Twin Cities, and sediment mercury concentrations were high for a variety of urban and forested sites. High trace element concentrations in fish livers did not always correspond with high concentrations in stream sediments.

Groundwater

In addition to the groundwater nutrient and contaminant information covered in previous sections, two studies provided basic information on groundwater quality, with secondary emphasis on contaminants. Andrews et al. (1998) monitored 30 shallow groundwater wells in the Twin Cities metropolitan area. High sodium and chloride concentrations and frequent pesticide and VOC detections were found in the wells. Shallow groundwater in the area appeared highly susceptible to contamination, particularly in areas with heavy industrial and transportation development. Hanson (1998) modeled contamination susceptibility of sand and gravel aquifers throughout the basin and measured pesticide and nitrate contamination. High concentrations of pesticides and nitrates generally corresponded to areas with high modeled susceptibility, but were also associated with land uses such as agricultural cropland. Fong (2000) measured more than 200 constituents in groundwater in wells throughout the UMIS study unit. Groundwater quality corresponded to geologic and land use characteristics in a manner similar to surface water. Nitrate concentrations were highest in the agricultural wells, pesticides were most commonly detected in agricultural and urban wells, and VOCs were detected primarily in urban areas. Groundwater in sand-gravel aquifers tended to be most susceptible to contamination.

Strengths and needs

Research at UMIS has focused heavily on nutrient and contaminant issues, which are primary water resource concerns in the study unit. These studies have provided a regional representation of nutrient and contaminant patterns in surface and groundwater. They have also indicated the importance of land use characteristics in shaping water quality and biological assemblages in the study area. The next phase of studies at UMIS will capitalize on this information base, and aims to explore the effects of nutrient enrichment on small watersheds along a gradient of agricultural intensity. UMIS activities have generated high quality scientific information applicable to both river parks (MISS and SACN) in the Great Lakes Network. The regional nature of the study unit allows a comparison of attributes and issues between the river basins, and provides an opportunity to share management objectives and strategies. To date, UMIS research has been short on biology and ecology, providing little information about how water quality or contaminants affect important biological resources or how biological resources change over time. Additionally, UMIS data sets could be tailored to address specific concerns on smaller spatial scales for both the Mississippi and St. Croix River subbasins. Mississippi National River and Recreation Area and SACN should continue to contribute to the planning and execution of UMIS activities, and should explore opportunities to enhance their usefulness in addressing Park resource issues.

Considerations for monitoring

Directly from the literature

- Water quality studies at UMIS suggest that primary inputs are from nonpoint sources (e.g., Kroening 1998). Future monitoring and management should focus on understanding these sources.

- Periphyton diversity and richness indices did not reliably indicate known disturbances in small streams of UMIS (ZumBerge et al. 2003). Measures of periphyton biovolume and relative abundance were more useful.
- Results from McNellis et al. (2000) indicated that PCBs in fish tissues are still high at some sites in MISS and SACN. Continued monitoring is warranted.
- Results from Fallon et al. (1997) and Fong (2000) suggested that future pesticide and VOC monitoring should focus on agricultural and urban areas.

Derived from the literature by the synthesis authors

- Kroening et al. (2000) noted that trace elements as measured in bed sediments and fish livers did not relate predictably to one another. Similarly, McNellis et al. (2000) noted that organochlorine concentrations in bed sediments and whole fish did not correspond. Concentrations in both fish and sediment could be confounded by riverine fish movement and sediment transport processes. Future research and monitoring efforts should seek to account for this uncertainty.

Considerations for research

Derived from the literature by the synthesis authors

- Several studies noted the influence of the Minnesota River on water quality in the Mississippi River. Future research at MISS should involve partnerships not only with resource management agencies in the Twin Cities area but also throughout the Minnesota River basin.

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GREAT LAKES NETWORK-WIDE SYNTHESIS

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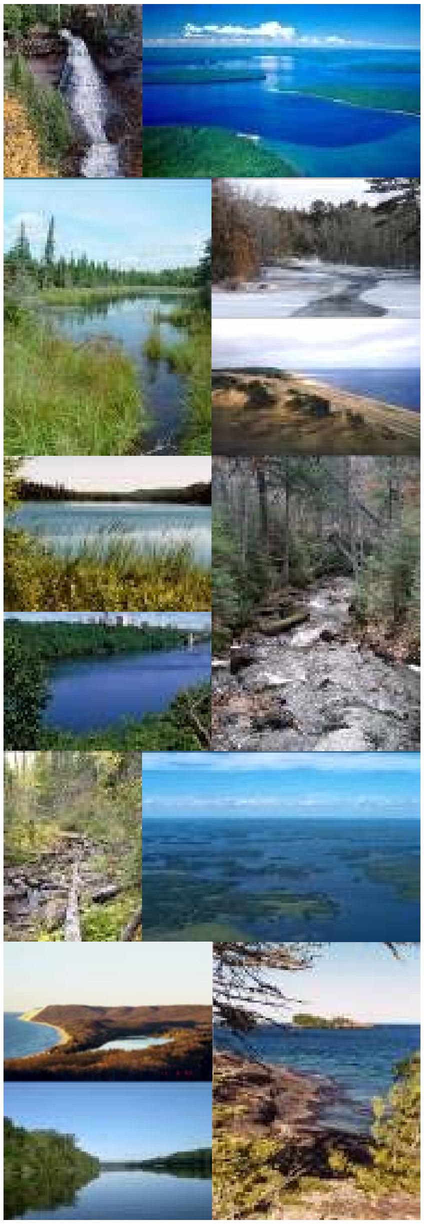

Photographs, clockwise beginning at upper left: Pictured Rocks National Lakeshore (J. Glase), Apostle Islands National Lakeshore (Erickson Post Cards & Souvenirs), St. Croix National Scenic Riverway (R. Ferrin), Indiana Dunes National Lakehore (Lakeshore photograph files), Pictured Rocks National Lakeshore (B. Lafrancois), Voyageurs National Park (Park photograph files), Isle Royale National Park (B. Lafrancois), St. Croix National Scenic Riverway (R. Ferrin), Sleeping Bear Dunes National Lakeshore (P. Murphy), near Grand Portage National Monument (S. Gucciardo), Mississippi National River and Recreation Area (Park photograph files), Isle Royale National Park (B. Lafrancois), and Voyageurs National Park (D. Szymanski).

OVERVIEW OF LITERATURE

In our review of aquatic research conducted in Great Lakes Network (GLKN) parks, we collected more than 600 pertinent studies and reports. Total numbers of aquatic studies varied among parks but were generally related to the prominence of the park's water resources. Accordingly, parks with the highest numbers of studies included St. Croix National Scenic Riverway (SACN), Voyageurs National Park (VOYA), and Isle Royale National Park (ISRO) (Table 4), which are dominated by aquatic habitats (Table 1, pg. 2). Grand Portage National Monument (GRPO), on the other hand, has very few water resources and has not been frequently studied (Table 4). Studies in Great Lakes area parks have explored aquatic habitats ranging from small streams to large rivers and from small splash pools to Lake Superior. They have addressed diverse aspects of water resources, including water quality, aquatic biota (fish, plankton, mussels, macroinvertebrates, wildlife, and aquatic vegetation), contaminants, hydrology, groundwater, and physical processes (see Table 2 for complete definitions). Of these, fisheries, water quality, and basic limnological studies have received by far the greatest emphasis network-wide (Figure 2). A significant number of studies have also provided information on contaminants and hydrology, but fewer studies have addressed wetlands and aquatic vegetation, and only a small number of studies have addressed aquatic wildlife, amphibians and reptiles, groundwater, or physical processes (Table 5, Figure 2).

Table 4. Number of studies reviewed and included in this synthesis document for each Great Lakes Network park. APIS=Apostle Islands National Lakeshore, GRPO=Grand Portage National Monument, INDU=Indiana Dunes National Lakeshore, ISRO=Isle Royale National Park, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks National Lakeshore, SACN=St. Croix National Scenic Riverway, VOYA=Voyageurs National Park, and UMIS=Upper Mississippi National Water Quality Assessment site.

Park	Total Number of Studies
APIS	68
GRPO	9
INDU	55
ISRO	109
MISS	42
PIRO	56
SACN	125
SLBE	63
VOYA	77
UMIS	20
Total	624

The composition of research has differed among Great Lakes area parks, often reflecting critical resource issues or local interests at individual parks (Figure 3). Research at Apostle Islands National Lakeshore (APIS), for example, has included a strong emphasis on fisheries and more studies of amphibians and reptiles than other parks. Other APIS research has been spread fairly evenly across categories, with a number of water quality, biology, and aquatic wildlife studies represented. Few water resource studies have been conducted at GRPO; studies noted in this synthesis focused on fisheries, water quality, and contaminant issues. Indiana Dunes National Lakeshore (INDU) had one of the higher numbers of water quality studies among the Great Lakes parks, many of which focused on fecal indicator bacteria.

Additionally, several wetland and aquatic vegetation studies have been conducted at INDU due to the significance of the Lakeshore's large marshes, interdunal ponds, and bog habitats.Because of ISRO's remote location, more studies of long-range contaminant transport have been conducted there than at any other park. More fisheries-related studies were found in ISRO files than at any other park, and the potential impacts of contaminants on sport fisheries of Lake Superior and inland lakes have been investigated repeatedly. Other strong points of ISRO's research history include wide-ranging aquatic biology and ecology studies and more than 20 years of long-term research in the Wallace Creek watershed.

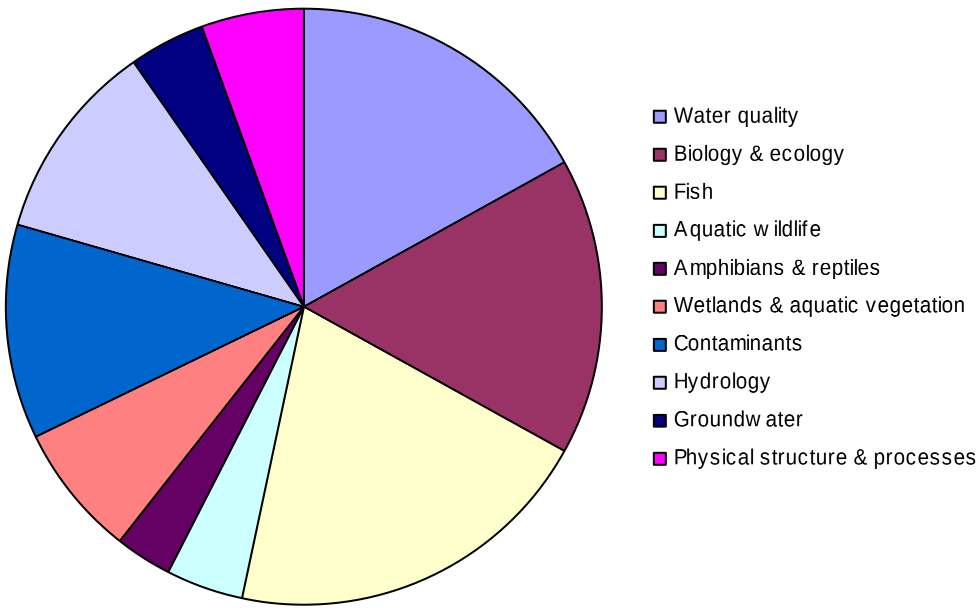

Figure 2. Relative composition of aquatic research themes across nine parks in the Great Lakes Network. See Table 2 for complete research category definitions.

Table 5. Total number of studies addressing each research category for each Great Lakes Network park. Note: some studies addressed multiple research categories and were counted for each category. See Table 2 for complete research category definitions and Appendix C for study citations and source data. APIS=Apostle Islands National Lakeshore, GRPO=Grand Portage National Monument, INDU=Indiana Dunes National Lakeshore, ISRO=Isle Royale National Park, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks National Lakeshore, SACN=St. Croix National Scenic Riverway, VOYA=Voyageurs National Park, and UMIS=Upper Mississippi National Water Quality Assessment site.

	Water quality	Biology and ecology	Fish	Aquatic wildlife	Amphibians & reptiles	Wetlands & aquatic vegetation	Contaminants	Hydrology	Groundwater	Physical structure & processes
APIS	10	14	36	9	13	9	6	3	2	3
GRPO	5	1	3	0	0	0	5	1	1	0
INDU	25	20	15	2	7	21	18	11	5	5
ISRO	24	20	46	11	5	8	30	18	1	2
MISS	25	10	19	1	0	1	18	18	21	6
PIRO	15	12	26	4	3	7	13	10	0	11
SACN	44	67	38	0	5	6	19	28	12	24
SLBE	28	25	17	1	2	11	5	11	4	8
VOYA	20	16	32	19	2	20	19	25	0	6
UMIS	15	4	7	0	0	0	11	5	9	2

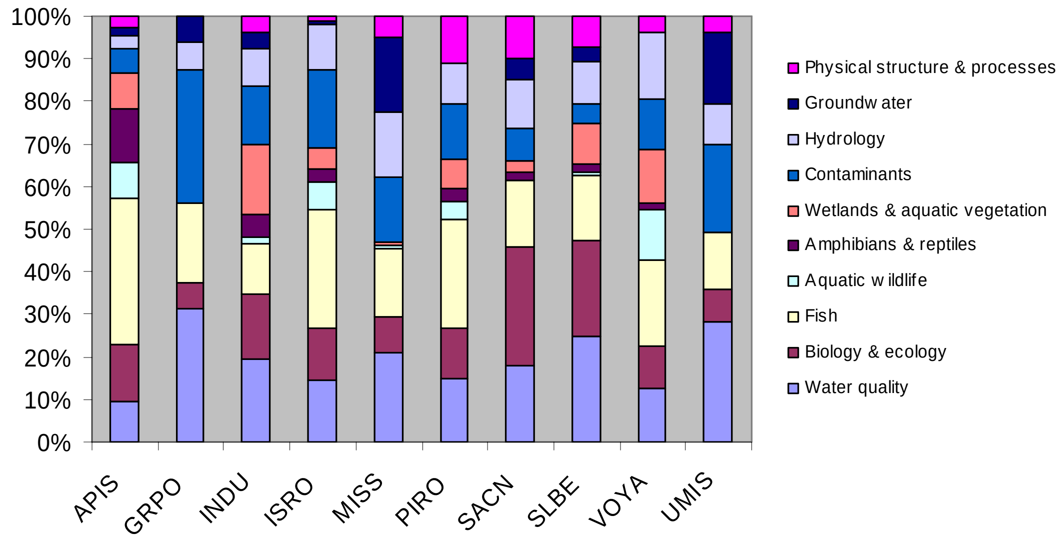

Figure 3. Composition of aquatic research themes in Great Lakes Network parks, displayed as relative number of studies addressing each research category for each Great Lakes Network park. Some studies addressed multiple research categories. APIS=Apostle Islands National Lakeshore, GRPO=Grand Portage National Monument, INDU=Indiana Dunes National Lakeshore, ISRO=Isle Royale National Park, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks National Lakeshore, SACN=St. Croix National Scenic Riverway, VOYA=Voyageurs National Park, and UMIS=Upper Mississippi National Water Quality Assessment site.

Research at Mississippi National River and Recreation Area (MISS) has been conducted almost exclusively by other agencies and has focused heavily on water quality, contaminants, fisheries, hydrology, and groundwater. More studies of groundwater resources have been conducted at MISS than at any other park, primarily because of groundwater withdrawal issues in the Twin Cities Metropolitan Area. Aquatic research studies at Pictured Rocks National Lakeshore (PIRO) have been primarily broad-based limnological or ecological projects addressing water quality along with some biological components. A high proportion of PIRO studies have also emphasized fishery resources and physical geomorphic processes. . St. Croix National Scenic Riverway has hosted a great deal of aquatic research, much of which has focused on requirements of endangered mussels and issues of nutrient and sediment loading. . St. Croix National Scenic Riverway research also features a series of shoreline studies that provide more extensive information on physical processes than is available for most Great Lakes area parks. Research at Sleeping Bear Dunes National Lakeshore (SLBE) has focused strongly on basic limnology, with particular emphasis on water quality issues in the Glen Lake and Platte River watersheds. The research program at VOYA has touched on nearly every component of aquatic ecosystems, often with respect to the issue of lake level regulation. Fisheries work has been very prominent at VOYA, particularly when studies conducted by State agencies are considered. Aquatic wildlife studies addressing beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), otter (*Lutra Canadensis*), and common loon (*Gavia immer*) are better represented at VOYA than at most other parks in the Great Lakes area. Due to the objectives of the National Water Quality Assessment program, studies in the Upper Mississippi River Basin unit (UMIS) have primarily targeted surface and groundwater water quality issues, particularly contaminants, and have contributed greatly to the knowledge base at MISS and SACN. Unlike research at most parks, UMIS studies have rarely addressed biological attributes.

SUMMARY AND CONSIDERATIONS BY RESEARCH CATEGORY

Water quality

Summary

Water quality studies in the Great Lakes Network parks have taken a variety of forms. Most water quality work has involved broad chemical or limnological surveys of inland waters. Water quality studies in nearshore and offshore Great Lakes waters have generally been limited to bacteriological studies. Water quality studies have emphasized spatial rather than temporal variability, and for many parks little is known about seasonal variation in water quality. In addition to basic survey work, some parks have featured more intensive water quality studies. For example, long-term water quality monitoring records exist for Washington Creek and the Wallace Lake watershed at ISRO, for the Mississippi River at MISS, and for Lake St. Croix at SACN. Our review of the National Park Service Baseline Water Quality Data Inventory and Analysis Reports indicated the highest total numbers of water quality observations, sampling stations, and parameters were found at INDU, MISS, and SACN (Table 3, pg. 14), reflecting the accessability of these parks to local agency and university experts, their substantial length (MISS, SACN), and the severity of their water resource threats (INDU, MISS). The total numbers of observations at ISRO, PIRO, and VOYA, on the other hand, appear disproportionately low relative to the quality and extent of their water resources, perhaps owing to their remote locations. Intensive watershed-based studies have been conducted at the two river parks (MISS and SACN) as well as ISRO, producing a more complete view of land-water interactions in these parks. Paleolimnological reconstructions of water quality conditions (phosphorus, pH) at SACN and PIRO have provided a historical perspective on water quality conditions. Ongoing, in-house water quality monitoring takes place at only a few Great Lakes area parks. In general, our understanding of water quality in Great Lakes area parks would be improved by acquiring information on nearshore Great Lakes waters, increasing the temporal resolution of monitoring to address seasonal and interannual variability, and further examining effects of land use change, point and nonpoint source pollution, and atmospheric deposition on water quality.

Considerations

- *Water quality parameters* – Previous research suggests that several water quality parameters are of particular interest for Great Lakes area parks or subsets of parks.
    - Loading of nutrients and sediments affects most parks, but is of greatest concern at parks with substantial portions of their watersheds outside park boundaries or in agricultural use (e.g., SACN, MISS).
    - Nitrate concentrations have increased at SACN and MISS over the past several decades and should continue to be monitored. Additionally, nitrogen can be the limiting nutrient for algae in northern lakes. Nitrate should be monitored in those waters susceptible to increases in atmospheric nitrogen deposition.
    - Dissolved organic carbon is an ecologically important parameter that affects light penetration, microbial processes, and mercury methylation in northern lakes and streams influenced by bogs and coniferous forests (e.g., APIS, GRPO, ISRO, PIRO, SACN and VOYA). Its concentration in inland waters is also linked to changes in land cover, watershed processes and climate, making it a good candidate for future monitoring.

  - Secchi depth has been a useful measure of lake trophic status on some occasions, but is confounded by high dissolved organic carbon at many Great Lakes area parks, and by marl formation at SLBE.
  - Bacteriological monitoring is conducted routinely at SLBE and INDU. Research and experience has indicated some drawbacks in the methodologies currently available. Continued attention to advances in bacteriological methods (such as rapid assessment tools and source tracking) is needed.
- *Watershed studies* – Aquatic research in several parks (notably MISS, ISRO, and SACN) has been conducted with a strong watershed perspective. Studies at ISRO have examined the effects of atmospheric deposition and climate change on a full suite of watershed and water quality parameters. Watershed studies at MISS and SACN, on the other hand, have focused on effects of nutrient and sediment inputs. This watershed focus has helped create a more complete understanding of terrestrial processes, water chemistry, and hydrology in these parks, and should be considered as a possible framework for future monitoring and research.
- *Long-term monitoring* – Long-term water quality records are rare among Great Lakes area parks, but those that do exist (e.g., at ISRO, MISS, SACN, and VOYA) have been invaluable for understanding water quality trends and patterns in these parks. Existing long-term sampling sites should be incorporated into future monitoring designs in order to maintain data continuity. Insights gained from existing long-term data can help generate future research hypotheses and provide support for future monitoring efforts.
- *Historical reconstructions* – Historical water quality conditions have been reconstructed using fossil diatom remains from lake sediment cores at several parks (ISRO, PIRO, and SACN). At SACN, for example, lake sediments were used to reconstruct nutrient and sedimentation histories for the St. Croix Basin. Upcoming paleolimnological studies will target water quality changes in the large lakes of VOYA and the backwaters of the St. Croix River. Understanding historical conditions in this way provides national parks with a water quality baseline and a useful perspective on current conditions and resource management objectives.
- *Water quality bioindicators* – Various biological groups have been used as indicators of water quality in Great Lakes area parks. These include benthic invertebrates, diatoms, chironomids, and mussel shell chemistries. Of these groups, benthic invertebrates have been used the most frequently, and have generally been analyzed in the context of bioassessment. The usefulness of benthic invertebrate data in discerning patterns among sites has generally depended on the metrics used and the type of data analysis applied. Diatoms have also been used frequently in both historical reconstructions (SACN, PIRO, and SLBE) and bioassessment studies (at SACN and MISS through the National Water Quality Assessment program). Diatoms appear to be particularly sensitive indicators of past changes in nutrient loading.
- *Partnerships and cooperation* – Studies from many parks cited a need for increased interagency coordination on water quality monitoring efforts. St. Croix National Scenic Riverway has been particularly effective at organizing research, monitoring, and management activities in the basin, and their “Basin Team” model may prove useful for other Great Lakes area parks as well.

Biology and ecology

<u>Summary</u>

Research evaluated under this catch-all category varied widely, from general limnological surveys to taxa-specific research projects. Basic limnological studies generally included an assessment of biological components such as phytoplankton, zooplankton, and benthic macroinvertebrate assemblages. Such surveys were particularly common at SLBE and PIRO. In most cases, the authors provided species lists for these groups but little in the way of ecological analysis. Often these surveys emphasized spatial variation among waters of an individual park, with less attention to seasonal patterns. In addition to general limnological studies, several taxonomic groups have received individual study, including plankton, benthic macroinvertebrates, and unionid mussels. Plankton research projects have been scarce, and those conducted have been largely descriptive. Benthic macroinvertebrate assemblages have been investigated in all of the Great Lakes area parks and evaluated in relation to environmental characteristics such as water quality, land use, and habitat. They have also been used regularly as bioassessment tools. Freshwater mussels are a prominent part of the aquatic biota in the large river parks. St. Croix National Scenic Riverway, in particular, is recognized for its diverse mussel assemblage and has facilitated intensive research on mussel communities, endangered mussels, and zebra mussel status and trends. Recent mussel surveys have also been conducted at MISS, ISRO, PIRO, and SLBE.

Considerations

- *Aquatic nuisance species* – GLKN parks are located in and around the Great Lakes, which harbor an increasing number of non-native aquatic species. Many of these species represent a very significant threat to native park biota.
    - Risk assessments should be conducted for each park to identify invasion pathways and vulnerable resources.
    - Monitoring should be conducted to detect introduction and/or establishment of exotic species.
    - Great Lakes Network and Midwest Region staff should participate in interagency rapid response planning for aquatic invasions. A model response plan is currently under development by the Great Lakes Commission and the Rapid Response Advisory Team through a grant from the U.S. Environmental Protection Agency's Great Lakes National Program Office (http://www.glc.org/ans/panel.html).
    - The U.S. Geological Survey recently began a Non-indigenous Aquatic Species alert system that provides email alerts of new exotic species introductions (http://nas.er.usgs.gov/AlertSystem/register.asp). State watches and species watches are two of the services provided. Park resources staff will be able to stay current on exotic species introductions with this new service.
    - Public outreach and education efforts related to the effects and prevention of invasive species introductions are needed. Increased coordination among staff at GLKN parks, Sea Grant offices, and the National Park Service Great Lakes Research and Education Center would be beneficial.
    - Most GLKN parks have experienced aquatic species invasions (including zebra mussels (*Dreissena polymorpha*), spiny water fleas (*Bythotrephes longimanus*), rusty crayfish (*Orconectes rusticus*), Eurasian ruffe (*Gymnocephalus cernuus*), purple loosestrife (*Lythrum salicaria*), and more) in recent years. Research should be initiated to determine the ecological effects of recent and previous species introductions on native park biota.
- *Ecological investigations* – Although various aspects of aquatic biology have been investigated and lists of aquatic biota are generally available for park waters, few studies have addressed aquatic ecology in an integrated, systemic way. In particular, future research and monitoring should target ecosystem functions (e.g., primary productivity, nutrient cycling), ecological interactions (e.g., among different biological groups, between trophic levels) and ecological relationships (e.g., relationships of aquatic biota to water chemistry or habitat).
- *Long-term monitoring* – A handful of long-term water quality monitoring studies have been conducted in GLKN parks, but none of these has included aquatic biological components. Existing biological studies have generally been short-term research projects. Where possible, biological monitoring (e.g., diatoms, benthic invertebrates) should be integrated into ongoing and upcoming water quality monitoring activities.
- *Biology of unique and unstudied aquatic habitats* – The majority of biological studies have taken place in prominent park waters such as lakes and streams. Great Lakes Network

parks, however, feature many other kinds of aquatic habitats that may support rare or unstudied biota. Unique habitats that have received little study include: large river backwaters (SACN, MISS), wetlands (coastal wetlands, woodland ponds, interdunal ponds), small intermittent streams (especially APIS, PIRO), springs (e.g., SLBE's Aral marl springs), and coastal lagoons (APIS, SLBE, INDU). Additionally, little information is available on the biota, ecology, and structure of nearshore habitats at the National Lakeshore parks. In order to effectively respond to potential spills or exotic species introductions, baseline information on nearshore environments is needed.

Fish

Summary

Isle Royale National Park, APIS, SACN, and VOYA have had the greatest number of fisheries investigations in the GLKN, due in part to the diversity of fish populations in these parks. Pictured Rocks National Lakeshore has also had a considerable amount of work, but further work could easily occur there based on the amount of aquatic and fisheries habitat at the Lakeshore. Isle Royale National Park, SACN, and VOYA reports provide the most diverse types of information. Isle Royale National Park studies range from comprehensive inland lake surveys to genetics investigations of Lake Superior lake trout and brook trout stocks. St. Croix National Scenic Riverway investigations cover a wide range of subjects and include several population assessments and descriptions of the status of some species of interest such as lake sturgeon (*Acipenser fulvescens*), but comparisons over time are difficult because historic investigations have been conducted using a wide range of methodologies. Voyageurs National Park assessments have also encompassed a variety of techniques, due to differences between Minnesota Department of Natural Resources and National Park Service sampling, although comparisons between older and more recent data appear more feasible as indicated by the work of Cohen and Radomski (1993). Creel surveys at VOYA provide some very useful information, in some cases indicating a potential for overharvest of species such as walleye (*Sander vitreus*) due to the overwhelming popularity of the large lakes with anglers.

Voyageurs National Park has also conducted a number of studies relating to effects of artificial lake level fluctuations on fish and other species.

Contaminants are a network-wide issue for fisheries, and are the subject of much study in some of the parks that have sufficient fisheries resources to warrant concern. Early ISRO investigations were some of the first to indicate how extensive airborne transport of contaminants could be and the subject has been well studied there, while airborne and direct point source pollution impacts have been studied at MISS. Aquatic habitat at INDU has been greatly impacted by point source pollution from local industry and fish species assemblages indicate this.

Genetics is another subject that receives attention at multiple parks. Isle Royale National Park, PIRO, and VOYA all have concerns regarding either potential loss of historic stocks, such as at ISRO, or concerns with past stocking practices that compromise genetic integrity of a population.

Most of the fisheries investigations that have occurred at the parks either relate to popular game species or a single species of concern. While many of the parks still need further investigations of some of these important species, all of the parks lack information on fish community assemblages. Investigations of predator/prey relationships, effects on native fish communities from non-native species introductions, and changes in trophic structure due to changes in food web dynamics could all be helpful in understanding why some populations may be healthy while others are not.

Considerations

- *Population dynamics*: Although most parks have assembled species lists, there has been little work to examine populations over time or species interactions within or throughout trophic levels. Opportunities exist at almost every park, but some specific areas stand out.
    - Voyageurs National Park should explore the potential relationship of introduced smelt (*Osmerus mordax*) with native forage species and what impacts this may have on food web dynamics as suggested by Duffy et al. (1994).
    - Spiny water flea invasions of inland lakes of PIRO and in Lake Superior at ISRO will likely have a cascading effect on trophic dynamics. Studies in inland lakes at PIRO are scheduled to begin in 2008; the nearshore waters at ISRO should be examined soon in order to track potential changes to fish and other aquatic communities in these locations.
    - SLBE has an opportunity to determine effects of energy exchange from introduced Pacific salmonids in the Platte River and how this affects aquatic organisms and overall ecological function.
- *Genetics investigations, stock differentiation*: Genetics and stock differentiation has been investigated at ISRO and VOYA and other parks are certainly candidates for similar work.
    - Pictured Rocks National Lakeshore has delayed their ongoing coaster brook trout (*Salvelinus fontinalis*) stocking in 2004 due in part to concerns that some resident fish may have coaster characteristics and that perhaps locally adapted stocks would be more appropriate for stocking efforts. Determining whether these fish are genetically distinct from the Isle Royale strain that is currently being stocked there would help determine if stocking should continue, and what measures should be taken to protect resident stocks.
    - Isle Royale National Park lake trout (*Salvelinus namaycush*) have been examined to determine genetic integrity of stocks around the island. Further investigations that help determine if stocks are unique should occur so that fisheries managers can learn whether greater protection of certain stocks is warranted.
    - Kallemeyn et al. (2003) also indicated that there are different walleye stocks between the basins of Rainy Lake at VOYA. Further work here could help determine if past stocking efforts have impacted these stocks.
    - Sleeping Bear Dunes National Lakeshore should investigate the species that utilize the Aral Springs area, as these fish may be isolated enough from other populations that they have unique characteristics.
- *Habitat Restoration*: Although there are ample opportunities for rehabilitation of aquatic habitats, relatively few parks have embarked on significant projects.
    - The effort at SACN to rehabilitate stream habitat in Cap Creek provides an opportunity to examine whether techniques applied there will produce the desired results of a self-sustaining brook trout (*Salvelinus fontinalis*) population. Similar stream rehabilitation projects could occur in many areas throughout the GLKN.
    - Indiana Dunes National Lakeshore may have a daunting task in the area of stream habitat rehabilitation, but the potential for the Grand Calumet and Little Calumet Rivers is evident, and reestablishing native communities in conjunction with habitat rehabilitation would be an exciting and worthwhile project.
    - Mississippi National River and Recreation Area species could potentially benefit from efforts to construct artificial islands or vegetate shoreline areas as suggested by Johnson and Jennings (1998), as long as these projects are carefully planned and do not compromise fluvial function or cause an increase in unwanted exotic species.
- *Long-term monitoring*: Surveys and assessments that follow any sort of schedule are lacking in nearly all GLKN parks. Voyageurs National Park has a U.S. Geological Survey fishery biologist located at the Park who has conducted a multitude of investigations. The State of Minnesota has also conducted regular assessments and surveys of the large

lakes and some of the smaller inland lakes at VOYA, making this the only park with any sort of consistent long-term fisheries monitoring. Standardized sampling techniques with easily repeatable methodologies could be established throughout all GLKN parks. This would allow for long-term monitoring and tracking of any changes that may occur within species assemblages throughout the network.

- *Historical management information:* Along with long-term monitoring, an effort to compile historic information on fisheries throughout all the GLKN parks would be useful. A document that provides comprehensive information on native species assemblages and management actions such as stocking and removal could be used by the parks for future management decisions.

Aquatic wildlife

Summary

Relatively few studies have examined aquatic wildlife in Great Lakes area parks, and most have focused on the population and breeding ecology of individual species. These studies have addressed aquatic and semi-aquatic birds (gulls (*Larus argentatus* and *L. delawarensis*), double-crested cormorant (*Phalacrocorax auritus*), common loon (*Gavia immer*), and bald eagle (*Haliaeetus leucocephalus*)), and mammals (moose (*Alces alces*), muskrat, otter, and beaver). Most aquatic wildlife work has been conducted at APIS, VOYA, and ISRO, and we found no record of aquatic wildlife studies at GRPO, INDU, or MISS. Aquatic bird studies generally involved an assessment of population size and reproductive success over a single field season, although some studies examined short-term trends in population size. Factors affecting bird reproductive success were often evaluated, and ranged from human disturbance and nest predation to prey availability and contaminant levels. Several studies investigated patterns and effects of mercury bioaccumulation in loons; most of these are included in the contaminants category. Moose feeding behavior and its effects on aquatic ecosystems has been examined in detail at ISRO. These studies addressed how moose browsing and trampling influence aquatic vegetation in wetlands and lake littoral areas. Muskrat populations have been investigated at VOYA, primarily in relation to lake level fluctuations. Beaver are perhaps the best studied aquatic mammal in this group of parks, with intensive beaver studies conducted at APIS, ISRO, and VOYA. In general, these studies emphasized beaver population ecology, effects of lake level fluctuations on beaver activity and lodges (VOYA), and effects of beaver on aquatic habitats at the landscape scale.

Considerations

- *Beavers as landscape drivers* – Effects of beaver on landscape processes and aquatic habitats have been cited in various park reports, but only at VOYA have attempts been made to quantify these effects over space or time. Monitoring of beaver populations and related landscape changes should be conducted at regular time intervals at many of the GLKN parks (APIS, GRPO, ISRO, PIRO, SACN, SLBE, and VOYA), using aerial photographs or other means.
- *Breeding bird monitoring* – GLKN parks likely provide important breeding grounds for a variety of aquatic-based birds, particularly those associated with shoreline habitats and inland lakes and ponds. Populations of breeding and migrating aquatic birds should be monitored regularly over the long-term, and their habitat requirements should be identified and maintained if possible.

Amphibians and reptiles

Summary

Research on amphibians and reptiles has been very limited in GLKN parks, and available information is quite general. However, most parks have assembled species lists based on known or expected species distributions, and several parks have conducted basic amphibian and reptile surveys. The Great Lakes Network has recently contracted with a herpetology expert at the Milwaukee Public Musem (Dr. Gary Casper) to conduct amphibian inventories at MISS, PIRO, ISRO, and SLBE. To date, most surveys have been conducted using a variety of methods ranging from traps and dip nets to song surveys and opportune hand captures. . Apostle Islands National Lakeshore has had the highest number of amphibian and reptile studies, and was the only park to have been surveyed park-wide prior to the establishment of the GLKN. A number of amphibian studies have been conducted at ISRO, but these have been focused on shoreline splash pools, leaving interior amphibians relatively unexamined. Turtles have been studied intensively at only one park, SACN. Two parks, SACN and VOYA, have been selected for systematic survey and monitoring activities by GLKN and the U.S. Geological Survey's Amphibian and Reptile Monitoring and Inventory program (ARMI). Continued monitoring and analysis of both park-specific and network-wide amphibian patterns are needed to better understand the issue of amphibian population decline as it relates to GLKN parks. Protocols developed through the ARMI program, along with results from Dr. Gary Casper's ongoing work, should help support the development of amphibian and reptile monitoring plans in GLKN parks.

Considerations

- *Amphibian habitat requirements* – Previous amphibian surveys have rarely included detailed information on location or habitat characteristics. As a result, little is known about habitat requirements or quality for most amphibian species in GLKN parks. Useful information might include pool size and hydroperiod, surrounding vegetation, water quality, and fish presence/absence.
- *Amphibian population monitoring* – Most surveys have provided only qualitative information on amphibian densities and populations in GLKN parks. Given mounting global concern about amphibian declines, amphibian population sizes should be monitored more closely and with greater quantification than in the past.
- *Amphibian deformities* – Frog physical deformities have been well-publicized in recent years. The frequency of occurrence for such deformities has been evaluated only at APIS. Future monitoring activities should include some attention to the frequency of deformities and the environmental context of deformed frogs.
- *Survey considerations* – Several amphibian and reptile studies noted that species lists were improved by the use of multiple collection and survey methods. Future monitoring and research protocols may be most successful if multiple survey methods are included.

Wetlands and aquatic vegetation

Summary

Wetland habitats and aquatic vegetation have been addressed in GLKN parks in a variety of ways and to varying degrees. For some parks, insights on aquatic vegetation are limited to brief notes and species lists derived from general ecological surveys, or qualitative maps of aquatic macrophytes derived from basic limnological surveys. Few parks have conducted detailed assessments of wetlands or aquatic vegetation on a park-wide basis; however, a park-wide aquatic vegetation survey is underway at ISRO, and information is available for much of SACN, parts of APIS, and for INDU's large wetland complex. Many wetland studies have emphasized the influence of hydrology on the composition of aquatic vegetation. Research at VOYA has addressed effects of water level fluctuations on aquatic vegetation in the Park's large lakes, research at INDU has addressed effects of water table changes from settling pond seepage, and several studies at SACN noted the importance of flow and hydrologic connectivity with the mainstem river. A handful of studies has addressed exotic wetland species, particularly purple loosestrife. These studies have examined factors regulating purple loosestrife populations as well as potential eradication techniques. Finally, a unique series of studies at ISRO addressed the effects of moose browsing and trampling on aquatic vegetation in ponds and lake littoral zones.

Considerations

- *Park-wide wetland surveys* – Wetlands are widely recognized for their important ecological services, their roles in ecosystem function, and their diversity. While National Wetland Inventory maps are available for most parks, these coverages are frequently imprecise, dated, or inadequate. Detailed wetland surveys on a park-wide basis should be conducted to identify the extent and types of wetland habitats, and to determine their species composition.
- *Understanding hydrology* – Ground and surface water hydrology play an important role in determining the presence and composition of aquatic vegetation. There is a need to improve our understanding of this relationship, particularly in parks where water levels and flow regimes are managed or affected by human activities such as dams or groundwater extraction.
- *Monitoring exotic species* – Several invasive plants represent current and potential threats to wetlands and littoral zones of GLKN parks. Purple loosestrife has so far received the most attention. Monitoring activities should target changes in known populations of aquatic invasive plants as well as potential establishment of new ones.

Contaminants

Summary

A wide variety of contaminants affect water resources in Great Lakes area parks. Some parks are affected directly by localized urban and industrial sources of pollution (e.g., INDU, MISS). Others are vulnerable to runoff and wastewater from surrounding agricultural or metropolitan areas (e.g., INDU, MISS, and SACN). Several parks are primarily affected by contaminants deposited atmospherically (e.g., GRPO, ISRO, PIRO, and VOYA). Industrial contaminants have received the most attention at INDU, where studies have explored the influence of fly ash settling ponds, industrial landfills, and highway runoff on concentrations and toxicity of heavy metals, road salts, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) in park waters. Urban and agricultural contaminants have been investigated most extensively at MISS and SACN, particularly in the Twin Cities Metropolitan Area. Studies at these parks have ranged broadly, addressing VOC contaminants in groundwater, trace metals and pesticides in river water and bed sediments, organochlorine bioaccumulation in fish, and, most recently, effects of hormonally active agents on fish physiology. Due to their more remote locations, contaminant research at several parks (ISRO, PIRO, and VOYA) has focused mainly on atmospherically deposited contaminants. Studies of long-range contaminant transport have been especially common at ISRO. Mercury has been by far the most commonly investigated contaminant in Great Lakes area parks, with particularly intensive research occurring at VOYA and ISRO. Most mercury studies have focused on its bioaccumulation in consumable or charismatic species such as fish and loons; however, recent and ongoing work at VOYA and ISRO aims to understand mercury bioaccumulation in other components of inland lake food webs.

Considerations

- *Contaminant monitoring* – Authors of contaminants studies in GLKN parks have offered various suggestions for future monitoring. They have noted the usefulness of predator fish in detecting and monitoring bioaccumulative contaminants; identified juvenile loon feathers as useful mercury monitoring tools; noted variation in contaminant accumulation in fish and loons according to age, size, and sex; suggested that mussels may be of future use in contaminant studies due to their long lives and relative lack of mobility; and identified ISRO as an excellent location for monitoring long-range atmospheric contaminant transport.
- *Biological effects* – Most contaminant studies in GLKN parks have emphasized the presence and concentration of contaminants relative to known toxic levels for human consumption. With the exception of some reference to reduced loon productivity and fish reproductive impairment in high mercury lakes, little attention has been given to the effects of these contaminants on the organisms themselves. Future studies should address how known levels of contaminants may affect the survival, reproductive biology, and physiology of aquatic biota.
- *Emerging contaminants* – There is increasing interest in personal care product and pharmaceutical chemicals that are released untreated to park waters via wastewater effluent. These may include drugs, detergent byproducts, fragrances, cosmetics, and other chemicals. Some such compounds have been implicated in the feminization of fish and amphibians. Several parks receive significant wastewater inputs (e.g., INDU, MISS, and SACN), and effects of these emerging contaminants on their biota should be further investigated. A study at SACN aims to address this information need for the Riverway (PMIS #108153).
- *Mercury methylation* – Despite indications that mercury bioaccumulation in fish and other organisms is affected by watershed and in-lake mercury methylation, little is known about this process. Future research should address which landscape or lake-specific factors most influence mercury methylation, with special attention to likely factors such as lake level fluctuations (especially at VOYA), sulfur and nitrogen concentrations, and wetland processes.
- *Fuel and oil contamination* – Several studies in GLKN parks have addressed effects of fuel spills and hydrocarbon contaminants on aquatic ecosystems. Many of the parks are vulnerable to such contaminants due the proximity of Great Lakes shipping lanes, the presence of fuel storage tanks for power generation and transportation within park boundaries, and the public use of pleasure boats and personal watercraft in or near park waters. Recognizing the potential for fuel spills and contamination, baseline ecological data should be collected for particularly vulnerable locations and resources. Additionally, spill response plans, such as the one currently under development for ISRO, are needed.
- *Trend analysis* – Most studies indicated that levels of polychlorinated biphyenyls (PCBs) and organochlorine pesticides have declined in fish tissues since the 1970s. Follow-up studies to more consistently monitor these declines would be desirable.

Hydrology

Summary

Many water quality and biological studies have acknowledged the important role of hydrologic processes in GLKN parks, but only a handful of studies have dealt strictly with hydrology. Those studies treating the topic individually focused mainly on stream flow, lake levels, and effects of dams. Stream flow studies explored long-term trends as well as seasonal patterns and flood events. Lake level studies included both inland lakes and the Great Lakes, with inland lake level studies addressing significant fluctuations on VOYA's large lakes as well as more moderate fluctuations on Glen Lake at SLBE. Studies addressing historic fluctuations of the Great Lakes generally focused on how previous lake levels have affected present-day inland water resources. Regulation of dams is an ongoing concern at SACN, SLBE, and

VOYA, and all three parks have devoted research attention to biological effects of the dams. Fluctuating outflows from dams at SACN and SLBE may affect downstream biota, and this possibility has been explored using instream flow investigations at both parks. At VOYA, dam operations have resulted in large lake level fluctuations, and upstream water resources have received the most attention.

Considerations

- *Gage installation and monitoring* – Because hydrology significantly affects water quality, biology, and ecological processes in GLKN parks, there is a need for increased monitoring of stream flow in many locations on a year-round basis. Key gage sites will be those co-located with water quality monitoring sites.
- *Great Lakes lake levels* – Lakes Michigan and Superior have experienced large-scale lake level fluctuations in their history, but are also subject to shorter-term fluctuations as a result of human lake level manipulation, diversion projects, and climate. Effects of these shorter-term fluctuations on nearshore and shoreline resources in GLKN parks may be of interest, and parks should continue to participate in ongoing diversion policy discussions for the Great Lakes Basin.
- *Seiches* – Ecological function and energy transfer from seiche activity would likely be of interest to those parks on Lakes Superior and Michigan that have coastal or riverine resources affected by this phenomenon.
- *Small dams and culverts* – Hydrology in many park streams is affected by small dams, culverts, and regulatory structures. The individual and cumulative effects of such structures on hydrology, water quality, and stream biota should be evaluated, and their potential improvement or removal should be considered where appropriate.

Groundwater

Summary

Groundwater investigations have been conducted in only a few of the Great Lakes area parks. Most studies have taken place at MISS and SACN in the Twin Cities Metropolitan Area, and have focused on basic issues of groundwater quantity and quality. These studies have evaluated geologic features underlying parks; monitored hydraulic heads and withdrawal rates; and analyzed groundwater quality with respect to major ions, pesticides, and volatile organic compounds. Some studies relevant to MISS and the lower part of SACN have primarily addressed groundwater supply and availability, using both current estimations of availability and model projections of groundwater demand and withdrawals. Groundwater-surface water interactions have been suggested in reports from various parks, but only INDU and MISS have explored these interactions quantitatively. At INDU, seepage rates from settling ponds to groundwater have been examined, and groundwater flow models have been constructed to determine effects of ditch dredging on groundwater levels. At MISS, several studies have addressed effects of urbanization on groundwater recharge rates as well as effects of groundwater inputs on surface water hydrology in the Mississippi River.

Considerations

- *Groundwater-surface water interactions* – More thorough investigation of these interactions is needed in many GLKN parks in order to protect wetland vegetation, maintain natural surface water hydrology, and understand the transport of contaminants in either direction.

  - o At MISS, groundwater inputs to the Mississippi River should be monitored, particularly in drought years when surface water levels are reduced and groundwater withdrawals are high. Adequate flows are needed to maintain ecological functions and to dilute inputs of nutrients and sediments from the Minnesota River and Metropolitan Wastewater Treatment Plant.
  - o At SACN and MISS, a better understanding of the groundwatershed and groundwater nutrient inputs to the rivers would help guide nutrient management activities.
  - o At INDU, seepage from ponded surface water to groundwater affects critical wetland habitats via changes in groundwater levels, and also provides a pathway for contaminant transport to groundwater. These interactions should be monitored to ensure success of wetland restoration efforts and to help prevent groundwater contamination.
  - o At SLBE, there is frequent reference to the role of groundwater in stabilizing both lake levels and stream flows. Better information on groundwater-surface water interactions would help guide water level management in the Glen Lake-Crystal River watershed and help protect unique habitats like the Aral marl springs.
- *Groundwater withdrawals* – Rapid population growth and urban development in the vicinity of INDU, MISS, and the lower St. Croix River will place additional pressure on groundwater resources. . The Great Lakes Network parks and the Water Resources Division should participate in future discussions about groundwater withdrawals from the Great Lakes and Mississippi River basins.

Physical processes

Summary

Studies of physical aquatic attributes and processes in Great Lakes area parks fall into four general categories: historic geomorphic processes, modern bank and shoreline erosion processes, dredging and beach nourishment activities, and stream geomorphometry and bed characteristics. Investigations of geomorphologic processes affecting the landscape and water resources throughout the Holocene period and recent post-European history have received considerable attention at PIRO. Modern geomorphic processes and features have often been evaluated against this historic backdrop. Bank and shoreline erosion have been addressed in Great Lakes coastal areas (e.g., APIS and PIRO) and in the St. Croix River, often with reference to recreational pressure and related bank instability. Sediment dredging activities take place annually at the mouth of the Platte River at SLBE and in the Mississippi River at MISS, and beach nourishment activities take place at INDU. Effects of these activities have been addressed only generally. Stream geomorphometry has been addressed in habitat classification studies at SACN, and studies from many parks have indicated the importance of streambed stability and substrate characteristics for benthic biota.

Considerations

- *Shoreline dynamics* – The National Lakeshore parks (APIS, PIRO, SLBE, and INDU) all protect sandy shoreline features susceptible to erosion, mass wasting, and general movement and redistribution. Changes in these dynamic shorelines should be monitored, with specific attention to the role of lake level fluctuations in affecting shoreline processes, the magnitude of the shoreline changes relative to historic variability, and the effects of shoreline changes on shorebird habitat and critical cultural resources.
- *Streambed characteristics* – Dynamic equilibrium (a state of continual change but overall stability in a streambed) along with substrate quality are important to benthic invertebrates, mussels, fish, and aquatic vegetation in rivers. These characteristics can be altered by shifts in surrounding land use. Sediment characteristics and loading should be monitored, particularly at MISS, INDU, PIRO, SACN, and SLBE.

- *River geomorphology* – Channel morphology factors influenced composition and abundance of turtles at SACN, and are likely important habitat factors for fish and aquatic wildlife as well. Geomorphology of large river systems like SACN and MISS should be monitored over time, perhaps via remote sensing.
- *Large woody debris* – Large woody debris has been studied only at SACN, but is likely an important factor shaping stream geomorphology and habitat in many parks. Bank stability, diverse habitat formation, nutrient and energy exchange, and cover for several species are all important features of large wood in streams. Effects of debris dams and large woody debris accumulations on fish and invertebrate habitat could be further explored in GLKN parks.

OVERALL CONSIDERATIONS FOR THE GREAT LAKES NETWORK PARKS

Overall research and monitoring needs

Of the research categories identified in this synthesis document, the strongest knowledge base is available for the fisheries, water quality, and basic aquatic biology categories. While we have identified many remaining needs for future research and monitoring in these categories, basic data needs have been met at most GLKN parks. Other categories, however, have received comparatively little attention Network-wide (e.g., wetlands, amphibians, hydrology, and groundwater) or are in need of further study in the future (e.g., contaminants).

Wetlands and aquatic vegetation, for example, remain relatively unexplored at most parks and baseline inventories and assessments are needed. Amphibians are a taxonomic group of global conservation concern, but data on their distribution, abundance, species composition and habitat requirements are unavailable or unquantified for most GLKN parks. Hydrologic information is critical for understanding water quality and biological data in GLKN parks, and installation of gages in key locations and support for existing U.S. Geological Survey gaging stations may be needed. Groundwater-surface water interactions are important issues, particularly at some of the southern GLKN parks (MISS, INDU, and SLBE). These will require greater attention as population growth and development place increased pressure on groundwater resources. Contaminant studies have taken place in many GLKN parks, and represent a continued and evolving water resource concern.

Several overarching issues affect multiple parks and span many of the research categories we identified in this synthesis. These issues include aquatic nuisance species, contaminants, landscape change, climate change, and fisheries management. Each of these issues would benefit from increased and more coordinated monitoring, research, and management attention on a regional scale.

Aquatic nuisance species

The Great Lakes have a long history of species invasions, and aquatic invasive species are a continuing concern at GLKN parks. The current list of non-native aquatic species in the area includes representatives of many biological groups, including fish, mussels, crayfish, zooplankton, algae, aquatic plants, and more. These and other potential invaders represent perhaps the most significant and imminent biological threat to GLKN aquatic resources. . The Great Lakes Network parks should take all appropriate steps to understand and manage this threat, including:

1) Identifying invasion pathways and preventing species introductions where possible
2) Coordinating outreach and education efforts with organizations such as SeaGrant and other federal and state agencies for effective public outreach and education
3) Conducting baseline surveys of vulnerable habitats or sensitive resources

4) Participating in ongoing regional Rapid Response Planning efforts for aquatic invasive species
5) Conducting monitoring to detect new species introductions
6) Attempting to control or mitigate effects of introduced species
7) Facilitating and conducting research to determine ecological effects of existing invasive species

Because of the regional nature of the threat, its resolution can only be accomplished through coordinated international, interstate, and interagency efforts. The Great Lakes Commission, SeaGrant Institutions, and state or provincial departments of natural resources will be critical partners in these efforts. An increased National Park Service presence in regional invasive species policy and response planning is needed, and may be facilitated through involvement in the recently established Aquatic Nuisance Species Strategy Team, established in 2004 as part of the Great Lakes Task Force Executive Order (refer to http://www.aisstrategyteam.org/ for details).

Contaminants

The Great Lakes region has been affected by a range of pollutants, and both existing and emerging contaminants consistently rank high on the list of regional environmental priorities. Some contaminant issues, such as acid deposition and bioaccumulation of PCBs and organochlorine pesticides, are gradually diminishing in importance due to air quality regulations and manufacturing bans. Others, such as leakage from industrial landfills (e.g., at INDU and MISS), urban runoff (e.g., at INDU, MISS, and SACN), mercury bioaccumulation, and boat-related pollution, are ongoing. Still other contaminant issues have received increased attention in recent years. These include transport and biological effects of newer pesticides (e.g., triazine herbicides) and new persistent bioaccumulative toxins, as well as ecological effects of unstudied wastewater contaminants (e.g., pharmaceuticals and personal care products). Wastewater contaminants are of particular concern for riverine parks (i.e., MISS and SACN) and for parks with high numbers of industrial dischargers (see Table 3, pg. 14, INDU, MISS, and SACN). Coordinated efforts to address the boat-related pollution in all water-based parks, pesticide and wastewater issues in the large river parks, and mercury issues in northern parks (including effects of recent changes in power plant emission standards) would be beneficial. Some of the contaminant issues affecting Great Lakes Network parks are currently being addressed by the Persistent Bioaccumulative Toxics Strategy Team, established in 2004 as part of the Great Lakes Task Force Executive Order (refer to http://www.great-lakes.net/pbtstrategyteam/ for details).

Landscape change

GLKN parks are situated in a complex mosaic of land use, with some parks such as PIRO located adjacent to areas that undergo somewhat regular resource extraction, and others, INDU and MISS for example, located near heavily industrialized and urbanized areas. Others such as SACN and SLBE are located in rural areas and are affected by agricultural activity. Only ISRO is nearly completely isolated from direct impacts of human habitation, although limited resource exploitation occurred there in the past and some signs of this are still evident.

As urbanization and development occur, precipitation runoff patterns change, thus affecting streamflow patterns, surficial water levels, and groundwater storage. Erosional forces will change as streamflow intensity increases with flashier runoff and greater extremes in high and low flow patterns. Riparian vegetation may change, in turn altering instream and lake littoral habitat. In some areas, agricultural activity may actually be in decline compared to several years ago, with reforestation occurring and establishing landscapes that are perhaps more similar to those that existed prior to agricultural development. In parks that are more remote, such as ISRO and VOYA, landscape change can often be attributed less to anthropogenic sources and more to impacts from fire or extensive windthrow, or activities such as beaver dam construction. Other wildlif,e such as moose at ISRO, may also greatly affect both terrestrial and aquatic vegetation growth, potentially leading to moderate scale landscape changes.

Climate change

A recent report produced jointly by the Union of Concerned Scientists and the Ecological Society of America (Kling et al. 2003) provided strong evidence that climate in the Great Lakes region has changed in recent decades and will continue to grow warmer and drier during the twenty-first century. Additional changes will likely include shifts in the seasonal pattern of precipitation and increased intensity and length of precipitation events. The projected changes in climate are expected to cause hydrologic alterations, changes in the thermal qualities of aquatic habitats, and changes in watershed biogeochemistry. Responses of aquatic ecosystems to these changes are expected to be significant and wide-ranging.

Projected hydrologic changes include reductions in stream flow, increased flood intensity and frequency, changes in the seasonal patterns of stream hydrographs, changes in lake levels in the Great Lakes as well as inland lakes, and changes in groundwater recharge and groundwater-surface water interactions. Changes in the thermal qualities of aquatic habitats, such as water temperature, lake stratification, and ice-on and ice-out dates are likely to affect breeding habits of aquatic biota, primary productivity, and responses to nutrient enrichment, and distribution of fish and other aquatic species. Finally, work at ISRO and elsewhere has shown that nutrient and carbon cycling is tightly linked to both precipitation and temperature in northern watersheds. Projected climate changes will thus affect the transport and quality of nutrients and organic matter to aquatic habitats.

The climate change issue is relevant to aquatic ecosystems in all GLKN parks, and understanding and managing its effects will require coordinated research and monitoring efforts. . Isle Royale National Park, due to its remote location, represents a unique environment for continued climate-related watershed studies. . St. Croix National Scenic Riverway spans a latitudinal gradient of more than 320 km (200 miles), and presents an opportunity to monitor changes in species distributions over time. . The Great Lakes Network itself spans a significant climatic gradient, and monitoring and analysis of climate-related shifts from a regional perspective will be useful. Future monitoring efforts should be designed with attention to possible climate-induced changes in species composition or hydrology.

Fish management – stocking, hybridization with exotics, loss of genetic diversity

Fisheries within the parks have been managed primarily by state agencies in the past, with some federal research assistance from the U.S. Fish and Wildlife Service and U.S. Geological Survey. This traditional game species management by state agencies is often in direct conflict with National Park Service fisheries management policies and has created some difficulties when parks attempted to apply their policies towards management of populations within park jurisdiction. Stocking of non-indigenous species has been widespread throughout the states, and parks have been greatly affected by this. Impacts of competition with non-natives as well as stocking practices that introduce outside stocks of the same species have raised concerns among some park resource managers. In light of this, genetics investigations of fish populations have received significant attention at ISRO, and to a lesser degree at PIRO and VOYA. Research at parks has addressed current rehabilitation efforts, concerns related to fisheries impacts from past declines in specific strains of fish, and stocking practices by the states that may compromise genetic integrity of populations. Other genetic concerns in all GLKN watersheds are impacts from invasions of aquatic nuisance species that may hybridize with native species and consequences of the invasion of transgenic fish from aquaculture.

Opportunities for multi-park research and monitoring

As is evident from this synthesis project, parks in the Great Lakes area are each unique, but share a common geographical context and many similar water resources and issues. We have addressed widespread water resource concerns affecting all GLKN parks. Certain resources and issues, however, are most similar for smaller subsets of parks, presenting additional opportunities for coordinated research and monitoring. Some similarities concern analogous aquatic habitats. For example, SLBE and INDU have prominent dune-swale topography and feature interdunal ponds and wetlands. Bar lakes and lagoon-type ecosystems are present at both APIS and SLBE. Inland northern or boreal lakes at ISRO and VOYA present an opportunity for comparative or island biogeographical studies. In addition to their large river qualities, MISS and SACN share similarities in terms of backwater habitats and tributary streams. Sandy shoreline features and processes along the Great Lakes are common to APIS, INDU, PIRO, and SLBE.

Along with these habitat-related similarities are a variety of shared aquatic resource issues among subsets of parks. . Indiana Dunes National Lakeshore and SLBE both face bacterial contamination and beach closure issues. . Indiana Dunes National Lakeshore, MISS, and the southern part of SACN have significant urban development concerns related to waste disposal, urban wastewater and runoff, and groundwater withdrawal. Parks situated immediately adjacent to or in Lakes Michigan and Superior (APIS, INDU, ISRO, PIRO, and SLBE) are susceptible to fuel or oil spills from Great Lakes shipping traffic. To date, spill response strategies are under development at ISRO only. Several northern parks (APIS, GRPO, ISRO, and PIRO) share Lake Superior fisheries issues and have begun coaster brook trout restoration efforts. Finally, while aquatic nuisance species are a concern for all GLKN parks, certain species are of most imminent concern at parks located closest to invaded Great Lakes waters. For example, the spiny water flea is a current concern for parks along Lakes Michigan and Superior (APIS, ISRO, PIRO, and SLBE). These and other parallels in aquatic habitats and water resource issues should provide opportunities to increase operational efficiency and broaden the ecological insights gained from research and monitoring efforts.

Opportunities for coordination with agencies, tribes, and scientific institutions

Most Great Lakes Network parks encompass relatively small land areas, are influenced by factors well beyond their boundaries, and are managed by skilled but small natural resource staffs with limited aquatic expertise. Only VOYA, SACN, and PIRO feature full time aquatic resource professionals. Additionally, many of the Great Lakes Network parks are situated within or next to lands managed by other agencies or entities (e.g., the U.S. Forest Service, U.S. Fish and Wildlife Service, state and local agencies, and various tribes), and many share management jurisdiction of their waters and fisheries resources with the states. For example, the National Lakeshore parks (APIS, INDU, PIRO, and SLBE) have boundaries extending a quarter of a mile into Lake Michigan or Superior, but their jurisdiction is limited to only the surface of the water. Furthermore, inland fisheries at many of the GLKN parks are currently managed by State Departments of Natural Resources or in joint cooperation with them.

These limitations of time and aquatic expertise at GLKN parks, coupled with strong linkages to surrounding landscapes and management entities, makes coordination with other management agencies, tribes, and research institutions essential. First, there is a need for continued cooperation with states on water resource and fisheries ***management*** issues. Second, the Great Lakes Network parks should seek, to the the extent possible, to coordinate their ***monitoring*** strategies with those of the states, the U.S. Geological Survey, the Environmental Protection Agency, and local entities. This would serve to minimize redundancy and strengthen the body of information available to the parks. Third, Great Lakes Network parks should seek to maintain and strengthen their relationships with local and regional *research* institutions. Finally, Great Lakes Network parks should assume a greater role in regional ***policy*** discussions related to the Great Lakes and the Upper Mississippi River Basin. A variety of Great Lakes current policy issues may affect aquatic resources in area parks, including: 1) new ballast water exchange rules; 2) proposed infrastructure improvements to the Great Lakes-St. Lawrence navigation system; and 3) the 2001 Great Lakes Charter Annex Implementing Agreements, which relate to future water diversions. In the Upper Mississippi River Basin, policy and management issues related to MISS and SACN include the prevention of invasive species introductions; mitigation of the Gulf of Mexico hypoxia issue through reduction of nutrient and sediment loading; and commercial navigation issues related to dredging activities, water levels, and the lock and dam system. A continued and enhanced National Park Service presence in regional management, monitoring, research, and policy discussions would help ensure that Park waters and related public interests are protected.

Design considerations

In developing monitoring plans and study designs, decisions about which endpoints to measure are critical. Equally important, however, are decisions about where and how to measure them. Should the selected endpoints be measured at all possible sites, or a subset of sites? What are the best ways to optimize site selection? When should the endpoints be measured, and how often? Should community data be collapsed into simple indices or metrics? While much of this synthesis document has focused on what has been or should be monitored in the future, our review of the literature also provided some insights about site selection, sampling frequency, and biological metrics that merit discussion.

Site selection

Our analysis of basic water resource characteristics demonstrated some patterns in the abundance of water resource types among parks. These patterns have implications for where to focus monitoring efforts in the future. For example, Great Lakes coastal and open water resources are best represented at ISRO and APIS (Table 1, pg. 2). Among Great Lakes Network parks, ISRO and APIS provide the most suitable places to monitor effects of large-lake stressors such as fuel spills, species invasions, and lake level fluctuations. Further, ISRO has jurisdiction over a considerably larger area of Great Lakes waters than other parks (Table 1, pg. 2), and is in a better position to improve protective measures against these stressors. Flowing water resources are best represented in the two river parks, MISS and SACN. . St. Croix National Scenic Riverway, in particular, has the largest number of named streams and protects the greatest length of perennially flowing waters (Table 1, pg. 2). . Mississippi National River and Recreation Area and SACN thus provide the best locations for monitoring biota, ecological processes, and environmental stressors associated with flowing water. Intermittent streams are found in most parks, but are best represented at APIS and SACN (Table 1, pg. 2). Efforts to study the potentially unique biota and vulnerabilities of intermittent streams should focus on these parks, as well as ISRO, MISS, and PIRO. Inland lake resources are most plentiful at ISRO and VOYA (Table 1, pg. 2) and should be focal points of aquatic monitoring programs at both parks. These inland lake resources also provide opportunities for comparative studies of lake chemistry and biota within and between the two parks. Finally, wetland resources appear to be most extensive at ISRO, MISS, and VOYA (Table 1, pg. 2). . Isle Royale National Park and VOYA provide opportunities to monitor boreal and beaver-generated wetland types, whereas MISS provides opportunities to investigate floodplain wetland types.

Many studies reported significant spatial heterogeneity in measurement endpoints among lakes or sampling sites. For example, water chemistry varied significantly among inland lakes at ISRO and VOYA, even within the same watershed (Rapp et al.1985, Kallemeyn 2000). Similarly, sampling sites along the St. Croix River showed wide variation in water quality and assemblages of benthic invertebrates and periphyton (Payne et al. 2002, ZumBerge et al. 2003). Such spatial variability can complicate the selection of representative sites for sampling and monitoring. Often, however, this variability is nonrandom, making it possible to group sites into categories based on similar characteristics. Several of the studies we reviewed acknowledged this possibility and offered suggestions on natural site groupings. To cite a few, Wilcox and Simonin (1987) noted systematic variation in the chemistry and macrophyte composition of INDU's interdunal ponds, with similar ponds situated in sequential dune rows. At ISRO, Larson et al. (2000) identified clusters of lake types based on zooplankton assemblages and water quality. At SACN, Glenn-Lewin et al. (1992) identified several different wetland types along the lower Riverway, and Macbeth et al. (1999) identified river segment types using channel gradient and local geomorphology. In each of these cases as well as others throughout GLKN parks, such site groupings may make it possible to select subsets of sites that adequately represent the natural variability found among park waters.

Sampling frequency

Decisions about sampling frequency and timing should take into account seasonal patterns and the degree of temporal variation exhibited by the monitoring endpoint of interest. Some variables (e.g., temperature) vary diurnally and seasonally, whereas others (e.g., fish community composition) may be more stable. In our review of studies at GLKN parks, two main insights about sampling frequency emerged. First, water quality parameters varied seasonally and in response to snowmelt and storm events. Snowmelt was a particularly strong water chemistry driver in northern parks (e.g., ISRO and PIRO), and rainfall events were particularly influential in river parks (e.g., MISS and SACN). Multiple sampling visits per year, with special attention to snowmelt and storm runoff periods, would be required to understand water quality trends and patterns in most GLKN parks. That said, repeated samplings in several streams at GRPO showed that water chemistry was seasonally coherent among the streams (Grand Portage National Monument 2000), such that intensive temporal sampling at one stream could be used to provide insights on the other two. Secondly, literature from GLKN parks indicated that seasonal variation also occurred in biological communities (e.g., benthic macroinvertebrates and zooplankton) and was seldom accounted for in sampling designs. Long-term monitoring protocols should address this variation by sampling biological components repeatedly during each season, sampling at the same time each year, or utilizing integrative endpoints such as annually deposited diatoms.

Biological metrics

The use of biological metrics in assessment and monitoring has gained popularity over the past two decades, particularly with respect to benthic macroinvertebrates, algae, and fish. Many studies in GLKN parks have surveyed these communities, and data have often been reported as basic metrics such as abundance, species richness, or diversity, with infrequent use of more elaborate biological indices. Many authors noted that these metrics performed poorly with regard to differentiating impacted and unimpacted sites or detecting community-level changes over time and space. Those studies that have used biological metrics successfully in GLKN parks have involved strong disturbance gradients or indices derived from multiple taxonomic groups (e.g., Stewart et al. 1997, 1999, Simon et al. 2000, Stewart et al. 2000). They have emphasized a weight-of-evidence approach. Detecting changes in relatively undisturbed sites over time may require the development of site-specific biological metrics or detailed multivariate analyses with attention to species identities, ecological requirements and tolerances, and species-environment relationships. On the other hand, site-specific metrics often involve distinct protocols for sampling and analysis, making them less comparable to metrics developed by the states or other management entities. Design and use of biological metrics by GLKN should be considered with these issues in mind.

CONCLUSION

National Parks, Lakeshores, and Riverways of GLKN contain some of the most intact and diverse water resources found in the Upper Midwest. Collectively, these park units protect 987 km (613 miles) of Great Lakes coastline and over 183,000 ha (452,000 acres) of nearshore waters in Lakes Michigan and Superior. The parks also preserve 234 km (146 miles) of intermittent streams, 1,272 km (790 miles) of perennially flowing waters, all or part of three regionally significant large rivers, 129 named lakes, and over 43,000 ha (106,000 acres) of wetlands. The impressive extent and variety of water resources in Great Lakes area parks has stimulated many research and monitoring activities in recent decades. To date, however, there has been little effort to synthesize this body of information. We undertook a wide-ranging synthesis of aquatic research in Great Lakes Network parks in order to 1) help guide the development of long-term monitoring strategies; 2) identify common issues and research needs across the Network or subsets of parks; and 3) emphasize the significance of park water resources, issues, and research needs.

In the preparation of this synthesis we reviewed over 600 documents addressing a wide range of aquatic biota, habitats, and resource issues. From this body of literature, we identified ten primary categories of aquatic studies, including water quality, biology and ecology, fish, aquatic wildlife, amphibians and reptiles, wetlands and aquatic vegetation, contaminants, hydrology, groundwater, and physical structure and processes. Each of the reviewed documents was placed into one of these categories and summarized on both a park-by-park and a network-wide basis. Fisheries, water quality, and basic limnological studies have received by far the greatest emphasis network-wide, although a significant number of studies have also provided information on contaminants and hydrology. Fewer studies have addressed wetlands and aquatic vegetation, and only a small number of studies have addressed aquatic wildlife, amphibians and reptiles, groundwater, or physical processes. Total numbers and topics of aquatic studies varied among parks; in general, more studies have been conducted in parks with prominent water resources, and study topics have often focused on local or issue-specific themes.

In addition to compiling and summarizing previous aquatic studies for these parks, we provided both general and category-specific considerations for future research and monitoring. These considerations were based on our analysis of the literature, discussions with park staff, and our own experience, and were expressed on both a park-by-park and a network-wide basis. We also identified several broad aquatic issues affecting all area parks, including aquatic nuisance species, landscape change, contaminants, climate change, and fish management, and suggested ways to pursue monitoring, management, and research coordination on these issues. We outlined specific opportunities for multi-park research and monitoring based on similarities in aquatic habitat types and shared aquatic resource issues. Finally, we offered literature-based recommendations related to monitoring and study design, including considerations for site selection, sampling frequency, and use of biological metrics.

Although one of our objectives was to provide GLKN with a needed summary of aquatic research information and general considerations for future monitoring, this synthesis document may serve other groups and purposes as well. For example, the park planning process generally requires a summary of existing information that may benefit from the list of studies compiled here (e.g., Resource Stewardship Plans, Water Resource Management Plans, and Fisheries Management Plans). The newly funded Watershed Condition Assessment Program will also benefit from such a summary. Additionally, our park-specific recommendations addressed both monitoring and research considerations. Research considerations could be used to stimulate discussion, communicate needs to cooperators, and develop future research proposals. Finally, given the volume of literature included, this synthesis represents a common reference document to be consulted as needed by park managers and shared with interested partners into the future.

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APPENDIX A

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Source Data and Methods for Great Lakes Network Water Resource Statistics

The aquatic summary statistics developed for this document were primarily derived from the National Hydrography Dataset (NHD). The NHD provides nationwide hydrography in geodatabase format, delineated by eight-digit hydrologic unit code boundaries (HUCs). Some units did not include wetland data, and National Wetland Inventory data were used for those areas.

The data, available on-line, is in geographic coordinates, the "high resolution" data is produced from the hydrology drafted on 24k U.S. Geological Survey topographic maps. The high resolution (24k) data is currently available for all parks. The 24k hydrography is the nationally accepted layer for water resources, though many limitations exist with these data in terms of currency (many topographic maps are circa 1970s or earlier), the intermittent drainage is typically not drafted from photo base, and positional accuracy is on the order of 66 feet. More accurate and detailed (12k) data is available for one park in the Network, Apostle Islands National Lakeshore, but this dataset was not used in producing the summary statistics to maintain consistency between parks.

General Methods Used to Create the Aquatic Statistics for all Parks

NHD datasets were downloaded by HUC boundary. All watersheds affecting parks were acquired, including watersheds upstream of park water resources. Only those watersheds within park boundaries were included in the analysis. The NHD geodatabase includes numerous feature datasets, but only the NHDflow, NHDwaterbody and NHDarea were brought into ArcGIS, as these contained the necessary spatial and attribute information to compile the data. Each of these files was converted to a shapefile in order to facilitate easy manipulation (merging adjacent watersheds, clipping to park boundary, length and area calculations). The data were then converted from geographic coordinates, (latitude/longitude), to UTM NAD83 in order to derive length and area measurements. NWI data were typically in NAD27, requiring additional processing to NAD83 using NADCON conversion.

Data for each park were merged, and then clipped to park boundary, (using the Geoprocessing Wizard in ArcGIS). The park boundary coverages were typically converted to shapefiles, and boundary polygons were edited to ensure entire shoreline or river corridor were included in the clip because park boundary files and NHD datasets did not align accurately (due to different source data and scale). This process was done so as not to affect the summary statistics, only to include all length and area measurements within park jurisdiction. This resulted in creating three basic shapefiles for each park, NHD_flow (length measures), NHD_waterbody (area measures of lakes and wetlands), and NHD_area (area measures of large rivers).

The next step involved adding Description fields to the dbf (database file), and linking the FCode (Feature Code) to description field in order to create meaningful attributes rather than coded values. This was done in MS Access, using the original geodatabase files, (NHDFCode). These files were then opened in ArcGIS 8.3, and length and area measures were calculated using X Tools Pro, an extension to ArcGIS. The next step was to query specific components within the data:

Quantity Measures
Named Streams
Named Lakes
Un-named Lakes (defined as non-wetland standing waters greater than 1 ha in area and 1 m in maximum depth)

Length Measures
Perennial Streams
Intermittent Streams
Shoreline Length (Great Lakes only)

Area Measures
Great Lakes Waters Within Park Jurisdiction
Named Lakes
Un-named Lakes
Wetlands

The data were then copied from Access database queries and pasted into Excel spreadsheet format. Both full lists of all stream segments, lakes, and wetlands, as well as summed values for each park were calculated, with Reach Codes included in tables for reference back to source data.

The results from these tables were then synthesized down to basic summary statistics and condensed into Table 1, pg. 2 within the Aquatic Synthesis.

Ulf Gafvert
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APPENDIX B

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Summary Table listing and describing each study reviewed during the aquatic synthesis process. Studies are organized by park and by aquatic research category (refer to Table 2 for research category definitions). Complete references to each study may be found in the literature cited section.

APOSTLE ISLANDS NATIONAL LAKESHORE Back to Table of Contents

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Van Stappen	1999	Natural resources monitoring plan, Apostle Islands National Lakeshore	APIS, park-wide.	Current monitoring program summarized.	Current monitoring: Sandscape vegetation, purple loosestrife, bald eagles, breeding birds, colonial nesting birds, migratory birds, piping plover, ruffed grouse, woodcock, frogs and toads, beaver, water quality, forage fish, river ruffe, mollusks, campsites, bluffs and visitor use.	This monitoring plan provided a good synthesis of current research and monitoring efforts, including those performed by or in cooperation with other agencies. Author also noted future monitoring and inventory needs for the park: Monitoring: Forest vegetation, bears, air quality, and biological indicators. Inventory: Bats, otter, mink, fisher, fox, coyote, snowshoe hare, loons, mergansers, small mammals, amphibians and reptiles, insects, arachnids, deer, coaster brook trout, wetlands, exotic vegetation, ticks, fire weather and fuel loading, visitor use.
Anderson and Stowell	1985	Wildlife management plan for select habitats and species of the Apostle Islands National Lakeshore	APIS, all but 6 islands	Vegetation types identified and mapped. Small mammals trapped, counted, measured and aged. Other animals inventoried by field sign and direct observation.	Found 16 species of amphibians and 3 species of reptiles on the islands inventoried. Intact spruce bogs noted and recommended for protection. Cover type maps provided.	Report provided a fairly comprehensive inventory of APIS wildlife. Management and monitoring recommendations were presented for several animals linked to water resources: cormorants, herons, loons, eagles, gulls, mergansers, beaver, etc.
WATER QUALITY						
National Park Service	1999	Baseline water quality data inventory and analysis: Apostle Islands National Lakeshore	Apostle Islands National Lakeshore and some surrounding area.	Report summarized results of extensive data retrieval efforts using Environmental Protection Agency databases.	# water quality observations: 20,681 # parameters: 479 # monitoring stations (study area/park): 222/44 # parameters with exceedences (study area/park): 6/2 # stream gages (study area/park): 2/0 # dischargers: 6 # drinking water intakes: 0	Authors concluded that water quality at Apostle Islands was generally good, with some issues concerning spring runoff and erosion, marine traffic, atmospheric deposition, recreation, and nearby dischargers, quarrying operations, agricultural and forestry operations.
Balcer and McCauley	1989	Water resources of Apostle Islands National Lakeshore, 1986-1988	Bacteria: Near Outer Island, South Twin, Little Sand Bay, Presque Isle, and Long Island. Twice weekly, 1986-1987. Long Island and Presque Isle peninsula in 1988. Sediments: Near Presque Isle Bay and Oak Island, Presque Isle Harbor. Mid-summer 1986-1987. Water quality: Presque Isle Bay. Aug. 1986, July and Sept. 1987.	Bacteria: Sampled at 3-5 m depths near suspected sources for FC, FS and FC:FS. Sediment: Ponar dredge samples from Presque Isle Bay and Oak Island, analyzed for total solids, TOC, TP, particle size, Hg, and for invertebrate identification and density. 1ft-long sediment cores from Presque Isle Harbor were pooled and analyzed for moisture content, oil and grease, TP, NH_3-N, and TKN. Water Quality: Basic parameters plus Hg measured at Presque Isle Bay, at multiple depths. Basic parameters measured at Outer, Michigan and Stockton Island lagoons, at deepest points. Water quality suite and stream height at gage for Oak Island stream.	Bacteria: Generally very low FC, although Stockton and Long Islands more variable. FS much more abundant and variable than FC. FC:FS seldom exceeded 0.1, indicative of non-human sources. Sediment: Sediments finer grained with higher TP and organic C at Presque Isle than at Oak Island. Hg barely detectable; oil and grease concentrations near the dock low. Benthic invertebrate communities in Lake Superior dominated by oligochaetes, midge larvae and *Pontoporeia.* Water Quality: Presque Isle Bay waters well mixed during mid-summer sampling. TOC, conductivity, and TP all quite low. Michigan Island Lagoon had low levels of dissolved oxygen but did not stratify; waters dilute. Stockton Island Lagoon had higher oxygen levels and was unstratified. Outer Island water quality differed little between its two basins; waters were	Report presents a good broad baseline, but the temporal resolution of the data, except for bacteria, will limit its usefulness for detecting subtle future changes. Future studies will need to better characterize temporal variability in water chemistry and biological communities. Bacteria were monitored at a high frequency level, allowing legitimate comparisons to current conditions at those sites. Net plankton samples exclude much of the phytoplankton community in oligotrophic systems. Future studies should include nannoplankton as well. Authors recommended monitoring contaminants in water, sediments, fish, benthos and zooplankton, along with monitoring for eutrophication effects.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
			Outer, Michigan and Stockton Island lagoons. Twice annually, 1986-1987. Oak Island stream. Weekly, May-Sept. 1986 Benthic invertebrates: Lagoons, and near Presque Isle Bay and Oak Island. Late spring, summer, 1986-1987. Phytoplankton: Little Sand Bay, South Twin Island and Presque Isle Bay. Surface water movements: Presque Isle Harbor. Midsummer, 1987.	Benthic invertebrates: Replicate Ponar grabs from each site, invertebrates identified and counted. Phytoplankton*:* Net phytoplankton collected with tow net and identified to genus. Surface Water Movements: Continuous vector readings from current meter installed at 3-4 m depth. Surface and bottom currents measured weekly at 10 stations on 3 and 10 m depth contours.	dilute and generally acidic. Conductivity, alkalinity and pH of the Oak Island stream ranged from 41-68 mg/L $CaCO_3$, 45-95 umhos/cm^2, and 7-7.5, respectively. Benthic invertebrates: Benthic invertebrates were dominated by midge larvae and oligochaetes. Phytoplankton: Dominant net phytoplankton were *Asterionella, Dinobryon, Tabellaria,* and *Fragillaria* . Surface Water Movements: Highly changeable rather than unidirectional; predominantly from the northwest.	
Rose	1988	Water resources of the Apostle Islands National Lakeshore, Northern Wisconsin	Mainland streams: Sand and Raspberry Rivers, and Red Cliff Creek. 1982-1984. Island streams: Oak Island. June 1983, July 1984. Stockton Island. August 1980, July 1984. Lagoons: Outer Island. July 1983. Michigan Island. August 1984. Lake Superior: Deep Lake Superior waters. July 1981-1982. Shallows near Presque Isle Bay, Rocky-South Twin passage. July 1982-1983.	Mainland Streams: Water quality suite measured a total of 10 times. In 1982, discharge, sediment loads, TP determined for Sand River. Regression equations for TP and sediment loads established. Island Streams: Base flow and water quality suite measured. Lagoons: Morphology, hydrology, and water quality suite measured. Lake Superior: Deepwater areas (>85 ft) sampled at 4 sites, 3 depths at each site plus bottom sediment. Shallow water (<80 ft), heavy use areas monitored at 9 sites each. Parameters were TP, TOC, TIC and Hg measured in water and sediment. Benthic invertebrates collected from sediment, identified and counted for density estimates. Groundwater: Information related to availability, and geological and chemical qualities of wells and well water.	Mainland Streams: Constituents found in highest concentrations at base flow. Suspended sediments and TP positively related to discharge and to each other. 88% of the sediment load was suspended. Island Streams: Many intermittent. Flashy hydrographs, steep gradients, low soil permeability and little basin storage capacity, especially on Oak Island. Constituents found in higher concentrations on Oak Island. At base flow, Oak Island streams dominated by groundwater and Stockton Island streams by seepage from wetlands and beaver ponds. Lagoons: Both lagoons at higher level than Lake Superior and separated from lake by bars. Outer Island bar artificially breached in the past. Shallow lagoon with acidic and dilute chemistry, perhaps due to nearby bog, and no stratification. Michigan Island lagoon is shallow and small, with poor mixing and weak stratification. Chemistry more similar to Lake Superior than to Outer Island lagoon; calcium/magnesium bicarbonate-dominated. Lake Superior: Deepwater water column concentrations of TP, TOC and recoverable Hg low. No pesticides detected. Sediment TP related to % fine-grained sediment. DDE and/or DDT detected at two sites. *Pontoporeia affinis* dominated all sites; Sphaeriid clams also common. Shallow water areas did not, in general, demonstrate	USGS data from 1979-1984 summarized and reported in many useful tables and graphics. Good baseline, but the temporal resolution of most data collection will limit its usefulness for detecting subtle future changes. Author cited a need for detailed monitoring focused on “specific water resources most subject to degradation, such as heavy-use areas of Lake Superior.” Conclusions of no-effect from study of heavy-use areas may be premature. PAH contamination and shoreline disturbance were not reported, but may be occurring. Paleolimnological histories of the lagoons would be scientifically interesting and could be compared with histories of North and South Bar Lakes at SLBE. Specifically, how have species composition, water chemistry and productivity been affected by periodic contact with the big lakes?

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					disturbances from heavy use. Thermal stratification noted at both sites, but dissolved oxygen near saturation at all times and depths. Water column concentrations of TP, TOC and recoverable Hg low and bacteria not detected. In bottom sediments, nutrients and TOC generally higher at Rocky-South Twin site; Hg undetected or low. *Pontoporeia affinis* dominated all sites; Chironomidae (midge family) and Planorbidae (gastropod family) also common.	
U.S. Geological Survey	1980	Data summary of low-flow and water quality reconnaissance survey	3 sites on Sand River, 9 sites on Stockton Island, Red Cliff Bay, Quarry Bay, and Presque Isle Bay. One sample, August 1980	Water sampled for discharge, temperature, dissolved oxygen, specific conductance, pH, fecal coliform, and fecal streptococci. For sites with no flow, water samples were collected from nearby beaver ponds.	Flow zero or very minimal for Stockton Island sites. Temperatures ~20 °C for Stockton Island sites and 14-20 °C for Sand River sites. Dissolved oxygen <5 mg/L at several Stockton Island sites. Specific conductance in Sand River sites ~200, but only 20-50 for Stockton Island sites. pH slightly alkaline for Sand River sites and slightly acidic for Stockton Island sites.	Several of Stockton Island's streams are ephemeral. Persistent streams and nearby beaver ponds are dilute and have relatively low pH and low dissolved oxygen.
BIOLOGY & ECOLOGY						
Lake Superior Ecosystem Research Center	1997	Lake Superior food web: Apostle Islands ONRW	Lake Superior sites: off Outer, Sand, Rocky, Long and Stockton Islands Lagoon sites: Outer, Stockton, Michigan Islands. Summer 1996.	All sites monitored monthly during summer 1996 for basic water quality parameters, nutrients and chlorophyll *a*. Samples collected monthly for zooplankton (net) and benthos (dredge), and preserved for enumeration and identification.	<u>Lake Superior sites</u>: Oligotrophic with respect to nitrogen, phosphorus, chlorophyll *a* and Secchi. Seasonally stable with respect to nutrients and silica. Zooplankton a mix of warm nearshore and cool offshore species, including *Bythotrephes.* Benthos low density and similar to the 1970s. <u>Lagoon sites</u>: Waters warm, nutrient poor, very colored, and acidic. Zooplankton composition variable. Very low benthic organism densities.	Authors supplied recommendations for future monitoring: Fish and feathers as contaminant integrators Benthic invertebrates as indicators of stress Nutrients, zooplankton and benthos as indicators of nutrient enrichment Bacteria as indicators of human fecal contamination.
Doolittle	1991	Monitoring of Phylum Molllusca: Part I. Class Bivalvia, Order Unionoda at the Apostle Islands National Lakeshore	Stockton Island Lagoon, Outer Island Lagoon, Presque Isle Bay, Quarry Bay, Sand Bay, Raspberry Bay, Red Cliff Bay and Chequamegon Bay side of Long Island. August 1991.	Initial SCUBA dive conducted to assess presence of freshwater mussels. When present, two or more 60 m^2 beltline transects and timed random grabs were performed. Mollusks found living or dead were identified, sized, aged, and examined for gravidity. Bottom substrates noted and probed to 1 foot. Video of sampling activities available.	911 mussels (841 live) collected. *Elliptio complanata, Adonata g.* form *grandis, Anodontoides ferussacianus, Anodonta cataracta marginata, Lampsilis radiata siliquiodea,* and *Lasmigona c. complanata* were documented. *Elliptio complanata* dominated at all sites, followed by *Anodonta g.* form *grandis.* Mean density was 9.7 mussels/60 m^2, and highest was 14 mussels/60 m^2 at Long Island sand cut area. Raspberry Bay had greatest richness (5 species) and *A. ferrussacianus* and *L. c. complanata* were found only there. Indications of normal recruitment at most sites. Siltation in Red Cliff Bay cause for concern. Rarity and low numbers of *L. c. complanata* also a cause for concern. Appears that no zebra mussels were found.	*Elliptio complanata, Anodonta g.* form *grandis,* and *Lampsilis radiate siliquoidea* noted as potentially important biomonitoring taxa due to their longevity, abundance, and their role as toxin bioaccumulators. Author suggested additional research focused on growth and recruitment, as well as ongoing monitoring every 5 years. *Elliptio complanata* may be an appropriate species for monitoring contaminants because of their wide distribution and known biology.
Montz	1986	The littoral benthos of Apostle Islands National Lakeshore	5 islands, 7 transects each, 4 depths/transect. Every 4 weeks, May	Ponar grab sampler used in soft substrates. Artificial substrate samplers used for rocky areas. Benthic invertebrates identified to lowest taxa	<u>Two major communities</u>: Rock-rubble communities with sparse, mostly lotic taxa, and soft substrate communities with higher densities and mostly lentic taxa. Soft substrate communities differed whether	Study represents a great baseline data source with important ecological insights regarding species distributions by depth and substrate at APIS.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
			12-October 26, 1984	possible and densities quantified.	sand or vegetation was predominant. Depth gradient: Lower densities in shallow areas. Site characterizations also provided, such as shoreline type, substrate type, etc.	The role of turbulence and disturbance in shaping APIS invertebrate communities was noted frequently; changes in APIS disturbance regimes may affect invertebrate community structure.
Anderson et al.	1983	Basic ecological inventory and recreational resource inventory of Basswood, Manitou and Hermit Islands, Apostle Islands National Lakeshore	APIS, Basswood, Manitou and Hermit Islands.	Soil mapping and analysis conducted. Vegetation surveys conducted and successional trends projected. Mammals, amphibians, reptiles and birds inventoried using traps, field sign, and direct observation.	Vegetation cover maps provided. List of animal species provided. Shoreline nesting gulls inventoried and cormorant colony noted on Gull Island. Basswood Island beavers expected to disappear as quality vegetation is depleted. Variety of herpetofauna found.	Report provides some basic resource information, but information is general and there is little in the way of aquatics. Authors recommended more intensive surveys of herpetofauna.
Brander and Bailey	1983	Environmental assessment: natural resources inventory and management, Apostle Islands National Lakeshore	Apostle Islands National Lakeshore.	Review of several aquatic aspects of APIS ecology provided.	Aquatic life: Benthic organisms have been sampled within the Lakeshore; dominance of pollution-intolerant invertebrates noted. *Cladophora* growths noted but only moderate in extent. Water quality: Several Lake Superior studies summarized briefly; phosphorus enrichment noted in Duluth and Chequamegon Bays. DDT, dieldrin, mercury, PCBs, and asbestos analyzed in fish and sediment; results often indicated contamination. Bacteria levels undetected in open Lake Superior waters.	Report summarizes some previous studies and generally characterizes water quality conditions and aquatic biota in Lake Superior; APIS-specific information is limited.
Anderson et al.	1982	Basic ecological study of Sand Island at Apostle Islands National Lakeshore	Sand Island	Soils and vegetation information assembled. Amphibians and reptiles: Inventoried using 15.2 m drift fences in and around wet areas and decayed logs. Birds: Inventoried by direct observations. Nesting examined with direct counts of nests and young of great blue heron, herring gull and double-crested cormorants.	Amphibians and reptiles: Included eastern garter snake, red-billed snake, 3 salamander species (blue-spotted, 4-toed, and spotted), and 3 anurans (American toad, wood frog, spring peeper). Birds: Species associated with water or aquatic prey included bald eagle, osprey, double-crested cormorant and great blue heron	This is largely a descriptive management document, with emphasis on campsite and trail suitability.
Anderson et al.	1980	Inventory of select Stockton Island resources for recreational planning	Stockton Island: Water samples: Presque Isle Bay, Quarry Bay, Julian Bay, stream mouth and mouth of the lagoon.	Soils and vegetation information assembled. Water samples: Collections analyzed for basic suite, fecal coliform, nutrients. Bank erosion: Evaluated using baseline measurements and monitoring. Animals: Beaver colonies noted from aerial photos and field inspections, and loons and sandhill cranes, surveyed by direct observation. Reptiles and amphibians: Surveyed by searching likely habitat types.	Vegetation: Shrub bog, spruce bog and alder swamp vegetation types present. Water samples: Results showed low fecal coliform levels, mildly acidic low conductivity conditions in streams, indicative of wetland-derived water, and relatively high phosphorus and nitrate levels were found in Lake Superior waters. Bank erosion: Rates averaged 0.03 m^2/m during June-September, and were highest at sites with moderate to heavy use. Animals: 21 beaver colonies documented and available winter food sources noted; 3 sandhill cranes observed regularly in bogs and upland sand dune; 16 non-breeding loons documented. Reptiles and amphibians: 2 snake, 1 turtle, 5 frog/toad, and 3 salamander species were found.	This is largely a descriptive management document with emphasis on recreational management. Authors suggested the impact of commercial fishing on local loon populations was worth some further investigation.
Anderson et al.	1979	Basic ecological study of Outer Island, Apostle	Outer Island sites including lagoons	Water quality: Analyzed for basic suite in July/August.	Water quality: Warm, acidic, low in conductivity and hardness, and variable in nutrients and dissolved	Sampling seems spatially thorough, and species lists should be useful.

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		Islands National Lakeshore	and beaver flowages, 1978.	Aquatic vegetation: Identified along existing trails, bogs, and flowages and lagoons. Fish: Collected from lagoon by electrofishing and seining and from beaver flowages with funnel traps. Invertebrates: Collected from lagoon and flowages with dip nets and an Ekman dredge. Amphibians and reptiles: Observed and recorded incidentally; salamanders collected in drop cans. Plankton: Collected using a Wisconsin net in lagoons, or by bucket in flowages. Beaver: Locations determined by field inspection and aerial census in November.	oxygen. Aquatic vegetation: Detailed species lists provided for several aquatic-semiaquatic habitat types. Lagoon edges, bog areas, open water areas covered 170 ha or 5% of Outer Island. Fish: northern pike and central mud minnow captured in lagoon; brook stickleback captured in flowages. Amphibians and reptiles: 9 herptiles recorded (3 reptiles and 6 amphibians); habitat recorded. Invertebrates: Taxa list provided. Plankton: Taxa list provided. Beaver: Presence noted after 1938 and before 1963; 33 family colonies and 13 single or pair colonies.	Author noted that beavers strongly influenced stream drainage patterns on Outer Island.
Stern	1979	The freshwater mollusks (Gastropoda and Bivalvia) of the Apostle Islands and adjacent mainland	12 islands and 3 adjacent mainland sites. July-August 1979.	Habitats sampled included streams, beaver flowages, lagoons, shorelines. Mollusks collected, preserved and identified, with vouchers kept at UW-Stevens Point.	Gastropods were found in high relative abundance at island sites, but with lower species diversity than on mainland sites and at ISRO. Bivalvia were confined to beaver ponds, natural ponds, and lagoons on islands and were less diverse than on mainland or ISRO. Sphaeriids were dominant; a single species of Unionidae was collected from Stockton Island, and an additional unionid was collected from a mainland stream outlet. Archaeological sites on Madeline Island hint that unionids were more common historically. No endemic or T&E species collected.	This survey provides a good baseline, but is now dated. Given the potential for exotic mussel invasions, a new survey effort may be in order. Methods are not clearly stated, so data cannot be reliably compared with those of Doolittle (1991). A research project could follow up on the suggestion that unionid fauna were historically more common at APIS.
Stadnyk et al.	1974	An ecological survey and environmental impact study of Stockton Island, Apostle Islands National Lakeshore	Stockton Island. Early 1970s.	Water samples collected from Quarry Bay, Quarry Bay Bog, and a stream near Presque Isle Bay and analyzed for core water quality suite. Zooplankton collected from Quarry Bay Marsh. Fish fauna collected from bogs, marshes and streams. Amphibians collected.	Water quality: pH and alkalinity low in the bog and stream sites; higher in Presque Isle Bay. Several well-developed bogs noted and vegetation map included. Fish: Northern redbelly dace, golden shiner, brook stickleback, central mudminnow, and black bullhead. Amphibians: American toad, wood frog, spring peeper, mink frog, northern cricket frog and red-backed salamander. Zooplankton: Species in marsh very different than those in Lake Superior.	Report provides some basic resource information, but sampling effort was too limited to provide much insight about water quality and zooplankton in particular.
Winter	1971	Water quality and trophic condition of Lake Superior (Wisconsin Waters)	APIS, sampling transects at stations 1, 2.5 and 5 km from shore. Additional transect between the MN and WI borders with 11 sites in 113 km.	Water chemistry: Basic parameters analyzed. Bottom sediments: Sampled with a Peterson dredge; visual observations made. Benthos: Sampled by Peterson dredge, identified to genus and categorized according to sensitivity to organic pollution or low DO. Seston: Collected with a Clarke-Bumpus sampler, analyzed for total, fixed and volatile solids. *Cladophora*: Examined by visual observation. Comparisons of Apostle Island sites with those in nearby bays and tributaries provided.	Water chemistry: Near saturation away from industrial inputs. TP and inorganic and organic N were “low” around APIS (0.18, 0.1 and 0.242 mg/L, respectively) relative to nearby sites. Turbidity for APIS region was also lowest (1.06), and transparency varied with distance from shore. Bottom sediments: Highly variable composition. Benthos: *Pontoporeia* was most common sensitive organism. *Hexagenia* was also found. Highest densities were found in silt substrates. Seston: Copepods, cladocerans and ostracods most common. *Melosira* and *Tabellaria* common diatoms. Few blue-green algae noted. *Cladophora*: Present but not nuisance-level.	A good baseline characterization of Lake Superior waters at APIS, including data tables. Author noted difficulty in measuring differences or changes in such a dilute system. Presumably methods have advanced since 1971 and this is no longer as difficult.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
Hiltunen	1969	Invertebrate macrobenthos of western Lake Superior	16 stations near Apostle Islands in June 1964. 3 stations in June July and August from 1959-1963. 3 stations in July 1967.	Peterson dredge samples collected, preserved, counted and identified to species where possible. Plankton tows conducted in 1964 for fish fry capture.	First record of Neorhabdocoela (flatworm group). Oligochaete fauna similar to other Great Lakes. Two species of leeches and one species of amphipod (*Pontoporeia affinis*-the most abundant benthic organism) were found. Ostracods were lost to screening. Dipteran larvae were generally Tendipedidae and most diverse in shallower areas. One species of snail and two mollusk genera noted. Plankton tows yielded a hydra, some *Hyalella azteca,* two naidid worms, *Mysis relicta,* and exuvia of midges and mayflies. Fauna similar to the other Great Lakes, although *Pontoporeia affinis* may be much less dense in Lake Superior.	Study provides a good older baseline for invertebrate taxa; describes benthic fauna composition three decades ago.
FISH						
National Biological Survey	1995	Fishes of Apostle Islands National Lakeshore 1963-1994, with emphasis on trends in abundance, bathymetric distribution, and toxic contaminants	Synthesis of existing data	Summarized fish abundance data by species and year Summarized bathymetric distribution by season of major species Summarized all information on toxics in fish	Provides good information on fish distribution and abundance. General information about specific contaminants and implications for fish at APIS is discussed in report. Developed recommendations for sampling protocols	There remains a need for more information on fish contaminants around APIS Contaminants information was lacking, which compromised report summary.
Hudson et al.	1995	Predator-prey relations and competition for food between age-0 lake trout and slimy sculpins in the Apostle Island region of Lake Superior	June-September, 1988 through 1991. Gull Island Shoal and near Michigan Island	Investigated diets of 511 age 0 lake trout and 562 sculpins collected at lake trout spawning reef (Gull I. Shoal) and rearing area (Michigan I. Area)	*Mysis* was dominant food for lake trout comprising 68% of food volume in stomachs and in ¾ of fish examined. *Mysis* dominated diet at nursery but diets were more diverse on the reef than on nursery area. *Mysis* was also important for sculpin over the spawning reef, but not the rearing area. Sculpins also consumed some lake trout eggs in November	Sculpins examined as a culprit in the decline or slow recovery of salmonid population. Authors suggested that in Lake Superior, where natural lake trout production is well established, the coexistence of the two species appears “amicable.” However they also suggested that in areas with higher sculpin to lake trout ratios on reefs, the coexistence of the two species may create a bottleneck for age-0 lake trout.
Bronte et al	1995	Density-independent survival of wild lake trout in the Apostle Islands area of Lake Superior.	Lake trout age data, Gull Island Shoal. From 1960s.	Evaluated abundance of wild age 0 recruits and the number of age 7-11 fish recruited to the fishable stock. Used Varley-Gradwell method to test for density-dependent survival between these life stages.	Found that survival from age-0 to age 7-11 was not affected by increasing density, suggesting that further increases in recruitment and stock size were still possible.	Not familiar with Varley-Gradwell method; and only abstract and first page of document reviewed, so method description not available. Authors suggested that testing for density dependent survival can be used to indicate recovery of lake trout populations.
Slade	1994	Fisheries surveys of Oak Island tributaries at Apostle Islands National Lakeshore	Oak Island, One sample. June 1994	Standard stream electrofishing surveys in “Trib 6” and “Trib 7.” Memo to APIS resource manager.	“Trib 7,” found juvenile brook trout only. “Trib 6,” brook trout and one slimy sculpin. All brook trout appeared to be juveniles, but this was based on size, not age; apparently no scales were taken. Adult habitat appears limited.	Demonstrates need for additional information on numbers and sizes. Report referenced earlier efforts in 1983 with suggested future sampling; neither earlier report nor results found for this review. Assumed brook trout were part of coaster population since instream habitat for larger fish is lacking or possibly intermittent. Indicated genetic samples were to be collected in 1995.
McCauly et al.	1989	Abundance and distribution of forage fishes in the Apostle Islands National Lakeshore	5 sites around islands sampled	Trawl sampling used to determine distribution and abundance Sites chosen in consultation with park staff for even spatial distribution.	Documented 17 species. Samples taken for contaminant analyses, but results not presented.	The contaminant results would provide useful comparison to other studies. Basic information for comparison with other efforts near APIS and in the Lake Superior Basin

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
Bronte	1987	Results of the 1986 spring lake trout assessment in management units MI-2 and WI-2 of Lake Superior.	Sampled areas not covered by Wisconsin Department of Natural Resources within APIS. Also examined Michigan waters adjacent to this management unit.	Compared wild/hatchery catch per effort with Wisconsin Department of Natural Resources results in other areas of the same management zone.	Reported amount of gill net fished, catch per effort, number of year classes, fish length, annual mortality, and other fishery management statistics. Seventeen year classes of lake trout were observed.	Provides standardized data for comparison with other years and current status. Park may want to acquire documents from Wisconsin Department of Natural Resources or Red Cliff tribal offices for assessments conducted in subsequent years.
Bronte et al.	1986	Red Cliff commercial fishery statistics for the Wisconsin waters of Lake Superior, fishing year 1986.	Nov. 1985 to Nov. 1986.	Effort and yield for 15 species of fish in APIS area	Provides age and size (growth) information for 6 species	Park should acquire subsequent commercial fishery reports from Red Cliff, if available.
Sigurd Olson Environmental Institute and The Center for the Great Lakes	1984	Lake Superior: The state of the lake	Status and trends	Symposium at Northland College. General information including biology, chemistry water use conflicts, land use impacts in Lake Superior watershed.		Recommendations for Lake Superior management would be worth reviewing to see how they compare with current recommendations from the Great Lakes Regional Working Group as part of the Great Lake Annex 2001 initiative
Wisconsin Department of Natural Resources	1984	Wisconsin Department of Natural Resources, Report to Lake Superior Committee	Summary. 1970-1982.	Reported on commercial and sport fishing and lake management agreement with Red Cliff band.	Gull island lake trout populations were healthy, but other areas remain suppressed, purportedly due to heavy fishing pressure. Herring populations varied; 1970-1975; year classes were poor or very poor 1976; strong year class 1977; very poor 1978; strong 1979; fair 1980; Very strong 1981; strong 1982; poor	Report presented to Lake Superior Commission on lake trout rehabilitation efforts. Theory for differences in herring year class strength not presented, but may merit investigation.
Bronte and Gurnoe	1983	Walleye assessment fishery in southwest Lake Superior	Extreme western area of Apostle Islands and further west. July-September 1983	Assessed commercial fishery west of APIS Age, size, sex, growth, mortality, population estimates. Similar to Busiahn (1982).	Determined that continuation of a 5,000 lb commercial fishery (annual) was feasible, based on this pilot fishery.	Investigate continuance of walleye fishery subsequent to this report.
Busiahn	1983	Abundance, origin, and age composition of pre-recruit lake trout in the Apostle Islands, 1983	Devil's Island. June-July 1983. Sand Island. September 1983.	Continues work conducted in 1982. Used gill nets to survey sub-legal lake trout abundance. Abundance estimates by year class. Also reported on routine sampling of commercial catches of sub-legal sized lake trout.	Gives distribution information and relative survival of stocked lake trout Indicated significant eastward movement of fish stocked west of the Sand Island survey area. Suggested that lake trout stocked as fingerlings offshore on Devils Island Shoal was considerably less than that of onshore yearling plants.	Similar comments in 1982 survey. Did not indicate if greater abundance of stocked yearling classes was due to better survival or greater rate of site fidelity/homing by those fish. This information might be useful for brook trout stocking efforts.
Busiahn	1983	Assessment of lake trout spawning in the western Apostle Islands, 1983	Same area as 1982 plus locations west of Cornucopia and	Added additional net sizes to this year's assessment and used 14,000 ft of gill net – 8,400 ft more than 1982 surveys.	Similar results as 1982. Squaw Point had most spawning fish.	Compare with cruise report from US Fish and Wildlife Service.

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			east to Bear and Raspberry Islands.			
Busiahn	1983	Changes in condition and growth of lake trout in the Apostle Islands	Summarized samples from commercial catch in APIS area.	Fish sampling from commercial catch. Length:weight relationship analyzed.	Appeared that fish around APIS actually lost weight, due possibly to declines in smelt prey base.	Presentation at 5th APIS research conference. Determine if further investigations by USFWS or Lake Superior Technical Committee are available on this subject.
Pycha	1983	Sea lamprey wounding rates on lake trout in Lake Superior, 1982	Compiled information presented to Great Lakes Fishery Commission, March 1983	Consolidated report for all sea lamprey wounding for all jurisdictions bordering Lake Superior.	Great Lakes Fish Commission presentation provides information on sea lamprey woundings of Lake trout in Lake Superior – not APIS specific. In Wisconsin, wounding rates increased on smaller fish (17.0-20.9 inches) but fell sharply on larger fish sampled (25.0 inches and greater)	Although not specific to Apostle Islands, could be useful for comparisons with more current data from similar areas to determine if sea lamprey threat in region is increasing or decreasing.
US Fish and Wildlife Service	1983	Lake trout spawning assessment in the APIS area	Cruise Report		Information on reefs fished, numbers captured, compares results with previous efforts	Cruise reports need to be compared to of Busiahn and Red Cliff surveys for same years.
Wisconsin Department of Natural Resources	1983	Wisconsin Department of Natural Resources, Status of fish stocks – Wisconsin waters of Lake Superior	Status of management, summary report.	Lake trout data for Gull and Michigan Island areas and other Chequamegon Bay areas outside APIS. Similar information at Devil's Island. Limited information for populations and fishery for whitefish, herring, smelt, and salmon. Commercial production for lake trout, whitefish, chub, siscowet, smelt, and herring. Sport fishing creel information. Proposed stocking information.	Gull-Michigan island shoal lake trout population continued trend of increasing abundance of native spawning population. Other Apostle Island spawning reef lake trout populations remained low. Suggested direct stocking of yearlings on Devil's Island Shoal appeared to be a failure.	Presentation at meeting Lake Superior Committee, Great Lakes Fishery Commission. Make direct comparisons with Busiahn's 1983 investigations. Although Busiahn said stocked fingerlings at Devil's Island were considerably less than onshore stocked fish, he did not describe the effort as a failure as Wisconsin Department of Natural Resources did. Determine if subsequent investigations were carried out and what was found. Determine if any Devil's Island stocked fish were recovered at later dates.
Busiahn	1982	Assessment of lake trout spawning in the western Apostle Islands, 1982	6 areas of extreme western end of Apostle Islands area. 19-27 October 1982.	5,600 ft of gill net fished overnight throughout period. Also tagged and released lake trout for homing and survival study. Released all live lake trout. Relative abundance, age, origin (hatchery vs. wild) of lake trout at suspected spawning areas.	Oldest lake trout was from 1974 year class. Captured native lake trout from 1974-1977 year classes indicating successful reproduction from 1973-1976. Most abundant stocked year class was from 1975. Eagle island shoal appears to be area with most suitable spawning habitat.	Author suggested that stocked 1975 year class was expected to make up a large proportion of mature lake trout in Apostle Islands for years to come. Investigate if this was ultimately the case and try to determine why this year class was so successful. May be difficult to determine this if sampling was not done during 1980s.
Busiahn	1982	Abundance, origin, and age composition of pre-recruit lake trout near Devil's Island Lake Superior, 1982	Devil's, Sand and Eagle Islands. 1982	Abundance estimates by year class	Gives distribution information and relative survival of stocked lake trout fingerlings, which was considerably less than previous yearling plants.	Did not indicate if greater abundance of stocked yearling classes was due to better survival or greater rate of site fidelity/homing by those fish. This information might be useful for brook trout stocking efforts.
Busiahn	1982	Walleye assessment fishery in southwestern Lake Superior, 1982.	Areas adjacent to APIS. 1982	Commercial fishery assessment – Red Cliff Band (similar to 1981 fishery). Objectives: allow controlled harvest, and collect basic biological and fishery data to help determine productive potential of walleye	Reports general catch, growth, mortality, age, size and sex composition information.	Compare with 1983 report and determine if commercial fishery was continued after that point. If continued past 1983, compare all years where data is available to determine trends in fishery.
Wisconsin Department of Natural Resources	1982	Lake management plan-Wisconsin waters of Lake Superior	Wisconsin waters of Lake Superior, including APIS	Primarily targeting lake trout fishery and regulations that would incorporate refuge areas and fishing areas; included APIS area	Evaluated 5 alternatives creating a mix of sport, commercial and tribal harvest plus both permanent and seasonal refuge areas.	Determine if there is a follow up document that describes the effect or success of implementing this management plan.
Pycha	1981	Sea lamprey wounding rates on lake trout in U.S.	US waters of Lake Superior	Compiled information presented to Great Lakes Fishery Commission, December 1981. First	Great Lakes Fish Commission presentation provides information on sea lamprey woundings of lake trout in	Although not specific to Apostle Islands, could be useful for comparisons with more current data from

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		waters of Lake Superior, 1981		attempt to provide consolidated report for all sea lamprey wounding for all jurisdictions bordering Lake Superior.	Lake Superior in general, not APIS specific. Wisconsin wounding rate had trebled in two years and was as high as rate in Michigan.	similar areas to determine if sea lamprey threat in region is increasing or decreasing.
Coberly and Horrall	1980	Fish spawning grounds in waters of the Great Lakes	–	UW Madison Sea Grant Institute	–	Listed by Apostle Islands as occurring in files but not located. Need to find document.
Dean	1980	Fishery program, Apostle Islands National Lakeshore	Mouth of Sand River, Oak Island streams, Outer Island lagoon. One time, summer 1979.	Basic fish presence investigations by electrofishing and creel surveys..	Sand River mouth: 11 species sampled by electrofishing; yellow perch 37% of captures, white sucker 39%, walleye and northern pike also captured. “No other species were significantly represented.” Oak Island, small permanent unnamed stream on south side of island: Classified as “class II trout stream:” 3 brook trout (3.5-5.5 in) and 2 sculpin captured Outer Island Lagoon: 1 northern pike (4.6 in) Four anglers had 3 northern pike (16-20 in). “Old timers” report that lagoon had been open to Lake Superior within past 30 years but was closed during survey by 4 ft-high sand berm.	Update investigations would be useful, especially in light of ruffe invasion and documentation of species at Sand River.
Horal et al.	1980	Surveys of lake trout reefs and a study of factors influencing the reestablishment of self sustaining stocks of lake trout	Devil’s Island and Sand Cut Shoal	Looked at lake current, speed and direction and temperature near Gull Island.	Investigation was to gather information for use in Lake Michigan lake trout restoration efforts.	–
Weimer	1980	Lake trout: the second time around	–	–	Primarily a Lake Michigan restoration effort, but mentions populations and natural reproduction occurring near APIS	–
Albrecht	1975	The Chequamegon Bay Apostle Islands fishery	–	Describes physical, chemical characteristics of are and why productivity is relatively high. Also presented some Wisconsin Department of Natural Resources fish productivity information.	Symposium presenting information on biological, social, economic, and legal aspects of area fishery. Meant to enhance communication between area fishermen.	This appears to be a symposium presented during a time of difficulty and transition regarding Native American fisheries. Apparently, information on growth of walleye, lake trout, and whitefish in that area was limited or unavailable.
Bailey	1972	Age, growth, reproduction and food of the burbot, *Lota lota* (Linnaeus), in southwestern Lake Superior	3 areas of southern Lake Superior: 7 sites around Apostle Islands. 1966-1969.	Age determination with otoliths. Length: weight relationship analyzed. Gill net and trawl samples to determine size at maturity.	Inconclusive information for spawning time, but most Bayfield area fish had spawned by late February; some offshore APIS fish collected in January and March had not spawned. Indicates possible protracted spawning times. Fish taken in January fed almost exclusively on fish (97%); smelt and chubs were primary prey. Volume of crustaceans in diet increased in April-June (principally *Pontoporeia affinis*) and preferred fish became smaller cottids. *Mysis* became more common in diet later in summer and early fall.	Most characteristics were compared with other large lakes such as Lakes Winnipeg and Erie. Would be very useful for comparisons with contemporary populations to see if prey base and any characteristics previously studied have changed.
Bailey	1969	Age growth and maturity of the longnose sucker, *Catostomus catostomus*, of western Lake Superior	5 sites at or near APIS. March-November 1964. May-October 1965.	Gill net and trawl sampling. Also took some fish from sea lamprey barrier on Brule River, WI.	Collected 1760 fish in western Lake Superior. Abundant specific statistics on length and weight at maturity, fecundity, spawning and rearing.	Good information for comparisons with contemporary populations.
Bailey	1964	Age, growth, maturity and	Chequamegon Bay,	Used 1-1.5 in gill net both at bottom and	Collected 4561 smelt. Large overlap of length at age	Estimated that yearly sport catch by smelt dippers

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		sex composition of the American smelt, *Osmerus mordax* (Mitchill), of western Lake Superior	APIS, Brule River, Superior Harbor. January- March 1960-1961.	suspended under ice. Also sampled April-December with standard gang gill nets. Otter trawls from US Bureau of Commercial Fisheries Research vessel Siscowet. Brule River fish collected at lamprey barrier.	made length a poor indicator of age. All smelt greater than 2 yrs were mature. Fecundity averaged 31,338 eggs/female at lengths of 7.3-8.8 inches. Commercial production in Great Lakes peaked at nearly 16 million pounds in 1960; including 948,000 pounds in Lake Superior.	may be almost double the commercial catch as based on estimates from Green Bay. Compare available information on feeding habits and growth of lake trout and other Lake Superior predators as it relates to smelt fishery and abundance.
Dryer	1964	Movement, growth and rate of recapture of whitefish tagged in the APIS area of Lake Superior	APIS area, various sites. November 1959-1961; June-July 1960.	Mark and recapture survey of 1303 whitefish equipped with spaghetti tags. Estimated exploitation rates from recovery statistics. Estimated growth rates from returns.	Less than half of recoveries were within 5 miles of tag site. Greatest movement was 25 miles.	–
Bailey	1963	Age, growth and maturity of round whitefish of the Apostle Islands and Isle Royale regions, Lake Superior	APIS area; 1958-1960. ISRO; 1958, 1960.	Nine nylon gill nets, 300 ft in length with 1-5 in mesh, set end to end on bottom. Otter trawl sample obtained at APIS on April 30, 1959.	Collected 1173 fish at APIS, including 36 by otter trawl. Collected 103 fish at ISRO. Average age was 4.2 yr at APIS, 6.0 yr at ISRO. Takes 7 years to reach commercially acceptable size of 14 inches at both sites. Males mature as age 5, females mature at age 6.	Most data appears to be generated for commercial fishery information
Eschmeyer and Bailey	1954	The pygmy whitefish, *Coregonus coulteri*, in Lake Superior	Keweenaw Bay, Siskiwit Bay at Isle Royale, and Apostle Islands. 1952-1953.	Bottom trawls.	Collected 1623 fish ranging from 1.2-5.7 in and averaging 3.4 inches. APIS populations had fastest growth rate. Males mature at age 2 and total length of 3.6 inches. Most females mature at age 3 and 4.2 inches. Spawning in 1953 occurred in November or December. 77% of food volume consisted of crustaceans, primarily ostracods and amphipods, with copepods found in young fish.	Fish previously reported only from northwestern U.S. Represents a disjunction in range between Lake Superior and the Columbia River basin.
AQUATIC WILDLIFE						
Smith and Jenkins	1994	Population dynamics of beavers in two unexploited populations	VOYA, 2 large lake sites, 1984-1986; inland sites, 1991-1993. APIS, 2 island sites, 1988-1989.	Live-trapping in September or October. Beaver tagged, sexed, and measured for mass, length, zygomatic arch, tail length, and width and length of hind foot. Age classes assessed. Forest composition determined using 30 m transects perpendicular to the water's edge.	Total of 804 beavers captured. Age structure and number of kits per family differed between VOYA and APIS, but family sizes were similar. Recruitment did not occur in beaver colonies that were resource limited. Populations were biased toward females. Aspen abundance and population density likely affected sex ratios, with higher male mortality at higher densities. Trend is toward fewer, entrenched family colonies rather than numerous, small, productive colonies.	More thorough data presentation and analysis is desirable. Authors addressed management implications of their study and suggested that regional population trajectories should help guide management decisions. Authors suggested future studies using molecular techniques to examine beaver social structure and polygyny, and adaptive management experiments.
Smith and Peterson	1991	Beaver ecology in Apostle Islands National Lakeshore	APIS-wide, November 1987-May 1990.	Examined aerial photographs from 1938 forward. Conducted two complete aerial counts of active beaver lodges and visited impounded drainages. Captured beavers by live trapping. Determined productivity, movements, family size, and physical characteristics. Assessed forest type and cutting preferences and estimated pond water levels.	Most beaver activity was observed on Stockton and Outer Islands. Beaver populations declined from 1979-1989. APIS beaver population was 159 in 1989. 118 beavers trapped, measured and tagged. Colony size averaged 5.3, and productivity was low; only 16% of catch were YOY. Beavers moved between ponds, but not far. Beavers subsisted on poor quality paper and yellow birch, mountain maple and shrubs. Aquatic vegetation scarce in beaver ponds due to	In general, APIS beavers had low fecundity, poor food resources, variable water levels, site instability and bear predation issues; however, core areas for permanent beaver occupation were present. Authors offered 5 beaver management options and discussed probable outcomes of each. Authors suggested a monitoring regime consisting of aerial surveys every 1-3 years and transect habitat or beaver cutting surveys every 3-5 years. They also suggested bear scat content monitoring and live trapping for more detailed information.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					fluctuating water levels. Black bears preyed on Stockton Island beavers.	
Craven et al.	1984	Ecology of the double-crested cormorant in the Apostle Islands with special emphasis on food habits and depredation abatement	Primarily the Gull Island colony. May-October 1983 and May-September 1984.	Counted birds by 4 aerial surveys in 1983. Fishing nets censused. Cormorants on Gull Island banded and aged. Feeding activity observed, and pellets and regurgitation materials examined. Deterrent techniques tested at experimental net sites.	Gull Island colony the only one known in the area, although some non-breeding cormorants roost at Eagle, Little Manitou and Hermit Island Rock. Colony population increased dramatically from discovery in 1978 to 243 pairs in 1984. Opportunistic feeders, with small forage fish taken most frequently, rarely whitefish or trout. Cormorants adjusted to all abatement devices, although combined techniques worked best. Some fisheries losses occurring.	Authors recommended annual surveys to determine size of Gull Island colony and to verify presence/absence of nesting cormorants in all suitable APIS habitat. Regarding the fisheries issue, authors recommended an "integrated approach of abatement, possible compensation programs or incentives, and long-term monitoring."
Matteson	1979	Status of breeding gulls and terns on the Wisconsin shore of Lake Superior in 1979	Along shores of Bayfield Peninsula, Chequamegon Bay, Long Island, and the Apostle Islands. May 22-June 6 and July 2-13, 1979.	Note: Methods represent a repeat of previous survey in 1974. <u>May and June</u>: Motorboats and canoes used to locate, count and map all nesting pairs of gulls and terns. Nest parameters (height above water, distance to cliff top or forest floor, accessibility to predators) and egg production documented. Collected 7 Herring Gull eggs for PCB, DDE and HCB analysis. <u>July</u>: Selected 11 island colonies for gull reproductive success study.	<u>Herring gull</u>: 1052 nesting pairs documented; cliffs were preferred nest sites, average clutch size of 3 eggs, 5% population increase since 1974 survey. Higher contaminant levels in some gulls may have been due to wintering on Lake Michigan. <u>Ring-billed gull</u>: 98 nesting pairs in Gull Island colony, 80+ pairs in Long Island colony; both sites up from 1974. Eggs laid on pebble-stone beaches; undetermined if total reproductive failure was due to Herring Gull aggression or severe weather. <u>Common tern</u>: 50 pairs documented, down from 56 in 1974, in 2 colonies at Washburn boat landing and Ashland pier. Reproductive success low due to human disturbance and possibly conflicts with gulls. <u>Piping plover</u>: Total of 3 pairs found on Long Island and Chequamegon Point; plovers appeared very susceptible to human disturbance. <u>Double-crested cormorant</u>: 41 pairs documented on Gull Island. <u>Great blue heron</u>: New rookery discovered on Michigan Island.	Author provided specific recommendations for management and protection of gulls and terns, including habitat improvements for common terns and exclusion of boats and humans from certain islands during the breeding season. Author recommended that similar studies be repeated every 5 years, and that further research should more specifically address the possible effects of human activities on gull, tern, and plover breeding ecology.
Amphibians and Reptiles						
Casper	2001	Amphibian inventory of the Apostle Islands National Lakeshore, with an evaluation of malformity rates, monitoring recommendations, and notes on reptiles	Apostle Islands National Lakeshore, park-wide, 1998-1999.	Previous occurrence records searched and summarized. Amphibians detected and captured, identified, examined for malformities, aged, sexed, measured and released; vouchers collected. Survey methods: visual reconnaissance, aquatic funnel traps, frog loggers. Relative abundance estimated as number of amphibians per search hour.	Consulted 109 sources of occurrence records which reported 24 species. Encountered 16 species during 1998-1999 surveys. Most common species were blue-spotted, spotted and four-toed salamanders, eastern American toads, northern spring peepers, and wood frogs. All these are terrestrial forest species dependent upon shallow, fishless wetlands for egg and larval stages. Of 300 amphibians inspected, only 3 gross malformities were detected. Records and distribution discussed and mapped for each species. Amphibian breeding sites discussed and mapped included ponds, lagoons, terrestrial and Lake Superior bays.	This is the one most comprehensive amphibian resource documents available for any GLKN park; the approach used here could be a model for use in other parks. Author noted that terrestrial forest habitat was excellent and that APIS supported high densities of forest amphibian species. Wetland breeding site availability may be a limiting factor for APIS amphibians. Author included detailed recommendations for a monitoring plan utilizing call and visual encounter surveys and funnel trapping; survey sites and timing are specified.
Ernst	1998	Baseline inventory of	Stockton Island,	As in Krenz (1998) study.	Captured and examined 82 individuals in 4 species.	As in Krenz (1998) study.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		amphibians and evaluation of catastrophic deformities on Stockton Island	especially around Julian Bay Lagoon, also creeks and beaver flowages. May 19-July 30, 1997.		No deformities observed. From all methods combined, 5 amphibian species were found on Stockton Island. Mink frogs, chorus frogs, and blue-spotted and four-toed salamanders were encountered previously, but not during this study.	
Krenz	1998	Baseline inventory of amphibians and evaluation of catastrophic deformities on Sand Island	Sand Island, especially large forested wetland spreading NW from East Bay. Biweekly, May 28-July 23, 1997.	Methods included observations of natural cover objects, hand capture and examination for deformities, and both night and day auditory surveys for occurrence, distribution and relative abundance.	Captured and examined 101 individuals in 4 species. One wood frog was missing right hind limb, possibly due to predation. From all methods combined, 5 amphibian species were found on Sand Island. Salamanders and chorus frogs also likely inhabitants but were not encountered.	Results of auditory surveys and hand captures showed that neither method yielded a complete species list. Author stated use of both methods was preferable for future monitoring.
Rogers et al.	1995	A baseline inventory of amphibians, reptiles, mammals and owls on Long Island	Long Island, divided into 4 one-mile wide zones. Once in July 1995.	Amphibians and reptiles surveyed by meander-searches. Ponds sampled with dip net and sorted to collect larvae or egg masses. All cover types and individuals recorded.	Identified 6 amphibian and 4 reptile species. Only northern leopard frog and eastern garter snake found in all four sampling zones. Eastern American toad and eastern gray treefrog found in three zones. All other species found in one zone only. Notes on cover type associated with each species included.	A first attempt at documenting amphibians and reptiles on newly acquired Long Island. Limited sampling period may have limited the number of species encountered, although number of species is similar to Ludwig's song-survey report (1998) on island fauna. Ponds and associated wetlands were most species-rich and merit further investigation.
Ludwig	1993	Anuran (frogs/toads) survey for Apostle Islands National Lakeshore	Mainland Unit, 5 sites, 1990-1992. Outer and Stockton Island, 2 sites; and Sand Island, 1 site, 1991-1992. Three times during breeding season.	Song surveys conducted for 5-10 minutes after sunset during three calendar periods. Relative abundance recorded by species. Sites included beaver ponds, lagoons, bogs, rivers, creeks, swamps and ephemeral pools.	Mainland Unit: Reported 9 species, with spring peepers the most abundant and widespread among sites, followed by eastern gray treefrogs, American toad and green frog. Island Units: Reported 7 species, but not all occurred on each island. Spring peepers most abundant at all sites. Green frogs, found on Stockton and Outer Islands, were second most common, followed by wood frog and American toad.	Report included specific methodological recommendations useful for future monitoring, including more precise site location descriptions, consistency in site locations among years, continued use of three calendar periods for the surveys, and adequate observer training.
Patzoldt	1978	Demography of the vertebrate populations of Raspberry, Rocky, York and Oak Islands, Apostle Islands National Lakeshore, Wisconsin	Raspberry, Rocky, York and Oak Islands. June-August 1976-1977.	Reptiles and amphibians surveyed by walking 12 randomly selected 2000 m transects on Oak Island and 6 1500 m transects on the other islands, foraging under dead logs, rocks and in small ponds. Random encounters also noted.	Encountered 8 species of amphibians and 2 species of reptiles (garter and red-bellied snakes); turtle tracks observed. Study provides the first record of the four-toed salamander for APIS. American toad and eastern wood frog were most abundant. Oak Island had richest diversity with 8 herptile species.	Thesis focused more on terrestrial birds and mammals than amphibians and reptiles. Amphibian/reptile species list is useful but only limited ecological context was provided in appendix.
Patzoldt and Brown	1977	Tentative checklist of amphibians, reptiles and mammals observed on Raspberry, Rocky, York and Bear Islands	Raspberry, Rocky, York and Bear Islands, APIS.	Methods not described in report.	Predicted 4-5 species of amphibians and reptiles would occur on each island. Northern redbelly snake and gray treefrog only found on Rocky Island. Four-toed salamander only found on Raspberry Island.	Amphibian and reptile fauna has low richness on these islands.
Wetlands and Aquatic Vegetation						
Meeker	2000	Characterization and establishment of	Devils Island bog, Little Sand Bay,	Permanent transects established to describe different cover types and monitor areas that will	Two groups of wetlands were identified: peat or inorganic substrates, with 10 distinctive wetland	Author urged development of consistent monitoring guidelines and protocols for all of the monitored

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		permanent sampling plots on select Apostle Islands National Lakeshore wetlands	Michigan Island lagoon, Outer Island lagoon and bog, Stockton Island lagoon and bog.	describe successional pathways and vegetation changes due to species invasions. Quadrats 1 m x 1m were placed along transects that varied from 5 m to 50 m in length. Stem densities assessed for cattail, common reed grass, beaked sedge, reed canary grass, purple loosestrife, and woolgrass.	cover types described among the two groups. Baseline information was provided for each of the sampled wetlands.	wetlands.
Meeker	1998	Wetlands of Long Island, Apostle Islands National Lakeshore	Long Island. October 1995-July 1996.	Wetland types identified using photo interpretation and field reconnaissance. Wetland types mapped by digitizing false color and monochromatic images. Established 8 permanent monitoring transects that varied from 15 m to 60 m in length. Percent cover and stem densities of select aggressive species recorded: *Phragmites australis, Carex utriculata, Phalaris arundiacea, Lythrum salicaria,* and *Scirpus cyperinus*. Lines of advance for *C. utriculata* and *T. latifolia* marked with GPS.	Two groups of wetlands were identified, with 9 wetland cover types described among the two groups. Peat substrates were either *Sphagnum*-based (3 subtypes) or sedge peat (1 type). Inorganic substrates were saturated most of the year (3 subtypes) or were under standing water (2 subtypes). Seven wetland types were mapped. Wetlands occupied >25% of the area mapped. Over half the wetlands were newer wetland types. Plants in 70 taxa were identified along the 8 transects.	A thorough baseline with useful monitoring recommendations for wetlands: All sampling should be in late July-mid August. 8-10 year survey intervals would suffice for *Sphagnum* communities, although monitoring aggressive species within these communities should take place every 1-3 years. Lake Superior-influenced vegetation types should be sampled every 4-6 years, except for aggressive species within them, which should be sampled every 2-3 years.
Judziewicz and Koch	1993	Flora and vegetation of the Apostle Islands National Lakeshore and Madeline Island, Ashland and Bayfield Counties, Wisconsin	Apostle Islands NL, plus Madeline Island. Five times per year, except Gull and Eagle Islands, sampled twice; 1972-1983 (Koch) and 1990-1992 (Judziewicz).	Collection trips were made to each island during different periods of the year. The vegetation survey included upland forest plots only.	Plant communities described by category: hemlock/ white pine/northern hardwood, boreal forest and krummholtz, sandscapes, dunes, pine savanna and forest, bogs, alder thickets and beaver flowages, clayscapes, rockscapes, disturbed areas. Coastal bogs inland from dune ridges are dominated by sedges, ericads and *Sphagnum* spp. mosses. Perched bogs on hilltops have poorer flora than coastal bogs, but ericads and insectivores usually present. Alder-dominated thickets are frequent at APIS, and common around sandscape bogs, beaver flowages and old roads. Federally listed lake cress (*Armoracia lacustris*) occurs in Lakeshore, along with 37 state listed species. Island-specific summaries and species lists provided.	Authors estimate this species list accounts for 98% of APIS flora. Species lists provide a good framework for future aquatic research on bog and beaver flowage habitats.
CONTAMINANTS						
Strachan and Glass	1978	Organochlorine substances in Lake Superior	Lake Superior, including ISRO and APIS sites.	Published and governmental reports examined for information on polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCs) in water, sediments and fish.	PCBs, DDT residues and dieldrin were most often measured, and often exceeded International Joint Commission water quality goals. Other contaminants also found. Some of the earliest fish OC records were from APIS region. APIS region may be a relatively hot PCB spot.	Follow-up monitoring on western Lake Superior trend analysis and synthesis is needed for this information.
Wisconsin Department of Natural Resources	1977	Untitled report on PCB and dieldrin levels in several Lake Superior fish species	Lake Superior sites including some near APIS, GRPO and ISRO.	Percent fat, PCBs, dieldrin measured in whitefish, chubs, shallow water cisco, herring, siscowet, lake trout, lawyer, smelt, Menomonee, walleye, brown trout, rainbow trout, white sucker, longnose sucker, Chinook, and Coho.	Fish in Lake Superior had lower PCB levels than Lake Michigan fish, except for siscowet, which had levels exceeding the proposed 2 ppm action level. Whitefish in some areas, including APIS, had dieldrin levels approaching 0.3 ppm but these were expected to drop due to a recent ban.	Bans on production and use of these chemicals since 1977 should be evidenced in a downward trend of fish contaminant levels Follow-up studies and monitoring should be initiated, or data obtained from other agencies.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
Groundwater						
U.S. Geological Survey	1980	Letter to Apostle Islands regarding well sampling	Presque Isle Point, Quarry Bay, Rocky Island, Little Sand Bay, Sand Island.	Data include total well depth, static water level, water level while pumping, drawdown, pumping rate.	–	–
Physical Processes						
Green and Dunning	1992	A monitoring program for Long Island	Long Island. 1990.	Beach profile, bluff positions, beach features and long shore currents measured.	Pilot monitoring program developed for Long Island's shoreline. Full report at APIS.	Report provided methods that could be used for future shoreline monitoring at APIS or other parks.
Milfred	1987	Measurement of bank erosion along the Presque Isle campground on Stockton Island, Apostle Islands National Lakeshore, 1984-1986	Stockton Island, Presque Isle campground. 1986.	Established 17 baselines in 1984. In 1986, distance from baseline endpoints was re-measured, and 9 new baselines were established.	Bank edges retreated between 1984 and 1986. Higher erosion in 1985-1986 may have been due to number, location and intensity of storms.	Follow-up monitoring of bank erosion using the newer baselines would be useful.

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AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Goldstein	2000	Grand Portage Reservation environmental monitoring program	Grand Portage Reservation: lakes, streams, Pigeon River, wetlands and Lake Superior Bays.	Streams: Pigeon River, Poplar and Grand Portage Creeks included. Chemistry, sediment, fish, invertebrates and algae. Lake Superior Bays: Grand Portage Bay included. Chemistry, depth profiles, phytoplankton tows for enumeration and identification.	Proposed monitoring plan prepared for Grand Portage Band of Minnesota Chippewa. No data generated in this effort.	Proposed monitoring plan included to note that several GRPO waters may be monitored by Grand Portage Reservation or U.S. Geological Survey. Proposed monitoring protocols appear fairly comprehensive could be coordinated with any GLKN monitoring efforts at GRPO.
WATER QUALITY						
Grand Portage National Monument	2000	Grand Portage National Monument level 1 water quality survey, 2000	Grand Portage, Poplar and Snow Creeks; 4 sites. Monthly, May-November 2000.	Samples collected for basic physical and chemical characteristics, nutrients, solids, ions, and metals. Biological components measured. Contaminants measured on single sample. Length, gradient and watershed size calculated for each stream.	Grand Portage Creek drains 7.10 mi^2, runs 5.7 miles and falls as 130 ft/mi. Poplar Creek drains 6.74 mi^2, runs 7.8 miles and falls at 60.9 ft/mi. Snow Creek drains 2.37 mi^2, runs 2.7 miles and falls at 9.3 ft/mi. Grand Portage and Poplar creeks short, high gradient. Snow Creek more gradual and sluggish, drains wetland complex, has higher chlorophyll a. No evidence of excess nutrients or fecal coliform, Hg or PCB contamination.	Streams seasonally coherent with one another for most parameters. Inferences about all the creeks may be possible using monitoring data from just one creek.
Winterstein	2000	Water quality data from lakes and streams in the Grand Portage Reservation, Minnesota, 1997-98	Grand Portage Reservation; 2 streams, 2 wetlands, 4 lakes, all outside GRPO. June and October 1997; May 1998.	Samples measured for basic physical and chemical characteristics, nutrients, solids, ions, and metals. Lake sediments measured for metals and organic compounds.	Raw data provided without interpretation. Streams generally low in conductance and nutrients.	Report included to note that data from streams near GRPO are available for comparison.
National Park Service	1999	Baseline water quality data inventory and analysis: Grand Portage National Monument	GRPO, surrounding area.	Summarized results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	# water quality observations: 2,578 # parameters: 173 # monitoring stations (study area/park): 28/7 # parameters with exceedences (study area/park): 6/0 # stream gages (study area/park): 2/0 # dischargers: 1 # drinking water intakes: 0	Authors concluded that water quality at GRPO was generally good, with potential sources of contaminants including municipal wastewater discharges, stormwater runoff, mining operations, recreational use, logging, and atmospheric deposition.
Ruhl	1997	Physical and chemical properties of water and sediments, Grand Portage and Wauswaugoning Bays, Lake Superior, Grand Portage Indian Reservation, Northeastern Minnesota, 1993-96	Grand Portage and Wauswaugoning Bays, 9 sites. Summer, September 1994-June 1996.	Vertical profiles of temperature, pH, conductivity and dissolved oxygen at 5 sites. Water quality analyzed from fixed point samplers at 3 sites. Fecal coliform and streptococcal bacteria counted. Pesticide, phenol, and trace metals measured. Bottom sediment trace metals measured at 5 sites.	Bacteria counts were low. Dissolved phosphorus and TP were very low. Nitrate ~0.4 mg/L N, which is relatively high. Calcium ~14-15 mg/L. Trace metals low in water and suspended sediments, but detected in bottom sediments included Hg, Cd, Ni, Mn, Fe, As, Al and Pb. Atrazine detected in water.	Only data reported, no analysis or interpretation provided. Calcium data may be used to assess whether or not colonization by zebra mussels is likely.
BIOLOGY & ECOLOGY						
Boyle and Richmond	1997	Report on the ecological monitoring of two streams in Grand Portage National	Grand Portage Creek, mouth and tributary, Poplar	Physical: Temperature and benthic particle size. Chemical: Dissolved oxygen, TN, TP and alkalinity.	Physical: Baseline thermograph from Grand Portage Creek provided. All sites dominated by small boulders with some smaller particles present.	Report provided some monitoring guidance and suggested watching at all sites for change in particle size through siltation and change in nutrients.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		Monument	Creek at foot bridge; 4 sites. Summers 1994-1995.	Biological: Benthic invertebrates sampled monthly with Surber sampler.	Chemical: Dissolved oxygen near saturation for all dates; pH circumneutral and alkalinity 36-86 mg/L $CaCO_3$. TP always > 0.6 mg/L, which is higher than expected. TN:TP ratios very low, always < 3) indicating possibly N limitation. Biological: Identified 140 invertebrate taxa. Densities lowest in spring samples, highest in late summer-fall.	Suggest monitoring temperature on Grand Portage Creek tributary because of dam construction. Authors recommended monitoring particle size annually and benthic invertebrates every three years. Algal productivity in creeks is likely N limited; N deposition could be a concern in future. (See additional review under fish category.)
FISH						
Boyle and Richmond	1997	Report on the ecological monitoring of two streams in Grand Portage National Monument	Grand Portage Creek, mouth and tributary, Poplar Creek at foot bridge; 4 sites. Summers 1994-1995.	Baseline data set of physical, chemical and biological measurements. Concerned with potential for logging on tribal lands adjacent to Monument that may alter stream conditions. Benthic macroinvertebrates collected. Pebble counts to determine particle size of benthic substrate Water temperature collected *in situ* on tributary below site where dam may be constructed to mitigate water temperatures for brook trout rehabilitation efforts.	Temperatures showed normal variation for time period sampled on Poplar Creek. Expect temperatures on Grand Portage Creek tributary to decrease when reservoir constructed. Dissolved oxygen was near saturation at all locations. Near neutral pH and alkalinity indicated substantial buffering capacity. Macroinvertebrate population relatively diverse with >120 taxa of insects and 20 taxa of other invertebrates identified in study. Overall, chemical, physical and biological characteristics appear healthy in these streams.	Good baseline information; useful for comparisons if land use in area changes. Not clear how proposed dam would keep temperatures low in Grand Portage Creek. Possibly through maintaining base flow during low water periods, but should be explained. (See additional review under biology and ecology category.)
Newman and Johnson	1996	Development of a reintroduced, anadromous brook trout population at Grand Portage, Minnesota, 1991-1996	Grand Portage Reservation: Little Creek, 1991-1996; Hollow Rock Creek, 1992-1995; Mile Creek, 1991; Reservation River, 1992. GRPO: Grand Portage Creek, 1991-1995.	Stocked eggs and swim up fry. Artificial redds were created for egg stocking in Little Creek and Grand Portage Creek, with upwellings created in redds by running PVC pipe from upstream to substrate under redd site. Used plexiglass incubators in egg stocking sites to estimate hatch rates.	Egg stocking in unimproved sites appeared to be unsuccessful, but eggs in artificial redds showed high hatch rates. In Little Creek, YOY were common from 1993-1995; some yearlings were captured in 1994 and 1995. Only likely source, according to authors, was from stocking effort since no brook trout were present before this effort. Found sexually mature brook trout in Grand Portage Creek and Hollow Rock Creek in 1994 and 1995, but number of fish per stream was not indicated.	Final report for Newman (1993). According to US FWS Ashland FRO website, stocking continued until 2000 with natural reproduction evidenced in Hollow Rock Creek (1997) and Grand Portage Creek (1998 -1999). Dispersal of fish unknown, but Minnesota DNR reported more brook trout caught along North Shore during three years prior to 1996 report. If increased captures are due to rehabilitation efforts, special regulations protecting fish until reproducing or populations are self sustaining are appropriate.
Newman	1993	Progress report on coaster brook trout restoration at Grand Portage Reservation	Grand Portage Reservation: Hollow Rock Creek, Little Creek, Mile Creek. GRPO: Grand Portage Creek. 1992. Introduced Nipigon strain brook trout eggs and fry	Introduced Nipigon strain of brook trout from Dorian, ON, CN hatchery: 50,000 eyed eggs in January 1992, and 50,000 eyed eggs in December, 1992. Stocked four streams with artificial redds, usually over upwelling areas resembling natural sites suitable for redd construction. Used incubators in gravel with subsample of eggs to determine hatch rate. Fry stocked in 1992; 30,000 total fry, 10,000 per stream.	Hatch rate at incubator sites was >90% One incubator lost at Hollow Rock Creek. Stocked fry apparently stayed in streams through summer, based on visual observation by tribal fisheries staff indicating fry inhabited pool areas. Heavy rain in August and September probably caused fish to emigrate; September electrofishing efforts resulted in low captures.	Eggs covered with gravel to depth of ½ to 3 inches, but no indication of how this depth of cover was determined. No reference to cover depth in natural brook trout redds.
GROUNDWATER:						
Ruhl	1994	Water resources of the Grand Portage Indian Reservation, Northeastern Minnesota	Pigeon and Reservation Rivers; 15-min intervals. Grand Portage Creek; 5 times	Climate and geology summarized. Stream flow data collected from 3 streams. Hydrology and aquifer properties described. Storage coefficients, estimated transmissivity, and aquifer yields reported.	Peak stream flows in April-May, with flashy events in summer and secondary peaks in October-November. Estimated peak stream flow on Grand Portage Creek 1520 cfs, with a 1% probability of exceedence. Groundwater supplied mainly from bedrock aquifers	–

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
			weekly. 1992 water year. Nine groundwater wells.	Groundwater quality described from wells.	rather than sand and gravel aquifers. Water types included sodium-chloride, calcium-chloride, sodium-bicarbonate, and calcium bicarbonate. Three wells had higher dissolved solids and dissolved chloride than their EPA secondary maximum contaminant levels, and two had higher dissolved iron. Toluene detected at a gravel aquifer well down-gradient of an abandoned landfill.	

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AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Garza et al.	2002	Ecological characterization of Long Lake, Porter and Lake Counties, Indiana	INDU, Long Lake, west side.	Appears to be a data mining/literature review effort.	This report describes the history, physical characteristics, hydrology, sediment chemistry, water chemistry, plankton, vascular plants, macroinvertebrates, fish, amphibians and reptiles, mammals, birds, T&E species, and contaminant information available for Long Lake.	Provides good categorical baseline information about Long Lake. Lacks synthesis, analysis, and recommendations for management or research, but provides useful information. (See additional review under fish category.)
Whitman et al.	2002	A series of papers on the restoration of the biological communities of the Grand Calumet River Basin	Grand Calumet River Basin, Indiana.	A review of past, present and potential conditions for flora and fauna of the Grand Calumet Basin. Inspired by the Army Corps of Engineers' plan to dredge the Grand Calumet and a request for concurrent restoration ideas.	History and environmental setting Geology Wetland flora Aquatic macroinvertebrates Fish communities Amphibians and reptiles Mammals Birds Overall ecological potential	In the final chapter, authors describe restoration potential and recommend actions including nonnative species control, prescribed burning, sediment removal, wetland establishment and re-introduction of extirpated species.
Dolak	1985	Water resources management at the Indiana Dunes National Lakeshore: a baseline inventory, 1985	Indiana Dunes National Lakeshore.	This is a reference and planning document related to water resources throughout INDU.	Components addressed in the document include: Inventory of water resources Summary of water resources literature Description of hydrogeologic processes Identification of water resource issues/problems Identification of gaps in knowledge Clarification of legal mandates and options	Document provides valuable general information about INDU water resources. Since this document is nearly 20 years old, the water resource issues and knowledge gaps sections might benefit from an update.
WATER QUALITY						
Byappanahalli et al.	2003	Growth and survival of *Escherichia coli* and enterococci populations in the macro-alga *Cladophora* (Chlorophyta)	East of INDU, at Michigan Park Beach. 2002.	*Cladophora* collected from Washington Park Beach, Michigan City, near INDU. Bacteria recovered from *Cladophora* and sand. *Cladophora* leachate prepared. Effects of temperature, *Cladophora* leachate, sand, and lake water on bacteria growth evaluated. *E. coli* genetic analysis conducted.	*Cladophora* leachate supported in vitro reproduction of *E. coli* and enterococci; growth directly related to leachate concentration. *E. coli* survived >6 months in dried, cold *Cladophora.* Strains of *E. coli* associated with *Cladophora* were closely related genetically.	Authors note that "even if environmental *E. coli* and enterococci are found not to originate in *Cladophora,* evidence that these bacteria persist and multiply in *Cladophora* may compromise their use as fecal indicators in areas rich in macro-algae."
Byappanahalli et al.	2003	Ubiquity and persistence of *Escherichia coli* in a Midwestern coastal stream	Dunes Creek watershed and beach outflow; 14 stations. Weekly 1999-2000.	*E. coli* measured in water, sediment, soils.	Correlations between *E. coli* in stream water, sediment and soils noted. Sediment moisture correlated with *E. coli*. Direct fecal input inadequately explained the widespread and consistent occurrence of *E. coli*. *E. coli* in riparian sediments may account for chronically high counts.	*E. coli* counts appear related to more than just sewage. Authors cite ditching, increased drainage and loss of wetlands as possible reasons for the chronically high *E. coli* counts.
Whitman and Nevers	2003	Foreshore sand as a source of *Escherichia coli* in nearshore water of a Lake Michigan Beach	West of INDU, at 63rd St. Beach. April-September 2000.	Water and sand samples collected 1-2 times daily at 2 depths on 3 consecutive days per week. Hydrometeorological conditions, bird and bather distributions recorded.	*E. coli* concentrations in sand and water significantly correlated, with highest concentrations in foreshore sand, followed by submergent sediment and water. Gull contributions to *E. coli* concentrations apparent the day after gull activity in a given area. *E. coli* recolonized newly placed foreshore sand within 2 weeks.	Foreshore beach sand may be a net source rather than a net sink for *E. coli.* *E. coli* may be able to sustain population density during summer months without external inputs.
Whitman et al.	2003	Occurrence of *Escherichia coli* and Enterococci in	10 Lake Michigan beaches, including	*Cladophora* sampled from water, rock pilings and beach sand.	*E. coli* in *Cladophora* high but very variable across sites.	Author questions usefulness of these bacteria as indicators of sewage since they appear to derive from

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		Cladophora (Chlorophyta) in nearshore water and beach sand of Lake Michigan	Washington Park Beach near INDU; South Manitou Island at SLBE. June 24-November 7, 2002.	Sand and lake water collected along transects at 2 sites. *E. coli* and enterococci analyzed in lake water, *Cladophora*, and sand. Sunlight exposure and mat thickness experiments conducted *in situ*. Bacterial persistence explored using dried and rehydrated *Cladophora.*	*E. coli* and enterococci strongly correlated in southern Lake Michigan beaches but not northern ones. Both *E. coli* and enterococci survived for over 6 months in sun-dried *Cladophora* mats stored at 4 °C. *Cladophora* may be an important environmental source of indicator bacteria.	other sources as well.
Whitman et al.	1999	Interaction of ambient conditions and fecal coliform bacteria in southern Lake Michigan waters: monitoring program implications	INDU beaches. Weekly samples; fecal coliform bacteria 1984-1989; *E. coli* 1990-1995.	Analyzed fecal coliform and *E. coli* monitoring data collected during the Memorial Day through Labor Day period for 12 summers.	Analyses showed it was not possible to predict one day's fecal coliform count based on the previous day's result. Dispersal and deposition of bacteria not uniform among sites or over time. Other factors include rainfall, wind direction, water temperature, and bacteria source.	Authors suggest that current beach monitoring/closure protocols are inadequate and that other ambient variables should be used as predictors of indicator bacteria concentrations. The refinement of such predictive tools for INDU and SLBE would be very useful.
Simon et al.	1997	Physical and chemical limnology of four natural lakes located within Indiana Dunes National Lakeshore, Northwestern Indiana	INDU, 4 shallow lakes.	Morphometric characteristics measured. Water chemistry measured, including pH, conductivity, major ions, and nutrients.	Lakes were shallow depressions with depths generally less than 3 m. Lakes did not stratify or become anoxic. pH was neutral to slightly alkaline, conductivity ranged widely (40-1339 uS/cm), and total dissolved solids ranged from 49-67 mg/L.	Authors noted that the oxidized microzone at the sediment-water interface prevented metals and nutrients from being recycled within the lakes. Nitrogen levels were comparable to other mesoeutrophic lakes in the area, but phosphorus levels were an order of magnitude higher than most comparable lakes.
Whitman et al.	1995	Use of coliform bacteria in assessing human sewage contamination	Derby Ditch watershed, 42 sites. Late summer-fall 1990. Dunes Creek watershed, 13 sites. Late summer-fall 1991.	Basic water quality suite plus optical brighteners measured. Bacteria (TC, FC, and FS) counted. FC:FS calculated and bacterial composition analyzed.	Optical brighteners absent from Dunes Creek, indicating non-human sources. FC:FS not significantly different between residential and natural habitats.	Bacterial indicator species may not be adequate predictors of human waste contamination. Author suggests using select human pathogens, such as *Salmonella, Vibrio, Legionella, Bifidobacterium,* or *Yersina*, as an alternative to fecal coliform testing.
National Park Service	1994	Baseline water quality data inventory and analysis: Indiana Dunes National Lakeshore	INDU, and surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	<u># water quality observations</u>: 165,608 <u># parameters</u>: 743 <u># monitoring stations (study area/park)</u>: 337/50 <u># parameters with exceedences (study area/park)</u>:23/12 <u># stream gages (study area/park)</u>: 9/3 <u># dischargers</u>: 46 <u># drinking water intakes</u>: 3	Authors concluded that water quality at INDU was heavily affected by surrounding human activities, including industrial and sewage effluents, stormwater runoff from roads and parking lots, and atmospheric deposition.
Hardy	1983	Chemical and biological quality of streams at the Indiana Dunes National Lakeshore, Indiana, 1978-80	Grand Calumet Lagoons, Little Calumet, Dunes Creek, Derby ditch and Kintzele ditch basins; 52 sites. November 1978-July 1980.	Sampled for water quality suite, periphyton with mylar strip substrates, and benthic invertebrates with jumbo-multiplate substrates during high flows in November 1978 and August 1979, and during low flow conditions in July 1980. Fecal coliform and fecal streptococci measured in November 1978 and February, March and August 1979. Streambed trace elements and chlorinated hydrocarbons measured.	<u>Grand Calumet Lagoons</u>: Storm sewers were primary source of nutrients, Pb, Zn, and chlorinated hydrocarbons. Landfill was a source of high dissolved solids and ammonia. Low dissolved oxygen likely in winter. <u>Little Calumet Basin</u>: Urban, residential and industrial discharges contributed salts, organic materials, nutrients, metals, chlorinated hydrocarbons and bacteria. Ammonia and bacteria were high, and benthic invertebrates indicated heavy sediment loads at high flows. <u>Kintzele Ditch Basin</u>: Urban, residential and industrial discharges contributed to all the measured	Good source of baseline information for these waters. Data appendices and taxonomic lists included. Chemical and biological attributes were variable among sites within a given lagoon complex or drainage basin. Such variability is likely linked to local land uses and discharges, and should be considered in water quality monitoring plans. INDU streams are good candidates for multiple stressor research.

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					constituents. Pb, Zn, DDT and PCBs in streambeds of Brown Ditch exceeded background. Agricultural and wetland areas were a source of sediment, organic material and nutrients. Derby Ditch Basin: Septic seepage and lawn fertilizers may account for high nitrate concentrations. Wetland areas were associated with higher organic materials, nutrients, sulfates and Fe. Dunes Creek Basin: Septic seepage and road salt runoff likely increase nitrates and salts, and periphyton indicated high organic materials at low flow. Road runoff was associated with Pb, Zn, chlordane and PCBs. Wetland areas were associated with higher organic materials and Fe.	
Arihood	1975	Water-quality assessment of the Indiana Dunes National Lakeshore, 1973-74	INDU, water resources within boundary, including groundwater; 78 points.	Chemical, organic and bacteriological quality of surface and groundwater assessed; water quality sampled quarterly. Flow measured in 6 main streams. Insecticide residues measured in Long Lake sediments. Precipitation chemistry evaluated.	INDU geology consisted of unconsolidated lake and glacial deposits composed of sand, silt till, and clay till, with sandy parts yielding the greatest water supply. The 6 main streams were generally circumneutral in pH, had high specific conductance and oxygen levels, and showed occasional fecal contamination; Markowitz Ditch had higher conductance, and higher salt and contaminant concentrations than other streams. Bogs and marshlands had lower conductance, acidic pH values and lower dissolved oxygen. Long Lake sediments had no organophosphorus insecticide residues, but significant amounts of chlorinated hydrocarbon insecticides and PCBs. Influence of fly ash ponds on nearby interdunal ponds was noted. Groundwater quality was moderately to very hard, and varied with depth and location, but not over time. Precipitation lead and zinc levels were significant.	Author noted several problem areas: · Interdunal pond B is influenced by ash pond 4 of NIPSCO, · Bethlehem Steel culvert outlet discharges warmer and more highly concentrated water than surrounding areas, · Pinhook Bog contains agricultural runoff, · NIPSCO and Markowitz Ditch sites showed elevated chloride, · Little Calumet River showed elevated trace elements in sediments, · Derby Ditch site showed human fecal contamination, and Long Lake, Pinhook Bog, the Little Calumet River, Markowitz Ditch and Kintzele Ditch all had elevated pesticide residues.
BIOLOGY & ECOLOGY						
Nevers and Whitman	2004	Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks	VOYA, ISRO, PIRO, SLBE, INDU; 2 lakes in each. Monthly, May or June-September for 2 years.	Phytoplankton sampled from 1m depth and analyzed for composition, species richness, Shannon-Wiener diversity, and species evenness. Water quality suite measured using YSI sonde and Kemmerer sampler. MDS ordination of Bray-Curtis Similarity for mean water chemistry and individual species counts, phytoplankton species counts for each sample, and combined species counts and water chemistry variables for each sample.	Collected 176 phytoplankton taxa from all lakes. Diatoms and chlorophyte taxa most common. INDU lake dominated by euglenoids. SLBE lakes dominated by diatoms. PIRO lakes dominated by chrysophytes and diatoms. Northern lakes had variable composition. Northern lakes clustered together in terms of chemistry and composition.	Study provides some useful background and baseline phytoplankton information for these lakes. Non-random lake selection limits inference to the larger set of lakes at each park. Dataset could be explored further to: · Show how seasonal patterns differ among lakes, · More thoroughly describe grouping patterns among lakes in terms of phytoplankton composition and water chemistry, and · Provide more park-specific insights.
Whitman and Garza	2002	The impact of beach nourishment activities on the meio- and macrobenthos of Mt.	Lake Michigan south shore, 10 transects. 2001-2002.	Meio- and macrobenthos sampled using petite Ponar samples at 1.5, 3 and 6 m along transects. Sieve mesh size 106 micron.	Identified 40 taxa, with *Chaetogaster diastrophus*, an oligochaete, and Nematoda dominant. Fauna at shallow sites (≤ 3m) adapted to wave and sediment disturbance. Fauna at deeper sites (6 m)	Many confounding factors complicate conclusions: sediment grain size, storm events and Kintzele Ditch sediments. Additional data needed to support findings.

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		Baldy, Indiana Dunes National Lakeshore, 2001 and 2002			more diverse and stable. Decrease in densities downdrift of beach nourishment activities between 2001 and 2002. Diversity, richness and evenness unaffected.	Authors note that very little is known about these nearshore benthic communities.
Horvath et al.	2001	Establishment of two invasive crustaceans (Copepoda: Harpacticoida) in the nearshore sands of Lake Michigan	INDU, Mt. Baldy area, offshore. Annually 1996-2000.	Meio- and macrobenthos sampled with a petite Ponar sampler along four transects at 1.5, 4, and 6 m in 1996-1999. In 2000, samples were collected in triplicate along a single transect at depths of 1, 1.5, 4, 6, 9, and 15 m. Sieve mesh size 106 microns. Sites in Chicago harbors similarly sampled.	Found 5 species of harpacticoids: native species *Canthocamptus robercokeri* and *Epactophanes richardi*; exotic previously confirmed in all Great Lakes, except Superior, *Nitokra hibernica*; and newly documented exotics *Schizopera borutzkyi* and *Heteropsyllus* sp. *Schizopera borutzkyi:* Found in the Black Sea-Danube River delta in shallow muds and sands; ballast water is the likely invasion vector here. *Heteropsyllus* spp.: Known mostly from the marine coasts of North America and northern Europe, but this species' origin is unclear. New invasive species were numerically dominant. Timing of these introductions and ecological implications remain uncertain.	Invasions of exotic benthic microfauna have received little attention in comparison with pelagic invaders. Given the ecological importance of benthic habitats and processes, more attention is warranted.
Stewart et al.	2000	Land use, habitat, and water quality effects on macroinvertebrate communities in three watersheds of a Lake Michigan associated marsh system	Great Marsh of Dunes Creek, Derby Ditch and Kintzele Ditch watersheds; 21 sites. Monthly, 1993-1994.	Land use: Data acquired and categorized. Stream habitat: Scored at each site using the riparian, channel, and environmental inventory. Water quality: Sample suite measured monthly from summer 1993-summer 1994 at each site. Macroinvertebrates: Collected using Hester-Dendy samplers, identified and collapsed into metrics.	Macroinvertebrate patterns related more to local site-specific abiotic factors than catchment-wide factors. Structural (relative abundance of key taxa) and functional (feeding groups) metrics best distinguished among sites. In general, macroinvertebrate community metrics reflected degraded stream and wetland conditions.	Study helps identify which metrics may be most useful in future monitoring efforts.
Stewart et al.	1997	Ecological assessment of three creeks draining the Great Marsh at Indiana Dunes National Lakeshore	Great Marsh of Dunes Creek, Derby Ditch and Kintzele Ditch watersheds; 21 sites, June 1993-May 1994.	Land use: Data acquired and categorized. Water quality: Data collected monthly. Bacteria: Collected monthly. Diatoms: Collected using periphytometers in August 1993 and identified. Macroinvertebrates: Collected using Hester-Dendy samplers in August and December 1993. Habitat evaluation performed in fall 1993. Aquatic plants: Surveyed several times at 18 sites throughout spring and summer of 1994 using abundance scale rating and indices.	Land use: Kintzele Ditch had largest drainage area and most heavy use areas, whereas Derby Ditch had the most natural areas and wetlands. Water quality: Kintzele Ditch had highest levels of nutrients and turbidity in heavy-use areas; whereas Derby Ditch had lowest pH and dissolved oxygen, and highest Fe and ammonia in wetlands. Bacteria: Highest counts in August, lowest in January, with highest counts occurring in Kintzele Ditch. Diatoms: Species clustered according to drainage basin and related water quality characteristics. Macroinvertebrates: Variable within and among ditches, but generally pollution-tolerant types. Aquatic plants: Sites clustered according to local habitat rather than broad land use qualities; hydrology primary factor affecting diversity.	Detailed and useful study of chemistry and biology of Lakeshore creeks. Land use, water quality, bacteria, aquatic plant data most valuable; diatom and macroinvertebrate data less useful due to the limited number of sampling dates and the sampling methodologies used.
Whitman et al.	1994	Composition, spatial-temporal distribution and environmental factors influencing the interstitial beach meiofauna of southern Lake Michigan	Burns Waterway, near outlet; 3 sites on pollution level and splash zone gradients. April-November 1990.	Meiofauna sampled quantitatively April-August 1990, counted and identified. Basic interstitial water quality suite measured at various depths. Sediment samples collected for texture analysis in October-November 1990.	Biota extend as far as 30 m landward and as deep as 2 m below the sand surface of the open beach. Fauna dominated by Oligochaeta, Nematoda and the crustacean *Parastenocaris* spp. Oligochaete mean densities were highest at 1 m from splash zone, where as *Parastenocaris* increased	Meiofauna may be sensitive to environmental degradation, such as siltation or organic loading, and reflect conditions in both surface waters and interstitial waters.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					from the splash zone landward.	
Whitman et al.	1991	Ecology of Miller Woods: aquatic biology	Miller Woods, ponds in ridge and swale area. Fall 1984, spring 1985.	Pond morphometry. Aquatic plant distribution, subjective relative abundance and cover. Phyto- and zooplankton composition. Benthic fauna composition.	Some ponds permanent, others vernal or aestival. Aquatic plants mapped for several ponds. Species lists and densities provided for phytoplankton, zooplankton, and benthic fauna.	–
Whitman et al.	1988	Biological assemblages of Miller Woods ponds, Indiana Dunes National Lakeshore, Gary, Indiana	Miller Woods, interdunal ponds. 1984-1985.	Pond surface area, perimeter and morphometry evaluated. Aquatic vascular plants mapped using infrared and visible aerial photographs coupled with ground observations. Plankton in 6 ponds sampled summer and fall 1984. Bottom fauna sampled from 6 ponds in fall 1984 and spring 1985.	Ponds generally shallow, fishless, some with vernal characteristics. Vernal ponds had highest phytoplankton densities, and included *Pandorina*, chrysophytes, diatoms. Dredged, large permanent ponds had lower phytoplankton and higher zooplankton densities. Variation among ponds likely due to extensiveness of littoral areas, varying water levels, presence or absence of fish, dredging.	Authors suggest that characterizing the ponds based on biological composition is difficult. If ponds were to be included in long-term monitoring efforts, sites should be chosen carefully with this in mind.
FISH						
Simon et al.	2004	Distribution of fish assemblages in the Valparaiso Chain of Lakes, Porter County, Indiana, with emphasis on lake condition assessment	Valparaiso Lakes, including Long Lake in INDU. 1950-present.	Fisheries records reviewed from 1950-present, mostly from Indiana Department of Natural Resources.	Species diversity was relatively low, only 34 species in 10 families, including 3 exotic species: goldfish, common carp, and grass carp. The most diverse families were the Centrarchidae and Cyprinidae. Biological integrity relative to other northern Indiana sites ranged from “very poor’” to “fair”.	The Valparaiso Chain of Lakes, like many sites in or near INDU, appeared biologically impaired relative to other sites in northern Indiana.
Simon et al.	2004	Implications of Chinook salmon presence on water quality standards in a Great Lakes Area of Concern	Grand Calumet River watershed. Fall 1999.	Grand Calumet River watershed, including Indiana Harbor Canal, surveyed weekly to monthly during fall spawning run to determine occurrence of salmonids.	Chinook salmon present from mid-October to late November. Collected 465 Chinook salmon and 3 rainbow, or steelhead, trout . Chinook salmon found throughout the watershed, but no successful reproduction observed.	Authors noted that presence of Chinook salmon could force a more conservative water quality standard and require reduction of pollutant inputs.
Garza et al.	2002	Ecological characterization of Long Lake, Porter and Lake Counties, Indiana	INDU, Long Lake, west side.	Data mining effort for historical record; references 1923 and 1988 surveys of Long lake ecology and fish species. Purpose of study was to characterize west side of Long Lake due to lack of data from this area. Sampling sites and frequencies not well described in document.	Species documented in 1923: yellow perch, large mouth bass, and chain pickerel. Species found in 1988: yellow perch, large mouth bass, chain pickerel, GSF, bluegill, carp, black bullhead, yellow bullhead, golden shiner, and fathead minnow. Yellow perch not identified since 1990 when fish kill occurred. Purported “winter die-off” was reason for fish kill.	Limited fisheries information, historic references to some species, but comprehensive historic species list is lacking. (See additional review under general resource category.)
Simon and Moy	1999	Past, present and potential of fish assemblages in the Grand Calumet River and Indiana Harbor canal drainage with emphasis on recovery of native fish communities	Calumet River; tributaries, lagoon and drainage canal. Various, early 1900s-mid 1990s.	Combined literature review of investigations since early 1900s and brief investigations in mid-1990s for comparative purposes. Current methods not well documented.	Species lists provided for past and present. Fish community greatly altered since early 1900s due to extreme modification of riverine habitats and exotic species introductions. Changes in species assemblage due to habitat degradation. Some recovery during 1990s, but not to early 1900 levels. Recommendations include reducing fish contaminant levels, removal of contaminated sediments, habitat restoration, reducing thermal profiles, increasing macroinvertebrate forage and increasing heterogeneous substrates in areas with low habitat diversity.	Good evidence of impact industrialization had on fish populations and how this changed species assemblages. Suggestions for improving conditions are offered, but specific details are lacking and were not within the scope of the document. Costs for improvement efforts are not estimated, but would be very high due to large amounts of physical modifications necessary. All references that pertain specifically to Grand Calumet River should be obtained for park files.

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Simon and Stewart	1999	Structure and function of fish communities in the Southern Lake Michigan basin with emphasis on restoration of native fish communities	Riverine areas including headwater streams, ditches and moderate size rivers, and Lake Michigan shoreline. 1985-1996.	Daytime inventories to determine fish community structure using electrofishing, beach seines, or minnow traps, depending on location and physical structure of habitat. Representative samples collected at each site to document species diversity.	Difficult to reconstruct historic fish distribution of INDU area in southern Lake Michigan. Existing data indicate number of native species in entire watershed, including nearshore Lake Michigan, declined by 22%. Few remnants of natural fish communities exist; principally in Miller Woods ponds, Grand Calumet lagoons, and Little Calumet River. "These communities have maintained relatively diverse assemblage of fishes despite large scale anthropogenic disturbances in the area." Authors also state highest proportion of exotic fish species of any wetland in northwest Indiana is in Grand Calumet River.	Describes information needs to pursue restoration of fish communities. Suggests that stocking programs contribute to impairment of native populations; therefore, stocking of nonindigenous species needs to be evaluated to determine impacts to potential native fish restoration efforts.
Simon and Stewart	1998	Application of an index of biotic integrity for dunal, palustrine wetlands: emphasis on assessment of nonpoint source landfill effects on the Grand Calumet Lagoons	Grand Calumet lagoons. Eight 100-m reaches.	Fish collected using electrofishing and seining. Indices of species composition, trophic composition and fish condition calculated, along with traditional indices like species richness, diversity, dominance, evenness. Patterns in these characteristics evaluated using similarity indices and cluster analysis.	No sensitive species, hybrids, headwater species collected from any of the lagoon sites. The most disturbed areas were adjacent to the industrial landfill and the west lagoon outlet. Fish communities negatively impacted by proximity to the landfill.	Simon's 1998 index of biotic integrity accurately predicted biological quality at most sites in this study, but application to other sites and to lagoons < 3 ha may be limited.
Simon et al.	1998	New distribution records for exotic and non-indigenous fish species in the Lake Michigan drainage, Indiana	Tributary mouths, industrial ports, and nearshore Lake Michigan waters. 1992-1998.	Various waters in the Lake Michigan drainage of Indiana sampled for fish between 1992 and 1998.	New exotic fish recorded in Lake Michigan nearshore waters included: grass carp, rudd, and round goby. White perch, striped bass, and three-spine stickleback, all non-indigenous, have extended their range into the Grand Calumet River, Little Calumet River, and Lake Michigan nearshore.	Authors noted that declines in toxic sediments due to restoration efforts and chemical load reductions have enabled new exotic or nonindigenous fish species to get established in and near INDU.
Simon	1992	New icthyofaunal records for the Calumet, Kankakee, and Iroquois drainages of Indiana	Calumet, Kankakee, and Iroquois River drainages. Summer 1990.	Fish collected from each site by minnow seines or electroshocking, either on foot or from a boat.	New distribution records noted for 13 fish species, including: 3 previously unknown in the State, 4 previously unknown in the Calumet River drainage, 2 previously unknown from the Kankakee River drainage, and 2 previously unknown from the Iroquois River drainage.	Surveys were part of a state-wide effort to develop biological criteria for the Central Corn Belt Plain Ecoregion.
Eshenroder	1989	A perspective on artificial fishery systems for the Great Lakes	–	Concerns with loss of key species in 1940s-1950s	Fish restoration efforts have suggested plans using artificial methods. Alert managers of risk associated with perpetuating artificial systems.	Presented at Wild Trout Symposium IV, September 1989, Yellowstone National Park. Not INDU specific. Great Lakes and Lake Michigan fish introductions.
Spacie	1988	Fishes of the Indiana Dunes–Species distributions and habitats	INDU; Kintzele and Derby Ditches, Dunes Creek, Little Calumet River, Long Lake, Miller Woods ponds, Pinhook Bog. 1987.	Used backpack electroshocker for stream sections, modified shocker for ponds and seines in ponds with suitable substrate and bottom.	Captured 22 species of fish representing 10 families. Included intentional and non-intentional exotics such as sea lamprey ammocoetes, brown trout, steelhead, carp and goldfish.	Recommendations from study: · Avoid further fragmentation of fish habitats at INDU. · Consider habitat improvement projects in selected areas of interdunal drainage network. · More detailed study of salmonid and white sucker reproduction in interdunal system. · Closer examination of fish distribution of Miller Woods area. · Genetic comparison of mudminnow pops of Pinhook Bog and adjacent waters. · Fish habitat inspected annually to monitor condition.

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						Reasonably comprehensive coverage of aquatic habitats and information on fish species present. Useful document for managers that may need to know species present for restoration work. Historic information on species is needed for any true restoration efforts that INDU may pursue.
Amphibians and Reptiles						
Glowacki and Grundel	2005	Status of the eastern massasauga rattlesnake at Indiana Dunes National Lakeshore	INDU, suitable habitats park-wide. 2002-2003.	Three phases of survey methods: · Visual searches conducted on warm days, · 14 drift fences and funnel traps in East Unit, · Artificial cover objects placed near drift fences. Massasauga and other herptiles identified, measured, marked and released. Habitat mapped within 200 m of drift fences.	Encountered 23 species of amphibians and reptiles: 9 anurans, 5 salamanders, 2 turtles, 1 lizard, and 6 snakes, including massasauga rattler. Single massasauga captured in a drift fence near Beverly Shores train station; another probable sighting near bike trail.	List of species and method(s) by which each was encountered will be useful in developing future taxa-specific or community monitoring techniques for herpetofauna in the area. Authors noted drift fences were the most successful survey method, with visual searches unsuccessful in summer conditions of heavy vegetation, and cover boards attracting few amphibians or reptiles. Authors noted that potential massasauga habitat should be incorporated into park management plans, and urged further research into the rattlesnake's status and habitat use.
Resetar	1994	Amphibians and reptiles in the most recent land additions of the Indiana Dunes National Lakeshore	INDU, 13 areas. 23 May 23-October 24, 1993.	Herpetofauna collected opportunistically at all sites; drift fences used on 6 sites.	Found 11 species of amphibians and 13 species of reptiles, many in the recent land additions. Several Indiana state-listed species noted.	Several management concerns cited, including: · Shading on turtle nest sites due to increased tree cover, · Fragmentation of habitats, · Domestic cat predation, and · Box turtle poaching. Solid species lists organized by site are included in appendix, creating a useful baseline for future monitoring. Management concerns are thorough and thoughtfully presented.
Resetar	1992	The amphibians and reptiles of the Indiana Dunes National Lakeshore	INDU, park-wide. 1992	Herpetofauna collected opportunistically and with drift fences.	History of herpetofaunal studies at INDU described. Distribution and ecology of herpetofauna of northwest Indiana described with emphasis on INDU. Historic and current abundances of select species in INDU described. Recommendations provided.	Solid species lists create a useful baseline for future monitoring. See Reseter (1994) addendum.
Resetar	1985	The status of state-listed herpetofauna within the Indiana Dunes National Lakeshore	INDU, park-wide, 19 sites. 1985	Amphibians and reptiles surveyed using opportunistic collecting and drift fences. Noted locality, date, size, vertical and horizontal position, temperature, plants, substrate, cloud cover and behavior. Species localities marked on maps, and areas with similar habitats marked as potential habitat.	Encountered 27 species of amphibians and reptiles incidentally. Presence of 3 state-listed species confirmed; 3 not found but may still exist at INDU.	Author indicates further study is necessary to determine population size, age class structure, home ranges, breeding potential, predation pressure and other limiting factors.
Wetlands and Aquatic Vegetation						
Simon et al.	2001	Development of multimetric indices of biotic integrity for riverine and palustrine wetland plant communities along southern Lake Michigan	Great Marsh and the Grand Calumet Lagoons; 28 sites.	Vegetation from various sites was sampled using a modified Braun-Blanquet Cover Abundance Scale Method percent cover method. Evaluated 20 characteristics of aquatic plant communities in order to develop 12 metrics in five categories: structural attributes, species	Recorded 95 plant species in 42 families, including 5 listed as threatened, endangered, or rare in Indiana. Sites receiving the highest scores included several of the *a priori* least impacted sites; sites with low scores were located near a large industrial landfill. The index showed similar results for riverine and	Authors note that the index needed further validation but showed potential as a rapid index of biotic integrity. Authors further noted that such an index would be useful in identifying high quality wetlands for careful protection.

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				tolerance/sensitivity measures, functional aspects of communities, individual health and condition.	palustrine wetland types.	
Simon et al.	2000	Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan	INDU: Miller Woods area, 62 wetlands. Mid-summer.	A minnow seine was used to collect amphibians, crayfish, and fish from each wetland in mid-summer, covering littoral zones, deep pools, submerged vegetation beds, and backwaters or coves. 25 wetlands were used to develop reference condition expectation; 37 were used to test the newly modified index of integrity.	The index of biotic integrity based on 3 crayfish, 12 fish, and 7 amphibian species provided a more complete assessment than indices based on any one group. Index of biotic integrity was able to differentiate high-quality biological assemblages from disturbed ones. Scores for the Miller Woods were skewed to the low end of biological integrity, and increased with distance from Lake Michigan and proximity to edges.	Metrics previously developed for larger wetlands did not work as well as those developed specifically for small wetlands and vernal pools in this study. Inclusion of multiple taxonomic groups appeared to improve the ability of the indices to differentiate reference sites from disturbed ones. Authors suggested that many of the Miller Woods wetlands were significantly degraded, and that more could be done to protect them.
Edwards	1995	A hierarchical study of *Lythrum salicaria* L. ecology in Indiana Dunes and Sleeping Bear Dunes National Lakeshores	INDU and SLBE; 6 field populations. Sampled for 3 years.	*Lythrum* life history examined (shoot biomass, fertility, fecundity, demography) in relation to environmental gradients of soil chemistry and hydrologic regime. Competition experiment between *Lythrum* and *Calamagrostris canadensis* conducted. Physiological parameters of INDU populations measured to investigate reasons for invasion success.	INDU populations affected by small-scale environmental factors such as nutrient levels and hydrologic regime. SLBE populations affected more by large-scale climatic factors and density of other plants.	*A priori* predictions about what constrains *Lythrum* populations unsuccessful since specific site conditions can be very influential; a single control method won't work for all situations. Restoration of wetlands and native plants and a suite of *Lythrum* control methods may be most effective.
Stewart et al.	1993	Intrafen and interfen variation of Indiana fens: water chemistry	Indiana; 9 fens, including Cowles Bog. Two or more samples each.	Water quality suite measured. Factor analysis and canonical discriminant analysis used.	Among-fen variation in water chemistry was high, seasonal variation was lower. Factor 1 described ion concentration-conductance gradients, and factor 2 described nutrient gradients.	Authors suggest investigating the relationship between types of vegetation, ion concentration and nutrient levels.
Wilcox and Simonin	1988	The stratigraphy and development of a floating peatland, Pinhook Bog, Indiana	Pinhook Bog, 39 cores along a longitudinal transect, and additional cores along transverse transects.	Surface topography along each transect noted. Relative depths of horizon interfaces noted. 3-dimensional contour maps generated. 6 samples radiocarbon-dated.	Bog is a clay lined basin with 3 major sub-basins. Deeper parts contain fibrous limnic peats with some lacustrine sediment deposited 12000-4200 years before present. Upper, younger peats are mostly *Sphagnum.*	–
Wilcox and Simonin	1987	A chronosequence of aquatic macrophyte communities in dune ponds	5 ponds from each of 5 pond rows. Plant species, August 1982. Water chemistry, 3 samples 1988. Sediment chemistry, April 1984.	<u>Plant species</u>: Occurrence and percent cover documented along 5 transects, 4 quadrats each, for each pond. <u>Water chemistry</u>: Collected from random transect locations. <u>Sediment chemistry</u> : Collected from 2 locations in each pond. Detrended correspondence analysis (DCA) used.	Radiocarbon dating shows the pond rows formed sequentially, starting 3000 years B.P. Plant types in ponds of each row differed, and were affected by water depth and fluctuation. Ponds were well-buffered hard water pools with fairly low nutrients; chemistry was similar across pond rows. Sediment chemistry differed among pond rows, with higher organic matter in older pond rows. Results suggest linear succession pattern, but anthropogenic disturbance also recognized.	Solid study design, sampling scheme and analyses. Good baseline dataset for dune ponds.
Hiebert et al.	1986	Vegetation patterns in and among pannes (calcareous intradunal ponds) at Indiana Dunes National Lakeshore, Indiana	INDU, West Beach Unit; 9 pannes. April, July, October 1983.	For each panne, water chemistry measured from drive point wells, shallow waters (10 cm) and deeper waters (40-50 cm). Vegetation sampled from multiple locations along transects in each panne. Water depth was determined at each vegetation sampling site.	Identified 8 Indiana threatened or endangered plant species. Aquatic zones were dominated by *Chara*, the pond edge by *Rhynchospora capillacea, Juncus balticus,* and *Utricularia cornuta,* and the area around the pond by *Hypericum kalmianum.* Chemistry was characteristically hard water type. Species distribution within pannes was related to	Pannes apparently harbor unique and threatened flora and should be noted for their conservation value. Because vegetation was related to water depth, the hydrology of the area (and human activities that could affect it) should be closely monitored.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					water depth.	
Wilcox	1986	The effects of deicing salts on water chemistry in Pinhook Bog, Indiana	INDU; Pinhook Bog. Biweekly, June-October 1979-1983.	Established 2 transect lines. Water quality sampled from wells along transects. Bog stratigraphy evaluated with cores.	Elevated salt concentrations in interstitial waters associated with altered bog vegetation. Salts transported vertically by water movement. Snowmelt and heavy precipitation reduced salt levels, drought conditions gradually increased them. Highway runoff was the major source of salts.	Recovery of the bog following management measures to reduce salt inputs should be monitored, including both water quality and bog vegetation. Climate warming and/or droughts would likely slow the recovery rate of Pinhook Bog.
Wilcox	1986	The effects of deicing salts on vegetation in Pinhook Bog, Indiana	INDU; Pinhook Bog, 1979-1983.	Established 2 transect lines, one located near deicing salt pile. 2 x10 m quadrats set up for vegetation sampling along transects. Water quality sampling sites (see Wilcox 1986 above) co-located with vegetation sites. Vegetation identified and relative abundance assessed.	Impacted and unimpacted zones identified based on water chemistry. Nearly all endemic plant species absent from the impacted portion of the bog. Impacted areas dominated by nonbog, salt-tolerant or pioneering species, including *Typha angustifolia.* As salt concentrations declined by 50% in 4 years, many bog plants returned and some nonbog species declined.	A follow-up study evaluating vegetation recovery 2 decades after management measures were put in place would be useful.
Wilcox et al.	1986	Hydrology, water chemistry and ecological relations in the raised mound of Cowles Bog	INDU; Cowles Bog wetland complex.	Vegetation maps updated with 1983 color infrared aerial and 1984 color aerial photographs and ground surveys. Stratigraphic cross section constructed using soil augers and piston corers. Radiocarbon dates obtained for some sites. Installed 10 groundwater wells along transects. Basic water chemistry suite monitored in wells and surface waters.	Mapped 8 vegetation types; these were generally correlated with water level fluctuations. Well waters highly buffered with high concentrations of inorganic solutes. A breach in the clay layer beneath the mound allows water to flow upward. The marl and organic lake sediments in the wetland derive from the Nippissing level of Lake Michigan. The peat mound developed gradually as the lake levels fell, rather than catastrophically.	–
Wilcox et al.	1984	Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog wetland complex, Indiana Dunes National Lakeshore	INDU; Cowles Bog wetland complex. 1982.	Interpreted available black and white and color aerial photographs (1938-1982) and identified 4 main vegetation types. Conducted ground-truthing along 3 north-south transects. Percent cover of each species estimated in 1 m^2 plots.	Vegetation shifts began in the mid-1960s; cattail vegetation type increased from 2 ha in 1938 to 38 ha in 1982, and sedge-grass type decreased. Shifts associated with stabilized, increased water levels due to seepage from diked ponds constructed upgradient.	Authors offer some options for reducing cattail dominance and restoring sedge meadow vegetation, but note difficulties associated with each. INDU researchers are currently (2003) exploring ways to reduce cattail dominance and restore sedge meadows in experimental plots.
Contaminants						
Stewart et al.	2003	Response signatures of four biological indicators to an iron and steel industrial landfill	Grand Calumet lagoons and ponds, 12 sampling sites. Water chemistry, June 1996. Sediment chemistry, 1994-1995. Algae, 1996. Fish, 1994.	<u>Sediment chemistry</u>: 20-30 cm cores in 1994 and 1995, analyzed for PAHs. <u>Algae</u>: Periphytometers incubated for 2 weeks; algae identified. <u>Aquatic plants</u>: Surveyed once during late summer using modified relevé sampling with Braun-Blanquet cover estimation. <u>Macroinvertebrates</u>: Littoral sweep netting <u>Fish</u>: Eletroshocking at 2 sites, daytime inventories at 12 sites. Carp analyzed for PAHs.	PAHs increased with proximity to landfill. Algal communities differed with proximity to landfill in terms of species richness, diversity and abundance. Aquatic plant communities were missing whole growth habits near the landfill. Macroinvertebrate community and fish community data also depressed closest to the landfill. Carp PAH concentrations highest near the landfill. In general, typical PAH response patterns noted.	Weight-of-evidence approach useful in showing impairment.
Ingersoll et al.	2002	Toxicity assessment of sediments from the Grand Calumet River and Indiana Harbor Canal in Northwestern Indiana, USA	Grand Calumet River and Indiana Harbor Canal; 30 stations.	Toxicity tests conducted on sediments from 30 sites, with 10-day sediment exposures using the amphipod *Hyalella azteca* and 31-day exposures using the oligochaete *Lumbriculus variegatus.*	Toxic effects on amphipod survival observed in 60% of samples from the study area. Toxicity tests with oligochaetes showed that sediments were too toxic to be used in proposed bioaccumulation testing. The most toxic samples had the highest	Authors noted that sediments from the Grand Calumet/Indiana Harbor area were “among the most contaminated and toxic that have ever been reported.”

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					concentrations of metals, PAHs, and PCBs, along with excess metals.	
MacDonald et al.	2002	Assessment of injury to fish and wildlife resources in the Grand Calumet River and Indiana Harbor Area of Concern, USA	Grand Calumet River and Indiana Harbor Area of Concern; 9 reaches.	Information compiled on chemical composition of sediment and tissues, on the toxicity of sediments, pore water and elutriates to fish, on status of fish communities, and on fish health. These data were compared to regional benchmarks to assess injury.	Five distinct lines of evidences pointed toward injury to fish and wildlife throughout the study area. PCBs were the primary bioaccumulative contaminant, but authors noted that data on other contaminants were less available. It was unclear which substances caused the negative effects on fish, but in addition to PCBs, potential culprits included metals, PAHs, alkenes, dioxins, organochlorine pesticides, phthalates, and furans.	Further investigations into which contaminants are the cause of fish impairments would be useful.
MacDonald et al.	2002	An assessment of injury to sediments and sediment-dwelling organisms in the Grand Calumet River and Indiana Harbor Area of Concern, USA	Grand Calumet River and Indiana Harbor Area of Concern; 9 reaches.	Information compiled on chemical composition of sediment and pore water, on toxicity of whole sediments, pore water, and elutriates and on the status of benthic invertebrate communities. These data were compared to regional benchmarks to assess injury.	Up to four lines of evidence pointed toward sediment injury throughout the assessment area. Contaminants present at concentrations sufficient to cause sediment injury included metals, PAHs, and PCBs.	–
Perkins et al.	2000	Airborne trace metal contamination of wetland sediments at Indiana Dunes National Lakeshore	INDU, park-wide; 25 sites.	Sediment cores were collected from a variety of wetland sites. Concentrations of Cd, Cr, Cu, Mn, Ni, Pb, Se, and Zn were determined at many intervals. A single core was ^{210}Pb dated.	Metal concentrations near the surface were comparable to other sites in the region but above background levels. Zn, Pb, and Mn were particularly high. Surficial concentrations of Pb, Zn, Cr, and Cu were elevated at sites in closest proximity to anthropogenic sources. Pb, Cr, and Cu appeared immobile after deposition, but Ni, Cd, and Se showed some mobility. Duration and/or frequency of flooding were important in determining mobility of Zn and Mn.	Authors noted that their work had implications for wetland restoration projects in the area.
Stewart et al.	1999	Ecological assessment of the Grand Calumet Lagoons and adjacent ponds: water quality, aquatic communities, sediment contaminants and toxicity testing	Grand Calumet Lagoons and ponds, 12 sites.	<u>Water quality</u>: Suite measured twice. <u>Algal communities</u>: Sampled once using artificial substrate periphytometers. <u>Aquatic plant communities</u>: Surveyed once in late summer for percent cover, relative abundance and species composition. <u>Benthic macroinvertebrates</u>: Collected with sweep nets at each site; taxonomic composition (coarse), diversity, richness examined. <u>Fish</u>: Sampled by electroshocking, examined for deformities, lesions and tumors, and identified; carp analyzed for PAHs. <u>Sediments</u>: Analyzed for PAHs and heavy metals. <u>Toxicity tests</u>: Performed on lagoon sediments using *Pimephales*.	<u>Water quality</u>: Generally poorer in the western part of West Lagoon; pond results ambiguous. <u>Algal species</u>: Encountered 116 algal species. Clustered according to pond or lagoon. Algal species richness and diversity lower in West Lagoon and West Pond than East Lagoon and East Pond; abundance showed opposite pattern. <u>Aquatic plants</u>: Showed distinct composition in West Lagoon sites, and western West Lagoon sites had lower floristic quality indices and fewer submergent plants. <u>Benthic macroinvertebrates</u>: Differed in each pond and lagoon, but diversity and richness were similar among sites. <u>Fish</u>: Species composition differed in East vs. West Lagoon. Fish from West Lagoon had high PAH concentrations. <u>Sediments</u>: Showed extremely high PAH concentrations in West Lagoon (orders of magnitude higher than biological effects levels); metals high but below toxic levels. <u>Toxicity tests</u> showed extreme toxicity of West	Much of observed contamination and reduced biological integrity attributed to adjacent industrial landfill.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					Lagoon sediments but not water.	
Cole et al.	1990	Past atmospheric deposition of metals in Northern Indiana measured in a peat core from Cowles Bog	Cowles Bog, sampled once.	Collected 2 sediment cores from the center of Cowles Bog. Total concentrations of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr, and Zn measured at intervals along the cores. Cores were dated by ^{210}Pb, radiocarbon and pollen analysis.	Deposition of airborne metal particulates rose dramatically from pre-settlement levels, concurrent with upwind industrialization. Some metals increased by two orders of magnitude. Recent accumulation rates are half peak rates of the 1970s, due to emission controls and reduced production.	Authors noted the usefulness of sediment cores from calcareous fens for understanding historic trends in airborne contaminants, because such fens lack inputs of clastics from streams and avoid the problems of sediment redistribution typical of lacustrine environments.
Wilcox	Circa 1982	Effects of coal fly-ash disposal on water chemistry in an intradunal wetland at Indiana Dunes	INDU; Blag Slough, 6 sites. 12-16 samples, September 1976-May 1978.	Samples sites along a transect beginning upgradient of fly-ash settling ponds downgradient to surface and groundwater sites. Sampled for water chemistry.	Seepage from fly ash ponds increased the concentrations of Ca, K, sulfate, Al, boron, Fe, Mn, Mb, Ni, Sr, and Zn in downgradient waters. Interaction with organic matter limited transport of Al, Fe, Ni, and Zn. Soils in dewatered wetland basin have high Al, B, Mn and Zn, and may be potentially phytotoxic.	Study suggests phytotoxicity of areas previously flooded with fly-ash slurry, but additional study would be needed to determine whether or not this is occurring at Blag Slough.
Groundwater						
Isiorho et al.	1996	Seepage measurements from Long Lake, Indiana Dunes National Lakeshore	Long Lake, 11 stations. May-November 1992.	Seepage rates evaluated using seepage meters and minipiezometer nests. Hydraulic conductivity determined with a slug test. Groundwater velocity flow direction determined using borehole dilution tests. Basic surface water chemistry measured.	Water seeps out of Long Lake, recharging the groundwater. Seepage rates are variable, but Long Lake accounts for > 50% of the total recharge for the basin of the lake. Aerial contaminants, such as Hg, Se, nitrates, sulfates, could enter groundwater via seepage from Long Lake.	Links between contaminated surface waters and groundwater could be explored further. Authors recommend continued monitoring of the lake and surrounding groundwater.
Shedlock and Harkness	1984	Shallow ground-water flow and drainage characteristics of the Brown Ditch Basin near the East Unit, Indiana Dunes National Lakeshore	Brown Ditch Basin. Summer 1982.	Profiles of Brown Ditch established before 1983 dredging in Town of Pines. Digital model used to compute likely changes in water table head due to dredging.	Pre-dredging profiles indicated 6 times higher streambed slope in the Lakeshore versus the upstream arm of the ditch; upstream reach contained sluggish, clogged sections. Dredging to create uniform stream gradient would lower water table in Town of Pines by 0.2 to 2 feet; dredging to lower ditch stage in INDU by 0.5-1 foot would cause additional water table decline of < 0.5 foot in the Town of Pines. Dredging in upstream arm could lower water table in INDU by nearly a foot.	Authors conclude that high water tables in the Town of Pines were not related to the condition of the ditch in the Lakeshore.
Meyer and Tucci	1979	Effects of seepage from fly-ash settling ponds and construction dewatering on groundwater levels in the Cowles Unit, Indiana Dunes National Lakeshore, Indiana	INDU; Cowles Unit.	Digital groundwater flow model constructed to determine the effect of seepage from the ponds and construction dewatering on INDU groundwater levels.	Seepage from coal fly ash settling ponds created a groundwater mound 15 feet above natural water levels and raised groundwater levels in this unit up to 4 feet. Seepage from the ponds into underlying sand occurred at rates of 2 million gallons per day. Decline of water levels resulting from construction dewatering would be 3-5 feet.	Given heavy industrial uses and the ecological prominence of marshes and wetlands at INDU, groundwater levels and quality should be closely monitored.
Physical Processes						
Great Lakes Coastal Research Laboratory, Purdue University	1986	Indiana Dunes National Lakeshore shoreline situation report: executive summary	INDU shoreline, divided into 3 reaches.	3-year study of shoreline characteristics and processes. Decision-making document for water level and shoreline protection issues.	Maps of wave, current, and erosion patterns created. Site-specific recommendations provided for each study reach.	–

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Bick et al.	1985	Isle Royale Biosphere Reserve: history of scientific studies	ISRO, park-wide.	Overall assessment of history of scientific study at ISRO, including bibliography. Emphasizes research since 1900.	Geology, soils, climate, vegetation, terrestrial fauna, aquatic systems, and disturbance history each addressed. Aquatic systems section specifically covers physical and chemical properties: discharge, water quality, contaminants; and aquatic biology: fish, benthic invertebrates, and aquatic vegetation.	Useful as a reference document Characterization of water quality and biology very general.
Wallis	1966	Long range aquatic resources management plan, Isle Royale National Park, 1966-1975	ISRO, park-wide.	Plan was developed "to recognize aquatic resources and to direct management activities necessary to insure their adequate protection and appropriate use."	Aquatic resource characteristics and fishing issues addressed. Substantial fishing emphasis. Provides general management objectives and specific guidelines regarding shoreline development, biodiversity, fishing, etc. Lakes categorized according to trophic status, aquatic communities, etc. Fish management classes listed for streams.	General lake classifications supply good background information on the study lakes, and fish species distributions form a useful baseline. Plan needs updating, which is underway via the ISRO Water Resources Management Plan and Fisheries Management Plan (both in progress).
Linn et al.	1966	Isle Royale National Park natural sciences research plan	ISRO, park-wide.	Plan designed to "broadly outline the fields in which natural science research is needed to meet…federal requirements."	Resource characteristics described, including aquatic resources and issues, such as bogs, swamps, beavers, lakes, fish, invasive species, sea lamprey, aquatic vegetation and moose.	Plan describes several research needs related to aquatic biology: · A suite of fisheries studies. · Aquatic habitats: hydrographic maps for each lake, swamp and bog, and water quality for each. · Effects of external influences, such as moose, visitors, beaver, and fires. Plan is interesting but dated; some research needs will be addressed in forthcoming ISRO Water Resources Management Plan.
WATER QUALITY						
Stottlemyer et al.	2002	Long-term ecosystem studies in Isle Royale, Olympic, and Rocky Mountain National Parks, Noatak National Preserve, and Fraser Experimental Forest	5-site network, including Wallace Lake and Sumner Lake Watersheds at ISRO. Continuous since 1982.	Long-term monitoring program network designed to: · Detect changes from human and non-human stress. · Quantify magnitude of change. · Statistically separate human-induced component. Atmospheric sulfate and nitrogen deposition key themes early on. Current studies focus on climate change issues and its interaction with nitrogen deposition and the carbon cycle. This document summarizes research findings from each site to date.	ISRO receives highest atmospheric loadings among network sites. As of 2001, 19 years of precipitation and streamwater chemistry data collected at ISRO. Conceptual and hydrologic flowpath models developed. Effects of changes in dissolved organics on surface water examined. ISRO lakes generally high DOC; most lake DOC from allochthonous terrestrial sources. Warming soils at ISRO increase terrestrial DOC production and export. DOC flux to lakes varies seasonally, greatest during snowmelt. Greater DOC in lakes increases light extinction and may reduce primary production. Climate change at ISRO would likely change relative importance of different N forms (nitrate vs. DON).	Climate change likely to affect ISRO lakes via alterations in carbon and nutrient availability and quality. Addition of biological monitoring in Wallace Lake would enhance the insights gained from long-term water quality monitoring there.
Herrmann et al.	2000	Biogeochemical effects of global change on U.S.	GRSM, BIBE, OLYM, ISRO,	Long-term monitoring network. Watershed research summary for each site.	Temperature increased at the northern sites, including ISRO.	This analysis demonstrates the value of long-term monitoring datasets for understanding complex

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		National Parks	NOAT. Continuous since 1982.	Climate and precipitation trends analyzed. Input/output budgets derived from stream water chemistry weekly means.	Growing season has increased at northern sites. Sulfate and hydrogen ion deposition has declined at all sites. Terrestrial N cycle at ISRO dominated by soil processes. ISRO streamwater nitrate highest during snowmelt and during late fall high flows. Soil processes, hydrologic flowpath and snowmelt rates primary factors regulating stream water outputs.	systems and processes.
Stottlemyer and Toczydlowski	1999	Seasonal relationships between precipitation, forest floor and streamwater nitrogen, Isle Royale, Michigan	ISRO; Wallace Lake Watershed. May 1992-May 1997.	Precipitation nitrogen (N) inputs, snowpack N content, forest floor N pool, N mineralization and streamwater N concentrations measured. 0.1ha plots established along transects under 3 species cover types: alder, birch, and spruce.	Average N in precipitation: 3 kg/ha/y. Snowpack peak N content averaged 0.55 kg/ha. Forest floor inorganic N pools, mostly ammonium, averaged 2 kg/ha and increased with temperature. Streamwater nitrate peaked in winter; inorganic N peaked in late fall. N mineralization positively correlated with streamwater nitrate. Forest floor nitrate beneath alder positively correlated with streamwater nitrate. At watershed mouth, streamwater nitrate positively correlated with precipitation N input and precipitation amount. Strong ecosystem N retention. Little streamwater nitrate derived directly from precipitation or snowmelt.	Streamwater nitrate and inorganic N output not directly related to seasonal N inputs from precipitation or snowpack content. Important factors influencing streamwater nitrate included: large forest floor and surface soil inorganic N pools, winter N mineralization in unfrozen soils, seasonally variable N mineralization rates, and terrestrial nitrate mobilization during percolation and snowmelt.
Mast and Turk	1999	Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the West-Central United States, 1963-95	ISRO; Washington Creek. Monthly 1967-1969. Bimonthly 1970-1982. Quarterly 1983-1995.	Stream hydrology and water quality suite. Cation balances calculated. Unadjusted and flow-adjusted concentrations, and Seasonal Kendall test used to analyze time trends analyzed. Precipitation data from Wallace Lake NADP site incorporated. 1992 synoptic survey also conducted.	Sulfate and nitrate accounted for 61% and 36% of anions in precipitation. Volume-weighted means of all constituents presented and correlations calculated. Washington Creek moderately concentrated (57-250 uS/cm) and well-buffered (820-2120 ueq/L). Most atmospheric N retained by vegetation and soils in basin; N concentrations in stream water less than volume-weighted mean in deposition. Most streamwater sulfate accounted for by atmospheric deposition. pH significantly increased; potassium significantly decreased over period of record. Authors suggest this is the result of methodological, not environmental, changes. Tributary chemistry similar to chemistry at gaging site. Highly colored organic anions likely important.	Time trend analysis indicated relatively stable water quality in Washington Creek since 1967. Long-term averages useful in characterizing general water quality. Long-term seasonal variation could be further explored and summarized.
Stottlemyer et al.	1998	Biogeochemistry of a mature boreal ecosystem: Isle Royale National Park, Michigan	ISRO; Wallace Lake Watershed. 1982-1996.	Watershed biogeochemistry monitored with: · Precipitation quantity and chemistry. · Throughfall and stemflow. · Soil processes. · Stream water flow and chemistry. · Snowpack chemistry. · Aboveground biomass and nutrient distribution.	Annual precipitation averaged 75 cm, 40% as snow. Snowpack depths sufficient to keep soils unfrozen except beneath spruce. Unfrozen soils and mid-winter thaws reduced snowpack ion content. Precipitation H^+ and SO_4^{-2} declined since 1982. 90% of precipitation entered forest soils and was significantly modified by soil processes. Soil N mineralization rates occurred year-round and	This publication is the most comprehensive summary of ISRO watershed science research available, and the best source of information about ISRO hydrology, biogeochemistry, and ecosystem processes.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
				· Windthrow.	peaked in May-June. Net N mineralization declined as soil temperature increased; gross mineralization increased with temperature and moisture. Microbial N immobilization greatest beneath alder and increased with soil temperature. Streamflow dominated by snowmelt. Stream water acid neutralization capacity declined during snowmelt from dilution. Watershed base cation output exceeded input by 17 times. Watershed retained 99% of H^+ inputs and 75% of NO_3^- and NH_4^+ inputs.	
Stottlemyer	1997	Streamwater chemistry in watersheds receiving different atmospheric inputs of H^+, NH_4^+, NO_3^- and SO_4^{-2}	Watersheds in Denali NP, Fraser Experimental Forest, ISRO, and Calumet Watershed. Monitored weekly, precipitation 1983-1992; streamwater 1988-1990..	Precipitation chemistry monitored for ions. Streamwater chemistry monitored.	Highest concentrations of H^+, NH_4^+, NO_3^- and SO_4^{-2} at Calumet, lowest at Denali. Streamwater chemistry did not reflect precipitation chemistry overall, but did so more at Calumet and ISRO than other sites. "Space-for-time model using these sites indicates little alteration of stream water chemistry by precipitation across a range of atmospheric inputs." Important factors affecting streamwater chemistry included soil processes and winter mineralization and nitrification.	Link between precipitation chemistry and streamwater chemistry weaker than initially expected, suggesting quick direct effects of precipitation changes on streamwater quality unlikely; while slower longer-term, indirect effects more likely.
National Park Service	1995	Baseline water quality data inventory and analysis: Isle Royale National Park	ISRO and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	# water quality observations: 9,248 # parameters: 366 # monitoring stations (study area/park): 26/15 # parameters with exceedences (study area/park): 7/7 # stream gages (study area/park): 3/1 # dischargers: 0 # drinking water intakes: 0	Authors concluded that water quality at ISRO was very good due to the park's remote location and wilderness designation, with small effects of human activities noted in late summer and fall.
Stottlemyer	1989	Effects of atmospheric acid deposition on watershed/lake ecosystems of Isle Royale and Michigan's Upper Peninsula	PIRO: Little Beaver drainage, Legion, Upper Shoe and Lower Shoe Lakes; ISRO: Wallace Lake watershed. Calumet watershed. 1979-1983.	Precipitation chemistry collected biweekly. Multiple stream gages installed. Stream chemistry suite monitored. Snow accumulation and quality measured. Soil chemistry evaluated.	Inputs of SO_4^{-2} likely exceed biotic requirements and soil adsorption capacity, especially in boreal coniferous forest. Mean pH values higher in hardwood soils and increase with depth, and organic matter and C content higher under conifers. Acid deposition affected watersheds indirectly, by leaching SO_4^{-2} and base cations. NH_4^+, H^+, and NO_3^- strongly retained by watersheds.	Contains lots of summary details on precipitation, snowpack, and streamwater chemistry, both seasonally and interannually, as well as preliminary information on the Legion Lake study.
Meldrum	1987	Bacterial water sampling program, 1984-1985	ISRO, 18 sites. 1984-1985.	Samples collected from creeks, harbors, campgrounds and analyzed for total coliform, fecal coliform, and fecal streptococcus. Fecal coliform:fecal streptococcus ratio examined.	FC:FS ratio generally <0.7:1, indicating non-human sources, except at Benson Creek, Chickenbone West, Moskey Basin and McCargoe Cove. Rock Harbor sites had relatively higher levels of bacteria than Lake Superior open water.	Study is adequate but dated. New study with emphasis on drinking water safety and new visitor use hot spots may be needed from a management perspective.
Stottlemyer	1984	Effects of atmospheric acid deposition on watershed/lake ecosystems of Isle Royale	SEKI, ROMO, and OLYM watersheds; ISRO: Wallace Lake and Sumner Lake	Input-output budgets: Deposition monitored and lake inflow and outflow streams gaged and monitored for discharge and ions. Vegetation: Plots and biomass analyses	High precipitation and stream flow common in fall. Input-output budgets: Calcium output greatly exceeded inputs for Wallace but not Sumner Lake watershed; sulfate output from both watersheds	A fairly comprehensive summary of research conducted on atmospheric deposition and watershed processes through 1984. Analysis and interpretation of data somewhat limited.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		and Michigan's Upper Peninsula	Watersheds; Trout Lake (near PIRO).	conducted. <u>Lake studies</u>: Trout, Wallace and Sumner Lakes sampled 3 times at multiple depths during 1984 (May-August) for water quality suite, phytoplankton, primary production (^{14}C), and chlorophyll *a.* <u>Snowpack nutrient dynamics</u>: Snowpack quantity and chemistry monitored. <u>Upper peninsula survey</u>: 18 streams and 12 lakes in UP of Michigan, plus 16 streams and 25 lakes on ISRO, surveyed in 1980-1982 for water chemistry.	similar and larger than inputs by about 1.6x; nitrate output less than input for both watersheds; ion concentrations highly variable and not consistently correlated with stream discharge; relationship of ion concentrations to discharge steeper in low discharge years. <u>Lake studies</u>: No thermal stratification on sampling dates; chlorophyll *a* and primary production low in all study lakes (chlorophyll generally <6 µg/L); plankton of Wallace and Sumner Lakes more similar to each other than to Trout Lake; plankton species lists provided; diatoms dominant in all lakes; zooplankton species lists affected by sample timing at ISRO lakes vs. Trout Lake. <u>Upper peninsula survey</u>: Bicarbonate and sulfate the dominant anions; calcium and magnesium the dominant cations; lake water chemistry in between concentrations observed in other studies to the east and west.	
Stottlemyer	1982	The neutralization of acid precipitation in watershed ecosystems of the Upper Peninsula of Michigan	PIRO, Little Beaver drainage; ISRO, Washington Creek drainage. Biweekly, 1980-1985.	Precipitation chemistry measured biweekly. Stream gages installed. Stream chemistry suite monitored. Snow accumulation and quality monitored. Short-term experimental pH reductions conducted at PIRO only.	Precipitation acidic but quickly neutralized in upper portions of first-order streams. Experimental acid additions in Beaver Creek drainage were quickly neutralized and had little effect on downstream cation concentrations.	Stottlemyer notes streams at both parks appear to have relatively high buffering capacity but cites a need for more comprehensive stream water chemistry surveys. Stream chemistry shows high seasonal variability due to snowmelt. Future stream studies should address this seasonality.
Stottlemyer	1982	Variation in ecosystem sensitivity and response to anthropogenic atmospheric inputs, Upper Great Lakes Region	PIRO, Little Beaver drainage; ISRO, Moskey Basin drainage. November 1980-1982	Precipitation chemistry measured. Stream gages installed. Water chemistry suite monitored. Snow accumulation and quality monitored.	Snowfall and snow moisture increased with elevation above Lake Superior. No significant variation in precipitation quality with elevation. Precipitation acidic but modified by forest canopy, particularly maple, and soil types. Spring reductions in pH found at PIRO, but in general PIRO better buffered than ISRO.	Shifts in vegetation or soil disturbance will affect watershed processing of atmospheric inputs. Higher elevation sites get more precipitation and consequently more contaminants; they may be most sensitive to atmospheric deposition. Precipitation chemistry may interact with vegetation and soils to produce a complex mix of sensitive and vulnerable ecosystems.
Stottlemyer	1981	Ecosystem responses to acid precipitation-Isle Royale National Park	ISRO, 3 watersheds; PIRO, 1 watershed; Calumet watershed. Monitored for "several years."	Precipitation chemistry and quantity, snowpack chemistry, forest canopy throughfall, and streamwater chemistry evaluated. Seasonal variation in water quality evaluated. Vegetation effects on precipitation quantity and quality evaluated. Influence of alkaline glacial till on streamwater quality evaluated. Qualitative changes in precipitation with elevation evaluated.	Precipitation generally acidic; mean 3.87 pH for Mott Island and 4.88 for Windigo. Precipitation quantity increased as snowfall increased with elevation above Lake Superior, but precipitation quality did not. Forest canopy significantly altered quality, quantity and chemistry. Throughfall from conifers had lower pH than atmospheric precipitation and much lower pH than throughfall from hardwoods. Low precipitation pH quickly neutralized in streams with abundant glacial till; less so in more Precambrian geologic areas. Sulfate and nitrate elevated in spring runoff at Washington Creek.	These results and insights underscore the need for watershed/ecosystem scale approaches to understanding surface water quality and ecosystem function.
Biology & Ecology						

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
Nevers and Whitman	2004	Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks	VOYA, ISRO, PIRO, SLBE, INDU; 2 lakes each park. Monthly during growing season, May or June-September, 2 years.	Phytoplankton sampled from 1 m depth and analyzed for composition, species richness, Shannon-Wiener diversity and species evenness. Water quality suite measured using YSI sonde and Kemmerer sampler. MDS ordination of Bray-Curtis Similarity for mean water chemistry and individual species counts, phytoplankton species counts for each sample, and combined species counts and water chemistry variables for each sample.	Collected 176 phytoplankton taxa from all lakes. Diatoms and chlorophyte taxa most common. INDU lake dominated by euglenoids. SLBE lakes dominated by diatoms. PIRO lakes dominated by chrysophytes and diatoms. Northern lakes had variable composition. Northern lakes clustered together in terms of chemistry and composition.	Study provides some useful background and baseline phytoplankton information for these lakes. Non-random lake selection limits inference to the larger set of lakes at each park. Dataset could be explored further to: · Show how seasonal patterns differ among lakes. · More thoroughly describe grouping patterns among lakes in terms of phytoplankton composition and water chemistry. · Provide more park-specific insights.
Nichols et al.	2001	Status of freshwater unionid populations of Isle Royale National Park, 1999-2000	ISRO, 11 inland lakes, plus McCargoe Cove. 1999-2000.	Mussels sampled by initial visual scouting and qualitative surveying, followed by quantitative grid sampling. Triangular grids placed along transects extending perpendicular from shore. Species type, shell length, sex, gravidity noted. Population characteristics determined; age and growth rates estimated. Contaminants in soft tissue analyzed, including pesticides, PCBs, mercury and heavy metals. Basic habitat characteristics, depth, and substrate type recorded. Water quality suite measured at each lake.	ISRO unionids limited in species diversity but have unusually high abundance and recruitment compared with other Midwestern sites. Density ranged up to 33/m^2, high in comparison with other national parks in the area. No unionids found in Feldtmann, Hatchet or Leech Lakes This could be related to high copper levels. No contaminants were above consensus deleterious levels, but the amounts stored in mussels on a lake-wide basis could be substantial. Habitat preferences unclear from this study. Sponge colonies noted in lakes of the Chickenbone/LeSage corridor.	Author emphasizes the rarity and value of this stable mussel resource. Genetic endemism hypothesized, particularly for *P. cataracta* found in LeSage and Livermore. Further investigations of sponge fauna and how it relates to unionid distributions at ISRO needed. Author provides recommendations for management, including issues related to invasive species, monitoring, habitat requirements, etc. Study is well designed and represents the best available information on ISRO mussel fauna.
Larson et al.	2000	Zooplankton assemblages of inland lakes in Isle Royale National Park, Michigan, USA	ISRO, 36 inland lakes. Summers 1995-1996.	Vertical zooplankton tows from near lake bottom to lake surface, 63 micron net. Water quality samples collected. Lake morphometric data collected. Sampled in concert with fish surveys (Kallemeyn 2000).	Zooplankton assemblages similar among lakes, with *Bosmina longirostrirs, Keratella chochlearis, Conochilus, Polyarthra dolichoptera,* and *Ploesoma hudsoni* most common. *B. longirostris* also common in nearby Ontario lakes, and rotifer taxa similar to northern Michigan lakes. Neither rotifer/crustacean density nor richness/diversity strongly correlated with environmental variables. Lake groups proposed based on cluster analysis of water quality and morphometric variables.	Author notes little is known about temporal variability of ISRO zooplankton. Long-term monitoring program recommended. Integrated analysis of zooplankton and fish survey data might provide better insights about lake classifications and groupings.
Van Buskirk	1993	Population consequences of larval crowding in the dragonfly *Aeshna juncea*	Edwards, North Government, and other islands northeast of Rock Harbor, 12 sites. June 1986-1992; August 1987-1989.	Sampled rock pools on small islands. Population size and density estimated in each pool using capture-recapture techniques and examined for density-dependence. Field experiments conducted in 12 pools to establish causal connections between density and larval performance measures.	*Aeshna juncea* showed density-dependence and competition when natural densities high, with developmental delays and reduced survivorship in crowded pools. 5-week experiments showed reduced feeding activity and growth in crowded conditions.	Study describes *Aeshna juncea* population regulation and confirms the importance of density-dependent interactions.
Van Buskirk	1992	Competition, cannibalism, and size class dominance in a dragonfly	Edwards, North Government, and other islands northeast of Rock Harbor, 12 sites. June 1986-1992; August 1987-1989.	Population size and density of *Aeshna juncea* estimated in each pool using capture-recapture techniques. Feeding behavior observed and diet composition measured. Competition vs. cannibalism between *Aeshna juncea* size classes evaluated.	Cannibalism common and large larvae aggressive. Small larvae showed reduced activity and reduced feeding success. Experiments showed 2-year-old larvae more secretive and faced higher mortality than 3-year-olds. Adjacent age classes interacted most strongly.	Study illustrates how competition influences behavior, larval performance and population size structure.

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				Small container experiments performed.		
Van Buskirk	1992	The Odonata of Isle Royale, Michigan	ISRO, park-wide.	Odonate records gathered from published sources, museum records, author's field observations and collections from 22 ponds, bogs and streams.	Reported 38 species of Anisoptera and 12 species of Zygoptera; 9 new records for ISRO. Species typical of boreal regions of North America.	Report represents the most current and detailed account of ISRO odonates. Some related habitat information reported.
Johnson	1980	Ecological relationships of aquatic invertebrates in Siskiwit River, Isle Royale National Park, Michigan	Siskiwit River, Siskiwit Lake and Malone Bay. June-July 1976.	Established 31 stations in riffle sites using a stratified random design in lower, middle and upper portions of the River. D-frame kick net used to collect triplicate invertebrate samples at each site. Minimal drift sampling conducted. Artificial substrates (hardware cloth screening and beach stones) employed to sample lentic invertebrates. Basic water chemistry measured at both lentic and lotic sites in July only.	Identified 64 macroinvertebrate taxa in Siskiwit River. Insects, snails, clams, oligochates and leeches accounted for 98%. Most abundant organisms: Chironomidae, *Optioservus,* Sphaeriidae, *Baetis, Tricorythodes, Gyraulus parvus*, Oligochatea, *Simulium, Cheumatopsyche*, and *Leuctra*. 6 groups identified using similarity and cluster analyses, but major differences were quantitative rather than qualitative. Many taxa showed preferences for certain sites. Factors affecting Siskiwit River invertebrate distribution likely included substrate, current, depth, shade, detrital food, temperature, and importantly, outwash from Siskiwit Lake.	Author found Shannon-Wiener diversity indices not useful for comparing stations, but possibly useful for long-term monitoring. Stream information very useful baseline; lentic site insights more limited.
Bowden	1981	Benthic macroinvertebrates and chemistry of three streams on Isle Royale National Park, Michigan	Little Siskiwit River, Grace Creek and Washington Creek. Monthly, May-October 1979.	Water chemistry suite measured at each site. Discharge monitored using cross-sectional area and mean current velocity. Benthic macroinvertebrates collected using triplicate D-frame kick net samples.	pH, alkalinity, and cations inversely related to discharge and lower at headwater sites vs. downstream sites. pH and alkalinity ranged from 6-8 and 9.2-89.7, respectively. Diverse macroinvertebrates found in all streams. Composition similar to other Lake Superior basin streams. Diptera dominant upstream, whereas Ephemeroptera, Coleoptera, Plecoptera and Trichoptera dominant downstream. Various factors appeared to influence invertebrate distribution, including longitudinal variation in substrate, organic mater, chemistry, and light conditions.	Author suggests streams sensitive to acid precipitation, with headwater sites most vulnerable. Year-round monitoring of discharge and water chemistry recommended, with emphasis on snowmelt season.
Toczydlowski	1978	Aquatic baseline on Isle Royale, Michigan	ISRO, several lakes, harbors and creeks. Summer samples.	Basic limnological samples: vertical water quality profiles for physical and chemical characteristics. Phytoplankton sampled at several depths, identified and counted for relative abundance. Aquatic insects sampled using a D-ring net from streams and lakes. Aquatic plants qualitatively assessed and vouchers collected. Aquatic plants mapped for Wallace Lake.	Low lake pHs (5.3-6.5) and alkalinities (26 mg/kg $CaCO_3$). Small unidentified flagellates dominated phytoplankton of most lakes; list provided. Phytoplankton reflected oligotrophic conditions in Siskiwit and Wood Lakes, and more eutrophic conditions in Feldtmann. Aquatic insects were dominated by Trichoptera and Diptera; 111 genera were identified. 5 new bryophyte species and 10 new aquatic plant species reported. In Wallace Lake, 5 vegetation zones noted.	Methods and analyses somewhat unclear, but study does serve as an early baseline for ISRO inland waters. Species lists for phytoplankton, aquatic invertebrates, and aquatic plants useful as baseline information.
Prescott	1940	A concluding list of desmids from Isle Royale, Michigan	ISRO. Summer 1930.	Algae samples collected in connection with a biological survey of Isle Royale.	ISRO desmids similar to those of Canada, Newfoundland, New England; also more similar to Wisconsin flora than previously thought. Documented 221 species and varieties from ISRO.	–

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					Author notes many more may exist, but planktonic species not sampled effectively.	
Prescott	1939	Desmids of Isle Royale, Michigan: The genera *Stamastrum*, *Micrasterias, Xanthidium*, and *Euastrum*, with a note on *Spinoclosterium*	ISRO. Summer 1930.	Algae samples collected in connection with a biological survey of Isle Royale.	Some new records for Michigan. Species lists, basic ecology, and location and/or habitat information provided.	–
Prescott	1937	Further notes on the desmids of Isle Royale, Michigan: the genus *Cosmarium*	ISRO. Summer 1930.	Algae samples collected in connection with a biological survey of Isle Royale.	Number of large *Cosmarium* species in ISRO samples was greater than other north temperate areas. Some new records for Michigan. Species lists and some location and/or habitat information provided.	–
Prescott	1936	Preliminary notes on the desmids of Isle Royale, Michigan	ISRO. Summer 1930.	Algae samples collected in connection with a biological survey of Isle Royale.	Desmids of ISRO are more like the New England and northern Canada floras than the Wisconsin and the Western United States. Some apparently undescribed species found.	–
Taylor	1935	Phytoplankton of Isle Royale	ISRO: Wallace and Sargent Lakes, coves and harbors of Lake Superior; 10 sites. July-August 1930.	Net samples collected and preserved in formalin.	Three main groups identified: species from littoral macrophyte zones, from offshore Lake Superior, and from Lake Superior harbors and coves. Species lists provided. Lake Superior dominated by *Dinobryon,* diatoms and *Botryococcus*. Harbors and inland lakes dominated by *Anabaena lemmermanni,* with *Ceratium, Asterionella* and *Tabellaria* also common. Author emphasizes that rare elements were missed.	A preliminary look at phytoplankton on Isle Royale. Insights limited by the small number of samples collected and the short time period examined (July-August).
FISH						
Quinlan et al.	In Prep	Isle Royale National Park Fisheries Management Plan	ISRO, park-wide	Summarizes fisheries information from both inland and Lake Superior waters of the park, but makes specific recommendations only for inland waters.	First fisheries management plan for inland lakes and streams of Isle Royale. Compiles information from several sources including state and federal government surveys and tribal data where applicable.	Will be useful for park and state fisheries managers when it is complete. Will aid in management of species both in inland waters and Lake Superior because of the amount of information included in document.
Stott et al.	2004	Genetic variability among lake whitefish from Isle Royale and the Upper Great Lakes	ISRO, Lakes Siskiwit and Desor. 1996, 2002. Lake Superior and Lake Huron. 1999, 2002	Fin clips were taken from whitefish for genetic analysis. Isle Royale samples taken during fishery surveys at the island. Lake Huron samples taken from western shore near Alpena, MI. Lake Superior samples from four locations at the western end of the lake. Analyzed 40 whitefish each from Lakes Huron and Superior, and 28 and 38 fish from Lakes Desor and Siskiwit, respectively.	Genetic distance was smallest between Great Lakes samples and greatest between two Isle Royale samples.	Desor and Siskiwit Lakes have been isolated from Lake Superior for 8,700 to 10,000 years. This isolation is the reason for the greater level of genetic distancing between ISRO lake whitefish and Lake Superior whitefish. The authors indicated that all sample collections were genetically distinct but that values did not exceed those generally associated with species or sub-species boundaries.
Gorski et al.	2003	Factors affecting enhanced mercury bioaccumulation in inland lakes of Isle Royale National Park, USA	Sargent Lake, Lake Richie. 1998-1999.	Sampled water, zooplankton, macroinvertebrates and fish. Investigated factors causing northern pike Hg concentrations to exceed consumption advisory level (>500 ng/g). Collected samples from Lake Richie, which is a “non-advisory” lake.	Hg levels in Sargent Lake northern pike were significantly higher than in Richie, but mean concentrations of total Hg and MeHg in open water samples were slightly higher in Lake Richie. Sargent L zooplankton had higher average concentrations of Hg and MeHg than in L Richie; Hg in macroinvertebrates was similar between lakes.	Investigate the transferability of these findings to other lakes that have pelagic-based food web. How difficult would it be to determine food web dynamics in other lakes? Would investigations in a few more lakes be worthwhile? (See additional review under contaminants category.)

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					Levels were similar for age-1 and adult yellow perch, but large perch in Sargent Lake had twice the concentrations as Lake Richie. Conclude that bioavailability of MeHg is higher and bioaccumulation may be more likely in Sargent Lake possibly due to food web being more pelagic-based in Sargent and benthic-based in Lake Richie.	
Various authors	2000-2003	MEMOS – Inventory of the remnant coaster brook trout populations at Isle Royale National Park	ISRO.	Several memos pertaining to coaster brook trout restoration, primarily between US Fish and Wildlife Service and National Park Service. Planning and project proposals for coaster brook trout inventory at ISRO	Study is ongoing at Tobin Harbor and Siskiwit Bay. Low numbers, possibly >100 fish, at Tobin Harbor, but probably sustainable with no additional pressure above natural mortality. Siskiwit Bay area numbers extremely low, possibly a few dozen coaster brook trout in this area.	Special regulations for all coaster brook trout at island should be considered until genetic traits of coasters and characteristics island populations are better understood.
Guinand et al.	2003	Genetic variation over space and time: analyses of extinct and remnant lake trout populations in the Upper Great Lakes	Lakes Michigan, Huron, Superior, several locations. 1940-1959; 1995-1999.	Historic and current DNA analysis: 15 historic scale samples from Lake Superior, Huron, Michigan and 3 contemporary samples from Huron and Superior only. Included 1959 and 1995 samples from ISRO	Lake Michigan stocks extirpated. Lake Superior stocks, including ISRO have probably been affected by hatchery populations. ISRO stocks not as "introgressed" as Gull Island stocks. Lake Huron Perry Sound populations appear to be temporal replicates of ancestral populations.	Difficult to determine sample structure from ISRO. Appears to be one location sampled from 1959 scale data and one form 1995. Doesn't describe in detail potential historic diversity around the island or if contemporary samples taken from more than one location. Further investigations or discussions with one of the authors, such as Burnham-Curtis, may help.
Carlisle	2002	Summary of recent analyses of Isle Royale aquatic resources.	ISRO, 32 inland lakes. June – September 1997 (See Kallemeyn 2000.)	Examined limnological characteristics of inland lakes reported by Kallemeyn, and described lakes in four categories based on these factors.	One page report to Isle Royale Natural Resources Specialist	
Lockwood et al	2001	Survey of Angling in Lake Superior Waters at Isle Royale National Park, 1998	ISRO, nearshore waters. May 30-August 31, 1998. Included weekdays and weekend days.	Individual boater interviews at island ports; interviews on Ranger III and Voyageur II ferry; and at Grand Portage, MN. Nearshore waters divided into 14 sampling grids; grid based on prior observations by ISRO personnel of fishing activity.	Most non-charter anglers from Minnesota and Michigan (95%). Total angler hours were 62,232; lake trout made up 90% of sport catch, with 9612 lake trout harvested; 10,760 additional fish caught and released. Reported 8 other species in catch.	Creel survey should be conducted on regular basis every 5 –7 years.
Kallemeyn	2000	A comparison of fish communities from 32 inland lakes in Isle Royale national park, 1929 and 1995-1997	ISRO, 32 inland lakes. Fish sampling: 19 lakes, June 15-September 10, 1995; 13 lakes, June 12-September 8, 1996. Water chemistry: all lakes, June-September 1997. (See Carlisle 2002.)	Limnological measurements taken near location identified in 1929 as deepest point of each lake. Water chemistry: Temp/O2 profile, Secchi, chlorophyll, pH, conductivity, TDS, DOC, NH_4-N, alkalinity, total N, and P, Cl, NO_3-N, SO_4 , Na, K, Mg, Ca, and Al. Fish: Sampling included use of minnow traps, beach seine, gill nets. Hg analyses conducted for 6 species. Se determined for one n. pike or walleye per lake. Other: Morphometric and geographic variables also determined. Voluntary postcard creel survey conducted concurrently. Cards provided to anglers on ferries during trip to island.	Water chemistry: pH ranged from 7.3-8.9 conductivity 50.7 to 99.5 μmhos/cm Secchi range 1.3 to 9.0 m Fish: collected 28 of 30 species sampled by Koelz in 1929. Brook trout and mottled sculpin were the two species not collected. Other: Lake areas range from 1.3 ha (Epidote) to 1635.2 ha (Siskiwit). Siskiwit Lake maximum depth 46 m. All other lakes <15 m. In accordance with Bailey and Smith (1981), author did not recognize subspecies listed by Hubbs and Lagler (1949) for 5 species.	Only comprehensive fishery survey of inland lakes since 1929. Information is more thorough than earlier surveys which included fish and some basic habitat and limnological information. Should be referenced for any future fisheries studies of inland lakes.
Quinlan	2000	Stocking of brook trout at Isle Royale, Michigan	Fall 2000	Memo to ISRO Natural Resource Manager describing detection of bacterial kidney disease (BKD) in Siskiwit Bay strain brook trout reared at	Decided not to stock any of the 55,000 fish proposed from Iron River into Siskiwit Bay scheduled for fall 2000, in order to prevent introduction or increasing	BKD is present in Lake Superior, and is sometimes common in Pacific salmon in the lake. Sufficient information on the status and level of BKD in fish at

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				Iron River National Fish Hatchery.	prevalence of the disease at Siskiwit Bay. 12,000 fish reared at the Genoa, WI hatchery were stocked because they tested negative for BKD	ISRO was unknown at the time, and may still be unknown. Not stocking fish from a group that tested positive for BKD was the appropriate measure in this case.
Baker and Hites	2000	Siskiwit Lake revisited: time trends of polychlorinated dibenzo-*p*-dioxin and dibenzofuran deposition at Isle Royale Michigan	Siskiwit Lake, 2 sites. 1998.	Sediment cores used to analyze historic deposition of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/F).	Proposed that decrease in these contaminants was slower than expected. Suggest that another source of PCDD/F is from the photochemical generation of octachlorodibenzo-*p*-dioxin from pentachloraphenol – a wood preservative. Volatilization of product from wood continues to introduce compound to atmosphere.	Suggest utility poles as a source. Many applications of product were banned in 1970s, but much is present. Need to investigate prevalence and rate of degradation. (See additional review under contaminants category.)
Newman et al.	1999	A brook trout rehabilitation plan for Lake Superior	Lake Superior	Assessed current efforts by various agencies to rehabilitate coaster brook trout populations. Describes habitat rehabilitation initiatives, progress to date, issues deterring efforts and strategies.	Public education, changes in regulations, research for further information on all life cycle stages were all considered important needs. Genetic, morphologic and merisitc analysis and behavioral studies all needed.	Planning document prepared by the Brook Trout Subcommittee for the Lake Superior Technical Committee of the Great Lakes Fish Commission. Determine which of the needs listed in document have been partly or completely met. Public education appears to be occurring, but still may have a ways to go. Some regulation changes have been put into effect, but could probably use further restrictions in critical areas, especially at Isle Royal where stocks are seen as possibly unique but at extremely low numbers.
Quinlan et al.	1999	Coaster brook trout gamete collection at Isle Royal	Tobin Harbor, Big and Little Siskiwit River, Siskiwit and Hay Bays. September-October 1998.	Non lethal capture of brook trout for gamete collection for population restoration efforts at ISRO.	<u>Tobin</u>: Gametes collected from 15 female, 16 male brook trout in Tobin Harbor. 3000 eggs used to generate 1998 year class of brook trout. <u>Siskiwit Bay Area</u>: No gametes collected because the only ripe fish collected were progeny of previous artificial propagation efforts.	Memorandum from U.S. Fish and Wildlife Service to National Park Service. This information is critical to understanding early coaster brook trout restoration efforts at the island.
Quinlan	1999	Biological characteristics of coaster brook tout at Isle Royale National Park, Michigan, 1996-1998	Siskiwit Bay and Rivers, Tobin Harbor, Washington Harbor. Fall 1996, Spring and Fall 1997, Fall 1998.	Gamete collection for brood stock. Biological and population structure data; relative and absolute abundance; tissue samples for genetic analysis; habitat descriptions and spawning locations; determine contribution of stocked fish to Siskiwit Bay populations.	Captured 863 brook trout at all locations from 1996 to 1998.: <u>Tobin Harbor</u>: (capture/recapture) 786/260 <u>Big Siskiwit River</u>: (capture) 60 <u>Little Siskiwit River</u>: (capture) 8 <u>Siskiwit Bay</u>: (capture) 1 Recaptures from Siskiwit Bay area: 22 <u>Washington Harbor</u>: (capture/recapture) 8/1	Need to get solid population estimates with confidence limits to know status at Tobin Harbor. Assume Siskiwit Bay numbers are extremely low based on captures. Other reports from the brook trout subcommittee of Lake Superior Technical Committee provide information on status of coaster brook trout throughout Lake Superior. Most mention Isle Royale when discussing various stocks of coaster brook trout around the lake.
Curtis et al.	1998	Decline and recovery of lake trout populations near Isle Royale, Lake Superior, 1929-1990	Sites near Isle Royale. 1929-1990.	Commercial and sport angler harvest: Abundance trends; analysis of historic data back to 1929	Annual commercial harvest near Isle Royale averaged 164,220 kg from 1929 through early 1950s. Declined to < 10,000 kg during 1954-1959. Sport angling increased in 1970s. Estimate from postcard and creel surveys indicated annual angler harvest possibly as large as commercial harvest after 1970. Although "overexploitation contributed significantly to lake trout declines along south shore of Lake Superior, the relative roles of commercial fishing and sea lamprey predation in lake trout declines near ISRO are not as conclusive."	Draft report submitted for publication to Transactions of American Fish Society. Current report is with Michigan Department of Natural Resources, Marquette Fisheries Station. Important information for ISRO fisheries management plan.
Peck	1998	Assessment of lake trout at	Sivertson and	Commercial lake trout fisheries data: Compares	Sivertson fishery catch composed of 97-98% wild	"It is likely that locally adapted stocks exist that are

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		Isle Royale, 1991-1997	Edison fisheries. June-October 1991-1997.	some results for Isle Royale with information from inshore stock in Keweenaw Bay. Collected length, fin clip information to determine origin of fish, sea lamprey scarring information and scale or otolith for aging.	lake trout. Sea lamprey scarring and wounding decreased from 1991 to 1997. Edison fishery catch increased from 93% wild lake trout in 1991 to 99% wild lake trout in 1995-1997. Sea lamprey scarring and wounding decreased from 1991 to 1995-1996, then increased in 1997. Age of fish ranged from 4-31 years, but most were 7-12 years.	not assessed by either Sivertson or Edison fisheries." Information is useful for assessing stocks that are sampled, but these efforts don't likely represent other stocks around island.
Day	1997	Siskiwit Lake results from 1996 Michigan Fish Contaminant Monitoring Report	Siskiwit Lake. August 9, 1996.	Sample of 10 lake trout fillets and one sample of 10 whole fish analyzed for Hg, toxaphene, several organochlorines, 4 PCB congeners and total PCBs.	Memo to ISRO Resource Manager. Hg appeared to be only contaminant above Michigan Public Health trigger levels.	Apparently, toxaphene levels in Siskiwit Lake may be decreasing, but Lake Superior levels still seem high (See also Wright 1995, Wood 1994.)
Various authors	1996-1997	FILE FOLDER: lake trout spring assessment surveys	–	Various memos during mid- to late 1990s regarding spring lake trout assessment at ISRO and proposals to conduct such.	Communications between NPS, Keweenaw Bay Indian Community and Lake Superior Technical Committee of Great Lakes Fish Commission discussing possibility of conducting spring assessments at ISRO.	Isle Royale natural resources staff should review these memos as part of ongoing discussions with US Fish and Wildlife Service and State of Michigan to conduct lake trout surveys near the island.
Newman and Bast	1996	Coaster brook trout egg collection on Isle Royale	Big Siskiwit River area, Hay Bay. 20 September-19 October 1995.	Plan for collecting gametes (up to 300 eggs per female fish) from up to 25 pairs of coaster brook trout. Record age and size information, and relative abundance. Collect tissue samples for genetic analysis. Fyke and short-term gill net sets, backpack shocker, and angling were all used to capture fish, except no boom shocking in Lake Superior.	Captured 40 brook trout, with 9 recaptures: 12 from Lake Siskiwit and 28 from Big Siskiwit River, none from Lake Superior. Only age 0, 1 and 2 fish were captured.	This effort provides initial indications that Siskiwit Bay area populations might be very small. Also captured one adult male Coho salmon in Big Siskiwit River in spawning condition. Perhaps investigations on use of these streams by spawning pacific salmon should be investigated or at least look in early spring to see if juveniles are present in rivers and competing with brook trout.
Burnham-Curtis	1995	Population genetics of ISRO lake trout	ISRO; historic literature review, genetic analysis. 1981, 1988, 1993.	NPS workshop presentation on genetic analysis of ISRO stocks; protein electrophoretic analyses, mitochondrial DNA analysis.	Historically up to 12 morphological variants of three phenotypes. "…evidence that though historical morphological diversity was lost, genetic diversity was not."	Report is an argument for protecting this area of stocks against lake trout stocking because local adaptations can be lost through outbreeding. Preservation of existing diversity important, as is further information on ISRO stocks.
Hansen et al.	1995	Lake trout (*Salvelinus namaycush*) populations in Lake Superior and their restoration in 1959–1993.	–	Evaluated regulations, artificial (stocking), and natural repopulation after fishing restrictions and sea lamprey control throughout Lake Superior Based on historic data from mid 20th Century to 1990	Inshore stocks of wild lake trout about 61% of historic levels in Michigan and 53% in Wisconsin. Not enough historic information for determination of Minnesota and Ontario recovery. Further recovery requires continued sea lamprey control	Discusses diversity of stocks throughout lake and mentions historic diversity of Isle Royale. Genetic diversity of all stocks decreased due to destruction of local stocks, interbreeding between stocked and wild fish and introgression between once isolated stocks. Important for future ISRO genetic studies.
Wright	1995	ISRO results of Michigan fish contaminant report for 1994	Michigan waters. ISRO: Siskiwit Lake and Lake Superior near Isle Royale. 1987, 1989, 1992, 1993	Memo to ISRO natural resource manager reporting results for park. Michigan Department of Natural Resources, Surface Water Quality Division contaminants sampling program.	Siskiwit Lake: No changes in Hg level over time period, but levels were below several different (agency) health advisory guidelines. Total PCBs, chlordane appeared to be declined significantly; toxaphene also declined, but not significantly. DDT and isomers were declining, also; levels were far below consumption advisory triggers.	States that toxaphene-like substances are difficult to quantify, and questions if apparent declines are real or are due to new lab technology. Useful information for long-term monitoring of contaminant trends. (See Day 1997, Wood 1994)
Slade	1995	Results of 1994 cooperative angler program	ISRO: various sites. 1994	Voluntary creel designed by USFWS. NPS employee angler diaries.	Only three diaries completed and returned; and those returned were thorough. Northern pike and lake trout were only two species that anglers reported fishing for.	Additional effort could be useful if encouraged by park natural resources personnel. Information on inland and Lake Superior waters could be acquired. If conducted for long-term, may provide useful information on fish statistics such as catch and harvest per effort.
Slade	1995	October 1994 Isle Royale	Washington and	Follow up to preliminary investigations in 1993,	Washington Creek: 30 brook trout captured, but all	

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		brook trout assessment	Grace Creeks, Big and Little Siskiwit Rivers, Hugginen Cove and Grace Harbor. October 1994	because minimal information collected in earlier effort. Obtained further biological information, identified spawning locations and evaluated use of several tributaries as spawning locations. Fyke and small mesh gill nets used to catch fish by teeth instead of gill plates in order to reduce stress and mortality.	appeared to be juveniles or not in spawning condition; all were considered stream fish, not coasters. Rainbow trout, white sucker and northern pike also captured. Rainbows were most abundant of all fish. <u>Grace Creek/Grace Harbor</u>: 29 brook trout captured in creek, none in harbor, only one male in spawning condition, others were considered juveniles or in pre-spawn condition; all considered stream fish. Several redds were observed in riffle areas and spawning substrate appeared good .25 mi downstream from Feldtman trail crossing. Flow conditions indicate that spawning was probably from stream fish because coasters would have difficulty entering stream from Lake Superior. White sucker, northern pike, longnose sucker captured in Grace Creek; lake herring and round whitefish in Grace Harbor. <u>Big Siskiwit R/ Siskiwit Bay</u>: 13 brook trout captured in estuary area of river. All brook trout were silver in color and of larger average size than in other tributaries and appeared to be coasters. Several males in spawning condition, two females that appeared to have already spawned. No spawning activity observed. White sucker, lake whitefish, mottled sculpin, rainbow trout also captured. <u>Little Siskiwit River</u>: No brook trout captured below falls which is apparent upstream migration barrier at Section 23/24 border; observed one dead and partly decomposed brook trout below falls, approximately 10 inches long. Good spawning habitat exists below falls; observed juvenile rainbow trout indicating successful rainbow spawning in that area. Captured 5 brook trout above falls: one ripe male, one female in possible pre-spawn condition, and three unknown sex. White sucker, rainbow trout mottled sculpin captured below falls; lake chub, above falls.	Grace Harbor –Big Siskiwit – Little Siskiwit-below falls;
Burnham-Curtis and Smith	1994	Osteological evidence of genetic divergence of lake trout	US and Canadian waters of Lake Superior. 1988-1989	Lake trout collected by trawls at several depths. Recorded external morph characteristics, skeletal structure of cranial and jawbones. Compared with skeletal specimens from University of Michigan museum.	All fish collected at > 110 m by commercial fishers possessed Siscowet characteristics. Slight overlap of phenotypes in capture depth near Isle Royale	Evidence that Siscowet and humper lineages of lake trout originated in Lake Superior. Significant level of differentiation between three phenotypes; Limited gene flow among phenotypes. Unclear if potential differentiation among stocks at Isle Royale is possible.
Slade	1994	A pilot study on the status of coaster brook trout in the waters of Isle Royale National Park, Lake Superior	Tobin Harbor, Washington Harbor and Grace Harbor areas. September, 1993	Sampled for one week using non-lethal capture gear and methods. Some gill nets used, but examined every 1-3 hours and not fished overnight. Documented all species captured, measured 50 randomly selected fish if >50 individuals captured. Took blood samples for genetic investigations. Referred to lake captured brook trout as "coasters" and those in tributaries as "stream trout."	Captured 17 coaster brook trout at Tobin Harbor and three "stream trout" in Tobin Creek. No coasters captured in Washington or Grace Harbors. Two stream fish captured by electrofishing in Washington Creek and an unnamed creek near Windigo. Based on discussions with anglers, most Park Service employees, an estimated 175 large brook trout (12 to 20 in) had been harvested from several pools in Grace Creek prior to this assessment. Due	Further discussions with park staff regarding populations at this end of the island might be helpful. Sivertson fishery may provide some helpful historic information also. If anecdotal accounts are true, this furthers the argument for suspending all brook trout fishing at the ISRO.

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					to small size and flow of this creek (<2 cfs at time of survey) it is unlikely that these would have been resident fish. If these accounts are close to accurate, this would suggest a coaster population had migrated into the stream and was harvested prior to spawning.	
Slade and Olson	1994	Results of 1993 survey of the species composition and relative abundance of fish in Isle Royale tributaries to Lake Superior	Big and Little Siskiwit River, Washington Creek, Chickenbone Lake outlet, Grace Creek, Tobin Creek. One sample, summer 1993.	Backpack electroshocking and/or minnow traps used to determine types and relative abundance of stream fish species.	Captured and identified 13 species. Rainbow trout only non-native species captured. Field data sheet copies included in file. Some invertebrate and habitat information included.	Only baseline stream information found in files. Useful for species presence comparisons for future investigations, population data is only relative abundance.
Wood	1994	Michigan fish contaminant monitoring program 1994 annual report.	Michigan waters. ISRO: Siskiwit Lake and Lake Superior.	Native fish collection and caged fish bioconcentration studies.	Lake trout exceeded Michigan Department of Public Health fish consumption advisory trigger levels (in one or more fish) for Hg, total DDT, total PCBs, total chlordane and toxaphene.	The only lake trout in the entire state of Michigan (2 fish) that were above the trigger level for Toxaphene came from Lake Superior near Isle Royale. Author suspects one fish was a Siscowet due to high fat content (30%); however, Siscowet can have much higher fat content than this reported level. (See also Day 1997, Wright 1995)
Karamanski et al.	1991	The enticing island: a history of Isle Royale National Park	Historic information: fish stocking records.	Review of past fishery and stocking information for whitefish, lake trout.	Hatchery constructed in Duluth in 1886; in 1895 2,7500,000 lake trout eggs collected at Todd, Rock and Washington Harbors and Fish Island. Fertilized eggs sent by ship *America* to mainland. Between 1916 and 1940, 34 million lake trout and 42 million whitefish eggs taken from ISRO waters. During same period, 81 million trout fry and 31 million whitefish fry planted in island waters.	Information from ISRO cultural resources; only pages 88-89 available for review. Biggest question: if 34 million lake trout eggs taken, but 81 million fry planted during same period, what were origins of the additional 40+ million fry that were planted at ISRO. Big genetic implications.
Swackhamer and Hites	1988	Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior	Siskiwit Lake.	Used whole fish: 18 lake trout in 4 size classes, 15 whitefish in 3 size classes. Composite samples homogenized for analysis. Examined for *several* contaminants.	Toxaphene was generally the most abundant contaminant. Most abundant single pesticide in all samples was DDE, then dieldrin. They suggest high DDE concentrations may be due, in part, to localized DDT application. Apparently, ISRO officials recalled that some DDT was used on the island in the 1960s.	Siskiwit Lake contaminants are well studied. (See additional review in contaminants category.)
Swain et al	1986	Long range transport of toxic organic contaminants to the North American Great Lakes.	Lake Huron (Michigan side and Bruce Peninsula). ISRO: Siskiwit Lake. 1980	Sampled lake trout, whitefish and, reportedly bowfin. Snow sampled from lake surface. Persistent organic contaminants, similar to earlier sampling procedures.	Values from 1978 published study showed very high PCB levels. However, refined procedures in this study suggested that "derivatives of toxaphene may have been enumerated with PCB peaks, thus being inadvertently reported as total PCB."	Determine if current analytical procedures show any further changes in total PCBs or other contaminants. Assume that fish identified as bowfin may be mis-identified burbot, since bowfin have not been identified there in fishery surveys
Strachan	1983	Organic substances in the rainfall of Lake Superior	Caribou Island in eastern Lake Superior and ISRO.	"Triplicate Samples." Rainfall sampling program initiated in 1983 to compare two "open water" sites at opposite ends of Lake Superior.	West side of lake received average of twice the concentrations found on the east end. Spring rains contained elevated levels relative to other times.	ISRO copy is executive summary and report. Submitted to Journal of Environmental Toxicology and Chemistry. Publications from this study should be obtained.
Bierman and Swain	1982	Mass balance modeling of DDT dynamics in Lakes Michigan and Superior	Lakes Michigan and Superior. Annual 1969-1978.	DDT residues in coregonid fishes. Investigation of response of Lake Michigan and Superior biota to 1969 ban on DDT. Used available data for both lakes for a retrospective analysis of DDT dynamics.	DDT levels in both lakes decreased at rates greater than expected based on hydraulic detention times and degradation rate for DDT in the environment. However, 60-95% of loss from water column was attributed to particulate settling.	Re-suspension of DDT from lake bottom disturbances should be investigated for the effective will have on long-term persistence.
Lagler and	1982	Fishes of Isle Royale, 3rd	ISRO, park-wide.	Descriptive text of fish of Isle Royale.	Describes habitat and species found in Lake Superior	Useful for general information of fish around island.

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Goldman		edition			and streams and lakes on island. Also describes fishing opportunities for various species around island	Guide for anglers with some life history and physiologic descriptions.
Swain	1978	Chlorinated organic residues in fish, water, and precipitation from the vicinity of Isle Royale, Lake Superior	ISRO: Siskiwit Lake, Lake Superior areas. Duluth/Superior area, northeast of Apostle Islands.	Analysis of persistent contaminants in fish and water samples. Several compounds including DDT and isomers, PCB, HCB Dieldrin, Diethyl Dibutyl and Diethylhexyl Phthalate	Values for several organic residues in fish from Siskiwit Lake on Isle Royale were higher than levels in fish from Lake Superior. "PCBs were nearly double Lake Superior mean values; *p,p*-DDE showed a more than 10 fold increase in Siskiwit Lake."	Siskiwit Lake chosen as "control" to compare with Lake Superior due to remote location with supposedly minimal impacts from human development. Additional studies conducted later to investigate Siskiwit Lake. Should be continued in future to determine if airborne contamination is decreasing or not.
Rakestraw	1968	Commercial fishing on Isle Royale, 1800-1967	ISRO waters.	Historic account of commercial fishing at island.	Describes Isle Royale fishermen as "splitters" when defining stocks of lake trout. Several "subspecies" described by spawning characteristics, are mentioned: redfin, spawn early and in shallow gravel bottoms. 3-4 ft water. Channel salmon spawn in mud bottom with weeks in bays or channels. Silver gray, smoky, gray salmon, paperfin (supposed spring and fall spawner). Rock of Ages trout, black and white Siskiwit, with the black usually three times as large as white. Mooneyes from the north side, toward Gull Rock. Siskiwit was "unpalatable eaten fresh, but, if salted was considered a delicacy and was much sought after during the early days of commercial fishing."	Valuable historic anecdotal information on different lake trout phenotypes found around the island. Includes information on relative commercial importance of other species such as whitefish, lake herring.
Wallis	1966	Long range aquatic resources management plan, Isle Royale National Park, 1966-1975	ISRO, park-wide.	Primarily an evaluation of fishery resources from existing data and reports	202 lakes and ponds on the island; 162 > 1 acre. Discusses past fish management actions, such as stocking (and purported stocking) of various species at Isle Royale, including walleye at Lake Richie and Moskey Basin. Brown trout planted in Tobin Harbor, Conglomerate Bay and streams flowing into Moskey Basin and Chippewa Harbor in 1942. Brook trout stocked at Big and Little Siskiwit Rivers, and Tobin and Rock Harbors in 1932.	Discusses unique fish of island that were reported as 5 subspecies and one species that are endemic to the island. Annotated bibliography describes several useful reports on early and mid century investigations of island.
Sharp and Nord	1960	A fishery survey of some of the lakes of the Isle Royale National Park	August 18-28, 1960	Lake surveys to supplement earlier surveys by Koelz (1929).	Most data presented in appendixes not with copy of document reviewed. Included recommendations for management of northern pike by increasing size limit from 14 to 20 in.	Described little utilization of yellow perch and suggested no size or creel limit was necessary. There are current reports from park staff that a fishery for perch exists in some locations; this should be investigated to determine impacts to populations where fishery exists.
Eschmeyer and Bailey	1954	The pygmy whitefish, *Coregonus coulteri*, in Lake Superior	Lake Superior: several sites. ISRO: Siskiwit Bay. Fall-Winter 1953.	Bathymetric distribution; length frequency; length at age; catch per effort; sex ratio.	Several fish taken at Siskiwit Bay, with several YOY fish among the catch. Growth rate was very slow, compared with Keweenaw Bay.	Current status of this fish should be investigated.
Hubbs and Lagler	1949	Fishes of Isle Royale, Lake Superior, Michigan, 1st edition	ISRO; several sites. 1945.	Made collections in several waterbodies to supplement previous investigations. Compiled data from Ruthven (1906, 1909), Koelz (1929), and US Fish and Wildlife Service.	Described 49 kinds of fish representing 41 species, 31 genera and 14 families.	This information, along with Koelz (1929) provides baseline to which later investigations are compared. Proposed contemporary genetic investigations of some species stem from these earlier investigations and reports of subspecies in some island lakes. Authors also question Ruthven's early documentation of muskellunge at the island (p. 93).

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Hubbs	1932	The Fishes of Isle Royale	Isle Royale, most waters.	Summarized data from Koelz (1929), Ruthven (1906, 1909) and commercial fisheries returns.	Describes occurrences of species throughout island. Author describes sub-species both as determined by Koelz, and as further determined by Hubbs after conferring with Koelz.	Cool stuff, but much of the sub-species delineation has since been refuted. Useful for continuing investigations on coregonids and cyprinids of the island.
Koelz	1929	A survey of the lakes of Isle Royale, with an account of the fishes occurring in them	Isle Royale; 38 lakes. August-October 1929.	Fisheries and limnological surveys using standard fisheries sampling. Collections taken for ichthyologic specimens held at University of Michigan.	Somewhat detailed limnologic and fisheries descriptions of each lake surveyed. Included some aquatic invertebrate and vegetation descriptions. Surmises that moose may affect aquatic faunal communities by extensive browsing of aquatic vegetation.	Included description of unique coregonid populations at the island. Subspecies descriptions were questioned in later investigations.
Ruthven	1909	The cold-blooded vertebrates of Isle Royale	Isle Royale waters. Summer 1905.	Supplement to other papers from 1905 survey, included sampling in more areas. Reported on fish and other fauna of Isle Royale.	Documented 18 species; 6 of those were documented in previous survey, and 2 from previous survey were not documented in this report	Investigated more areas than previous survey, but still not comprehensive. Some genus and species names have been changed at least once since this report was made.
Ruthven	1906	The cold-blooded vertebrates of the Porcupine Mountains and Isle Royale, Michigan	Isle Royale: Washington Harbor. 1904.	Early investigations from University of Michigan. Fisheries sampling apparently only occurred in Washington Harbor area. Accounts of early collections of fish, amphibians at Isle Royale, not comprehensive	Only 8 species recorded at Washington Harbor Recorded capture of one muskellunge near shore of Washington Harbor.	One an incomplete copy available for review, but it appears that limited investigation was conducted. Only species found in Lake Superior reported, leading to the conclusion that inland waters were not investigated during early surveys. Curious documentation of muskellunge (*Lucious masquinongy*). Seems unusual to find this species here, although there is limited Lake Superior population information around the island for species other than salmonids. This is the only documentation of muskellunge at the island. Was this a mis-identified northern pike? No other northern pike were documented in this investigation.
Raymond	1897	In memory of our fishing trip in the Lake Superior region, summer of 1897	Isle Royale: Washington Harbor, Siskiwit Bay, Rock Harbor, Tobin Harbor	Angling for brook trout and lake trout around the island.	Few brook trout caught at western end of island and Siskiwit Bay. Caught two brook trout at Wright's Island weighing over 2 and 3 pounds. Caught 54 brook trout at Tobin Harbor in one day totaling approx. 70 pounds.	Provides good anecdotal (or perhaps better) information about brook trout at Isle Royale in late 19th century. In cultural resource files at ISRO.
Various authors	1990s	Brook trout subcommittee of the Lake Superior Technical Committee, Great Lakes Fish Commission	–	Memos and minutes in files pertaining to proceedings of meetings of the brook trout subcommittee. Information usually includes progress of brook trout management planning in Lake Superior and efforts to conduct investigations at ISRO.	Extensive notes and memos–too numerous to include here. Some notes may contain specific information on methods or results.	All of this information should be found in more thorough detail in reports on brook trout rehabilitation efforts conducted at the island, several of which are included in this table.
AQUATIC WILDLIFE						
Peterson and Vucetich	2004	Ecological studies of wolves on Isle Royale	ISRO, park-wide. 2003-2004.	Summer field work and annual winter study.	Moose declined from an estimated 900 to 750 during 2003-2004, while wolf populations surged from 19 to 29. Moose declines attributed to winter tick, which may cause high mortality and poor reproduction, and summer heat and drought, which may increase vulnerability of moose to predation.	Authors indicated the recent declines in the moose population (1998-2002) may be caused by unusually warm and dry weather occurring due to global climate changes and warming trends. The long-term monitoring records for moose and wolf on ISRO are of tremendous value and should continue to be supported.
Smith and Shelton	2002	Isle Royale beaver study – 2002	ISRO, park-wide. 23-24 October 2002.	Aerial census is 15th such survey since 1962. Beaver colonies with food caches identified and recent activity noted by fresh cuttings or mud on lodges.	73 colonies with food caches, and 8 other sites with beaver sign, for a total of 81 active sites. Numbers had not changed since the 2000 survey, but have declined since the mid-1980s.	Authors note that aerial surveys generally underestimate the actual number of active colonies by 20% or more. Declining colony size also makes active areas harder

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
				Some hiking and ground-truthing conducted to evaluate food quality at beaver sites.	Harbor and inland lake colonies were both stable. Colonies located in the 1936 burn area were still the primary area of beaver occupation. Further population declines were predicted due to declining habitat quality, increased wolf predation, and recent drought.	to spot from an airplane.
Egan and Oelfke	2000	2000 common loon survey at Isle Royale National Park, Michigan	ISRO: interior lakes, 47 sites; Lake Superior shoreline, 45 sites. Summer 2000.	As in previous years, sites surveyed for loons by boat, canoe, kayak, or walking along the shoreline. Defined loon territories based on an atlas completed by BioDiversity Research Institute.	According to territory atlas, there were 98 confirmed territories on ISRO, 63 of which were on inland lakes. Estimates of productivity based on the territory atlas were 0.3 young per territory. 30-50% of breeding pairs were successful in 2000, the same average for loons elsewhere.	These repeated loon survey efforts should be continued as part of a long-term monitoring for ISRO.
Aho and Jordan	1979	Production of aquatic macrophytes and its utilization by moose on Isle Royale National Park	ISRO, beaver ponds of two drainages at the western end. 1973-1975.	Selected 4 blocks in each study pond with one exclosure treatment and control in each block. Standing crop in paired units sampled, sorted by species and compared.	Present moose population leaving sufficient plants to assure adequate plant reproduction under normal climatic conditions. Climate and beaver activities affect macrophytes and moose forage.	Macrophytes provide forage and sodium that moose need. Drought, declines in beavers, and high moose densities may affect availability of macrophytes. Further research could address moose foraging patterns with respect to aquatic vegetation over space and time. (See additional review under wetlands and aquatic vegetation category.)
Jordan	1978	Miscellaneous information and speculation on moose and their impact on vegetation and some other herbivores at Isle Royale	Park-wide.	General review of moose ecology, interactions with wolves, effects on vegetation, and history on ISRO provided.	Food sources in most seasons are terrestrial. In summer, 10-20% of moose food intake is submerged aquatics. Author suggests that terrestrial feeding does not provide sufficient sodium in the moose diet, and that aquatics help provide the needed amount. Author notes that moose consume 30-90% of current production of aquatics in some ponds.	Author suggests more research is needed to determine effects of moose on aquatic vegetation and sodium balance in ponds.
Jordan and Aho	1978	Ecological studies of moose foraging at Isle Royale National Park with primary emphasis on aquatic feeding and sodium dynamics	ISRO: Grace Creek Pond and "Coastal Pond," western end. 1975-1976.	<u>Exclosure experiments</u>: Two beaver ponds selected; 4 experimental blocks (paired moose, no moose) designated. Standing crop measured in each block during late summer for two years. Plant species identified and ranked in order of abundance. Sodium concentrations in plants, waters and substrates determined. <u>Extensive inventory</u>: ISRO surveyed via aerial photography and randomly selected aquatic habitats were classified, mapped, and sampled in late summer.	<u>Exclosure experiments</u>: Moose exclosure caused a marked increase in standing crop; moose removed 62% and 92% of the production in the two pond systems, respectively, generally in proportion to plant availability. Plant sodium was higher in plants from exclosures, perhaps due to less turbidity and disturbance from moose trampling. <u>Extensive inventory</u>: Lakes contained 74% of the total standing crop of aquatic plants at ISRO, but beaver ponds were a more important source of aquatic vegetation due to their uniform distribution and shallower depths. These habitats are susceptible to drought and colonization. Plant species lists provided for each sampled site.	Authors concluded that because aquatic vegetation withstood removals of >50% of standing crop and survived to the next year, availability of aquatics at ISRO was sufficient to sustain existing moose populations.
Murie	1934	The moose of Isle Royale	ISRO, park-wide. 1929-1930.	Historic moose numbers, physical description, growth and development, shedding, senses, home range, daily activity, sociability, insect pests, accidents and disease, mating behavior, and feeding habits all described.	Author noted that moose browsed mostly on sedges, grasses and weeds, including aquatic vegetation in summer. Feeding in aquatic habitats was generally limited to water less than 6 feet deep. List of food plants provided. Destruction of lake plants was noted, and decimation	Author noted potential effects of moose browsing on the distribution and abundance of aquatic vegetation, emphasizing potential effects on fish habitat.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					of pondweeds observed in lakes frequented by moose.	
Amphibians and Reptiles						
Milanowski et al.	2000	Isle Royale frog and toad survey, 2000	ISRO trails; 4 transects. Early spring, late spring, summer 2000.	Qualitative call indices recorded at 10 survey points per transect, based on relative abundance of animals calling. 6 different wetland types included in surveys: vernal pond, wet meadow, bog, marsh, wooded swamp, and pond.	Only 5 of 6 species were present on ISRO have been heard each year since surveys began in 1996; mink frog only heard in 1998 and 2000. All 6 species were heard in 2000. Relative abundance estimates for each species were similar to previous ISRO surveys and matches other regional data from State of Michigan. Beaver ponds appear to have the highest abundance of anurans on ISRO.	Authors recommended more frequent surveys throughout the season, perhaps focusing on the most species-rich habitats, to ensure that peak calling times are captured. Authors suggested doing incidental counts of American toads along the survey transects. Authors noted a need to understand how factors like rainfall, temperature, and humidity may affect anuran populations and estimations of their size.
Smith and Van Buskirk	1995	Phenotypic design, plasticity, and ecological performance in two tadpole species	North Government Island; rock pools. 1990-1991.	Reciprocal transplant experiment, with two species of tadpoles (*Pseudacris crucifer* and *P. triseriata*) and two types of habitat. Tadpole densities, behavior, body shape, etc. measured.	Spring peepers were found high on the shore at low densities in persistent pools with predators; functional traits favored predator avoidance. Chorus frogs found in both habitats and had more variable growth and development; functional traits favored fast food processing. Transplant experiment showed change in phenotype to favor predator avoidance. Both species survived poorly when placed in upper pools with predators. Competition between species was slight.	–
Van Buskirk and Smith	1991	Density-dependent population regulation in a salamander	Edwards and North Government Islands; rock pools. Summers 1986-1989.	Blue-spotted salamander larvae presence and water depth monitored every other day throughout studies. Salamander densities and body sizes monitored summer 1989. Field density manipulations conducted.	Increasing density significantly reduced survival and growth. Density effects were likely due to interference competition. Density dependence of salamander larvae appeared commonplace in Isle Royale splash pools.	Study provides good estimate of larval salamander population sizes and variability among pools.
Smith	1987	Adult recruitment in chorus frogs: effects of size and date at metamorphosis	North Government Island; rock pools.	Tadpole density, length at metamorphosis, and population size determined. Tadpoles marked; adults recaptured. Effect of body size and date at metamorphosis on survivorship monitored.	Long larval period and small body size at metamorphosis influenced recruitment to the breeding population by delaying maturity. Frogs that metamorphosed at large size maintained size advantage at maturity. Effect of size and date of metamorphosis on survivorship appeared small.	Author stresses a need for more demographic information on frogs after metamorphosis and a need for links between tadpole information and adult information.
Smith	1983	Factors controlling tadpole populations of the chorus frog (*Pseudacris triseriata*) on Isle Royale, Michigan	Edwards and North Government Islands; rock pools. 1979-1980.	Pool locations, size and persistence determined. Tadpole abundance, survivorship and growth monitored. Field experiment tested effects of food and density on survivorship and growth.	Pool persistence increases with size and distance from lake. Small pools don't last long enough for metamorphosis, but large permanent pools contain predaceous dragonfly larvae and salamanders. Highest tadpole densities in intermediate level pools.	Useful baseline information about pool permanence which could be used for monitoring climate change monitoring in regard to tadpole requirements and constraints.
Wetlands and Aquatic Vegetation						
U.S. Geological Survey	Circa 2000	Isle Royale National Park vegetation mapping project for the USGS-NPS vegetation mapping program	ISRO, park-wide. 1994, 1996.	Aerial photography flights conducted in 1994 and 1996. Field work conducted to identify and classify vegetation, both semi-aquatic and terrestrial. Geospatial data assembled and mapping conducted. Aerial and ground photographs and interpretations provided.	Aquatic or semi-aquatic vegetation classes included: · Black ash (white cedar) mixed hardwoods swamp complex. · Northern tamarack rich swamp. · Red maple-ash-birch swamp forest. · Sedge/sphagnum meadow complex. · Sedge meadow complex. · Speckled alder swamp.	Part of an NPS service-wide program. This study represents the most comprehensive and sophisticated aquatic vegetation study available to any GLKN park (other than VOYA, for which a similar study was completed), and will be useful for some time into the future. All mapping products and text are available online.

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<tr><td>Judziewicz</td><td>1999</td><td>Isle Royale National Park aquatic vascular plant species</td><td>ISRO; inland lakes and ponds, Duncan Bay, Tobin Harbor.</td><td>Based on author's knowledge and previous vegetation studies. Created list of truly aquatic vascular plant species.
Splash pools, bedrock beaches, bogs, marshes and beaver ponds excluded.</td><td>Species list and information on relative abundance, habitat and location, where available.</td><td>Author notes that most plant surveys conducted in 1930, with little effort since.</td></tr>
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(See additional review under aquatic wildlife category.)</td></tr>
<tr><td colspan="7">CONTAMINANTS</td></tr>
<tr><td>Swackhamer and Hornbuckle</td><td>2004</td><td>Assessment of air quality and air pollutant impacts in Isle Royale National Park and Voyageurs National Park</td><td>VOYA and ISRO, park-wide data synthesis. 2003.</td><td>Synthesis of available information, providing descriptions and contaminants background information including relevant regulations.
Emissions sources identified.
Monitoring and research activities summarized for visibility, nitrogen sulfur, persistent organic pollutants (POPs), mercury, arsenic, etc.
Research and monitoring needs described.</td><td><u>ISRO</u>: Sulfate deposition has declined and pH has increased; stream water chemistry not correlated with precipitation chemistry, but instead modified by vegetation and soil processes; despite acid deposition, may be no significant effects on the ecosystem; POPs in fish and sediments investigated in Lake Superior and Siskiwit Lake, confirming long-range transport of PCBs, DDT, triazine herbicides and other compounds. Mercury examined in fish-varies by species and lake; fish mercury appears to have declined since 1929; mercury in food webs of Sargent and Richie Lakes also examined, along with loons and wildlife.
<u>VOYA</u>: Deposition monitored at Sullivan Bay, PCBs and DDE found in plasma of bald eagle nestlings collected in 1999. Perfluorooctane sulfonate being analyzed in water, air, and fish from two inland lakes. Mercury examined extensively in lake sediments, fish tissue, and bald eagle feathers; factors affecting mercury bioaccumulation now under examination.</td><td>Assessment presents a fairly comprehensive summary of air quality issues and research and monitoring themes for ISRO and VOYA.
<u>Primary vulnerabilities</u>: (both parks):
· Effects of mercury and POPs on fish-eating birds and wildlife.
· Effects of mercury on anglers.
· Effects of mercury and POPs on terrestrial food webs.
<u>Research and monitoring needs</u>:
· Program for recording human activities such as snowmobile use.
· Air and fish contaminant trend monitoring program for mercury and select set of POPs.
· Emissions study for PAHs and VOCs from snowmobiles.
· Comparative modeling study investigating impact of local vs. distant/regional sources of pollutants since long range transport likely at these parks.
· Quantification of risks associated with toxics in fish as well as birds and mammals.
· Mercury cycling and bioaccumulation research.</td></tr>
<tr><td>Gorski et al.</td><td>2003</td><td>Factors affecting enhanced mercury bioaccumulation in inland lakes of Isle Royale National Park, USA</td><td>ISRO; Sargent and Richie Lakes. 1998-1999.</td><td>Water, zooplankton, macroinvertebrates and fish collected and analyzed for mercury.
Sargent Lake has fish mercury advisory; Lake Richie does not; mercury information from throughout each lake's food web compared.
Stable isotopes of carbon and nitrogen in pike examined.</td><td>Open water total and methyl mercury both slightly higher in Lake Richie.
Zooplankton total and methyl mercury higher in Sargent Lake.
Macroinvertebrate total and methyl mercury similar in two lakes, but different between taxa.
Total mercury in northern pike and adult yellow perch higher in Sargent Lake.
Stable isotopes of carbon and nitrogen showed that pike from both lakes are positioned similarly but that Sargent Lake's food web is more pelagic-based than Lake Richie.</td><td>Authors note that predicting which lakes or lake types will have higher mercury is not possible at this time, but cite factors that could account for differences in northern pike mercury.
System components that could be explored with further study:
· Bioavailability and bioaccumulation of filterable mercury as it relates to differences in DOC levels.
· Mercury biomagnification and bioaccumulation differences at the zooplankton level.
· Growth efficiency, food web structure, energy pathways.</td></tr>
</table>

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
						(See additional review under biology and ecology category.)
Carlisle	2002	Draft ecological assessment of an Isle Royale stream following a fuel spill	ISRO; Washington Creek. Summer-fall 2001.	Site upstream of spill selected as a reference; 2 locations downstream selected as test sites. Invertebrates, sediment and water chemistry, leaf-litter breakdown and habitat monitored.	Sediment chemistry similar between reference and test sites. Invertebrates differed between sites but likely due to substrate differences rather than spill. Abundance of capniid stoneflies and a freshwater shrimp, both sensitive to contaminants, was lower at the test site. Species richness and leaf-litter decomposition similar between sites. Ecological processes and species richness have recovered, but sensitive species remain low.	Monitoring near fuel-handling locations should take place to ensure better remediation and recovery in the event of any future spills.
Gostomski	2002	Investigations of mercury in the food web of Isle Royale National Park, Michigan: a summary of research projects completed under a grant from Canon USA	ISRO, park-wide. 1995-2002.	Summarizes mercury data from fish (Kallemeyn 2000), geologic sources (Cannon and Woodruff 1999), terrestrial sources (Cannon and Woodruff 2000), loons (Kaplan and Tischler 2000), deer mice (Vucetich and Vucetich 2000), lake food webs (Gorski et al. 2001), and moose and human teeth (Peterson et al. 2002).	Results presented in executive summary formats for each study. Literature citations provided.	A solid summary of recent mercury research at ISRO. Each study provides useful indications of future research and monitoring directions.
Gorski et al.	2001	An investigation of mercury levels in the food web of Isle Royale National Park, Michigan: report for the aquatic subproject, Sargent and Richie Lake, summer 1998-1999.	ISRO; Sargent and Richie Lakes, 1998-1999.	Water, sediment, zooplankton, macroinvertebrates and fish collected and analyzed for mercury. Sargent Lake has fish mercury advisory; Lake Richie does not. Mercury information from throughout each food web compared. Sediment cores for both lakes examined for diatoms, mercury and phosphorus.	Lakes had similar physical and watershed characteristics; both had anoxic hypolimnia with associated increases in methyl mercury. Lake Richie had slightly higher mercury in water samples and higher DOC, suspended particulate matter, chlorophyll *a*, and blue-green algal pigments. Stream inflows for both lakes had higher DOC and methyl mercury than lakes. Food web results as reported in Gorski et al. (2003). Sediment cores indicated recent increases in total mercury, and increasing phosphorus concentrations in Lake Richie. Cores suggest atmospheric mercury sources. Elevated mercury levels in Sargent Lake pike not explained by mercury in water, sediments or food items.	This project report provides similar information but greater detail than the Gorski et al. (2003). Implications for future research: · Bioavailability and bioaccumulation of filterable mercury as it relates to differences in DOC levels. · Mercury biomagnification and bioaccumulation differences at the zooplankton level. · Growth efficiency, food web structure, energy pathways.
Baker and Hites	2000	Siskiwit Lake revisited: time trends of polychlorinated dibenzo-*p*-dioxin and dibenzofuran deposition at Isle Royale, Michigan	Siskiwit Lake. 1998.	Two sediment cores collected from Siskiwit Lake and analyzed for polychlorinated dibenzo-*p*-dioxin and dibenzofurans (PCDD/F).	Cores indicate that PCDD/F deposition increased in the 1930s and peaked in the late 1970s, then declined to current levels that are 50% the 1970s levels.	Study provides evidence of atmospheric contaminant transport to ISRO. Follow-up studies may be needed to confirm continued decline. (See additional review under fish category.)
Kaplan and Tischler	2000	Mercury exposure in the Common Loon (*Gavia immer*) at Isle Royale National Park, Michigan	ISRO; 6 inland lakes.	Mercury concentrations measured in loon blood and feathers. Sargent Lake loons were compared with Lake Superior loons.	No significant differences among adult loons sampled on Sargent Lake vs. Lake Superior, but Sargent Lake juveniles had significantly higher blood and feather mercury. Interior lake territories with elevated fish mercury levels hatched significantly fewer chicks than Lake Superior territories, but fledging rates were similar. Loon mercury at ISRO moderate to low compared	Juveniles most reliable indicator of mercury exposure for a given water body, since feed exclusively in natal territory. Authors suggest that the possible relationship between mercury and loon productivity be studied further.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					with other North American sites.	
Kuruntha-chalam et al.	2000	Polychlorinated napthalenes and polychlorinated biphenyls in fishes from Michigan waters including the Great Lakes	Michigan waters: Great Lakes. Siskiwit Lake. 1996-1997.	Whole body and fillet of fishes measured for polychlorinated napthalenes (PCNs) and polychlorinated biphenyls (PCBs).	PCNs found in all fishes analyzed. PCNs and PCBs significantly correlated. Isomer/congener profiles differed among sampling locations and species. Siskiwit Lake and Lake Superior samples contained greater proportions of congeners with high bioaccumulative potential.	Study provides further evidence of atmospheric contaminant transport to ISRO. Since PCNs found in all fishes, may be easily monitored.
Thurman and Cromwell	2000	Atmospheric transport, deposition, and fate of triazine herbicides and their metabolites in pristine areas at Isle Royale National Park	ISRO; inland lakes. 1992-1994.	Deposition collected at Lakes Wallace and Richie and analyzed for triazine herbicides. Water samples collected from 12 lakes across ISRO and analyzed for triazine herbicides.	Atrazine, deethylatrazine, deisopropylatrazine, and cyanazine detected in rainfall from mid-May to early July (0.005-0.18 µg/L). Atrazine and deethylatrazine found in ISRO lakes in increasing concentrations throughout the deposition periods. Deep lakes had residence times for atrazine that may exceed 10 years; shallow lakes may have faster degradation.	Study provides further evidence of atmospheric contaminant transport to ISRO. Deposition corresponded to 0-4 week post herbicide application season. Concentrations less than toxicity criteria for aquatic organisms, but authors encourage monitoring the lakes on a 5-10 year basis to verify that concentrations are not increasing.
Evers et al.	1998	Geographic trend in mercury measured in common loon feathers and blood	North America, 5 regions, including Upper Great Lakes, ISRO, VOYA. June-September 1991-1996.	Loons netted from boats, sexed, aged, feathers and blood collected for total mercury analysis. Water chemistry collected at 1 m from each lake.	Mercury in adult feathers ranged from 2.8-36.7 µg/g and in blood from 0.12-7.80 µg/g. Mercury in juvenile blood ranged from 0.03-0.78 µg/g. Blood and feather mercury were correlated within individuals. Blood and feather mercury higher in males for each region. Blood mercury increased from west to east. Blood mercury in Upper Great Lakes region less influenced by variation in mercury deposition than by hydrology and lake chemistry. Loons breeding on low-pH lakes in the Upper Great Lakes at greatest risk.	Assessing mercury exposure in loons will require stratification of data by sex, age, tissue type and geographic distribution.
McVeety and Hites	1988	Atmospheric deposition of polycyclic aromatic hydrocarbons to water surfaces: a mass balance approach	ISRO; Siskiwit Lake.	Mass balance model constructed to explain PAH movements in and out of Siskiwit Lake. Rain, air, lake, snow, winter air samples, sediment cores and sediment trap samples collected.	Rain was 4 times more efficient than snow in removing PAH-containing aerosols from the atmosphere. Average dry to wet deposition ratio was 9:1. Much of the deposition input was lost through surface volatilization for most PAHs. Outflow of lake water an insignificant loss mechanism for PAH in Siskiwit Lake. Overall mass transfer was dominated by the liquid phase resistance.	Author recommends several new research avenues: Apply mass balance model to a different set of chemicals, e.g. PCBs. Investigate relationship of particle size to PAH aerosols. Explore role that fog deposition plays in atmospheric removal process.
Swackhamer and Hites	1988	Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior	ISRO; Siskiwit Lake.	Lake trout and whitefish netted, grouped by size and analyzed for polychlorinated biphenyls (PCBs) and several chlorinated pesticides.	Long-range contaminant transport confirmed. Fish characteristics, such as size and weight, are important in determining bioaccumulation in a species.	Lake trout and whitefish appear to accumulate chlorinated organic compounds in measurable quantities. This characteristic may be useful for future contaminant monitoring. (See additional review under fish category.)
McVeety	1986	Atmospheric deposition of polycyclic aromatic hydrocarbons to water surfaces: a mass balance	ISRO; Siskiwit Lake.	Dissertation. Mass balance model constructed to explain PAH movements in and out of Siskiwit Lake. Rain, air, lake, snow, winter air samples,	Rain was 4 times more efficient than snow in removing PAH-containing aerosols from the atmosphere. Average dry to wet deposition ratio was 9:1.	Author recommends several new research avenues: Apply mass balance model to a different set of chemicals, e.g. PCBs. Investigate relationship of particle size to PAH

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		approach		sediment cores and sediment trap samples collected.	Much of the deposition input was lost through surface volatilization for most PAHs. Outflow of lake water an insignificant loss mechanism for PAH in Siskiwit Lake. Overall mass transfer was dominated by the liquid phase resistance.	aerosols. Explore role that fog deposition plays in atmospheric removal process.
Czuczwa et al.	1984	Polychlorinated dibenzo-*p*-dioxins and dibenzofurans in sediments from Siskiwit Lake, Isle Royale	ISRO; Siskiwit Lake.	Sediment core collected from Siskiwit Lake and analyzed for polychlorinated dibenzo-*p*-dioxin and dibenzofurans (PCDD/F).	Polychlorinated dibenzo-*p*-dioxin and dibenzofurans (PCDD/F) found in Siskiwit Lake sediments.	Study represents early evidence of long-range atmospheric transport of these contaminants to remote locations.
Strachan	1983	Organic substances in the rainfall of Lake Superior: 1983	Lake Superior: open waters near Caribou Island and ISRO. 6 weeks 1983.	Rainfall monitored at Isle Royale in 1983 for organic compounds. Alpha-BHC, lindane, heptachlor epoxide, dieldrin, endrin, DDT residues, methoxychlor, PCBs, HCB, alpha- and gamma-chlordane, mirex and toxaphene.	Alpha-BHC and HCB occurred in measurable amounts. Concentrations were twice as high on the west side of Lake Superior (ISRO) and were highest in springtime rain.	Good baseline data but ecological implications and follow-up monitoring needs unclear. (See additional review under fish category.)
Gschwend and Hites	1981	Fluxes of polycyclic aromatic hydrocarbons to marine and lacustrine sediments in the northeastern United States	Northeastern United States; ISRO: Lake Superior, Siskiwit Lake.	Sediment cores collected by SCUBA divers, dated, and analyzed for PAHs from 1900, 1950, and 1980.	Remote sites demonstrate present-day deliveries near 1 ng/cm^2/y; urban sites much higher. Sedimentary historical records suggest anthropogenic activities began introducing large quantities of PAHs 80-100 years ago. Levels diminished during 1960s-1980s. Relative abundance of individual PAHs slightly altered during atmospheric transport, but not by biological or chemical removal in lake water or sediment.	Follow-up monitoring may be warranted to confirm continued decline in atmospherically-deposited PAHs.
Eisenreich et al.	1980	Polychlorinated biphenyl and other microcontaminant-sediment interactions in Lake Superior	Lake Superior, including sites near ISRO and APIS.	Summarized PCB, DDT, and arachlor levels in Great Lakes fish. Identified uptake pathways. Collected sediment cores and separated into depth intervals.	Surface sediment PCBs were relatively high at sites near APIS and ISRO, in the extreme western arm of Lake Superior and in the central lake between the Keweenaw Peninsula and Thunder Bay.	Authors concluded that sediments may be a lingering source of PCBs to overlying waters and biota.
Frank et al.	1980	Organochlorine insecticides and PCBs in the surficial sediments of Lake Superior	Lake Superior waters, 405 sites. 1973.	Surface sediments (0-3 cm) collected from Lake Superior sites and measured for a suite of organochlorines and PCBs.	Low levels of most organochlorines found. Higher concentrations of DDE and PCBs were found between Thunder Bay and Isle Royale, particularly near the northeastern tip of the island.	Authors concluded that contaminant levels were patchy in Lake Superior, but generally lower than in the other Great Lakes.
Eisenreich et al.	1979	Accumulation of polychlorinated biphenyls (PCBs) in surficial Lake Superior sediments	Lake Superior waters; sites near ISRO, APIS.	Sediment cores collected from 9 deepwater locations in Lake Superior.	Concentrations of PCBs were highest in western Lake Superior between the Keweenaw Peninsula and Thunder Bay. No residues of endosulfan, endrin, heptachlor epoxide or chlordane were detected.	Authors suggested that localized industrial and urban sources likely influenced PCB input to Lake Superior near ISRO.
Strachan and Glass	1978	Organochlorine substances in Lake Superior	Lake Superior waters; sites near ISRO, APIS.	Examined published and governmental reports examined for information on polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCs) in water, sediments and fish.	PCBs, DDT residues and dieldrin were most often measured, and often exceeded International Joint Commission water quality goals. Other contaminants also found. USGS found PCBs and OCs in ISRO sediments during 1967-1974. Some of the earliest OCs reports in fish were from APIS region. APIS region may be a relatively hot PCB spot. Siskiwit Lake fish contained high levels of PCBs,	Follow-up monitoring or western Lake Superior trend analysis and synthesis needed for this information.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					HCB, alpha-BHC and DDT compared with Lake Superior open-water fish.	
Kelly et al.	1975	Historical changes in mercury contamination in Michigan walleyes (*Stizostedion vitreum*)	Michigan waters: Lake Erie, Saginaw Bay, 5 inland lakes including Whittlesey, Chickenbone and Dustin (ISRO).	Mercury in historical samples compared with recent (1971) walleye samples.	Mercury levels over 0.5 ppm common only on Isle Royale, in Saginaw Bay and western Lake Erie. Mercury in both historical and recent collections positively correlated with age and size. Isle Royale walleye mercury similar in historic vs. recent samples. Atmospheric sources not considered.	Old preserved fish specimens can be used in mercury analysis and compared with new samples to examine changes over time.
Hydrology						
Raymond et al.	1975	Postglacial and recent sediments of inland lakes of Isle Royale National Park, Michigan	ISRO, inland lakes, 12 sites. 1973- 1974.	Surface elevation of lakes ranged from 187-300 m. Sediment cores (1.67-7.85 m in length) collected and examined for color, texture, pollen and charcoal analysis.	Reddish-brown silty clays at the base of the sedimentary section of 10 lake cores places initiation of sedimentation at Valders age. Major stratigraphic feature is homogeneous gray clay overlying basal reddish clays, which is indicative of whether or not basin was affected by high water levels during Minong-Nipissing interval. Possible to separate basins covered by only Lake Minong from those covered by both lakes. Sedimentation rates varied between basins. Radiocarbon dates and pollen analysis to follow.	–
Groundwater						
Grannemann and Twenter	1982	Groundwater for public water supply at Windigo, Isle Royale National Park, Michigan	ISRO, 3 sites, Windigo. 1981.	Test holes drilled, output measured, and lithologic descriptions provided.	Ophitic basaltic lava flows underlying the area contain little water at depths <175 feet. Glacial deposits offer best groundwater development opportunities (5-10 gallons/minute).	ISRO groundwater resources limited, at least in the Windigo area.

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AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Kloiber	2003	Aquatic resource assessment for the Twin Cities Metropolitan Area: natural resources inventory and assessment	Twin Cities Metropolitan Area (TCMA).	Report provides relative rankings of the regional importance of various water resources for water supply use, recreational use and ecological values. Ecological values included biological (presence of rare and species, presence of trout, presence of obligate aquatic species) and physical habitat (presence of riparian vegetation, water clarity, stream channel geometry) characteristics.	Water supply use: Mississippi used for water supply in TCMA at withdrawal site in Fridley. Recreational use: Mississippi and St. Croix Rivers ranked outstanding for recreational importance as they are maintained at sufficient flow for navigation. Ecological value: Mississippi River ranked outstanding for ecological use, but also showed signs of significant degradation due to urban development.	Report gives a general assessment of water resource status for the Mississippi River without providing firm numbers for any of the ranking criteria. Report does serve to highlight the importance of the Mississippi River relative to other TCMA waters.
Minnesota Department of Natural Resources	1999	Island management options report	MISS, 10 NPS-owned islands	Report summarizes characteristics of each island, along with maps, photographs and an inventory of vegetation, wildlife, T&E species, exotic species, physical characteristics, adjacent jurisdictions, management partners, land use, public access, and management recommendations.	Island 101-1: High quality; one of the "best" islands. Island 101-2: "Disturbed" with abundant buckthorn. Island 102-1: Small island with erosion and purple loosestrife. Island 108-01: Much human use, many trails. Island 111-01: Now a peninsula with open sandy portions, adjacent barge fleeting area. Island 111-02: Now a peninsula with few natural communities or native species. Island 111-03: Pond present on island, 3 miles downstream of the Metro WWTP outfall. Island 112-01: Island lost in 1997 flood. Island 112-02: Some upland areas present, a rare condition for Mississippi islands; heavy recreational use and exotic species common in lower areas. Island 112-03: "Disturbed" with intense recreational use and no natural communities.	Plant and animal species lists for all islands presented in appendix.
Metropolitan Council Environmental Services	1998	Water resources management policy plan	Twin Cities Metro Area (TCMA).	Plan addresses role of Metropolitan Council in protecting water quality and supply in the Mississippi River through the TCMA.	Water quality focal points include pollution prevention, non-point source management, treatment plant operations and improvements, control of contaminants and phosphorus, clean-up of contaminated sites, and monitoring.	Plan provides little or no actual water resource information but provides a useful perspective on Metropolitan Council role in managing water quality at MISS.
Winterstein	1982	Annotated report and data inventory for the Mississippi and Minnesota Rivers, Minneapolis-St. Paul Metropolitan Area	Mississippi River: Anoka to Hastings. Minnesota River: Jordan to mouth. Compiled in 1981-1982.	Inventory of reports and data on the Mississippi and Minnesota Rivers in the Twin Cities Metropolitan Area. Information compiled by contacting agencies in the metropolitan area, conducting interviews and reviewing library materials. Previous annotated bibliographies were also reviewed and included.	Includes 260 annotated citations: 176 reports, 8 computer models, 76 data entries from reports, field notes, lab sheets and computer databases. "Citations of all reports and data that might conceivably be useful in understanding and interpreting the biological and chemical quality of the Minnesota and Mississippi Rivers in the past, present or future were included."	Document contains references to many reports potentially useful to MISS but which are not included in this aquatic synthesis. Document has good background information on MISS issues.
WATER QUALITY						
Kloiber	2004	Regional progress in water quality: analysis of water quality data from 1976-2002 for the major rivers in the Twin Cities	Twin Cities Metro Area (TCMA): Mississippi River at Anoka, Red Wing. Minnesota River at Jordan. St. Croix River at Stillwater.	Water quality samples collected using a vertical Van Dorn sampler, a stainless steel sampler or a polypropylene sampler from 1 m below the surface. Measured 32 water quality parameters. Include 10 in trend analysis: NH_4-N, BOD5, Chlorophyll *a*, DO, fecal coliform, NO_x-N, TKN-N, TP, TSS,	Summary statistics provided by site and parameter. Water quality highest in St. Croix River, followed by Mississippi and Minnesota River. Mississippi at Anoka: Decreasing trends for BOD5, NH_4, TP, TSS and turbidity; increasing trend for NO_x; largest trends were for NH_4 and BOD5. St. Croix at Stillwater: Decreasing trends for fecal	A solid analysis of trends in ecologically important water quality parameters, with useful load comparison information for the TCMA rivers.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
			Most parameters, biweekly 1976-2002.	and turbidity. Data adjusted to remove effects of flow. Seasonal Kendall tau test for trend applied to data. Loads estimated using FLUX program.	coliform bacteria, BOD5, TKN, NH_4, TSS and turbidity; increasing trends for DO and NO_x; largest trend was for NH4 (81%). Loads: Mean relative flow contributions of the 3 rivers comparable, but loads of NO_x, TP and TSS dominated by Minnesota River contribution (75%, 53% and 75%, respectively). Load estimates indicate storage of TP and TSS within the TCMA over the period of record.	
National Park Service	1995	Baseline water quality data inventory and analysis: Mississippi National River and Recreation Area	MISS and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	# water quality observations: 273,531 # parameters: 803 # monitoring stations (study area/park): 541/184 # parameters with exceedences (study area/park): 24/22 # stream gages (study area/park): 43/4 # dischargers: 98 # drinking water intakes: 7	Authors concluded that water quality at MISS was heavily influenced by human activities as a result of its urban/suburban setting. Potential contaminant sources included industrial and municipal wastewater dischargers, stormwater runoff, and urban/suburban development.
Have	1991	Selected water-quality characteristics in the Upper Mississippi River Basin, Royalton to Hastings, Minnesota	Upper Mississippi River Basin: 7 primary streams. All seasons, several years.	Water quality data compiled from Minnesota Pollution Control Agency, Metropolitan Waste Control Commission, and U.S. Geological survey. Differences among sub-basins examined.	Water quality differed among sub-basins due to differences in land use. High dissolved solids and nitrates were found in streams draining row-cropped sub-basins. Water quality changed in the Twin Cities Metropolitan Area with increases in conductivity and decreases in dissolved oxygen below the confluence with the Minnesota river and below the Metropolitan sewage treatment plant. Chloride and sodium concentrations increased over time, and ammonia reaches yearly maximum concentrations during winter ice cover.	Water quality leaving the study unit at Hastings was not representative of the study unit. The Metropolitan sewage treatment plant and the Minnesota River greatly affected water quality within MISS. Authors noted that sampling across each of the three sub-basins (Crow River, Rum River, and Mississippi River) was needed to understand water quality in the study unit. Authors also noted the influence of large hydrologic events on water quality and recommended that future monitoring occur on both a regular and event-based schedule.
Ayers et al.	1985	Runoff and chemical loading in small watersheds in the Twin Cities Metropolitan Area, Minnesota	Twin Cities Metropolitan Area: 6 rural, 11 urban watersheds. 1980.	Discharge, rainfall and water quality data collected during precipitation events in 1980. Event or daily load models constructed for COD, TSS, TKN, NN, TP, Cl and Pb for the period of 1963-1980.	In storm-sewered watersheds, total rainfall was the most significant factor controlling runoff and loads, annual runoff averaged 27% of precipitation, and percentage runoff increased with storm size. In rural watersheds, runoff and loads were greatest in snowmelt period and didn't follow seasonal rainfall patterns as closely as sewered watersheds.	Authors note that as topographic relief and urbanization increases, runoff volume and constituent loading will also increase. Practices that increase detention in urban watersheds will reduce constituent loading to MISS. Water quality in MISS and its urban tributaries is likely more event-driven than SACN; water quality monitoring design should account for this difference.
Payne et al.	1982	Quality of runoff from small watersheds in the Twin Cities Metropolitan Area – hydrologic data for 1980	Twin Cities Metropolitan Area: 6 rural, 11 urban watersheds. 1980.	Discharge, rainfall and water quality data, collected during precipitation events in 1980. Basin characteristics and land used determined. Event or daily load models constructed for COD, TSS, TKN, NN, TP, Cl and Pb for the period of 1963-1980.	This document provides the data used in Ayers et al. (1985), as well as data on metals, bacteria, pesticides and PCBs.	Authors note that as topographic relief and urbanization increases, runoff volume and constituent loading will also increase. Practices that increase detention in urban watersheds will reduce constituent loading to MISS. Water quality in MISS and its urban tributaries is likely more event-driven than SACN; water quality monitoring design should account for this difference.
Larson et al.	1976	Graphic and analytical methods for assessment of stream-water quality – Mississippi River in the	Mississippi River mainstem stations: 14 stations, 1971-1973. 5 long-term	Compiled historical water quality data from 5 stations with about 40 years of records. Data from 14 mainstem stations used to guide future sampling via "time-space contouring."	Long-term records showed that since metro WWTC began operation, dissolved oxygen has remained constant and BOD and coliform bacteria have increased at most sites.	Changes in water quality in MISS were attributed to increased population growth in the metro area. Authors suggest that their time-space contour figures could be used to the select locations and time

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		Minneapolis-St. Paul Metropolitan Area, Minnesota	monitoring sites.		Time-space contouring analysis helped identify problem spots in space and time for key variables.	periods for which continuous monitoring would be most useful, such as during low flows or high temperatures.
BIOLOGY & ECOLOGY						
U.S. Fish and Wildlife Service	2004	Higgins Eye Pearlymussel (*Lampsilis higginsii*) recovery plan: first revision	Upper Mississippi River drainage, MISS, SACN.	Plan revised in response to severe zebra mussel threat at nearly all of the designated critical habitat areas. The SACN site at Interstate Park was the only non-infested site at the time of the revision.	Highest priority recovery actions are intended to address the zebra mussel threat. Recommendations include zebra mussel monitoring, mussel relocations, and cleaning of infested adults. Construction activities, contaminants and poor water quality also addressed as threats. Specific recommendations related to the above threats also included.	The goal of the recovery plan remains the recovery and removal of Higgins Eye mussels from the Federal list of Endangered Wildlife. (See also Hornbach et al. 1998 and Stern et al., 1982.)
Kelner and Davis	2002	Final Report: Mussel (Bivalvia: Unionidae) survey of the Mississippi National River and Recreation Area Corridor, 2000-2001	MISS: entire 72-mile corridor, 138 sites.	<u>Qualitative surveys</u>: Conducted with timed searches and hand collection while wading, snorkeling and diving. Determined species richness, relative and overall abundance, distribution of species, presence of rare species, age demographics and mussel bed location. <u>Quantitative surveys</u>: 5 sites sampled. Mussel bed boundary mapping. Used 0.25 m^2 samples within mussel beds for density, relative abundance and population demographics.	Encountered 28 live species; an additional 12 species collected as empty shells, including *Lampsilis higginsii* and *Quadrula fragosa.* Recent and ongoing recruitment occurring. Two Minnesota Endangered species found (*Arcidens confragosus, Quadrula nodulata*). Range expansion occurring above St. Anthony Falls, historically a faunal barrier. Zebra mussels absent above Lock and Dam 1, and in low densities in Pool 2 and upper Pool 3.	Recruitment and recovery in MISS, once nearly a dead zone, should be monitored. Authors suggest MISS could serve as a major mussel refuge. Zebra mussel threat should be evaluated as for SACN. The possible reestablishment of threatened or endangered species found as empty shells should be considered as a research/restoration theme.
Hornbach et al.	1998	Revised Higgins' Eye mussel (*Lampsilis higginsii*) recovery plan	Historic range of Higgins' Eye Pearlymussel: Upper Mississippi River (Brownsville, MN to Burlington, IA), St. Croix River (Prescott, WI to Hudson, WI).	Technical/agency team was convened to draft revisions to the original 1982 recovery plan in response to the zebra mussel invasion and the flood of 1993.	<u>Habitat requirements</u>: Associated with large rivers, stable substrates, current velocities < 1 m/s, in species-rich assemblages with densities > 10/m^2. Defined 10 essential habitat areas, including one on the Wisconsin River. <u>Recovery criteria</u>: As in original plan. <u>Recommendations</u>: Reformulated to emphasize immediate needs to limit impact of zebra mussels, develop uniform protocols for data collection, confirm and modify the essential habitat areas, and require the use of double hull barges.	– (See also U.S. Fish and Wildlife Service, 2004, and Stern et al., 1992.)
Wilson et al.	1995	Declining populations of the fingernail clam *Musculium transversum* in the upper Mississippi River	Historical data: Mississippi River, 8 pools. 1973-1990. New data: 6 Pools Summer 1991-1992.	Both historical data (1973-1990) on fingernail clam densities and new sample collections included Pool 2 in MISS. Trends evaluated using Mann-Kendall tests. Causal factors evaluated.	Significant population declines were found in 5 of the 8 pools, including Pool 2. Declines were linked to point-source pollution rather than dredging activity, hydrology or commercial navigation traffic. A gradient of *M. transversum* density was noted along a pollution gradient, with lower densities found in areas with higher sediment metal and ammonia concentrations.	Declines in fingernail clams may affect populations of certain fish and wildlife. Fingernail clams appear to be sensitive to sediment and water quality gradients. Residual effects of some contaminants are still felt by benthic biota in MISS.
Stern et al.	1982	Higgins' Eye mussel recovery plan	Historic range of Higgins' Eye Pearlymussel: Upper Mississippi River (Brownsville, MN to Burlington, IA), St. Croix River (Prescott, WI to	Higgins' Eye Recovery Team identified recovery criteria, a recovery plan, several essential habitat areas and action recommendations.	<u>Recovery criteria</u>: Establish five separate viable reproductive populations in five distinct navigation pools. <u>Recovery plan</u>: 10-year study of 7 good mussel beds to determine presence of reproducing females, presence of juveniles, presence of host fish, and good sex and size class distribution. <u>Essential habitat</u>: 7 sites including Hudson, WI,	– (See also U.S. Fish and Wildlife Service, 2004, and Hornbach et al., 1998.)

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
			Hudson, WI).		Lansing, IA, Harpers Ferry, IA, Prairie du Chien, WI, Guttenburg, IA, Cordova, IL, and Moline, IL. <u>Recommendations</u>: Monitor mussels in essential habitat areas, develop relocation and artificial propagation techniques, and develop clam harvesting regulations.	
FISH						
Koel	2004	Spatial variation in fish species richness of the upper Mississippi River system.	Mississippi River: Minneapolis to St. Louis, Navigation Pools 4, 8, 13, 26, and open reaches. 1994-1999.	Analyzed main channel borders, side channel borders and contiguous backwater shorelines to describe patterns of fish species richness, evenness and diversity. Used electrofishing, fyke nets, hoop nets and seines to collect fish. Objective was to examine species and habitat diversity and describe how connectivity of off-channel habitat with main channel affects species richness.	Collected 650,000 fish representing 106 species. Within pools, species richness differed significantly among habitats and was highest in backwater shorelines and lowest in main channel borders. Relationship between native species richness and habitat diversity was highly significant.	Results support efforts aimed at conservation and enhancement of connectivity between river channel and floodplain or off-channel habitats. Author suggests results could be used as guidance for restoration of degraded areas.
Lee et al.	2000	Use of biological characteristics of common carp (*Cyprinus carpio*) to indicate exposure to hormonally active agents in selected Minnesota streams, 1999.	Minnesota waters: 22 stream sites. 1999.	Paired site analysis of common carp at sites up and downstream of wastewater treatment plants (WWTP) around the state.	Biological indicators selected for study indicated wastewater treatment plant effluent is a potential source of hormonally active agents (HAAs) in streams. Found that sites upstream of WWTPs that drained primarily agricultural land showed indications of HAAs.	Important information for an issue that will likely see increased research. Information from this and other similar studies could help in persuading communities to find solutions for persistent contaminants that may affect park resources. (See additional review under contaminants category.)
Talmage et al.	1999	Water quality, physical habitat, and fish-community composition in streams in the Twin Cities Metropolitan Area, Minnesota 1997-98	TCMA: 13 streams. September 1998.	Selected sites based on range of human population density. Characterized water quality, physical habitat and fish community composition.	Collected 38 species of fish and one hybrid from 10 families. Found high percentages of omnivores and tolerant species with few intolerant species. IBI scores were low with ratings of fair to very poor. Percent impervious surface was positively correlated with sodium and chloride concentrations and human population density, but negatively correlated with fish species richness and diversity.	Some species don't do well in urban streams, and diversity appears to decrease with an increasing amount of impervious surfaces.
Lee and Anderson	1998	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin–olychlorinated biphenyls in common carp and walleye fillets, 1975-95	Upper Mississippi River Basin, including mainstem Mississippi River in Twin Cities. 1975-1995	Summarized spatial and temporal information of PCB levels in common carp and walleye.	During 1975-1979 and 1980-1987, 10% and 4% of walleye samples and 45% and 36% of common carp samples, respectively, exceeded the U.S. Food and Drug Administration guideline of 2 mg/kg PCB in fish tissue. After 1987, PCB concentrations in individual common carp and walleye samples were below 2 mg/kg. Median PCB concentrations at individual sites and within stream segments were generally greatest in common carp and walleye from Mississippi River segments in the Twin Cities area during 1975-1979 and 1980-1987. Most of the river segments exhibited over 80% decline in median PCB concentrations in common carp and walleye between the 1975-1979 and 1988-1995 time periods.	Current information should be sought to determine if downward trend has continued.
Johnson and Jennings	1998	Habitat associations of small fishes around islands	Mississippi River: 20 islands from 30 km	Investigated wide variety of island habitats located in areas bordering main channel, in side	Collected 62,845 fish representing 44 taxa at 62 sites.	Use caution when considering modifications that increase vegetation solely for the purpose of

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		in the Upper Mississippi River	north of Winona, MN, to Prairie du Chien, WI. July 25-September 6, 1990.	channels, and in backwaters. Islands ranged in size from 0.3 to 25 ha. Divided habitat features into six macro-habitat or large-scale features associated with island and five meso-habitat or smaller-scale features. Collected fish with 10 x 1.8 m bag seine. Most fish ranged from 15-60 mm, with larger fish accounting for <0.2% of total catch.	Densities of all species positively correlated with vegetation abundance. Meso-habitat features of sites were more important than macro-habitat features of islands in determining density of small fishes. Suggested that modifications that increase abundance of vegetation around island are most likely to increase fish density.	increasing fish density. Building artificial islands and vegetating them may provide habitat benefits for some species, but modifications to existing islands, even increased vegetation, could create unnatural conditions and compromise habitat function.
Mundahl et al.	1995	Fish communities of channel and backwater shoreline habitats in Pool 6, Upper Mississippi River.	Mississippi River: Pool 6. July-August 1994.	Collected fish by electrofishing in backwater and main channel habitats of Pool 6. Determined species assemblages and relative abundance, and compared species diversity between habitat types.	Fish were more abundant in backwater shoreline habitats than in similar main channel habitats. Some species were restricted in distribution, but communities occupying channel and backwater shoreline were very similar.	Basic assemblage information would be useful when combined with information from other areas to get more complete picture of species distribution and habitat use.
Metz and Frie	1995	Influences of habitat modifications on an Upper Mississippi River backwater fish community	Mississippi River: Weaver Bottoms backwater in Pool 5. Summer-Fall 1984-1994	Used trap nets, gill nets, electrofishing to capture fish at 11 backwater locations. Evaluated effects of side channel closure and artificial island construction to fish community structure.	Prior to experiment, sampled 8754 fish of 69 species from 1984-1986. Post experiment sampled 25,508 fish of 69 species from 1988-1994. Species composition changed from dominance by bluegill and black crappie to shared predominance by bluegill, black crappie, gizzard shad and white bass. Authors attributed change in composition to habitat modifications.	No indication if change was anticipated as a result of channel closure and island construction. Authors did not evaluate whether such change was a desired result, or not
Hausler et al	1995	Experimental analysis of the impact of water movement and macrophytes on northern pike (*Esox lucius*) growth and food web interactions	–	Experimental study using riverine enclosures to evaluate effect of water movement on trophic interactions between northern pike, bluegill and invertebrates, and to see how structure moderates this effect.	Pike growth was reduced in enclosures with flowing water and no structure but was not reduced in enclosures with flow and structure. Abundance of *Daphnia sp* and *Polyphemus pediculus* were greater in the presence of pike because pike released these zooplankton from bluegill predation. Authors state that aquatic macrophytes may reduce the energetic demand on northern pike exposed to moving water.	Classic bioenergetics research; results for northern pike energy expenditure demonstrate that fish need shelter from velocity.
Holland-Bartels and Duval	1988	Variations in abundance of young of the year channel catfish in a navigation pool of the Upper Mississippi River	Upper Mississippi River: 5 sites in Pool 7. July-October 1984-1986.	Examined spatial and temporal variations in abundance of YOY channel catfish from 154 trawls taken over course of investigation	Did not find consistent differences in catch per unit effort among the 5 sampling stations. Found no consistent longitudinal variation in abundance or length of YOY fish that would suggest any major preferences within habitat.	Authors cite other investigations that suggest young catfish may congregate in areas based on current preferences or preferences for other habitat features. Authors then state that a diversity of habitats exist throughout Pool 7, and that in areas where habitat diversity is lower, distinct abundance patterns might be more likely to occur in association with limited critical habitat. Further investigations of additional navigation pools would provide information towards understanding habitat use and preference throughout more areas of Upper Mississippi.
Waller and Holland-Bartels	1988	Fish hosts for glochidia of the endangered freshwater mussel *Lampsilis higginsii* Lea (Bivalvia: Unionidae)	Mississippi River: near Prairie du Chien, WI. June 1988.	Exposed 9 species of fish to glochidia	Largemouth bass, smallmouth bass, walleye, and yellow perch all considered fully suitable hosts. Some development on green sunfish. Bluegill and northern pike considered marginal hosts. Common carp and fathead minnow sloughed all glochidia within 48 hours of infestation.	As with other mussel and fish host investigations, this research has implications for management of both fish and mussels as well as riverine habitat protection. Results of study pertinent to other areas, such as St. Croix and other rivers in the region.
Holland	1986	Effects of barge traffic on distribution and survival of ichthyoplankton and small	Mississippi River: 2 sites; at confluence with Black River,	Assessed direct impacts of commercial vessel passage by monitoring mortality and changes in distribution from samples taken at fixed point	Barge traffic caused significant short-term changes in distribution of eggs and larvae. Mean catch of ichthyoplankton was reduced after passage of loaded	Authors suggest another method is needed to evaluate impacts of barge passage because more than 200 vessel passages would need to be

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		fishes in the Upper Mississippi	downstream of Lake Onalaska. June 6–July 11, 1983.	before and after vessel passage. Sampled shortly before, and 0, 45 and 90 minutes after passage. Used two 0.5 m diameter 0.505 mm mesh plankton nets simultaneously to obtain surface and bottom samples for ichthyoplankton. Used 3.0 m trawl with 3.0 cm mesh for surface samples of age-0 and small adult fish. Bottom collections for fish taken with 4.9 m semi-balloon trawl.	downstream vessels. Mean catch in surface waters increased immediately after upstream passage of unloaded vessel. No consistent effect on catch of age-0 or small adults was evident. There was significant physical damage to eggs, but not to larvae or small fish.	monitored to obtain minimally acceptable levels of accuracy and precision.
Waller et al.	1985	Artificial infestation of largemouth bass and walleye with glochidia of *Lampsilis ventricosa* (Pelecypoda: Unionidae)	Laboratory studies. 1982-1983.	Preliminary studies in 1982: Tested 8 species of fish, representing cyprinidae, ictaluridae, centrarchidae and percidae, as hosts for *L. ventricosa.* Studies in 1983: Used largemouth bass and walleye as these species had sustained attachment by glochidia in the preliminary studies up to 35 days. Infected both species, then held in separate aquaria for 21 days.	Found transformed juveniles from day 13 to day 20 post infestation in largemouth bass aquarium and day 13 to day 21 in walleye aquarium. Recovered more juveniles from walleye aquarium, but this may have been due to high mortality of largemouth bass. Authors stated that largemouth bass mortality was not related to glochidia infestation.	Authors hoped to use *L. ventricosa* as a surrogate to determine suitable hosts for *L. higginsii* in order to develop recovery plan for this endangered mussel.
Eddy et al.	1963	The fish fauna of the Mississippi River above St. Anthony Falls as related to the effectiveness of the falls as a migration barrier	Mississippi River: near St. Anthony Falls. 1960-1961.	Combination of field sampling and literature review to determine species distributions above and below falls.	Provide a thorough description of species found above and below St. Anthony Falls, including speculation on invasion of areas during glacial retreat. Reported 123 species known from Minnesota and contiguous Wisconsin waters below the falls, and 64 species known from drainage area above the falls. Also discussed pollution of river as a chemical barrier to dispersal up to St. Anthony Falls.	Excellent reference for historic species assemblages in the area around St. Anthony Falls as well as the greater drainage areas above and below the falls.
CONTAMINANTS						
Lee et al.	2000	Use of biological characteristics of common carp (*Cyprinus carpio*) to indicate exposure to hormonally active agents in selected Minnesota streams, 1999	Minnesota streams and rivers: 22 sites near WWTP sites. Mississippi River, St. Paul; St. Croix River, above and below Stillwater, MN. Summer 1999.	Paired sites selected upstream and downstream of WWTP discharges, including the Metropolitan WWTP in St. Paul. Collected >400 carp upstream and downstream by electrofishing. Four biological characteristics considered as potential indicators of hormonally active agents: · Concentrations of vitellogenin in male versus female fish. · Concentrations of sex steroid hormones. Gonado-somatic index. · Gonad histopathology.	Measured biological characteristics indicated that WWTPs were a potential source of hormonally active agents. Biological characteristics also showed indications of hormonally active agents at upstream sites draining agricultural and forested land, possibly related to agricultural pesticides.	Authors recommend controlled studies to confirm the effects of particular chemicals on fish reproduction and population structure. Site-specific conclusions difficult to draw from the data as presented. (See additional review under fish category.)
Anderson and Perry	1999	Comparison of temporal trends in ambient and compliance trace element and PCB data in Pool 2 of the Mississippi River, USA, 1985-1995	Mississippi River: Pool 2. 1985-1995.	Trace element (As, Cd, Cr, Cr^{+6}, Cu, Pb Hg, Ni, Se, Zn) and PCB data compiled for water column, bed sediments and fish tissues. Both ambient (instream) and compliance (wastewater) data analyzed. Mann-Kendall trend test used to determine temporal trends.	Compliance data showed decreasing trends for most trace elements in water and bed sediment but not fish tissue. PCBs in water declined at the Metropolitan WWTP. Trends in ambient water quality data were confounded by differences among monitoring programs.	Authors recommend increased coordination, quality assurance and metadata collection in monitoring efforts.
Brown	1984	Atmospheric deposition of selected chemicals and	TCMA: 1 rural, 3 urban watersheds.	Atmospheric deposition and subsequent runoff concentrations measured for TKN, nitrate/nitrite-	Seasonal patterns of wetfall and dryfall were similar for all constituents in both rural and urban drainages,	Authors recommend that future investigations of non-point source runoff in the area account for

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		their effect on nonpoint-source pollution in the Twin Cities Metropolitan Area, Minnesota	Growing season 1980.	N, TP, sulfate, Cl, and Pb.	suggesting regional sources. Local industrial, agricultural, and vehicular sources influenced rate and magnitude of deposition, but not seasonal trends. Highly urban Shingle Creek had the highest peaks due to local industry and traffic. Atmospheric contribution to non-point source runoff of nitrate-N and Pb was very high, as much as 84%. Contribution of phosphorus and chloride were low, averaging 6%.	atmospheric nitrate and lead deposition.
Hydrology						
Mitton	2002	Flooding in the Mississippi River Basin in Minnesota, Spring 2001	Mississippi River Basin: 44 gages, sites in MISS, SACN. 2001.	Peak stages and discharges were recorded and reviewed for these 44 gage stations.	Record flows were recorded at 9 gaging stations, with14 stations recording second or third highest peaks. Previous high water events were also reported for stations with at least 20 years of record. Mississippi River at St. Paul and St. Croix River at St. Croix Falls recorded 50-100 year floods in 2001.	–
Schoenberg and Mitton	1990	Monthly mean discharge at and between selected streamflow-gaging stations along the Mississippi, Minnesota and St. Croix Rivers, 1932-1987	Mississippi River Basin: 10 gages, sites in MISS, SACN. 1903-1987.	Long-term flow records were used to calculate monthly mean discharges at 10 gaging stations. Differences in monthly mean discharge between selected upstream and downstream stream gaging stations were calculated.	Monthly mean discharges were reported for each site by year and month.	–
Groundwater						
Metropolitan Council	2004	Water demand and planning in the Twin Cities Metropolitan Area	Twin Cities Metropolitan Area	Report analyzes water demand and water supply planning for the metropolitan area.	Reported 292 million gallons/day (mgd) of water used for municipal supply, plus 871 mgd for power generation and other uses. Groundwater is primary source for 1.6 million municipal users and 230,000 well water users; Mississippi River supplies 870,000 users. No correlation found between residential per capita water use and lot size, household income, or price of water. Limitations in the region's groundwater supply include lack of access to Prairie du Chien-Jordan aquifer and adverse impacts of withdrawals and contamination.	Coordinated, comprehensive region-wide water supply planning program needed to ensure long-term availability and viability of the water supply. Related groundwater supply and contamination issues may be of interest to MISS.
Ruhl et al.	2002	Estimates of recharge to unconfined aquifers and leakage to confined aquifers in the seven-county Metropolitan area of Minneapolis-St. Paul, Minnesota	Twin Cities Metropolitan Area: 7 counties, MISS, SACN.	Objective was to assist water managers in the Twin Cities metropolitan area with issues related to long-term groundwater depletion. Recharge to unconfined aquifers was estimated by five methods. Leakage estimated by two methods.	Recharge estimates varied within 10 inches/year among methods. Leakage, which was less than 1 inch/year, varied widely within 1-4 orders of magnitude.	Authors note that impervious land areas in metropolitan areas have little or no recharge potential, whereas surficial sand and gravel areas (e.g. Washington County near St. Croix River) have great recharge potential. Authors provide a comparison of different methods of estimation for recharge and leakage.
Payne	1995	Groundwater baseflow to the upper Mississippi River upstream of the Minneapolis-St. Paul area, Minnesota, during July 1988	Upper Mississippi River: 6 subreaches upstream of Twin Cities. July 1988.	Groundwater baseflow to 6 subreaches estimated for the drought period of July 1988. Low-flow frequency characteristics calculated for the Mississippi River near Anoka and near St. Paul.	Anoka: Groundwater baseflow per river mile was 2.59 cfs; average Mississippi River discharge at Anoka was 1090 cfs. Low flows of 620 cfs lasting 30 days were predicted to occur only once every 100 years. St. Paul: Low flows of 890 cfs lasting 30 days were predicted to occur only once every 100 years.	Study presents only data, no interpretation. It appears that groundwater contributions to Mississippi River at Anoka are very small.
Schoenberg	1994	Characterization of	Twin Cities area. 3	Available data were compiled from logs of test	Between Fridley and Brooklyn Center: Shallow	Study provides good insights into groundwater-

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		groundwater discharge from bedrock aquifers to the Mississippi and Minnesota Rivers at three areas, Minneapolis-St. Paul area, Minnesota	study sites.	holes and water wells. Hydraulic properties were estimated from split-spoon cores and slug tests analysis. Groundwater flow in cross section was simulated.	groundwater flow in the near surface gray and upper red tills. Sand and gravel outwash aquifer discharges to springs along the edge of the river. Groundwater flowing through the rubble zone and upper part of the Prairie du Chien-Jordan aquifer discharges through alluvial deposits to the river. Between Eagan and Bloomington: Confining units under the Minnesota River impede discharge of groundwater from the underlying aquifer to the river. Groundwater discharges to springs, lakes and wetlands along both sides of the river. Above confluence with Minnesota River: Groundwater flows from the St. Peter aquifer through overlying post-glacial alluvium to the Mississippi River.	surface interactions at MISS.
Lindgren	1990	Simulation of ground-water flow in the Prairie du Chien-Jordan and overlying aquifers near the Mississippi River, Fridley, Minnesota	TCMA aquifers.	Developed 3-D groundwater flow model to understand response of groundwater systems to withdrawals near Minneapolis Water Works.	Leakage to the confined drift and St. Peter aquifers in the 1885-1930 steady state simulation ranged from 1-2.3 inches/yr. Leakage for the 1970-1979 simulation increased 0-3 inches above the steady state results, representing additional leakage caused by lowering of hydraulic heads during groundwater withdrawal. Simulations of additional groundwater withdrawal of 27.5 mgd during summer resulted in maximum drawdowns of 60-80 ft. Hydraulic heads rebounded following cessation of the withdrawals.	Author concludes that contaminated water from areas of known contamination could move toward depressions in the potentiometric surfaces of the aquifers if additional groundwater is withdrawn near the Minneapolis Water Works.
Schoenberg	1990	Effects of present and projected groundwater withdrawals on the Twin Cities aquifer system, Minnesota	TCMA aquifers.	Steady state groundwater model used to simulate potentiometric surfaces of the aquifers during the 1970s, assuming a withdrawal rate of 190 mgd. Projected changes in potentiometric surfaces were calculated using this model.	Mount Simon-Hinckley aquifer would be lowered as much as 400 feet if pumpage from that aquifer increased by 125% over 1980 levels. Prairie du Chien-Jordan aquifer would be lowered by 400 feet if withdrawals increased by 200% over 1980 levels.	Author estimates that the limit of groundwater availability in the Twin Cities is between 500 and 800 mgd.
Schoenberg	1989	Relation of ground-water flow in bedrock aquifers and Mississippi and Minnesota Rivers, St. Paul and Minneapolis, Minnesota	TCMA aquifers.	Groundwater contributions to Mississippi and Minnesota River flows estimated using water well logs and soil borings.	Seepage from 4 bedrock aquifers augmented mean January flow during dry years. Wells that withdraw water from the bedrock aquifers intercept water that might otherwise reach the rivers. Hydraulic connections between ground and surface water being investigated.	Author recommends future work on seasonal changes in aquifer and river chemistry.
Horn	1984	Annual ground-water use in the Twin Cities Metropolitan Area, Minnesota, 1970-1979	TCMA aquifers.	Annual ground-water use in the area from 1970-1979 presented by aquifer and type of use.	Most groundwater withdrawn from wells in the Prairie du Chien-Jordan aquifer. Major uses are for industry and public supplies. Results presented by county and use type, including public supply, industry, commercial air conditioning, irrigation, lake level maintenance, and dewatering.	–
Schoenberg	1984	Water levels and water level changes in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers, Twin Cities Metropolitan Area,	TCMA aquifers.	Water levels in aquifers monitored and analyzed for the period of 1971-1980.	Water levels in the Prairie du Chien-Jordan aquifer changed <5 feet on average, but varied by up to 25 feet locally in response to pumping or recharge. Water levels in the Mount Simon-Hinckley aquifer increased by nearly 60 feet at the center of the cone of depression in response to reduced pumping, and	Results of the study suggest that changes in groundwater withdrawals can greatly affect groundwater levels in relatively short time spans.

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		Minnesota, 1971-1980			the cone of depression contracted by nearly one-third.	
Horn	1983	Ground-water use trends in the Twin Cities Metropolitan Area, Minnesota, 1880-1980	TCMA aquifers.	Groundwater information from local, state and federal agency records and publications. Groundwater use analyzed by use category and aquifer.	Currently, 80% of groundwater withdrawn from wells in the Prairie du Chien-Jordan aquifer. Of this, 82% used for self-supplied industry. Groundwater use increased from 1880 until the early 1970s when conservation increased to reduce sewage treatment and energy costs. Intensity of withdrawals has decreased within the St. Paul and Minneapolis city limits but increased outside the city limits. Seasonal variability of groundwater use increased with increased irrigation and air conditioning.	–
Norvitch et al.	1973	Water resources outlook for the Minneapolis-St. Paul Metropolitan Area, Minnesota	TCMA, including MISS, SACN.	Purposes: · Describe physical occurrence and operation of the hydrologic system affecting the TCMA area. · Establish a hydrologic baseline. · Identify future research needs. · Estimate the maximum water withdrawal the system can withstand before mining groundwater occurs.	General geohydrology and hydrology described. Surface water resources of the Twin Cities area not sufficient to meet all needs during a severe drought. Groundwater available from 6 aquifer systems – about 75% from the Prairie du Chien group. Industry used greatest amount of groundwater (43%), followed by domestic, commercial, irrigation and other uses. Groundwater withdrawal from closely spaced wells causes cones of depression in summer. Groundwater withdrawal >375 mgd would exceed recharge. Potential locations identified for well fields.	Authors recommend future studies that focus on data collection, geohydrologic mapping, hydraulic characteristics of subsurface geohydrologic units, hydrology of lakes, and hydrologic systems monitoring. They conclude that "groundwater sources alone could be developed to provide for the increasing water needs of the metro area for at least the next 30 years."
Maderak	1965	Chemical quality of ground water in the Minneapolis-St. Paul Area, Minnesota	Hennepin, Carver, Scott, Ramsey, Washington, Anoka, Dakota, and Sibley Counties. 1960-1963.	Report described geologic formations in this 2,500 mi^2 area, as well as groundwater quality for each aquifer, estimates of change over time, and levels of contamination (nitrates, phosphates, alkyl benzene sulfonate, boron) from domestic wastewater sites in Richfield and Brooklyn Park.	Glacial drift, St. Peter Sandstone, Shakopee and Oneota Dolomites, and Jordan, Franconia and Galesville, Mount Simon and Hinckley Sandstones yield large amounts of groundwater. Almost all groundwater in the area is the calcium bicarbonate type. Dissolved solids concentrations increase from the eastern or northeastern reaches of the study area to the southwest. Little evidence of groundwater chemistry changes from 1899-1963 was found. In some areas, nitrate contamination of shallow water aquifers may affect water quality in deeper aquifers over time.	Study is from a largely water-use perspective.
PHYSICAL PROCESSES						
Hendrickson	2003	Bed material budget for the St. Paul District reach of the Upper Mississippi River, Anoka, Minnesota to Guttenburg, Iowa	Mississippi River: Anoka, MN, to Guttenburg, IA.	Bed material sediment budget developed using available information on sediment transport, long-term channel dredging, sediment deposition, and hydraulics.	Distinct reaches were identified: Reach 1: Upstream from Lake Pepin, dominated by sediment inputs from the Minnesota and upstream Mississippi Rivers. Reach 2: Extends through Lake Pepin, with much material deposited at the upstream end. Reach 3: Below Lake Pepin and influenced by sediment from the Chippewa River and secondarily by smaller tributaries.	–

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GENERAL RESOURCE DOCUMENTS AND PLANS						
Loope	2001	Aquatic monitoring plan for Pictured Rocks National Lakeshore	PIRO, park-wide.	Stressors identified as exotic species, atmospheric contaminants deposition, climate change, stream sedimentation, bacterial contamination, personal water craft emissions, watershed disturbances in the inland buffer zone and related nutrient inputs. Based on existing information, samples taken.	Monitoring parameters: Stream discharge, epilimnetic temperature and depth, transparency, ice-off dates for South Bay (possibly other lakes), nutrients, bacteria, contaminants (Cu, S, Pb, Hg in sediment), exotic mussels, lamprey, zooplankton, mussel contamination, anuran populations, macrophytes (attention to exotics, T & E species), stream sedimentation.	Plan outlines some good monitoring activities that will complement and enhance GLKN's monitoring efforts.
Pictured Rocks National Lakeshore and Michigan Department of Natural Resources	1995	Fisheries management plan for Pictured Rocks National Lakeshore	PIRO, park-wide.	Historic and current PIRO fish management described.	Research needs: More science-based management, including pre-European settlement information on aquatic systems, limnological surveys for all waters, habitat suitability analyses, inventories, fish and social science surveys.	Monitoring program and vital signs will need to be developed against the backdrop of historic changes. Lake sediment cores would help understand historic conditions and relative impacts of European settlement and logging. Reference conditions are unknown at this time. ((See additional review under fish category.)
Michigan Technological University, Department of Biological Sciences	Circa 1980	The ecosystems of Pictured Rocks National Lakeshore: their attributes and limitations for visitor use	PIRO, park-wide	Results of previous water quality studies summarized. Geology, soils, watersheds, climate, wildlife, plant patterns and recreational suitability described.	Dominant watersheds: Miners Creek, Mosquito River, Hurricane River and Sable Creek, and two that originate in PIRO, Spray and Sevenmile Creeks. Stream banks generally steep. Waterfalls present over the Munising or Jacobville cliff formations. Beavers and their effects on PIRO landscape noted. Bald eagles present in 1960s but no longer. Plant species lists presented in appendix.	Authors note that the lakes are relatively eutrophic and that their "ecological status" needs further study. Report is valuable as a general resource.
WATER QUALITY						
National Park Service	1995	Baseline water quality data inventory and analysis: Pictured Rocks National Lakeshore	PIRO and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	# water quality observations: 7,466 # parameters: 237 # monitoring stations (study area/park): 76/35 # parameters with exceedences (study area/park): 4/3 # stream gages (study area/park): 0/0 # dischargers: 0 # drinking water intakes: 0	Authors concluded that water quality at PIRO was relatively good, with some water quality effects noted due to local development.
Lewin	1991	Acidification mechanisms in a small, clear-water, low pH seepage lake, Upper Peninsula of Michigan	PRIO: Legion Lake, Upper Shoe and Lower Shoe Lakes.	Water chemistry: Precipitation quantity and chemistry monitored by NOAA and NADP. Throughfall and soil solution monitored monthly. Lake and stream water chemistry monitored monthly or biweekly from June 1985-December 1989. Sediments: 3 sediment cores taken from Legion Lake; one core taken from both Upper and Lower Shoe Lakes. Cores analyzed for S, Pb, Cu, Zn, Ca, Mg, and K. Pollen record analyzed, diatom reconstruction	Water Chemistry: Average pH=4.8 over study period, with no seasonal trend; fluctuations closely related to SO_4^{-2} concentrations. DOC averaged 1.98 mg/L but decreased significantly from 1987-1990, possibly related to drought conditions. Precipitation and lake water chemistry were similar (See Table 5), but watershed chemistry differed from lake chemistry. Patterns similar in Upper and Lower Shoe Lakes. Sediments: Shift in tree species >200 years ago. Recent sediments not represented in Legion Lake A	Legion Lake catchment has no recent land development, which increases its value for monitoring. In general water chemistry and watershed information appear solid, but core data is difficult to interpret.

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				conducted, sediment accumulation calculated. Benthic grab samples taken at several depths (one time only) and invertebrates identified.	or B or Shoe Lakes. Dating might be inaccurate and diatoms poorly preserved in sediment. Cores don't show evidence of early logging effects; instead sedimentation increased in 1950s. Minimal seepage and overland flow limit the buffering capacity for Legion Lake.	
Stottlemyer	1989	Effects of atmospheric acid deposition on watershed/lake ecosystems of Isle Royale and Michigan's Upper Peninsula	PIRO: Little Beaver drainage, Legion, Upper Shoe and Lower Shoe Lakes. Also similar study at ISRO and Keweenaw. 1979-1983.	<u>Long Term Data</u>: Precipitation chemistry monitored biweekly. Stream gages installed; discharge monitored. Stream chemistry monitored. Snow accumulation and quality monitored monthly at PIRO. Soil chemistry analyzed (detailed at ISRO). <u>Legion Lake Study</u>: Lake sediment cores taken at Legion, Upper Shoe and Lower Shoe Lakes. Cores analyzed for pollen and diatoms. Benthic invertebrates and plankton also sampled. Macrophytes evaluated qualitatively.	<u>Long Term Data</u>: SO_4^{-2} inputs likely exceed biotic requirements and soil adsorption capacity, especially in boreal coniferous forest. Mean pH values higher in hardwood soils and increase with depth, and OM and C content higher under conifers. Acid deposition affecting watersheds indirectly, by leaching SO_4^{-2} and base cations. NH_4^+, H^+, and NO_3^- strongly retained by watersheds. <u>Legion Lake Study</u>: Legion Lake is one of the most (naturally) acidic clear water lakes in the nation. DOC levels were also low. Legion Lake was largely disconnected from watershed processes and groundwater. Macrophytes and benthic mosses were common due to high light penetration.	Paper contains summary details on precipitation, snowpack, and streamwater chemistry, both seasonally and interannually, as well as preliminary information on the Legion Lake study. Stottlemyer notes that Legion Lake presents a good opportunity to study "role of benthic mosses and macrophytes in the extreme oligotrophic nature of such water bodies."
Mullen	1988	An evaluation of standard timber harvest practices on stream dynamics in the Pictured Rocks National Lakeshore inland buffer zone	PIOR: Mosquito River, 3 stations. Biweekly, November-May 1986-1988.	Stream discharge measured and hydrographs generated for each site. Grab samples analyzed for water quality suite. Soil solution chemistry analyzed. Forest floor organic content analyzed.	Harvest-related stream flow changes not apparent. No water quality or soil quality changes apparent. Seasonal patterns in water chemistry noted. *Disclaimer*: Only 15% of watershed harvested, harvest was selective and during winter, and data were collected early in the growing season. NO_3-N got as high as 1.3 mg/L during winter at all sites during reference year, but dropped below 0.5 mg/L during growing season.	Author concludes that small winter harvests will not have a large effect on PIRO streams water quality; however, the analysis is brief and conclusions are weakened by several disclaimers. High stream NO_3-N values may be of interest. Longer-term post-harvest monitoring may show effects of altered vegetation types on litter quality, dissolved organic matter, large woody debris, and functional stream measures.
Handy & Twenter	1985	Water resources of Pictured Rocks National Lakeshore, Michigan	PIRO: 4 inland lakes,1 Lake Superior site, 10 streams. One per year, either spring, late summer or fall 1979-1981 .	Geologic background and setting described. Stream drainage area, discharge, water quality suite, and groundwater quantity and quality determined. Results compared with EPA guidelines. Results for Miners River above and below Miners Lake compared.	Lake Superior water quality similar to other studies over 70-80 years. Water chemistry was suitable for aquatic life; however, color exceeded EPA guidelines. Miners River was different upstream vs. downstream of lake.	Analysis and interpretation was limited but data are available in appendices. Report documents that streams are modified by lake processes. Future research might explore how lakes mediate various watershed impacts (logging, atmospheric deposition, etc.) to streams.
Stottlemyer	1982	The neutralization of acid precipitation in watershed ecosystems of the Upper Peninsula of Michigan	PIRO: Little Beaver drainage. ISRO and Keweenaw. 1980-1985	Precipitation chemistry analyzed, approximately biweekly. Stream gages installed and discharge monitored. Stream chemistry monitored. Snow accumulation and quality monitored monthly at PIRO. Short-term pH reductions experiments conducted.	Precipitation acidic but quickly neutralized in upper portions of first-order streams. Experimental acid additions in Beaver Creek drainage were quickly neutralized and had little effect on downstream cation concentrations.	Stottlemyer notes that PIRO streams appear to have high buffering capacity but cites a need for more comprehensive stream water chemistry surveys. Stream chemistry shows high seasonal variability due to snowmelt. Future stream studies should address this seasonality.
Stottlemyer	1982	Variation in ecosystem	PIRO: Little Beaver	Precipitation chemistry analyzed.	Snowfall and snow moisture increased with elevation	Shifts in vegetation types or soil disturbance would

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		sensitivity and response to anthropogenic atmospheric inputs, Upper Great Lakes Region	drainage. ISRO and Keweenaw. November 1980-1982.	Stream gages installed and discharge monitored. Water chemistry monitored. Snow accumulation and quality monitored.	above Lake Superior. No significant gradient in precipitation quality with elevation. Precipitation acidic but modified by forest canopy, particularly maple, and affected by soil types. Spring reductions in pH found at PIRO, but in general PIRO better buffered than ISRO.	likely affect watershed processing of atmospheric inputs. Higher elevation sites get more precipitation and consequently more contaminants. They may be most sensitive to atmospheric deposition.
Biology & Ecology						
Nevers and Whitman	2004	Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks	VOYA, ISRO, PIRO, SLBE, INDU; 2 lakes in each. Monthly, May or June-September for 2 years.	Phytoplankton sampled from 1m depth and analyzed for composition, species richness, Shannon-Wiener diversity, and species evenness. Water quality suite measured using YSI sonde and Kemmerer sampler. MDS ordination of Bray-Curtis Similarity for mean water chemistry and individual species counts, phytoplankton species counts for each sample, and combined species counts and water chemistry variables for each sample.	Collected 176 phytoplankton taxa from all lakes. Diatoms and chlorophyte taxa most common. INDU lake dominated by euglenoids. SLBE lakes dominated by diatoms. PIRO lakes dominated by chrysophytes and diatoms. Northern lakes had variable composition. Northern lakes clustered together in terms of chemistry and composition.	Study provides some useful background and baseline phytoplankton information for these lakes. Non-random lake selection limits inference to the larger set of lakes at each park. Dataset could be explored further to: · Show how seasonal patterns differ among lakes, · More thoroughly describe grouping patterns among lakes in terms of phytoplankton composition and water chemistry, and · Provide more park-specific insights.
Nichols et al.	2001	Status of freshwater unionid populations at Pictured Rocks National Lakeshore, 1999-2000	PIRO: 8 lakes 5 streams and rivers. 1999-2000	Initial visual scouting followed by qualitative and quantitative sampling using SCUBA and 100 m^2 grids. Stratified and random sample site selection. Habitat descriptors: depth, fish, substrate type, vegetation, temperature. Mussel variables: density, age and growth rates, contaminants in soft tissues. Maps provided: satellite and bathymetric.	Unionids found in 6 of 8 lakes. Unionids found in Chapel Creek only; which may result from winter freeze or the bedrock substrates available. Found 4 genera (*Elliptio, Lampsilis, Potamilus, Pyganadon),* with 7 species, none threatened, endangered, or of state special concern. *L. luteola* dominant in all lakes but Grand Sable, followed by *L. radiata.* Highest densities found in 5-10 ft depth zone. Densities highest in Chapel Lake (1.143/m^2), Lowest in Grand Sable (0.008/m^2). Main factor controlling distribution was depth. Consistent recruitment apparent in all lakes but Grand Sable Lake. Community unstable in Grand Sable Lake; unclear if yellow perch crash or human harvest is responsible. Organic contaminants in tissues low in all lakes.	Authors note threat from exotic species: zebra mussels, round gobies, and rusty crayfish. Author recommendations include: live bait ban, boat/trailer inspections, zebra mussel annual surveys, public education efforts for SCUBA divers, fisherfolk and researchers, maintenance of host fish populations, preservation of the 0-10 ft depth zone, 10-year monitoring intervals in inland lakes, more frequent surveys in Grand Sable Lake. Study provides a valuable baseline for PIRO mussels and insightful management recommendations. The Grand Sable situation requires further investigation and possibly restoration efforts.
Michigan Department of Environment al Quality	2000	A biological survey of selected coastal Lake Superior tributaries in Chippewa, Luce and Eastern Alger Counties	PIRO: Sable Creek Likely sampled once.	Michigan GLEAS procedure, including fish and macroinvertebrate communities, physical habitat status, and water chemistry.	Sable Creek supports coldwater fish on a seasonal basis. Sable Creek macroinvertebrate communities rated "acceptable" due to variable flows from Sable Lake and sand inputs from Dunes. Excessive sedimentation (from land use change and road construction) is cited as primary water quality issue for all streams in survey.	Future studies should explore residual effects of past land use on PIRO waters. Paleolimnological approaches would provide a preliminary understanding of how sedimentation rates, nutrient export, etc., have changed since settlement.
Boyle et al.	1999	Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: an ecologically-based	PIRO: 6 lakes, once each 1995 and 1996; 5 streams, once each 1995 or 1996.	<u>Lakes</u>: Secchi depth, pH, alkalinity, TP, TKN, and trophic state measured. <u>Streams</u>: Substrate size/character and benthic macroinvertebrate communities evaluated by CCAs and a community metrics. Fish sampled	<u>Lakes</u>: N:P ratios indicated P limitation or NP co-limitation of algal growth; Miners Lake may be N limited. Carlson's Trophic State Index indicated mostly mesotrophic conditions. <u>Streams</u>: Substrate size (gravel, cobble, boulder,	Benthic invertebrate communities would likely be sensitive to changes in stream substrates due to catchment disturbances. Risk analysis fell short of objective to determine where road building and timber cutting would have

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		inventory and estimation of the effects of land use practices		with electroshocking; identified, counted and abundance estimated.	etc.) linked to benthic invertebrate community variation in three main creeks.	the most impact: little explanation, supporting data or graphics provided. N limited lakes likely sensitive to N deposition from nearby or regional sources.
Loope	1998	A review of the limnology of six small lakes in Pictured Rocks National Lakeshore	PIRO: Miners, Chapel, Little Chapel, Legion, Little Beaver, Trappers Lakes. 1997-1998.	Literature review plus some temperature and dissolved oxygen profile data from PIRO staff. For each lake, information summarized for physical characteristics, aquatic biota, and water chemistry; no fish data.	Appendices summarize patterns among the six lakes as data tables. A nice compilation of lake studies and data. Analysis and interpretation limited. Species list compilations useful.	Single sampling dates scattered across seasons complicate interpretation (exception: Lora's temperature/dissolved oxygen profiles). Better understanding of seasonal patterns in water quality is needed. Monitoring should be attentive to issues of data comparability from year-year and lake-lake. (See additional review under fish category.)
Loope	1998	Spiny water flea and its presence at Pictured Rocks National Lakeshore	PIRO: Beaver Lake.	Zooplankton collected during Whitman et al. inland lakes monitoring project.	1-page report. *Bythotrephes* first collected in summer 1997 in open, deep water. *Bythotrephes* not in littoral areas or other PIRO lakes yet.	Monitor Beaver Lake for changes in *Bythotrephes* abundance and possible effects on other plankters and fish such as yellow perch. Monitor other PIRO lakes for *Bythotrephes*.
Kamke	1987	Limnology in four lakes in Pictured Rocks National Lakeshore	PIOR: 4 inland lakes, deepest point; bays & inlets. 6 times, representing ice-out, mid-summer, mid-fall, July 1983-May 1985	Sonar mapping conducted. Water quality suite and chlorophyll monitored at several depths. Measured Al, Pb, Hg, and Zn. Zooplankton collected using a plankton net and density determined. Benthos sampled along transects with an Ekman dredge plus a kick net, and presence/absence determined. Aquatic macrophytes surveyed by wading and diving. Trophic state and water quality indices calculated.	Lakes well oxygenated, colored and sandy. <u>Miners</u>: Eutrophic impoundment. <u>Chapel</u>: Meromictic. <u>Beaver</u>: Mesotrophic and polymictic. <u>Grand Sable</u>: Oligotrophic and stratified. Water color most important indicator of trophic status. Heavy metal concentrations either low or below detection. Nutrients variable but below nuisance levels.	Clearly written and represents a valuable source of information for these lakes. Standard indices of trophic status did not prove effective for PIRO lakes because color and transparency are confounding factors. Chlorophyll could not be predicted based on nutrient concentrations in PIRO lakes.
Doepke	1972	Alger County lakes study	5 lakes, in PIRO Beaver, Little Beaver, and Grand Sable Lakes. Once each.	Detailed lake morphometry provided. Watershed soil types and watershed area determined. Water quality suite measured. Fish data from Michigan Department of Natural Resources examined for presence/absence. Results compared with Institute for Fisheries Research data (1953) and Limnetics, Inc. data (1970).	<u>Beaver Lake</u>: Strong wind effects. Productive with abundant wildlife and plants in shallows. <u>Little Beaver Lake</u>: Small, shallow and colored. Warm water fishery, abundant wildlife and macrophytes. Hypolimnetic anoxia. <u>Grand Sable Lake</u>: Sandy bottomed. Small, low-fertility watershed. Acidic (pH=6.7) and colored. Poor fishery and plants, but wildlife abundant.	Study is data-poor but descriptive. Lakes quite productive, so 1) nutrients should be monitored and inputs managed, and 2) historical eutrophication should be examined. DOC and color are important in these lakes and in the context of climate change. These two parameters should be part of long-term monitoring regime.
Limnetics, Inc.	1970	A preliminary survey of the environmental quality of the Pictured Rocks National Lakeshore and Recreational Area, Alger County, Michigan	PIRO: Lake Superior, 8 sites; inland lakes, 8 sites; streams, 13 sites. Once each.	Water quality suite measured. Phytoplankton and zooplankton identified to species and relative abundance estimated. Macroinvertebrates collected in streams, identified to species and relative abundance estimated. Fish data from Michigan Department of Natural Resources examined for presence/absence. Sediment quality examined for % solids, % organic matter. Air and noise issues evaluated.	Lake Superior nearshore chemistry indicated high water quality. Lake and stream water quality variable, but generally productive, brown-water systems. Pesticide residues not detected in water, but were in Lake Superior fish and terrestrial samples.	Study represents a good, early baseline with data fully reported. Nutrient monitoring is important for PIRO waters.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
FISH						
Newman	2003	Inventory of nearshore fish and mudpuppy (amphibian) in Lake Superior, Pictured Rocks National Lakeshore	PIRO: nearshore waters, entire shoreline to 0.25 m. One week each in May, July, September 2002.	Used boat electroshocker, bottom trawls, gill nets, fyke nets, beach seines, and modified Windermere traps to collect fish. Recorded sampling locations with GPS unit. Randomly selected sites from four habitat types: embayment, rocky point, cliff face and beach. Fish were enumerated and lengths of first 50 per species were measured. Weights were not taken. All splake were killed and preserved for genetic and morphological study per request from Michigan Department of Natural Resources.	No mudpuppies were captured during the survey. Captured 29 species of fish plus 12 splake. 9 species and splake had not previously been confirmed from PIRO waters of Lake Superior. Longnose sucker was most numerous fish (535) followed by trout-perch (245) and steelhead (210). Only one brook trout was captured in all surveys.	Author noted that preliminary pyloric caeca counts of two splake were not within published ranges, suggesting that splake may reproduce and produce offspring with pyloric caeca counts intermediate to those of brook and lake trout. Author states that 73 species are likely to occur in PIRO region. However, habitat along the Lakeshore is possibly not diverse enough to hold several species, or some species may only use the area for short periods and missed detection during this survey. Somewhat discouraging that only one brook trout was captured, but 210 steelhead were. Rocky point habitat assumed to have high fish diversity yielded only four species. Low and medium diversity beach and cliff face habitats had 21 and 18 species, respectively.
Armichardy and Leonard	2003	Seasonal movements of resident and Lake Superior anadromous fishes in the Beaver Lakes basin Pictured Rocks National Lakeshore, Michigan, USA	PIRO: Lowney Creek, Beaver Lake Channel, Beaver Creek, Beaver Lake and Little Beaver Lake. Fall 2001-2002; Spring 2002	Preliminary results for 2001-2002. No text; just graphics presented at 2003 coaster brook trout meeting at PIRO.	Brook trout pit tagged in 2001-2002, but no apparent recovery of those fish when this update was presented.	Even though brook trout information is limited, there is a good amount of information on movement of several other species found in the basin as well as precipitation and temperature information.
Sreenivasan and Leonard	2003	Comparison of growth parameters between migrant and resident strains of brook trout	Mosquito River and lab studies. Much of year.	Measured length, weight, condition factor, growth rates and morphometrics of Tobin Harbor strain stocked coasters and PIRO resident brook trout. Measured gill Na^+/K^+ ATPase activity, blood plasma and gill surface areas.	Lab study (June 2003-December 2003) found significant difference in length, weight and condition factor between migrant and resident brook trout. Field study (May 2003-December 2003) also showed significant differences in L, W and condition factor in both strains.	Progress report: study is ongoing and will be expanded to include investigations of competition between brook trout and non-native salmonids (especially steelhead). Competition study will be much anticipated, especially in light of capture results from Newman (2003) listed above.
Newman	2001	Stream assessment of Pictured Rocks National Lakeshore, 1998	PIRO: streams. One sample, 1998	Single pass electrofishing in several streams to determine species present. Summarized efforts from 1997 – 2000	List of species and numbers collected at each stream sampled.	Aimed at determining feasibility of conducting coaster brook trout restoration efforts in PIRO streams. Can only indicate species present Sample method cannot generate population estimate, possibly relative abundance if conducted in additional years.
Heritage Research, Ltd.	1999	Historical study of fish and fisheries at Pictured Rocks National Lakeshore	–	Literature review of several information resources and data analysis. Document research for historical references to fish management activities and anecdotal accounts from long time area residents.	Primarily reported on changes over time of fisheries as a result of past land management activities, recreational fishing, and fish stocking.	Good source of historic information, but mostly anecdotal; primary numeric information is for historic stocking with minimal information on population statistics, abundance estimates, etc.
Baker et al.	1999	Action plan for restoring coaster brook trout to Pictured Rocks National Lakeshore	–	Plan developed from information presented in brook trout status report prepared for Lake Superior Technical Committee of Great Lakes Fishery Commission. Evaluated potential impediments to coaster brook trout rehabilitation efforts, such as harvest, habitat, genetics,	Recommend three streams for coaster brook trout reintroduction and recommended further investigation in three other areas.	Due to potential coaster behavior observed in native brook trout at PIRO in 2003 questions about approach to stocking have been brought forward by PIRO staff. Ongoing genetics investigations of Lake Superior brook trout populations may provide information that will aid in future restoration efforts.

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				competition, and financial resolve.		Specific investigations at PIRO should also occur.
Loope	1998	A review of the limnology of six small lakes in Pictured Rocks National Lakeshore.	–	–	No specific fisheries information, but fish habitat parameters as they relate to limnology	Although there is no specific fisheries information, limnological and habitat information is useful for fisheries managers and for those that may participate in preparation of fisheries management plans for PIRO. (See additional review under biology and ecology category.)
Pictured Rocks National Lakeshore and Michigan Department of Natural Resources	1995	Fisheries management plan for Picture Rocks National Lakeshore	PIRO: 14 streams, 10 lakes, 2 pond systems.	Brief summary of fisheries management at PIRO Summary of existing fisheries survey information and current (1995) information on management at PIRO	Provides management recommendations for lakes and streams. Some recommendations for specific regulations and identification of study needs.	Management plan should be revisited and updated to include more current information. (See additional review under general resource documents and plans category.)
Gerovac and Whitman	1995	Fishes of the Pictured Rocks National Lakeshore	PIOR: 18 streams and 4 lakes. Summer 1995.	Samples collected with two seines (4 x 30 ft; 4 x 15 ft) in lakes and streams.	Collected 29 species among 1657 individual fish.	More effective sampling could have occurred with additional sampling gear. A better representation of species present would have been attained.
Pictured Rocks National Lakeshore	1994	Resource Management Plan	–	Reviews existing information and identifies threats to aquatic resources.	Fishery needs/recommendations: · Develop a thorough inventory and monitoring program for aquatic resources, especially wetlands and streams · Revise the cooperative PIRO fish management plan developed with Michigan Department of Natural Resources approved in 1983, and revised in 1987, to better maintain self-sustaining populations of native species.	Recommends development and implementation of comprehensive resource inventory and monitoring program. Conflicts with Michigan Department of Natural Resources management objectives for fisheries management.
Grimm	1990	Status of the fishery resource – 1989, Grand Sable Lake, Alger County	PIRO: Grand Sable Lake. Fisheries assessment, 1989.	Included general limnological information Also reviewed historical information and 1949 fisheries survey.	1949 species present included rockbass, northern pike, yellow perch, smallmouth bass, white sucker and minnow species. Rainbow trout, splake, smelt, smallmouth bass, largemouth bass, northern pike, bluegill, lake trout. Evaluation of smelt populations in 1980 resulted in opening of Towes Creek for smelt dipping. White sucker manually removed in 1985 at a rate of 6.8 lb/acre Lake trout fishing seen as successful during spring effort. Current survey found few smallmouth bass, rockbass, yellow perch or white sucker. O_2 ranged from 8.3 on the top to 5.6 at the bottom; Secchi depth was 12 ft; pH 8.0	Suggested managing lake as a “two story” fishery with lake trout and coolwater species; smelt as forage species. Although it may still difficult to absolutely determine what species were present historically, this report gives somewhat useful information for management actions if PIRO has the goal of restoring native assemblages. Survey should be updated.
Grim	1990	Status of the fishery resource – 1988, Beaver Lake, Alger County	PIRO: Beaver Lake. Fishery assessment 1988	Reviewed historic assessments, reported current species present	Stated early records indicated presence of yellow perch, rock bass, northern pike, smelt, rainbow trout, brook trout, smallmouth bass and minnow species Lake trout and splake have been stocked in past Walleye stocked from 1982-1984 Found Coho salmon and white sucker in 1988, along with above listed species . Only captured 1	Although it may still difficult to absolutely determine what species were present historically, this report gives somewhat useful information for management actions or if PIRO has the goal of restoring native assemblages. Survey should be updated.

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					smallmouth bass and 1 walleye. Yellow perch were dominated by 3-6 in fish and were "over-abundant" Recommended stocking walleye again in 1990	
Nuhfer	1988	Chapel Lake gill net survey	PIRO: Chapel Lake. Fishery survey; August 1988.	Length (range and average) and number captured for 3 species.	Northern pike: n=9, L ave=24.3 in, range=20.6-35.0 in. White sucker: n=3, L ave=15.9 in, range=15.7-16.1 in. Yellow perch: n=8, L ave=7.0 in, range=6.5-8.2 in.	Although it may still difficult to absolutely determine what species were present historically, this report gives somewhat useful information for management actions or if PIRO has the goal of restoring native assemblages. Survey should be updated.
Loope and Scott	1987	A reintroduction of grayling (*Thymallus arcticus*) to the inland waters of Picture Rocks National Lakeshore, Michigan	PIRO: Miners River, Spray Creek, and Section 34 Creek	Treated Spray and Section 34 Creeks with rotenone in order to provide more optimal conditions for grayling survival. Stocked 12,000 grayling from Montana strain May 31 and June 1, 1987.	Follow-up investigations were to occur in fall of same year.	Grayling reintroduction efforts were ultimately unsuccessful, but information on post reintroduction monitoring effort would be useful. Follow up on how long stocked fish were present and reason for lack of success may provide instructive information.
Loope	1986	Environmental assessment: grayling reintroduction, Pictured Rocks National Lakeshore	–	–	Suggests locations and stocking strategies for reintroducing grayling to stream of PIRO.	–
Loope	1983	Lamprey control plan: Pictured Rocks National Lakeshore	PIRO streams with suitable sea lamprey habitat.	Describes history of sea lamprey control efforts, effectiveness and drawbacks of program.	Recommends coordination with U.S. FWS, treatment and monitoring. Also suggested that NPS conduct a threatened and endangered species survey and develop an Integrated Pest Management strategy for sea lamprey.	Not so much a control plan as it is a recommendation that NPS coordinate with U.S. FWS annually to determine necessary lamprey control actions. Points out that native lamprey are greatly impacted by sea lamprey control. Brings attention to the need to monitor native populations, if present, and minimize impacts during treatment if possible.
Michigan Department of Natural Resources	1981	Pictured Rocks National Lakeshore Draft Fisheries Management Plan	PIRO: 15 streams, 9 lakes and ponds.	Classic management approach such as suggestions for removal of fallen trees from streams, stocking recommendations to maintain sport fisheries, and management for Pacific salmon that use streams.	State management recommendations for the various waterbodies.	Final version of plan not available for review. Newer plan completed in 1995, but needs to be updated again.
Gruhn	1976	Series: The trout streams of Michigan. No. 29 – Mosquito River.	Entire mainstem of Mosquito River, with some tributary investigations.	Stream characteristics; fisheries information limited.	Describes habitat characteristics of Mosquito River and principal game species present (rainbow and brook trout. Some forage species are also mentioned.	Useful as reference for presence of Pacific salmonids and forage species in PIRO streams as these affect brook trout populations and ongoing brook trout restoration efforts.
Doepke	1972	Alger county lakes study	Beaver, Little Beaver and Grand Sable Lakes	Biological and physical characteristics of 5 lakes	–	(See review in biology and ecology category.)
Edsall	1960	Age and growth of the whitefish *Coregonus clueaformis* of Munising Bay, Lake Superior	Fish survey, 1953.	Gill net and trawl catches to assess unexploited population in Munising Bay.	Growth in length and weight of Munising Bay whitefish was slowest recorded from Great Lakes waters. Population densities were much greater than other areas sampled in Lake Superior.	Not in PIRO waters, but useful information regarding native species in area. Due to ongoing stocking of non-native salmonids in Munising Bay that may compete with native brook trout, any information on species assemblages here could be useful to help determine impacts of these types of management actions.
Aquatic Wildlife						
Bowerman	1991	Factors influencing breeding success of bald eagles in Upper Michigan	Sites throughout Hiawatha NF; one near PIRO. Late March-April and mid-May.	Two aerial nesting surveys conducted. Ground visits conducted to band nestlings. Habitat coarsely classified: Great Lakes, riverine, and inland lakes. Fish management assessed near nests.	Nesting eagles prey primarily on northern pike, bullheads and suckers. Reasons for low eagle productivity: Loss of prey fish in inland lakes (via rough fish removal projects).	Author recommends mapping and monitoring potential breeding areas, contaminant concentrations in eggs, plasma and feathers near Lake Superior, and contaminants in prey species. If eagle nests found in PIRO, author recommends

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				Eagle productivity measured.	Environmental contamination with pesticides and PCBs in areas near Great Lakes.	annual productivity monitoring.
Daues	1991	Furbearer activity relative to habitat in Pictured Rocks National Lakeshore.	PIRO: stream courses and lake perimeters. Late October 1989-1990.	Conducted aerial surveys for beaver and muskrat, and to identify browse piles and lodges after leaf fall and before ice over.	Beaver colony density of 0.21/km^2 was at low end of average range for North American densities (0.15-4.6/km^2). The inactive to active lodge ratio was also reported as low.	Because beaver can have such large ecological effects, it would be useful to determine historic abundance of beaver in this area if possible, and to monitor lodges and populations through time. This may help determine if park management actions and inland buffer zone management effects reestablishment of beaver to historic population structure.
AMPHIBIANS AND REPTILES						
Premo and Davis	1990	A survey of herpetofauna along the proposed Beaver Rim Road in the Pictured Rocks National Lakeshore	6 zones (A-F) along proposed Beaver Rim Road corridor. Canoe surveys of 4 lakes. April to August, several times per zone.	Reptiles and amphibians identified by vocalizations or collected by hand, dip net, baited minnow traps, and modified fyke nets. Species identified and abundance or relative abundance estimated.	Found 12 amphibian and 7 reptile species. Species collected in each zone are listed. Relatively rich fauna – 73% of known Upper Peninsula herptiles collected. Zones A and F had richer fauna than others. Potential impacts include habitat destruction and traffic-induced mortality. Sandy construction site areas will attract fauna.	Authors recommend continued amphibian monitoring, but not necessarily as it relates to traffic mortality. If there are target herptiles for monitoring, study may be used to identify where they likely to be found.
Werner	1989	Amphibian/reptile survey of Sand Point area, Pictured Rocks National Lakeshore	Sand Point area, May-June 1989.	Herpetofauna captured by hand, dip net, minnow traps or modified fyke nets and identified using keys or vocal calls. Blood sampled for blood parasite analysis. Relative density index recorded.	Encountered 46% of known Upper Peninsula amphibians and reptiles, with green frogs, mink frogs and painted turtles most common. Boreal chorus frogs not heard, nor egg masses encountered; therefore, not likely present in area. No snakes sighted but may be present. 4 fish species noted. No blood parasites found. Species list, density index, and habitat noted.	Low densities and richness attributed in part to the presence of active beavers, which reduce aquatic vegetation and invertebrate abundance, and increase turbidity and siltation.
WETLANDS AND AQUATIC VEGETATION						
MacKinnon	2004	Species collected during the 2003 field season for Pictured Rocks National Lakeshore	PIRO, park-wide. Field season 2003.	Targeted meander searches used to establish a flora representing at least 90% of the extant flora of PIRO.	Several wetland or aquatic plant species verified. A large number of species found in the Kingsgton Lake area in the Inland Buffer Zone due to habitat and microhabitat complexity in this area. Sandy plains and shallow, seepage fed, sandy bottomed lakes and wetlands, and open peatlands in this area supported species not found elsewhere in PIRO.	Author noted that open peatlands near Lower Shoe Lake were sampled late in the season and should be revisited earlier in the growing season in future years. This would likely yield additional species.
Loope	2001	Wetland types in Pictured Rocks National Lakeshore	–	Brief summary of resources. Information compiled from NWI maps.	<u>Wet meadow marshes</u>: Located In fee zone and inland buffer zone, in several headwater areas and associated with beaver ponds. <u>Northern bogs</u>: Near Legion Lake and Big and Little Shoe Lakes. <u>Eastern vernal pools</u>: Throughout PIRO in deciduous woods. <u>Cedar swamps</u>: Upstream from Miners Falls, around Nobel Lake, Sullivan Creek, Au Sable Point and in Beaver Basin.	Author recommends basic inventories of wetland resources.
Crispin et al.	1984	A survey for endangered, threatened and special concern plant species in	PIRO: Banks of Sable Creek, Grand Sable Dunes,	Plant occurrence and distribution records reviewed prior to survey. Plant species identified and at least one	Identified 19 state endangered, threatened, special concern and federal candidate plant species from previous or current survey efforts.	Of the wet meadow and inland lake plants previously documented, none were found in the 1984 survey. Authors urge further survey work in PIRO inland

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		Pictured Rocks National Lakeshore, Michigan	Chapel Beach-Grand Portal Point area, Beaver Lake area, and Grand Sable Lake. Summer 1984.	specimen collected for documentation.	Northern wet meadows: *Aster nemoralis* (state special concern) found on sand flats along inland lakes. Inland lakes: *Callitriche hermaphroditica* (state special concern) found in Little Beaver Lake, *Myriophyllum alterniflorum* (state special concern) found in Beaver Lake, and *Myriophyllum farwellii* (state threatened) found in Chapel Lake.	lakes by boat for these species, as well as two other state special concern species (*Potamogeton confervoides* and *Littorella Americana*) which are known to exist in nearby inland lakes.
Contaminants						
Michigan Department of Natural Resources	1992	Fish contaminant data for Grand Sable Lake	Grand Sable Lake October 1987, May 1991.	Data only. 1987: 6 lake trout collected and skin-off fillets analyzed for Hg; 3 northern pike collected and skin-on fillets analyzed for Hg. 1991: 12 lake trout collected and whole fish analyzed for Hg along with many pesticides and other contaminants.	1987: Mean Hg for lake trout was 0.562 mg/kg; mean Hg for northern pike was 0.740 mg/kg. 1991: Mean Hg was 0.317 mg/kg. Many contaminants were low or near detection limits, but measurable amounts of total chlordane (mean 0.033 mg/kg), DDD, DDE and DDT were found.	Letter to Pictured Rocks National Lakeshore containing data only for 1987 and 1991. Hg levels were high in the late 1980s and borderline in 1991; monitoring should be continued. In particular, higher sample sizes and more northern pike representation is needed. Fish Hg variation among PIRO lakes should also be investigated.
Michigan Department of Natural Resources	1991	Assessment of mercury contamination in selected Michigan Lakes, 1987-1990: historical trends, environmental correlates, and potential sources	Michigan waters: 66 lakes, including Grand Sable Lake. Sampled once.	Sediment cores: 66 lakes, analyzed for percent solids, percent dry weight, and metals, along with P and TKN. Benthic invertebrates: 66 lakes, two samples per lake collected with Ekman dredge, quantified and identified to genus where possible. Fish: Collected by electroshocking in 40 lakes and analyzed for Hg. Bald eagles: Feathers near 10 eagle nests collected and analyzed for Hg. Mergansers/Kingfishers: Examined near Michigamme River.	Sediment cores: Hg higher in surficial sediments, averaging 0.157 mg/kg in lakes without point discharges. No apparent geographic pattern. Fish: 78% of the lakes had at least one fish with Hg > 0.5 mg/kg, including Grand Sable Lake. Northern pike had the highest Hg concentrations; carp had lowest. No apparent relationship between surficial sediment Hg and fish Hg or benthic invertebrate densities.	Despite PIRO's remote location, its fish Hg concentrations are above consumption guidelines.
Michigan Department of Natural Resources	1989	Michigamme project: Grand Sable Lake, Alger County	PIRO: Grand Sable Lake July 13, 1989.	Data only, description of methods not provided. 28 cm sediment core analyzed for percent solids, percent dry weight, and metals, along with P and TKN. Benthic invertebrates sampled from silt and detritus in oxic sediments at water depths of 18.3 m. Two samples taken for identification and density determinations.	Hg and other metals and nutrients were generally highest in surface sediments (0.085 mg/kg). Cumulative dry weight was negatively correlated with Hg. Bulk of the invertebrate density was accounted for by Oligochaetes and Orthoclad midges.	Study was limited in scope, but does provide background values for metals in sediments and contribute a few more taxa to the invertebrate list.
Hydrology						
Fisher and Whitman	1999	Deglacial and lake level fluctuation history recorded in cores, Beaver Lake, Upper Peninsula, Michigan	PIRO: Beaver Lake, 6 sites.	Sediment cores from deep and shallow Beaver Lake zones taken using a concrete vibrator during winter ice cover period. Lithostratigraphy analyzed. Deep cores radiocarbon dated.	Shallow and deep cores characterized by 9 units. Minimum deglacial date is 9480 BP. Sand-dominated depositional environment from a low lake stand present approximately 8500 BP to present. Record is consistent with other regional data.	Lake Superior lake level history is apparent in the sediment record of Beaver Lake.
Physical Processes						
Loope et al.	2004	A Holocene history of dune-mediated landscape change along the southeastern shore of	Grand Sable Lake, cored recently.	Deep cores retrieved from Grand Sable Lake. Bathymetry of Grand Sable Lake and features of its watershed evaluated. Wood fragments in buried sediments and soils	Grand Sable Lake was formed during multiple episodes of damming on ancestral Sable Creek, mediated by levels of Lake Superior. High Lake Superior levels drove stream damming	Late Holocene lake level changes left measurable hydrologic and geomorphic signatures on shoreline resources.

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		Lake Superior		radiocarbon dated. Ancestral Sable Creek valley revealed by ground penetrating radar.	and impoundment, and falling levels reduced sand supply to dune dams and increased dam breaching.	
Fisher and Whitman	1998	Sedimentologic and stratigraphic analysis of Beaver Lake sediment cores, Pictured Rocks National Lakeshore, Michigan	PIRO: Beaver Lake. Cored during ice cover, 1997.	Collected 9 lake cores with a vibracore from Beaver Lake littoral zone at depths of 0.89-2.74 m. Height from base of unit, thickness of unit, nature of lower contact, color, grain size, presence of grading, and structures were noted for each core.	Similar processes were recorded in sediments throughout the lake. Thousands of years of sediment accumulation recorded in lake sediment. Beaver Lake has likely been sandy since long before European settlement. Walleye habitat likely no more plentiful historically.	Authors concluded that Beaver Lake substrates had not been significantly altered by artificially high water levels caused by damming during the 20th century.
Gerovac et al.	1996	Surficial sediment characteristics of Beaver Lake, Pictured Rocks National Lakeshore, Michigan	Beaver Lake, surveyed once.	Beaver Lake substrate probed to locate buried gravel beds suitable for walleye spawning.	Little probe resistance was found in deeper parts of the lake. One area, on the southeast shore, had higher resistance. A sand shelf existed between the 25 and 50 cm water depth marks.	Authors concluded that there was no evidence of buried, pre-logging era coarse substrates.
Hoff	1996	Substrate survey of Beaver Lake, Pictured Rocks National Lakeshore, with special reference to natural reproduction of walleye	Beaver Lake, surveyed once, July 1996.	Beaver Lake shoreline surveyed at water depths <1.5 m and between the high and low seasonal watermarks. Substrate sizes determined qualitatively by eye. Suitable walleye spawning habitat mapped.	Substrates in the 0.5-1.5 m depth zone were mostly sand. One area, 120 m in length along the southeast shore, was suitable for walleye spawning; it comprised <2% of the lakes shoreline.	Author notes the possibility that suitable substrates may have been buried by sand following construction of a dam at the lake outlet. Shallow lake sediment cores were recommended to test this hypothesis.
Blewett	1994	Late Wisconsin history of Pictured Rocks National Lakeshore and vicinity	–	Literature synthesis on PIRO geomorphology . All published and available unpublished information on glacial geomorphology at PIRO evaluated. New large-scale topographic maps helped resolve aspects of final deglaciation.	Described 6 phases of deglaciation, including formation of the Upper Kingston outwash plain, ice-marginal retreat to the Lower Kingston position, incision caused by opening of lower outlets south of Grand Marais, formation of the highest Beaver Basin surface, incision of lower Beaver Basin surfaces and formation of the Chapel and Little Chapel channels. The Miners River area featured well developed subglacial or englacial drainage systems associated with warm-based glaciers. Other areas had features indicative of changing conditions during final deglaciation, from cold glaciers to warm-based glaciers.	Spatial and temporal variations in glacier processes during deglaciation resulted in different surficial sediments in western vs. eastern parts of PIRO.
Loope	1993	Evidence of physical and biological change within the Beaver Lake watershed attributable to a turn-of-the-century logging dam	PIRO: Beaver Creek.	Dam history derived from historical records and interviews. Beaver Creek dam was manipulated for log drives, causing water level fluctuations in the Beaver Lakes. Dam removed by local residents in 1960. Physical, biological, and landscape level changes associated with the water level fluctuations described.	Narrow terrace about a half meter above lake level apparent in Beaver Lakes; terrace exposed about 30 years ago and vegetation there is young. Beaver Lake littoral zones are characterized by a uniform underwater shelf generally devoid of vegetation and low in substrate and invertebrate diversity. Narrow terrace exists about 0.3 m above level of Beaver Creek, and tag alder has colonized.	Author mentions several management related issues: · How long will it take Beaver Lakes to recover from logging activity? · Were current rare plant inhabitants of Beaver lake islands historically present? · What is preventing loons from nesting on Beaver Lake? · Will alder become dominant along the Beaver Creek terrace? Author points to the utility of historical accounts in understanding present resource conditions.
Loope	1992	Shoreline dynamics and issues of shoreline protection at PIRO	PIRO Lake Superior shoreline.	Glacial history described. Lake level fluctuations, both natural and human-related, characterized. Shoreline areas of concern at PIRO discussed.	Existing water level regulation and diversion in the Great Lakes can affect lake levels, but generally climatic conditions are the more dramatic drivers. Naturally occurring lake level changes affect shoreline resources, especially in sandy areas.	Author notes several management issues related to lake level fluctuations and shoreline changes, noting that long-term protection strategies should focus on vulnerable cultural resources and account for rare extreme events, general wind direction and time of

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					At PIRO, shoreline changes are a concern in many areas, including Sand Point, Au Sable Point and Sullivan's Landing, due to cultural resources and physical structures. Sand movement, beach changes, and bedrock collapses all occur.	ice cover protection. Artificial shoreline protection was discouraged, as it offers only short-term protection and interferes with natural processes.
Loope and Holman	1991	An assessment of stream bed and stream bank characteristics within Pictured Rocks National Lakeshore	PIRO: 10 streams. Assessed at 100 m intervals, summer 1986.	Recorded 15 parameters every 100 m: width, depth, erosion, natural barriers, % shade, beaver activity, topography, pool development, bottom type, bank stability, streamside vegetation, and aquatic vegetation.	Bank stability ratings were high and there was little evidence of excessive sand loading in these streams. Tag alder was found only in low-gradient reaches. Natural barriers and treefall were most prevalent in reaches with streamside white cedar. Hurricane and Sevenmile Creeks showed convex profiles due to underlying rock.	Authors conclude that PIRO streams do not contain residual sand bed loads due to past logging and land use change, perhaps because PIRO streams are high gradient and frequently flushed. Authors recommend additional work to survey transient bedload and bank stability upstream in the inland buffer zone.
Farrell and Hughes	1984	Wave erosion and mass wasting at Pictured Rocks National Lakeshore	PIRO: Sand Point, Miners Beach, Chapel Beach, Beaver Creek Campground. 1982-1983.	Baselines established with steel pins. Photographs used to document bluffs and shorelines. Aerial photographs from 1939-present interpreted and used for mapping. Magnitude of one-year changes noted for each site.	Sand Point changed up to 56 feet per year in the past, now growing out from the mainland at a rate of 5 feet per year. Bluffs suffer wave erosion and periodic mass wasting, accelerated by human foot traffic. Natural versus anthropogenic mass wasting difficult to separate.	Authors provide some recommendations for reducing human effects on bluffs and adjacent uplands.

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GENERAL RESOURCE DOCUMENTS AND PLANS						
Davis	2003	St. Croix Basin water resources planning status report	St. Croix Basin.	Summary report of St. Croix Basin Team activities and progress on issue statements: nutrients, urban stormwater runoff, monitoring, public involvement and stewardship, water quality standards development and standardization.	Progress has been made on each of these issues, particularly nutrients, since the inception of the Basin Team. Recommendations for action are included for each issue.	Monitoring has been mostly based on short-term studies; a long-term monitoring plan is still needed.
St. Croix Basin Team Nutrient Technical Subcommittee	1998	St. Croix River Basin nutrient monitoring, modeling and management	St. Croix Basin.	Objectives included: · Monitor water quality to determine baseline conditions. · Determine relative loadings from tributaries, Determine perceived acceptable water quality conditions from citizen monitoring. · Develop a predictive nutrient model for mainstem St. Croix.	Plan outlines variables to be monitored, along with approaches for the other objectives. Much of plan has been executed successfully (See Davis 2003).	St. Croix Basin Water Resources Planning Team report.
Holmberg et al.	1997	Water resources management plan for St. Croix National Scenic Riverway.	SACN.	Literature and data reviewed, resource description provided.	Hydrology, geology, land use description. Wetlands: Glenn-Lewin (1992) inventory described. Water quantity: Fago and Hatch (1993) discharge report and others referenced. Dams and obstructions described. Water quality summary and comparison of current vs. 1965-1977 conditions provided. Fish: Fago (1986) survey, Fausch's IBI study (1987) cited. Macroinvertebrates: Boyle (1992) and Montz (1991) Mussels: Hornbach's (1992) analysis and report appended. Other biota: Macrophyte survey and MCES data provided.	The plan summarized current conditions, research efforts, and future research and monitoring strategies, many of which are underway. Summary of research could be updated to include recent work.
Malischke et al.	1994	St. Croix Basin water quality management plan	St. Croix Basin.	Format: Recommendations Report, Water Quality Report (by watershed), Non-point Source Report, and Lakes Report.	Recommendations: Interstate consistency, common database, coordinated water quality monitoring plan, along with a series of very specific project or monitoring-oriented recommendations for particular watersheds, etc.	Report provides insight on management objectives over the past decade and a good place to look for future research needs. Thoughtful list of recommendations and findings is too extensive to include here.
WATER QUALITY						
Edlund	2004	Historical trends in phosphorus loading to the St. Croix National Scenic Riverway from permitted point source discharges, 1900-2000	St. Croix River watershed, 1900-2000.	Historical loadings estimated based on discharge volumes, demographics, industrial sources, wastewater technologies and from facility discharge records when available. Point source discharges compared to historical total loadings estimated in Triplett et al. 2003.	Since sewering began in Stillwater in 1905, there have been 169 permitted point source discharges basin-wide, including municipal, industrial and agricultural facilities. Untreated sewage discharged early in the century, with secondary treatment in place at most facilities by the 1960s-1970s and tertiary treatment available to much of the population by the 1990s. Peak discharges occurred in the 1960s-1970s, followed by declines due to phosphorus detergent bans, greater use of land and groundwater effluent discharges, and technological improvements. Current point source loadings represent about 10%	Author noted that 16-19% of the anthropogenic phosphorus loading to the river were attributable to point sources. While the point source inputs currently account for a relatively small portion of total phosphorus loading, the bioavailability of point source phosphorus is much higher than non-point source phosphorus. Future research should target the relative effects of increased point source phosphorus (high proportion of free ortho-phosphorus) versus non-point source phosphorus (high proportion of bound organic or

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					of total phosphorus loading, with this proportion projected to increase to 13% by 2020.	mineral phosphorus) on algal growth.
Kloiber	2004	Regional progress in water quality: analysis of water quality data from 1976-2002 for the major rivers in the Twin Cities	Twin Cities Metro Area (TCMA): Mississippi River at Anoka, Red Wing. Minnesota River at Jordan. St. Croix River at Stillwater. Most parameters, biweekly 1976-2002.	Water quality samples collected using a vertical Van Dorn sampler, a stainless steel sampler or a polypropylene sampler from 1 m below the surface. Measured 32 water quality parameters. Include 10 in trend analysis: NH_4-N, BOD5, Chlorophyll *a*, DO, fecal coliform, NO_x-N, TKN-N, TP, TSS, and turbidity. Data adjusted to remove effects of flow. Seasonal Kendall tau test for trend applied to data. Loads estimated using FLUX program.	Summary statistics provided by site and parameter. Water quality highest in St. Croix River, followed by Mississippi and Minnesota River. Mississippi at Anoka: Decreasing trends for BOD5, NH_4, TP, TSS and turbidity; increasing trend for NO_x; largest trends were for NH_4 and BOD5. St. Croix at Stillwater: Decreasing trends for fecal coliform bacteria, BOD5, TKN, NH_4, TSS and turbidity; increasing trends for DO and NO_x; largest trend was for NH4 (81%). Loads: Mean relative flow contributions of the 3 rivers comparable, but loads of NO_x, TP, and TSS dominated by Minnesota River contribution (75%, 53%, and 75%, respectively). Load estimates indicate storage of TP and TSS within the TCMA over the period of record.	A solid analysis of trends in ecologically important water quality parameters, with useful load comparison information for the TCMA rivers.
Lenz	2004	Analysis of streamflow and water quality at two long-term monitoring sites on the St. Croix River, Wisconsin and Minnesota	St. Croix River: Danbury, St. Croix Falls.	Flow: Monitored since 1914 at Danbury, and since 1902 at St. Croix Falls. Analyzed for long-term trends in annual mean flow and flow by season. Water Quality: Suite collected mostly in mid 1970s to early 1980s (See also Lawrence 1982, Graczyk 1986) and from 1995-2001 (USGS NAWQA).	Flow: 7-day low, peak daily, mean, and instantaneous peak flows all increasing significantly at St. Croix Falls and marginally at Danbury since the beginning of record. Trend increases at St. Croix Falls were significant for fall, winter and spring but not summer. Water Quality: No significant trends at either site, even for flow-weighted data. Conductivity, nutrients, sediments, alkalinity and temperature were generally higher and more variable at St. Croix Falls.	Authors attribute the flow increases at St. Croix Falls to increased population and land use changes. High temporal variation in data and inconsistent monitoring record make trend analysis more difficult.
Triplett et al.	2003	A whole-basin reconstruction of sediment and phosphorus loading to Lake St. Croix	Lake St. Croix, 8 transects, 3 sediment core sites on each..	Sediment cores dated by Lead-210, Cesium-137 and radiocarbon methods, correlated by magnetic susceptibility, and analyzed for loss-on-ignition, grain size, phosphorus, biogenic silica, pigments and diatom concentrations.	Significant changes occurred in Lake St. Croix, especially since the mid-1900s, including increased sediment accumulation, increased phosphorus loading, and changes in diatom production and composition. Diatom composition shifted from benthic species to pelagic species dominance.	Authors acknowledge uncertainties related to pre-settlement flow estimates, sediment dating for several transects, and phosphorus reconstruction from diatoms because diatom-inferred phosphorus concentrations are likely conservative estimates. Despite above uncertainties, study provides an essential water quality baseline for SACN.
Payne et al.	2002	Water quality and aquatic community characteristics of selected reaches of the St. Croix River, Minnesota and Wisconsin, 2000	St. Croix River: 14 sites, Danbury-Prescott. Synoptic sampling during low-flow, August-September 2000.	Water quality suite measured, and stream flow measured. Physical habitat assessed with 3 transects per reach for basic habitat measurements. Fish collected by electrofishing, identified to species, and analyzed for community IBI and species richness. Benthic macroinvertebrates collected from11 sites from rocky, woody and mixed substrates; species composition assessed and community metrics calculated.	Dissolved residues increased gradually downstream, with abrupt increases downstream of Sunrise River (Ca^{+2} and Mg^{+2}) and downstream of Nevers Dam (Cl^- and SO_4^{-2}). Most N was as NO_3^- and organic N; these increased with drainage area. Total N load increased downstream of Sunrise River, Nevers Dam and Kinnickinnic. Dissolved P was always low. Particulate P increased below Clam River, Yellow River, Sunrise River and Nevers Dam. Biological measures indicated good water quality, particularly in upper reaches above the Sunrise River. Invertebrate community indices indicated	More investigations of why invertebrate communities indicate physical/chemical changes in sites 10-13 may be needed. Several studies, especially this one, indicate the Sunrise River is a significant contributor of nutrients and sediments. A comparison of Graczyk (1985), Fallon and McNellis (2000), Lenz (2001), and Payne's studies might help pinpoint which tributaries are regularly high contributors and in need of more detailed research. Study suggests NO_3^- loading to Lake St. Croix increases after confluence with Kinnickinic Investigations should indicate if this is related to the

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					physical/chemical changes at sites 10-13.	overall NO_3^- increases seen in Lake St. Croix since the 1970s.
Robertson and Lenz	2002	Response of the St. Croix River pools, Wisconsin and Minnesota, to various phosphorus loading scenarios	Existing biweekly monitoring data. 1997-1999.	Modeled P effects for 4 Lake St. Croix pools, Lake Mallalieu and St. Croix Falls Reservoir. BATHTUB model calibrated for May-September using pool and tributary data. P sources and outputs described.	N:P for Lake St. Croix Falls was 10:1 (suggesting N-P co-limitation). N:P for Lake St. Croix pools was always >17:1 (suggesting P limitation). Residence time in Lake St. Croix averaged 21 d. BATHTUB model failed for St. Croix Falls Lake; short residence time is better suited to river model. Linear increases in P loads produces nonlinear increases in chlorophyll, increases in bloom frequency, and decreased water clarity. Dry years would exacerbate these patterns. A 50% reduction in P loading would drop Lake St. Croix into the 'mesotrophic' category with respect to P and chlorophyll. Highly colored water confounds water clarity responses to P changes.	More information is needed to understand how increases in chlorophyll will affect water clarity. Changes in temperature and residence time as a result of climate warming would exacerbate Lake St. Croix's responses to ambient or increased P. This suggests residence time may be an important monitoring endpoint.
Edlund and Engstrom	2001	Post-European settlement sedimentation and nutrient loads in Lake St. Croix, a natural impoundment of the St. Croix River	Lake St. Croix near Prescott, WI and Lakeland, MN. October 1999.	Collected 2 sediment cores for determination of loss-on-ignition and calculation of sedimentation rates. Microfossil analysis performed, including diatom community analyses. TP concentrations reconstructed using transfer function from Minnesota lakes.	<u>Sedimentation rates</u>: Increased in the Lakeland core beginning in 1850, peaking ~1970. In the Prescott core, sedimentation rate did not increase until 1920, peaking in 1959. <u>Loss-on-ignition</u>: Showed similar trends in inorganic sediment accumulation. <u>Microfossil analysis</u>: Showed consistently higher abundance of microfossils at Lakeland vs. Prescott, and increases in accumulation beginning in 1920 at Lakeland and 1950 at Prescott. Diatoms shifted from benthic to pelagic types. <u>TP reconstruction</u>: Showed increasing TP concentrations in both cores since ~1910.	All signs point toward eutrophication over the past century. Authors suggest that differences between cores (downstream vs. upstream) may indicate a gradual downstream advance of eutrophication through Lake St. Croix. Diatom communities and abundance were good indicators of nutrient enrichment for Lake St. Croix and would serve as good biomonitoring tools.
Lenz et al.	2001	Nutrient and suspended sediment concentrations and loads and benthic invertebrate data for tributaries to the St. Croix River, Wisconsin and Minnesota, 1997-1999	St. Croix River system: 11 tributaries; synoptic study. 4 times per year,1998. 10 tributaries; intensive sampling. Monthly and during storm events, 1998-1999.	Stream flow monitored. Nutrients and suspended sediment concentrations, loads and yields calculated. Benthic invertebrates collected from 15 tributaries, fall 1999 only; various biotic and diversity indices calculated. Environmental characteristics evaluated included land use, soil, and surficial geology.	<u>1998 Synoptic</u>: Apple, Willow, Kinnickinnic Rivers during both events and base flow. Trade, Wood, Snake, Sand, Crooked and Lower Tamarack were big contributors during events. <u>1998-1999 monitoring</u>: Sediment loads and yields were determined for each tributary; results were largely event-driven and unrelated to land use or cover. Sunrise River looks like big contributor. <u>Benthic invertebrates</u>: Indices indicated no water quality impacts except for Valley Creek, Willow River and Kettle River.	<u>Confounding factors</u>: · Precipitation amounts, intensity and timing were highly variable in 1999, affecting load estimates and confounding tributary comparisons and relationships to land use. · Benthic invertebrate conclusions likely confounded by substrate/habitat differences. Benthic invertebrate indices were not good indicators of nutrient and sediment problems in these tributaries. Ordination methods might have improved understanding, but algal biomonitoring might be still better.
Kroening	2000	Fecal coliform and *Eschericia coli* bacteria in the St. Croix National Scenic Riverway, summer 1999	St. Croix and Namekagon Rivers: 22 locations, headwaters to near Marine on St. Croix, MN. May-September.	Fecal coliform and *E. coli* analyzed. Hydrological conditions noted.	Maximum, mean and median fecal coliform and *E. coli* greater in St. Croix than Namekagon. No counts exceeded state or federal standards. Highest bacteria counts were at Leonards and Trego for Namekagon, St. Croix Falls for St. Croix. No consistent seasonal patterns. Fecal coliform and *E. coli* were not significantly	Sampling spanned several months and results may have been confounded by temporal variability. Stream discharge was above average and point source bacteria may have been diluted. Author advises long-term monitoring on a monthly to

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					correlated (Kendall's tau) to discharge.	quarterly basis and further investigations into how bacteria concentrations relate to flow.
Meyer et al.	1999	Phosphorus, chlorophyll and suspended sediment in the lower St. Croix River	Metropolitan Council data from Stillwater, MN, and Prescott, WI. Biweekly 1976-1996.	Water quality measured: TP, SRP, chlorophyll, TSS, and SBS. Loads of the above parameters calculated.	Annual TP concentrations and loads at Prescott were 0.05 mg/L and 262 metric tons/year. TP declined from 0.07 to 0.04 mg/L since 1976; SRP may have also declined. TP was predominantly SRP in low flow years. Mean monthly TP concentrations were highest in April and September; TP loads highest in April. Point sources dominated P loads during low flow. Annual and summer mean chlorophyll at Prescott were 9 and 13 ug/L; peak in August. TSS significantly declined since 1976. Organic content of TSS may have increased.	Data provide indications that TP and TSS have declined gradually since 1976. Limiting top point sources of P will reduce P load minimally; both point and non-point source efforts will be necessary to manage eutrophication. More study of non-point source loading patterns is needed.
National Park Service	1995	Baseline water quality data inventory and analysis: St. Croix National Scenic Riverway	SACN and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	<u># water quality observations</u>: 113,022 <u># parameters</u>: 628 <u># monitoring stations (study area/park)</u>: 469/107 <u># parameters with exceedences (study area/park)</u>: 19/14 <u># stream gages (study area/park)</u>: 47/2 <u># dischargers</u>: 41 <u># drinking water intakes</u>: 0	Authors concluded that water quality at SACN was affected by human activities such as industrial and municipal wastewater discharges, stormwater runoff, agriculture, forestry, and urban and residential development.
Troelstrup et al.	1993	A short paleolimnological history of two riverine impoundments on the St. Croix River	St. Croix Falls and Lake St. Croix impoundments. August 1991.	Three sediment cores collected from each impoundment. Sediment cores analyzed for sedimentation rates, organic matter, carbonates, chlorophyll derivatives and % native chlorophyll, midge community characteristics. Water quality sampled at time of coring.	Anoxic or near anoxic conditions in both lakes. <u>St. Croix Falls</u>: All 3 cores < 40 years old; sediment accumulation rates estimated to be 1 to 4 mg/cm^2/yr. Three distinct increases in OM (< 3%-25%) corresponding with changes in carbonates, chlorophyll and midges. No apparent midge composition pattern. Sedimentation linked to fall hydrology over the short term. <u>Lake St. Croix</u>: Accumulation slower, 0.11-0.43 mg/cm^2/yr. Bayport basin had highest accumulation rates. OM and carbonates increased in upper levels of each core; eutrophication occurred over the past 40-50 yrs. Chlorophyll changes pronounced. LSC midge densities low, and decreased near surface; *Chironomus* dominates, possibly due to O_2 stress. General eutrophication response noted. Downstream gradient in responses noted.	Good insights on long-term changes. Reference to *Chironomus* and possible oxygen stress in LSC may be worth pursuing given the importance of benthic resources for the Riverway.
Troelstrup and Foley	1993	Examination of mussel growth and shell chemistry as indicators of water quality within the Lower St. Croix National Scenic Riverway	Lower SACN: 21 locations divided into 7 reaches. August-September 1991.	Collected 63 specimens of *Ablema plicata*. Morphologic measurements taken. Aging and growth rates assessed. 19 elements in shells analyzed using x-ray microanalysis.	*A. plicata* distributed widely but unevenly along the lower Riverway; results suggest higher mortality in Lake St. Croix reaches. Shell morphology measurements changed, with decreased values occurring in downstream reaches. Age was higher and growth rates lower downstream. Element intensity peaks for Ca, K, Mg, P, S, Si, and Zn were higher in lower reaches. Differences among reaches were attributed to a shift from riverine to lacustrine habitats and differing water quality. Some element groups reflected soil disturbance and	There may be more direct ways to measure effects of land use change and eutrophication. Report provides a good baseline on *A. plicata* distribution.

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					fertilizer, whereas other groups reflected urban sources.	
Graczyk	1985	Water quality in the St. Croix National Scenic Riverway, Wisconsin	SACN: 10 sites; 9 stations at high, medium and low flows, twice a year 1975-1983. St. Croix Falls, monthly 1975-1983.	Water quality suite analyzed. Water quality of streams classified. Average annual loads of sediments and nutrients calculated. Some parameters analyzed for trends from 1974-1981. Water quality compared with other Wisconsin rivers.	Most constituents increased downstream, and were lower than other Wisconsin streams. Mean TP ranged from 0.02 to 0.08 mg/L, mean TN from 0.42-1.30 mg/L and suspended sediment averaged 7.7 mg/L. Trace metals, except for Mn and Fe, were below drinking water standards. No pesticides detected in water or sediment above or below cranberry bogs. Suspended sediment and organic carbon may have declined from 1974-1981; ammonia likely increased.	Relative to other Wisconsin waters, St. Croix ranked well in terms of nutrient and sediment loads in the late 1970s-early 1980s. Data set could be mined further to look at differences between St. Croix sites. Comparisons with a more recent tributary study might help determine whether or not the chief tributary contributors of nutrients and sediments have changed over the past 2 decades.
Environmental Protection Agency Region V	1975	Report on Lake St. Croix, Washington County, Minnesota and St. Croix and Pierce Counties, Wisconsin	National Eutrophication Survey: including Lake St. Croix, 3 sites. 1972.	Sampled 3 times in ice-free season; samples retrieved from ≥2 depths. Basic water quality suite analyzed, phytoplankton identified coarsely, counted, and analyzed for chlorophyll. Nutrient loadings calculated for tributaries, minor tributaries and immediate drainages, and municipal wastewater plants. Lake and drainage basin characteristics also reported.	Mean residence time: 23 days. Major tributaries are St. Croix, Kinnickinnic and Willow Rivers. <u>Largest P point sources</u>: River Falls, Hudson, Stillwater, and Oak Park Heights treatment plants. Largest N point sources: Stillwater, River Falls, and Hudson treatment plants. <u>Largest tributary P and N sources</u>: St. Croix River, Kinnickinnic River, Willow River, and Valley Branch. 212,110 and 153,590 lbs of P and N accumulate each year, "dangerous" according to one model. Non-point nutrient export by subdrainage was highest in the Kinnickinnic River, followed by St. Croix River, Valley Creek, and Trout Brook. Non-point exports constituted 88% of TP load. N:P ratios indicated P limitation in November and N limitation in June and August.	Lake St. Croix was considered eutrophic in 1975, and non-point sources were predominant. Evidence of N limitation may be significant given that nitrate has increased over the last 25 years. Investigations into point versus non-point source nutrient contributions are important for managing eutrophication in Lake St. Croix.
McKersie et al.	1972	St. Croix River pollution investigation study	St. Croix River Basin.	Water quality standards reviewed. Sources of pollution assessed. Additional treatment recommended for certain point sources.	Noted 59 different point sources or areas of waste discharge, most of which were municipally owned and operated. Of 33 municipalities investigated, 28 had a municipal sewage collection and disposal systems. 3 were still using primary treatment. Industrial waste adversely affected treatment processes at some municipal treatment plants.	Several industries were noted for needing improved treatment facilities, including the fish hatchery at St. Croix Falls. Authors concluded that water pollution in the St. Croix River was generally minor but could be improved at some sites.
Biology & Ecology						
U.S. Fish and Wildlife Service	2004	Higgins Eye Pearlymussel (*Lampsilis higginsii*) recovery plan: first revision	Upper Mississippi River drainage, MISS, SACN.	Plan revised in response to severe zebra mussel threat at nearly all of the designated critical habitat areas. The SACN site at Interstate Park was the only non-infested site at the time of the revision.	Highest priority recovery actions were intended to address the zebra mussel threat. Recommendations included zebra mussel monitoring, mussel relocations, and cleaning of infested adults. Construction activities, contaminants and poor water quality were also addressed as threats. Specific recommendations related to the above threats were also included.	The goal of the recovery plan remains the recovery and removal of Higgins Eye mussels from the Federal list of Endangered Wildlife. (See also Hornbach et al, 1998, and Stern et al., 1982)
Newton et al.	2003	Effects of ammonia on	<u>*In situ* experiments</u>:	<u>Toxicity tests</u>: 96-hr and 10-d sediment toxicity	<u>Toxicity tests</u>: For 96-hr and 10-d tests, LC50s	Toxicity tests indicate that national water quality

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		unionid mussels: a threat to their biodiversity in the St. Croix National Scenic Riverway	Main channel, tributaries and bay. August 28-September 7, 2000; July 20-August 17, 2001. Survey sites: Snake River, St. Croix up and down from Snake River, Osceola Bay.	tests with juvenile *Lampsilis cardium.* *In situ* experiments: Exposures of juvenile *Lampsilis cardium* to a perceived ammonia gradient in St. Croix River. Molluscan surveys: Collected at sites with no previous unionid data; snail and sphaeriid data also collected.	averaged 146 and 117 µg NH_3-N/L, respectively, about half the acute national water quality criterion. Sublethal effects observed ~85-96 µg NH_3-N/L. *In situ* experiments: Survival highly variable and generally unrelated to ammonia. Molluscan surveys: Abundance and richness variable among sites, possibly due to substrate differences. Snake River had large substrates (boulder and cobble) and was shallower. Juvenile unionids found at all sites except Snake River. Gravid unionids collected everywhere live unionids were found. Non-unionid mollusks were sparse.	criterion for ammonia might not sufficiently protect juvenile mussels. Juvenile survival would not make a good monitoring endpoint because of its high variability. Episodic toxicity may occur when sediment temperatures and pH are elevated and ammonia is un-ionized. Ammonia monitoring should continue and should perhaps include concentrations in sediment pore water as well as the water column.
Hove and Hornbach	2002	Mussel communities in the St. Croix National Scenic Riverway: an outstanding natural resource – 2001 field season	Riverside, WI, Wild River State Park, MN, Franconia, MN, Prescott, WI. Each site had been surveyed previously.	Species distributions determined via SCUBA dive searches. Quantitative density estimates, age class measurements, and habitat quality assessments conducted at long-term monitoring locations.	Mussel diversity and density generally declined over time at these sites. Highest densities were found at Wild River, followed by Prescott, Franconia and Riverside. Sediment composition shifted toward finer particles over time. Winged mapleleaf mussel valves were found as far upstream as Wild River State Park, 42 km upstream of the present range.	Essentially a progress report. Declines in mussel density may be part of natural population cycles, but authors urge further monitoring.
Boyle and Strand	2001	The status of the macroinvertebrate community in the St. Croix River, Minnesota and Wisconsin: an examination of ecological health using techniques of multivariate analysis	St. Croix River system: 8 locations above major tributaries. Biweekly, May-September 1989.	Appears to be subset of data from Boyle et al. (1992). Water chemistry: Temperature, pH, TKN, nitrate-nitrite, TP, organic matter (CPOM and FPOM, VPOM), chlorophyll. Benthic invertebrates: 5 replicates of either Ekman or Surber samples at each site, identified and enumerated, EPT taxa noted. CCA analysis performed.	Found 119 macroinvertebrate taxa. Date, drainage area, substrate, temperature and chlorophyll individually explained variation in benthic invertebrate data; forward selection picked all but chlorophyll. CCA plot showed strong spatial and temporal patterns. Cluster analysis identified 3 time intervals. Late spring: P, date and CPOM/NO_3, substrate. Mid summer: substrate, drainage area, chlorophyll, date, CPOM and temperature. Late summer: VPOM and substrate.	Factors affecting benthic invertebrate composition varied across the summer and across sites. Effects of organic matter and NO_3 may have been stronger in streams draining agricultural areas. Study provides no indication of which taxa were associated with various species-environment patterns, so insights are limited. Study results imply high seasonal variability of invertebrates and a need for multiple samples during a growing season.
Grantsburg High School	2001	A quantitative survey of unionid mussel shells on the Upper St. Croix River north of the Highway 70 bridge	St. Croix River, 1.5 miles upstream of the Highway 70 bridge.	Site was a rock run normally covered by water, but exposed during sampling due to dry conditions and a channel shift following flood of 2001. All abandoned mussel shells collected and identified. Shell length, width and height measured.	Encountered 17 native pearly mussels; muckets and spikes were most common. Purple pimplebacks, Wisconsin endangered, and round pigtoes, Minnesota threatened, both found. All 6 species of special concern in Minnesota were also found. Most species had normal distributions, including recruitment.	These data establish a qualitative baseline for that particular site.
Hornbach	2001	Macrohabitat factors influencing the distribution on Naiads in the St. Croix River, Minnesota and Wisconsin, USA	SACN, park-wide; divided into 16 sectors. Data from many studies and reports.	Calculated number of mussels collected, species richness, Shannon-Wiener diversity, species evenness. Conducted a correspondence analysis followed by cluster analysis using canonical coefficients.	St. Croix has a very diverse assemblage and relatively high densities. Correspondence and cluster analysis showed a major split in mussel composition above vs. below the dam at St. Croix Falls, perhaps due to fish host distribution. Composition within these clusters was linked to stream gradient. Subfamily distributions also varied longitudinally, with lampsilines dominant in upper reaches of the river	Hornbach suggests that more research is needed to understand effects of fish host distribution and stream gradient on mussel distribution. Future monitoring plans should account for spatial variability in mussel composition throughout the Riverway. The 16 stream segments identified by Holmberg et al. (1997) and used here appear to be a biologically meaningful way to approach this.

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					and ablemines dominant in the lower reaches.	
Bartsch et al.	2000	Development of *in situ* refugia as a method of preserving the biodiversity of unionid mussels in the St. Croix River	St. Croix River: Mussels relocated from Lakeland, MN upstream to Franconia, MN. 1996-1998.	Experimental *in situ* relocation project. *Quadrula pustulosa, Elliptio dilatata, Lampsilis higginsii* relocated to three 5 m x 5 m grids. Mussel survival, recovery and substrate characteristics monitored annually for 2 years.	Recovery rates were high (90-98% in 1997; 92-100% in 1998), as were survival rates (85-100% in 1997; 93-100% in 1998). Substrates in grids did not differ significantly from year to year.	Relatively high survival and recovery shows that "system-specific, *in situ* refugia are a viable tool preserving the biodiversity of unionid mussels."
Hornbach et al.	2000	Developing a sampling strategy to examine population trends for the endangered Winged Mapleleaf Mussel: the results of a workshop sponsored by the National Park Service, St. Croix National Scenic Riverway	Previously collected *Quadrula fragosa* data used.	Team of researchers and managers met to discuss sampling protocols for *Q. fragosa*..	A two-step approach was suggested: · Sample the entire mussel community quantitatively. · Qualitatively assess whether or not the proportion of the *Q. fragosa* has changed. Statistical issues are considered for future trend analysis.	Continued monitoring using this approach is recommended.
Hove et al.	2000	Brooding behavior and suitable host for Winged Mapleleaf (*Quadrula fragosa*)	University of Minnesota, Wet Lab. Laboratory observations and experiments.	Performed 45 trials on 35 fish species or mudpuppies under laboratory conditions.	Glochidia released individually or in conglutinates. 2 juvenile winged mapleleaf collected from a single channel catfish.	Author notes that additional work is needed to verify that ictalurids serve as glochidial hosts under natural conditions.
Hove and Hornbach	2000	Community analysis of the mussel population downstream of the St. Croix Falls hydropower dam	St. Croix River: Interstate State Park, Osceola, WI, Bayport and Lakeland, MN. Previously sampled sites.	Stratified quantitative sampling conducted at each of 4 sampling locations using SCUBA. Each location had 10 sub-sampling sites, and 10 0.25 m^2 quadrats within each sub-sampling site. Mussels identified and shells measured, along with community structure, age distribution, population density, depth, location, flow rates and substrate types.	Mussel densities lower at all sites compared to earlier periods. Most marked declines occurred at Bayport, but none of the declines were statistically significant. High juvenile mortality or lack of recruitment cited as possible reasons. Fine sediments increased at all locations.	Authors note that declines in sediment size are a concern.
Heath et al.	2000	Determination of basic reproductive characteristics of the Winged Mapleleaf mussel (*Quadrula fragosa*) relevant to recovery. Job 1: determination of gravidity period.	St. Croix River. 1997-1999.	Brooding condition of 10 ablemine species observed every 2 weeks during the open water seasons for 3 years.	Identified 4 temporal subsets of brooders: · Very early brooders (April 21-July 29), · Early subset (May 4-August 26), · Mid-season subset (June 10-August 5). · Late season subset (August 31-October 11). *Q. fragosa* was the only species in the late season subset, and brooding period was very short. Brooding season of *Q. fragosa* did not overlap with other ablemines, but resembles that of *Q. quadrula.* Brooding frequency of *Q. fragosa* linked with water temperatures.	Links between *Q. fragosa* brooding frequency and stream temperature may become important in a climate change context.
Westrick	2000	The classification and prediction of macro-invertebrate communities to the Upper St. Croix River Basin	Upper St. Croix Basin: 41 third order streams. July-September 1998-1999.	Macroinvertebrates collected from riffles using a kick net, identified mostly to genus. Water chemistry suite analyzed. Discharge, riparian cover, substrate, and physical habitat, land use recorded. Sites clustered into biologically similar groups; discriminant function analysis used to select variables that distinguished groups.	Identified 164 species, 105 genera. Cluster dendrogram identified 3 biological groups. Model correctly allocated 85% of sites to the correct classification group based on 4 variables: discharge, stream length, conductivity and % gravel.	Author recommends model validation using additional sites. Macroinvertebrate monitoring strategies for SACN should account for variation in discharge, stream length, conductivity and % gravel.
Macbeth et al.	1999	Assessment and classification of aquatic	St. Croix River: 90 miles from	Nested hierarchy approach: study area, major segment, minor segment, reach, habitat patch.	Major segments classified by basin-level properties like slope, geology, land use/cover, climate and	"This assessment and classification system is based on benthic macroinvertebrates only. Other

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		habitat in the St. Croix National Scenic Riverway	confluence of Namekagon to 10 miles below St. Croix Falls.	Different variables defined each scale. Benthic invertebrates collected with kick net at transect/reach scale and identified. Biological metrics and indices calculated.	ecoregion. Minor segments classified using channel gradient: high vs. low. Reaches in high gradient segments can be classified from local-scale geomorphologic features. Macroinvertebrate metrics related to physical environment in such segments. Reaches in low gradient segments are less readily classified and related to macroinvertebrates. Both longitudinal and lateral reaches and patches are needed. Unique, sensitive, diverse habitats most likely to occur upstream, within high gradient segments, in transition areas between high and low gradient segments, at tributary confluences and near dams.	biophysical data (e.g., fish, native mussels, water quality, etc.)…should be incorporated routinely into a comprehensive aquatic habitat data base built as a geographic information system database for the Riverway. Future studies should be planned with reference to and in consideration of the hierarchical classification system." "More biophysical data are needed to help unravel the longitudinal and lateral organization of low-gradient minor segments." This report appears to provide a framework for understanding spatial variability and for designing future studies within SACN.
Davis	1998	Invertebrate communities on large woody debris in the St. Croix River	St. Croix River: 4 km reach near William O'Brien State Park; 10 randomly chosen sites. Summer 1997.	Recorded 13 large woody debris (LWD) variables: age, dissolved oxygen, velocity, area, wood volume/pile volume, depth, # intersects, volume, surface area, surface area/volume, and LWD diameters. Recorded 5 invertebrate variables: density, richness, Biotic Integrity score, diversity, and % chironomid.	All invertebrate metrics, especially richness, diversity and % chironomid, were predicted nicely by multiple regressions using measured LWD variables. Results suggest that protecting younger and smaller LWD in shallow waters with high velocities will support more diverse and rich fauna.	Author poses several questions for further research: "What influence does seasonality have on models' predictive abilities? Will conglomerates of LWD piles exhibit different community attributes than isolated piles?" Quantity of LWD surface area affects invertebrate density, but LWD qualities are important to richness and diversity. Continued new inputs of LWD are important.
Hornbach et al.	1998	Examination of the larval stage (glochidia) of the winged mapleleaf mussel (*Quadrula fragosa*)	St. Croix River: presumably Interstate Park when gravid females present in fall.	Two methods for identifying glochidia of *Q. fragosa* explored: morphometric measurements of glochidia using SEM, and DNA fingerprinting using polymerase chain reaction. Project is linked to host fish studies.	Glochidia of different *Quadrula* species were distinguishable based on size, but DNA/PCR methods were more definitive.	*Q. fragosa* appears to be gravid in the fall, but it is unknown how long females hold onto glochidia; therefore, minimum winter flows below the dam should perhaps be considered, along with emergency spill plans for winter periods.
Hornbach et al.	1998	Revised Higgins' Eye mussel (*Lampsilis higginsii*) recovery plan	Historic range of Higgins' Eye Pearlymussel: Upper Mississippi River (Brownsville, MN to Burlington, IA), St. Croix River (Prescott, WI to Hudson, WI).	Technical/agency team was convened to draft revisions to the original 1982 recovery plan in response to the zebra mussel invasion and the flood of 1993.	<u>Habitat requirements</u>: Associated with large rivers, stable substrates, current velocities < 1 m/s, in species-rich assemblages with densities > 10/m^2. Defined 10 essential habitat areas, including one on the Wisconsin River. <u>Recovery criteria</u>: As in original plan. <u>Recommendations</u>: Reformulated to emphasize immediate needs to limit impact of zebra mussels, develop uniform protocols for data collection, confirm and modify the essential habitat areas, and require the use of double hull barges.	– (See also U.S. Fish and Wildlife Service, 2004, and Stern et al., 1992.)
Doolittle and Heath	1997	Second sampling of freshwater mussel communities for long-term monitoring of the Saint Croix National Scenic Riverway, Minnesota and Wisconsin	SACN: 5 long-term monitoring sites identified. 1987. Resampled Marine 2 CTH K and the Narrows. 1995. Surveyed Marine 2 and Upper Namekagon sites.	SCUBA divers assessed population characteristics using randomly chosen 1 m^2 quadrats for population density, richness, composition, age, total length distributions, living/dead and male/female ratios. Specific microhabitats for rare taxa also targeted.	Found 30 taxa in 1995-1996. Greatest taxa richness and densities found in mid-stream study areas; least found in downstream and headwater areas. More than 300 samples would have been required to detect a 50% change in geometric means for specific taxa. Total mussel densities decreased since 1987 at Marine 2 and the Narrows; other sites stable.	Taxonomic lists provided for both surveys. Large sample sizes needed for long-term monitoring and trend analysis of mussels. Authors outline future monitoring protocols, including sampling sites, methods, metrics, etc. Author recommendations include further study of the

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			1996.		Areas showing declines in mussel density had the largest proportion of dead shells and declining recruitment for all taxa.	upper Namekagon and investigations of host fish distribution and relationships to mussel communities.
Ecological Specialists, Inc.	1997	Unionid relocation near Stillwater, Minnesota	Proposed US Hwy 36 bridge site: Mussels relocated, August 19, 1996. Monitored, September 1996.	Relocated 18,119 individuals of 25 species, including 9 Federal or State T&E species. Installed 5 m x 5 m test grids to monitor survival, growth and movement of three common species. Used 1 m x 5 m grids to monitor 10 T&E species.	Most mussels were between shore and 3 m, with densities of 4.5/m^2. Relocation site was 100-1500 m upstream of bridge site. Recovery in 5 m x 5 m grids several months after relocation was > 100% and no mortality was observed; for 1 m x 5 m grids recovery was 50% with no mortality observed.	Sample size in monitoring grids was low and the grids may have been monitored too soon after relocation to detect differences.
Hornbach et al.	1997	Freshwater mussel ecology of the St. Croix River: comparison of juvenile and adult habitats	Interstate Park: 5 locations along 5 transects, 3 samples. June-August 1997	Juveniles obtained using a Surber sampler; adults excavated from 0.25 m^2 quadrats. Microhabitat characteristics measured were: flow, depth, average substrate particle size. PVC tubes used to estimate rate of sediment and juvenile mussel deposition.	Found 22 species. Juvenile density highly variable. Overall mussel density was variable among sites but not correlated with microhabitat, suggesting consistency of water level may be more important. Small juveniles most common in deep side channels, possibly due to fish host behavior. Adult densities low in regions experiencing frequent dewatering from dam.	High variability in mussel distribution even in this small sampling area. Authors recommend larger sample sizes.
Vaughan	1997	Winged mapleleaf mussel (*Quadrula fragosa*) recovery plan	SACN, park-wide, emphasis on winged mapleleaf habitat.	Interagency team of experts.	Outlines "reasonable actions believed required to recover and/or protect the species," including specific tasks such as "maintain the St. Croix River population of *Q. fragosa"* and "improve understanding of the biology and ecology of *Q. fragosa."*	Plan provides a thorough review of winged mapleleaf information and a comprehensive list of recommendations for winged mapleleaf recovery.
Hornbach	1996	Bivalves in the St. Croix River: a report for the Water Resources Management Plan	Entire St. Croix River.	Background and literature review.	General taxonomic and morphologic descriptions provided. Listed 40 St. Croix mussel species. Two federally endangered species (*Quadrula fragosa* and *Lampsilis higginsii*) present. Good information and analysis on mussel distribution provided. Biology, ecology and life history presented. Requirements and threats discussed, including zebra mussels. Conservation measures presented and recovery goals discussed.	A thorough and synthetic review of mussel research and status on the St. Croix. Species differences noted above vs. below the dam at St. Croix Falls and between riverine and lacustrine segments downstream. Little variation in mussel density or species richness explained by physical habitat, suggesting fish host distribution likely important. Author recommends a comprehensive mussel management plan for the St. Croix River.
Hornbach et al.	1996	Factors influencing the distribution and abundance of the endangered winged mapleleaf mussel *Quadrula fragosa* in the St. Croix River, Minnesota and Wisconsin	Interstate Park, 15 sites; Franconia, MN, 10 sites. 1991-1993, 1995.	Some areas resampled to characterize temporal variability in habitat characteristics. Quantitative quadrat samples conducted using SCUBA, and targeted searches for *Q. fragosa.* Habitat characteristics evaluated were velocity, depth and substrate composition.	Overall density and richness peaked at ~2 m. *Q. fragosa* found in areas of slightly lower velocity and depth; associated with dense and diverse mussel assemblages. *Q. fragosa* not found at depths < 0.42 m. *Q. metanerva, Truncilla truncata* and *T. donaciformis* all significantly associated with *Q. fragosa.* A common fish host (sauger) was hypothesized for all these species.	Authors conclude that management that benefits the whole mussel community should also help protect *Q. fragosa.*
Hanson and Leonard	1995	Review of an instream flow study performed on *Quadrula fragosa* in the	Interstate Park, 3 channels; and Franconia, MN.	Critical review of methods and findings of the Johnson (1995) instream flow study.	Study site representativeness, habitat suitability criteria, PHABSIM calibration and Johnson's approach to evaluating impacts of peaking were all	Authors recommend more study and modeling. (See also Johnson 1995.)

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		Lower St. Croix River, Wisconsin			subjected to critique. Lack of pre-dam records also noted. Whether or not flow modifications would improve habitat conditions was questioned.	
Hay et al.	1995	Distribution, status and life history of the winged mapleleaf mussel *Quadrula fragosa* in the St. Croix River, Minnesota and Wisconsin	St. Croix River: St. Croix Falls dam 14 km downstream to Osceola, WI.	Methods detailed in Hornbach (1992) and Johnson (1995).	Results detailed in Hornbach (1992) and Johnson (1995).	Recommendations included: · Higher non-navigation season peaking flows. · Winged mapleleaf population monitoring. · Essential habitat monitoring. · Surveys to identify other existing or potential *Q. fragosa* sites within the lower St. Croix River. · Host fish studies.
Hornbach	1995	The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park	St. Croix River: Interstate Park, 2 transects in east channel. June 1995.	Water depth and flow measured, substrate evaluated qualitatively, and mussel collections made every 5 m along transects.	Encountered 22 species from transect searches, with *Truncilla truncata* dominant. Mussel densities and richness lowest in the middle of transects, where water was shallow. Maximum density and richness were at 1.5-1.75 m. Density and richness not related to sediment types or bottom flow. Depth effects on mussel densities especially pronounced for small mussels. Paddleboats running aground and human mussel collectors may also affect *Q. fragosa*. Exposed substrate at discharge of 1750 cfs.	Authors corroborate results found in Johnson (1995) and suggest a discharge of > 4000 cfs needed to protect mussel habitat.
Hornbach	1995	The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park. An addendum.	Additional transect sampled. August 1995.	Water depth and flow measured, substrate evaluated qualitatively, and mussel collections made every 5 m along transects.	One additional species found, but *Truncilla truncata* still dominant. Depth patterns still held, and still there was no relationship between mussel densities or richness and bottom flow or sediment types.	Addendum to Hornbach (1995). Authors corroborate results found in Johnson (1995) and suggest a discharge of > 4000 cfs needed to protect mussel habitat.
Hornbach et al.	1995	Abundance and distribution of the endangered mussel, *Lampsilis higginsii* in the Lower St. Croix River, Minnesota and Wisconsin	St. Croix River: Known *Lampsilis higginsii* sites; Interstate Park, Franconia and Lakeland, MN, Prescott, WI.	Qualitative and quantitative collection methods employed at each site. Distribution, abundance, microhabitat and species associations evaluated.	Significant *L. higginsi*18-28 populations found only at Lakeland and Prescott; at other sites only dead or widely dispersed individuals found. *L. higginsii* generally found in regions of high unionid density and species richness, at greater depths than most species, in low current velocities, and in sand/silt substrates.	Authors state that *L. higginsii* is in real danger of extinction. The remaining populations of *L. higginsii* are located in the lacustrine parts of the Riverway most threatened by zebra mussels. Reasons for the decline in *L. higginsii* populations at upstream sites should be further investigated.
Johnson	1995	Instream flow requirements of *Quadrula fragosa* and the aquatic community in the Lower St. Croix River downstream of the Northern States Power Hydroelectric Dam at St. Croix Falls, WI	St. Croix River: Interstate Park, 3 channels and Franconia, MN.	Instream flow incremental methodology (IFIM) and PHABSIM hydraulic and habitat modeling used to assess flow needs of mussels, macroinvertebrates and fish. 2 sites, 3-5 transects each. Stage-discharge relationship developed, streambed profiles constructed, and microhabitat data (substrate, velocity, depth) and habitat suitability criteria (professional judgment) recorded.	Most suitable mussel substrate was gravel, followed by sand and cobble substrates; very fine or very large substrates were less suitable. Most suitable velocity was moderate. Mussel density increased with depth, and species richness was highest at intermediate-deep depths. Habitat diversity was limited at high and low flows, and highest at intermediate flows of 2000-4000 cfs (800 and 1600 cfs are the low impounding flows for winter and summer). Availability of mussel habitat was strongly influenced by flow. Flow recommendations were provided, emphasizing that 800 cfs is too low and that rapid fluctuations are	Study provides quantitative information on flow-habitat relationships. The fact that flow and habitat availability don't explain all the variation in mussel composition in density suggests that other factors, such as fish hosts, food quality/quantity, etc., are also important.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					also a concern.	
Johnson	1995	Response to the review of an instream flow study performed on *Quadrula fragosa* in the Lower St. Croix River, Wisconsin	St. Croix River: Interstate Park, 3 channels and Franconia, MN.	Instream flow incremental methodology (IFIM) and PHABSIM hydraulic and habitat modeling used to assess flow needs of mussels, macroinvertebrates and fish. 2 sites, 3-5 transects each. Stage-discharge relationship developed, streambed profiles constructed, and microhabitat data (substrate, velocity, depth) and habitat suitability criteria (professional judgment) recorded. Additional analyses provided.	Concerns of Hanson and Leonard (1995) are addressed individually.	Results of additional modeling and analysis support the results of the original instream flow study (Johnson 1995).
Lillie	1995	A survey of rare and endangered mayflies of selected rivers of Wisconsin	Wisconsin waters: 25 rivers, including St. Croix near Danbury, WI. May-July 1991-1993.	Mayflies collected using dredges, pumps, kick nets and hand picking. Sand-bottomed areas targeted. Microhabitat conditions noted.	St. Croix had the second highest number of mayfly taxa and the highest number of unique taxa of all sampled rivers.	The study successfully expanded the known ranges for several taxa and documented many taxa. Author recommends more such comprehensive surveys to understand distribution and environmental requirements of mayflies and other invertebrates. St. Croix River is relatively species rich.
Helms & Associates	1994	Results of a mussel survey conducted in the St. Croix River near Stillwater, Minnesota	St. Croix River: 118-block grid near Stillwater, MN.	0.25 m^2 quadrat samples taken at randomly selected blocks. Mussels identified and shell lengths measured. Depth, water temperature, substrate characteristics recorded.	Recorded 11 taxa at average densities of 7/m^2. Composition was dominated by threeridge, Wabash pigtoe and giant floater. No federal or state T&E species found. No live zebra mussels or Asian clams found.	Analysis and discussion are very brief, but report may provide good baseline data for that site.
Troelstrup and Hornbach	1994	*Quadrula fragosa* (Conrad) in the Saint Croix River: distribution and abundance relationships with community structure and water quality	Lower St. Croix River: up and downstream of 4 permitted dischargers, and select other locations.	Mussel communities evaluated using qualitative transect and quantitative quadrat sampling. *In-situ* benthic respiration, shell erosion, abnormalities and epiphytes evaluated above and below dischargers.	Physical habitat characteristics not related to *Q. fragosa* distribution. *Q. fragosa* mostly found in areas of high mussel density and richness. 5 species positively associated with *Q. fragosa*: *Q. metanerva, Truncilla donaciformis, T. truncate, Tritogonia verrucosa,* and *Obovaria olivaria.* Effects of dischargers ambiguous.	Author provides research recommendations: · Life-history attributes and ecological relationships for the 5 mussel species associated with *Q. fragosa* · Identification of fish hosts and their distribution · Further examination of habitat and water quality attributes.
Fago and Hatch	1993	Aquatic resources of the St. Croix River Basin, Biological Report 19	St. Croix Basin.	Objectives: Summarize geology, analyze land use and land cover patterns, summarize surface water quality and relate to land features, use and cover, list aquatic biota (fish, benthic invertebrates, mussels), evaluate fish community status, identify upcoming issues.	Found 1,770 tributaries and 628 lakes in basin, of which 98 streams drain directly into the mainstem. Represents 3 ecoregions. Discharge may be increasing. Population in basin (especially Minnesota side) increasing, along with recreational boating. Water quality generally declines downstream, but no sites violated MPCA standards; PCB and Hg contamination are significant. Extensive fish review provided: 110 species present (6 introduced); species presence/absence listed by basin. Upper St. Croix basin and Lower St. Croix basin have different fish assemblages. Fausch (1987) developed fish IBI for 38 sites, found most sites to be fair-excellent. 39 mussel species found in basin (mostly mainstem); two federally endangered. Asian clam (*Corbicula flaminea*) present in lower basin. 332 aquatic invertebrate species found in basin	This is a fairly thorough and insightful review of aquatic resources at SACN. (See additional review under fish category.)

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					(mostly mainstem): more species, more insect and EPT taxa in upper basin. St. Croix generally healthy and diverse; trouble spots may be Snake and Sunrise River subbasins, and the Twin Cities metro area.	
Troelstrup et al.	1993	Changing patterns of water quality and biology within the lower St. Croix National Scenic Riverway	Lower St. Croix River: 7 reaches and subbasins.	Characterized 13 waste and cooling water (NPDES) dischargers. Historical water quality and biological data collected and organized, with an emphasis on long-term or large scale studies. Statistical summaries, seasonal summaries, limited trends provided.	Water quality: At Prescott 1934-1990, generally good water quality in terms of mean values; some exceedences for pH, bacteria, DO. Most variables quite seasonal. TP values high relative to recommended 30-40 ug/L for region. Water quality (most nutrients, metals, PCBs) generally declined downstream, but Hg and un-ionized ammonia were higher upstream. Comparisons of 1950-1975 and 1976-1990 periods showed no major differences. Invertebrates: 268 taxa recorded, excluding Unionids. Good review of existing studies. % EPT high (> 30%). Species list provided. Unionid mussels: 41 species confirmed; 2 federally endangered. Species richness declines along lower St. Croix. Species listed. Fish: Species richness highest in lower reaches. Several Wisconsin 'listed' species found. IBI shows poor to fair richness below St. Croix Falls; may be related to peaking flows at dam site. Bottom fish most susceptible to contamination; PCBs high below Marine. Species list provided.	Monitoring expansion and standardization across agencies and states needed. Report provides a solid basic statistical summary of water quality and a comprehensive listing of invertebrate and fish fauna.
Troelstrup et al.	1993	Elemental accumulation in the tissues of *Ablema plicata* (Say): a longitudinal evaluation within the Lower St. Croix National Scenic Riverway	Lower St. Croix River: 7 reaches, 21 sites. August-September 1991.	Whole soft tissues analyzed for elemental concentrations and signatures, including Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Ha, Ni, P, Pb, Rb, S, Si, Sr, Ti, V, and Zn. Analyzed for longitudinal trends, relationships to watershed area, dischargers, water velocity, land use, and boat traffic.	Nearly all of the 27 elements examined were measurable in tissues, but most were well below those reported from heavily impacted waters. Found 13 elements varied longitudinally, increasing downstream. Several elements were positively correlated with boat traffic and negatively with percentage urban land and watershed area.	Author suggests that unionid mussels may be good biomonitoring tools for water quality conditions given their high concentration factors. More intensive monitoring of reaches 1, 6 and 7 is recommended given high concentrations in these areas.
Vogt and Smith	1993	*Ophiogomphus susbecha* spec. nov. from North Central United States (Anisoptera: Gomphidae)	St. Croix River. June 1989 – May 1990.	Exuviae, final instar larvae, and field adults collected.	Species and diagnostic characters described. Larvae known only from large rapid rivers with pristine water quality.	Macroinvertebrate monitoring efforts should be aware of this taxa and make note of its occurrence at new SACN sites.
Boyle et al.	1992	An evaluation of the status of macroinvertebrate communities in the St. Croix National Scenic Riverway, Minnesota and Wisconsin	St. Croix River: up and downstream of major tributaries. Biweekly, summer 1987, 1989.	Water chemistry: Temperature, pH, TN, TP, organic matter (CPOM and FPOM, VPOM), and chlorophyll. Benthic invertebrates: 5 replicates of either Eckman or Surber samples at each site, identified and enumerated, EPT taxa noted, diversity and richness calculated.	N and P: Higher at Sunrise and Apple Rivers than other tributaries. Chlorophyll highest at Clam, Snake Sunrise and Apple River locations. Longitudinal nutrient and chlorophyll increases. VPOM also increased downstream. Macroinvertebrate richness and density declined downstream, and Clam River invertebrates were distinct. More shredders present just below tributaries, probably due to CPOM inputs. Effects of dams on invertebrate communities	"…this report [recommends] to use benthic macroinvertebrates as a community level biological indicator for a long-term data base, but only if the local natural and present anthropogenic factors affecting the structural and functional community attributes are taken into consideration." Taxa lists and functional groups are included.

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					suspected based on reduced invertebrate densities and richness noted from Interstate Park to the Apple River.	
Hornbach	1992	An examination of the population structure, community relationships and habitat characteristics of the Winged Mapleleaf mussel (*Quadrula fragosa*) at Interstate Park, Saint Croix River, Wisconsin and Minnesota	St. Croix River: Interstate Park, 15 sites.	SCUBA diving (0.25 m^2 quadrats) and visual searches used to find *Q. fragosa.* Water depth, flow, particle size and suspended solids measured. Water quality measured at sediment-water interface and 0.5 m above the bottom.	Suspended materials at sediment-water interface were mostly fine sand. Encountered 29 species; and community was dense and diverse. Variability in community characteristics was mainly due to substrate type and water depth; few relationships found between suspended solids and mussel metrics. *Q. fragosa* found in areas with high density and richness of other mussels as well (i.e. in high quality habitat in general). Mussel recruitment may be related to years where flow did not reach critically low levels.	Water depths of at least 2 m seemed to support the highest number of mussels – water depth clearly an important factor to monitor in terms of availability of prime habitat, particular in variable flow areas like below dams. Report provides useful graphs relating mussel metrics to habitat variables.
Boyle and Beeson	Circa 1990	The effects of Pacwawong and Phipps flowages on ecological aspects of the Namekagon River	Pacwawong and Phipps flowages: 2 sites above, 2 sites downstream. Biweekly, May-September.	Water quality suite measured. Benthic macroinvertebrates collected with a Surber sampler. Qualitative aufwuchs sampled in vegetation. Diversity indices calculated.	Suspended solids net release from flowages during low flow. Temperature higher downstream of flowages. FPOM markedly reduced by flowages. Phipps Flowage generated UPOM via phytoplankton. At Pacwawong, noted significant increases in density, richness and diversity and altered functional groups downstream of the dam, with exclusion of scrapers and shredders. Similar, less distinct patterns in Phipps Flowage.	Dams likely sequestering substantial organic matter and affecting the character of substrate and invertebrate communities. It would be interesting to explore how far downstream these effects last and whether or not there's a cumulative effect of the dam series on Namekagon River biota.
Heath and Rasmussen	1990	Results of baseline sampling of freshwater mussel communities for long-term monitoring of the St. Croix National Scenic Riverway, Minnesota and Wisconsin	SACN: 5 study areas. June-September 1988, April-August 1989.	SCUBA dives conducted within 1 m^2 quadrats, and random supplemental dives. Population density, community composition, age and total length distributions, ratio of living/dead and sex ratios evaluated for each area.	Encountered 39 taxa. Taxa richness greatest downstream, densities greatest upstream. Numbers of quadrats needed to determine x% change in population density determined. Lowest living/dead ratios in lowest density areas.	Author makes monitoring recommendations: · Sampling during same times each season to avoid problems with seasonality and juvenile recruitment events. · Monitoring annually for 5 consecutive years and thereafter every five years. · Using consistent methodology. · Basing number of quadrat samples on desired level of statistical certainty. · Analyzing trends in the metrics used in this study.
Busacker	1989	A biological assessment of *Lampsilis higginsii* in the St. Croix River at Stillwater, Minnesota: possible impacts associated with replacing the St. Croix Crossing between Stillwater, Minnesota and Houlton, Wisconsin	St. Croix River: near Stillwater, MN.	–	Neither *Lampsilis higginsii* nor any other endangered or proposed endangered species was found alive. 5 *Lampsilis higginsii* empty shells were found and several looked freshly dead, suggesting species likely lives there. Mussel reproduction occurred at all sites.	–
Havlik	1987	Naiad mollusks (Mollusca: Bivalvia: Unionidae) of the St. Croix River at seven proposed bridge/tunnel	St. Croix River: near Stillwater, MN July 22-August 17, 1987.	SCUBA and wading semi-qualitative collections	Collected 30 Unionid species. No live *Lampsilis higginsii* found but 5 shells were found; species likely present at three sites. Moderately dense, diverse bands of mussels along	Preferred bridge/crossing sites are listed. Relocations and transplants are recommended.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		sites, Stillwater, Minnesota			shorelines. *Amblema p. plicata* was dominant (63%). Juveniles were found for 21 of 30 species. Recruitment decreased downstream.	
Mackay and Waters	1986	Effects of small impoundments on hydropsychid caddisfly production in Valley Creek, Minnesota	Valley Creek, tributary to Lake St. Croix, 3 sites. 1982-1983.	Annual production of Hydropsychids compared in riffles above and below small impoundments or ponds.	Hydropsychid production higher downstream, likely due to increase in abundance or quality of seston, as well as more periphyton and less abrasive sand.	This study has implications for small dams and impoundments on many St. Croix tributaries. It may be useful to quantify the net effect of all these impoundments on the amount and quality of organic matter, nutrients and sediments entering the St. Croix River.
Newman and Waters	1984	Size-selective predation on *Gammarus pseudolimnaeus* by trout and sculpins	Valley Creek, a tributary to Lake St. Croix. July 1979-May 1980.	Drift and benthic *Gammarus* sampled. Diets of sculpin and brook, brown and rainbow trout analyzed. Length distributions of *Gammarus* evaluated.	*Gammarus* in fish stomach contents larger than those of benthic samples. *Gammarus* drifting at night larger than day drifters. Size-selective predation may influence *Gammarus* most in winter (low growth rates).	–
Stern	1983	Depth distribution and density of freshwater mussels (Unionidae) collected with scuba from the lower Wisconsin and St. Croix Rivers	Wisconsin River: 4 sites. St. Croix River: St. Croix Falls. Low water periods 1978.	SCUBA diving conducted along 40 m^2 transects at several depths. Mussels collected and identified in lab. Basic water quality measured. Substrate particle size and current velocity measured.	Collected 28 species. Greater species diversity and density in transects with variable particle sizes. Depth distributions noted. Comparisons made to Baker (1928) survey.	Changes in mussel fauna from 1928 to 1978 were noted and attributed to water quality changes, host fish elimination, impoundments and overexploitation. Few insights particular to the St. Croix were provided.
Stern et al.	1982	Higgins' Eye mussel recovery plan	Historic range of Higgins' Eye Pearlymussel: Upper Mississippi River (Brownsville, MN to Burlington, IA), St. Croix River (Prescott, WI to Hudson, WI).	Higgins' Eye Recovery Team identified recovery criteria, a recovery plan, several essential habitat areas and action recommendations.	Recovery criteria: Establish five separate viable reproductive populations in five distinct navigation pools. Recovery plan: 10-year study of 7 good mussel beds to determine presence of reproducing females, presence of juveniles, presence of host fish, and good sex and size class distribution. Essential habitat: 7 sites including Hudson, WI, Lansing, IA, Harpers Ferry, IA, Prairie du Chien, WI, Guttenburg, IA, Cordova, IL, and Moline, IL. Recommendations: Monitor mussels in essential habitat areas, develop relocation and artificial propagation techniques, and develop clam harvesting regulations.	– (See also U.S. Fish and Wildlife Service, 2004, and Hornbach et al., 1998.)
Waters	1981	Seasonal patterns in production and drift of *Gammarus pseudolimnaeus* in Valley Creek, Minnesota	Valley Creek, a tributary to Lake St. Croix. Monthly 1968-1973.	*Gammarus* sampled monthly. Production rate, drift, standing stock, and growth rate measured.	Production, drift and growth all associated with warm summer months. Production rates high enough to account for observed drift without requiring compensatory upstream migration.	–
Shiozawa	1986	The seasonal community structure and drift of microcrustaceans in Valley Creek, Minnesota	Valley Creek, a tributary to Lake St. Croix.	Benthic densities and drift rates quantified.	Collected 16 species in benthic samples. 2 additional species found in drift samples. 2 general groups noted: epibenthic types in depositional stream habitats, hyporheic types in erosional habitats. Seasonal peaks in abundance and drift occurred in spring and early summer.	–
Holt and Waters	1967	Effect of light intensity on the drift of stream	Valley Creek, a tributary to Lake St.	Experiments conducted with artificial light and artificial darkness.	Continuous artificial light at night for 4 days depressed nocturnal drift rates.	–

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		invertebrates	Croix.	Drift of *Baetis vagans* and *Gammarus limnaeus* measured.		
Waters	1966	Production rate, population density and drift of a stream invertebrate	Valley Creek, a tributary to Lake St. Croix. Late 1960-mid-1963.	*Baetis vagans* production rates estimated using two different methods. Production rates related to population density and drift rate.	Production rates higher for summer vs. winter generations, but winter production significant. Summer generations drifted more than winter ones.	–
Waters	1965	Interpretation of invertebrate drift in streams	Valley Creek, a tributary to Lake St. Croix.	Drift collections, standing crop measurements, and experimental drift blocking.	*Baetis vegans* and *Gammarus limnaeus* were the two main drifters. Both species drifted at various depths. Standing crop was not enough to account for drift. Permanent downstream displacement likely.	–
Waters	1962	Diurnal periodicity in the drift of stream invertebrates	Valley Creek, a tributary to Lake St. Croix.	Intensive drift sampling conducted.	Larval insect drift was generally greater at night.	–
Waters	1961	Standing crop and drift of stream bottom organisms	Valley Creek, a tributary to Lake St. Croix; 4 other streams.	Streams sampled represented a productivity gradient. Drift and standing crop sampled by Surber sampler. Drift measured for 1 hour at each site biweekly during August and September 1958.	Valley Creek had higher drift than northern Minnesota streams, implying that drift is related to production. Standing crop not related to expected productivity for each stream unless limited to organisms with 2 or more generations per year.	–
FISH						
National Park Service	2003	Draft Environmental Assessment – Restore Cap Creek to a brook trout stream: the Schultz Pond project.	Cap Creek, a tributary to Namekagon River.	EA prepared as required for restoration activities in Cap Creek. Proposed project would remove ponds that were once a part of Schultz's Silver Springs trout hatchery.	Two alternatives analyzed; no action and restoration alternative.	
Wisconsin Department of Natural Resources	2002	The state of the St. Croix Basin – an integrated management plan developed by Wisconsin Department of Natural Resources and partners	–	Fisheries section reports on current state of fisheries, resource concerns, and priorities until 2007.	References report by Fago (1996) that documented 93 species of fish in St. Croix Basin.	Resource management plan. Some proposed actions outside of SACN boundaries will possibly impact resources inside SACN. Population management through stocking, for example.
Benike and Michalek	2001	Lower St Croix River baseline monitoring – fisheries inventory	Lower St Croix River. Field seasons, 1999-2000.	–	Collected 64 fish species. Documented 14 new species. 6 species collected in 1980s surveys were not observed. 10 of the 64 species collected are listed on state endangered, threatened or special concern list. Index of Biotic Integrity sampling indicates lower St. Croix fish community is in excellent condition.	Authors attribute fish community health to the fact that dams have not fragmented the lower St. Croix and nearshore habitat degradation is minimal. Non-native species are present, but there is no discussion on their potential impacts to native species.
Hove et al.	2000	Determine host fishes for winged mapleleaf (*Quadrula fragosa*)	St. Croix River. April-October 1997-1998	Collected fish and glochidia to identify key life history information needed for effective conservation management. Determined gravid period for adult mussels prior to project to secure glochidia for lab infestation of fish. Laboratory artificial glochidia infestation of fish; plan to collect likely host fish in wild DNA extraction and amplification for glochidia identification	16 of 19 infested fish sloughed the glochidia in 2-3 weeks. Glochidia grew on yellow and black bullhead, slender madtom, and channel catfish. Growth appears better on larger fish and less sloughing occurred.	Progress report. Good guidance for traditional fisheries managers that might be considering multi-species or ecosystem approach to management.
Niemela and	2000	Index of biotic integrity	St. Croix Basin:	Provides guidance and methodologies for	Most metrics in IBI were significantly correlated with	Could provide repeatable methodology for

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Feist		(IBI) guidance for coolwater rivers and streams of the St. Croix River basin in Minnesota	Minnesota waters.	sampling, metrics such as species richness, trophic composition and reproductive function, abundance and condition. Scoring criteria are given for drainage areas <20 mi^2, 20 – 54 mi^2 , 55-270 mi^2, and > 270 mi^2. Provides a list of IBI scores for over 100 sampling sites throughout the basin	disturbance. Found no significant redundancies between metrics in small or moderate sized streams, but a few metrics were correlated with each other in very small streams (< 20 mi^2,) IBI scores in very small streams were correlated with watershed disturbance, but least and most disturbed sites were not significantly different from each other. Also found that some streams scored much lower than would be expected even though watershed disturbance was low. Concluded that some watersheds with unique features may need to be separated into a distinct class and a new IBI developed for this type of stream	determining changes over time. Could be applied to entire basin, but additional effort may be necessary to classify unique watersheds as mentioned by authors.
Goldstein et al.	1999	Development of a stream habitat index for use with an Index of Biotic Integrity in the St. Croix River Basin, Minnesota	St. Croix River Basin: Minnesota waters, 70 streams. Summer low flow conditions, 1996-1998.	Streams sampled represented varying sizes and characters. Fish captured by electrofishing. Habitat qualities assessed (13-15 transects per stream). 5 groups of habitat variables addressed: hydrology, geomorphology, instream habitat, substrate, and riparian zone/land use. Data collected at one of 3 levels of scale (basin, segment and reach). 3 data sets developed for index development, verification and testing. Number of variables reduced using PCA; stepwise multiple regression used to determine which habitat variables best explained the fish community data Concurrence analysis with PCA conducted.	Habitat variables that best described physical habitat were mostly substrate-related and geomorphologic. Core variables accounting for IBI scores were drainage area, number of pools, wetlands within 100 m. Core variables accounting for species richness were drainage area, number of pools, % woody debris and wetlands within 100 m. Neither of these models accurately predicted IBI scores or richness on a test data set.	Habitat variables/index could not be used to effectively predict fish community data in terms of IBI or species richness.
Ferrin et al.	1999	Fisheries management plan for the Namekagon and St. Croix Rivers	Various: through much of watershed within NPS boundaries	Coordination between NPS, Minnesota and Wisconsin Departments of Natural Resources to manage fisheries resources. Describes issue areas, biological and habitat, human intervention, water quality. Divides into various zones based on water type: warmwater riverine, impoundments, coldwater riverine, and tributaries.	Describes 5 goals of plan: · Maintain or restore integrity of near-natural riverine plant, fish and wildlife communities · Maintain, restore, and evaluate habitat to provide sustainable fisheries · Manage river corridor to restore or maintain a climax riparian vegetative cover. · Develop a fish management strategy that places primary emphasis on habitat protection over promotion and development of recreational uses. · Fish habitat restoration activities will focus on correcting detrimental, human induced habitat alterations, mimic or use natural processes and features, and be applied to accelerate well studied recovery needs.	Extensive fish management plan provides suite of recommendations. A good example of coordinated effort between several agencies/entities concerned with fish management. Plan implementation identifies several projects to help reach objectives of plan.
Holmberg et al.	1997	Water resources management plan for St. Croix National Scenic Riverway	–	–	Fisheries section includes valuable information from other documents including number of species, state of Wisconsin and Minnesota endangered or threatened species, and IBI classifications.	General planning document. Only includes a couple of pages in fisheries section, but useful as a quick reference for general habitat information. and fish species list.

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Sewell and Morse	1998	A creel survey of the St. Croix River (Minnesota/Wisconsin border to Taylor's Falls)	St. Croix River: Hwy 35 bridge to Northern States Power dam. May 3-October 31, 1997,	Creel survey sampled anglers and recreational users. Used aerial surveys to determine fishing and recreational pressure and two creel clerks to determine catch information. Interviews were conducted at accesses on river. Creel clerks were from Minnesota and Wisconsin Departments of Natural Resources and conducted surveys on corresponding banks of river. Airplane pilot was from Minnesota Department of Natural Resources.	Total fishing pressure estimated at 74,854 hours. Monthly total pressure was similar for May through August with slight decrease in July. Pressure decreased substantially in September/October. Boat anglers accounted for 79% of total fishing pressure, with 21% from bank anglers. Fishing accounted for 1/3 of recreational use of Upper St. Croix in 1997. Canoeing was most popular activity at 105,797 total hours. In Area 3 (Sunrise River to the NSP dam) houseboating was almost as popular as canoeing. 60%of angling parties were targeting at least one fish species. Smallmouth bass was most common species targeted; 40.3% of anglers sought smallmouth either alone or in combination with another species. Walleye and channel catfish were the next two most sought species with 35.3% and 12.2% of anglers targeting these fish, respectively. Anglers caught an estimated 44,710 fish. The most commonly caught species were smallmouth bass at 21,554, and walleye at 9,465. Caught 19 species, but only 12 were harvested. Although more smallmouth bass were caught, more walleye were harvested. A total of 4,648 fish were harvested, resulting in a release rate of nearly 90%.	Minnesota Department of Natural Resources completion report. A good report for both park and fisheries managers to refer to for decisions regarding fishing and recreation. Authors did not provide specific recommendations based on results of survey, but there is a lot of useful information, including some on recreational use beyond angling. This type of survey should be conducted every 5-10 years, especially since fishing pressure will likely increase as the populations in the metropolitan areas of Minneapolis and St. Paul continue to grow.
Hove	1997	Ictalurids serve as suitable hosts for the purple wartyback	St Croix River: Minnesota waters. 1996.	Obtained glochidia from gravid female *Cyclonaias tuberculata* and exposed to channel catfish, flathead catfish, black bullhead	Channel catfish appeared to be superior host, however size of channel catfish was much greater than other species. First documentation of flathead catfish and black bullhead identified as suitable hosts. 3 previous attempts with black bullhead indicated they were not suitable hosts	–
Hove and Kapuscinski	1997	Determination of fish host requirements of three rare Minnesota mussels – Phase II Report	St. Croix River: near Interstate Park 1996.	Determined suitable fish host: fish considered suitable host when glochidia encystment and metamorphosis to juvenile stage occurred. Determine natural infestation: mussel tissue samples collected from 22 species for genetic marker determination for future identification of glochidia from wild fish.	*Cumberlandia monodonta*, *Tritogonia verrucosa*, *Epioblasma triquetra*, and *Cyclonaias tuberculata* glochidia tested for host use. 25 fish and mudpuppy species tested as hosts. No species facilitated glochidia metamorph for *C monodonta*. Yellow bullheads facilitated *T. verrucosa*. Some glochidia growth observed of *T verrucosa* on black bullhead and creek chubs. Logperch and blackside darters served as hosts for *E. triquetra*. Four ictalurids suitable hosts for *C. tuberculata*. *V. ellipsisformis* metamorphosis occurred on blackside darter.	Similar thoughts to Hove et al. (2000) for ecosystem management implications.
Hove and Kapuscinski	1996	Determination of fish host requirements of three rare Minnesota mussels – Phase I Report	St. Croix River: near Interstate Park 1996.	Determined suitable fish host – Fish considered suitable host when glochidia encystment and metamorphosis to juvenile stage occurred. Determine natural infestation – mussel tissue samples collected from 22 species for genetic marker determination for future identification of glochidia from wild fish.	(See Hove and Kapuscinski 1997.)	(See Hove and Kapuscinski 1997.)
Wisconsin	1994	Effects of flow regulation	Middle St. Croix and	Preliminary surveys to determine needed	Collected 26 species representing 7 families of fish in	Not clear if further surveys conducted in 1996 as

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
Department of Natural Resources		and restriction of passage due to hydroelectric project operation on the structure of fish and invertebrate communities in Wisconsin's large river systems	Middle Chippewa Rivers. July-August 1995	sampling effort for 1996 surveys. Mapped aquatic habitat types: · Main channel pools, riffles/rapids, and runs. · Backwaters and tributary mouths. · Side or secondary channels with substantial permanent flow. Established one mile long fish sampling station on each river. Used grid electrofishing to sample fish, but could not effectively sample deep water areas.	St Croix site; and 16 species in 7 families in Chippewa River.	mentioned in document. Comparisons between years would provide more useful information than preliminary investigations of 1995.
Fago and Hatch	1993	Aquatic resources of the St. Croix River Basin, Biological Report No. 19	Entire St. Croix Basin	Broad resources investigation: fisheries component includes reviews of several documents to determine species assemblages and distribution.	Includes list of all species found in basin, listed by major subbasins from 1889 to 1990. Also includes historic species that have not been collected after 1974.	One of the few documents that summarizes some information on non-game species such as southern brook lamprey and crystal darter. (See additional review under biology and ecology category.)
Pratt	1993	Lake Hayward hydro-relicensing fishery survey, 1991	Lake Hayward and tailwater area. Fyke net samples: 21 sites in April. Boomshocking samples: 2 nights, late April; 2 mid May; 1 early October. Seine net samples: 20 stations mid-August. Creel survey: May-October 1991.	Objectives: · Quantify game fish. · Update distribution and relative abundance for other species. · Determine angler use and catch statistics. · Determine status of fishery and fish pops with special reference to effects of dam and operating regime. · Formulate fish management recommendations for inclusion in FERC license and/or long range management plans. Primarily gamefish populations; some information on non-gamefish, such as catostomids and moxostomids.	Lake Hayward gamefish dominated by northern pike and largemouth bass; lesser populations of stocked walleye and muskellunge. Bluegill, yellow perch, black bullhead dominate panfish community. Non-gamefish community biomass-dominated by large catostomids and moxostomids and number-dominated by small cyprinids and percids. Tailwater provides warmwater, coolwater and coldwater species. Brown and rainbow trout stocked below dam. Management recommendations include walleye stocking, minimum flow designation and habitat modification for spillway channel	States that dam and operation do not appear to have impact on fishery. No indication if results obtained were compared to undammed streams to support this assertion.
Damman	1993	Upper St Croix Basin sturgeon management report.	St. Croix River: from Hwy 70 downstream 2.5 miles to mouth of Wood River, and Pansy Landing downstream to Danbury 1991.	Stations were selected because these areas had largest concentrations of sturgeon during 1959 surveys. Used combination of AC and DC electroshockers to captured fish. Fish > 29 in were given a metal numbered dorsal tag. Compared Minnesota and Wisconsin surveys of 1988, 89 and current survey with information from 1959.	Indicated 50 to 98% reduction in sturgeon electrofishing catch per effort compared to 1959 data. Dams may have affected populations, but juveniles were abundant 30 or more years after dams were in place. Suggested past overharvest as probable cause for declines. One large fish captured in electrofishing surveys was reported caught and released by an angler one year later, 60 miles downstream from original capture. Indicated that 1959 surveys captured mostly immature fish with only 10% over 25 in, whereas 54% were > 25 in during current surveys.	Author's recommendations: · Close all sturgeon fishing in Upper St. Croix boundary waters and tributaries up to first dam. · Reintroduce sturgeon above Trego dam. · Closure of Namekagan River above Trego Dam to Hayward dam or perhaps entire river. · Closure of St Croix and tributaries should continue until population has recovered and regulatory plan agreed to by both states.
Pratt	1992	Evaluation Report – protected length interval, Namekagon River, Sawyer county	Namekagon River: 6.6 mile section of regulated stream in Sawyer Co. 1983. Follow up 1984-1986.	Population estimate and creel survey in 1981 led to 10-15 inch slot limit and artificial bait only protections for trout. 6.6 mi Lenroot treatment zone, with special regulations. 4.4 mi Phipps control zone, with standard regulations.	New regulations attracted and redistributed fishing pressure. Effort increased 40% in treatment zone and declined 28% in control area Non-compliance criteria were met with only 2% of total harvest comprised of slot size trout; which was in violation of regulations. Overall catch and harvest rates declined. Catch and release effort increased. Recruitment declined in both zones.	Mortality rate on caught and released fish should be determined. Not clear if increased effort in treatment zone was required to catch harvestable fish outside slot limit, and thereby resulting in greater catch/release. Author states that regional environmental conditions, especially winter severity resulted in decreased recruitment in both zones Other causes should be investigated.

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McComas	1990	Trego flowage fish survey, 1990	April-May 1990.	Fyke net sampling in flowage, backpack shocking in flowage and tailwater. Standard fishery survey techniques to determine population status for several species.	Improvements in walleye, muskellunge, smallmouth bass, yellow perch and black crappie compared to last Wisconsin Department of Natural Resources survey in 1983. Largemouth bass and bluegill community have declined.	Only summary of report available for review. Basis for comparison not clear from graphed data. Assuming certain species populations may have improved based on one year survey in April and May is asking a lot from information collected.
Montz et al.	1989	Biological survey of the St. Croix River	Stream survey. Summer, 1988-1989.	Surveyed same sections as Kuehn et al. (1959) plus 3 additional sections. Included physical characteristics, vegetation, wildlife characteristics, fisheries and aquatic macro-invertebrates. Used single, timed electrofishing pass to collect fish. Sampled 43 stations totaling 38.8 miles of river in 9 study sectors.	Captured 68 species representing 15 families of fish. Provides some statistics such as weight and catch per effort for some but not all species.	Draft report. Although macroinvertebrates were part of survey, these results aren't in the copy available for review. Recommendations section is also missing.
Simon	1988	Biological Survey – Instream fish water quality evaluation, St Croix River drainage, Burnett County, Wisconsin	Burnett County sections of Loon Creek, Yellow River and St. Croix River, 6 stations. July 5-8, 1988.	Completed 5 of 6 criteria developed by the Ohio EPA for a Quality Habitat Evaluation Index (QHEI). Scoring incorporates substrate quality, instream cover, channel morphology, riparian zone and bank erosion, and pool and riffle quality based on drainage area. Used 12 IBI metrics for fisheries evaluations. Collected fish with 50-foot bag seine. Objectives were: · Evaluate utility of instream biological surveys to characterize overall water quality. · Find appropriate tool to allow states and tribes to meet section 304 toxic list requirements of Water Quality Act of 1987. · Demonstrate potential use of rapid assessment techniques for fish as screening tools for toxic and conventional pollutants. · Collect baseline information for St. Croix Chippewa Indians for proposed salmonid hatchery on St. Croix River.	IBI rating of excellent for one of the Yellow River stations and between excellent and good at all other stations.	Author suggested that proposed salmonid hatchery for Loon Creek location should have negligible impacts on the St Croix River due to the dilution factor. Assume this means dilution of outflow volume from hatchery into main St Croix River. However, there is no mention found in document of which salmonid species, little discussion on what type of production is proposed from hatchery, and no discussion on what competitive impacts there may be if hatchery produces fish to be released into St. Croix system.
Waller and Holland-Bartels	1988	Fish hosts for glochidia of the endangered freshwater mussel *Lampsilis higginsii* Lea (Bivalvia: Unionidae)	Mississippi River: near Prairie du Chien, WI. June 1988.	Exposed 9 species of fish to glochidia	Largemouth bass, smallmouth bass, walleye, and yellow perch all considered fully suitable hosts. Some development on green sunfish. Bluegill and northern pike considered marginal hosts. Common carp and fathead minnow sloughed all glochidia within 48 hours of infestation.	As with other mussel and fish host investigations, this research has implications for management of both fish and mussels as well as riverine habitat protection. Results of study pertinent to other areas, such as St. Croix and other rivers in the region.
Cochran	1987	The southern brook lamprey (*Ichthyomyzon gagei*) in the St. Croix River drainage of Wisconsin and Minnesota	Namekagon River: native lamprey collections. May 1982.	Morphological comparison of brook lampreys	Describes form of brook lamprey that is morphologically indistinguishable from southern brook lamprey that has previously only been described in southern Missouri. Theorizes that this could also be independently evolved satellite of *I. castaneus*, the brook lamprey.	Only first page of available for review. Description of native lampreys is critical since these species in Great Lakes systems are being greatly impacted by treatments for sea lamprey.
Fausch	1987	Development and use of the index of biotic integrity to monitor fish communities in the St. Croix National Scenic	St. Croix River; 38 sites. Namekagon River: 18 sites.	Modified original methodology using 12 attributes of stream fish communities to include more appropriate attributes for St. Croix drainage. Used past references to compile list of species present in study area.	IBI scores for sites along Namekagon River generally declined in an upstream direction but dams along this reach didn't' appear to be the cause.	Author recommended establishing permanent fish sampling stations for long-term monitoring that might provide useful information regarding impacts from potential perturbations such as sewage treatment plant activity, proposed peat mining sites, and

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		Riverway				cranberry bog activities. Determine if permanent monitoring were stations established; and if impacts of potential perturbations listed above were monitored over time.
Hatch	1986	Comparative growth, reproduction, habitat and food utilization of darters of the St. Croix River drainage.	St Croix drainage upstream of the St Croix Dalles.	–	–	Only incomplete document found for review; limited to introduction page and page of reproduction timing information.
Johannes	1984	Evaluation of walleye recruitment, muskellunge fingerling survival and general update of Trego Flowage fish population – Washburn County, 1983.	Namekagon River, Trego Flowage. March, April, September 1983.	Objectives: · Fish community information and update of species list. · Relative abundance of species present · Collect age and growth information with scale samples. · Determine natural recruitment status of walleye. · Evaluate correlation of Catostomidae (sucker) population density in relation to muskellunge growth rates. · Determine behavior and survival of stocked radio tagged muskellunge fingerlings. · Determine habitat characteristics of muskellunge fingerling. Used fyke nets and boom shocking to collect fish. Radio tagged 13 muskellunge fingerlings in group of 900 fish that were stocked on September 21, 1983. Monitored closely for first 96 hrs, then 1 to 2 times daily until October 25, 1983.	Collected 24 species. Provided length frequency measurements for game and panfish. Walleye growth was relatively slow. Walleye fingerling production appeared to be non-existent according to fall electrofishing surveys. Only one confirmed natural walleye fingerling was captured in two nights of boom shocking. Natural recruitment of muskellunge also appeared to be non-existent. Survival of stocked muskellunge was approximately 77% based on tracking of tagged fish. Most fish found cover under nearby docks and did not move far shortly after stocking, but dispersed along shoreline after initial resting period. Shoreline cover from downed trees was frequently used as cover, and only a few fish crossed deeper open water of reservoir. Abundance and quality of resident bluegill population was considered one of the real "bright spots" of the Trego fish community. Growth rates are well above average for northwest Wisconsin.	Author provides several management recommendations and indicates that natural production of all species except walleye and muskellunge is currently adequate. Public access to flowage is currently adequate for angler access and no alteration of current fishing regulations was recommended. Basis for growth rate comparison was not clear.
Pratt	1982	Comprehensive trout fishery survey, Namekagon River, Sawyer County, 1981-1982	Sawyer County sections of Namekagon River: Non-trout section, 0.4 mi downstream of Lake Hayward; Hayward section, 4.4 mi Phipps flowage to Lake Hayward; Lenroot section, 6.6 mi Pacwawong to US Hwy 63. July-August, 1981.	Objectives: · Determine need and effectiveness of trout stocking. · Determine status of wild trout and natural production. · Monitor fishing pressure. · Evaluate quantitative and qualitative differences in trout populations on Hayward vs. Lenroot sections. · Evaluate trout potential of "non-trout" waters and review Class II status of river above Lake Hayward. · Evaluate trout food base; abundance, and distribution of aquatic invertebrates. · Determine relative abundance and distribution of non-salmonids. Electrofishing used to capture fish. Mark and recapture used for population estimates. Aquatic invertebrates sampled biweekly from 10 stations throughout summer.	Past and current surveys indicate 44 species of fish present Trout, not identified to species, made up 12% of total fish population by number and 15% by weight in DeLury station which is likely representative of mainstem Namekagon as a whole. Determined that trout fishery is under utilized compared to estimated capacity of fishery to sustain certain amount of fishing pressure. Brown and rainbow trout only salmonid species reported in creel. Growth rates were well above statewide average. Mortality estimates were considered excellent for this region. Natural production of trout appears to be very good, but stocked trout fared poorly in 1981.	Several management recommendations provided by author related to trout stocking, fishing regulations, monitoring strategies and habitat management. Some recommendations are contradictory to NPS policy. An update of status of the fisheries here, in light of policy differences would be useful.

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				A creel survey was conducted 5 days per week throughout entire trout season which included 99 of the 152 day season.		
Johannes	1980	Lake sturgeon tagging study along the Upper St. Croix, Clam, Namekagon, and Yellow Rivers, 1960-1976.	Namekagon River: Trego Dam downstream 30 mi to confluence with St. Croix, and from confluence downstream 82 mi to Indianhead Flowage.	Fish captured by electrofishing in 1960 and 1961; marked with dorsal fin tags to be returned by anglers.	Anglers returned 21 tags, 19 of which were originally tagged in the Namekagon River, 1 in the Yellow River, and 1 in the Clam River. All fish, except 1 captured in the Namekagon, had been captured in the St. Croix River. 1 fish was captured 9 years later 112 miles downstream. Longest period between tagging and recapture was 15 years, 2 months.	Originally number of tagged fish not reported. Author determined population is self sustaining based on age classes present. Pressure from harvest appears to be low Suggested preservation of habitat is most important factor in maintaining conditions suitable for reproduction survival and growth of sturgeon. Update of information would be valuable.
Rieckhoff	1977	Namekagon Lake survey, Bayfield County	1976	27 nights of boom shocking 7 seine hauls 14 fyke net lifts 4 gill net lifts Voluntary creel survey and aerial boat count.	Provides brief stocking history and present fish resources. Number, size range, and catch per effort provided for 25 species collected.	Brief two page report with limited information, but useful for species assemblage information
Peterson	1964	Distribution and relative abundance of fishes in the St. Croix River impoundment at Taylors Falls, from 1959 to 1963.	Reservoir at Taylors Falls. October,1961, May, July, September 1963	Used gill nets, seine nets and electrofishing to sample fish.	Production appeared to decrease in walleye from 1959 to 1963. Bluegill and crappie production appeared to increase from 1959 to 1963, based on captures. Walleye that were stocked in 1962 were "not present in any detectable numbers" in 1963, that is, none were captured. Also gives some information on distribution of YOY and adult fish.	Focus of survey appears to have been to determine success of walleye stocking effort. Assumed that larger sport fish either move out of impoundment , do not survive there, or populations are low enough to be undetectable.
AMPHIBIANS AND REPTILES						
DonnerWright et al.	1999	Responses of turtle assemblage to environmental gradients in the St. Croix River in Minnesota and Wisconsin, USA	St. Croix River: 12 1.6-km study reaches. June-August 1994, 1995.	Equal numbers of traps were set at even intervals at each site and baited every other day. Captured turtles were aged, sexed, weighed, measured, marked and released. Habitat characteristics were measured along 5 transects in August 1995: mean and maximum water depth, water level variation, channel width, bank slope, velocity, bottom substrate, open sand banks/bars, number of basking locations, and latitude.	Documented 7 species; 5 were generalists with wide distributions. Most of the variation in species abundance was accounted for by channel morphology and physical characteristics. Common snapping, false map, and painted turtles were associated with muck substrates and number of basking sites, which increased downstream. Spiny softshell turtles were related to higher water velocity and depth. Common map turtles were associated with open sandy areas, uniform channel bottoms and gravel.	Author notes that "geomorphic changes along the river influence the turtle assemblage and should be considered in efforts to preserve and restore components of this assemblage." Habitat characterization along the Riverway provides useful information for future studies.
DonnerWright	1996	1994 Field Season Summary	Interstate Park, Wild River State Park, Afton State Park, Pine Needles, County O, Marine Ferry Landing, Old River Road, Science Museum. 1994.	Time search, pitfall and turtle trapping used to document herptiles. Upland, lowland and open sites included.	Interstate Park: Blue-spotted, redback and spotted salamander, wood frog, spring peeper and American toad (many), garter snake. Wild River State Park: Wood frog, spring peeper, American toad, western hognose snake. Afton State Park: American toad, garter snake, fox snake. Pine Needles: Wood, leopard, and green frog, American toad. County O: Wood frog, American toad, redback salamander. Marine Ferry Landing: Blue-spotted and redback salamander, wood, leopard, and green frog, spring	Letter report summarizing field season; data appended, but not analyzed.

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					peeper, American toad. Old River Road: Blue-spotted salamander, central newt, wood, leopard, green and chorus frogs, American toad. Science Museum: American toad, prairie skink, garter snake. Turtles caught: Common map, common snapping, spiny softshell, Blanding's, wood, and western painted turtles Blanding's and wood turtles are state threatened.	
DonnerWright	1994	1993 Field Season Summary	Pitfall traps: Marine Ferry Landing; Dunn's Cabin. Time searches: Afton State Park and Wild River State Park. Turtle traps: North of Hwy 70, Wild River State Park vicinity, south of Osceola bridge, Apple River confluence. 1993.	Pitfall trapping: Mid-April to May 4, and August 30 to mid-September. Time searches: Conducted in spring in upland habitats (April 14-May 4) and fall in upland, lowland, and open land habitats (August 30-September 17). Turtle trapping: Conducted from July 5 to August 23.	Pitfall traps: 9 species captured; blue-spotted salamanders, American toads and wood frogs most common. Time searches: 2 species found in spring (eastern garter snake and gray treefrog), and 6 species found in fall (American toads, spring peepers, leopard, wood, and green frogs, and bullsnakes). Turtle traps: 123 turtles captured, about half of which were captured at Osceola site; 5 species caught: snapping (n=56), spiny softshell (n=32), common map, false map, and painted. The record for the false map turtle extends its northern range to Chisago and Polk Counties.	–
Savage	1993	Wood turtle survey in Washburn and Burnett Counties	Namekagon River: 24 mi reach. May 1993.	On-the-water survey with 7-member team of NPS and Wisconsin Department of Natural Resources personnel.	Wood, map, spiny softshell, painted, and snapping turtles identified. Spiny softshell and painted turtles were most common.	This is a correspondence memorandum summarizing field effort.
Probst et al.	1991	Landscape ecology of reptiles and amphibians of the Saint Croix River Valley	St. Croix River: lower and middle sections. 1992 .	Turtles trapped and upland search methods tested.	Two new county records for red-backed and blue-spotted salamanders noted in St. Croix County, and range extension for the false map turtle. Time-searches useful but estimates were improved by use of pitfall data. 1993 field work will include Upper St. Croix sites.	Abstract describes general approach but includes little in the way of data.
WETLANDS AND AQUATIC VEGETATION						
Konkel	2000	St. Croix River vegetation study, 1999	St. Croix River: Upper segment, 1-mi reach below St. Croix Falls. Lower segment, 1-mile reach north of Stillwater, MN..	Vegetation surveyed via rake sampling with stratified random transects and 4 depth zones. Species identified and density rating recorded; diversity calculated. Sediment type and shoreline cover recorded.	Plant growth occurred to 6-ft depth in the upper segment and to 3-ft depth in the lower segment; most plants found in the 0-1.5 ft zone. More vegetation found in upper segment. Most common substrate types were sand and gravel/rock. 18 species (14 emergent) identified. *Phalaris arundinacea* was most dense and frequently occurring in St. Croix. Poor water clarity, soft water, dominance of high-density sand and rock substrates, and fluctuating water levels and velocities may limit plant growth.	Future aquatic vegetation work on the St. Croix might explore how wave action from recreational boating affects macrophytes via water level fluctuations and increases in suspended sediments.
Barr Engineering Company	1994	Trego flowage macrophyte survey and management plan	Trego Flowage; upper third. August 1994	Surveyed 45 transects for macrophytes.	Macrophytes occurred at depths of ≤ 6 ft and were diverse. Noted 27 species, including submersed, floating leaf,	Authors evaluate several management scenarios, and recommend localized management to create open water for recreation, including harvesting, and

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					and emergent types, and the alga *Chara*. *Potamogeton crispus* was the only nonnative species.	spot treatment.
Glenn-Lewin et al.	1992	The wetlands of the Lower St. Croix National Scenic Riverway, Wisconsin and Minnesota, from Stillwater to the headwaters of the St. Croix and Namekagon Rivers	St. Croix River: Stillwater, MN, to headwaters. Summers 1987, 1990.	Sites identified from aerial color photographs. Each site searched during 1987. General structure and environmental setting described, plant species identified and abundance estimated qualitatively. Each wetland assessed for quality as a natural area and for preservation.	Identified total of 183 potential sites. Total of 49 wetlands inventoried. Identified 328 total plant taxa. No evidence of general disturbance or sedimentation. Cluster analysis identified 11 vegetation types; the primary division separated wetlands that were hydrologically dependent vs. independent of the St. Croix River. DCA showed this same separation. 10 wetland types ultimately identified: flowing deep river marsh, exposed banks and mudflats, still deep river marsh, fluctuating marsh, fluctuating marsh/shrub carr, deep basin marsh, flowage marsh/woodland, hydric mature woodland, hydric semi-woodland, and wet/mesic woodland.	Study builds on previous work (Glenn-Lewin 1988, Glenn-Lewin et al. 1991) and identifies additional categories of wetlands. Changes in flow regimes would likely affect wetlands in close contact with river, particularly flowing water, banks and mudflat types and permanently flowing submerged types.
Glenn-Lewin et al.	1991	The wetlands of the Lower St. Croix National Scenic Riverway, Wisconsin and Minnesota, from Stillwater to Steven's Creek	St. Croix River: Stillwater, MN, to Steven's Creek. Summers 1987, 1990.	Sites identified from aerial color photographs. Each site searched during 1987. General structure and environmental setting described, plant species identified and abundance estimated qualitatively. Each wetland assessed for quality as a natural area and for preservation.	Identified 26 additional potential wetland sites, 15 visited. Total number of vascular plant species identified reached 244, of which 147 were from 1987. No evidence of general disturbance or sedimentation. Cluster analysis identified 6 vegetation types with combined 1987 and 1990 data: permanently flowing, banks/mudflats, still water, marshes with fluctuating water levels, marshes with consistently deep water, and wetlands with strong woody component. DCA showed similar patterns with flowing vs. still water, and a longitudinal pattern interacting with hydrology. Each type described.	Study builds on previous work (Glenn-Lewin 1988) and identifies some useful categories of wetlands. Future monitoring programs might include representative sites from the different wetland types, or should identify particularly sensitive wetland types and focus on these. Changes in flow regimes would likely affect wetlands in close contact with river, particularly flowing water, banks and mudflat types and permanently flowing submerged types.
Glenn-Lewin	1988	The wetlands of the Lower St. Croix National Scenic Riverway, Wisconsin and Minnesota, from Stillwater to Never's Dam	St. Croix River: Nevers Dam above St. Croix Falls to Stillwater, MN. Summer 1987.	Sites identified from aerial color photographs. Each site searched during 1987. General structure and environmental setting described, plant species identified and abundance estimated qualitatively. Each wetland assessed for quality as a natural area and for preservation.	Identified 22 potential wetland sites. Identified 147 vascular plant species. No evidence of general disturbance or sedimentation. Cluster analysis identified 4 vegetation types: flowing water types (mostly submerged vs. banks and exposed mudflats), still water types, and riparian/shrub carr types. DCA showed similar patterns, with the flowing water wetlands sharply distinguished from the still water and shrub carr types. Each type described.	–
CONTAMINANTS						
Payne and Hansen	2003	Reconnaissance of mercury and methylmercury in the St. Croix River and selected tributaries, Minnesota and	St. Croix River: 6 mainstem, 16 tributary sites. July 2000-October 2001.	Water samples collected from surface water at each site, once during summer low flows in 2000. Namekagon River at Leonards sampled 6 times May-October to examine seasonal variability and	Total and methylmercury increased between Nevers Dam and Franconia on the St. Croix mainstem and were highest in July on the Namekagon river. Methylmercury yields greater in Namekagon River and Rush Creek than for other tributary streams, and	Study provides a synoptic look at SACN mercury conditions and suggests that land use and land cover influence stream mercury loads. Upcoming fish mercury study in SACN will help clarify biological implications of this work.

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		Wisconsin, July 2000 through October 2001		relationships with stream flow. Total and methylmercury and total organic carbon analyzed, along with basic water quality parameters.	generally greater in tributaries draining wetland/forest watersheds vs. tributaries draining agricultural/forested watersheds.	
Brigham	2002	Elemental chemistry of streambed sediments of the St. Croix River Basin, 2000	St. Croix Basin: 30 sites, 18 of these on tributaries. June-August 2000.	Streambed sediments collected upstream and downstream of the larger cities in basin. Concentrations of trace elements measured and compared to criteria and guidelines.	Abundance of aluminosilicate clay materials correlated well with most trace metals concentrations, indicating geological sources are most likely. Trace metals low relative to urbanized streams. No basin-wide pattern of increased trace element concentrations downstream of cities. Effects Range Median values not exceeded in any samples, although As and Hg exceeded Probable Effects Concentrations at 7 sites and 1 site, respectively.	No large anthropogenic contributions of trace elements apparent in St. Croix basin.
Lee et al.	2000	Use of biological characteristics of common carp (*Cyprinus carpio*) to indicate exposure to hormonally active agents in selected Minnesota streams, 1999	Minnesota streams and rivers: 22 sites near WWTP sites. Mississippi River, St. Paul; St. Croix River, above and below Stillwater, MN. Summer 1999.	Paired sites selected upstream and downstream of WWTP discharges, including the Metropolitan WWTP in St. Paul. Collected >400 carp upstream and downstream by electrofishing. Four biological characteristics considered as potential indicators of hormonally active agents: · Concentrations of vitellogenin in male versus female fish. · Concentrations of sex steroid hormones. Gonado-somatic index. · Gonad histopathology.	Measured biological characteristics indicated that WWTPs were a potential source of hormonally active agents. Biological characteristics also showed indications of hormonally active agents at upstream sites draining agricultural and forested land, possibly related to agricultural pesticides.	Authors recommend controlled studies to confirm the effects of particular chemicals on fish reproduction and population structure. Site-specific conclusions difficult to draw from the data as presented. (See additional review under fish category.)
Stewart and Butcher	1999	The effects of cranberry operations on water quality, macroinvertebrate communities and pesticide concentrations of the St. Croix National Scenic Riverway	Namekagon and St. Croix Rivers: 4 reaches; Springbrook, Gordon, Seeley and Howell. Spring/Fall 1996.	Sites located upstream and downstream of cranberry operations. <u>Water chemistry</u>: Temperature, dissolved oxygen, pH, specific conductance, turbidity, alkalinity, hardness, nitrate, ammonia and total phosphate. <u>Benthic invertebrates</u>: Hester-Dendy samplers, in triplicate at each site. Analyzed for species composition, functional groups, diversity and EPT indices, rapid assessment, and cluster analysis. <u>Pesticides</u>: Sediments sampled and analyzed.	<u>Water chemistry</u>: No indication of nutrient additions from cranberry operations. Gordon site water chemistry distinct from other reaches due to more lentic conditions. <u>Benthic invertebrates</u>: 166 species found in spring, 190 in fall. No measure of diversity differed significantly upstream vs. downstream except for Howell reference reach, where in spring several indices were higher downstream. Cluster analysis showed site groupings. <u>Pesticides</u>: No pesticides found in the spring. In fall, azinphosmethyl found near Seeley output in relatively high concentrations; chlorpyrifos found at an upstream site from other source.	Substantial differences were noted among sites, but few differences were found between upstream and downstream sites. The Gordon site was distinct. Authors found no apparent effects of cranberry operation, but sampling was infrequent and detection limits were high. Azinphosmethyl was found at potentially toxic levels; sediment toxicity is unknown. Determine if more toxicology work has been done with this chemical since then. Authors recommend invertebrate monitoring and toxicity tests with target pesticides.
HYDROLOGY:						
Mitton	2002	Flooding in the Mississippi River Basin in Minnesota, Spring 2001	Mississippi River Basin: 44 gages, including sites in MISS and SACN. 2001.	Peak stages and discharges were recorded and reviewed for these 44 gage sites.	Record flows were recorded at 9 gaging stations, with14 stations recording second or third highest peaks. Previous high water events were also reported for stations with at least 20 years of record. Mississippi River at St. Paul and St. Croix River at St. Croix Falls recorded 50-100 year floods in 2001.	–
Schoenberg and Mitton	1990	Monthly mean discharge at and between selected	Mississippi and St. Croix Rivers: 10	Long-term flow records were used to calculate monthly mean discharges at gaging stations.	Monthly mean discharges were reported for each site by year and month.	–

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		streamflow-gaging stations along the Mississippi, Minnesota and St. Croix Rivers, 1932-1987	gaging stations, including sites in MISS and SACN. 1903-1987.	Differences in monthly mean discharge between selected upstream and downstream stream gaging stations were calculated.		
Groundwater						
Metropolitan Council	2004	Water demand and planning in the Twin Cities Metropolitan Area	Twin Cities Metropolitan Area	Report analyzes water demand and water supply planning for the metropolitan area.	Reported 292 million gallons/day (mgd) of water used for municipal supply, plus 871 mgd for power generation and other uses. Groundwater is primary source for 1.6 million municipal users and 230,000 well water users; Mississippi River supplies 870,000 users. No correlation found between residential per capita water use and lot size, household income or price of water. Limitations in the region's groundwater supply include lack of access to Prairie du Chien-Jordan aquifer and adverse impacts of withdrawals and contamination.	Coordinated, comprehensive region-wide water supply planning program needed to ensure long-term availability and viability of the water supply. Related groundwater supply and contamination issues may be of interest to MISS.
Ruhl et al.	2002	Estimates of recharge to unconfined aquifers and leakage to confined aquifers in the seven-county Metropolitan area of Minneapolis-St. Paul, Minnesota	Twin Cities Metropolitan Area: 7 counties, MISS, SACN.	Objective was to assist water managers in the Twin Cities metropolitan area with issues related to long-term groundwater depletion. Recharge to unconfined aquifers was estimated by five methods. Leakage estimated by two methods.	Recharge estimates varied within 10 inches/year among methods. Leakage, which was less than 1 inch/year, varied widely within 1-4 orders of magnitude.	Authors note that impervious land areas in metropolitan areas have little or no recharge potential, whereas surficial sand and gravel areas (e.g. Washington County near St. Croix River) have great recharge potential. Authors provide a comparison of different methods of estimation for recharge and leakage.
Norvitch et al.	1973	Water resources outlook for the Minneapolis-St. Paul Metropolitan Area, Minnesota	TCMA, including MISS, SACN.	Purposes: · Describe physical occurrence and operation of the hydrologic system affecting the TCMA area. · Establish a hydrologic baseline. · Identify future research needs. · Estimate the maximum water withdrawal the system can withstand before mining groundwater occurs.	General geohydrology and hydrology described. Surface water resources of the Twin Cities area not sufficient to meet all needs during a severe drought. Groundwater available from 6 aquifer systems – about 75% from the Prairie du Chien group. Industry used greatest amount of groundwater (43%), followed by domestic, commercial, irrigation and other uses. Groundwater withdrawal from closely spaced wells causes cones of depression in summer. Groundwater withdrawal >375 mgd would exceed recharge. Potential locations identified for well fields.	Authors recommend future studies that focus on data collection, geohydrologic mapping, hydraulic characteristics of subsurface geohydrologic units, hydrology of lakes, and hydrologic systems monitoring. They conclude that "groundwater sources alone could be developed to provide for the increasing water needs of the metro area for at least the next 30 years."
Physical Structure and Processes						
Griffin et al.	2000	Quantitative shoreline studies	Lower St. Croix River: 14 sites; above Stillwater, MN, to Soo Line swing bridge. Summer and fall, 1995-2000.	Twice a year surveys. Shoreline profiles surveyed to 3-ft depth. Identified 4 impact categories for sites: · No trampling or boat waves. · No trampling but boat waves., · Trampling but no waves. · Both trampling and boat waves.	Changes from erosion and deposition noted at all sites. 11 sites had net erosion, 3 had net deposition. Sites with no waves or trampling had net deposition.	Trampling and boat waves may be affecting island erosion. It is unclear whether or not these sites had different deposition patterns even in the absence of human impacts; this confounds the conclusions.
Johnson	2000	Recreational boat use	Lower St. Croix River: Arcola to Boomsite. Summer 1999.	Air photography used to monitor boat use patterns. Air photography, flight days and starting times randomized.	8.5% of the total boating in the 52-mile Lower Riverway occurred within the study area. Density averaged 11.2 acres per moving craft, over the recommended-action point at 10 acres/craft.	–

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
Johnson	1999	Characterizing shoreline sediment mobilization using controlled runs	Lower St. Croix River: 3 sites.	Recreational boat used to generate waves in increment heights with 23 runs at 3 sites. Sediment traps, water samples and erosion pins used to quantify sediment mobilization.	Maximum wave heights, turbidity and erosion generally increased with increasing boat speed. At < 5 mph, little sediment mobilized. Maximum wave height of 0.4 ft cited as the erosive energy threshold for St. Croix sands.	Boating activity likely influences turbidity in the short term and island and shoreline erosion in the longer term.
Johnson	1999	The effects of recreational boating on shoreline sediment erosion, resuspension and deposition	Lower St. Croix River: 9 locations. Summer 1995, 1998.	Automatic samplers recorded turbidity, TSS and chlorophyll every 10 minutes on 3 peak and 3 off-peak boating days. Erosion pins were used to measure changes in surface profile.	Turbidity generally low but slightly higher on peak boating days. Erosion pin findings inconclusive. 0.4 ft wave sediment mobilization threshold confirmed. The higher the maximum wave height, the greater the amount of sediment mobilized and redeposited. Runabouts and cruisers had highest correlation to measured maximum wave height, amount of sediment mobilized and number of waves greater than 0.4 ft.	Boating-related changes in turbidity were short lived; sediment trap data provide more robust insights about boating-related effects.
Johnson	1999	The effects of wind generated waves on shoreline sediment mobilization	Lower St. Croix River: 40 stratified random sites. September 1997.	Wind direction and speed, wave height, advective flow velocity and sediment mobilization measured. Sites stratified based on wave and trampling criteria.	Winds southwesterly and above average during study, thereby having optimum fetch. Wave height and wind speed positively related but correlation low. Sediment mobilization low. Wind-generated wave heights all less than 0.4 ft; to get wind-generated waves of 0.4 ft, would need wind speeds of 36 mph at airports, which occur 1% of the year.	St. Croix River is sheltered relative to airports. Author concludes that wind-related erosion is low relative to boat-related erosion for the Lower Riverway.
Johnson	1999	Advective flow velocities and shoreline erosion	Lower St. Croix River: 40 stratified random sites. September 1997.	Profiled channel bottom and vertical flow velocity profiles over a range of flow conditions.	Velocities below critical velocity thresholds for the mean shoreline particle size. Velocities higher in the water column than in nearshore or channel bottom. Flood velocities higher and sometimes greater than the critical velocity.	Flood events may contribute to erosion.
Konkel	1999	St. Croix island vegetation study	St. Croix River: multiple sites, 1996-1998. 59 sites, 1998.	Vegetation recorded along transects running inland from shore 1996-1998. Percentage of each species and/or bare soil estimated. Transects stratified by wave and trampling criteria.	Boats and trampling, boats only, and trampling only sites were dominated by bare soil. No boats or trampling sites had lowest dominance of bare soil, more plant species and higher coverage by both perennials and annuals. Amount of bare soil at boats and trampling sites did not decrease much until 5 m from shore, compared with 1 m from shore for no boats or trampling sites.	–
Pitt et al.	1999	Geomorphic changes in the St. Croix River islands from 1969-1991	Lower St. Croix River: above Stillwater, MN, to Soo Line swing bridge.	Aerial photographs from 1969 and 1991 used to examine island morphology and recreational boating. Study focused on forest vegetation.	Forest area above Arcola Sandbar larger than below in 1969 and 1991. Forest area above the Sandbar increased 1969-1991 while below the Sandbar decreased. Number of forest polygons below the Sandbar increased and mean area decreased, becoming more fragmented below Sandbar and more agglomerated above.	Smaller sandbars appeared more susceptible to further reductions in size/area.
Ferrin et al.	1998	Qualitative assessment of the erosion condition of the islands and shoreline of the St. Croix River above	Lower St. Croix River: above Stillwater, MN, to Soo Line swing	Erosion potential and condition assessed qualitatively by two qualified observers. Results entered into GIS. Field-checked subset of sites in 1998.	Nearly 25% of the shoreline was in the moderate erosion category. Most low-erosion sites were located away from the main navigation channel.	–

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		Stillwater, Minnesota	bridge. September 1996.		Most high and moderate sites were in the main navigation channel. Maps included.	
Troelstrup et al.	1993	An examination of large woody debris accumulations in the St. Croix National Scenic Riverway	Lower St. Croix River: 7 reaches. Air photos 1977, 1983, 1989.	Selected 5 random locations within each stream reach. Snag accumulations enumerated and their location/habitat noted. Percent change in urban development along Riverway estimated with GIS.	More snag accumulation in upper reaches than lower reaches, and more in 1989 than in 1983 or 1977. Changes appeared related to channel geomorphology and urban development. Islands and sand bars collected snags. Boat traffic and snag density negatively correlated, but interaction complex.	Limitations: Changes in depth influenced ability to detect snags in deeper portions of channel, and analysis was limited to snag accumulations rather than individual snags. Increased recent snag accumulation resulting from increased urbanization and recreation are likely in the short term.

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GENERAL RESOURCE DOCUMENTS AND PLANS						
Heiman and Woller	2003	Glen Lake/Crystal River Watershed Management Plan	Glen Lake/Crystal River watershed.	Plan intended as a "framework to be used by watershed stakeholders to maintain and improve the quality of the Glen Lake/Crystal River watershed." Plan summarizes governmental jurisdictions, geology, soils, human history, land use (22% lake, 50% forest, 5% residential), groundwater recharge (constitutes 50% of water supply), fisheries, wetlands, water quality, critical areas, stressors, designated and desired uses, water quality protection goals.	<u>Fisheries</u>: Glen Lake stocked with various species since 1912; now only stocked with lake trout. Little Glen features a premier yellow perch fishery. Crystal River has a limited bass fishery, marginal anadromous fishery, and no record of stocking. <u>Wetlands</u>: Cedar swamps and other wetlands present, considerable filling occurring. <u>Water quality</u>: Glen Lake oligotrophic, some fish advisories. Crystal River nutrients relatively low, somewhat affected by sedimentation. <u>Critical areas</u>: Hatlems Creek and Crystal River dune swale complex, which support rare species and habitats. <u>Stressors</u>: Key stressors described: nutrients, exotic species, habitat loss, sediment, harmful bacteria, thermal pollution, and toxic substances.	This document presents a very accessible review of existing resources and stressors and outlines specific goals and strategies related to watershed protection. It should be referred to as SLBE identifies research and monitoring needs as well as potential partnerships.
Vana-Miller	2002	Water Resources Management Plan for Sleeping Bear Dunes National Lakeshore	SLBE, park-wide.	This document describes existing resource conditions and the water quality monitoring program, and outlines water resource planning issues and recommendations.	Specific management objectives included: maintain biological diversity and ecosystem integrity, maintain natural fluvial and lacustrine processes, ensure park operations do not adversely affect water resources, acquire sufficient knowledge to participate in state and local management and planning, and meet inventory and monitoring requirements, control or eradicate nonnative species, promote public awareness of water resource issues, provide for environmentally sensitive recreation, and evaluate external influences on upland processes that could affect SLBE water resources.	High priority needs included: a full-time water resource professional, a wetland inventory, a water quality monitoring plan, more detailed bacterial investigations, studies of Crystal River flow during drought, studies of recreational stream use, and inventory and monitoring of amphibian and reptiles. (See additional review under fish category.)
WATER QUALITY						
Whitman et al.	2003	Occurrence of *Escherichia coli* and Enterococci in *Cladophora* (Chlorophyta) in nearshore water and beach sand of Lake Michigan	10 Lake Michigan beaches, including Washington Park Beach near INDU; South Manitou Island at SLBE. June 24-November 7, 2002.	*Cladophora* sampled from water, rock pilings and beach sand. Sand and lake water collected along transects at 2 sites. *E. coli* and enterococci analyzed in lake water, *Cladophora*, and sand. Sunlight exposure and mat thickness experiments conducted *in situ*. Bacterial persistence explored using dried and rehydrated *Cladophora.*	*E. coli* in *Cladophora* high but very variable across sites. *E. coli* and enterococci strongly correlated in southern Lake Michigan beaches but not northern ones. Both *E. coli* and enterococci survived for over 6 months in sun-dried *Cladophora* mats stored at 4 °C. *Cladophora* may be an important environmental source of indicator bacteria.	Author questions usefulness of these bacteria as indicators of sewage since they appear to derive from other sources as well.
Murphy	2002	Water quality and aquatic ecology at Sleeping Bear Dunes National Lakeshore: 2002 year end review	SLBE: 14 lakes. June and July 2002.	Vertical profiles measured for temperature and dissolved oxygen. Water quality samples collected analyzed for basic parameters plus turbidity, alkalinity, hardness, sulfate, nitrate, ammonia, total phosphorus, color and chlorophyll *a.* Water quality monitored at several sites on Otter Creek due to concerns about high nitrate	Carlson TSI indicated same lake trophic statuses as in Murphy (2001). SLBE participated in The Great Secchi dip-in. Lake levels in Bass (Leelanau), Shell, and School Lakes rose during wet periods, perhaps due to groundwater influence, and Bass and School Lakes became connected via an inlet-outlet stream. Zebra mussels discovered in Platte River, Loon,	Author provides several recommendations: · Continue zebra mussel monitoring. · Complete fish inventory. · Develop stream survey program. · Map macrophyte beds in inland lakes. · Survey and map springs in Otter Creek watershed. · Ground truth SLBE wetlands. Otter Creek nitrate levels highest after heavy rains

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
				concentrations. Bacteria (*E. coli*) monitored at popular shoreline areas.	North Bar, Bass (Benzie) and Otter Lakes. Brick artificial substrates placed in each lake for monitoring zebra mussels, but not often recovered. Freshwater sponges noted in Narada Lake. 8 beaches had *E. coli* levels that would have required official closures during 2002.	and in autumn. Year-round sampling for nitrate and bacteria recommended to help determine source of high nitrate levels.
Murphy	2001	Water quality and aquatic ecology at Sleeping Bear Dunes National Lakeshore: 2000-2001 year end review	SLBE: inland lakes and rivers. Once or twice monthly, 2000-2001.	Some samples collected in conjunction with Whitman et al. (2001). Vertical profiles measured for temperature and dissolved oxygen. Water quality samples collected and analyzed for basic parameters plus turbidity, alkalinity, hardness, sulfate, nitrate, ammonia, total phosphorus, color and chlorophyll *a.* Crystal River surveyed for water quality and macroinvertebrates.	According to Carlson's TSI, Big and Little Glen Lakes are oligotrophic, Day Millpond and South Bar Lake are eutrophic, and other lakes are mesotrophic. Lake mixing characteristics described; most dimictic, some polymictic. Dr. Jerrie Nichols (USGS) began a unionid survey in 2000; School and Bass (Leelanau) Lakes had dead shells but few live clams, and Crystal River had old, large populations below the Glen Lake dam. Zebra mussels discovered in Bass (Benzie) and Otter Lakes. *Cladophora*-zebra mussel study mentioned. Glen Lake *E. coli* issues discussed. NPS "greenbelt" of higher grasses around the shoreline appeared to keep geese away and reduce *E. coli.*	Author provides several recommendations: · Continue zebra mussel monitoring. · Complete fish inventory. · Map macrophyte beds in inland lakes. · Survey and map springs in Otter Creek watershed.
Canale	1998	Sediment phosphorus content of area lakes	Platte Lake, near SLBE.	Surface sediment phosphorus concentrations measured. Phosphorus release rates under anoxic conditions calculated using the Nurnberg equation.	Water, sediment phosphorus concentrations were substantially higher in Platte Lake than in other nearby lakes. Phosphorus release rates were also higher.	Platte Lake data point was an average from 1990-1998, whereas other lakes appear to have been measured only once; this complicates comparison and interpretation.
Fuss	1998	Platte Lake Improvement Association versus the Michigan Department of Natural Resources	Platte Lake watershed and hatchery, near SLBE. 1988-1998.	Report represents a summary of the Platte River Watershed-Platte Hatchery issues. Watershed features, water quality monitoring program, watershed modeling efforts, hatchery efforts, and future efforts were all summarized, and a timeline provided.	Monitoring protocols were described for river, lake and hatchery sites. Several modeling efforts were conducted. Hatchery activities included low-phosphorus diets, reduced flow volumes, and phosphorus removal. Current state of the lake included summer marl formation.	Report was mainly intended to summarize the case and issue for the new Court Master. Author noted a need to study the lower weir, continue to watch-dog the monitoring efforts, review the Walker (1998) report, remain current on the lake association's efforts to contest the NPDES permit, and investigate increasing P loads in the Platte River.
Walker	1998	Evaluation of alternative phosphorus loading scenarios for the Platte River watershed and hatchery	Platte Lake, near SLBE. 1990s.	Phosphorus-balance models developed and applied to evaluate alternative hatchery and watershed load scenarios. Most likely scenarios included two watershed loads (historical or detrended), and two hatchery loads (1993-1996 or zero) Evaluation of alternative scenarios provided.	Predicted phosphorus levels in Platte Lake were provided for various scenarios. Scenario results were provided in terms of annual means, summer means, year-round monthly means and summer monthly means for phosphorus.	Author noted importance of framing results in terms of monthly versus annual averages.
Walker	1998	Analysis of monitoring data from Platte Lake, Michigan	Platte Lake, near SLBE. 1990s.	Phosphorus-balance models developed and applied to evaluate alternative hatchery and watershed load scenarios.	Predicted phosphorus levels in Platte Lake were provided for various scenarios. Hatchery phosphorus contributions to Platte Lake appeared to be in the 5-10% range. Author noted that the <8 ppb target level could not be maintained on a monthly basis for any of the scenarios.	Later court reports note that these results may have been affected by limitations in the data supplied to Walker by Michigan Department of Natural Resources and the secretive nature of his contract.
National Park Service	1997	Baseline water quality data inventory and analysis: Sleeping Bear Dunes	SLBE and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire	<u># water quality observations</u>: 51,317 <u># parameters</u>: 294 <u># monitoring stations (study area/park)</u>: 149/76	Authors concluded that water quality at SLBE was relatively good, with some water quality effects noted due to industrial and municipal wastewater effluent,

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		National Lakeshore		period of record.	# parameters with exceedences (study area/park): 8/4 # stream gages (study area/park): 4/1 # dischargers: 3 # drinking water intakes: 0	septic leakage, stormwater runoff, and recreational uses.
Last et al.	1995	Limnological variation of selected lakes of Sleeping Bear Dunes National Lakeshore, Michigan	SLBE: 12 lakes. Summer 1994, 1995.	Lakes sampled in July or August each year. Vertical profiles recorded in deepest part of each lake. Water quality samples collected from surface or as depth-composite samples. Chlorophyll *a* measured from limnetic waters.	Thermal stratification noted in all lakes but Little Glen, Tucker, School, Bass and Shell Lakes, which were shallow and polymictic. Metalimnetic oxygen maxima noted in Bass and Glen Lakes due to algal productivity near thermocline. Loon and Narada Lakes had significant hypolimnetic oxygen depletion. High pH values common. Lower specific conductance in School, Shell, Bass and Narada Lakes likely due to groundwater influences. Lakes are in the meso-oligotrophic range for nutrients and chlorophyll *a*.	Surface water-groundwater interactions poorly understood and possibly important in explaining differences among lakes at SLBE.
Environmental Protection Agency Region V	1992	Clean Lakes Program: Glen Lake, Leelanau County, Michigan	SLBE: Glen Lake area. Assessed in early 1990s.	Glen Lake Association, Michigan Department of Natural Resources, and EPA Region V all contributed to data collection for this study. Report describes geology, history, socioeconomics, point source discharges, and historical and current limnological data. New limnological data collected using methods similar to Curry (1977), including quality, plankton, and benthos samples. Other work involved lake sediment cores, hydrologic and nutrient budgets (groundwater, surface water, and precipitation), aquatic vegetation surveys, soil analysis, and contaminants.	Glen Lake was found to be oligo-mesotrophic based on a variety of measures. Paleolimnological work (Fritz and Engstrom 1992) suggested an increase in lake productivity over past 150 years based on increased diatom and sediment accumulation. Subsurface groundwater comprised 52% of the water inputs to the lake, precipitation 27%, and groundwater-supplied surface water (seeps) 21%. Phosphorus was the limiting nutrient, 62% of which was delivered to the lake via direct precipitation. Most soils around Glen Lake could effectively immobilize phosphorus from septic systems. Hypolimnetic oxygen depletion occurred but did not cause large phosphorus release from sediments. Organic contaminants and mercury in fish were consistent with other nearby lakes.	Author concluded that further investigation was needed on several fronts: atmospheric pollutants, particularly phosphorus and mercury, nutrient “hot spots” around the lake due to fertilizer usage or leaking septic fields, runoff from County Road 677 during storms. Management issues posed by the author included: septic system maintenance, use of green belts, stormwater management, and continued water quality monitoring. This document provides a fairly comprehensive and current review of Glen Lake and the issues it faces.
Ellis	1991	Soils ability to remove phosphorus from septic systems around Glen Lake	SLBE: Glen Lake area.	Previous survey information collected. Soils collected from 4 locations and phosphorus adsorption capacity determined.	Soil maps and types provided a general estimation of phosphorus adsorbing capacity. The soil types present had varying phosphorus adsorption capacity. Author suggested that soils with low adsorption capacity were likely already leaching phosphorus; these soils comprised about 20% of the soils in the study area	Phosphorus inputs from septic fields were estimated at 200 pounds per year; author described this input as negligible annually but possibly important cumulatively.
Fritz and Engstrom	1992	Historical trends in water-quality and erosion rates in Glen Lake, Michigan	SLBE: Glen Lake. Cored in summer 1990.	Sediment core collected at 40 m depth with gravity corer and lead-210 dated. Diatom and chrysophyte fossils identified. Loss-on-ignition analyzed. Sediment geochemistry analyzed.	Glen Lake sediments were composed of >80% carbonate throughout the core, with slight increases in inorganic matter noted during peak logging activity. Sediment accumulation rates began to increase c. 1855, peaking in the mid-1900s at 3 times pre-European rates, and remaining high to the present day.	Authors suggested that changes in Glen Lake have occurred since European settlement, but that increased sedimentation and diatom accumulation rates do yet not indicate the kind of significant degradation seen in small mesotrophic lakes in the area.

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					Increased sedimentation was attributed to increased algal productivity due to the carbonate dominance. Diatom and chrysophyte data indicated oligotrophic conditions throughout the last 200 years, although accumulation rates increased sharply in the 1970s and remain elevated.	
Nürnberg	1992	The trophic state of Glen Lake with emphasis on hypolimnetic anoxia and sediment release of phosphorus	SLBE: Glen Lake. Monitored in 1990.	Current trophic state assessed using existing data. External phosphorus input data derived from a previous study (apparently unpublished data). Internal phosphorus loading calculated using an anoxic phosphorus release model.	Glen Lake was phosphorus-limited and oligo-mesotrophic, with phosphorus levels comparable to northern boreal lakes. External phosphorus inputs were very low (<8 mg/L), below the predictive range of the model. Using the model, however, predicted internal loads were up to 2/3s of the external load.	Author recommended further measurements of phosphorus release using undisturbed sediment core tubes in the laboratory or measuring phosphorus profiles during summer stratification. Author also recommended further paleolimnological investigation of sediment cores in order to assess trophic state changes in an historic context. Internal phosphorus loading is important in Glen Lake and duration of anoxic conditions should be closely monitored.
Biology & Ecology						
Nevers and Whitman	2004	Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks	VOYA, ISRO, PIRO, SLBE, INDU; 2 lakes in each. Monthly, May or June-September for 2 years.	Phytoplankton sampled from 1m depth and analyzed for composition, species richness, Shannon-Wiener diversity, and species evenness. Water quality suite measured using YSI sonde and Kemmerer sampler. MDS ordination of Bray-Curtis Similarity for mean water chemistry and individual species counts, phytoplankton species counts for each sample, and combined species counts and water chemistry variables for each sample.	Collected 176 phytoplankton taxa from all lakes. Diatoms and chlorophyte taxa most common. INDU lake dominated by euglenoids. SLBE lakes dominated by diatoms. PIRO lakes dominated by chrysophytes and diatoms. Northern lakes had variable composition. Northern lakes clustered together in terms of chemistry and composition.	Study provides some useful background and baseline phytoplankton information for these lakes. Non-random lake selection limits inference to the larger set of lakes at each park. Dataset could be explored further to: · Show how seasonal patterns differ among lakes, · More thoroughly describe grouping patterns among lakes in terms of phytoplankton composition and water chemistry, and · Provide more park-specific insights.
Lowe and Carter	2004	Benthification of algal biomass in northern Lake Michigan by zebra mussels with implications for aquatic trophic webs	SLBE: Lake Michigan shoreline.	Seston and benthos examined along the shoreline. Shifts in productivity evaluated.	Zebra mussel filtration increased the flow of organic matter and energy to the benthic zone. Improved light conditions led to increased *Cladophora* growth. Increased surface area provided by *Cladophora* led to increases in epiphytic periphyton, and subsequently amphipods, isopods, decopods, snails and chironomids.	Conference abstract only. Authors concluded that affects on higher trophic levels may be profound – future research should explore this possibility.
Wearly et al.	2004	Shifts in algal community structure in an oliotrophic inland lake following zebra mussel (*Dreissena polymorpha*) invasion	Lake Leelanau, very near SLBE boundary.	Lake Leelanau featured a gradient of zebra mussel density due to lake morphometry and invasion history. Phytoplankton communities and productivity monitored and analyzed for differences along the zebra mussel gradient.	Phytoplankton communities differed along the gradient of zebra mussel density, with blue-green algae becoming dominant in the more densely populated areas.	Conference abstract only. Full report expected in late 2004 or early 2005.
Whitman et al.	2002	Study of the application of limnetic zooplankton as a bioassessment tool for lakes of Sleeping Bear Dunes National Lakeshore	SLBE: 10 lakes, plus Crystal Lake. Biweekly, April-October 1998.	Water quality sampled from 1 m below surface, analyzed for nutrients, sulfate, alkalinity, total hardness and calcium hardness. Zooplankton collected using vertical tows at deepest point in each lake. Data analyzed using biotic indices and multivariate statistics.	Carlson TSI indicated a range of trophic conditions; only Big Glen and Crystal Lakes were oligotrophic. Chlorophyll *a* suggested eutrophic conditions in most lakes, but Secchi depths mesotrophic. School Lake had highest zooplankton densities, mostly rotifers, and Glen Lake had lowest densities but highest diversity. Rotifer abundance high in May in most lakes.	Authors conclude zooplankton useful as indicators of trophic status using various metrics and levels of aggregation, but using them may be prohibitively time-consuming and expensive. Authors recommend that future studies stick to the biweekly sampling regime due to high temporal variability.

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					Zooplankton composition similar across lakes, except Glen and Crystal in early spring. Small zooplankton dominant, suggesting predation by fish. Water quality and chlorophyll *a* similar to Stockwell and Gannon (1973-1974) data and Boyle and Hoefs (1993) data.	High spatial replication/resolution may be less important than high temporal resolution in zooplankton sampling regimes at SLBE.
Heuschele	2000	What are the biomonitoring needs for the streams in Sleeping Bear National Lakeshore? A review of two macroinvertebrate surveys and suggestions for rapid bioassessment for the flowing waters of SLBE	SLBE streams: Platte and Crystal Rivers, Shalda and Otter Creeks.	Report summarizes and compares White (1987) and Boyle and Hoefs (1993) studies. Biomonitoring recommendations provided.	Recommendations from White (198)7: Sample in winter, and investigate sources of stream productivity to determine possible autotrophy. Recommendations from Boyle and Hoefs (1993): Select sampling dates carefully due to high seasonal variability, investigate high nitrogen in Otter Creek, investigate stream energy sources, utilize diversity indices, and incorporate sites outside park boundaries. Author compares sample design and results from the two studies; similar numbers of taxa encountered in both.	Author advises outlining potential impacts and disturbance and monitoring to detect such impacts, establishing a park reference collection of invertebrates, and establishing long-term monitoring sites.
Flower and Walker	1999	A biological survey of the Crystal River, Leelanau County, September 1998	Crystal River. One sample, September 1998.	GLEAS Procedure 51 used to document biological (fish and macroinvertebrate), habitat and chemical conditions. Habitat conditions evaluated at 3 sites, macroinvertebrate community evaluated at 1 site.	Macroinvertebrate community at Station 1 acceptable; attaining Michigan standards. Habitat at stations 1 and 2 rated as good; slightly impaired. Station 2; impairment likely influenced by poor culvert design and sluggish stream currents. Habitat at Station 3 rated fair; moderately impaired, with little habitat structure and subject to road crossing effects.	Authors note that maintenance of natural flow regimes is poor and effects of culverts may be significant. Authors recommend notifying Road Commission of road crossing issues.
Flower and Walker	1999	A biological survey of the Platte River system, Benzie County, August 1998	Platte River system, 13 stations. Surveyed August 1998.	GLEAS Procedure 51 used to document biological (fish and macroinvertebrate), habitat and chemical conditions. Special emphasis on effects of State hatchery on river.	River sustaining a coldwater fishery and meeting Michigan water quality standards from station 6 downstream. Good numbers of salmonids noted at 6 of 7 stations. Road crossing issues noted: undersized or improperly installed culverts, and erosion. Water quality samples showed low nutrient and metal concentrations. Station 6 notably lower for hardness, alkalinity and conductivity, likely due to groundwater influences. No clear persistent chemical or biological signals attributable to the Hatchery.	–
Whitman et al.	1994	Limnological characteristics of selected lakes and streams of Sleeping Bear Dunes National Lakeshore inspected during summer 1994	SLBE: 12 lakes and 4 streams. Sampled mid-summer 1994	As in Last et al. (1995) for lakes. 10 sites on 4 streams sampled for basic water chemistry suite, and 5 replicate collections for invertebrates using a Surber sampler.	As in Last et al. (1995) for lakes. Stream temperatures and dissolved oxygen and pH were high (21-24 °C, 8-15 mg/l, and > 8.3, respectively). Macroinvertebrate density and richness variable, but generally higher at upstream sites.	Only density and richness presented for benthic invertebrate data. Future stream monitoring should target other metrics or community analyses to enhance insights gained. Authors note that lakes with high usage and shoreline development are vulnerable. Limited analysis and interpretation provided.
Boyle and Hoefs	1993	Water resources inventory of Sleeping Bear Dunes National Lakeshore	SLBE: 4 streams, 20 inland lakes. Mid-spring-early	<u>Lakes</u>: Mid-summers, water quality suite, both deep and shallow samples, and basic vertical profiles determined for each lake.	<u>Lakes</u>: Generally hard-water, high alkalinity types with low nutrient concentrations, except for Florence Lake due to groundwater chemistry.	Study scope was intensive and report provides valuable monitoring insights: Secchi depth less variable within lakes than among

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
			autumn 1990-1992.	Streams: Seasonally, upstream and downstream sites, discharge, water quality suite. Benthic invertebrates biweekly or monthly, quantitatively with Surber samplers and Hester-Dendy plates, and qualitatively with kick net). Invertebrates identified and community indices calculated.	Epilimnetic oxygen depletion noted in Little Traverse and Loon Lakes. Streams: Variable discharges, with greatest discharge in the Upper Platte River. Longitudinal increases in discharge noted in all creeks, mostly due to groundwater inputs. Consistently high nitrogen concentrations found at the downstream site in Otter Creek. FPOM was the dominant organic matter fraction in all streams. Macroinvertebrate densities highest at downstream Otter Creek site; densities lowest in Platte River, and taxa and EPT richness and diversity highest at downstream Otter and Shalda sites. Filterers and gatherers dominant at upper sites near lake outflows.	lakes over 3 years. Secchi depth may be a good long-term monitoring indicator, although it is sometimes affected by marl formation. Benthic invertebrates below lake outfalls may be good indicators of changes in lake productivity. Qualitative sampling typically provided more complete inventory of stream communities than quantitative methods. Future monitoring should be conducted throughout watersheds and outside SLBE , where necessary.
Stevenson	1992	Report on Glen Lake plankton assemblages	Big Glen Lake, 3 sites: Little Glen Lake, 2 sites. August 1990-May 1991.	Plankton collected from each site with a vertical plankton tow raised up from the bottom of the lake. Plankton concentrated and counted in Sedgewick-Rafter cells; densities calculated. Nutrient and chlorophyll *a* concentrations assessed on 13 dates. Species lists and data provided.	Both Big and Little Glen Lakes were considered oligotrophic-mesotrophic, and phytoplankton densities and chlorophyll *a* were quite low. Nutrient ratios indicated phosphorus limitation of algal growth. Diatoms and chrysophytes predominated, with blue green algae common only in Little Glen Lake during August. Species composition differed somewhat between lake basins, with Little Glen Lake showing greater potential for algal growth. Zooplankton densities were low but peaked during periods of highest phytoplankton densities.	Based on nutrient ratios, increases in phosphorus concentrations would likely result in increased phytoplankton growth; nutrient inputs to Glen Lakes, particularly Little Glen Lake, should continue to be monitored.
Linton	1987	Analysis of habitat for invertebrates in stream systems of Sleeping Bear Dunes National Lakeshore	SLBE streams: Platte and Crystal Rivers, Shalda and Otter Creeks. Single survey each.	Each stream surveyed by wading or canoeing. Temperature, pH and current velocity recorded. Riffles, pools, and runs characterized. Canopy cover, snags, macrophytes, adjacent vegetation and substrate noted. Brief notes about aquatic invertebrate densities included. Hand-drawn maps provided.	Lotic habitats fell within 3 broad types: lotic erosional-riffles, lotic depositional-runs, and lotic depositional-marsh. Platte River: Lotic depositional runs and marshes dominated. Otter Creek: Lotic depositional marsh habitats dominated. Crystal River: Lotic depositional runs most common. Shalda Creek: Lotic depositional sand bottomed runs most common.	Study provides some preliminary habitat information for the major streams of SLBE and might be useful in planning future more detailed habitat studies in these streams.
White	1987	Analysis of the limnology of four streams (Platte River, Crystal River, Shalda Creek, Otter Creek) in the Sleeping Bear Dunes National Seashore based on the macroinvertebrate fauna	SLBE streams: 19+ sites on Platte and Crystal Rivers, Shalda and Otter Creeks. Summer 1987.	Invertebrates identified to genus and species, where practical, and assigned to functional feeding groups.	Streams warm, hard-water, potentially autotrophic types. Each stream passes through relatively rich shallow lakes, where dissolved organics from lakes may act as main food source for filter feeders downstream. Aquatic macrophyte beds extensive, especially near lake inflows and outflows, and are highly productive, producing marl deposits. Mid-reaches of streams have greater potential for periphyton accumulation and invertebrates. Identified > 50 taxa, none rare or endangered. Site-specific lists of taxa and feeding groups	Good ecological insights provided about stream characteristics and stream function along longitudinal gradients. Author strongly recommends sampling in winter and comparing with summer to understand whether or not streams tend toward autotrophy. Study provides good summer baseline information for these streams.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					included.	
Gannon and Stockwell	1978	Limnological investigation of Florence Lake, South Manitou Island, Michigan	Florence Lake. September 1974, March, May, September 1975.	<u>Lake morphometry</u>: Mapped. <u>Water quality</u>: Suite measured and vertical profiles of basic parameters recorded. <u>Zooplankton</u>: Collected on each sampling date from various depth intervals. <u>Phytoplankton</u>: Collected only September 1975 with plankton net. <u>Benthic community</u>: Sampled at several stations, along an east-west depth transect, along the shoreline with an Ekman grab; qualitative samples from macrophyte beds also collected. <u>Fish</u>: Sampled with gill nets and seines.	Florence Lake small, relatively shallow and elongated, with several sand spits. Watershed to surface area relatively large. pH averaged 7.9, alkalinity averaged 57 mg/l, cations and nutrient concentrations relatively low, and chlorophyll *a* moderate during study period. Lake thermally stratifies. Recorded 36 rotifer taxa and 30 micro-crustacean taxa. Noted 132 phytoplankton species; mostly eulimnetic forms with some tychoplanktonic species; blue-green and green algae common at this sampling date. Rooted macrophytes common at < 2 m depth. Recorded 110 macroinvertebrate taxa; 50% found in aquatic vegetation; composition varied along depth transects; densities highest in sand and organic matter at 1 m depth. Observed yellow perch, northern pike, smallmouth bass, and Iowa darter, but likely more fish species are present. Condition of fish appeared very good. Lake fed by groundwater seepage; there are no surface water inlets. Florence Lake is likely mesotrophic.	Authors note Florence Lake may be more susceptible to increased nutrient inputs than other SLBE lakes due to its soft water and sandy drainage basin. Authors urge implementing a monitoring program using these data as a baseline. Current Florence Lake conditions (Murphy 2002) should be characterized and compared with data in this study to examine changes over the last 25 years. (See additional review under fish category.)
Curry	1977	Species structure of midge (Diptera: Chironomidae) communities in Crystal River drainage basin, Leelanau County, Michigan, 1972	Crystal River drainage basin: 11 sites including Big Glen, Little Glen and Fisher Lakes; Crystal River and Hatlems Creek. 4 samples, February-October 1972.	Larval chironomids collected quantitatively using Ponar grab samples. Chironomids sorted from bottom materials and identified to species if possible. Taxonomic composition, Shannon-Weaver diversity, equitability, and standing crop (as density) analyzed. Basic water quality measured. Aquatic vascular plants collected, identified and compared with previous records.	Identified 79 species or groups of chironomids, with roughly equal representation of lentic vs. lotic taxa. Lentic communities less variable than lotic. Chironomids accounted for about 50-60% of invertebrate standing crop (density). <u>Dominant lentic midges</u>: *Tanytarsus gregarious* type 2, *Dicrotendipes nervosus* and *Procladius*. <u>Dominant lotic midges</u>: *Polypedilum* (*Tripodura*) *scalaenum, T. atridorsum,* and *Rheotanytarsus exiquus.* Identified 6 community types. Species structure most complex and diversity, and equitability highest for plant-associated lake sites and impounded stream sites. *Ceratophyllum gemersum, Myriophyllum exalbescans* and *Potamogeton* most abundant plants. Chironomid communities generally reflected good water quality.	Study provides highly valuable baseline information on chironomids, a key group of aquatic biota, for a politically and ecologically important drainage basin at SLBE. Aquatic vegetation likely important to maintaining diverse, abundant midge communities in SLBE lakes and streams. Chironomids continue to be used as indicators of ecological and trophic conditions worldwide, and species lists from this study are detailed enough to be used in future comparative studies and monitoring at SLBE.
Stockwell and Gannon	1975	Water quality studies in the Sleeping Bear Dunes National Lakeshore region-the lower Platte River system, Michigan	SLBE: 8 stations on Lower Platte River, Mud, Platte and Loon Lakes. November 1973, May 1974.	Platte River watershed, soils, land cover, hydrology described. Lake morphometry, bottom sediments, surrounding vegetation characterized. Surface water samples collected and water quality suite analyzed, including chlorophyll *a.* Plankton tows collected at all lake stations and analyzed for zooplankton.	Water throughout the study area slightly basic and fairly hard. Nutrients high above Platte Lake; Loon and Platte Lakes likely serve as nutrient sinks. Zooplankton in Platte River system reported as a species list with relative abundance estimates.	Authors use data presented in Stockwell and Gannon (1974) to critique the original Master Plan for SLBE. They note that sensitivity to human disturbance varies among water bodies, that Platte Lake water quality influences Platte River, and acknowledge the importance of cooperation with Benzie County and state resource managers for watershed management. Authors cite a need for water quality monitoring.

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Stockwell and Gannon	1974	Water quality studies in the Sleeping Bear Dunes National Lakeshore region- the lower Platte River system and Florence Lake, Michigan	SLBE: 8 stations on Lower Platte River, Mud, Platte and Loon Lakes. November 1973, May 1974.	Platte River watershed, soils, land cover, and hydrology described. Lake morphometry, bottom sediments, surrounding vegetation characterized. Surface water samples collected and water quality suite analyzed, including chlorophyll *a*. Plankton tows collected at all lake stations and analyzed for zooplankton. Ekman grab samples used for benthic invertebrates. Aquatic macrophytes surveyed qualitatively from shore. Critique of the SLBE Master Plan provided.	Water throughout the study area slightly basic and fairly hard. Nutrients high above Platte Lake; Loon and Platte Lakes likely serve as nutrient sinks. Zooplankton in Platte River system reported as a species list with relative abundance estimates. Benthic invertebrate samples dominated by Diptera and Oligochaeta in low densities, but limited sampling effort noted. Heavy fishing pressure in Platte River and Platte River Bay noted. (See also Stockwell and Gannon 1975.)	Data collection was limited but authors offered thoughtful interpretations and recommendations. Zooplankton species lists provide a useful baseline for these lakes, particularly in the event of exotic zooplankton invasions. Authors claim theirs are the first data obtained for Florence Lake, and note the excellent water quality of this lake. Site-specific management recommendations related to sensitivity of resources and potential threats are provided. Authors place considerable emphasis on an earlier study by Williams and Works, Inc., which suggested limitations to development in regions with poor soil and high water tables. A regular monitoring program is recommended.
Curry	1973	A base line survey of the Crystal River drainage basin, Leelanau County, Michigan	Crystal River drainage basin. February-November 1972.	<u>Water quality</u>: 10 stations sampled for basic parameters. <u>Bacteria</u>: 33 stations sampled during spring, summer and fall, analyzed for total and fecal coliform and fecal streptococcus. <u>Plankton</u>: 10 stations sampled qualitatively with Wisconsin net. <u>Bottom fauna</u>: 10 stations sampled using a Ponar dredge in winter, spring, summer and fall.	<u>Water quality</u>: Generally high dissolved oxygen and normal pH ranges for hard water lakes. <u>Bacteria</u>: Bacteria elevated in Crystal River and Fisher lakes, mostly in shallow shoreline areas, likely due to human sources. <u>Plankton</u>: 43 genera; diatoms most frequently observed, species lists for both phytoplankton and zooplankton provided in appendix. <u>Bottom fauna</u>: Species lists and abundances provided by site; a variety of pollution tolerant and sensitive species observed.	Author suggests nutrient enrichment and eutrophication may be occurring, citing high bacterial levels and presence of pollution-tolerant organisms. Species lists may be useful but analysis and interpretation were limited in this study.
FISH						
Canale et al.	2002	Annual report for year 2001 Consent agreement concerning operation of the Platte River Hatchery	Platte River Hatchery	Describes hatchery operations, Platte Lake water quality monitoring, tributary flows, and phosphorous loading levels as set by consent agreement reports numbers of Coho and Chinook salmon. Overall goal of consent agreement is to restore and preserve water quality of Platte Lake.	Net hatchery total phosphorous load for 2001 was 212 pounds, which was not in compliance with interim standard of 210 pounds maximum. Maximum loading for any 3-month period was 81 pounds, also not in compliance with standard of 75 pounds. Hatchery was undergoing renovation at the time and managers expected that renovations would help meet P loading requirements.	Important document regarding effects of hatchery and Pacific salmon entering Platte River system. Need update to determine if renovations alleviated noncompliance issues.
Vana-Miller	2002	Water Resources Management Plan for Sleeping Bear Dunes National Lakeshore	–	References Kelly and Price (1979) for fisheries information.	Provides extensive fish species list both for Lake Michigan species that would be expected near SLBE waters and watersheds within the Lakeshore boundaries.	Planning document. (See additional review under general documents and plans category.)
Yancho	2001	(E-mail memo.)	SLBE: Beach north of Esch Rd.	Information on Coho salmon mortality event.	Memo regarding dead Coho salmon on beach north of Esch Rd. Platte R hatchery manager suspected mortality caused by thiamin deficiency in Coho. Didn't state why thiamin deficiency might occur.	Sent by SLBE Steve Yancho to multiple recipients. Need to determine if thiamin deficiency is due to dominant species in available prey base, and if it occurs with any regularity that might be correlated with populations of alewife or coregonids that might make up food source at time of die-off.
Various authors	2001	(E-mails re: fish surveys and species lists)	–	–	Several emails regarding need for updated fish inventory at SLBE, review of fish species list for NPSPECIES	–
Michigan	1999	A biological survey of the	Platte River system:	Documented current biological, physical habitat	Stated that the Platte River and tributaries were high	The only fish species listed in tables of document

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Department of Environmental Quality		Platte River System, Benzie County, August 3-5, 1998.	13 stations upstream of Platte Lake, including tributaries. Summer 1998.	and chemical conditions to determine if there were measurable adverse impacts from the state salmon hatchery on the river.	quality streams. Fish and macroinvertebrate community data indicated that the river was sustaining a coldwater fishery and was meeting Michigan water quality standards. "Good number" of salmonids were present at 6 out of 7 stations sampled for fish.	were steelhead, brown trout, Coho salmon and mottled sculpin.
Michigan Department of Natural Resources	1998	–	–	Determination of cysts found on bluntnose minnows in Big Glen Lake.	Memo from Michigan Department of Natural Resources to Donald Matshke. Cysts were a myosporidian parasite. A common protozoan parasite.	Did not indicate if is harmless at levels observed or can cause problems in other species, but apparently concern was low.
Jennings	1997	Needs in management of native freshwater mussels in the national park system	NPS: 37 units with mussel populations.	Survey of mussel populations.	Makes specific recommendations to protect/manage mussel populations in NPS. No specific information on SLBE. Noted.	Technical Report NPS/NRWRD/NRTR-97/147. Seems like there should be specific SLBE information.
Sleeping Bear Dunes resource management staff	1996	(Memo)	Platte River.	Meeting for proposed electric lamprey barrier in Platte River. NPS, Michigan Department of Natural Resources, and U.S. FWS attended.	Proposal to seek funding from Great Lakes Fishery Commission for temporary electric barrier. If successful, it may be converted to permanent.	Memo regarding interagency meeting. Need to determine the outcome of this proposal.
Hoefs	1993	The Platte River Study; assessment of ecological integrity of stream invertebrate community	Platte River system. Summer 1992	Assessed impacts of gasoline leak that leached into Platte River. Assessment of ecological integrity of stream invertebrate communities Taxa richness, diversity, and density determined.	Impacts were mostly confined to area adjacent to spill leachate with recovery occurring rapidly below and downstream from the spill area.	(See additional review under contaminants category.)
Various authors	1990	(Email/letters)	Manitou Island lakes	Various emails and letters regarding Manitou Island fishing regulations	Michigan Department of Natural Resources implemented 18 in, 1 fish limit for bass, taken with artificial bait only on Manitou Islands. No minimum size for northern pike from Florence Lake.	–
Michigan Department of Natural Resources	1990	Increased size limit and reduced creel limit on smallmouth bass in North Manitou Lake, Leelanau County	North Manitou Island.	"Fishery management prescription."	Recommendations for special regulations for smallmouth bass. Copy of authority to Natural Resource Commission to implement special regulations for a 5 year period.	Not indicated if growth information from 1987 led to implementation of special regulations for smallmouth bass.
Michigan Department of Natural Resources	1987	North Manitou Lake, fish collection information	North Manitou Island. Fish survey, June-July 1987	Fish capture data. Depth/O2 profile and physical description of North Manitou lake in July.	Captured smallmouth bass, yellow perch, green sunfish, and white sucker. Bass growth rate was significantly greater than state average.	–
Michigan Department of Natural Resources	1983	Clean Lakes Program, Platte Lake Benzie County, Michigan. Phase I diagnostic feasibility study, final report	Platte Lake	Water quality report for Platte Lake.	Reports Platte River Hatchery as a point source of phosphorous loading in Platte River system. Hypolimnetic DO was depleted below 40 ft during late summer. Recommends hatchery management to keep phosphorous loading low. Develop monitoring plan for Platte Lake water quality. Recommended citizen advisory commission be established for duration of project.	Not clear if Clean Lakes Program was temporary, or an on-going monitoring program.
Michigan United	1982	Michigan's 50 best fishing lakes: the state's top inland	North Leelenau, Big Platte and Crystal	–	North Leelenau Lake: Stocked with brown trout and lake trout.	Appears to be a Michigan Department of Natural Resources publication. Only section that indicates

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Conservation Clubs		waters	Lakes.		Crystal Lake: Stocked with 11 different species since 1890s; currently stocked with lake trout. Big Platte Lake: Not sure about stocking or species historically present.	lakes within or near SLBE available for review. Not sure what species populated the lakes prior to stocking effort, or if any of stocked species were already present.
Organ et al.	1979	Past and presently known spawning grounds of fishes in the Michigan coastal waters of the Great Lakes	–	–	Michigan Department of Natural Resources Fish Division, Technical Report 79-1.	No text to review, only cover page available in SLBE resource files.
Kelly and Price	1979	Fishes of the Sleeping Bear Dunes National Lakeshore	SLBE watersheds: Crystal and Platte Rivers, Shalda and Otter Creeks. Single survey.	Fisheries survey using standard techniques in streams, inland lakes, and Lake Michigan nearshore waters.	Found 76 species within Lakeshore study area. Of 10 exotic fish species present, 8 were intentionally introduced; only sea lamprey and alewife were not.	This will be the baseline species information with which to compare 2003-2004 survey results. Just presence information, no density or other population characteristics. Interesting to note that four native lamprey species were found; in addition to sea lamprey.
Gannon and Stockwell	1978	Limnological investigation of Florence Lake, South Manitou Island, Michigan	South Manitou Island: Florence Lake. Fall 1974, Spring, Fall 1975.	Primarily limnological investigation. Some fish observations discussed. Used deepwater gill net sets and nearshore seining to collect fish.	Observed yellow perch, northern pike, smallmouth bass and Iowa darter. Perch and pike growth rates were above average compared with other lakes of the area. Fish were also infested with black spot and yellow grub parasites; frequency of parasites was especially high on perch and pike, but there was no evidence that parasites were negatively affecting fish populations.	Authors suggested that balance of open water and littoral weed beds provided optimum habitat for fish community. Discussed vulnerability of lake to phosphorous loading if any development were to occur. NPS plans to manage as wilderness, so phosphorous loading threat is low Good water quality benchmark (See additional review under biology and ecology category.)
University of Michigan Biological Station	1975	Natural History surveys of Pictured Rocks and Sleeping Bear Dunes National Lakeshores	SLBE: Platte River.	Shows fish collected in Platte River 1967-1972 (Taube, 1974). Reported fish as numerous, common, few, rare or “abundance not established.”	Final report to NPS from UMBS. 29 species reported in Platte River: 3 numerous 2 common to numerous 4 few to common 9 few 9 rare 2 abundance not established	Only one page of fish information from this report available for review. Interestingly, the only species counted as numerous were Pacific and European salmonids: Coho salmon, steelhead and brown trout.
Taube	1974	A descriptive and historical account of the Platte River, its surrounding area, and its salmonid fishery	–	Describes some of the physical, chemical and biological characteristics of the Platte River watershed and history of salmonids in river, both introduced and native. Cultural history from early to mid-1800s and activities/actions that would have affected the river	Fairly thorough sport fish (salmonid) information, except for grayling. Grayling were discussed but it appears that thorough information was lacking. Brook, rainbow brown trout, Coho and Chinook salmon histories all covered. Also describes management actions such as lamprey control, fish habitat improvements, regulations, etc.	Michigan Department of Natural Resources, Fish Resources Report No. 1809. Oriented towards salmonid sport fishery and historical changes in this fishery and the populations.
Scott	1920	Inland Lakes of Michigan	Michigan waters: inland lakes. 1913-1914, 1920.	–	–	Only the preface of this document was available for review. It describes value of lakes throughout the State, development along lakeshores at the time, and brief descriptions of methods to conduct physiographic study of lakes. Author strongly recommended the use of the camera for recording information.
Aquatic Wildlife						
Patton	1978	Response of the Manitou	SLBE: South	Gulls surveyed using a direct-count method and	Recorded 2,686 active ring-bill nests; lower than in	Author recommends continued monitoring of the ring-

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		gull colonies to an implemented management program	Manitou Island. May-July 1977.	nest density calculated. Colony disturbances monitored daily, including humans, red fox, avian predators. Mortality, egg losses and hatching success monitored.	1975-1976. Recorded 466 active herring gull nests; similar to 1975-1976. Mortality related to predation, gunshots, fishing lures and unknown causes. Fox disturbance lower than in previous years.	bill colony and attempts to determine reproductive efficiency. Author also recommends fox radio telemetry study to help understand effects of fox on gull colonies.
AMPHIBIANS AND REPTILES						
Linton and Kats	1987	A survey of the herpetofauna of Manitou Islands	SLBE: North and South Manitou Islands. August 1-5 1987.	Surveyed islands by turning over logs, rocks, debris and wading along the shoreline of Florence Lake. Compared relative abundance results with previous surveys.	South Manitou: 5 amphibians and 5 reptiles found. North Manitou: 7 amphibians and 6 reptiles found.	Authors recommend follow-up studies when weather conditions more agreeable.
McCann	1975	The terrestrial vertebrates of the Sleeping Bear region of Michigan	SLBE, park-wide.	Annotated list of probable vertebrates provided with specific reference to known sightings at SLBE locations.	Noted 17 amphibians and 16 reptiles.	Lists may be useful but would require verification. No interpretation provided.
WETLANDS AND AQUATIC VEGETATION						
Edwards	1995	A hierarchical study of *Lythrum salicaria* L. ecology in Indiana Dunes and Sleeping Bear Dunes National Lakeshores	INDU and SLBE: 6 field populations. Monitored for 3 years.	*Lythrum* life history examined (shoot biomass, fertility, fecundity, demography) in relation to environmental gradients of soil chemistry and hydrologic regime. Competition experiment between *Lythrum* and *Calamagrostris canadensis* conducted. Physiological parameters of INDU populations measured to investigate reasons for invasion success.	INDU populations affected by small-scale environmental factors such as nutrient levels and hydrologic regime. SLBE populations affected more by large-scale climatic factors and density of other plants.	*A priori* predictions about what constrains *Lythrum* populations unsuccessful since specific site conditions can be very influential; a single control method won't work for all situations. Restoration of wetlands and native plants and a suite of *Lythrum* control methods may be most effective.
Albert	1992	A survey of lakes, streams, and wetlands of the Sleeping Bear Dunes National Lakeshore	SLBE: Crystal River and Platte Rivers, Shalda and Otter Creeks, and Bass (Benzie and Leelanau Counties), School, Tucker and Otter Lakes. Each surveyed in August 1991.	<u>Streams</u>: Transects established at either canoe access sites, undisturbed sites, or sites corresponding with Boyle and Hoefs (1993); 5 sampling points per transect. Plant species, coverage, water depth, soil texture, and depth of organic material recorded. <u>Lakes</u>: Transects established arbitrarily on Bass (Leelanau County) and Otter Lakes; plant species, coverage, water depth, soil texture, and depth of organic material recorded. Macrophytes listed for School, Tucker and Bass (Benzie County) Lakes but no transects established. <u>Dune swales</u>: Transects established at Platte River and Shalda Creek, perpendicular to the beach ridges and swales; plant coverage (total, emergent and submergent), plant species, water depth, soil texture, and depth of organic material recorded. <u>Search for monkey-flower</u>: Aerial photographs used to identify possible sites; these sites visited and searched.	Vegetation at each site described. Platte and Crystal River sites with canoe access appeared to support little aquatic vegetation. Transect sampling not effective for inland lakes because vegetation, mineral soil and organic material could not be accurately sampled at depth. Wading reduced visibility, vegetation was patchy, and several transects per lake would have been necessary to characterize vegetation. Dune swale wetland hydrology was linked to substrate and drainage conditions rather than to Lake Michigan water levels; no sign of seepage from adjacent uplands. Vegetation gradient noted: wet meadows and emergent macrophytes near the present Lake Michigan shoreline, shrub or forested swamp vegetation common further inland. Monkey-flower not found within the Lakeshore boundaries, but a large colony found nearby along Hatlems Creek. State-threatened *Potamogeton hillii* and *Berula erecta* found in Otter Lake and Shalda Creek, respectively. State special concern species *Mimulus glabratus* var. *jamesii* found on Otter Creek.	Difficult to separate effects of natural stream substrate movement and instability from recreational impacts on aquatic vegetation. Author recommends establishing permanent transects if long-term monitoring desired. In general, insights from this study were limited by the relatively low amount of sampling effort; author recommends more intensive sampling.
Hazlett	1989	The aquatic vegetation and flora of the Sleeping Bear Dunes National Lakeshore,	SLBE: Lakes, streams and associated wetlands.	Field notes and collections made during various visits to each of the sites. Species lists and notes on occurrence and	Aquatic habitats described one-by-one, with notes on which species and community types were found at each site.	Excellent resource. Author provides thoughtful recommendations: · Preservation of unique undeveloped habitats.

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		Benzie and Leelanau Counties, Michigan	Intensive surveys, summer 1986. Follow-up surveys, summer 1987.	abundance of threatened species generated.	Undeveloped habitats noted, including Taylor Lake, Round Lake, the M-22 bog, wetlands in the Bow Lakes section, and the Otter Creek drainage. Bogs and sedge mats noted as sensitive to degradation due to visitor use. Notes on *Berula erecta* provided.	· Monitoring of *Berula erecta* and preservation of suitable habitat. · Stream monitoring at points of entrance and exit from National Lakeshore lands. · Lake monitoring using vegetation composition as an indicator of water quality (methods and possible indicators provided). · Purple loosestrife prevention, education and monitoring. Further research questions posed in detail.
Wilcox	1982	Report on survey of two bogs in Sleeping Bear Dunes National Lakeshore	SLBE: 2 unnamed bogs. August 1982.	Specific conductance measured, conspicuous plants identified, *Sphagnum* samples collected for species identification, and general observations made.	Both bogs fit ombotrophic or precipitation-fed category, due to lack of groundwater influence. Bogs differed in terms of vegetative structure and diversity, but author claims both are valuable, high quality peatlands.	Useful baseline information provided for these two bogs: species lists, inter-bog variation. No georeferencing data presented.
CONTAMINANTS						
Hoefs	1993	The Platte River study: assessment of ecological integrity of stream invertebrate community	SLBE: Upper Platte River, 8 sites above and below M-22 bridge. Sampled 3 times, summer 1992.	Sample sites selected above, adjacent to, directly below, and somewhat farther below spill site. Sites located in sand and gravel substrates. Benthic invertebrates collected using Surber sampler with 1000 micron mesh. Invertebrates identified to lowest possible taxon. Richness, density, diversity, EPT indices calculated.	Study to evaluate effects of a gas and fuel oil spill. Natural and spatial variation high. Density of oligochaetes, EPT taxa and mollusks appeared affected by the spill, but only at sites directly adjacent to spill area. Community parameters appeared to recover rapidly. Taxa richness, EPT richness and diversity not significantly different among sites.	Conclusions limited somewhat by high spatial and temporal variation. Study underscores the need for pre-spill baseline biological data. (See additional review under fish category.)
Cline and Chambers	1977	Spatial and temporal distribution of heavy metals in lake sediments near Sleeping Bear Point, Michigan	Sleeping Bear Point, Lake Michigan. July 1973.	Collected 39 surface samples and 18 piston cores. Analyzed for Cu, Ni, Cr, Zn, Mn, Ag, Cd, organic carbon, and cation exchange capacity.	In surface sediments, all heavy metals were significantly related to grain size. Accumulations in upper strata may be more a result of natural geochemical and physical factors than cultural loading. Metals covaried with grain size.	Authors caution against using cores as a method to obtain "pre-cultural" heavy metal loads for comparison with surface sediments.
HYDROLOGY						
Albright et al.	2002	Preliminary hydrologic and hydraulic characterization of instream flows of the Crystal River, Sleeping Bear Dunes National Lakeshore, Leelanau County, Michigan	SLBE: Glen Lake-Crystal River Watershed.	Existing data analyzed to describe historic Glen Lake levels and Crystal River flows. Relationships between river depth and flow established using Xspro computer model.	Sporadic Crystal River discharge measurements analyzed (1943-present); only 23 summer data points. Flow of 10 cfs will cover most of channel bottom to a maximum depth of 1 ft. Flow of 30 cfs needed to cover most of the main channel bottom to 1.5 ft. 30 cfs or greater required for canoe floatability and navigability. Calculations suggest small changes in dam discharge affect lake levels only modestly.	Author cites a need for more consistent discharge measurements, additional field quantification of instream flow needs for recreational and biological uses, and additional study of how minor changes in lake levels affect adjacent park resources.
GROUNDWATER						
Handy and Stark	1984	Water resources of Sleeping Bear Dunes National Lakeshore, Michigan	Groundwater from new and old wells. Springs, lakes and streams.	Groundwater quality and quantity measured and geologic maps drawn. Metals, pesticides, and basic water quality measured in lakes and streams. Discharge measured at 4 creeks plus lake outlets; rating curves constructed.	Geology summarized in detail. Surface water chemistry and physical characteristics summarized for SLBE lakes. Groundwater quantity concerns addressed. North and South Manitou Islands addressed in separate sections. In general, water quantity deemed sufficient for most	Study provides baseline information about water quantity and basic water quality characteristics at SLBE.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					uses. No pesticides found, and trace metals low.	
PHYSICAL PROCESSES						
Environmental Resources Management	1985	Platte River Corridor Study	Lower 6 miles of Platte River including mouth. August 1983-1984.	River mouth dynamics were documented from beach and river profiles, dredging observations, air photo interpretation and map study. Macrobenthic samples were collected at river mouth before and after dredging. 10 river sites were studied for visible impacts, natural erosion, and visitor use levels; 3 sites had paired field units with high and low recreational use.	River mouth processes described in detail. Macrobenthos scarce before and after dredging; authors attribute this to natural habitat instability. Dredging activities increase turbidity, reduce the size of the sand spit, and change substrate composition. 3 use categories identified on lower 6 miles of river: dominated by fishermen, dominated by boaters, and combined boating and fishing use. River showed signs of recreational stress at all monitored sites.	As adjustments to the existing dredging, authors recommend dredging to the least possible depth and placing dredge material further down the beach. Authors suggest a study to determine carrying capacity for the Platte River, and recommend monitoring sand spit geometry and beach shoreline as well as trampling, soil compaction, littering, sanitation, erosion, and exotic plants along the lower river.
Kemezis	1983	Visitor use survey, Platte River Corridor	Lower Platte River. June-August 1983.	Observations made at 10 minute intervals at various sites.	Motorboats conflicted with other users by creating large wakes, which may also affect shoreline resources.	Report is very brief, but author recommends creating a no wake rule to improve overall visitor experience and encouraging use of the river early or late in the day to reduce crowding.

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AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
GENERAL RESOURCE DOCUMENTS AND PLANS						
Kallemeyn et al.	2003	Aquatic synthesis for Voyageurs National Park	VOYA, park-wide, aquatic habitats.	Synthesis includes detailed information about climate, geology, hydrology, lake level regulation, morphometry, physical/chemical characteristics, biological communities (phytoplankton, zooplankton, zoobenthos, aquatic vegetation, fish, herpetofauna), mercury and other contaminants, and climate change.	The state of the knowledge on all of these components is described, followed by point-by-point recommendations for future research and monitoring.	This comprehensive synthesis is a tremendous resource for VOYA and for GLKN. The experience of the author strengthens the synthesis and adds weight to the recommendations for future research and monitoring. This should be a significant steering document for GLKN and VOYA aquatics programs. (See additional review under fish category.)
Weeks and Andrascik	1998	Voyageurs National Park, Minnesota, water resources scoping report	VOYA, park-wide, aquatic habitats.	This management document addresses legislation, natural resource characteristics, and water resource issues.	Water resource issues identified during the scoping meeting included aquatic ecological responses to regulated lake levels, water quality exceedences, mercury in fish and sediments, purple loosestrife, rainbow smelt invasion, wastewater treatment failures, and two stroke engines.	Good identification and discussion of primary water resource issues for VOYA. This report may aid in the development of new research and monitoring projects.
Bureau of Sport Fisheries and Wildlife	1969	An appraisal of the fish and wildlife resources of the proposed Voyageurs National Park	VOYA, park-wide assessment.	Document provides some historical perspectives on the area's land use and development. Document summarizes past and present fish and wildlife, rare and endangered animals, relevant National Park Service policies and possible effects of park operations on fish and wildlife resources.	<u>Aquatic-based wildlife</u>: Moose present on Kabetogama Peninsula, but in notably low densities, birds present, including the solitary sandpiper, mallards, black ducks, mergansers, ring-necked ducks, goldeneyes, common loon (hunters interviewed), beaver in increasing populations, otter and muskrats in low numbers, and abundant mink. <u>Fisheries</u>: Sport and commercial fishing common, although catch per unit effort may be declining. Walleye spawning and abundance linked to water level fluctuations in Rainy Lake. <u>Rare or Endangered Species</u>: Lake sturgeon found in the proposed parks' large lakes. Northern bald eagles (possibly 20 pairs) present in the proposed park. Ospreys use the area.	Authors suggest that formation of Voyageurs National Park would likely benefit otter, muskrat, and moose populations, provide sanctuary for eagles and osprey, improve waterfowl breeding populations and help sustain a good fishery.
WATER QUALITY						
Christensen et al.	2004	Effects of changes in reservoir operations on water quality and trophic state indicators in Voyageurs National Park, Northern Minnesota, 2001-2003	VOYA: 9 sites, 6 corresponding to Payne (1991). Biweekly. at most, May-October 2003.	Samples collected from top, middle, and bottom positions in the water column. Samples analyzed for conductivity, pH, temperature, Secchi depth, dissolved oxygen, major ions, TP, TKN, and chlorophyll *a.* Stream flow and lake elevation data acquired. Data compared with previous water quality data collected before the 2000 change in reservoir operations (Hargis 1981, Kepner and Stottlemyer 1988, and Payne 1991).	Rank sum tests showed significant decreases in chlorophyll *a*, but not TP, for Kabetogama and Black Bay. Based on mean chlorophyll *a* trophic state index, Sand Point, Namakan and Rainy Lakes were oligotrophic to mesotrophic. Kabetogama Lake and Rainy Lake at Black Bay were mesotrophic, compared with eutrophic before the change in reservoir operations.	Excessive precipitation events in 2001 and 2002, and drought conditions in 2003, made meeting the new rule curve difficult; this complicated comparisons of water quality data collected here versus before the rule curve change in 2000. The authors advised continued monitoring, with emphasis on the historically well represented May and August sampling of TP and chlorophyll *a.*
Payne	2000	Water quality of lakes in Voyageurs National Park, Northern Minnesota, 1999	VOYA: 7 sites (of original 41 in Payne 1988). Collected July 1999.	Water quality suite including Secchi transparency, trace metals, fecal coliform bacteria, chlorophyll *a* and *b.* Results compared with data collected during 1977-1984.	Most water quality parameters comparable to the results from 1977-1984. Oxidized nitrogen concentrations generally lower relative to 1977-1984, and phosphorus concentrations lower at 2 sites. Chlorophyll and most trace element concentrations were lower than in 1977-1984.	The comparisons made here may be of limited use due to the lack of monitoring data since 1984 and the one-time nature of the 1999 sampling. Author indicates the 1999 samples may have been influenced by heavy rains at some sites.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
					Fecal coliform counts were within standards.	
National Park Service	1995	Baseline water quality data inventory and analysis: Voyageurs National Park	VOYA and parts of surrounding area.	Report summarizes results of extensive data retrieval efforts using Environmental Protection Agency databases and addressing the entire period of record.	# water quality observations: 17,935 # parameters: 316 # monitoring stations (study area/park): 98/72 # parameters with exceedences (study area/park): 9/8 # stream gages (study area/park): 1/1 # dischargers: 0 # drinking water intakes: 0	Authors concluded that water quality at VOYA water quality was generally good, with some impacts from anthropogenic stressors like atmospheric deposition.
Payne	1991	Water quality of lakes and streams in Voyageurs National Park, Northern Minnesota, 1977-84	VOYA: 41 total sites; several large lakes, 19 interior lakes, and 2 rivers. Varied sampling frequency.	Water chemistry suite, chlorophyll *a*, vertical profiles, Secchi depth, phytoplankton composition and abundance, trophic state, sediment nutrients and trace elements. Seasonal changes examined.	Sand Point, Namakan and Rainy Lakes oligotrophic to mesotrophic; Kabetogama, Black and Sullivan Bays eutrophic (calcareous drift). Blue-green algae blooms noted in nutrient-enriched bays and lakes. Secchi depths limited by water color. Some sites exceeded criteria for oil and grease, phenols, sulfide and ammonia. Interior lakes stratified and had low nutrients, alkalinity and conductance; conditions which are sensitive to acid precipitation. Ash River water quality poorer than that of Namakan River, due to sediments and nutrients.	Study represents a useful baseline for aquatic resource conditions in VOYA. Inconsistent sampling frequencies and intensities at various sites complicate interpretation somewhat. A strong point of this study is its breadth in terms of sampling sites and parameters.
Kepner and Stottlemyer	1988	Physical and chemical factors affecting primary production in the Voyageurs National Park lake system	VOYA: Rainy, Namakan, Kabetogama and Sand Point Lakes; 2 stations in each. Monthly, summers 1985, 1986.	Water samples collected at each site at 1 m and 10 m depths, for alkalinity, pH, TOC, TKN, and major ions. Depth profiles determined for light, dissolved oxygen and temperature. Primary productivity measured using in situ ^{14}C method, and chlorophyll *a* measured spectrophotometrically. Phytoplankton samples collected in 1985 only.	Water chemistry and algal biomass and productivity were different (higher) in Kabetogama than in other VOYA lakes. Differences in Kabetogama were attributed to its distinct morphology and disproportionate effects of the 3 m drawdown on it. Authors speculated that drawdowns affected nutrient availability by concentration and dilution of chemical constituents, as well as by decomposition of affected aquatic vegetation.	This study represents a solid piece of water quality work for Voyageurs, encompassing several sites on the large lakes and spanning the ice-free season.
Payne	1979	Water-quality reconnaissance of lakes in Voyageurs National Park, Minnesota	VOYA: large lakes, 11 sites with paired near-shore/mid bay samples. March, August 1977.	Water quality: Samples collected and analyzed for common cations and anions, physical properties and nutrients. Phytoplankton: Collected; density and composition determined. Bottom sediment: Collected and analyzed for carbon and nutrient content.	Water quality: Generally low conductivity, high dissolved oxygen (near 100%), and moderately hard water alkalinity. Nutrient concentrations varied among sites. Phytoplankton: Variable among sites, but *Oscillatoria* common. Bottom sediment: Variable substrates across sites and between paired sites.	Author notes significant spatial and seasonal variability. Author provides suggestions for a monitoring program that: · Focuses on nutrient enrichment · Is attentive to emerging issues · Increases numbers of sites sampled. · Samples more frequently if using short-lived bioindicators like phytoplankton. Data provided in appendix.
Biology & Ecology						
Nevers and Whitman	2004	Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks	VOYA, ISRO, PIRO, SLBE, INDU; 2 lakes each park. Monthly during growing season, May or June-September, 2 years.	Phytoplankton sampled from 1 m depth and analyzed for composition, species richness, Shannon-Wiener diversity and species evenness. Water quality suite measured using YSI sonde and Kemmerer sampler. MDS ordination of Bray-Curtis Similarity for	Collected 176 phytoplankton taxa from all lakes. Diatoms and chlorophyte taxa most common. INDU lake dominated by euglenoids. SLBE lakes dominated by diatoms. PIRO lakes dominated by chrysophytes and diatoms. Northern lakes had variable composition. Northern lakes clustered together in terms of	Study provides some useful background and baseline phytoplankton information for these lakes. Non-random lake selection limits inference to the larger set of lakes at each park. Dataset could be explored further to: · Show how seasonal patterns differ among lakes. · More thoroughly describe grouping patterns

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
				mean water chemistry and individual species counts, phytoplankton species counts for each sample, and combined species counts and water chemistry variables for each sample.	chemistry and composition.	among lakes in terms of phytoplankton composition and water chemistry. · Provide more park-specific insights.
Hoven	1998	Zebra mussel monitoring program for Voyageurs National Park, 1998	VOYA: near visitor centers. 1998.	Conducted 3 plankton tows and contents examined for zebra mussel veligers. Substrate samplers installed.	Samplers lost or vandalized at 2 visitor centers. No veligers found in plankton tows. Author concludes zebra mussel invasion seems a slim possibility, but recommends monitoring docks and boats, keeping an eye out for other invasive species, and increasing public education efforts.	An analysis that addresses likelihood of invasions by zebra mussels, spiny water fleas, rusty crayfish, etc., should be conducted and used to address monitoring and research needs.
Kallemeyn et al.	1993	Rehabilitating the aquatic ecosystem of Rainy Lake and Namakan Reservoir by restoration of a more natural hydrologic regime	Rainy Lake and Namakan Reservoir ecosystem	Report uses previously collected data on water quality, aquatic macrophytes, benthic invertebrates, loons, aquatic mammals, and fish.	Alternative rule curve presented and analyzed. Phosphorus would be expected to decline from 34 to 30 µg/L under proposed rule curve changes. Aquatic vegetation structure and diversity would improve under proposed rule curve changes. Benthic invertebrate diversity and density, loon nesting and reproductive success, fish spawning habitat and reproductive success, and furbearer densities should be improved by new rule curves.	A useful summary of available data related to ecosystem components and lake level fluctuations.
Kallemeyn	1992	An attempt to rehabilitate the aquatic ecosystem of the reservoirs of Voyageurs National Park	Rainy Lake and Namakan Reservoir ecosystem	Paper presents previously collected data on water quality, aquatic macrophytes, benthic invertebrates, loons, aquatic mammals, and fish.	Addresses the findings noted in Kallemeyn et al. (1993). Discusses the development of management or rule curve alternatives.	Continued monitoring and interagency/international coordination needed.
Kallemeyn	1990	Reducing the impacts of regulated lake levels on the aquatic ecosystem of Voyageurs NP	Rainy Lake and Namakan Reservoir ecosystem	Describes the history of lake level studies, researchers involved, components investigated, and approach to solving the problem.	Research findings summarized. Process of analyzing management alternatives using hydrologic modeling described.	–
Kraft	1988	Effects of increased winter drawdown on benthic macroinvertebrates in Namakan Reservoir, Voyageurs National Park	Rainy Lake and Namakan Reservoir ecosystem. 1983-1986	Benthic macroinvertebrates collected at depths of 1, 2, 3, 4, and 5 m at each site. Water chemistry, primary productivity, substrate organic content, invertebrate density, composition, diversity, equitability. Rainy and Namakan invertebrates compared.	Dead and stranded invertebrates found in Namakan during winter drawdown. *Asellus* common in Rainy Lake but absent in Namakan. *Caenis, Chaoborus,* Gastropoda, *Hexagenia,* and *Sialis* less dense in Namakan than Rainy. Invertebrate densities more variable in Namakan than in Rainy, and diversity values lower. Invertebrate density in Namakan negatively correlated with the amount of drawdown.	This is the primary piece of work addressing benthic invertebrate responses to lake level fluctuations at VOYA.
Kallemeyn	1983	Action Plan for aquatic research at Voyageurs National Park	VOYA, park-wide.	Primarily addresses issues with large lakes, since these receive the most activity in the park.	Stated that regulated lake levels and acid precipitation were identified as resource problems in VOYA Resource Management Plan. Also discussed recreational fisheries. Provided creel survey information indicating approximately 800,000 hours of angling time are expended on VOYA fishery annually. Listed the five research elements of proposed lake level investigations: · A study of the hydrology of Namakan Reservoir and Rainy Lake. · Analysis of the impact of fluctuating water levels on the littoral biota, including vegetation and benthic	One page article taken from *Park Science* Much more detail about VOYA aquatic research is found in other documents, but this presents a good synopsis of current and proposed aquatic research at the park in 1983.

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					organisms. · The fish community with special emphasis on walleye and northern pike. · Shore and marsh nesting birds. · Beaver and muskrat colonies.	
Hargis	1981	Ecological analysis of plankton communities of Voyageurs National Park	VOYA: Kabetogama, Namakan, Sand Point, and Rainy Lakes, 13 stations; and 20 small lakes on Kabetogama Peninsula. Summer 1978-1981.	<u>Water quality</u>: Samples collected at each site using a Van Dorn sampler at 3 depths; analyzed for specific conductance, water clarity, pH, alkalinity, nutrients. Carlson's Trophic State Index calculated. <u>Phytoplankton</u>: Collected and analyzed for chlorophyll *a.* <u>Zooplankton</u>: Collected using triplicate vertical tows from various depths and analyzed for composition and biovolume. Simpson's diversity and dominance indices calculated, Morisita's index of community similarity used for between-year comparisons. Photographic identification file produced.	<u>Plankton inventory</u>: No rare or unusual zooplankton species encountered. Ubiquitous species included *Holopedium gibberum*, a cold-water, low-alkalinity species, *Daphnia galeata, Diaptomus sicilis,* and *Cyclops bicuspidatus*. Lake Agnes lacked the otherwise ubiquitous *Bosmina longirostris* and *Diaphanosoma leuchtenbergianum*; probably due to lack of open limnetic area in this lake. Natural history information accompanies species list. <u>Ecological analysis</u>: Author grouped lakes according to water clarity, as clarity was negatively correlated with chlorophyll *a* and zooplankton production. Based on N:P, algal growth in most lakes P-limited, but 5 small lakes are possibly nitrogen-limited. <u>Environmental indices</u>: Interior lakes higher diversity, lakes appeared to develop similar communities each year.	If a single zooplankton sampling period must be chosen, author recommends mid-July since full development of cladoceran fauna occurs by then. For interior lakes, author suggests a single sampling site should be sufficient. For the large lakes, multiple sites needed. This study presents useful zooplankton baseline information in addition to some good ecological context.
Mayasich	1981	Field assays of phytoplankton community response to acidification	Lake Kabetogama. June, August 1980.	*In-situ* experiments conducted in 20-L glass carboys filled with epilimnetic waters and incubated for 72 hours. Two treatments, each with three replicates, acidified to pH 5.0 and 3.8, respectively. pH in control carboys was 7.2 in June and 8.5 in August.	Acidified carboys showed reductions in pH, alkalinity, chlorophyll *a,* but relatively constant nutrient concentrations. Acidification resulted in altered phytoplankton community composition, particularly reduced abundance of diatoms. Responses of phytoplankton community composition, gross photosynthesis, and respiration differed in June vs. August experiments.	These experiments subjected phytoplankton to high levels of acid stress over very short time periods; therefore, relevance to issues of chronic acid stress may be limited.
Sharp	1941	Report of the investigation of biological conditions of lakes Kabetogama, Namakan, and Crane, as influenced by fluctuating water levels	Rainy Lake and Namakan Reservoir ecosystem.	Area of lake bottom exposed during April 1941 drawdown estimated for each bay. Effects of drawdown on fish, waterfowl, aquatic plants, muskrats, bottom fauna, and lake front property assessed. Photographs provided.	<u>Fish</u>: Spawning conditions altered, available food reduced due to destruction of bottom fauna, eggs washed up during rising waters, stranding during low waters. <u>Waterfowl</u>: Nest flooding reported. <u>Aquatic plants</u>: Various forms noted. <u>Muskrats</u>: No muskrat houses noted, and trappers reported that low water levels and freezing drove them out. <u>Bottom fauna</u>: Most affected were crayfish, mayfly larvae, snails, clams, fingernail clams, midges, leeches, and frogs. Stranding and freezing evident. <u>Lakefront property</u>: High water levels flooded roads and cottage sites; low water levels required dragging boats to water's edge.	Results and data largely observational or anecdotal but provide a frame of reference for later lake level studies. Author concluded that angling for walleyed pike had not been affected, but pickerel and whitefish spawning had suffered and minnows were lost via stranding. Waterfowl nesting and feeding conditions were reduced, as were conditions for muskrats. Bottom fauna was destroyed in large areas by exposure and ice.
FISH						
Kallemeyn et al.	2003	Aquatic Synthesis for Voyageurs National Park	VOYA, park-wide.	Synthesis of existing work of all things aquatic at VOYA	Thorough coverage of fisheries investigations that have occurred in the park, including Minnesota Department of Natural Resources, Ontario Ministry of	(See additional review under general resource documents and plans.)

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					Natural Resources and NPS work.	
McLeod	2002	A fisheries assessment strategy for Rainy Lake and the Namakan Reservoir	Ontario waters: Rainy Lake and Namakan Reservoir.	Historic review of methodologies. Describes existing methods for various fisheries monitoring needs. Includes descriptions of fall walleye netting, creel surveys, commercial catch monitoring and other methods for fish population assessments.	Provides proposed sampling schedule for various basins of both waterbodies and species of interest. Also describes potential useful sampling methods not currently used, but that may prove useful under certain conditions or if additional information is desired.	Classic fisheries management monitoring protocols. Coordinated with Minnesota Department of Natural Resources and NPS efforts, this will provide a component of ongoing fisheries assessment information. Will be especially useful for lake levels monitoring efforts.
Sorensen et al.	2001	The effect of exotic rainbow smelt (*Osmerus mordax*) on nutrient/trophic pathways and mercury contaminant uptake in the aquatic food web of Voyageurs National Park: a benchmark study of stable element isotopes	VOYA: Rainy and Namakan Lakes. 1996-1997. Small lakes, 8 sites. 1997-1998.	Sampled for Hg comparisons. Concerns with mercury uptake resulting from potential dietary changes. Examined food web linkages through stable isotope ratios of C and N in plants, forage fish, walleye and northern pike.	Small differences between N values suggested that smelt were currently a small part of the diet of walleye and pike. Large range in Hg was observed in smaller lakes, and median Hg concentration in these lakes for pike was approximately 2x that of Rainy and Namakan Lakes. Ryan Lake had extremely high Hg level for pike; the highest recorded for Minnesota lakes at 4500 and 1900 ng/g in 1997 and 1998.	Authors suggested further study to address following: · Perform more detailed survey with refined age increments of yellow perch to determine why ^{13}C depletion in YOY perch is so different form older perch · Perform more extensive survey and analyses of clams to determine if smaller than expected change in ^{15}N per trophic level is result of unrepresentative sampling · Stable N isotopes should be studied in another large lake (e.g. Sand Point) to compare trophic positions of game fish when nor smelt are present · Stable isotope analyses for game fish and mussels from Rainy and Namakan Lakes should be surveyed after 5 to 10 years to assess any changes in diets related to smelt. (See additional review under contaminants category.)
Schlosser and Kallemeyn	2000	Spatial variation in fish assemblages across a beaver-influenced successional landscape	Kabetogama Peninsula; 12 drainages along southern edge. Once per year, 1993-1995.	Fish sampled at each site between mid-May and late July using unbaited minnow traps. Fish identified in the field and richness and catch-per-unit-effort (CPUE) calculated. 5 successional stages identified: · Upland ponds. Lowland ponds. · Collapsed ponds with partially rebuilt dams. · Completely collapsed ponds. · Streams.	Fish richness and abundance affected by geologic barriers at outlets of some drainages. Within drainages, fish abundance and richness varied locally with beaver pond succession. Abundance was highest in upland ponds and richness highest in collapsed ponds and streams. Richness also increased with proximity to Kabetogama Lake. Geomorphic boundaries and beaver pond succession interactively affected fish at VOYA.	Categories of ponds based on successional stage may be useful in future work. Authors state that to "assure a productive and diverse fish assemblage, then the entire mosaic of successional habitats associated with beaver activity needs to be preserved." Future studies might address benthic invertebrate variation along beaver pond successional gradients.
McLeod	1999	An assessment of lake sturgeon populations in the lower Seine River system, Ontario, 1993-1995.	Crilly Dam (Sturgeon Falls) downstream 40 km to Kettle Point entrance of Rainy Lake. Spring, summer 1993-1995.	Used gill nets to capture sturgeon; tagged with external disc anterior to dorsal fin and released at capture site. Objectives: · Determine relative abundance and population dynamics of sturgeon in lower Seine River. · Determine movement patterns in the river system and Rainy Lake. · Quantify native subsistence needs and current harvest levels · Assess impact of current exploitation levels on sturgeon stocks and recovery of stocks.	Tagged 48 fish; population estimates not possible due to low recovery of tagged fish. No fish were recovered in commercial, sport or subsistence fisheries since 1993. Only three fish captured during Minnesota Department of Natural Resources assessments indicating either a very low summer population or migrations out of river into Rainy Lake prior to assessments. Mean age of fish was 19.3 years with fish up to 42 years old captured.	Report suggests monitoring water levels to establish minimum flow guidelines. Minimum flows should only be a starting point with a goal of natural flows that at least mimic a natural regime being more desirable. Several other good recommendations made for follow-up investigations, including sampling for larval fish to determine reproductive potential.
Minnesota Department of Natural Resources	1998	Minnesota-Ontario boundary waters fisheries atlas for Lake of the Woods, Rainy River, Rainy	Lake of the Woods, Rainy River, Rainy Lake, Namakan Lake, and Sand	This is an update of a previous fisheries atlas from 1992. Sand Point Lake has been added to this document. Reports on status of fisheries resources from	Fisheries information includes annual harvest by user group, target level harvest and potential yield for walleye, northern pike, black crappie, smallmouth bass, lake whitefish and lake sturgeon. Angling effort	A thorough documentation of fisheries harvest and potential yield as well as socioeconomic benefits of fisheries. Focuses almost exclusively on highly sought game fish. There is some reference to other

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and Ontario Ministry of Natural Resources		Lake, Namakan Lake, Sand Point Lake	Point Lake. Fishery surveys 1990-1996.	ongoing surveys in listed lakes as well as socioeconomic evaluation of same areas. For Minnesota waters, user groups divided into Minnesota local residents, Minnesota non-local residents, and non-residents.	by user groups is also included. Socioeconomic analysis includes fishery user profiles, economy of local areas, and revenues generated by tourist and commercial fishing industries Also includes information on water level management of reservoirs, land management activities and exotic species introductions and possible implications.	species, but not much information. Future information that could be useful would be inclusion of effects of intentional and non-intentional exotics on native species.
Soupir et al.	2000	Trophic ecology of largemouth bass and northern pike in allopatric and sympatric assemblages in northern boreal lakes	–	See Soupir (1998).	–	Journal publication of master's thesis; see Soupir (1998) implications relating to VOYA.
Soupir	1998	Trophic ecology of largemouth bass and northern pike in allopatric and sympatric assemblages of Voyageurs National Park, Minnesota	VOYA: inland lakes; Locator-War Club complex, Jorgens, Loiten, Quill, Oslo, and Brown Lakes, six study locations. Sampled May, July, August 1996-1997.	Angling and gill nets used to collect fish. Intent was to determine interactions between largemouth bass and northern pike and effects of bass on coolwater fish assemblages. Study investigated food web structure. Focused on basic food habits, isotopic signatures, bioenergetics modeling and comparative evaluations of fish communities and lake variables.	Lack of larger northern pike indicates slow growth or harvest of large fish. Growth of northern pike slowed after age-3 indicating possible lack of larger prey in study lakes. Relative weight of pike also indicates predator/prey imbalances. Northern pike consumed largemouth bass in sympatric populations, but converse was not observed. Based on food habits and carbon and nitrogen analysis, the degree of dietary overlap in sympatric assemblages ranged from 30% to 94%. However, bioenergetics modeling indicated bass had little or no restructuring effect on pike in sympatric populations. Concluded that pike populations not likely affected by bass at current densities, but that bass are likely being restructured due to pike, angler harvest, and lack of spawning and recruitment habitat.	Very useful information since this investigation relates to one of the important issues of NPS fisheries management, exotic species. Indicates that at least in study lakes investigated, the exotic species of concern may not have excessive negative impacts to native species of concern. Future investigations of impacts of bass on species at different trophic levels would be helpful, since this investigation compares species at similar trophic level.
Kallemeyn and Warner	1995	Potential for reintroduction of northern pike to Beast Lake, Voyageurs National Park	VOYA: Beast Lake. USGS water quality samples, 1982 and 1990. Fishery assessments 1960, 1970, 1990, and 1994.	Water quality assessment included temperature, dissolved oxygen, alkalinity, conductivity, pH and transparency measurements, biweekly during open water season (n=11 in both years) Limnetic zooplankton samples taken in 1982 Fisheries information obtained from assessments in 1960, 1970, 1990 and 1994	Lake was poisoned with toxaphene in 1961 by Minnesota Department of Natural Resources to create rainbow trout fishery. Fish survey in 1960 indicated northern pike and white sucker were present; 1970 survey captured white suckers and stocked rainbow trout. In 1990 and 1994, white suckers were present, but no rainbow trout, although 1 northern pike and 1 walleye were also present. 4 cyprinid, 2 percid and 1 gasterosteid species captured in seine and minnow trap sets. Collected 1 crayfish and 11 zooplankton species.	Authors suggest that restoration of a northern pike population is feasible and could be accomplished through several means (e.g., various stocking schemes, natural immigration). Special regulations may be needed during restoration effort, especially if adult stocking occurs. Authors also suggest restoring northern pike would present excellent opportunity to assess impact of restoring a keystone predator to an aquatic system.
Duffy et al	1994	Potential influence of rainbow smelt (*Osmerus mordax*) on the Voyageurs National Park Ecosystem	–	Recommendations from 8 member advisory board for education, monitoring, and research needs pertaining to potential rainbow smelt impacts on other species and ecosystem function.	Several recommendations in form of guidance to park staff: Education: Develop exotic species education program. Evaluate need for additional legislation or regulations. Monitoring: Develop aquatic resources monitoring program to provide information on smelt and influence on biota at Voyageurs. Includes evaluating	Determine current status of smelt monitoring and whether, or not, recommendations have been implemented.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					different sampling gear, developing fish community sampling protocol, monitoring Hg bioaccumulation as affected by smelt, monitor food web composition, and monitor limnological conditions. Research: Encourage research that leads to a better understanding of aquatic resources in Voyageurs and possible impact of smelt on these resources. Includes research on potential changes in limnology, recruitment dynamics of native fish, distribution and consumption by piscivorous fish and birds, possible destabilizing influence of smelt on energy flow in and flux from area ecosystem, potential negative impact on park revenues and local economies.	
National Park Service	1994	Resources management plan, Voyageurs National Park.	VOYA, park-wide.	Discusses various components of fisheries management and factors affecting fisheries. Detailed 3 alternative actions outlined for fish management program. · A. Abandon NPS participation in fisheries management; Minnesota Department of Natural Resources would continue all management responsibilities. · B. Continue current management direction with limited NPS participation. · C. Implement comprehensive fisheries management program. NPS would increase participation in management, monitoring and research of populations and harvest levels.	Recommends adoption of alternative C: Implement comprehensive fisheries management program. Several management, monitoring, and research actions are listed in document. Many of these require continued or increased coordination between NPS, Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources	Fisheries component includes history of fisheries issues in waters of park covering at least last 100 years Follow-up investigations would help to determine which actions have been implemented or modified and to what extent.
Cohen and Radomski	1993	Water level regulations and fisheries in Rainy Lake and the Namakan Reservoir	Rainy Lake and Namakan Reservoir.	Used commercial fisheries catch data for waters studied, except Rainy River, where Minnesota Department of Natural Resources data was used. Obtained daily water levels from Water Survey of Canada since 1911. Used water level data from Lac LaCroix, an unregulated lake approximately 100 km southwest of Rainy Lake for baseline water level information.	Determined that water level regulations affected frequencies and amplitudes of fluctuations in range of yearly maximum and minimum water levels compared with natural fluctuations. Also identified a clear link between changes in yearly range of maximum/minimum levels and changes in commercial fish catches. Also indicated 5 year moving variance of yearly max/min fluctuates regularly with periods of about 11.2 years (periodicity of sunspot cycles). This reflects the effects of within-year consecutive periods of storms and dry spells.	Authors suggest that fisheries managers should strive to maintain a certain amount of fluctuation in fish populations and not focus on population mean as indicator of population health. This is a somewhat complex analysis of lake level fluctuations and synchronization of fisheries population fluctuations.
Cohen et al.	1993	Assessing the interdependence of assemblages from Rainy Lake fisheries data	Rainy Lake: South Arm in both Minnesota and Ontario, Redgut Bay and North Arm. Data from long-term index studies.	Attempted to quantify differences among fish communities by analyzing data that was collected inconsistently over several years. Examined species diversity over time, identified synchronization in fluctuations of relative catch per effort between pairs of species. Examined ciscoe, walleye, sauger, yellow perch, white sucker, and northern pike.	In less disturbed communities, walleye contributed most to synchronization in fluctuations of yearly relative CUE among six common species. In more disturbed locations, contribution was primarily due to yellow perch and sauger. Disturbed community in one location exhibited decrease in species diversity. Of all locations, the dynamics of species assemblages in the North Arm was the most unique, and both locations in South Arm were similar.	Authors emphasized that this was a retrospective study and alternative analyses of data may provide different results. Determined that in large lakes, it may be necessary to identify local fish communities and address management problems locally. Need to find out if Minnesota Department of Natural Resources or NPS adopted this strategy for large lakes of VOYA.
Radomski	1990	Loiten Lake largemouth	Loiten Lake, during	Used angling to capture bass and temporarily	Angler catch rates increased from May 31 to June	Returns of volunteer creel cards indicate largemouth

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		bass population evaluation using angling and a recreational survey of the Locator chain of lakes.	spawning of largemouth bass. Spring, 1989.	mark fish with hole punch in pectoral fin. Recapture effort restricted to one day of effort, June 16, 1989. Volunteer angler cards issued to anglers that requested use of park watercraft for Locator chain of lakes.	20, probably as a result of increased nesting activity during the period. Captured 72 fish for age and growth analysis. Six age classes captured with mean age of 4.3 years. Growth was comparable to some Canadian lakes with growth estimates, but slightly below state average. Estimated population at 240 catchable sized bass, or 2.6 fish per surface acre. Volunteer creel cards indicated largemouth bass were captured in all lakes of Locator lake chain. Release rates were high for all lakes, ranging from 63.9 to 91.3%. Anglers released 82.6% of bass captured at Loiten Lake	bass populations could be easily over-exploited. Author recommended catch and release regulations on Loiten Lake, but Voyageurs may want to consider other possibilities in light of NPS policy on exotic species, since largemouth bass are introduced in this area. If bass compete with native species such as northern pike, then restrictive regulations that protect bass might not make sense.
Kallemeyn	1990	Recreational use and fishing pressure on the interior lakes of Voyageurs National Park, 1989	VOYA: 13 inland lakes. June-August, 1989	Follow-up to 1983 survey in which 24 of 26 inland lakes were surveyed by air. Routine ranger patrols, stratified according to month and day type (weekend/weekday) with day and time selected randomly. Rangers determined whether or not to travel into lake based on evidence of use at portages. Second method used visitor center records on use of park-owned boats on 5 lakes. Angler cards were provided to visitors that used park-owned boats.	Efficiency of survey relative to detecting use appeared to be low. Use appears to be underestimated based on concurrent effort from cabin owners reporting use on Net Lake. 37% of angler report cards (16 of 43) distributed by rangers were returned. 45% of cards (91 of 200) distributed at visitor centers were returned. Report cards usually positively biased.	Author suggests that comparative surveys using boat registration along with ranger and aerial surveys would provide indices of use. This would require several seasons of comparative surveys to determine effort needed for accurate indices. Most efficient method to monitor use without extensive comparative surveys would be with data from boat registration program. Report card method needs improvement in order to assure return of cards by unsuccessful anglers.
Kallemeyn	1990	Impact of sport fishing on walleye in Kabetogama Lake, Voyageurs National Park	Kabetogama Lake., May-September 1983-1985	Effort determined by aerial counts stratified by day type. Creel survey conducted by Minnesota Department of Natural Resources provided information on catch rates, size and age of walleye. Walleye in spring spawning population were tagged to provide additional population statistics	Effort: 367,670 hours in 1984 and 361,687 in 1985, or approximately 35 angler hours/ha. Annual harvest of approximately 45,000 walleye. Primary component of harvest were 2-5 year old fish. Tagged male and female walleye were exploited at similar rates. Harvest and effort were significantly less than reported in 1977 (44 angler hours/ha; 73,202 fish) 1978 (58 angler hours/ha; 138,306 fish) creel surveys.	Harvest exceeded level that boreal lakes appear capable of sustaining, but is comparable to yields reported from other Minnesota waters. NPS fisheries policy dictates that in natural areas mortality be compensated for by natural production with either increased reproductive success or reduced harvest (i.e. no stocking). Author suggests that reduced harvest may be necessary if exploitation increases from current levels. Also suggested yearly monitoring to determine exploitation rates so timely management actions could be implemented. Modifications to lake level fluctuations may improve walleye spawning success.
Kallemeyn	1989	Loss of Carlin tags from walleyes	Walleye spawning period. Spring 1984-1985.	Tagged and fin clipped 1796 walleyes in 1984, and 2498 in 1985. Continued sampling spawning run through 1987 to determine population statistics and check for tag retention.	Estimated annual tag loss of 24.2%. Correction for observed tag loss resulted in increased estimates of first-year exploitation of age-3 and older male walleyes by 27%; increased estimated survival rate from .35 to .44; decreased estimated population size by 8.5%.	Useful information not only for VOYA-specific investigations, but can be applied to fisheries population work being conducted anywhere. Information on improved tagging methods developed since this study would be useful. If none exists, there are opportunities for developing better means for estimating walleye populations.
Kallemeyn and Cole	1988	Alternatives for reducing the impacts of regulated lake levels on the aquatic ecosystem of Voyageurs National Park	–	Reports on research program initiated by VOYA to assess effects of present water management program on park aquatic ecosystem and to develop a hydrological model for assessing effects of alternative regulatory programs on power generation. Several alternatives were ultimately developed.	Recommended alternative that would restore more natural conditions on Namakan Reservoir but not on Rainy Lake. This alternative was chosen because more natural hydrologic conditions on Rainy Lake during summer drawdown would result in unacceptable losses of hydropower production. However, upgrading of turbines at International Falls	Only the executive summary was available for review; however, the full document will be useful for comparative purposes following implementation of new rule curves. A study that thoroughly examines potential effects of upgrading turbines at International Falls dam and potential for implementing other alternatives may be

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					dam may allow for implementation of other alternatives that more closely mimic natural fluctuations on Rainy Lake without serious impacts to hydropower production.	useful.
Kallemeyn	1987	Effects of regulated lake levels on northern pike spawning habitat and reproductive success in Namakan Reservoir, Voyageurs National Park	Kabetogama Lake: Daly Brook and Tom Cod Creek deltas. 1983-1985	Conducted topographic surveys of deltas for 1 ft contours in 1983, prior to spring flooding of reservoir, surveyed cover that may be available when submerged after flooding. Estimated northern pike production with YOY catches from June through August	All wetland or apparent northern pike spawning areas in Namakan Reservoir are routinely de-watered by late March or early April. Over 90% of emergent vegetation occurs above 1115 ft msl; flooding this habitat to preferred spawning substrate/vegetation would require a 5-6 foot water elevation increase. Northern pike reproductive success was higher in years when this occurred. This wouldn't occur in most years under 1985 rule curves	Date of report was not found on copy available; deduced earliest possible completion date from dates of references cited. This should be useful comparative information for evaluation of rule curve changes during upcoming fisheries investigations.
Ernst	1986	Commercial fishing summary, Minnesota waters of Namakan Lake, 1986.	Namakan Lake.	Tables of catch, catch per effort, mean value per pound and approximate value of tullibee, whitefish, burbot and white sucker. The only 2 active, licensed commercial fishermen each fish 3500 ft of gill net.	Total dollar value of four species: 1986: $1001.90	This information would be much more useful combined with other assessment information.
Ernst	1986	Commercial fishing summary, Minnesota waters of Rainy Lake, 1986	Rainy Lake.	Tables of catch, catch per effort, mean value per pound and approximate value of tullibee, whitefish, burbot and white sucker. The only 2 active, licensed commercial fishermen each fish 4000 ft of gill net..	Whitefish was only species reported as sold; total value: $7531.20. Three fishermen took buy-out offer in 1985 from State of Minnesota for a cost of $52,899.99.	This information would be much more useful combined with other assessment information.
Cole	1986	Reducing impacts from regulated lake levels in Voyageurs National Park	–	Summarizes results of research conducted since 1979 to assess effects of regulated lake levels, and to develop a computer model to predict effects of regulation changes on aquatic biota. References three reports from Kallemeyn investigating lake level effects on northern pike spawning in Namakan Reservoir, impacts on walleye and yellow perch in Namakan and Rainy Lake, and effects of fishing on walleye in Kabetogama Lake.	For all species concerned, in all waterbodies, modification to current flow regulations were suggested that would likely have positive effects on northern pike spawning habitat, and yellow perch and walleye YOY productivity. Fishing pressure at Kabetogama exceeding boreal lake estimated sustainable harvest levels slightly; combined with several consecutive years of unfavorable spawning conditions (due to water level regulation), could cause declines in walleye populations.	Author recommends modifications to flow regulations. Draft document, only, was available for review; therefore, no figures were attached that indicated what current (1985) levels are.
Ernst	1985	Commercial fishing summary, Minnesota waters of Namakan Lake, 1985.	Namakan Lake.	Tables of catch, catch per effort, mean value per pound and approximate value of tullibee, whitefish, burbot and white sucker. The only 2 active, licensed commercial fishermen each fish 3500 ft of gill net.	Total dollar value of four species: 1985: $2,006.66	This information would be much more useful combined with other assessment information.
Ernst	1985	Commercial fishing summary, Minnesota waters of Rainy Lake, 1985	Rainy Lake.	Tables of catch, catch per effort, mean value per pound and approximate value of tullibee, whitefish, burbot and white sucker. The only 2 active, licensed commercial fishermen each fish 4000 ft of gill net.	Whitefish was only species reported as sold; total value: $6178.46. Three fishermen took buy-out offer in 1985 from State of Minnesota for a cost of $52,899.99.	This information would be much more useful combined with other assessment information.
Kallemeyn	1985	Voyageurs National Park Aquatic Research	VOYA: Kabetogama, Namakan, Sand Point, and Rainy Lakes.	Compendium of progress reports of 4 studies that are part of VOYA aquatic research program, and 5 investigations conducted by contracted researchers.	Results of the 4 VOYA fisheries investigations are reviewed separately in this table. Investigators' annual reports are included for: · Analysis of fluctuating water levels on littoral biota of Namakan Reservoir and Rainy Lake, VOYA · Analysis of lake level fluctuations at VOYA	Progress report and summary of VOYA aquatic research.

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					· Investigation on the effects of regulated and natural water fluctuations on the species diversity, distribution and reproductive success of marsh and shoreline nest species in VOYA · Effect of drawdown on benthic macroinvertebrates in VOYA · Studies of beaver and muskrat response to over-winter drawdowns.	
Kallemeyn	1985	An evaluation of fishing pressure on Kabetogama Lake, 1983-1984 and Rainy Lake, 1984.	VOYA: Kabetogama Lake, portion of Rainy Lake within VOYA. 1983-1984.	Used aerial angler counts to obtain estimates of fishing pressure on both lakes, May-September. Also used rangers' counts of boats while on routine patrol.	Total fishing pressure on Kabetogama: Estimated from aerial counts: 1983: 366,921 ± 65,000 anglers hours 1984: 367,670 ± 53,202 Estimated from ranger counts: 1983: 293,142 1984: 342,544 1983 ranger count estimate was below aerial count 95% confidence limit. Rainy Lake estimates 1984: From aerial counts: 66,863 ± 11,713hours From ranger counts: 79,050; above aerial count 95% confidence limit. Rainy Lake total fishing pressure was only 18% of Kabetogama, even though sampled area was larger.	No management recommendations given but provides good comparative information for future surveys.
Kallemeyn	1985	An evaluation of the walleye, Stizostedion vitreum vitreum (Mitchill) population in Kabetogama Lake, 1984	Kabetogama Lake. April 27-May 20 1984.	Mark recapture during spawning migrations used to generate population estimate of walleye. Used frame nets and electrofishing to capture and tag walleye. Used Carlin tags with instructions for return. Resorts and creel clerks then recorded marked and unmarked fish to generate separate population estimates. Principal objectives are to estimate number of walleye, determine age structure and growth rate of population, assess movement patterns, and calculate fishing and natural mortality rates.	Female walleye grew faster than males, as in many other walleye populations. Growth rate for Kabetogama Lake is faster than in many other northern Minnesota lakes. 80% of fish tagged were less than 9 years old, although males up to 15 and females up to 13 were tagged. Dominant age class for males was 5 and 4 year olds with 8 and 6 year old fish dominating the female population. Population estimates male and female: Resorts: 179,404 (CI=138,714-231,778) Creel census: 191,996 (CI=95,318-419992) Most movement was within a few kilometers of tagging site. Half of fish were recaptured within 3.2 km of tagging site. Mean distance moved was 4.3 km. 2 fish caught outside Kabetogama in Kohler Bay, and Black Point, Namakan Lake. 1 fish moved at least 26 km.	Confidence interval for creel survey was broad due to relatively low number of tags returned. Author cautions that due to large confidence limits, estimate should be considered as approximate only. See Kallemeyn (1989) for follow up investigation.
Kallemeyn	1985	Relative abundance and species composition of adult fish in Kabetogama, Namakan, Sand Point, and Rainy Lakes, 1983-1984	Kabetogama, Namakan, Sand Point and Rainy Lakes. September, October 1983-1984.	Standardized gill net sampling (per Minnesota Department of Natural Resources Large Lake sampling protocol). Set 250 ft experimental gill nets at 20 stations on Rainy, Kabetogama, and Namakan Lakes, and at 15 stations on Sand Point Lake.	Collected 15 species collected in 1983 and 1984, of which 13 species were collected in two or more of the lakes. Only lake sturgeon and mooneye were collected in a single lake.	Author recommends continuing sampling method on annual basis, however additional sampling will be necessary to provide indices for species not adequately sampled by gill nets. Determine if Minnesota Department of Natural Resources large lake sampling protocol is still in use for VOYA waters, and if there is concern from the public regarding annual gill net surveys.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
Kallemeyn	1985	Abundance of young-of-the-year and small fish in Kabetogama, Namakan, Sand Point, and Rainy Lakes, 1984	VOYA: large lakes. Kabetogama Lake, 16 sites; Namakan Lake, 12 sites; Sand Point Lake, 10; Rainy Lake, 12. Biweekly, June 18-August 30 1984.	Seine hauls used to sample littoral area. Seine was 100 ft x 8 ft; anchored at shore perpendicular to shore and hauled in arc with net fully extended. Large fish were counted and measured in field. All other fish preserved in formalin and identified in laboratory. YOY darters were not identified to species. Attempted to measure at least 50 individuals of principal species.	Yellow perch were dominant species in all 4 lakes comprising between 42-78% of catch. YOY perch made up over 90% of perch catch in all lakes except Sand Point where they contributed 79%. Second most important group in Kabetogama and Rainy Lakes was cyprinids. Centrarchids were second most abundant group in Sand Point Lake, and catostomids, mostly white suckers, were second most dominant in Namakan Lake. Noted a major decrease in abundance of black crappie YOY in Sand Point Lake compared to 1983 efforts. Feeding habits of walleye also reported. Johnny and Iowa darters were most commonly identified prey in YOY walleye stomach samples.	Author suggests that this annual effort, which began in 1981, is beginning to provide good data to assess year-class strength, changes in abundance and growth. Indicates that spring spawning species such as yellow perch, walleye and white suckers in Kabetogama are apparently being influenced by the same factors. Such information is useful for management recommendations such as lake level manipulation and flow modifications.
Aquatic Wildlife						
Smith and Jenkins	1994	Population dynamics of beavers in two unexploited populations	VOYA, 2 large lake sites, 1984-1986; inland sites, 1991-1993. APIS, 2 island sites, 1988-1989.	Live-trapping in September or October. Beaver tagged, sexed, and measured for mass, length, zygomatic arch, tail length, and width and length of hind foot. Age classes assessed. Forest composition determined using 30 m transects perpendicular to the water's edge.	Total of 804 beavers captured. Age structure and number of kits per family differed between VOYA and APIS, but family sizes were similar. Recruitment did not occur in beaver colonies that were resource limited. Populations were biased toward females. Aspen abundance and population density likely affected sex ratios, with higher male mortality at higher densities. Trend is toward fewer, entrenched family colonies rather than numerous, small, productive colonies.	More thorough data presentation and analysis is desirable. Authors addressed management implications of their study and suggested that regional population trajectories should help guide management decisions. Authors suggested future studies using molecular techniques to examine beaver social structure and polygyny, and adaptive management experiments.
Smith	1994	Dispersal and cooperative breeding in beavers	VOYA: beaver colony sites. Fall 1994.	Trapped 62 active beaver colonies and surveyed for vegetation/habitat; 31 inactive ponds also surveyed. Radios implanted in 34 beavers. Pond observations made.	Captured 534 beavers. 13 of the radio-collared beavers dispersed, 20 did not.	–
Johnston and Naiman	1990	Aquatic patch creation in relation to beaver population trends	Kabetogama Peninsula.	Examined 6 series of aerial photographs, 1940-1986. Size and growth rates of individual patches determined. Numbers, area, density and establishment rate of the patch population calculated.	Rate of patch formation higher during first 2 decades of colonization than the next 2 decades. Average area of new ponds created decreased over time, and appears constrained by geomorphology, which limited availability of sites where large areas could be impounded. Early establishment related to larger pond sizes. Rate of new pond creation prior to 1961 greatly exceeded the increase in beaver colonies.	Authors say beaver population peaked in 1981 and predict that new pond establishment will eventually cease, restricting beaver disturbance to already disturbed areas. If new photos and beaver data have become available since 1986, the patterns and trends suggested in this study should be explored further, incorporating the new data.
Johnston and Naiman	1990	The use of a geographic information system to analyze long-term landscape alteration by beaver	Kabetogama Peninsula: 741 beaver ponds, 46-year period of record.	Examined 6 series of aerial photographs, 1940-1986. Impoundment hydrology and vegetation distributions assessed for each map date. Sediment cores from 9 impoundment areas analyzed for total and plant-available nitrogen.	Total area impounded increased from 1-13% between 1940 and 1986. Beaver population increased from near 0 to 1 colony/km^2. Most of the impoundment area increase occurred during first 2 decades. Nitrogen stocks tripled from 1940-1986.	GIS very useful tool for analyzing spatial and temporal changes on landscape scales. A follow-up study investigating further changes during the past two decades would be useful.
Naiman et al.	1988	Alteration of North American streams by beaver	Review paper; included VOYA study sites.	History of beaver in North America. Stream channel alterations. Riparian zone alterations.	Paper synthesizes knowledge of how beaver affect stream structure and dynamics from many studies, drawing substantially on studies conducted at VOYA.	Authors present a conceptual model of how beaver affect the landscape on Kabetogama Peninsula, which represents a useful framework for considering

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				A spatial and temporal mosaic. Changing image of stream ecosystems.		beaver/landscape dynamics.
Reiser	1988	Effects of regulated lake levels on the reproductive success, distribution and abundance of the aquatic bird community in Voyageurs National Park, Minnesota	VOYA: Large lakes; 6 sites, biweekly. Inland lakes; 8 sites, 1-3 week intervals. May-September 1983-1986.	Potential loon and grebe territories determined from past survey records and populations surveyed by boat. Marsh avifauna surveyed by sight and song. Nests found by intense searches in marshes. Nests monitored weekly except for loons. Nest site characteristics recorded and lake levels monitored.	Loon reproductive success higher in Rainy Lake than Namakan Reservoir lakes. Loon and grebe populations at VOYA lower than populations on nearby non-regulated lakes. Greatest loon nest losses due to rising water levels (60% losses on Rainy Lake, 71% losses on Namakan Lake, 0% losses on interior lakes). Significant proportion of failed loon and grebe nests explained by June lake level changes.	Author recommends that water levels should peak by the first week of June and remain stable through mid-July to improve reproductive success of aquatic avifauna.
Route and Peterson	1988	Distribution and abundance of river otter in Voyageurs National Park, Minnesota	Rainy Lake and Namakan Reservoir, April 1985-March 1987.	Otter live-trapped, fitted with radio transmitters, and monitored for breeding, productivity, and mortality. Home range areas estimated, diets analyzed from scat, and relative abundance estimated for Rainy and Namakan. Track surveys conducted in winter 1986-1987. Mercury analyzed from fur samples.	Productivity averaged 2.6 per breeding female. Home range area varied from 0.64-29.13 km^2 for a yearling female in winter to an adult male in summer. VOYA supported relatively high otter densities. Otter diets included fish and crayfish, with use of crayfish higher on Namakan, due to drawdowns. Otters shifted their home ranges to deeper water during winter drawdown, especially in Namakan. Mercury in one individual's fur was the highest concentration recorded for otter in North America at the time.	Author noted that otter are apex, resident predators in aquatic environments, and as such would make good bioindicators. Author also noted that crayfish are key prey for otter, key aquatic food web components, and could be useful for mercury monitoring.
Smith and Peterson	1988	The effects of regulated lake levels on beaver in Voyageurs National Park	September 1984-May 1987.	Beavers captured in Hancock live traps and measured, sexed and tagged. Movement, growth rate and over-winter weight loss determined from recaptures. Colony size and reproduction determined. Radio transmitters implanted in 26 beavers to monitor behavior and mortality factors. Beaver trends since 1900 estimated from aerial photos and trapper interviews. Food and water conditions quantified.	Detected 506 active beaver lodges in park, 391 inland, where beaver family size averaged 5.8. Number of active lodges on Kabetogama Peninsula increased greatly since mid-century. Pattern of beaver activity changed during winter drawdown: lodges and food caches dried up, beavers constructed canals and wood chip nests under ice, and some beavers foraged on land after abandoning lodges. Altered conditions and behavior resulted in losses due to predation and starvation. Family size and kit production reduced in drawdown and poor habitat locations.	Authors recommend a more natural hydrologic regime with minimal winter drawdowns (<0.5-0.7) to allow beavers to remain in lodges over winter.
Thurber and Peterson	1988	Effects of regulated lake levels on muskrats in Voyageurs National Park	VOYA: 5 bays and 2 creeks with suitable muskrat habitat. 1985-1987.	Muskrats captured in Tomahawk live traps, weighed, measured and tagged. Sign surveys, house counts, and radiotelemetry (11 muskrats) also conducted.	Muskrat habitat and population characteristics, mortality compared in Rainy Lake vs. Namakan Lake. Body measurements similar. Density estimates indicated higher densities in minimal drawdown areas. Overwinter survival of radioed muskrats very low, especially during freeze-up in early winter.	Authors conclude that lake-level related impacts on muskrats could be reduced under a more natural hydrologic regime with a partial drawdown of 1 m in early fall and further drawdown during winter, which would encourage deeper water muskrat houses and reduce food shortages and above-ice foraging time.
AMPHIBIANS AND REPTILES						
Palmer	1989	The reptiles and amphibians of Voyageurs National Park	VOYA: locations along large lakes, including Ash River and Rainy Lake Visitor Centers. Summer 1988.	Amphibians collected and identified using pitfall traps, dip nets and opportune searches with trap nets and seines.	Pitfall traps less effective than dip nets and opportune catches. Results divided into those species definitely in the park (n=10), those probably in the park (n=8), and those possibly in the park in small numbers (n=5).	Survey represents a good start, but does not include any inland habitats or provide much ecological or site-specific information. More intensive USGS Amphibian and Reptile Monitoring and Inventory studies at VOYA are ongoing (2004).
WETLANDS AND AQUATIC VEGETATION						
Hop et al.	2001	Voyageurs National Park	VOYA, park-wide.	Aerial photography flights conducted in 1995-	Aquatic or semi-aquatic vegetation classes included:	Part of NPS service wide program.

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		vegetation mapping project for the USGS-NPS vegetation mapping program		1996. Field work conducted to identify and classify vegetation; both aquatic and terrestrial. Geospatial data assembled and mapping conducted. Aerial and ground photographs and interpretations provided.	shrub bog, treed bog, shrub fens, gramminoid fens, wet meadows, emergent wetlands, rooted and floating aquatic marshes, rich hardwood swamps, rich conifer swamps, poor conifer swamps, and northern shrub swamps. Subcategories were identified for each of the above classes. Emergent wetlands were most common along Black Bay of Rainy Lake; forested swamps and bogs were most common south and west of Black Bay and Kabetogama Lake.	Study represents the most comprehensive and sophisticated aquatic vegetation study available to any GLKN park, other than ISRO, for which a similar study was completed, and will be useful for some time into the future. All mapping products and text are available online.
Grim and Leland	1998	1997 purple loosestrife (*Lythrum salicaria*) management report for Voyageurs National Park, International Falls, Minnesota	VOYA: loosestrife-invaded sites. Summer 1992-1997.	RODEO (glyphosate) mixed with CIDE KICK II (limonene) sprayed on loosestrife plants, while avoiding other plants. Informational signs placed. 13 plots established and monitored for loosestrife plants (numbers, ages).	Herbicide applications affected 3-4 year old plants more than 1-2 year olds, and effects were more readily distinguished.	Authors note that high costs and safety considerations might require alternative loosestrife control methods, such as biological control.
Pastor et al.	1996	Species-area curves and diversity-productivity relationships in beaver meadows of Voyageurs National Park, Minnesota, USA	VOYA: Bluefin and Shoepack Valleys; 4 meadows.	Established 3 plots each in each of 4 meadows, for nested quadrat sampling (0.25, 1, 4, 9 m^2). Water table depth, above ground biomass, soil nutrient data obtained. Plants in quadrats identified recorded.	Species-area relationships established for both grass and sedge sites. Parameters of the species-area power function not correlated with water table depth nor soil nutrients. Diversity-productivity relationships sensitive to plot size.	–
Bridgham et al.	1995	Potential feedbacks of northern wetlands on climate change	Kabetogama Peninsula. 1940-1988.	Draws upon previous GIS work by Johnston and Naiman to estimate how changes in amounts and types of VOYA wetlands have affected methane production.	Wetland acreage and type changed between 1940-1988, with increases in ponds and marsh types and declines in shrub and forested swamps. Methane production would have increased 3.7-fold. Relatively small landscape changes can greatly affect ecosystem processes.	Interesting piece of work linking landscapes, microbial processes, and climate.
Updegraff et al.	1995	Environmental and substrate controls over carbon and nitrogen mineralization in northern wetlands	VOYA: abandoned beaver pond and spruce-*Sphagnum* bog. August 1990.	Cores collected and measured for N (nitrogen) and C (carbon) mineralization. C partitioning into CO_2 and CH_4 measured. Incubated at two temperatures (15 and 30 C), both aerobically and anaerobically.	C and N mineralization were affected strongly by wetland type and substrate quality. Atmospheric feedback estimates from northern wetlands must account for "extreme local variation in substrate quality and wetland type."	–
Wilcox and Meeker	1992	Implications for faunal habitat related to altered macrophyte structure in regulated lakes in northern Minnesota	Rainy Lake and Namakan Reservoir ecosystem, and Lac La Croix; 2 sites in each. 1987.	Vegetation sampled from 1 x 1 m quadrats along 4 transects parallel to the shoreline at 0, 0.5, 1.25 and 1.75 m at each study site. Species identified; percent cover and importance values estimated. Taxa organized according to plant structural characteristics.	<u>Lac La Croix</u>: Unregulated lake supported structurally diverse plant communities at all depths. <u>Rainy Lake</u>: Dense beds of erect macrophytes dominated at permanently watered 1.75 m depth. These beds had reduced structural complexity and invertebrate densities, which reduced fish feeding efficiencies. <u>Namakan Reservoir</u>: Only rosette and mat-forming species found at the depths experiencing dewatering, which reduced habitat for invertebrates and reduced habitat for fish nursery and feeding. Timing of winter drawdowns likely reduced food and habitat for fish and wildlife.	Lake level fluctuations have direct as well as indirect effects on aquatic fauna.
Wilcox and Meeker	1991	Disturbance effects on aquatic vegetation in regulated and unregulated	Rainy Lake and Namakan Reservoir ecosystem, and Lac	Vegetation sampled from 1 x 1 m quadrats along 4 transects parallel to the shoreline at 0, 0.5, 1.25 and 1.75 m at each study site.	Lac La Croix, with unregulated water levels, supported structurally diverse plant communities at all depths.	Lac La Croix, with natural water level fluctuations, supported the greatest diversity and complexity of aquatic vegetation.

Author	Year	Title	Sampling Sites & Frequency	Variables, Study Components & General Approach	Findings	General Thoughts and Implications or Monitoring and Future Study
		lakes in northern Minnesota	La Croix; 2 sites in each. 1987.	Species identified, and percent cover and importance values estimated. Taxa organized according to plant structural characteristics.	Rainy Lake: Dense beds of erect macrophytes dominated at permanently watered 1.75 m depth. Namakan Reservoir: Rosette and mat-forming species found at the depths that experience dewatering.	
Benedict and Grim	1989	Purple loosestrife control plan	VOYA, park-wide.	Management document with descriptions of management alternatives and environmental consequences.	Recommended course of action included 3 components: · Education and loosestrife control. · Monitoring · Research.	Need for monitoring and research was explicitly acknowledged in this plan.
Monson	1986	An analysis of the effects of fluctuating water levels on littoral zone macrophytes in the Namakan/Rainy Lake system, Voyageurs National Park	Rainy, Kabetogama, Sand Point and Namakan Lakes; 11 study sites. Park-wide, vascular plant survey. Summers 1982-1983.	Established 3-m transects, with 4 quadrats each, parallel to shoreline and at 3 depths. Zones: Emergent zone, floating-leaf zone, submerged zone. Biomass samples collected using snorkeling or SCUBA during peak above-ground biomass times. ANOVA used to compare biomass among sites. Morisita's Index of Community Similarity used to compare species biomass among sites.	Wide variation in biomass from zone to zone, site to site and year to year; however, Morisita's index indicated high similarity between 1982-1983 at any one site within the same zone. Biomass of floating-leaf macrophyte zone low in some areas, possibly due to water level fluctuations; however, overall biomass was not decisively linked to magnitude of fluctuations. Author notes that wild rice populations may be affected by the unnatural water level regime. Vascular plant flora of Voyageurs includes 602 species; list included in Appendix III of document.	Author notes that the sampling effort was somewhat inadequate and that inconsistency in the magnitude and timing of water level fluctuations among years made it hard to link macrophyte biomass to water levels. Author also notes that the flora is relatively diverse given the area/size of Voyageurs.
Contaminants						
Lafrancois and Carlisle	2004	Mercury burdens and trophic position of the crayfish *Orconectes virilis* in Voyageurs National Park	VOYA: 7 interior lakes. Sampled once, summer 2002 or 2003.	Crayfish collected from lake littoral zones using baited minnow traps. Crayfish whole bodies analyzed for total and methyl mercury and carbon and nitrogen isotopes. Water chemistry data derived from Goldstein et al. (2003).	Variation in crayfish THg was better explained by TOC than by crayfish body mass, trophic position, watershed factors or lake morphometry. Crayfish mercury burdens were generally below known toxic concentrations for predators.	Watershed and in-lake processes controlling TOC concentrations (climate, hydrology, vegetation, fire) likely also affect THg accumulation in the biota of interior lakes at Voyageurs.
Swackhamer and Hornbuckle	2004	Assessment of air quality and air pollutant impacts in Isle Royale National Park and Voyageurs National Park	VOYA and ISRO, park-wide data synthesis. 2003.	Synthesis of available information, providing descriptions and contaminants background information including relevant regulations. Emissions sources identified. Monitoring and research activities summarized for visibility, nitrogen sulfur, persistent organic pollutants (POPs), mercury, arsenic, etc. Research and monitoring needs described.	ISRO: Sulfate deposition has declined and pH has increased; stream water chemistry not correlated with precipitation chemistry, but instead modified by vegetation and soil processes; despite acid deposition, may be no significant effects on the ecosystem; POPs in fish and sediments investigated in Lake Superior and Siskiwit Lake, confirming long-range transport of PCBs, DDT, triazine herbicides and other compounds. Mercury examined in fish- varies by species and lake; fish mercury appears to have declined since 1929; mercury in food webs of Sargent and Richie Lakes also examined, along with loons and wildlife. VOYA: Deposition monitored at Sullivan Bay, PCBs and DDE found in plasma of bald eagle nestlings collected in 1999. Perfluorooctane sulfonate being analyzed in water, air, and fish from two inland lakes. Mercury examined extensively in lake sediments, fish tissue, and bald eagle feathers; factors affecting mercury bioaccumulation now under examination.	Assessment presents a fairly comprehensive summary of air quality issues and research and monitoring themes for ISRO and VOYA. Primary vulnerabilities: (both parks): · Effects of mercury and POPs on fish-eating birds and wildlife. · Effects of mercury on anglers. · Effects of mercury and POPs on terrestrial food webs. Research and monitoring needs: · Program for recording human activities such as snowmobile use. · Air and fish contaminant trend monitoring program for mercury and select set of POPs. · Emissions study for PAHs and VOCs from snowmobiles. · Comparative modeling study investigating impact of local vs. distant/regional sources of pollutants since long range transport likely at these parks. · Quantification of risks associated with toxics in fish

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						as well as birds and mammals. · Mercury cycling and bioaccumulation research.
Goldstein et al.	2003	Mercury data from small lakes in Voyageurs National Park, Northern Minnesota, 2000-2002	VOYA: 20 interior lakes. 3 samples each, Summer 2001. 2 samples each, summer 2002.	Water collected from epilimnetic and hypolimnetic waters and analyzed for major ions, nutrients and organic carbon, as well as total and methyl mercury. Vertical profiles for conductance, temperature, DO, pH and Secchi also conducted.	Epilimnetic total mercury ranged from 0.34 ng/L to 4.81 ng/L; hypolimnetic total mercury ranged from 0.34 ng/L to 7.16 ng/L.	Report is short on analysis, but data indicate that total mercury in water varies substantially among lakes; total mercury is positively correlated with methyl mercury and organic carbon concentrations, and negatively correlated with pH and alkalinity.
Sorensen and Rapp	2001	The effect of exotic rainbow smelt (*Osmerus mordax*) on nutrient/trophic pathways and mercury contaminant uptake in the aquatic food web of Voyageurs National Park: a benchmark study of stable element isotopes	East and west basins Rainy and Namakan Lakes, and 8 interior lakes. 1996-1997.	Large lake component measured total mercury, selenium and stable isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) in northern pike and walleye, forage fish, zooplankton, *Chaoborus, Mysis relicta,* benthos (mayfly and amphipod), and aquatic vegetation. Interior lake component included mercury in northern pike only.	$\delta^{15}N$ correlated well with mercury across organism types and within northern pike. Log[Hg] correlated negatively with selenium. $\delta^{15}N$ of smelt vs. northern pike and walleye were similar, indicating smelt are small part of their diet currently. Interior lake northern pike mercury concentrations were approximately twice that of the large lakes. In general, isotope values from east and west basins of the large lakes corresponded well.	Authors recommend further studies to investigate: · Why ^{13}C in YOY yellow perch is so different from other age classes. · Whether small change in $\delta^{15}N$ per trophic level is real or an artifact of small sample size. · How N isotopes compare in game fish of lakes with no rainbow smelt in diets. · How stable isotopes of VOYA game fish change following diet changes related to rainbow smelt in 5-10 years. (See additional review under fish category.)
Engstrom et al.	1999	Trends in atmospheric mercury deposition across Minnesota: evidence from dated sediment cores from 50 Minnesota lakes	Minnesota waters: 50 lakes, including 4 at VOYA; each cored once.	Study lakes covered 3 Minnesota ecoregions (Metro Area, Northeastern Minnesota, and Central Minnesota). Lake cores retrieved using a piston corer in deep flat areas of each lake basin. Loss-on-ignition and geochemistry measured. Lead-210 used for sediment dating. Total and methylmercury measured from freeze-dried sediment samples from each core. GIS database constructed to derive watershed characteristics.	Present-day Hg accumulation was positively related to the percentage of urban or agricultural land use. Hg accumulation rates were higher in the Metro and West Central regions than in the Northeastern lakes, largely due to erosional inputs. Current Hg loading from direct atmospheric deposition averaged about 35% greater in the Metro area than in other regions. Methylated mercury concentrations have increased in Northeastern lakes in recent decades.	Authors note that increased methylmercury accumulation in northeastern lakes such as those at VOYA may be related to deposition of sulfate and nitrate and related increases in mercury methylation.
Glass and Sorensen	1999	Six-year trend (1990-1995) of wet mercury deposition in the upper Midwest, USA	Total mercury: precipitation measured, 6 sites, including International Falls. Weekly 1990-1995. Methylmercury: sampled at 7 sites. Select dates 1993.	Deposition collectors positioned at these sites. Precipitation analyzed for total mercury, and in a limited number of cases methylmercury.	Annual wet mercury deposition averaged 7.4 µg Hg/m²/y, varied considerably among sites and increased on average 0.6 µg Hg/m²/y. Mercury deposition and precipitation depth were generally lower at International Falls than other Minnesota sites. Annual precipitation depth also increased over the period of record, but not significantly. Methylmercury in wet deposition averaged 1.5% of total mercury in rain and was strongly correlated with total mercury, major ions and precipitation depth.	Correlations between mercury and major ions suggest a common source. Authors recommend additional study to identify sources of increasing atmospheric mercury.
Evers et al.	1998	Geographic trend in mercury measured in common loon feathers and blood	North America, 5 regions, including Upper Great Lakes, ISRO, VOYA. June-September 1991-1996.	Loons netted from boats, sexed, aged, feathers and blood collected for total mercury analysis. Water chemistry collected at 1 m from each lake.	Mercury in adult feathers ranged from 2.8-36.7 µg/g and in blood from 0.12-7.80 µg/g. Mercury in juvenile blood ranged from 0.03-0.78 µg/g. Blood and feather mercury were correlated within individuals. Blood and feather mercury higher in males for each region. Blood mercury increased from west to east. Blood mercury in Upper Great Lakes region less	Assessing mercury exposure in loons will require stratification of data by sex, age, tissue type and geographic distribution.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					influenced by variation in mercury deposition than by hydrology and lake chemistry. Loons breeding on low-pH lakes in the Upper Great Lakes at greatest risk.	
Webster and Brezonik	1995	Climate confounds detection of chemical trends related to acid deposition in Upper Midwest lakes in the USA	Upper Midwest: 28 lakes, up to 4 at VOYA. Sampled 3 times during ice-free season, 1983-1994.	Surface water samples analyzed for ANC, calcium, magnesium, pH, and other major ions. Precipitation data collected in quarterly time steps from 3 sites. Data analyzed for trends.	Decreases in sulfate corresponded with increases in pH and ANC for 3 of 4 Minnesota lakes, but lakes in Wisconsin and Michigan did not show the corresponding ANC increases. This difference was linked to declining cation inputs due to decreased groundwater inputs in the drier climatic conditions that occurred in Wisconsin and Michigan during this time.	Authors concluded that shifts toward warmer, drier climates may hinder improvements in pH and ANC in lakes affected by acid deposition.
Sorensen et al.	1994	Regional patterns of wet mercury deposition	7 sampling sites, including VOYA. 1990-1992.	Deposition samplers collected precipitation for mercury analysis.	Magnitude of mercury deposition related to quantity of precipitation; therefore, regional variation in mercury concentrations in precipitation explained by precipitation rate. Higher mercury concentrations in summer. Mercury in precipitation correlated with other ions. Statewide emissions > depositions for 1990-1992 by a factor of 2.	Authors recommend further study with regard to geographic patterns, precipitation rates, seasonal variations, related ions and emission and deposition inventories for unmeasured mercury sources.
Webster et al.	1993	Temporal trends in low alkalinity lakes of the Upper Midwest (1983-1989)	Upper Midwest: 28 lakes, including 4 in VOYA. 3 times per year, 1983-1989.	Precipitation and deposition measured for SO_4^{2-}, and pH. Water quality suite monitored in lake surface water.	In general, SO_4^{2-} trends negative, consistent with regional declines in emissions and deposition. VOYA lakes showed declines in SO_4^{2-} but no trend in ANC, DOC or Ca^{2+} and Mg^{2+}. SO_4^{2-} trends did not correspond with increase in ANC or pH except in 1 lake. ANC in one group of lakes declined with decreased Ca^{2+} and Mg^{2+} due to drought.	Climate variability influences hydrology and chemistry, which confounds deposition-related trends. Authors note that periods longer than 6 years are needed to discern subtle trends in atmospheric pollutants.
Ensor et al.	1992	Mercury and lead in Minnesota common loons (*Gavia immer*)	North-central Minnesota: lakes, including Kabetogama Lake. 1984-1990.	Loons collected using night lighting and observation. Feathers of live and dead birds analyzed for total mercury. Livers of dead birds analyzed for mercury, and if lesions present, analyzed for lead too.	Collected 221 loons; 128 were dead or dying. All loons sampled had mercury residues in livers and/or feathers, 22% of livers had levels indicative of reproductive impairment. Age influenced mercury more than sex. Feather mercury from juvenile loons from northeast Minnesota was higher than for loons from northwestern Minnesota. Juvenile loons dead from disease had higher feather mercury than loons dead from injury. Lead poisoning diagnosed as cause of death for 17% of adult loons.	Authors recommend comparing loon populations on lakes with high and low mercury contamination, collecting dead and dying loons for necroscopies, mercury and lead analysis, and investigating long-term regional trends in loon contaminant levels using juvenile feathers as a tool.
Sorensen et al.	1990	Airborne mercury deposition and watershed characteristics in relation to mercury concentrations in water, sediments, plankton and fish of eighty northern Minnesota lakes	Northern Minnesota: lakes, including many in VOYA. One sample each.	Precipitation collected at 3 sites. Lake surface water quality analyzed. Sediment sampled with drop corers. Plankton sampled with vertical tows and a plankton bucket. Mercury analyzed on all components. Watershed characteristics and fish mercury data from previous studies included.	Surface water mercury levels positively correlated with TOC and mercury in zooplankton and northern pike, and negatively correlated with pH. Sediment mercury positively correlated with TOC, % forest cover, mercury deposition and mercury in surface water, and negatively correlated with pH and lake size Zooplankton mercury positively correlated with mercury in surface water and northern pike and TOC, and negatively correlated with pH and zooplankton	Summary table very useful in providing basic statistics for a suite of variables related to mercury in each food web component, atmospheric deposition, water chemistry, land cover, hydrology, and morphometry. Correlations among variables across 80 lakes also insightful.

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					density. Northern pike mercury positively correlated with mercury in water and zooplankton, TOC and iron, and negatively correlated with pH. Primary mercury source atmospheric; geologic and point source contributions small.	
Rapp et al.	1985	Acid deposition and watershed characteristics in relation to lake chemistry in northeastern Minnesota	Northeastern Minnesota: 267 lakes, including some in VOYA. Fall 1978-summer 1983.	Atmospheric inputs characterized. Watershed parameters included area, topographic and hydrologic parameters. Surface water quality parameters included alkalinity, pH, conductivity, color, sulfate, chlorophyll *a,* TOC, iron and aluminum.	Color, sulfate and alkalinity correlated with variables representing sulfate inputs, hydrology and acid neutralizing capacity. Color related to hydrologic renewal time and presence of marsh or peat. Sulfate related to atmospheric deposition, evaporation, bedrock type and coniferous forest. Alkalinity difficult to predict except in headwater lakes, where variation explained by sulfate inputs, water renewal time, deciduous forest and bedrock weathering properties.	Heterogeneity within watersheds noted; as a result, averaging characteristics of larger watersheds weakened some relationships among variables.
HYDROLOGY						
Kallemeyn	2002	Establishment of an assessment program to evaluate the long-term effects of changes in the water level management program for Rainy Lake and Namakan Reservoir	Rainy Lake and Namakan Reservoir ecosystem.	Report highlights key hypotheses identified during the 2001 workshop, identifies roles and tasks for the international coordinating committee, and encourages leadership and action from committee members.	Author urges these considerations in developing a monitoring/assessment program: · Study design and analysis. · Multi-species, multi-factor ecosystem context. · Acknowledgement of social concerns.	–
Kallemeyn and Cole	1988	Alternatives for reducing the impacts of regulated lake levels on the aquatic ecosystem of Voyageurs National Park, Minnesota	Rainy Lake and Namakan Reservoir ecosystem.	Describes two main components of the water management research program, including: · Research on aquatic ecosystem components. · Hydrologic model to assess alternative regulatory programs.	Research findings summarized. Explored 11 alternative regulatory systems with hydrologic model. Restoration of more natural hydrologic regime recommended, as this would reduce adverse effects on aquatic biota without seriously conflicting with other water uses.	–
Flug	1986	Analysis of lake levels at Voyageurs National Park	Rainy Lake and Namakan Reservoir ecosystem.	Optimizing simulation model used to quantify the impact of alternate reservoir operating rules on various lakeshore interests.	Lake levels for Rainy Lake and Namakan Reservoir successfully calibrated from existing hydrologic data. Model indicates that under extreme hydrologic events, such as drought or floods, strict compliance with current rule curve impossible. Alternate target simulations for 1976-1980 also depicted.	Report describes how the model may be used to find the best rule curve compromise.
Flug	1986	Regulated lake levels and Voyageurs National Park	Rainy Lake and Namakan Reservoir ecosystem.	Optimizing simulation model used to quantify the impact of alternate reservoir operating rules on various lakeshore interests. Includes a diagrammatic overview of the hydrologic model.	Lake levels for Rainy Lake and Namakan Reservoir successfully calibrated from existing hydrologic data. Model indicates that under extreme hydrologic events, such as drought or floods, strict compliance with current rule curve impossible. Alternate target simulations for 1976-1980 also depicted.	Report describes how the model may be used to find the best rule curve compromise.

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GENERAL RESOURCE DOCUMENTS AND PLANS						
Andrews et al.	1996	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – review of selected literature	Upper Mississippi Basin: St. Croix, Mississippi and Minnesota Rivers. Initial phase: 1994-1999.	Review of literature (approximately 2000 citations) used to understand water quality issues in the basin and design the study.	Surface water studies: Hydrology, physical characteristics for some subbasins, 1993 flood reports, water use and availability (Twin Cities Metropolitan Area), urban land-water linkages, groundwater-surface water linkages, water quality reports. Groundwater studies: Comprehensive state-wide reports, potentiometric altitudes and maps for Twin Cities area, water quality reports. Aquatic biology and ecology: Invertebrate, fish, algal studies.	A concise summary of many of the relevant water resource studies for the Mississippi and St. Croix Rivers.
Stark et al.	1996	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – environmental setting and study design	Upper Mississippi Basin: St. Croix, Mississippi and Minnesota Rivers, Initial phase: 1994-1999.	Literature review (approximately 2000 citations) and initial characterization of Upper Mississippi Basin.	Previous studies described. Environmental setting described, including: climate, physiography, geology, soils, hydrologic setting, ecological setting, and anthropogenic setting. Study design and stratification also described.	Excellent source of basic information about the Upper Mississippi Basin.
WATER QUALITY						
Kroening et al.	2002	Water quality assessment of part of the Upper Mississippi River Basin study unit, Minnesota and Wisconsin – nutrients, chlorophyll *a*, phytoplankton and suspended sediment in streams, 1995-1998	Upper Mississippi Basin: 12 sites, including 1 at Anoka on Mississippi River, 3 on St. Croix and Namekagon Rivers. Monthly, water years 1996-1998.	Nutrients measured included dissolved nitrite N, dissolved nitrite plus nitrate N, dissolved ammonia N, total organic plus ammonia N (TKN), dissolved organic plus ammonia N, total N, total P, and dissolved orthophosphate P. Suspended sediments, chlorophyll *a* also measured. Loads and yields calculated.	Greatest concentrations of all nutrients found in drain-tiled agricultural streams, followed by urban-residential streams and forest streams, indicating land cover a primary influence on nutrients and suspended sediment in the study unit. Wastewater discharges also important. For Mississippi River, nutrients and sediments increased after Minnesota River confluence. For St. Croix River, total N, dissolved nitrite plus nitrate N and total organic plus ammonia N were greater at St. Croix Falls than Danbury. N constituents varied greatly seasonally in Mississippi and Minnesota Rivers. Greatest chlorophyll concentrations and algal abundances found at Minnesota and Mississippi River sites; TP was high there and in 1996 these sites were dominated by blue-greens. Algal abundance increased downstream for Mississippi and St. Croix Rivers. Diatoms dominated at Anoka and St. Croix Falls.	Water quality at MISS is greatly influenced by incoming Minnesota River water which carries high nutrient and sediment loads; Minnesota River management practices matter to MISS aquatic resources. Sampling or monitoring site selection should account for longitudinal patterns in Mississippi and St. Croix Rivers.
Fallon and McNellis	2000	Nutrients and suspended sediment in snowmelt runoff from part of the Upper Mississippi River Basin, Minnesota and Wisconsin, 1997	St. Croix River Basin: 20 sites, including Namekagon, Yellow, Clam, Kettle, Snake, Wood, Trade, Sunrise, Apple, and Kinnickinnic Rivers. Mississippi River: 19	Water quality suite analyzed, including nutrients and sediments. Stream discharge monitored. Stream mixing assessed using transects and basic water chemistry. Nutrient and sediment yields and loads estimated and compared for land use types.	Agricultural streams transported 2-10 times more N and 5-12 times more P during snowmelt than other land use areas, and more of their annual N and P load was snowmelt related. Nitrate was dominant N form in many streams but not in forested St. Croix sites, where DON and PN predominated. P was usually in particulate form. Some forested St. Croix sites had suspended sediment concentrations and yields similar to	"For forested areas, the type of surficial geology may be important to consider in strategies to reduce loads during snowmelt runoff." "For urban areas, limiting nutrients and suspended sediment during the growing season runoff may be more effective than during snowmelt" because snowmelt period does not contribute a disproportionate amount of the annual nutrient or

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			sites, along mainstem and tributaries.		agricultural sites, demonstrating that both land use and surficial geology are factors. In agricultural and forested streams, snowmelt can deliver large proportions of annual nutrients and sediments.	sediment loading.
Stark et al.	2000	Water quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995-1998	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers.	Appears to be a summary report of NAWQA activities to date.	Most results also covered in other studies. Some biological results do not appear to have been published or described in detail here.	Report provides useful nationwide perspective on conditions in Upper Mississippi Basin rivers. User-friendly reporting and graphics.
Kroening	1998	Nutrient sources within the Upper Mississippi River Basin, Minnesota and Wisconsin, 1991-1993	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers, 1991-1993.	N and/or P sources included fertilizer, manure, wastewater, atmospheric deposition, and legume residues.	Fertilizer and manure predominant nutrient sources to all basins. Atmospheric deposition more important to SACN than other basins because other inputs were low; wastewater more important in MISS due to direct discharges. Non-point sources dominate in all basins.	Nutrient inputs are largely non-point source. Monitoring and management need to address these sources more thoroughly.
Kroening and Andrews	1997	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – nitrogen and phosphorus in streams, streambed sediment and ground water, 1971-1994	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers.	Review of available data on nitrogen and phosphorus in streams, streambed sediments and groundwater. Seasonal Kendall trend tests performed on data sets > 5 years long; mostly from 1984-1993. Investigated temporal trends of nutrients in major rivers.	Fertilizer and livestock manure greatest N and P sources in basin; most in Minnesota basin. N concentrations greatest in spring-summer in agricultural streams, winter in forested streams. TP greatest spring and summer for all streams. Nutrients increased downstream of Twin Cities. Nitrate usually less than 10 mg/L; TP usually greater than 0.1 mg/L in agricultural areas. No trend in most nutrients during 1984-1993 outside Twin Cities. Ammonia-N decreased in Mississippi and Minnesota Rivers, coincident with increases in nitrite+/nitrate-N, probably in response to WWTP treatment changes. Nitrate in groundwater highest in agricultural or mixed forest-agricultural areas with unconfined sand and gravel aquifers. P generally low in groundwater; highest in urban areas.	Lake St. Croix monitoring data since 1975 shows similar N trends to those found in Minnesota and Mississippi River, which may be the result of WWTP operations. Changes in wastewater treatment practices are apparent in water chemistry records. This report provides useful information for both MISS and SACN.
Kroening and Stark	1997	Variability of nutrients in streams in part of the Upper Mississippi River Basin, Minnesota and Wisconsin	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers, 1984-1993.	Review of available data on nitrogen and phosphorus in streams, streambed sediments and groundwater. Seasonal Kendall trend tests performed on data sets > 5 years long; mostly from 1984-1993. Investigated temporal trends of nutrients in major rivers.	Fertilizer and livestock manure greatest N and P sources in basin; most in Minnesota basin. N concentrations greatest in spring-summer in agricultural streams, winter in forested streams. TP greatest spring and summer for all streams. Nutrients increased downstream of Twin Cities. Nitrate usually less than 10 mg/L; TP usually greater than 0.1 mg/L in agricultural areas. No trend in most nutrients during 1984-1993 outside Twin Cities. Ammonia-N decreased in Mississippi and Minnesota Rivers, coincident with increases in nitrite+/nitrate-N, probably in response to WWTP treatment changes. Nitrate in groundwater highest in agricultural or mixed forest-agricultural areas with unconfined sand and	Lake St. Croix monitoring data since 1975 shows similar N trends to those found in Minnesota and Mississippi River, which may be the result of WWTP operations. Changes in wastewater treatment practices are apparent in water chemistry records. This report provides useful information for both MISS and SACN.

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					gravel aquifers. P generally low in groundwater; highest in urban areas.	
Stark	1997	Causes of variations in water quality and aquatic ecology in rivers of the Upper Mississippi River Basin, Minnesota and Wisconsin	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers.	Presentation of environmental framework, both natural and human factors, and surface water quality and ecology.	Noted 3 land cover zones: forest, agricultural and transitional. Alkalinity lowest in Upper St. Croix, highest in Minnesota River. Sediments and nutrients highest in the Mississippi River below the Minnesota River. Minnesota River nitrate sometimes exceeded drinking water standards. Minnesota and Mississippi Rivers fecal bacteria sometimes exceed EPA standards. St. Croix Fe and Mn concentrations high but probably due to natural sources. Mississippi River Cd, Pb, and Hg greatest in sediments downstream of Twin Cities.	"Land use has accentuated natural differences in water quality and ecological conditions in each of the three major rivers in the Upper Mississippi River Basin." Heavy metal concerns are greater for MISS than for SACN.
BIOLOGY & ECOLOGY						
ZumBerge et al.	2003	Relation of periphyton and benthic invertebrate communities to environmental factors and land use at selected sites in part of the Upper Mississippi River Basin, 1996-1998	Upper Mississippi Basin: 12 sites, including 2 near MISS, 1 on Namekagon River, 2 on St. Croix River. Biology, physical characteristics, 1996. Water chemistry, 1996-1998.	Large rivers and small streams included. <u>Small streams</u>: Periphyton and benthic invertebrates both collected from woody debris. *Periphyton* analyzed for total density and biovolume, density and biovolume by division, and diversity and pollution indices for diatoms. *Benthic invertebrates* analyzed for total taxa, EPT taxa, and Dipteran/noninsect taxa. <u>Large rivers</u>: Periphyton and benthic invertebrates both collected from woody debris. *Periphyton* analyzed for total density and biovolume, and diversity indices calculated for diatoms. *Benthic invertebrates* analyzed for taxa richness and diversity.	<u>Small Streams</u> *Periphyton*: 173 taxa. Periphyton density least on Namekagon, greatest North Fork Crow River, suggesting a relation to nutrients. Diatoms dominated Namekagon. *Benthic Invertebrates*: 100 taxa found. Taxa richness indices not insightful. Particular and predictable sets of taxa associated with forest vs. agricultural streams. <u>Large rivers</u> *Periphyton:* 192 taxa; mostly diatoms (151) and green algae (19). Total density highest downstream; diatom relative abundance decreased downstream. Diatom diversity indices not useful. *Benthic invertebrates*: Diversity and taxa richness of invertebrates decreased downstream in Mississippi and St. Croix Rivers.	Indices such as diversity and richness did not perform as expected for small streams. Often the most disturbed streams had the highest values in the basin. Abundance, biovolume and relative abundance seemed to be more meaningful measures than diversity indices. Authors sampled only woody debris substrates; with no rationale provided for this choice. Periphyton in small streams was not always related to nutrients; other factors such as light, temperature substrate also important. Taxonomic data appendix is valuable.
FISH						
Goldstein et al.	1999	Relation of fish community composition to environmental factors and land use in part of the Upper Mississippi River Basin, 1995-1997	Upper Mississippi River Basin: small streams in varied land use areas. Mississippi River above and below St. Anthony's Falls and St. Croix River above and below Taylors Falls.	Sites characterized with respect to hydrology, water chemistry, habitat, land use and riparian zone. Fish community composition evaluated in relation to these factors.	Fish community composition differed among small streams. <u>Agricultural stream</u>: Were affected by nutrients from fertilizers, increased temperature from loss of shade, habitat modifications due to channelization and hydrologic modifications from dams and drain tiles. Fish species generally required some cobble and gravel substrates and detected prey visually; many invertivores. <u>Forested streams</u>: Contained fewer species, mostly invertivores and carnivores requiring cold clear water and cobble or boulder substrates. <u>Urban streams</u>: Contained many lentic species tolerant of silt, low dissolved oxygen and marginal	Land use characteristics affected habitat quality and fish species composition in small streams, along with habitat alteration and changes in river thermal regimes.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					habitats. Large river: Fish composition was affected by dispersal barriers, dams, and the Twin Cities Metropolitan Area. Fish in the metro area Mississippi River contained lentic, planktivorous species with higher thermal tolerances.	
Talmage et al.	1999	Water quality, physical habitat, and fish-community composition in streams in the Twin Cities Metropolitan Area, Minnesota 1997-1998	Twin Cities Metropolitan Area: 13 streams. Habitats, water quality, September 1997. Fish 1998.	Sites represented a range of population density. Water quality suite and stream flow measured at each stream. Physical measurements made at reach, segment and basin scales. Fish sampled at each stream by electrofishing. Species richness, Shannon diversity, and index of biotic integrity metrics calculated.	Nutrient concentrations generally low. Detected 17 pesticides and 5 metabolites; atrazine detected at all 13 streams. Fecal coliform ranged from 54 to 11,000 colonies/100 mL and was related to population density. Fish habitat poor; with little woody debris, boulders or cobble; index of biotic integrity scores low. Collected 38 species of fish; mostly omnivores and tolerant species. Percent impervious surface positively correlated with sodium and chloride; negatively correlated with fish richness and diversity.	Urban land use, percent impervious surface, water chemistry, temperature, geomorphology, substrate, habitat and migration barriers all influenced fish community composition. Future restoration efforts might target these attributes.
CONTAMINANTS						
Fallon	2000	Pesticides in streams in part of the Upper Mississippi River Basin, Minnesota and Wisconsin, 1974-1994	NAWQA study unit: 39 stream sites. 1974-1994.	Existing data on pesticide use and concentrations in streams and streambed sediments compiled from state and federal agencies.	Highest rates of pesticide use occurred in the Minnesota River basin. 27 times more herbicides than insecticides were used, mostly in corn and soybean fields, mostly atrazine, cyanazine, metolachlor and alachlor. Application rates in urban areas were similar to agricultural areas, but overall area was less. Stream water: Herbicides were the most frequently detected pesticide Bed sediments: Organochlorine insecticides were the most frequently detected pesticide.	Detection frequencies were related to pesticide type (mostly the more persistent triazine and acetanilide compounds) and land use (highest frequencies in areas with intense urban/agricultural use). The types of organochlorine insecticides detected increased in downstream reaches of MISS and SACN, with the most compounds in Pool 2 of the Mississippi River. Few samples had concentrations exceeding drinking water or freshwater-quality criteria for aquatic life.
Kroening et al.	2000	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – trace elements in streambed sediments and fish livers, 1995-1996	Upper Mississippi River Basin: 27 sites, including ~7 near MISS, ~5 in SACN.	Sediments sampled for 47 trace elements at low flow away from obvious contaminant sources. Collected 5-8 fish by electroshocking at each site and analyzed for 22 trace elements.	Occurrence and distribution of trace elements in sediment related to land use, especially for An, As, Cd, Cu, Pb, Hg, Ni, and Zn, and surface geology. Urban sites had highest concentrations; Shingle Creek highest. Cd sediment concentrations greatest downstream of Twin Cities. Hg sediment concentrations greatest in Mississippi River at Grand Rapids and Minneapolis, Shingle Creek, Namekagon River, St. Croix at Hudson, and Vermillion River. Trace elements detected in fish livers in concentrations similar to other NAWQA sites, but were not correlated to streambed sediment concentrations or distributed predictably.	Monitoring for trace elements could not rely exclusively on streambed sediment or fish liver concentrations as these were not correlated. Some elements strongly related to urban land use. Low dissolved oxygen or pH may trigger release of trace elements in streambed sediment.
McNellis et al.	2000	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin	Upper Mississippi Basin: > 20 sites, including Namekagon River at	Streambed sediments: 32 organochlorines analyzed. Fish: Carp, white sucker, shorthead and golden	Types and concentrations of organochlorines in sediment and fish varied by land use. Forest sites had lower sediment levels and fewer fish organochlorine detections than other land uses.	Organochlorines sometimes found in fish but not sediments from a given site. Both measures may be needed to be robust indicators of contaminant presence in biota.

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
		– organochlorine compounds in streambed sediments and fish tissues, 1995-1997	Leonards and near Hayward; Kettle River; St. Croix River near Danbury, Sunrise River and Hudson. At low flow 1995-1997.	redhorse collected and analyzed as whole-fish composites for 28 organochlorines.	*SACN:* Streambed sediments: *o,p'*-DDD detected in Namekagon River near Hayward, but low concentrations. Endosulfan found in St. Croix and Namekagon Rivers. Fish: St. Croix at Hudson had fish PCBs at half the national 90th percentile (well above the EPA consumption guideline) and fish DDE at the national 50th percentile. St. Croix at Danbury also had detectable fish DDE. Guidelines for aquatic life for DDT and metabolites not exceeded. *MISS:* Streambed sediments: No organochlorines detected in streambed sediments. Fish: PCBs were detected in fish downstream of metro area at Nininger, MN at levels approaching the national 90th percentile, and DDEs were detected in fish at both Anoka and Nininger at the national 50th percentile for DDT, not exceeding aquatic life guidelines. Fish organochlorines increased downstream.	Fish PCBs should be monitored for Lake St. Croix and at downstream end of MISS, near likely sources and contributing tributaries.
Lee and Anderson	1998	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – polychlorinated biphenyls in common carp and walleye fillets, 1975-1995	Upper Mississippi River: several sites upstream of Lake Pepin. 1975-1995.	Fish PCB data previously collected by Minnesota Fish Contaminant Monitoring Program and Wisconsin Department of Natural Resources analyzed for trends and patterns since PCBs were banned in late 1970s. Time periods defined as 1975-1979, 1980-1987, 1988-1995. Site comparisons available.	PCB concentrations in individual samples ranged from 0.07-33 mg/kg. Median concentrations were generally highest during 1975-1979 and 1980-1987, and generally lower in walleye than in carp. Most river segments showed an 80% decline in PCBs between 1975-1979 and 1988-1995, with greatest declines occurring in the Twin Cities Metropolitan Area. Spatial distribution of PCBs seemed related to population density.	Despite declines in PCBs since 1975, low concentrations of PCBs remain in the environment.
Fallon et al.	1997	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – pesticides in streams, streambed sediment and ground water 1974-1994	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers.	Review of available data on pesticides in streams, streambed sediments and groundwater.	Herbicides detected in every stream but the Kettle River, with highest incidences in row-crop areas and atrazine the most widely detected herbicide. Concentrations usually highest in July. Two herbicides never detected and likely not persistent. An urban stream had high pesticide levels. Streambed sediments had measurable DDT, heptachlor, lindane, metabolites (Twin Cities). Most groundwater detections were in sand and gravel aquifers under agricultural areas. Atrazine twice exceeded drinking water standards; a few pesticides exceeded chronic freshwater quality criteria.	Monitoring for pesticides should focus on agricultural and urban areas rather than forested areas, and sampling should target summer months in particular. Continued monitoring of sediment concentrations of organochlorine pesticides is advisable, particularly for MISS.
Andrews	1996	Few volatile organic compounds detected in rivers and groundwater in the Upper Mississippi River Basin, Minnesota and Wisconsin	Rivers and wells throughout Upper Mississippi Basin.	Volatile organic carbons (VOCs) are carbon containing chemicals that readily evaporate at normal temperature and pressure.	VOCs rarely detected in rivers, but a few St. Croix and Mississippi samples had measurable concentrations. VOCs found in wells throughout the basin. Highest concentrations usually near spills, leaks, or landfills. Gasoline components and solvents most common.	–

AUTHOR	YEAR	TITLE	SAMPLING SITES & FREQUENCY	VARIABLES, STUDY COMPONENTS & GENERAL APPROACH	FINDINGS	GENERAL THOUGHTS AND IMPLICATIONS OR MONITORING AND FUTURE STUDY
					Few samples exceeded EPA health guidelines; most in Twin Cities Metropolitan Area.	
Andrews et al.	1995	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – volatile organic compounds and ground water, 1978-1994	Upper Mississippi Basin: rivers and wells throughout.	Summary of data collected by Federal, State and local agencies.	Trace amounts of VOCs detected in all rivers. Several VOCs detected in Twin Cities water supply lakes. Target VOCs were in < 5% of groundwater samples. VOC concentrations higher in wells from sand and gravel aquifers. Most common VOC was trichloroethene, a degreasing agent. Wells with VOCs tended to be shallower. Chlorination of water increased the frequency of detection of trihalomethane compounds.	Results indicate VOCs need not be a monitoring priority for either SACN or MISS, since they were seldom detected in groundwater and even more rarely detected in river waters. If monitoring desired, results imply that the focus should be on well water from sand and gravel aquifers.
GROUNDWATER						
Fong	2000	Water quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin – groundwater quality in three different land use areas, 1996-1998	Urban wells, summer 1996. Agricultural wells, summer 1998. Forested wells, June 1998.	Groundwater quality measured for 200 constituents: physical parameters, major ions, trace elements, nutrients, DOC, pesticides, VOCs and tritium.	Conductivity higher and dissolved oxygen lower in urban vs. agricultural or forest sites. Alkalinities in agricultural study less than urban and forested study. Surficial aquifer for all areas is Ca-Mg-HCO_3 dominated. Nitrate-N highest in agricultural study; TP generally < 0.05 mg/L across land uses. Detected 19 pesticides; most in agricultural (atrazine and deethylatrazine) and urban (prometon) areas. Detected 21 VOCs; most in urban areas.	Study provides some indication of groundwater quality in the basin. Results imply that sampling for pesticide and VOC presence or exceedences should focus on urban/agricultural sites. Groundwater in agricultural regions with shallow sand-gravel aquifers is most susceptible to nitrate contamination.
Andrews et al.	1998	Water quality assessment of part of the upper Mississippi River basin, Minnesota and Wisconsin – groundwater quality in an urban part of the Twin Cities Metropolitan Area, Minnesota, 1996	Twin Cities Metropolitan Area: 30 shallow monitoring wells, urban residential and commercial land use areas. Spring 1996.	Groundwater levels monitored. Water quality measured for nutrients, ions, trace metals, pesticides, and VOCs.	Aquifer materials had high susceptibility to leaching. Shallow groundwater flowed primarily toward Mississippi River. Sodium and chloride concentrations were elevated. Iron and manganese exceeded EPA secondary maximum contaminant levels. Nitrate and phosphate concentrations were low to moderate. Pesticide compounds were detected in half the wells sampled. VOCs were detected in nearly all the sampled wells. Tritium concentrations indicated that shallow groundwater had been recharged since the 1950s and should be affected by urban development. Urban land uses increased frequency of detection for pesticides and VOCs. Areas recently developed had residual pesticide and nutrient concentrations from agricultural use.	Groundwater in the area of MISS is susceptible to contamination from urban and industrial activities.
Hanson	1998	Pesticides and nitrate in surficial sand and gravel aquifers as related to modeled contamination susceptibility in part of the Upper Mississippi River Basin	Upper Mississippi Basin: including St. Croix, Mississippi and Minnesota Rivers. 1971-1994.	Pesticides (366 samples) and nitrate (410 samples) analyzed from wells in surficial sand and gravel aquifers. Groundwater susceptibility model used to predict areas sensitive to contamination.	EPA exceedences generally corresponded to areas with high modeled contamination susceptibility. Land use and land cover was also related to contamination, with higher pesticides and nitrates found in cropland land use areas. Geologic and hydrologic predisposition influence groundwater susceptibility, as do human activities.	–

APPENDIX C

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SuperSummary table citing references to studies addressing each aquatic research category. In this table, a single study may be recorded in multiple categories if it addresses aspects of more than one category. This organization makes it possible to find, for example, all the studies that addressed water quality in Apostle Islands National Lakeshore, even if water quality measurements were only peripheral to the study. Complete references may be found in the literature cited section. The bottom line of each park's table notes the total number of studies addressing each category.

APOSTLE ISLANDS NATIONAL LAKESHORE

GENERAL RESOURCE PLANS AND DOCUMENTS	WATER QUALITY	BIOLOGY AND ECOLOGY	FISH	AQUATIC WILDLIFE	AMPHIBIANS AND REPTILES	WETLANDS AND AQUATIC VEGETATION	CONTAMINANTS	HYDROLOGY	GROUNDWATER	PHYSICAL STRUCTURE AND PROCESSES
Van Stappen 1999, Anderson and Stowell 1985, Anderson et al. 1983, Brander and Bailey 1983, Anderson et al. 1982, Anderson et al. 1980, Anderson et al. 1979, Stadnyk et al. 1974	National Park Service 1999, Lake Superior Ecosystem Research Center 1997, Balcer and McCauley 1989, Rose 1988, Brander and Bailey 1983, Anderson et al. 1980, USGS 1980, Anderson et al. 1979, Stadnyk et al. 1974, Winter 1971	Lake Superior Ecosystem Research Center 1997, Doolittle 1991, Balcer and McCauley 1989, Rose 1988, Montz 1986, Stern 1979, Brander and Bailey 1983, Anderson et al. 1982, Anderson et al. 1980, Anderson et al. 1979, Stern et al. 1979, Stadnyk et al. 1974, Winter 1971, Hiltunen 1969	NBS 1995, Slade 1994, Hudson et al.1995, Bronte et al 1995, McCauly et al. 1989, Bronte 1986, Red Cliff Fisheries 1986, Wis. Dept. of Natural Resources 1984, Bronte 1983, Brander and Bailey 1983, Bronte and Gurnoe 1983, Busiahn 1983a, 1983b, 1983c, USFWS 1983, Wis. Dept. of Natural Resources 1983, Bronte 1982, Busiahn 1982a, 1982b, Wis. Dept. of Natural Resources 1982, Gr. Lks. Fish Commission 1981, Coberly and Horral 1980, Dean 1980, Horral et al 1980, Weimer 1980, Anderson et al. 1979, Strachan and Glass 1978, Wis. Dept. of Natural Resources 1977, Albrecht 1975, Stadnyk et al. 1974, Bailey 1972, 1969, 1964, Dryer 1964, Bailey 1963, Eschmeyer and Bailey 1954	Smith and Jenkins 1994, Smith and Peterson 1991, Anderson and Stowell 1985, Craven et al. 1984, Anderson et al. 1983, Anderson et al. 1982, Anderson et al. 1980, Anderson et al. 1979, Matteson 1979	Casper 2001, Ernst 1998, Krenz 1998, Rogers et al. 1995, Ludwig 1993, Anderson and Stowell 1985, Anderson et al. 1983, Anderson et al. 1982, Anderson et al. 1980, Anderson et al. 1979, Patzoldt 1978, Patzoldt and Brown 1977, Stadnyk et al. 1974	Casper 2001, Meeker 2000, Meeker 1998, Judziewicz and Koch 1993, Smith and Peterson 1991, Anderson and Stowell 1985, Anderson et al. 1980, Anderson et al. 1979, Stadnyk et al. 1974	National Park Service 1999, Balcer and McCauley 1989, Brander and Bailey 1983, Matteson 1979, Strachan and Glass 1978, Wisconsin Department of Natural Resources1977	Balcer and McCauley 1989, Rose 1988, USGS 1980	Rose 1988, USGS 1980	Green and Dunning 1992, Milfred 1987, Anderson et al. 1980
8	10	14	36	9	13	9	6	3	2	3

GRAND PORTAGE NATIONAL MONUMENT

GENERAL RESOURCE PLANS AND DOCUMENTS	WATER QUALITY	BIOLOGY AND ECOLOGY	FISH	AQUATIC WILDLIFE	AMPHIBIANS AND REPTILES	WETLANDS AND AQUATIC VEGETATION	CONTAMINANTS	HYDROLOGY	GROUNDWATER	PHYSICAL STRUCTURE AND PROCESSES
Goldstein 2000	GRPO 2000, Winterstein 2000, National Park Service 1999, Boyle and Richmond 1997, Ruhl 1997	Boyle and Richmond 1997	Boyle and Richmond 1997, Newman and Johnson 1996, Newman 1993				GRPO 2000, Winterstein 2000, National Park Service 1999, Ruhl 1997, Ruhl 1994	Ruhl 1994	Ruhl 1994	
1	5	1	3	0	0	0	5	1	1	0

Indiana Dunes National Lakeshore

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
Garza et al. 2002, Whitman et al. 2002, Dolak 1985	Nevers and Whitman 2004, Byappanahalli et al. 2003 a, 2003 b, Stewart et al. 2003, Whitman and Nevers 2003, Whitman et al 2003, Garza et al. 2002, Stewart et al. 2000, Stewart et al. 1999, Whitman et al. 1999, Simon et al. 1997, Stewart et al. 1997, Whitman et al. 1995, Whitman et al. 1994, National Park Service 1994, Stewart et al. 1993, Wilcox and Simonin 1987, Wilcox 1986 a, 1986 b, Wilcox et al. 1986, Dolak 1985, Wilcox et al. 1984, Hardy 1983, Wilcox circa 1982, Arihood 1975	Nevers and Whitman 2004, Simon et al. 2004 a, Byappanahalli et al. 2003 a, Stewart et al. 2003, Whitman et al. 2003, Garza et al. 2002, Ingersoll et al. 2002, MacDonald et al. 2002 a, b, Whitman and Garza 2002, Whitman et al. 2002, Horvath et al. 2001, Simon et al. 2000, Stewart et al. 2000, Stewart et al. 1999, Stewart et al. 1997, Whitman et al. 1994, Whitman et al. 1991, Whitman et al. 1988, Hardy 1983	Simon et al. 2004 a, b, Stewart et al. 2003, Garza et al. 2002, MacDonald et al. 2002 a, Whitman et al. 2002, Simon and Moy 2000, Simon et al. 2000, Stewart et al. 1999, Simon and Stewart 1999, 1998, Simon et al. 1998, Simon 1992, Eshenroder 1989, Spacie 1988	Garza et al. 2002, Whitman et al. 2002	Glowacki and Grundel 2005, Garza et al. 2002, Whitman et al. 2002, Simon et al. 2000, Resetar 1994, Resetar 1992, Resetar 1985	Stewart et al. 2003, Garza et al. 2002, Whitman et al. 2002, Simon et al. 2001, Perkins et al. 2000, Simon et al. 2000, Stewart et al. 1999, Stewart et al. 1997, Edwards 1995, Stewart et al. 1993, Whitman et al. 1991, Cole et al. 1990, Wilcox and Simonin 1988, Whitman et al. 1988, Wilcox and Simonin 1987, Hiebert et al. 1986, Wilcox 1986 a, 1986 b, Wilcox et al. 1986, Wilcox et al. 1984, Wilcox circa 1982	Simon et al. 2004 b, Stewart et al. 2003, Garza et al. 2002, Ingersoll et al. 2002, MacDonald et al. 2002 a, b, Perkins et al. 2000, Stewart et al. 1999, Simon and Stewart 1998, Simon et al. 1997, National Park Service 1994, Cole et al. 1990, Wilcox 1986 a, 1986 b, Wilcox circa 1982, Hardy 1983, Meyer and Tucci 1979, Arihood 1975	Garza et al. 2002, Whitman et al. 2002, Isiorho et al. 1996, Edwards 1995, Hiebert et al. 1986, Wilcox et al. 1986, Dolak 1985, Shedlock and Harkness 1984, Wilcox et al. 1984, Meyer and Tucci 1979, Arihood 1975	Isiorho et al. 1996, Shedlock and Harkness 1984, Meyer and Tucci 1979, Wilcox circa 1982, Arihood 1975	Whitman and Garza 2002, Stewart et al. 2000, Simon et al. 1997, Great Lakes Coastal Research Laboratory 1986, Shedlock and Harkness 1984
3	25	20	15	2	7	21	18	11	5	5

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
Bick et al. 1985, Wallace 1966, Linn et al. 1966	Nevers and Whitman 2004, Gorski et al. 2003, Stottlemyer et al. 2002, Gorski et al. 2001, Herrmann et al. 2000, Kallemeyn 2000, Larson et al. 2000, Nichols et al. 2001, Mast and Turk 1999, Stottlemyer and Toczydlowski 1999, Stottlemyer et al. 1998, Stottlemyer 1997, National Park Service 1995, Stottlemyer 1989, Meldrum 1987, Bick et al. 1985, Stottlemyer 1984, Stottlemyer 1982 a, 1982 b, Bowden 1981, Stottlemyer 1981, Johnson 1980, Toczydlowski 1978, Wallace 1966	Nevers and Whitman 2004, Gorski et al. 2003, Carlisle 2002, Gorski et al. 2001, Nichols et al. 2001, Larson et al. 2000, Van Buskirk 1993, Van Buskirk 1992 a, b, Bick et al. 1985, Stottlemyer 1984, Johnson 1980, Bowden 1981,Toczydlowski 1978, Linn et al. 1966, Prescott 1940, Prescott 1939, Prescott 1937, Prescott 1936, Taylor 1935	Quinlan et al. In Prep,Gorski et al. 2003, Gostomski 2002, Guinard et al. 2002, Gorski et al. 2001, Lockwood et al. 2001, Kallemeyn 2000, Kurunthachalam et al. 2000, Quinlan 2000, Baker and Hites 2000, Newman and Bast 1999, Quinlan 1999, Quinlan and Bast 1999, Curtis et al .(1998) In Prep., Peck 1998, Day 1997, Newman and Bast 1996, Curtis 1995, Hansen et al 1995, Michigan Department of Natural Resources 1995, Slade 1995,Curtis and Smith 1994, Michigan Department of Natural Resources 1994, Slade 1994, Slade and Olson 1994, Karamansk et al. 1991, Swackhamer and Hites 1988, Bick et al. 1985, Strachan 1983, Bierman and Swain 1982, Lagler and Goldman 1982,	Peterson and Vucetich 2004, Gostomski 2002, Smith and Shelton 2002, Egan and Oelfke 2000, Kaplan and Tischler 2000, Evers et al. 1998, Aho and Jordan 1979, Jordan 1978, Jordan and Aho 1978, Linn et al. 1966, Murie 1934	Milanowski et al. 2000, Smith and Van Buskirk 1995, Van Buskirk and Smith 1991, Smith 1987, Smith 1983	U.S. Geological Survey Circa 2000, Judziewicz 1999, Aho and Jordan 1979, Jordan 1978, Jordan and Aho 1978, Toczydlowski 1978, Bick et al. 1985, Linn et al. 1966, Murie 1934	Swackhamer and Hornbuckle 2004, Gorski et al. 2003, Carlisle 2002, Gostomski 2002, Gorski et al. 2001, Baker and Hites 2000, Kallemeyn 2000, Kaplan and Tischler 2000, Kurunthachalam et al. 2000, Nichols et al. 2001, Thurman and Cromwell 2000, Evers et al. 1998, Stottlemyer 1997, National Park Service 1995, McVeety and Hites 1988, Swackhamer and Hites 1988, McVeety 1986, Bick et al. 1985, Czuczwa et al. 1984, Stottlemyer 1984, Strachan 1983, Stottlemyer 1982 a, b, Gschwend and Hites 1981, Stottlemyer 1981, Eisenreich et al. 1980, Frank et al. 1980, Eisenreich et al. 1979, Strachan and Glass 1978, Kelly et al. 1975	Herrmann et al. 2000, Stottlemyer et al. 2002, Mast and Turk 1999, Stottlemyer and Toczydlowski 1999, Stottlemyer et al. 1998, Stottlemyer 1997, Stottlemyer 1989, McVeety and Hites 1988, Smith 1987, McVeety 1986, Stottlemyer 1984, Stottlemyer 1982 a, b, Bowden 1981, Stottlemyer 1981, Bick et al. 1985, Smith 1983, Raymond et al. 1975	Grannemann and Twenter 1982, (see Stottlemyer publications under “Water Quality” for soil pore water quality information)	Nichols et al. 2001, Kallemeyn 2000

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
			Swain et al. 1986, Strachan and Glass 1978, Swain 1978, Kelly et al. 1975, Rakestraw 1968, Wallace 1966, Linn et al. 1966, Sharp and Nord 1960, Eschmeyer and Bailey 1954, Hubbs and Lagler 1949, Hubbs 1932, Koelz 1929, Ruthven 1909, 1905, Raymond 1897							
4	24	20	46	11	5	8	30	18	1	2

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
MISS Metropolitan Council 2004, Metropolitan Council 1998, Minnesota Department of Natural Resources 1999, Metropolitan Council 1998, Winterstein et al. 1982 UMIS Andrews et al. 1996, Stark et al. 1996	MISS Kloiber 2004, Kloiber 2003, Anderson and Perry 1999, Wilson et al. 1995, National Park Service 1995, Have 1991, Ayers et al. 1985, Brown 1984, Payne et al. 1982, Larson et al. 1976 UMIS ZumBerge et al. 2003, Kroening et al. 2002, Fallon and McNellis 2000, Stark et al. 2000, Goldstein 1999, Talmage et al.1999, Kroening 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews et al. 1996, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	MISS U.S. Fish and Wildlife Service 2004, Kloiber 2003, Kelner and Davis 2002, Hornbach et al. 1998, Wilson et al. 1995, Stern et al. 1982 UMIS ZumBerge et al. 2003, Kroening et al. 2002, Andrews et al. 1996, Stark et al. 1996	MISS Koel 2004, Lee et al. 2000, Anderson and Perry 1999, Johnson and Jennings 1998, Hausler et al. 1995, Metz and Frie 1995, Mundahl et al. 1995, Holland-Bartels and Duval 1988, Waller and Holland-Bartels 1988, Holland 1986, Waller et al. 1985, Eddy et al. 1963 UMIS Kroening et al. 2000, McNellis et al. 2000, Goldstein 1999, Talmage et al.1999, Lee and Anderson 1998, Andrews et al. 1996, Stark et al. 1996	MISS Minnesota Department of Natural Resources 1999		MISS Minnesota Department of Natural Resources 1999	MISS Lee et al. 2000, Anderson and Perry 1999, National Park Service 1995, Ayers et al. 1985, Brown 1984, Payne et al. 1982, Maderak 1965 UMIS Fong 2000, Kroening et al. 2000, McNellis et al. 2000, Andrews 1998, Hanson 1998, Lee and Anderson 1998, Fallon et al. 1997, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	MISS Kloiber 2004, Metropolitan Council 2004, Kloiber 2003, Mitton 2002, Ruhl et al. 2002, Payne 1995, Schoenberg 1994, Have 1991, Schoenberg and Mitton 1990, Schoenberg 1989, Ayers et al. 1985, Payne et al. 1982, Novitch et al. 1973 UMIS Fallon and McNellis 2000, Goldstein 1999, Talmage et al.1999, Andrews et al. 1996, Stark et al. 1996	MISS Metropolitan Council 2004, Ruhl et al. 2002, Payne 1995, Schoenberg 1994, Lindgren 1990, Schoenberg 1990, Schoenberg 1989, Horn 1984, Schoenberg 1984, Horn 1983, Novitch et al. 1973, Maderak 1965 UMIS Fong 2000, Andrews 1998, Hanson 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews 1996, Andrews et al. 1995, Stark et al. 1996	MISS Hendrickson 2003, Kloiber 2003, Kelner and Davis 2002, Minnesota Department of Natural Resources 1999 UMIS Goldstein 1999, Talmage et al.1999
7	25	10	19	1	0	1	18	18	21	6

PICTURED ROCKS NATIONAL LAKESHORE

GENERAL RESOURCE PLANS AND DOCUMENTS	WATER QUALITY	BIOLOGY AND ECOLOGY	FISH	AQUATIC WILDLIFE	AMPHIBIANS AND REPTILES	WETLANDS AND AQUATIC VEGETATION	CONTAMINANTS	HYDROLOGY	GROUNDWATER	PHYSICAL STRUCTURE AND PROCESSES
Loope 2001, Heritage Research, Ltd. 1999, PIRO 1995, Michigan Technological University circa 1980	Nevers and Whitman 2004, Loope 2001, Michigan Department of Environmental Quality 2000, Boyle et al. 1999, Loope 1998 a, National Park Service 1995, Michigan Technological University circa 1980, Lewin 1991, Stottlemyer 1989, Mullen 1988, Kamke 1987, Handy and Twenter 1985, Stottlemyer 1982 a, b, Doepke 1972, Limnetics, Inc. 1970	Nevers and Whitman 2004, Loope 2001, Nichols et al. 2001, Michigan Department of Environmental Quality 2000, Boyle et al. 1999, Loope 1998 a, b, Loope 1993, Lewin 1991, Michigan Department of Natural Resources 1991, Michigan Department of Natural Resources 1989, Kamke 1987, Limnetics, Inc. 1970	Newman 2003, Armichardy and Leonard 2003, Sreenivasan and Leonard 2003, Newman 2001, Mich. Dept. of Env. Quality 2000, Boyle et al. 1999, Heritage Research, Ltd. 1999, Newman and Baker 1999, Gerovac et al. 1996, Hoff 1996, Gerovac and Whitman 1995, PIRO 1995, PIRO 1994, Mich. Dept. of Natural Resources 1992, Mich. Dept. of Natural Resources 1991, Mich. Dept. of Natural Resources 1989, Grim 1988, Mich. Dept. of Natural Resources 1988, Loope and Scott 1987, Loope 1986, USFWS, NPS 1983, Mich. Dept. of Natural Resources 1981, Mich.Dept. of Natural Resources 1976, Doepke 1972, Limnetics, Inc. 1970, Edsall 1960	Michigan Technological University circa 1980, Bowerman 1991, Michigan Department of Natural Resources 1991, Daues 1991	Loope 2001, Premo and Davis 1990, Werner 1989	MacKinnon 2004, Loope 2001, Loope 2001, Crispin et al. 1994, Loope 1993, Kamke 1987, Crispin 1984	Loope 2001, Nichols et al. 2001, National Park Service 1995, Michigan Department of Natural Resources 1992, Bowerman 1991, Lewin 1991, Michigan Department of Natural Resources 1991, Michigan Department of Natural Resources 1989, Stottlemyer 1989, Kamke 1987, Stottlemyer 1982 a, b, Limnetics, Inc. 1970	Loope et al. 2004, Loope 2001, Fisher and Whitman 1999, Loope 1993, Loope 1992, Stottlemyer 1989, Mullen 1988, Handy and Twenter 1985, Stottlemyer 1982 a, b		Loope et al. 2004, Nichols et al. 2001, Michigan Department of Environmental Quality 2000, Fisher and Whitman 1998, Gerovac et al. 1996, Hoff 1996, Blewett 1994, Loope 1993, Loope 1992, Loope and Holman 1991, Farrell and Hughes 1984
4	15	12	26	4	3	7	13	10	0	11

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
SACN Metropolitan Council 2004, Davis 2003, Nutrient Technical Subcommittee 1998, Holmberg et al. 1997, Malischke et al. 1994, Fago and Hatch 1993 UMIS Andrews et al. 1996, Stark et al. 1996	SACN Edlund 2004, Kloiber 2004, Davis 2003, Newton et al. 2003, Lenz 2004, Triplett et al. 2003, Payne et al. 2002, Robertson and Lenz 2002, Boyle and Strand 2001, Edlund and Engstrom 2001, Lenz et al. 2001, Kroening 2000, Meyer et al. 1999, Stewart and Butcher 1999, Nutrient Technical Subcommittee 1998, Holmberg et al. 1997, National Park Service 1995, Malischke et al. 1994, Fago and Hatch 1993, Troelstrup and Foley 1993, Troelstrup et al. 1993, Troelstrup 1993, Boyle et al. 1992, Hornbach 1992, Boyle and Beeson circa 1990, Graczyk 1985, Stern 1983, EPA Region V 1975, McKersie et al. 1972 UMIS ZumBerge et al.	SACN U.S. Fish and Wildlife Service 2004, Newton et al. 2003, Triplett et al. 2003, Hove and Hornbach 2002, Payne 2002, Robertson and Lenz 2002, Boyle and Strand 2001, Edlund et al. 2001, Grantsburg High School 2001, Hornbach 2001, Lenz et al. 2001, Bartsch et al. 2000, Heath et al. 2000, Hornbach et al. 2000, Hove et al. 2000, Hove and Hornbach 2000, Westrick 2000, Macbeth et al. 1999, Stewart and Butcher 1999, Davis 1998, Hornbach et al. 1998 a, b, Doolittle and Heath 1997, Ecological Specialists, Inc. 1997, Holmberg et al. 1997, Hornbach et al. 1997, Vaughn 1997, Hornbach 1996, Hornbach et al. 1996, Hanson and Leonard 1995, Hay et al. 1995, Hornbach 1995 a, b, Hornbach et al.	SACN NPS 2003, Payne 2002, Wisconsin Department of Natural Resources 2002, Benike and Michalek 2001, Hove et al. 2000, Lee et al. 2000, Niemela and Feist 2000, Ferrin et al 1999, Goldstein 1999, Sewell and Morse1998, Holmberg et al. 1997, Hove and Kapuscinski 1997, Hove 1996, Low and Lyons 1995, Damman 1993, Fago and Hatch 1993, Pratt 1993, Troelstrup 1993, Pratt 1992, McComas 1990, Montz 1989, Simon 1988, Cochran 1987, Fausch 1987, Hatch 1986, Johannes 1984, Newman and Waters 1984, Pratt 1982, Johannes 1980, Rieckhoff 1977, Peterson 1964 UMIS Kroening et al. 2000, McNellis et al. 2000, Goldstein et al. 1999,		SACN DonnerWright et al. 1999, DonnerWright 1996, DonnerWright 1994, Savage et al. 1993, Probst et al. 1991	SACN Konkel 2000, Holmberg et al. 1997, Barr Engineering Company 1994, Glenn-Lewin et al. 1992, Glenn-Lewin et al. 1991, Glenn-Lewin 1988	SACN Newton et al. 2003, Payne and Hansen 2003, Brigham 2002, Lee et al. 2000, Stewart and Butcher 1999, National Park Service 1995, Troelstrup et al. 1993, Graczyk 1985 UMIS Fong 2000, Kroening et al. 2000, McNellis et al. 2000, Andrews 1998, Hanson 1998, Lee and Anderson 1998, Fallon et al. 1997, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	SACN Metropolitan Council 2004, Lenz 2004, Mitton 2002, Payne 2002, Lenz et al. 2001, Hove and Hornbach 2000, Kroening 2000, Westrick 2000, DonnerWright et al. 1999, Goldstein 1999, Johnson 1999 c, Hornbach 1998 a, Holmberg et al. 1997, Hornbach 1997, Hanson and Leonard 1995, Hornbach 1995 a, b, Johnson 1995 a, b, Fago and Hatch 1993, Schoenberg and Mitton 1990, Mackay and Waters 1986, Norvitch et al. 1973 UMIS Fallon and McNellis 2000, Goldstein 1999, Talmage et al.1999, Andrews et al. 1996, Stark et al. 1996	SACN Metropolitan Council 2004, Ruhl et al. 2002, Norvitch et al. 1973 UMIS Fong 2000, Andrews 1998, Hanson 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews 1996, Andrews et al. 1995, Stark et al. 1996	SACN Hove and Hornbach 2002, Payne 2002, Griffin et al. 2000, Johnson 2000, Westrick 2000, DonnerWright et al. 1999, Goldstein 1999, Johnson 1999 a, b, c, d, Konkel 1999, Macbeth et al. 1999, Pitt et al. 1999, Davis 1998, Ferrin et al. 1998, Hornbach et al. 1998 b, Holmberg et al. 1997, Hanson and Leonard 1995, Johnson 1995 a, b, Troelstrup et al. 1993 UMIS Goldstein 1999, Talmage et al.1999

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
	2003, Kroening et al. 2002, Fallon and McNellis 2000, Stark et al. 2000, Goldstein 1999, Talmage et al.1999, Kroening 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews et al. 1996, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	1995, Johnson 1995 a, b, Lillie 1995, Helms & Associates 1994, Troelstrup and Hornbach 1994, Fago and Hatch 1993, Troelstrup and Foley 1993, Troelstrup 1993, Troelstrup et al. 1993 a, b, Vogt and Smith 1993, Boyle et al. 1992, Hornbach 1992, Boyle and Beeson circa 1990, Heath and Rasmussen 1990, Busacker 1989, Havlik 1987, Mackay and Waters 1986, Newman and Waters 1984, Stern 1983, Stern et al. 1982, Waters 1981, Shiozawa 1978, EPA Region V 1975, Holt and Waters 1967, Waters 1966, Waters 1965, Waters 1962, Waters 1961 <u>UMIS</u> ZumBerge et al. 2003, Kroening et al. 2002, Andrews et al. 1996, Stark et al. 1996	Talmage et al.1999, Lee and Anderson 1998, Andrews et al. 1996, Stark et al. 1996							
8	44	67	38	0	5	6	19	28	12	24

SLEEPING BEAR DUNES NATIONAL LAKESHORE

GENERAL RESOURCE PLANS AND DOCUMENTS	WATER QUALITY	BIOLOGY AND ECOLOGY	FISH	AQUATIC WILDLIFE	AMPHIBIANS AND REPTILES	WETLANDS AND AQUATIC VEGETATION	CONTAMINANTS	HYDROLOGY	GROUNDWATER	PHYSICAL STRUCTURE AND PROCESSES
Heiman and Woller 2003, Vana-Miller 2002	Nevers and Whitman 2004, Heiman and Woller 2003, Whitman et al. 2003, Vana-Miller 2002, Murphy 2002, Whitman et al. 2002, Murphy 2001, Walker 1999 a, b, Canale 1998, Fuss 1998, Flower and Walker 1998 a, b, National Park Service 1997, Last et al. 1995, Whitman et al. 1994, Boyle and Hoefs 1993, EPA Region V 1992, Fritz and Engstrom 1992, Nürnberg 1992, Stevenson 1992, Ellis 1991, Handy and Stark 1984, Gannon and Stockwell 1978, Curry 1977, Stockwell and Gannon 1975, Stockwell and Gannon 1974, Curry 1973	Nevers and Whitman 2004, Lowe and Carter 2004, Wearly et al. 2004, Vana-Miller 2002, Murphy 2002, Whitman et al. 2002, Murphy 2001, Heuschele 2000, Flower and Walker 1999 a, b, Last et al. 1995, Whitman et al. 1994, Boyle and Hoefs 1993, EPA Region V 1992, Fritz and Engstrom 1992, Stevenson 1992, Linton 1987, White 1987, Gannon and Stockwell 1978, Curry 1977, Stockwell and Gannon 1975, Stockwell and Gannon 1974, Curry 1973, Hoefs 1993, Environmental Resources Management 1985	Heiman and Woller 2003, Canale et al. 2002, Vana-Miller 2002, Michgigan Dept. Env Qual. 1999, Flower and Walker 1999 a, b, Jennings 1998, Hoffs 1993, Michigan Department of Natural Resources 1990, Michigan Department of Natural Resources 1987, Michigan Department of Natural Resources 1983, Kelly and Price 1979, Walter et al. 1979, Gannon and Stockwell 1978, Univ. Michigan 1975, Michigan Department of Natural Resources 1974, Scott 1920	Patton 1978	Linton and Kats 1987, McCann 1975	Heiman and Woller 2003, Vana-Miller 2002, Edwards 1995, Albert 1992, EPA Region V 1992, Hazlett 1989, White 1987, Wilcox 1982, Curry 1977, Stockwell and Gannon 1975, Stockwell and Gannon 1974	National Park Service 1997, Hoefs 1993, EPA Region V 1992, Handy and Stark 1984, Cline and Chambers 1977	Heiman and Woller 2003, Albright et al. 2002, Murphy 2002, Vana-Miller 2002, Edwards 1995, Boyle and Hoefs 1993, Albert 1992, EPA Region V 1992, Handy and Stark 1984, Stockwell and Gannon 1975, Stockwell and Gannon 1974	Heiman and Woller 2003, EPA Region V 1992, Ellis 1991,Handy and Stark 1984	Lowe and Carter 2004, Flower and Walker 1999 a, b, Linton 1987, EPA Region V 1992, Fritz and Engstrom 1992, Environmental Resources Management 1985, Kemezis 1983
2	28	25	17	1	2	11	5	11	4	8

VOYAGEURS NATIONAL PARK

General Resource Plans and Documents	Water Quality	Biology and Ecology	Fish	Aquatic Wildlife	Amphibians and Reptiles	Wetlands and Aquatic Vegetation	Contaminants	Hydrology	Groundwater	Physical Structure and Processes
Kallemeyn et al. 2003, Kallemeyn 2002, Weeks and Andrascik 1998, Bureau of Sport Fisheries and Wildlife 1969.	Christensen et al. 2004, Nevers and Whitman 2004, Goldstein et al. 2003, Kallemeyn et al. 2003, Payne 2000, Weeks and Andrascik 1998, National Park Service 1995, Webster and Brezonik 1995, Webster et al. 1993, Kallemeyn et al. 1993, Kallemeyn 1992, Kallemeyn 1990, Sorensen et al. 1990, Kepner and Stottlemyer 1988, Kraft 1988, Payne 1991, Rapp et al. 1985, Hargis 1981, Mayasich 1981, Payne 1979	Nevers and Whitman 2004, Lafrancois and Carlisle 2004, Kallemeyn et al. 2003, Sorensen and Rapp 2001, Hoven 1998, Kallemeyn et al. 1993, Kallemeyn 1992, Wilcox and Meeker 1992, Payne 1991, Kallemeyn 1990, Sorensen et al. 1990, Kraft 1988, Kallemeyn 1983, Hargis 1981, Mayasich 1981, Payne 1979, Sharp 1941	Kallemeyn et al. 2003, McLeod 2002, Sorensen and Rapp 2001, Schlosser and Kallemeyn 2000, McLeod 1999, Minnesota Department of Natural Resources 1998, Soupir 1998, Weeks and Andrascik 1998, Kallemeyn and Warner 1995, Duffy et al. 1994, Cohen and Radomski 1993a, 1993b, Kallemeyn et al. 1993, Kallemeyn 1992, Wilcox and Meeker 1992, Kallemeyn 1990, Sorensen et al. 1990, VOYA 1990, Kallemeyn 1989, Kallemeyn and Cole 1988, Kallemeyn 1987a, 1987b, Cole 1986, Ernst 1986, 1986b, Kallemeyn 1985a, b, c, d, e, Bureau of Sport Fisheries and Wildlife 1969, Sharp 1941	Kallemeyn et al. 2003, Schlosser and Kallemeyn 2000, Evers et al. 1998, Smith 1994, Smith and Jenkins 1994, Kallemeyn et al. 1993, Ensor et al. 1992, Kallemeyn 1992, Wilcox and Meeker 1992, Johnston and Naiman 1990 a, b, Kallemeyn 1990, Naiman et al. 1988, Reiser 1988, Route and Peterson 1988, Smith and Peterson 1988, Thurber and Peterson 1988, Bureau of Sport Fisheries and Wildlife 1969, Sharp 1941	Kallemeyn et al. 2003, Palmer 1989	Hop et al. 2001, Kallemeyn et al. 2003, Rapp 2001, Grim and Leland 1998, Weeks and Andrascik 1998, Pastor et al. 1996, Bridgham et al. 1995, Updegraff et al. 1995, Smith 1994, Kallemeyn et al. 1993, Kallemeyn 1992, Wilcox and Meeker 1992, Wilcox and Meeker 1991, Johnston and Naiman 1990 a, b, Kallemeyn 1990, Benedict and Grim 1989, Naiman et al. 1988, Monson 1986, Sorensen and Sharp 1941	Lafrancois and Carlisle 2004, Swackhamer and Hornbuckle 2004, Goldstein et al. 2003, Kallemeyn et al. 2003, Sorensen et al. 2001, Payne 2000, Engstrom et al. 1999, Sorensen 1999, Glass and Sorenson 1999, Evers et al. 1998, Weeks and Andrascik 1998, Webster and Brezonik 1995, Sorensen et al. 1994, Webster et al. 1993, Ensor et al. 1992, Sorensen et al. 1990, Route and Peterson 1988, Rapp et al. 1985, Mayasich 1981	Christensen et al. 2004, Kallemeyn et al. 2003, Kallemeyn 2002, Weeks and Andrascik 1998, National Park Service 1995, Kallemeyn et al. 1993, Kallemeyn 1992, Wilcox and Meeker 1992, Wilcox and Meeker 1991, Johnston and Naiman 1990 a, b, Kallemeyn 1990, Kallemeyn and Cole 1988, Kepner and Stottlemyer 1988, Kraft 1988, Naiman et al. 1988, Reiser 1988, Route and Peterson 1988, Smith and Peterson 1988, Thurber and Peterson 1988, Flug 1986 a, b, Monson 1986, Rapp et al. 1985, Sharp 1941		Schlosser and Kallemeyn 2000, Bridgham et al. 1995, Smith 1994, Johnston and Naiman 1990 a, b, Naiman et al. 1988
4	20	17	32	19	2	20	19	25	0	6

GENERAL RESOURCE PLANS AND DOCUMENTS	WATER QUALITY	BIOLOGY AND ECOLOGY	FISH	AQUATIC WILDLIFE	AMPHIBIANS AND REPTILES	WETLANDS AND AQUATIC VEGETATION	CONTAMINANTS	HYDROLOGY	GROUNDWATER	PHYSICAL STRUCTURE AND PROCESSES
Andrews et al. 1996, Stark et al. 1996	ZumBerge et al. 2003, Kroening et al. 2002, Fallon and McNellis 2000, Stark et al. 2000, Goldstein 1999, Talmage et al.1999, Kroening 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews et al. 1996, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	ZumBerge et al. 2003, Kroening et al. 2002, Andrews et al. 1996, Stark et al. 1996	Kroening et al. 2000, McNellis et al. 2000, Goldstein 1999, Talmage et al.1999, Lee and Anderson 1998, Andrews et al. 1996, Stark et al. 1996				Fong 2000, Kroening et al. 2000, McNellis et al. 2000, Andrews 1998, Hanson 1998, Lee and Anderson 1998, Fallon et al. 1997, Andrews 1996, Stark 1996, Stark et al. 1996, Andrews et al. 1995	Fallon and McNellis 2000, Goldstein 1999, Talmage et al.1999, Andrews et al. 1996, Stark et al. 1996	Fong 2000, Andrews 1998, Hanson 1998, Fallon et al. 1997, Kroening and Andrews 1997, Kroening and Stark 1997, Andrews 1996, Andrews et al. 1995, Stark et al. 1996	Goldstein 1999, Talmage et al.1999
2	15	4	7	0	0	0	11	5	9	2

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a majority responsibility for American Indian reservvation communities and for people who live in island territories under U.S. administration.

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