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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Grand Portage National Monument

Natural Resource Report NPS/GRPO/NRR—2014/783

ON THE COVER
The Great Hall on the shore of Grand Portage Bay, Grand Portage National Monument
Photograph by Dave Mechenich

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Contents

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Figures (continued)

Page

Figures (continued)

Figures (continued)

Page

Tables

Page

Tables (continued)

Page

Tables (continued)

Page

Appendices

Executive Summary

Grand Portage National Monument (GRPO), established by an act of Congress (P.L. 85-910, 72 Stat. 1751) in 1958, is located in extreme northeastern Minnesota. It protects the site of the historic North West Company fur trading post on Lake Superior's Grand Portage Bay and the major canoe portage trail connecting the Great Lakes to the lakes and streams of the Canadian northwest. The Monument consists of 709 acres, 69 of which are in the Lakeshore Unit, which includes the trading post site. The canoe portage trail is 539 acres in a corridor 8.5 miles long and 600 feet wide which passes through an ancient gap in the hills and traverses areas of southern boreal forest and wetland. At the other end of the trail is the historic site of Fort Charlotte, a 101-acre site which today is largely undeveloped and serves as a campsite for trail users and canoers descending the Pigeon River from the Boundary Waters Canoe Area Wilderness. In 2010, nearly 114,000 people visited GRPO; 86,212 visited the Heritage (Visitor) Center, and 210 took out backcountry permits to camp at Fort Charlotte.

The trail corridor crosses a rugged landscape underlain by ancient sedimentary shale and siltstone bedrock, into which dikes of diabase, an igneous rock, intruded about 1,100 million years ago. The current landscape is the result of a glacial advance about 12,000 years ago that scoured high areas and filled in low areas. GRPO is in the USEPA Northern Lakes and Forests ecoregion, and over 92% of GRPO is covered by forest and woodland, with 74% of the forest in the southern boreal white-spruce-balsam fir group.

GRPO is located in an area of mid-continental climate, with hot summers and cold winters, but is greatly influenced by its location on Lake Superior, which moderates temperatures, increases precipitation, and creates a slight seasonal shift to later summers. In the western portion of the trail corridor, away from the Lake, temperatures are more extreme, and conditions are generally drier.

GRPO is surrounded by the reservation of the Grand Portage Band of Lake Superior Chippewa except where it is bordered by the Pigeon River. It is the only unit within the National Park Service that co-manages natural resources through a Tribal Self-Governance Act agreement. From an ecosystem management perspective, the relative narrowness of the trail corridor requires that GRPO resources be evaluated at larger landscape or watershed scales.

GRPO is located entirely within the Baptism-Brule subwatershed of the Lake Superior watershed. It crosses three smaller watersheds. The Grand Portage Creek watershed includes Grand Portage Creek, which enters Grand Portage Bay in the Depot area, and two small impoundments, Mt. Maud Lake and Dutchman Lake. These impoundments lie outside GRPO. The Poplar Creek watershed includes wetland areas where the trail crosses the creek. The Upper Pigeon River watershed includes Snow Creek and the Pigeon River at the end of the portage trail. Snow Creek and Poplar Creek are tributaries of the Pigeon River.

Animals of significance to GRPO include the beaver, moose, gray wolf, and coaster brook trout. The beaver is a critical element in the history of GRPO because of its importance to the fur trade; GRPO is the earliest fur trading site in the NPS. Within GRPO, the major active beaver colony is on Snow Creek. The moose population in northeastern Minnesota is in decline. GRPO has been designated an area of critical habitat for the gray wolf, which was recently removed from the federal Endangered Species list. Coaster brook trout, a distinct form of brook trout native to Lake Superior, are stocked in Grand Portage Creek by the Grand Portage Band. GRPO is additionally home to three Minnesota threatened fauna and four fauna of special concern. GRPO has one Minnesota endangered plant, four threatened plants, and 11 plant species of special concern.

This Natural Resource Condition Assessment was undertaken to evaluate current conditions for a subset of natural resources and resource indicators in GRPO. Using a framework developed by the Science Advisory Board of the USEPA, natural resources were evaluated in six categories: landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology and geomorphology, and natural disturbance regimes. A total of 42 resources and indicators were evaluated (Table i) by reviewing existing data from peer-reviewed literature and federal, state, and tribal agencies. Data were analyzed where possible to provide summaries or new statistical or spatial representations.

Natural resources and resource indicators in GRPO are affected by activities and processes at scales ranging from local (e.g., logging, road density, and sewage discharge) to global (e.g., atmospheric deposition and climate change). Conditions of significant concern are related to air resources (deposition of mercury and nitrogen) and exotic species in the Pigeon River; these are out of the jurisdiction of GRPO managers. Similarly, those resources that are in conditions of moderate concern, with a declining trend (the southern boreal forest, moose, and the hydrology of the Pigeon River) are primarily affected by climate change. Some resources and resource indicators such as beaver populations and water quality are in good and stable condition. Improvements have been noted in the aquatic macroinvertebrate populations in Grand Portage and Poplar Creeks, and levels of some organic contaminants (DDT and PCBs) have declined.

Although the Grand Portage Band and the NPS Great Lakes Inventory and Monitoring Network have collected a significant amount of data on natural resources in GRPO in recent years, much of it does not yet have a period of record sufficient to evaluate trends. Monitoring efforts in subject areas including water quality, aquatic macroinvertebrate populations, beaver populations, exotic species detection, and vegetation analysis should be continued.

Table i. Condition and trend of natural resources and resource indicators evaluated for Grand Portage National Monument.

Condition and Trend	Natural Resource or Resource Indicator
Condition good, improving trend	Aquatic macroinvertebrates in Grand Portage Creek and Poplar Creek Organic contaminants in fish – DDT and metabolites and total PCBs
Condition good, uncertain trend	Land cover Impervious surfaces Viral Hemorrhagic Septicemia virus (VHSv) *Didymosphenia geminata* (Didymo) Water quality of inland waters – chloride and total nitrogen Mercury in game fish – Grand Portage, Poplar, and Snow Creeks
Condition good, stable trend	Beaver Water quality of inland waters – specific conductance, pH, dissolved oxygen, water clarity, alkalinity, and total phosphorus Water quality of Grand Portage Bay – dissolved oxygen and E. coli Geomorphology of Grand Portage Bay
Condition of moderate concern, uncertain trend	Landscape pattern and structure Terrestrial exotic plant species Organic contaminants in fish – PFOS and other PFCs and PBDEs Water quality of Grand Portage Bay – turbidity and total phosphorus Mercury in game fish – Grand Portage Bay Organic contaminants in sediments – Grand Portage Bay Hydrology and geomorphology of Grand Portage Creek Hydrology of the Pigeon River
Condition of moderate concern, stable trend	Road density – moose and gray wolf Air – ozone, visibility, and wet deposition of total sulfur Mercury in soil
Condition of moderate concern, declining trend	Southern boreal forest Moose
Condition of significant concern, uncertain trend	Aquatic non-native and invasive species – Pigeon River Mercury in streams and aquatic organisms other than game fish Mercury in game fish – Pigeon River
Condition of significant concern, stable trend	Air – wet deposition of total nitrogen Mercury in precipitation
Condition unknown, improving trend	Coaster brook trout – Grand Portage Creek and Bay
Condition unknown, unknown trend	Water quality of inland waters – nitrate and nitrite nitrogen and chlorophyll *a* Aquatic non-native and invasive species – Grand Portage Bay

Acknowledgments

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Many people gave us helpful advice, often including locating and/or sharing old, unpublished, or very new data for us, or reviewing portions or all of the draft document. These include Ulf Gafvert, the GLKN project liaison; Mark Hart, Brenda Moraska Lafrancois, Suzanne Sanders, and Joan Elias of GLKN; Jay Glase of the NPS regional office, Brian Fredrickson and Anne Jackson of MPCA; Mark Sandheinrich and Jim Wiener of UW-La Crosse; Bill Monahan and Lisa Nelson of the NPS NPScape program office; Titus Seilheimer of USFS; and Christian Stewart of Christian Stewart Consulting. Special thanks go to Seth Moore and Margaret Watkins of the Grand Portage Band for sharing data and reviewing portions of the document. Thanks to Dan Mechenich for producing the symbols used to denote condition and trend.

List of Acronyms and Abbreviations

BWCAW	Boundary Waters Canoe Area Wilderness
DO	Dissolved oxygen
GCM	General circulation model
GLKN	NPS Great Lakes Inventory and Monitoring Network
Grand Portage Band	Grand Portage Band of Lake Superior Chippewa
Grand Portage Reservation	Grand Portage Indian Reservation
GPBNRM	Grand Portage Band Natural Resources Management Department
GRPO	Grand Portage National Monument
HUC	Hydrologic Unit Code
IRMA	NPS Integrated Resource Management Applications web portal
ISRO	Isle Royale National Park
MDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
NPS	National Park Service
TN	Total nitrogen
TP	Total phosphorus
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
UWSP	University of Wisconsin – Stevens Point
VOYA	Voyageurs National Park
ww	wet weight

Chapter 1 NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope; [1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products[4];
- summarize key findings by park areas;[5] and
- follow national NRCA guidelines and standards for study design and reporting products.

NRCAs Strive to Provide…
Credible condition reporting for a subset of important park natural resources and indicators
Useful condition summaries by broader resource categories or topics, and by park areas

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas.

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

NRCAs can yield new insights about current park resource conditions but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decisionmaking, planning, and partnership activities.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm.

NRCA Reporting Products…
Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public

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[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Grand Portage National Monument (GRPO) was established on September 2, 1958 by an act of Congress (P.L. 85-910, 72 Stat. 1751) as a unit of the NPS "for the purpose of preserving an area containing unique historic values…" and "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same" (Cockrell 1983, NPS 2003a). The monument is significant because of its association with the fur trade, the exploration and colonization of the Northwest, its historic/geographic link between the United States and Canada, and its excellent state of preservation in a semi-wilderness setting (NPS 2003b).

GRPO had previously been designated a national historic site in 1951 (Cockrell 1983). Its establishment as a national monument depended on the relinquishment of land titles and interests within the proposed monument boundaries to the Department of the Interior by the Minnesota Chippewa Tribe and the Grand Portage Band of the Minnesota Chippewa Tribe. On January 27, 1960 the last such relinquishments occurred, allowing for the creation of GRPO as a national monument (NPS 2003a). GRPO is the only unit of the NPS to be co-managed through a Tribal Self-Governance Act agreement.

2.1.2 Geographic and Cultural Setting

GRPO is located on the Lake Superior shoreline in extreme northeastern Minnesota near the Canadian border (Figure 1) and bisects the Grand Portage Indian Reservation (hereafter, Grand Portage Reservation) of the Grand Portage Band of Lake Superior Chippewa (hereafter, Grand Portage Band). The monument protects 287 hectares (ha) of land, including the historic trading post of the North West Company on Lake Superior's Grand Portage Bay (Figure 2) (28 ha), the site of Fort Charlotte on the Pigeon River (41 ha), and a historic canoe portage trail that is 13.6 kilometer (km) in length and 183 meters (m) in width for much of its length (218 ha) (Figure 1) (NPS 2011a). The resources trust zone of GRPO, the focus of this assessment, is 273 ha (94.9%) of the monument; other zones include the interpretive historic zone (8.1 ha, 2.8%), the primitive trail zone (4.0 ha, 1.4%), the visitor services development zone (2.1 ha, 0.7%), and the recreation zone at Fort Charlotte (0.6 ha, 0.2%) (GRPO 2004).

In the Lakeshore Unit, cultural features of the interpretive historic zone include a Heritage (Visitor) Center featuring museum exhibits and films and a stockade with three log buildings – a great hall, kitchen, and canoe warehouse – where staff dressed in period costumes conduct interpretive activities. Outside interpretive areas include an Ojibwe village, a voyageurs' encampment, a dock, and European kitchen and Ojibwe three sisters' gardens. Also in the Lakeshore Unit is the 1.6 km Mount Rose interpretive trail (NPS 2008). Visitors can also hike the Grand Portage corridor trail, which traverses rugged terrain covered by southern boreal forest (Gafvert 2009). Backcountry camping is permitted along the Pigeon River near the historic site of Fort Charlotte at the northern end of the trail (NPS 2008).

The Grand Portage corridor trail connects Grand Portage Bay, the deepest indentation of the Lake Superior shoreline in Minnesota (Schwartz 1928), with the navigable portion of the Pigeon

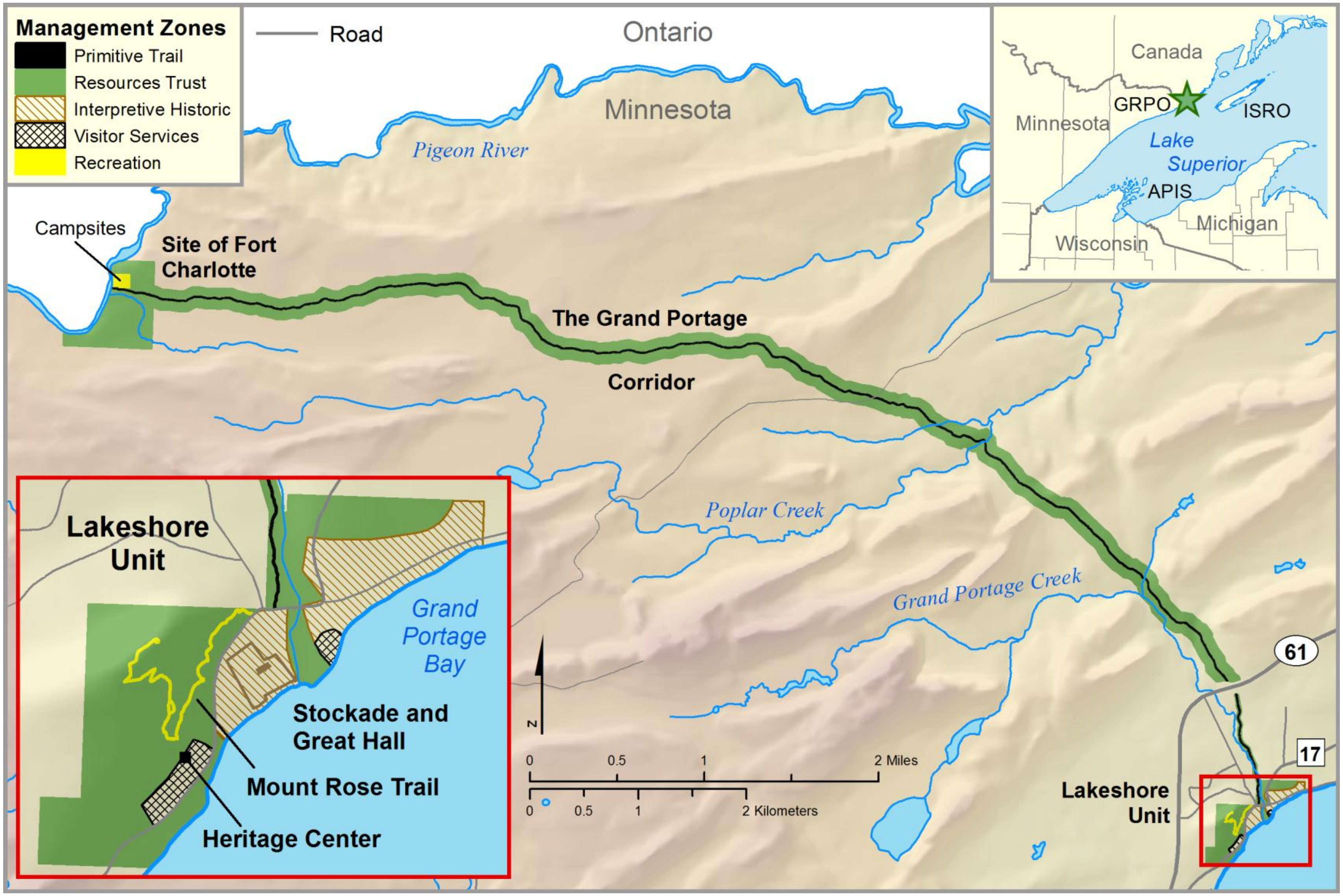

Figure 1. Location and features of Grand Portage National Monument (GRPO) in Minnesota. Locations of Isle Royale National Park (ISRO) and Apostle Islands National Lakeshore (APIS) are also shown.

Figure 2. The stockade, great hall, and kitchen buildings in the depot area, as seen from the Mount Rose trail at Grand Portage National Monument.

River, and from there, the lakes and streams of the Canadian northwest (Cockrell 1983, Woolworth 1993). The voyageurs, French fur traders and trappers, learned of “Le Grand Portage,” or “The Great Carrying Place,” from Native Americans, various groups of whom had used it since prehistoric times (Cockrell 1983). The period between 1783 and 1803 saw the heaviest European use at Grand Portage; the North West company built on the Bay a stockade which enclosed 16 buildings (Aby 2002), but the post quickly fell into disrepair after it was abandoned by the British in 1804 (Cockrell 1983).

This history of GRPO is very closely linked to its geology as well as its geography. GRPO is underlain by two major geologic formations: the ancient argillaceous shales and siltstones of the Rove formation of Middle Precambrian age and the harder, fine-grained, intrusive Pigeon River diabase of Keweenawan age, which forms dikes that cut across it (Figure 3) (Morey 1969, Gafvert 2009). The landforms seen at GRPO today are the result of the last glacial advance, roughly 12,000 years ago (Gafvert 2009). Dikes typically appear as prominent, steep-sided ridges surrounded by gently rolling to level topography in the valleys. Glacial action scoured many high landscape positions to bare rock and filled many low-lying areas (Gafvert 2009). The portage trail follows a gap created in the hills by more intense weathering through a fault-weakened section of ridge, crossing the Rove formation and avoiding the dikes in favor of a gentler gradient for foot travel (Figure 4) (Phillips 2003, Gafvert 2009). The bay and surrounding lowlands are a result of erosion of the soft shales (Schwartz 1928).

Two major soil associations make up 73% of GRPO soils: the Portwing-Herbster complex (50.6%) and the Cornucopia silt loam (22.4%) (Table 1) (Gafvert 2009). GRPO soils are primarily clayey and often mantled with silty to loamy deposits 15 to 25 centimeters (cm) thick (Figure 5) (Gafvert 2009). The unconsolidated sediments in which the soils have formed are

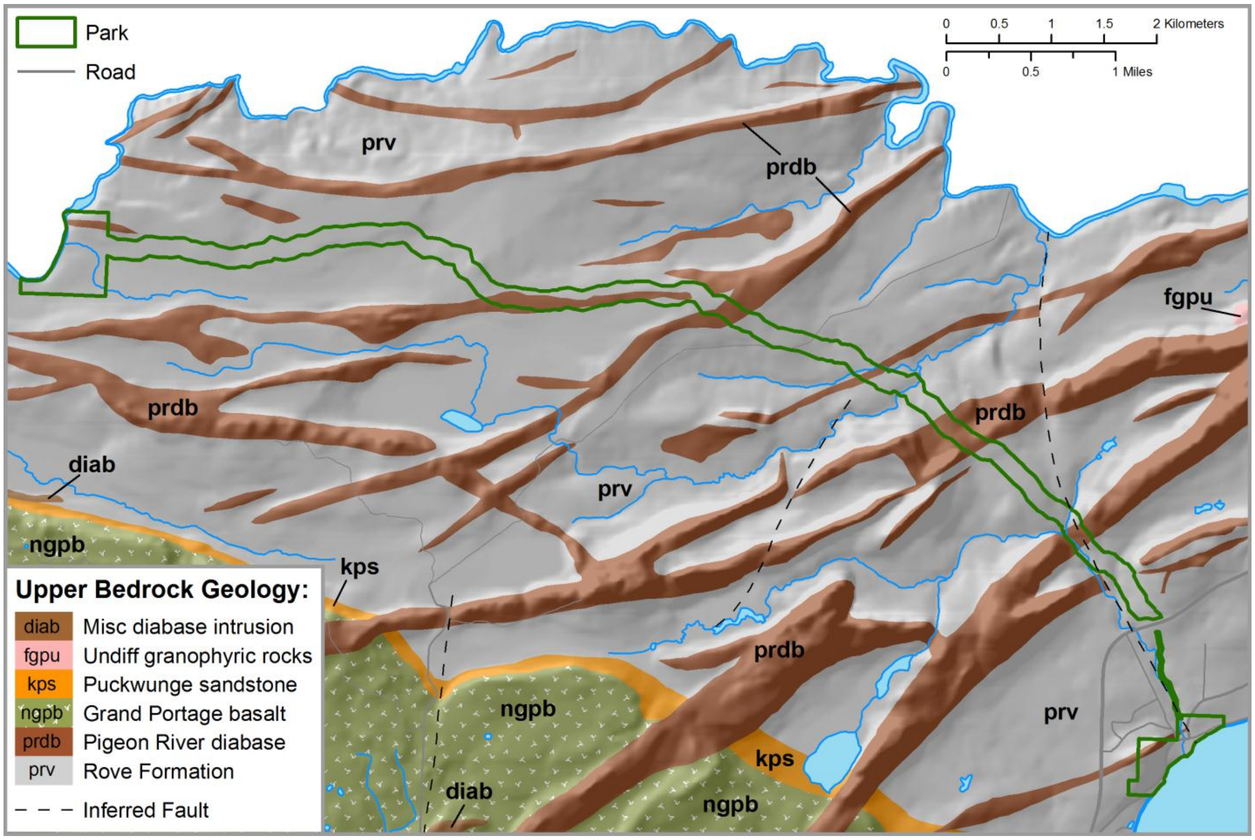

Figure 3. Upper bedrock geology of the Grand Portage National Monument area (Miller et al. 2002).

Figure 4. The weathered gap through which the Grand Portage trail passes (NPS photo).

Table 1. Soils of Grand Portage National Monument (Gafvert 2009).

Map Symbol	Map Unit Name	Slope (%)	Soil Group	Ha	%
388B	Pelkie, occasionally flooded, Dechamps, frequently flooded, complex	0-4	Alluvial (silty and loamy soils in floodplains)	5.8	2.0
6A	Moquah fine sandy loam, frequently flooded	0-3		1.2	0.4
7C	Beaches	2-12	Beaches	0.7	0.2
10C	Quetico-Minong-Rock outcrop complex, very stony	1-12	Bedrock (shallow soils over bedrock)	10.4	3.6
11F	Quetico-Peshekee-Rock outcrop complex	10-90		8.2	2.8
11E	Quetico-Peshekee-Rock outcrop complex, very stony	12-50		5.3	1.8
601C	Ishpeming-Rock outcrop complex, very stony	5-20		1.2	0.4
280F	Odanah silt loam	25-60	Clay (deep clay soils > 150 cm)	6.8	2.4
580B	Sanborg-Badriver complex	0-6		4.6	1.6
480B	Portwing-Herbster complex	0-6	Clay with silts, fine sands > 100 - 150 cm	146.1	50.6
481C	Cornucopia silt loam	6-15		41.5	14.4
481E	Cornucopia silt loam	15-45		23.0	8.0
479A	Lerch-Herbster complex	0-3		4.3	1.5
756B	Superior-Sedgwick complex	0-6	Clay (clay soils with 25 - 60 cm loamy surface)	6.5	2.3
756C	Superior-Sedgwick complex	6-15		5.5	1.9
517B	Annalake fine sandy loam, lake terrace	2-6	Loamy (stratified, loamy materials)	6.7	2.3
517C	Annalake fine sandy loam, lake terrace	6-15		0.2	0.1
375A	Robago fine sandy loam, lake terrace	0-3		0.2	0.1
407A	Seelyeville and Markey soils	0-1	Organic (Organic material, > 40 cm over mineral soil)	7.6	2.6
405A	Lupton, Cathro, and Tawas soils	0-1		0.5	0.2
W	Water		Water	2.5	0.9
			Total	288.9	100.0

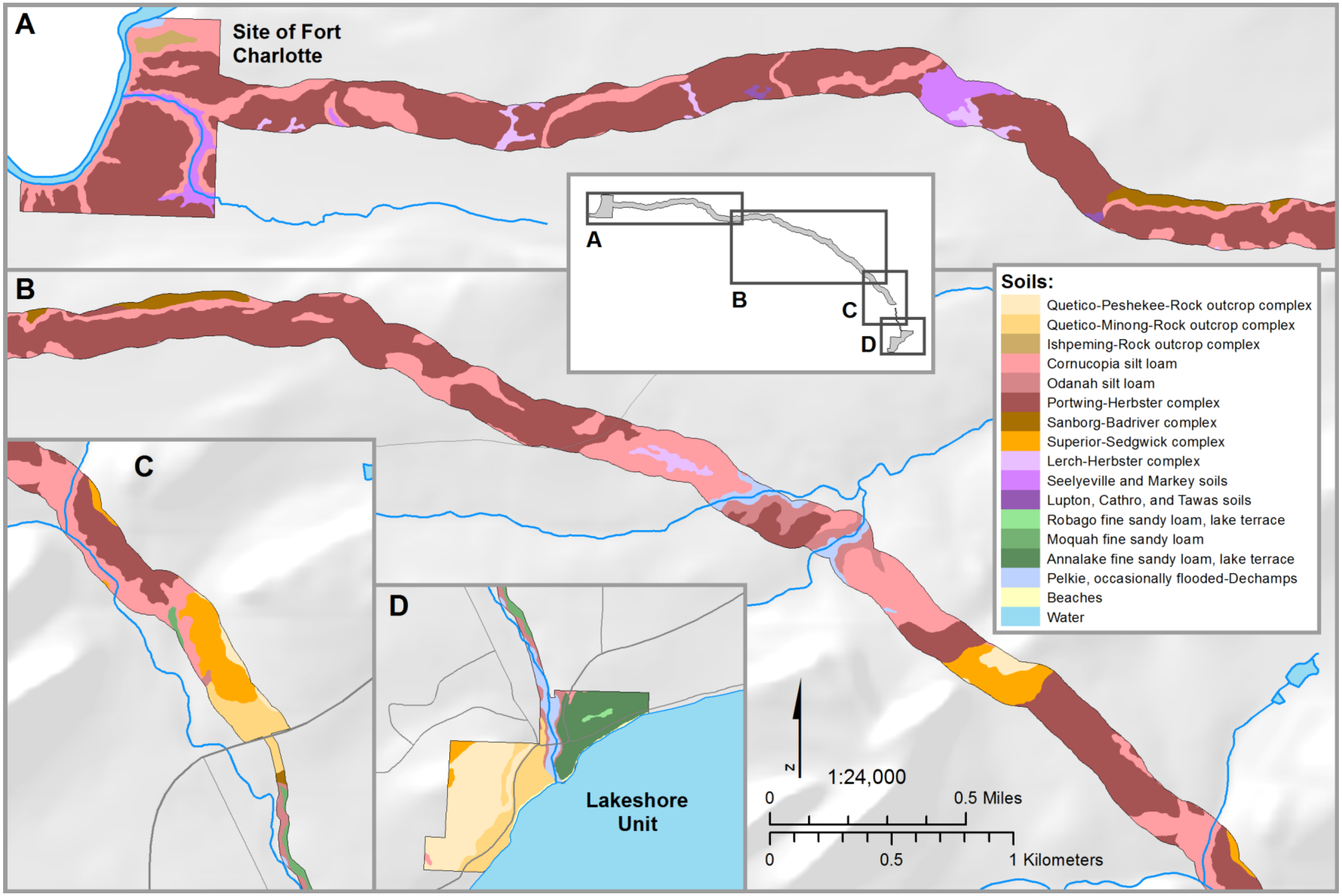

Figure 5. Soils of Grand Portage National Monument (Gafvert 2009).

largely derived from fine-grained bedrock (both basalts and shales) which have been repeatedly reworked and deposited during the numerous advances and retreats of glacial ice over the past several hundred-thousand years of the Pleistocene era (Gafvert 2009). Along the margin of Lake Superior, soils typically consist of silty material in the upper profile and grade into coarser sands and gravels with depth. These areas, which are now situated well above lake level, represent the Lake Superior shoreline at past higher lake stands (Gafvert 2009).

GRPO is located in a region of mid-continental climate (hot summers, cold winters), but is greatly influenced by its location on Lake Superior, which moderates temperatures, increases precipitation, and creates a slight seasonal shift to later summers (GRPO 2004, Route and Elias 2007). Route and Elias (2007) analyzed NOAA cooperative weather station data for the Pigeon River (station 216505, years 1948-1950 and 1951-1980) and Grand Portage (station 213296, years 1989-2006). The mean annual temperature at GRPO is 3.6°C, with a range of 2.7-5.7°C (Route and Elias 2007). Seasonal extremes range from -40°C to 38°C (GRPO 2004). Mean annual precipitation is 76.7 cm with a range of 55.4-99.6 cm (Route and Elias 2007). Most precipitation falls during summer months, but monthly totals are highly variable (GRPO 2004). Mean annual snowfall is 165.1 cm with a range of 76.2-264.2 cm (Route and Elias 2007). GRPO staff has observed that more extreme temperatures and generally drier conditions seem to prevail in the western portion of the portage trail corridor. The highlands of the Grand Portage area may reduce the moderating effect of Lake Superior (GRPO 2004).

2.1.3 Demographics and Visitation Statistics
GRPO and the Grand Portage Reservation are located in Cook County, Minnesota, a county in which population has generally increased since 1900 and increased markedly from 3,868 in 1990 to 5,168 in 2000 and 5,176 in 2010 (Forstall 1995, U.S. Census Bureau 2010). Similarly, the population of the Reservation increased from 294 in 1980 to 557 in 2000, but then fell to 518 in 2010 (Figure 6) (Grand Portage Transportation Steering Committee 2003, Grand Portage Band 2010).

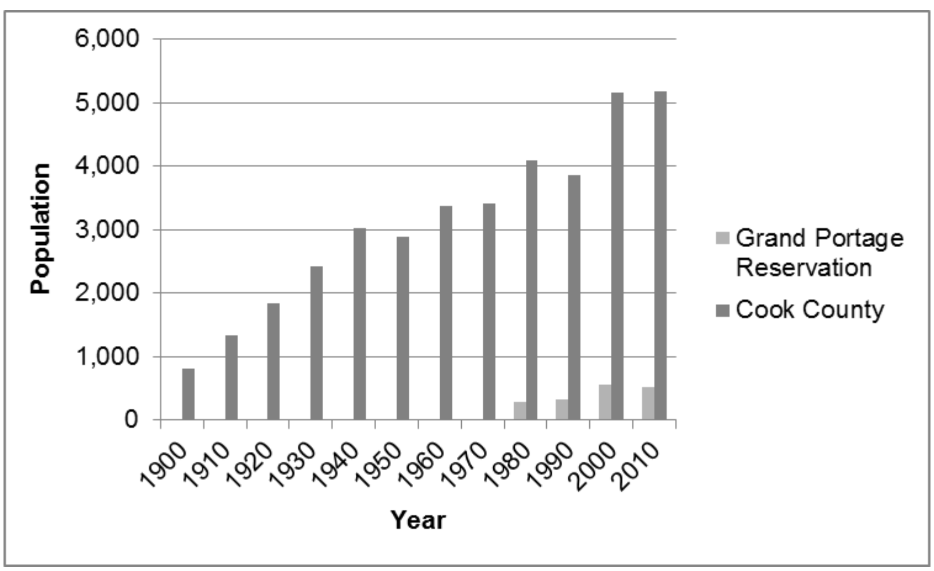

Figure 6. Population of Cook County, Minnesota from 1900 to 2010 and of Grand Portage Reservation from 1980 to 2010 (Grand Portage Transportation Steering Committee 2003, Grand Portage Band 2010).

The number of older adults (60+) in Cook County increased 170% from 1960 to 2000

(Arrowhead Area Agency on Aging et al. 2003). In the 2010 Census, 19.6% of Cook County's population was over the age of 65, greater than the Minnesota average of 12.7% (U.S. Census Bureau 2010). The population of people 60 years or older increased 40% from 1990 to 2000 and is projected to increase 71% by 2025 (Arrowhead Area Agency on Aging et al. 2003). By contrast, only 16.7% of Cook County's population was under the age of 18 in the 2010 Census, less than the Minnesota average of 23.9% (U.S. Census Bureau 2010). In 2000, 61% of Cook County's population aged 16 and over was in the labor force. The top industries in the county are tourism, education, health and social services, and retail (Arrowhead Area Agency on Aging 2003). The percent of people living below the poverty level in Cook County is 10.1% (U.S. Census Bureau 2010).

The population growth in Grand Portage accounted for 18% of the total population growth in Cook County from 1990 to 2000. The population increase on the reservation is attributed to revenue produced by the Grand Portage Lodge and Casino and an increased level of health and human services (Grand Portage Transportation Steering Committee 2003). The Lodge, originally named the Grand Portage Lodge and Conference Center, was built with federal grants and Band money and opened in 1975. It was run in cooperation with the Radisson hotel chain until 1980, when the Band assumed full control. In 1990, gaming was added, and the name was changed to Grand Portage Lodge and Casino (Gilman 1992).

Visitation at GRPO has ranged from 27,600 in its first year, 1961, to 113, 996 in 2010, with an average of 61,908 visitors per year over this time period (Figure 7) (NPS 2011b). Most visitors go to the Heritage Center (Table 2), and a much smaller number take out backcountry permits to camp at Fort Charlotte at the end of the Grand Portage corridor trail (NPS 2011b).

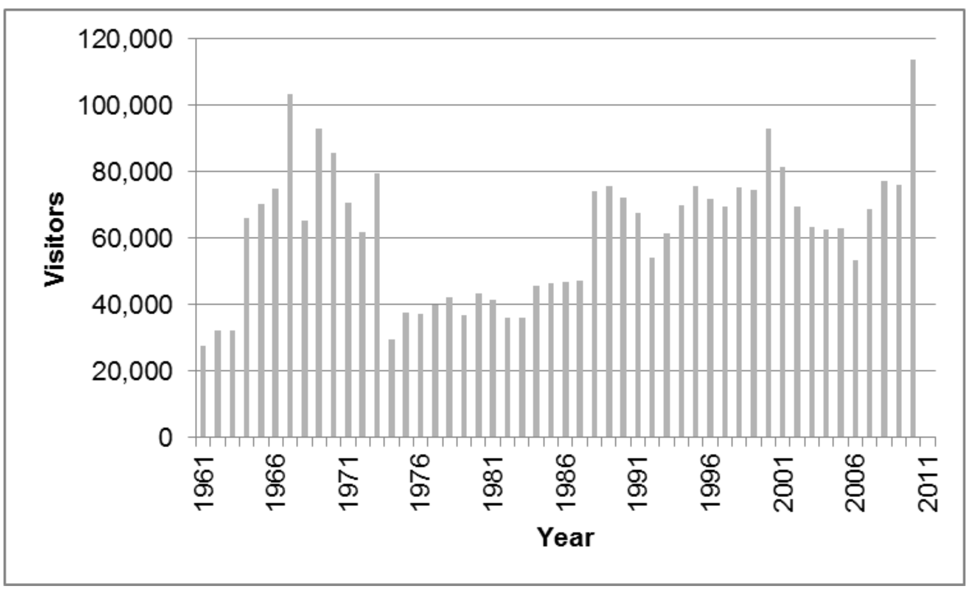

Figure 7. Visitors per year at Grand Portage National Monument, 1961 to 2010 (NPS 2011b).

Table 2. Visitation at Grand Portage National Monument, 2007 to 2011 (NPS 2011b).

Year	Total Visitation	Heritage Center Visitation	Backcountry Permits
2007	68,856	65,237	99
2008	77,323	73,120	125
2009	76,025	73,358	60
2010	113,996	86,212	210
*2011	86,837	57,933	143

*through September only

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

GRPO is located entirely within USEPA Level 3 ecoregion 50, Northern Lakes and Forests (USEPA 2010). Its northern section is within Level 4 ecoregion 50t, North Shore Highlands, and the remainder lies in Level 4 ecoregion 50n, Boundary Lakes and Hills. The former is described as "hills above Lake Superior with many streams draining into lake," while the latter is described as "forested hills with thin soils and irregular slopes interspersed with many lakes" (USEPA 2010).

The Minnesota Ecological Classification developed by the Minnesota Department of Natural Resources (MDNR) and the U.S. Forest Service (USFS) divides Minnesota landscapes into 26 subsections and classifies GRPO as being partly in the similarly-named Border Lakes subsection and partly in the North Shore Highlands subsection (Figure 8). Within the Border Lakes subsection, GRPO is in the Swamp River Till Plain Land Type Association (LTA), with thick deposits of loamy till and clayey lake sediments on a nearly level to gently rolling bedrock-controlled landscape (MDNR 2002, White and Host 2003). Within the North Shore Highlands, GRPO is in the North Shore Till Plain LTA, which is typified by rolling topography and predominantly clayey sediments (MDNR 2002, White and Host 2003). Small areas of the Sawtooth Mountain Bedrock Complex LTA are also included in GRPO's watershed.

According to the National Vegetation Classification Standard, 92.3% of GRPO (including developed areas and water) is in the forest and woodland class, with 74.4% of the forest (68.7% of the total land area) in the white spruce (*Picea glauca*) -balsam fir (*Abies balsamea*) forest group (Hop et al. 2010). Details about GRPO's southern boreal forest are presented in Chapter 4.

In the Lakeshore Unit, Great Lakes cobble beach is found along the shore of Grand Portage Bay. The mouth of Grand Portage Creek is terraced by speckled alder (*Alnus incana*), black hawthorn (*Crataegus douglasii*), and willow (*Salix* spp.) thickets (Hop et al. 2010). On Mount Rose, steep areas contain open talus slopes, while somewhat more level, dry slopes have rocky shrubs and woodlands. Forests along the Mount Rose Trail consist of white spruce, balsam fir, quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and Jack pine (*Pinus banksiana*) (Hop et al. 2010).

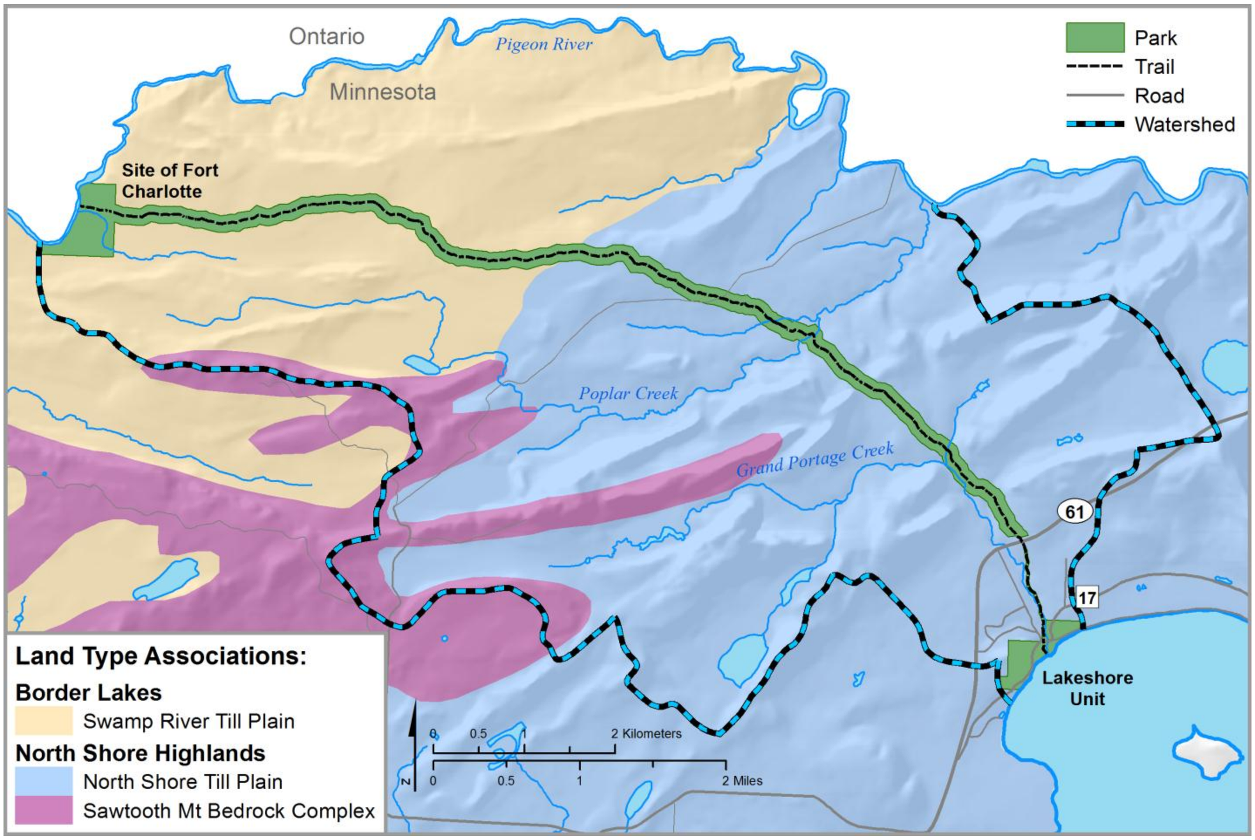

Figure 8. Minnesota Ecological Classification Land Type Associations in the vicinity of Grand Portage National Monument (MDNR 2002).

The Grand Portage trail passes through mesic boreal forests dominated by quaking aspen, white spruce, balsam fir, and paper birch. Stands of northern white cedar (*Thuja occidentalis*), although uncommon, are more frequent in the western third of the portage corridor. Somewhat shallower mesic soils contain stands of eastern white pine (*Pinus strobus*), with occasional red pine (*Pinus resinosa*) (Hop et al. 2010)

Lower, flat, poorly drained areas contain lowland hardwood wet swamp forests and are dominated by balsam poplar (*Populus balsamifera*), black ash (*Fraxinus nigra*), quaking aspen, and scattered northern white cedar, balsam fir, and, rarely, black spruce (*Picea mariana*). Beaver activity within some of the small streams forms open wet meadows and marshes. The most prominent of these is the extensive beaver meadow located midway between old U.S. Highway 61 and the site of Fort Charlotte. Hairy sedge (*Carex lacustris*) dominates this herbaceous wet meadow along with other common species including harlequin blueflag (*Iris versicolor*), bluejoint (*Calamagrostis canadensis*), woolgrass (*Scirpus cyperinus*), upright sedge (*Carex stricta*), and cattail (*Typha* spp.) (Hop et al. 2010).

The vegetation of GRPO along the Pigeon River near the site of Fort Charlotte is different from that in other areas of the park. Floodplain forests are dominated by black ash like the wet swamp forests more interior, but are here joined by green ash (*Fraxinus pennsylvanica*) and American elm (*Ulmus americana*) along with other boreal conifers and hardwoods (Hop et al. 2010).The rocky landscape surrounding the campsite location consists of a dry-mesic white pine-red pine forest with a very open understory dominated by rocky outcrops and blueberries (*Vaccinium angustifolium* and *V. myrtilloides*).

GRPO is located entirely within the northwestern Lake Superior watershed (United States Geological Survey [USGS] Hydrologic Unit Code [HUC] 040101), in the Baptism-Brule sub watershed (HUC 04010101) (Seaber et al. 1987). We have divided GRPO into three major watersheds using the watershed tool in ArcGIS (Figure 9): Grand Portage Creek, Poplar Creek, and the Pigeon River watershed north of Poplar Creek, including Snow Creek (hereafter, Upper Pigeon River). These are closely aligned with MDNR watersheds (Grand Portage Creek, 100500; Poplar Creek, 100400; and Upper Pigeon River, 111500).

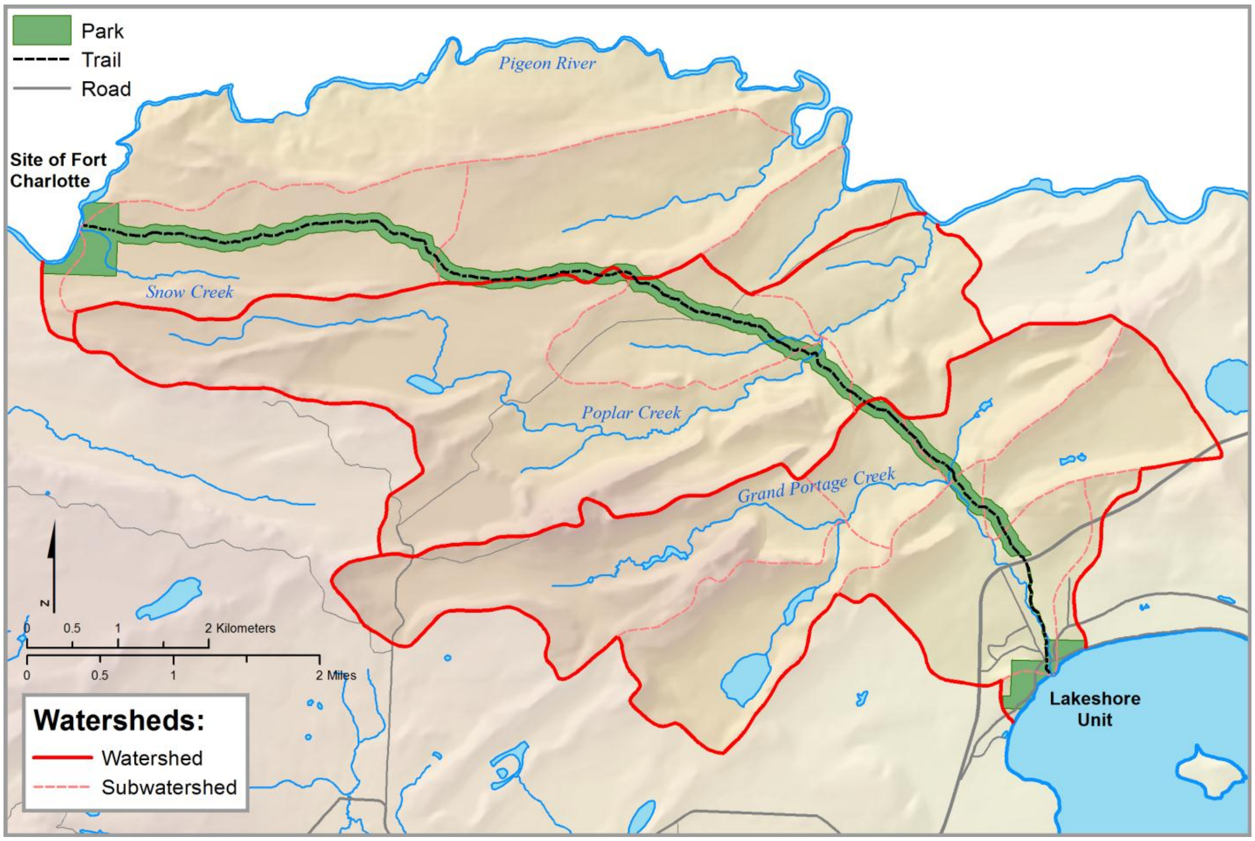

Figure 9. Watersheds within Grand Portage National Monument.

2.2.2 Resource Descriptions

GRPO is listed in its entirety on the National Register of Historic Places, and all 287 ha are listed as part of a historic district. GRPO is designated as a Class II airshed (Route and Elias 2007).

GRPO is within the range of the federal designated threatened Canada lynx (*Lynx canadensis*) (GRPO 2004). The formerly-listed bald eagle (*Haliaeetus leucocephalus*) was delisted on August 9, 2007 (http://www.fws.gov/midwest/eagle/). GRPO has 286.4 ha designated as critical habitat (Brian et al. 2011) for the formerly-listed gray wolf (*Canus lupus*), which was delisted on December 28, 2011 (http://www.fws.gov/midwest/wolf/).

State-listed fauna confirmed as present in GRPO are the threatened peregrine falcon (*Falco peregrinus*), common tern (*Sterna hirundo*), and horned grebe (*Podiceps auritus*). The bald eagle, gray wolf, northern long-eared bat (*Myotis septentrionalis*), least weasel (*Mustela nivalis*), and a caddisfly (*Asynarchus rossi*), state species of special concern, are also present (NPS 2011c). The MDNR also lists the mountain lion (*Felis concolor*) as a species of special concern that may occur in GRPO (GRPO 2004). Coaster brook trout (*Salvelinus fontinalis*), a species that was nearly extirpated from Lake Superior, are also found in GRPO; they enter the mouth of Grand Portage Creek for spawning (Route and Elias 2007).

No federal listed threatened or endangered plant species are found in GRPO, but the park has one confirmed state-endangered vascular plant, the auricled twayblade (*Listera auriculata*), as well as four state-threatened plants and 11 state plant species of special concern (Appendix B) (NPS 2011c). Most rare plants in GRPO are primarily restricted to small, rocky, steeply sloping sites on Mount Rose or in the wetland habitat of beaver ponds along the trail corridor (NPS 2003a). In addition, a state-endangered lichen (*Parmelia stictica*), which occurs on rock along the Lake Superior shoreline, has been reported for GRPO (NPS 2003a). Many other state-listed plant and animal species are listed as being probably present or unconfirmed for GRPO.

2.2.3 Resource Issues Overview

In its Long-term Ecological Monitoring Plan, the NPS Great Lakes Network Inventory and Monitoring Program (GLKN) has identified the primary threats to GRPO. These are the difficulty of managing a narrow corridor of habitat; entrenched populations of exotic plants, perhaps introduced more than 200 years ago; logging and other human uses on adjacent lands, and airborne pollutants (Route and Elias 2007).

The ecological systems considered very important at GRPO are soil genesis and edaphology, forest succession and disturbance regimes, watershed functioning and stream evolution, and the functioning food web of the ecological community. Important stressors of these systems are aerial and other non-point sources of contaminants and their environmental fate (nitrogen and mercury, for example), introductions of exotic species, anthropogenic generation of invasive species (not necessarily exotic), compounding environmental complexes (moose decline and birch die-back, for example), climate change, altered fire regime, and development. Many of these systems are outside the control of GRPO. Important endeavors at GRPO include education and advocacy to promote changes in human behavior, continued support of the GLKN efforts, follow-up analysis on baseline lichen flora and associated airborne contaminants, watershed assessment, forest disturbance management (in the style of Malcolm Hunter, which alternates necessary means to arrive at the same disturbance-oriented end), soil and water contaminant monitoring, land cover/land use change (especially in watersheds), translation of climate change models to the southern boreal region, and more (Brandon Seitz, GRPO, 12/12/11, email).

Of particular concern is the potential for exotic and/or invasive introductions of species. Horticultural variants such as reed canary grass have already invaded riparian corridors. Robust and vigorous horticultural selections of sweetgrass from Ohio roadsides are propagated en masse for retail distribution and threaten to directly invade or otherwise hybridize with the local phenotype that is much less robust, asexually less vigorous, but sexually much more fertile. Climate change-exacerbated invasives, such as poison ivy and red maple, are expanding ranges and increasing in abundance, threatening to occupy new ecological niches. Genetically modified organisms such as trembling aspen have the potential to directly invade and/or hybridize with local genotypes influencing native tree population dynamics (Brandon Seitz, GRPO, 3/5/13, email).

A more detailed look at resource management for GRPO in the context of management directives is included in section 2.3.1.

Climate Change

Although as noted in chapter 1, climate change is not a primary focus of NRCAs such as this, the large predicted impacts make it necessary to address this topic at least briefly. A 2011 report titled "Great Lakes National Parks in Peril: The Threats of Climate Disruption" (Saunders et al. 2011) describes predicted changes in climate and their effects on ecosystems, wildlife, visitor enjoyment, and cultural resources. Among its findings for GRPO are the spread of ticks that carry Lyme disease into GRPO for the first time; the bleak outlook for moose (*Alces alces*), which are important to visitors as well as the local Ojibwe people; the potential loss of habitat for Canada lynx; and the impact of severe Lake Superior storms on park infrastructure and cultural resources.

Global air temperatures increased $0.74 \pm 0.18^{\circ}$C from 1906-2005, mostly attributable to human activities (IPCC 2007). In addition to creating this general warming, climate change also likely contributes to rises in sea level; changes in wind patterns and extra-tropical storm tracks; increased temperatures on extreme hot nights, cold nights, and cold days; increased risk of heat waves; increased area affected by drought; and greater frequency of heavy precipitation events (IPCC 2007). Signs that climate change is already occurring in the Great Lakes region include increases in average annual temperatures, more frequent severe rainstorms, shorter winters, and decreases in the duration of lake ice cover. By the end of the 21st century, winter and summer temperatures in Minnesota may increase 3-6°C and 4-9°C, respectively (Kling et al. 2003). Saunders et al. (2011) projected that under a medium-high emissions scenario, the average summer temperature at nearby ISRO would increase 2.6°C over today's summer temperatures by 2040. Annual average precipitation may not change much, but may increase in winter and decrease in summer to the point where soil moisture declines and more droughts occur. The frequency of heavy rainstorms could increase 50-100% (Kling et al. 2003).

Significant uncertainty accompanies most predictions related to global climate change, not only in the magnitude of changes in physical parameters, but also in their ecologic implications. The uncertainty, though, is not in the general trend, but rather in how large the changes will be, the rate at which they occur, and the net effect of all of the indirect and interactive effects. A wide variety of ecologic processes (Aber et al. 2001) and species-specific responses (Walther et al. 2002, McKenney et al. 2007) have been, or will be, affected. An additional source of uncertainty is that average climate changes may not be key. The fluctuation in temperature among seasons, the extremes that occur, the timing of certain phenomena, and the duration of a condition could all have more of an impact than the average condition (Morris et al. 2008).

All predictions of future climate are based on one of several General Circulation Models (GCM), which vary in their predictions for the 21st century. Predictions of the ecologic impacts of climate change are achieved by taking the predictions of a GCM and plugging them into one or more other models (see Hansen et al. [2001] and Aber et al. [2001] for the common models used in this way). These, as well as the GCM models, are simplifications of reality and are based on a set of assumptions, creating further uncertainty in the predictions. Furthermore, there is not a single model that can even begin to predict the full range of phenomena that are likely to be affected, their interactions, and the net outcome. Thus, all models focus on a few of the changes and ignore the others. For example, we have limited capacities to predict what biotic disturbances are likely to influence a community if the average temperature increases by 3 or 4^{o} C, or where ice storms are going to be most frequent (Dale et al. 2001). The predictions of models apply to a finite scale, and the majority of ecologic models project for a smaller spatial scale than the GCMs. To make these mesh, either the GCM predictions have to be interpolated or the ecologic model extrapolated, creating yet another source of uncertainty.

More detailed discussions of climate change are included in the context of stressors to resources assessed in Chapter 4.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

This section of the NRCA was written with Brandon Seitz as the lead author as a statement of the park perspective on natural resource management.

As stated in NPS policy 4.2 (2006):

> *The Service will encourage appropriately reviewed natural resource studies whenever such studies are consistent with applicable laws and policies. These studies support the NPS mission by providing the Service, the scientific community, and the public with an understanding of park resources, processes, values, and uses that will be cumulative and constantly refined. This approach will provide a scientific and scholarly basis for park planning, development, operations, management, education, and interpretive activities.*

As such, an assessment of park-specific natural resource conditions and values must hinge upon the laws established by Congress to govern NPS units (Appendix C). The authority for interpreting and implementing these laws is exercised by NPS through the development of management policies. Management policy formalizes guidance in such a way as to make possible refinement of park-specific management goals and target values as described in park planning documents.

> *Park planning helps define the set of resource conditions, visitor experiences, and management actions that, taken as a whole, will best achieve the mandate to preserve resources unimpaired for the enjoyment of present and future generations. NPS planning processes will flow from broad-scale general management planning through progressively more specific strategic planning, implementation planning, and annual performance planning and reporting, all of which will be grounded in foundation statements (NPS Policy, Chapter 2, 2006).*

The General Management Planning process now begins with the development of foundation statements that are based on the park’s enabling legislation or presidential proclamation and that document the park purpose, significance, fundamental resources and values, and primary interpretive themes (NPS 2006, Policy 2.2). Fundamental resources and values are systems, processes, features, visitor experiences, stories, and scenes that deserve primary consideration in planning and management because they are critical to maintaining the park's purpose and significance. As GRPO's current General Management Plan predates the policy for inclusion of foundation statements, no such fundamental resources and values have yet been described. However, for the purposes of this document, provisional fundamental resources and values are offered to provide guidance to the NRCA. When general management planning efforts are updated at GRPO, these provisional, fundamental resources and values may or may not be maintained when the foundation statements are formally described and vetted.

For GRPO, fundamental natural resources are those that 1) have some positive effect on the visitor experience, 2) are important to the historic scene, and 3) contribute to a visitor's understanding of the period of significance. Importantly, the historic scene is managed under the umbrella of the Organic Act. Therefore, rather than provide for interpretation an 18^{th} century landscape depleted of its principal commodities (wood and mammals), the visitor is provided a stark comparison; an environment replete with that which suffered the most from commoditization and overutilization. At the historic depot, interpreters focus on natural resources as material commodities in order to interpret the period of significance. They interpret extrinsic values imposed upon natural resources by 18th century capitalism. As visitors leave the depot, the landscape that surrounds the trail presents for the visitor's own interpretation the intrinsic, ecological values of those same resources. The visitors' experience and understanding are two important fundamental values for GRPO. The natural resources that significantly contribute to these values are beaver populations and associated habitats, the southern boreal forest, and the Pigeon River. Descriptions of the importance of these resources and stressors affecting them are shown in Table 3 and Table 4.

Southern Boreal Forest

The condition of the current southern boreal forest of the Western Lake Superior basin is complex and potentially dynamic due to the interactions of fire, wind, insect and disease outbreaks, exotic/invasive species, and Lake Superior climatological influences. Since approximately 1800, there have been significant human influences in the region, and the anthropogenic impacts will probably increase throughout the 21st century. Extensive, severe disturbance during the latter half of the 19th century significantly altered this landscape. The abundances of many tree species were affected, including large reductions in the prevalence of eastern white pine, eastern larch (*Larix laricina*) (known hereafter by its other common name, tamarack), and northern white cedar. These three tree species are not regenerating well today, and thus it is not likely they will rebound in the near future. It is probable that the abundance and composition of other groups of organisms (e.g., invertebrates and fungi) closely linked to these species have been affected. White pine blister rust also inhibits succession of white pine. The alternations also include a simplification of the structural complexity of the landscape. This is evidenced by the limited amount of old-growth forest in the area. Critical ecological processes of the forest must be managed in order to reclaim, or where appropriate maintain, "best attainable" or "minimally disturbed" conditions as defined by Stoddard et al. (2006).

Beaver Populations and Associated Habitats

The wetlands constructed by beaver are a very dynamic habitat critical to numerous ecosystem processes and services. Their current spatial distribution upon the landscape is arguably natural, as they are as clear an outcome of an early- to mid-successional riparian forest as can be found.

Table 3. Provisional, fundamental resources for Grand Portage National Monument, shown in a comparative matrix with their corresponding ecosystem services and supporting ecological processes. General management plan updates may or may not include these as fundamental resources.

Fundamental Resources	Ecosystem Services and Values	Critical Ecological Processes
Beaver Populations and Associated Habitats	Interpretation Sediment Retention Delayed Water Flow Upstream Riparian Habitat Wetland Habitat Aquatic Habitat Pollutant Removal through Sediment Capture Water Temperature Regulation Aesthetic Value Habitat for Listed Species Flood Resilience Habitat Critical to Ecological Processes	Hydrological Processes Disturbance Regime Nutrient Cycling Biotic Interactions Population Dynamics Evolutionary Pressure
Southern Boreal Forest	Interpretation Conifer Thermal Cover Watershed Function Forest Habitat Water Temperature Regulation Aesthetic Value Habitat for Listed Species Flood Peak Attenuation Carbon Sequestration Habitat Critical to Ecological Processes	Hydrological Processes Natural Disturbance Nutrient Cycling Biotic Interactions Population Dynamics Evolutionary Pressure Structural Complexity Genetic Diversity
Pigeon River	High Value Visitor Experience Travel Corridor to/from BWCAW Wilderness Aesthetic Value Interpretation	Hydrological Processes Natural Disturbance Nutrient Cycling Biotic Interactions

Pigeon River

The Pigeon River is the principal conveyance from the Boundary Waters Canoe Area Wilderness (BWCAW) lake country to Lake Superior. It is responsible for the location of the Grand Portage and is necessary for a visitor experience that includes retracing canoe routes of 18th century voyageurs to GRPO. At this time, NPS has very limited influence over the preservation of the Pigeon River. It is currently managed by such various mandates as are enacted by departments of the State of Minnesota, Province of Ontario, Canadian Federal Government, United States Federal Government, and the Grand Portage Band. These parties currently present to the visitor a dissonant array of land management from South Fowl Lake to the site of Fort Charlotte. Any natural resource condition assessment of the Pigeon River will have to be offered in the context of very limited NPS management influence over what is now an incohesive network of land management bound by a shared riparian corridor.

Table 4. Stressors of provisional fundamental resources in Grand Portage National Monument.

Stressor	Resource		
	Southern Boreal Forest	Beaver Population and Associated Habitats	Pigeon River
Nutrient deposition	X	X	X
Climate and hydrological change	X	X	X
Sediment deposition		X	X
Air pollution	X	X	X
Water pollution		X	
Development			X
Homogenization of forest stand diversity – increased gap phase succession	X		X
Decreased stand-replacing disturbances	X	X	
Accelerated soil development and modified nutrient cycles caused by earthworms	X		
Low forest stand diversity stress on biotic interactions, genetic diversity, and structural complexities such as coarse woody debris, snags, and ecotones	X		X
Anthropogenically impaired disturbance regimes of insects, fire, and disease	X	X	X
Interrupted ecological processes caused by exotic/invasive organisms	X	X	X
Anthropogenically impaired population dynamics		X	
Land cover or land use changes in the riparian corridor and/or watershed			X

2.3.2 Status of Supporting Science

GRPO is one of nine National Park units in the Great Lakes Inventory and Monitoring Network (GLKN), one of 32 similar networks across the United States and part of the NPS strategy to improve park management through greater reliance on scientific information. The purpose of the inventory and monitoring (I&M) program is to design and implement long-term ecological monitoring and provide results to park managers, science partners, and the public. The intent is to provide periodic assessments of critical resources, to evaluate the integrity of park ecosystems, and to better understand ecosystem processes.

Specific GLKN goals (http://science.nature.nps.gov/im/units/glkn/index.cfm) are:

1. Determine the status of and trends in selected indicators of park ecosystems that allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.

2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.

3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.

5. Provide a means of measuring progress towards performance goals.

In 2007, GLKN completed its long-term ecological monitoring plan (Route and Elias 2007) which included a list of Vital Signs (select indicators that represent the health of natural resources in the nine parks) (Table 5). From these Vital Signs, GLKN selected eight focal indicators: Climate, Inland Lakes Water Quality, Large Rivers Water Quality, Diatoms, Terrestrial Plants, Amphibians, Land Birds, Persistent Contaminants, and Land Cover and Land Use. Monitoring protocols have been developed for all these except Climate; that protocol is in development.

Current GLKN activities for GRPO are in the areas that have monitoring protocols. A report was provided by Ulf Gafvert of the GLKN (email, October 14, 2011), who was designated as the contact person for this report; it is summarized below (Table 6).

Table 5. Vital Signs for the Great Lakes Network Inventory and Monitoring Program (Route and Elias 2007).

National Level[1]		Great Lakes Network[2]									
Level 1	**Level 2**	**Vital Sign name**	**APIS**	**GRPO**	**INDU**	**ISRO**	**MISS**	**PIRO**	**SACN**	**SLBE**	**VOYA**
Air and Climate	Air Quality	Air Quality	•	•	•	•	•	•	•	•	•
		Air Quality (AQRV)	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Weather	Weather	•	•	•	•	•	•	•	•	•
		Phenology	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Geology and Soils	Geomorphology	Aeolian, Lacustrine Geomorphology	Δ	–	Δ	–	Δ	Δ	Δ	Δ	–
		Geological Processes	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Stream Dynamics	Δ	Δ	Δ	Δ	+	Δ	+	Δ	Δ
	Soil Quality	Soils	+	+	+	+	+	+	+	+	+
		Sediment Analysis	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Water	Hydrology	Water Level Fluctuations	+	+	+	+	+	+	+	+	+
	Water Quality	Core Water Quality Suite	+	+	+	+	+	+	+	+	+
		Advanced Water Quality Suite	+	+	+	+	+	+	+	+	+
		Toxics in Water	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Toxics in Sediments	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Pathogens in Water	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		IBI	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Benthic Inverts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Freshwater Sponges	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Phytoplankton	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Diatoms	+	–	+	+	+	+	+	+	+
Biological Integrity	Invasive Species	Plant and Animal Exotics	•	•	•	•	•	•	•	•	•
	Infestations and Disease	Terrestrial Pests and Pathogens	+	+	+	+	+	+	+	+	+
	Focal Species or Communities	Aquatic Plant Communities	+	+	+	+	+	+	+	+	+
		Mussels and Snails	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Mammal Communities	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Problem Species (White-tailed deer)	+	+	+	+	+	+	+	+	+
		Special Habitats	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Lichens and Fungi	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Terrestrial Plants	+	+	+	+	+	+	+	+	+
		Fish Communities	+	+	+	+	+	+	+	+	+
		Zooplankton	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Terrestrial Invertebrate Communities	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Amphibians and Reptiles	+	+	+	+	+	+	+	+	+
		Bird Communities	•	•	•	•	•	•	•	•	•
		Biotic Diversity	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	At-risk Biota	Species Health, Growth and Reproductive Success	+	+	+	+	+	+	+	+	+
		T&E Species	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Human Use	Non-point Source Human Effects	Trophic Bioaccumulation	+	+	+	+	+	+	+	+	+
	Consumptive Use	Harvested Species	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Visitor Use	Land use Fine Scale	+	+	+	+	+	+	+	+	+
Ecosystem Pattern and Processes	Land Use and Cover	Land use Coarse Scale	+	+	+	+	+	+	+	+	+
	Soundscape	Soundscapes and Light Pollution	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Nutrient Dynamics	Nutrient Dynamics	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Trophic Relations	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Productivity	Primary Productivity	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Succession	+	+	+	+	+	+	+	+	+

+ = The Network plans to develop a monitoring protocol or SOP

• = Park or partner monitoring will continue with Network collaboration

Δ = Time and funds are currently not available

– = Not applicable in this park

1 = Level names are from the National Park Service's Vital Signs Ecological Framework

2 = APIS=Apostle Islands National Lakeshore; GRPO=Grand Portage National Monument; INDU=Indiana Dunes National Lakeshore; 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

Table 6. Activities of the Great Lakes Inventory and Monitoring Network at Grand Portage National Monument, fall 2011.

Water Quality: GLKN is not currently conducting water quality sampling at GRPO, but has provided equipment for the park to monitor flow on Grand Portage Creek. GRPO has been collecting water temperature data on Grand Portage Creek since the early 1990s. The Grand Portage Band collects water quality data on the Pigeon River and Grand Portage Creek and shares that data with the park. GLKN is working on a wadeable streams protocol and plans to implement that program at GRPO once completed. The Large Rivers Water Quality monitoring protocol is not applicable at GRPO. Contact: Joan Elias, Aquatic Ecologist, GLKN or Brandon Seitz, GRPO.

Diatoms: Sediment cores were recently taken by staff at the Saint Croix Watershed Research Station from two locations on adjacent tribal lands and one in the beaver meadow on park land. Data from the samples on tribal lands have been analyzed and a report completed. The beaver meadow samples have not yet been analyzed for diatom communities. Contact: Joan Elias, Aquatic Ecologist, GLKN.

(Note: Diatoms were not included in the original list of Vital Signs for GRPO).

Vegetation: Forest vegetation is monitored at each park on a six year return interval, with 2007 being the first year that monitoring was implemented at GRPO. The field crew established 20 permanent, long term sampling sites, with the first revisit scheduled for 2013. Contact: Suzanne Sanders, Terrestrial Ecologist, GLKN.

Landbirds: GLKN recently published a Landbirds monitoring protocol. Three years ago, GLKN assisted GRPO in implementing the protocol by funding a researcher to conduct the bird monitoring at the park, which typically occurs in June. Brandon Seitz, Natural Resource Specialist at GRPO, coordinates the program. Contact: Ted Gostomski, Biologist, GLKN.

Persistent Contaminants: GLKN is funding work on measuring mercury levels in water, sediments, and dragonfly larvae in 2010 and 2011, with plans for further study in 2012. Some sampling of fish communities has been completed on a wider array of contaminants, but with few detects due to only fish fillets collected. Sampling of whole fish will be attempted again in 2012. Contact: Bill Route, Ecologist, GLKN.

Land Use/Land Cover: High resolution imagery (aerial photography) is used to confirm natural or human related disturbances that are identified using techniques in remote sensing to analyze a dense time-stack of moderate resolution satellite imagery (Landsat). This analysis is being conducted for each park in the Great Lakes I&M Network on a six-year rotation, with work scheduled at GRPO in 2013 and 2014. The Network is also developing a trail monitoring program, with initial field studies to be conducted October, 2011 and protocol draft anticipated in 2012. Contact: Ulf Gafvert, GIS Specialist, GLKN.

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Chapter 3 Study Scoping and Design

3.1 Preliminary Scoping

A scoping meeting of GRPO staff and University of Wisconsin – Stevens Point (UWSP) researchers was held at GRPO on July 7, 2011. Topics discussed included the purpose of the NRCA; the historic and cultural significance of GRPO and the relationship of its cultural resources to its natural resources; and the unique relationship of GRPO to the Grand Portage Band, including their co-management of certain resources. A preliminary discussion of natural resources conditions, issues, and stressors was also conducted at this time. Staff provided names and citations for researchers conducting work at GRPO and a spreadsheet listing publications, data sets, and geospatial data resources collected in the NPS Integrated Resource Management Applications (IRMA) web portal. UWSP researchers also had the opportunity to browse the GRPO library collection of natural resource-related reports. Finally, GRPO staff provided a guided tour of the significant natural resources of the park.

During the summer and fall of 2011, NPS documents outlining the purpose and limitations of the NRCA process were shared, and park staff answered questions about their specific needs as well as management and planning directives that would influence the NRCA. A conference call between GRPO staff and UWSP researchers was held on December 19, 2011 to discuss progress, firm up the list of resources to be evaluated, and discuss available data resources.

The following questions were answered by GRPO managers during the scoping process:

In what ways is the NRCA expected to aid GRPO resource managers

- Compare the park's present application of science to management with knowledge gained through literature review and the investigators' expertise to show potential areas of improvement and growth in the park's natural resource management program.

- Reveal both park-centered and partnership-centered possible future management endeavors. Park-centered activities should speak to the park's fundamental values and the natural resources that support them. Activities with the Band may accomplish both mutual and disparate goals and objectives.

What specific project expectations and outcomes does GRPO have for the NRCA process?

- Consolidating, summarizing, and spatially displaying key data for the purpose of describing, managing, and interpreting those natural resources and associated ecological systems that contribute to GRPO's fundamental values.

- Defining, delineating, and describing the characteristics of reference conditions through the language of scientific inventory and monitoring. This is critical to the management of natural resources and processes that contribute to GRPO's fundamental values.

- Identifying "management critical" data; those that would reveal whether or not we have resources or processes within our 287 ha that are impaired or are on a trajectory to be considered so, keeping the Organic Act paramount.

- Describing the relationship between anthropogenic stressors and the natural resources and processes that contribute to GRPO's fundamental values, both within and outside the park.

What specific natural resources will be assessed in detail in Chapter 4 of this report?

The response to this question became the basis for section 2.3.1 of this report

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

The GRPO NRCA uses the six-category assessment and reporting framework developed by the U.S. Environmental Protection Agency Science Advisory Board (EPA–SAB) (USEPA 2002). The top reporting categories in this framework are landscape condition; biotic condition; chemical and physical characteristics of water, air, soil, and sediment; ecological processes; hydrology and geomorphology; and natural disturbance regimes. It was chosen because it was developed to build on the strengths of several of the alternative frameworks (such as the Heinz Center or National Research Council frameworks) and the key natural resources for GRPO fit well into its categories, with emphasis on ecological processes and natural disturbance regimes.

3.2.2 Reference Conditions and Trends

Reference conditions (sometimes called benchmarks, standards, trends, thresholds, desired future conditions, or norms) give a point of reference to which to compare a measurement or statement about an indicator (USFS 2004). A large body of literature has been developed around the development and interpretation of reference conditions. All NRCAs are required to define and apply reference conditions, but NPS has adopted a "pragmatic approach" that requires only that NRCAs apply "logical and clearly documented forms of reference conditions and values" (http://www.nature.nps.gov/water/nrca/conditionsandvalues.cfm).

Stoddard et al. (2006) has suggested that reference conditions fall into four categories, which they name "historic condition," "minimally disturbed condition," "least disturbed condition," and "best attainable condition." We have attempted, where possible, to apply this reference condition scheme as follows:

"Historic condition," in our judgment, is the condition of GRPO before European settlement. It assumes the absence of contaminants known to be primarily anthropogenic in origin or the presence of naturally sustainable populations of organisms.

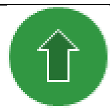
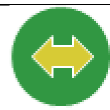
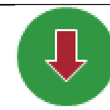
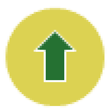
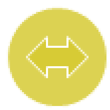
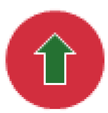
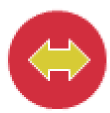
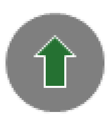
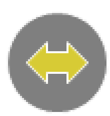
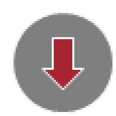
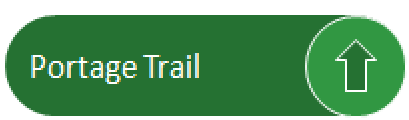
"Minimally disturbed condition" is defined by Stoddard et al. (2006) as "the condition of systems in the absence of significant human disturbance" and we apply this definition.

"Least disturbed condition" is defined by Stoddard et al. (2006) as "the best of today's existing conditions." We apply this reference condition in conjunction with regulatory standards or peer-reviewed guidelines; resources with levels of contaminants that do not exceed standards are deemed to be in "least disturbed condition."

"Best attainable condition" is defined by Stoddard et al. (2006) as "the condition that today's sites might achieve if they were better managed."

We use professional judgment to assess the trend of resource conditions, using statistical methods where appropriate data are available, but many GRPO resources do not have consistent measurements or assessments that occur at the same sites and use the same methods over time. We also use professional judgment to give a confidence ranking of good or fair to our assessments; these are based on the amount of data, the age of the data, and the proximity of the sampling locations to GRPO. Symbols were developed to provide a graphic representation of the status and trend of resources (Table 7).

Table 7. Symbols used to indicate resource condition and trend.

			
good condition, improving trend	good condition, stable trend	good condition, uncertain trend	good condition, declining trend
			
condition of moderate concern, improving trend	condition of moderate concern, stable trend	condition of moderate concern, uncertain trend	condition of moderate concern, declining trend
			
condition of significant concern, improving trend	condition of significant concern, stable trend	condition of significant concern, uncertain trend	condition of significant concern, declining trend
			
condition unknown, improving trend	condition unknown, stable trend	condition unknown, unknown trend	condition unknown, declining trend
			
example of a land symbol; green oval indicates land-based resource and has the name of the resource in white letters. Green circle and arrow indicate good condition and improving trend		example of a water symbol; blue oval indicates water-based resource and has the name of the resource in white letters. Yellow circle indicates condition of moderate concern and gray question mark indicates uncertain trend	

3.2.3 Reporting Areas

The focus of this report was the natural resource condition of the Resource Trust Zone, including the Lakeshore Unit, Fort Charlotte, and the Grand Portage corridor trail. Evaluation of condition sometimes required evaluation of conditions at other scales, such as the three watersheds through which the corridor passes, or Reservation lands adjacent to the trail. Particular emphasis was also placed on the condition of Grand Portage Creek and its watershed. Although not within GRPO, the condition of Grand Portage Bay was evaluated because of its interaction with the historic Depot area.

3.2.4 General Approach and Methods

As noted in Chapter 1, the primary objective of the GRPO NRCA is to report on current natural resource conditions relative to logical forms of reference conditions and values. Emphasis was placed on gathering existing natural resource data about GRPO. NPS inventory and monitoring reports and plans, management plans, and study reports by independent researchers were provided by GRPO and GLKN staff and taken from the GRPO, GLKN, and other NPS websites, including the IRMA web portal.

Data at larger scales were also collected. For example, the MDNR has produced watershed health assessment scores for Minnesota watersheds, and the USEPA has water quality data for Lake Superior. Many such data and agency reports fall into the category of grey literature. Agency staff in relevant programs was contacted when clarification or documentation was needed. Past and current peer-reviewed journals were also extensively reviewed to obtain general background information and appropriate data for reference conditions. Extensive gathering and analysis of spatial data was conducted to create maps and summary statistics used to evaluate conditions and compare GRPO natural resources to those of surrounding areas.

A scoping meeting and park tour was held at GRPO on July 7, 2011 with the UWSP NRCA development team and the GRPO superintendent and resource managers. Conference calls to discuss the project outline and data collection were held December 19, 2011 and March 22, 2012. The report was reviewed by GRPO resource managers, GLKN subject matter experts, and Grand Portage Band resource managers before being submitted to NPS for final approval and publication.

3.3 Literature Cited

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Chapter 4 Natural Resource Conditions

4.1 Landscape Condition

The EPA-SAB framework defines a landscape as “a mosaic of interacting ecosystems or habitat patches” and emphasizes the potential effects of changes in patch size, number, or connectivity on both biotic and abiotic processes. The framework recommends consideration of landscape extent, composition, and pattern and structure with metrics such as perimeter to area ratio, number of habitat types, and longitudinal and lateral connectivity. It identifies managing landscapes, not just individual habitat types, as an important element in insuring the maintenance of native plant and animal diversity (USEPA 2002). Topics considered in this NRCA under Landscape Condition are land cover, perimeter to area ratio, forest morphology, forest density, and road density.

4.1.1 Land Cover

<u>Description</u>

The GLKN has identified land use and land cover at the coarse scale as a key Vital Sign across a wide range of ecosystems (ranked 6th of 46 with a score of 3.8 out of 5) (Route and Elias 2007). Within the GRPO corridor, the largest land cover class in 2006 was evergreen forest (122 ha, 42.6%), followed by mixed forest (54.4 ha, 19.0%), scrub-shrub (45.5 ha, 15.9%), and deciduous forest (41.2 ha, 14.4%). Similarly, in the three watersheds through which the Portage Trail passes, the largest land cover classes in 2006 were evergreen forest (1,938 ha, 33.9%), deciduous forest (1,035 ha, 18.1%), scrub-shrub (970 ha, 17.0%), and mixed forest (909 ha, 15.9%). Land cover classes, excluding ‘developed’ ones, without appreciable canopy cover total approximately 20% of the GRPO watershed (Table 8).

<u>Data and Methods</u>

Land cover data and change data were obtained for 1996, 2001, and 2006 from the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) Regional Land Cover Database (NPS 2010a).

<u>Reference Condition</u>

Land cover should be stable within the GRPO watershed for the five-year time increments measured by the C-CAP program data. This represents a “least disturbed condition” or “the best of today’s existing conditions” (Stoddard et al. 2006).

<u>Condition and Trend</u>

Land cover appears to be stable in GRPO and its watershed; we rate its condition as good, with insufficient data to assess a trend, and our confidence in this assessment is fair. Changes in land cover within GRPO itself were minor between 1996 and 2006, with approximately 1.1 ha added to the developed category and 0.8 ha of wetlands lost (Table 8); however, the C-CAP documentation cautions against making interpretations of small-scale changes without a detailed site investigation. Within the larger GRPO watershed, 2.4 ha went from undeveloped to developed land from 1996-2006. The GLKN is planning to use aerial photos to make a more in-depth assessment of human-induced or natural changes detected by Landsat imagery; work for GRPO is scheduled for 2013 and 2014 (see Section 2.3.2).

Table 8. Land cover classes for Grand Portage National Monument and its watershed in 1996, 2001, and 2006 (NPS 2010a).

Land Cover Class		**1996 Hectares**	**2001 Hectares**	**2006 Hectares**	**% of total 2006**
			Park		
Developed Medium Intensity		0.7	0.8	0.8	0.3%
Developed Low Intensity		2.1	3.1	3.1	1.1%
Pasture/Hay		0.8	0.8	0.8	0.3%
Grassland/Herbaceous		0.7	0.0	0.0	0%
Deciduous Forest		39.5	41.2	41.2	14.4%
Evergreen Forest		121.9	122.2	122.2	42.6%
Mixed Forest		54.3	54.4	54.4	19.0%
Scrub/Shrub		48.0	45.5	45.5	15.9%
Palustrine Forested Wetland		10.5	11.1	11.1	3.9%
Palustrine Scrub/Shrub Wetland		2.5	2.0	2.0	0.7%
Palustrine Emergent Wetland (Persistent)		2.1	1.8	1.8	0.6%
Open Water		3.6	3.7	3.7	1.3%
	Total	286.7			
			Grand Portage Creek Watershed (including Park)		
Developed High Intensity		0.6	0.7	0.7	<0.1%
Developed Medium Intensity		5.2	5.6	5.6	0.3%
Developed Low Intensity		9.8	10.6	10.6	0.6%
Developed Open Space		0.5	0.5	0.5	<0.1%
Cultivated Crops		0.2	0.2	0.2	<0.1%
Pasture/Hay		3.5	3.5	3.5	0.2%
Grassland/Herbaceous		6.3	3.2	3.2	0.2%
Deciduous Forest		377.5	390.4	390.4	21.0%
Evergreen Forest		622.6	627.3	627.3	33.7%
Mixed Forest		274.8	277.2	277.2	14.9%
Scrub/Shrub		253.0	236.1	236.1	12.7%
Palustrine Forested Wetland		148.6	158.7	158.7	8.5%
Palustrine Scrub/Shrub Wetland		98.6	91.9	91.9	4.9%
Palustrine Emergent Wetland (Persistent)		33.3	30.6	30.6	1.6%
Barren Land		2.6	0.5	0.5	<0.1%
Open Water		24.8	24.9	24.9	1.3%
	Total	1,862.1			
			GRPO Watershed (including Park)		
Developed High Intensity		1.2	1.4	1.4	<0.1%
Developed Medium Intensity		6.4	7.0	7.0	0.1%
Developed Low Intensity		13.6	15.2	15.2	0.3%
Developed Open Space		0.5	0.5	0.5	<0.1%
Cultivated Crops		0.4	0.5	0.5	0.1%
Pasture/Hay		4.5	4.5	4.5	<0.1%
Grassland/Herbaceous		122.9	7.4	45.4	0.8%
Deciduous Forest		1,004.0	1,063.8	1,035.0	18.1%
Evergreen Forest		1,908.0	1,940.8	1,938.4	33.9%
Mixed Forest		922.5	913.9	909.1	15.9%
Scrub/Shrub		940.6	972.0	970.2	17.0%
Palustrine Forested Wetland		487.4	512.1	511.5	8.9%
Palustrine Scrub/Shrub Wetland		183.8	164.6	164.8	2.9%
Palustrine Emergent Wetland (Persistent)		77.0	73.1	73.1	1.3%
Barren Land		3.6	0.7	0.7	<0.1%
Open Water		41.4	40.5	40.5	<0.1%
	Total	5,717.9			

4.1.2 Impervious Surfaces

Description

Klein (1979), in a study of 27 small watersheds in Maryland, suggested that watershed impervious surface should not exceed 10% for sensitive stream ecosystems, such as those containing self-sustaining trout populations. Stranko et al. (2008) reported that in only one of six eastern Piedmont (Maryland) streams were brook trout found in watersheds where impervious land cover exceeded 4% as assessed from the 2001 National Land Cover Database (NLCD). Although the study was not specific to coaster brook trout, it should be noted that coaster brook trout do spawn in streams just as other brook trout do. The authors indicated that impervious land cover is correlated with increases in stream temperature, sediment, and habitat instability (Stranko et al. 2008 and citations therein).

Data and Methods

The percent of the Grand Portage Creek watershed in impervious cover was calculated using the constructed surface definitions provided in the C-CAP Land Cover Classification Scheme (Table 9). It was assumed that 100% of constructed materials are impervious; if materials such as porous pavement are used, the amount of impervious surface could be overestimated. However, Stranko et al. (2008) showed that the the use of high-resolution aerial photography from a similar time period showed substantially greater amounts of impervious land cover than results derived from the 2001 NLCD, so the amount of impervious surface might also be underestimated.

Table 9. Percent constructed surfaces by land cover type in Grand Portage Creek watershed (NPS 2010a).

Developed Land Cover Type	% Constructed Materials	Area in GPC Watershed (ha)	Area in Constructed Surfaces (ha)	Area in GPC Watershed below Hwy 61 (ha)	Area in Constructed Surfaces (ha)
High Intensity	80-100%	0.7	0.6-0.7	0.7	0.6-0.7
Medium Intensity	50-79%	5.6	2.8-4.4	5.2	2.6-4.1
Low Intensity	21-49%	10.6	2.1-5.2	8.2	1.6-4.0
Open Space	<20%	0.5	0-0.1	0.5	0-0.1
Total Developed		17.4	5.5-10.4	14.6	4.8-9.0
Total Watershed		1,862.1	(0.3-0.6%)	117.6	(4.1-7.6%)

Newman et al. (2003), in their development of a brook trout rehabilitation plan for Lake Superior, have indicated that a culvert at Highway 61 provides a barrier to brook trout movement in Grand Portage Creek. The authors list low flow rates during summer or winter and limited groundwater availability to maintain suitable stream temperatures and provide spawning habitat as stressors for brook trout in Grand Portage Creek.

Reference Condition

Impervious land cover should not exceed 4% within the Grand Portage Creek watershed for the protection of coaster brook trout. This represents a “least disturbed condition” or “the best of today’s existing conditions” (Stoddard et al. 2006).

Condition and Trend

The Grand Portage Creek watershed in its entirety is estimated to have 0.3-0.6% impervious surface (Table 9), well below the 4% needed for the protection of brook trout. Therefore, we rate the condition of Grand Portage Creek for coaster brook trout relative to impervious surfaces as good.

It should be noted that the portion of the watershed below Highway 61, that available to the fish, is 4.1-7.6% impervious surface, but the significance of this is uncertain. Although the culvert at Highway 61 prevents fish from traveling through the entire watershed, it does not prevent the water from the entire watershed from traveling to the part of the stream they can use. We recommend that a more refined calculation of impervious surface be made to accurately assess condition and especially trend, given the underestimation of impervious surfaces by NLCD noted by Stranko et al (2008), and we rate the trend as uncertain. Our confidence in this assessment is fair.

4.1.3 Landscape Pattern and Structure

Description

The Portage Trail at GRPO is a long, narrow corridor with overall dimensions of 31,378 m of perimeter to 2,866,403 m^2 of area, or a perimeter to area ratio of 0.0109 m m^{-2}. This ranks it 89th in terms of amount of edge among 387 NPS units (NPS 2011). Route and Elias (2007) noted "…difficulty of managing a narrow corridor of habitat…" among the primary threats to GRPO. GRPO is also located within the forestry land use district of the Grand Portage Reservation (Figure 10).

The shape and location of GRPO affect the amount and proportion of its core habitat, which is significant to both biotic and abiotic processes in the landscape (Turner 1989). In a forest, the presence of edge alters the micro-environment (temperature, relative humidity, and wind) for an appreciable distance into the forest (Matlack 1993, Chen et al. 1995). The spatial extent of these influences, and the corresponding changes in vegetation, vary substantially among studies, which have noted differences by aspect, region or forest type, and edge structure (Matlack 1993, Cadenasso and Pickett 2001, Nelson and Halpern 2005). A study in the boreal mixed-wood forest type of Alberta found a distinct aspect effect, with the edge width for shrubs narrowest on the east; shrub and herb abundance varied up to 20 m into the forest, and alien species reached their peak abundance 5-15 m from the forest edge (Gignac and Dale 2007). Of particular note is that small fragments generally contain more alien species, and these species may occur up to 40 m from the edge (Gignac and Dale 2007). Changes in the size or number of natural habitat patches, or a change in the connectivity between those patches, can lead to loss of diversity of native species, among other effects (Fahrig and Merriam 1985).

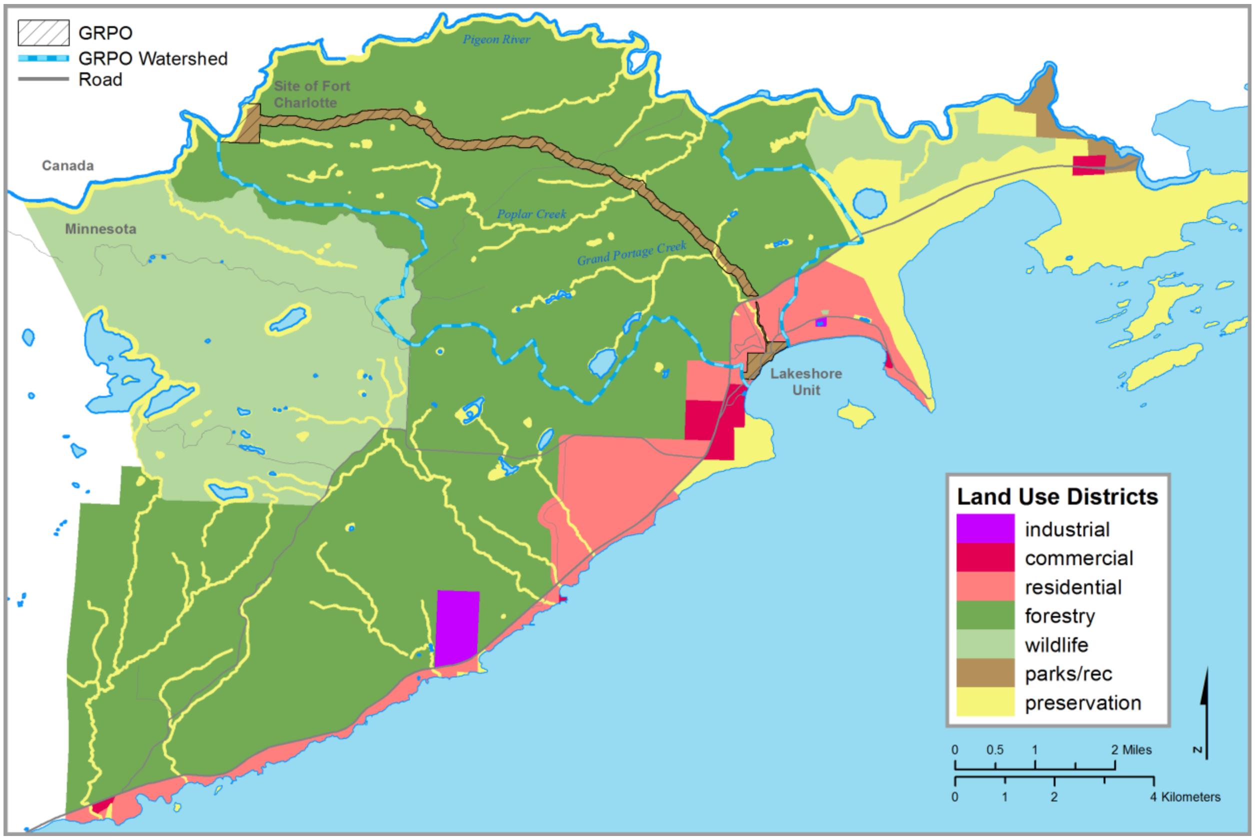


Figure 10. Land use districts on the Grand Portage Reservation (Frazier et al. 2006).

Data and Methods

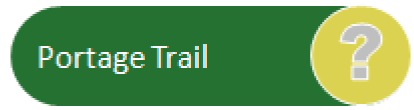
The degree to which the habitat of GRPO is intact was assessed by several methods. We used the landscape dynamics monitoring project NPScape to develop metrics of forest density (a measure of area-density which describes a very broad habitat category) and forest morphology (a measure that indicates the amount of core habitat vs. edge). Because the area of GRPO is small for the use of such landscape-scale metrics, we also examined forest disturbance data generated from Landsat images and inspected several aerial photos for evidence of recent forest changes.

The perimeter to area ratio for GRPO and, for comparison, all other NPS units was calculated in ArcGIS using the current NPS boundaries (NPS 2011) re-projected to USA_Contiguous_Albers_Equal_Area_Conic_USGS_version (NAD83) as used in the NPScape Standard Operating Procedures (SOP).

Forest density and forest morphology statistics were generated also using NPScape SOPs. We used the NPScape metrics generated from the 2006 NLCD and found in IRMA (NPS 2012). We also used qualitatively a set of 1991 and 2010 aerial photographs for GRPO. With these, we could assess canopy density across the watershed and roughly estimate the time it took a harvested area to re-establish a ‘canopy’ (i.e., a continuous layer of vegetation).

Titus Seilheimer, research ecologist with the USFS Northern Research Station in St. Paul, Minnesota, provided vegetation change tracker (VCT) data for GRPO that was generated from Landsat time series stacks using the methodology of Stueve et al. (2011).

Reference Condition
Because the lands surrounding GRPO are actively managed by the Grand Portage Band, the forest density conditions in the Superior National Forest are a reasonable point of reference. Therefore, at least 80% of the GRPO watershed should be in the dominant to intact area density class for forest density. This is considered a "least disturbed condition" because it establishes an acceptable level of human disturbance (Stoddard et al. 2006). A reference condition for forest morphology was not established because of the variability of species response (positive, negative, or neutral) to edge (Ries and Sisk 2004).

Condition and Trend


The GRPO watershed compares favorably to the Superior National Forest for forest density (83.1% to 81.6%). However, we rate the landscape pattern and structure at GRPO as a moderate concern, with an uncertain trend, based on a qualitative analysis using the USFS disturbance map and the aerial photographs. Sharp edges are created at the park boundary by forest harvesting and logging roads. Our degree of confidence in this assessment is fair.

Because the corridor is so narrow, the smallest appropriate unit at which forest density could be applied was the GRPO watershed. NPScape forest density was calculated for the watershed, a 30 km park buffer, and the Superior National Forest using a 30 m grid size and a 7 x 7 moving window (4.4 ha) in the analysis (NPS 2010b, Monahan et al. 2012). From a reference condition and habitat perspective, it is important to note the definitions utilized by NPScape. A grid is considered 'forest' if the proportion of cover contributed by woody vegetation at least 5 or 6 m tall is at least 20 or 25% (conflicting definitions are given at the NLCD website [http://www.mrlc.gov/nlcd06_leg.php]). A window is considered 'forest dominant' if at least 60 percent, but less than 90 percent, of the grids meet the definition for forest. This means that a given 4.4 ha area could have anywhere from ~20 to over 80% tree cover and meet the definition of 'forest dominant.'

As calculated by the NPScape forest density metric, over 83% of the GRPO watershed and nearly 82% of the landscape within 30 km of GRPO was in "dominant" (also called "variegated") to "intact" condition. Therefore, only 17-18% of the landscape was composed of 4.4 ha windows in which less than 60% of the grids met the threshold for forest. Percolation theory suggests that at this threshold, a landscape may "flip" from mostly interconnected areas to mostly small, isolated patches (Monahan et al. 2012 and citations therein). The percent of the landscape in this condition was similar to that in the nearby Superior National Forest (Table 10). Wickham et al. (2007, in Monahan et al. 2012), found area-density to be sensitive to loss in the area of dominant forest, even when patch size distribution was unchanged. However, for GRPO, this analysis may suggest a higher level of contiguous forest than is warranted for this "working" landscape; it lumps all forest types into one category and does not distinguish between a very young forest whose canopy recently closed (e.g., 30 years after logging) and an old one (perhaps 120 years or older).

Table 10. Forest density metric for the Grand Portage National Monument watershed, a 30 km buffer around the park, and the nearby Superior National Forest for 2006, using a 30 m grid size and a 7 x 7 moving window (4.4 ha) (NPS 2012).

Density Class Name	Area-Density for Forest Cover (p)	Location					
		GRPO Watershed		GRPO Buffer (30 km)		Superior National Forest	
		ha	%	ha	%	ha	%
No Focal Landcover	p = 0%	36	0.6	2,313	2.7	63,828	4.2
Rare	0% < p < 10%	56	1.0	1,006	1.2	22,461	1.5
Patchy	10% ≤ p < 40%	303	5.3	5,279	6.1	89,966	5.9
Transitional	40% ≤ p < 60%	576	10.1	7,167	8.3	104,828	6.9
Dominant	60% ≤ p < 90%	2,315	40.5	24,230	28.1	353,676	23.2
Interior	90% ≤ p < 100%	1,089	19.0	13,351	15.5	220,141	14.4
Intact	p = 100%	1,341	23.5	32,996	38.2	671,068	44.0
Subtotal – Dominant to Intact		4,745	83.1	70,577	81.7	1,244,885	81.6
Total		5,716		86,343		1,525,968	

We next examined landscape-level data regarding forest morphology with an NPScape SOP that uses Morphological Spatial Pattern Analysis (MSPA). This process uses image segmentation to classify individual grid cells in binary (forest/nonforest) maps into a set of pattern types (Figure 11). In NPScape, the eight basic landscape pattern types are core, islet, perforation, edge, loop, bridge or corridor, branch, and background (NPS 2010b).

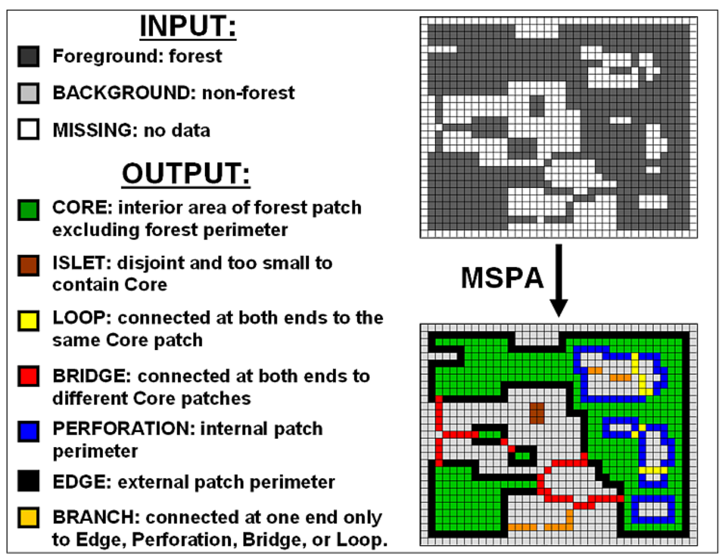


Figure 11. Explanation of Morphological Spatial Pattern Analysis (figure obtained from http://ies.jrc.ec.europa.eu/news/108/354/Highlight-November-2009/d,ies_highlights_details.html).

The most recent data set for which metrics had been calculated at the 30-m scale was the 2006 NLCD (NPS 2012). Because of the scale of this source dataset, the NPScape SOPs do not recommend using an analysis area of less than 30 km, or nearly 1,000 km^2 (NPS 2010b).

The results, which are a snapshot of forest morphology in 2006 for a large area relative to the size of GRPO, indicate that using an edge width of one cell (30 m), 62% of the land area within

30 km of GRPO was core forest, and 10% was edge. Nineteen percent was not forest, and the remaining 9% was in one of five categories (branch, islet, bridge, perforated, or loop) that identified it as an area that was either a type of connector between core forest areas or too small to be core forest. When the edge width was increased to five cells (150 m), the amount of land area in core forest dropped to 26%, 28% was edge, and 22% was classified as bridge between core forest patches (Figure 12). These landscape-level figures indicate patchiness in the landscape, where increasing the width of the area defined as edge (increasing the penetration into a forest) has a significant impact on the size of the area that can be defined as core forest. It should be noted that these evaluations cannot be applied to the corridor itself.

These landscape-level assessments were further refined by examining the 2006 C-CAP land cover map for the GRPO vicinity (NPS 2010a) to include the effects of forest type. The Portage Trail crosses parts of three small watersheds that total 5,718 ha. If the vegetation is categorized at a broad scale of three forest types (evergreen, deciduous, and mixed), one non-wetland shrub type, a grassland type, and three palustrine cover types, a strong pattern of inter-digitation is evident (Figure 13). There are a handful of relatively large evergreen communities, but generally the habitats are small and irregularly shaped. Much of the evergreen forest type exists as long, narrow fingers.

Further site-specific analysis reveals that in varying locations and at varying times, the landscape bordering the Portage Trail had no forest cover due to frequent cutting that creates open habitat. GRPO is located within the forestry district of the Grand Portage Reservation (Figure 10), and harvesting is done up to the edge of the 183-m wide trail corridor boundary. For example, Figure 14 shows an area that was logged prior to 1984 for 2,500 m parallel to the trail and a second area harvested post 2009 for 1,000 m along the trail corridor. These human-created openings persist for 10 to 20 years. Further evidence of a moderate level of regular, ongoing forest disturbance in the GRPO watershed was provided by the VCT data provided by the USFS, which shows areas of disturbance beyond those we detected in our limited aerial photo analysis (Figure 15).

The landscape structure is further affected by the abundance of shrub habitat and secondarily by palustrine habitats. These characteristics collectively mean that very little of the forested areas along the Portage Trail has much core (interior) habitat. Therefore, much of the forest area is being affected by the presence of ‘edge,’ that is, the micro-environment (temperature, relative humidity, and wind) is altered for an appreciable distance into the forest, and the limited data we have suggest that this condition will continue.

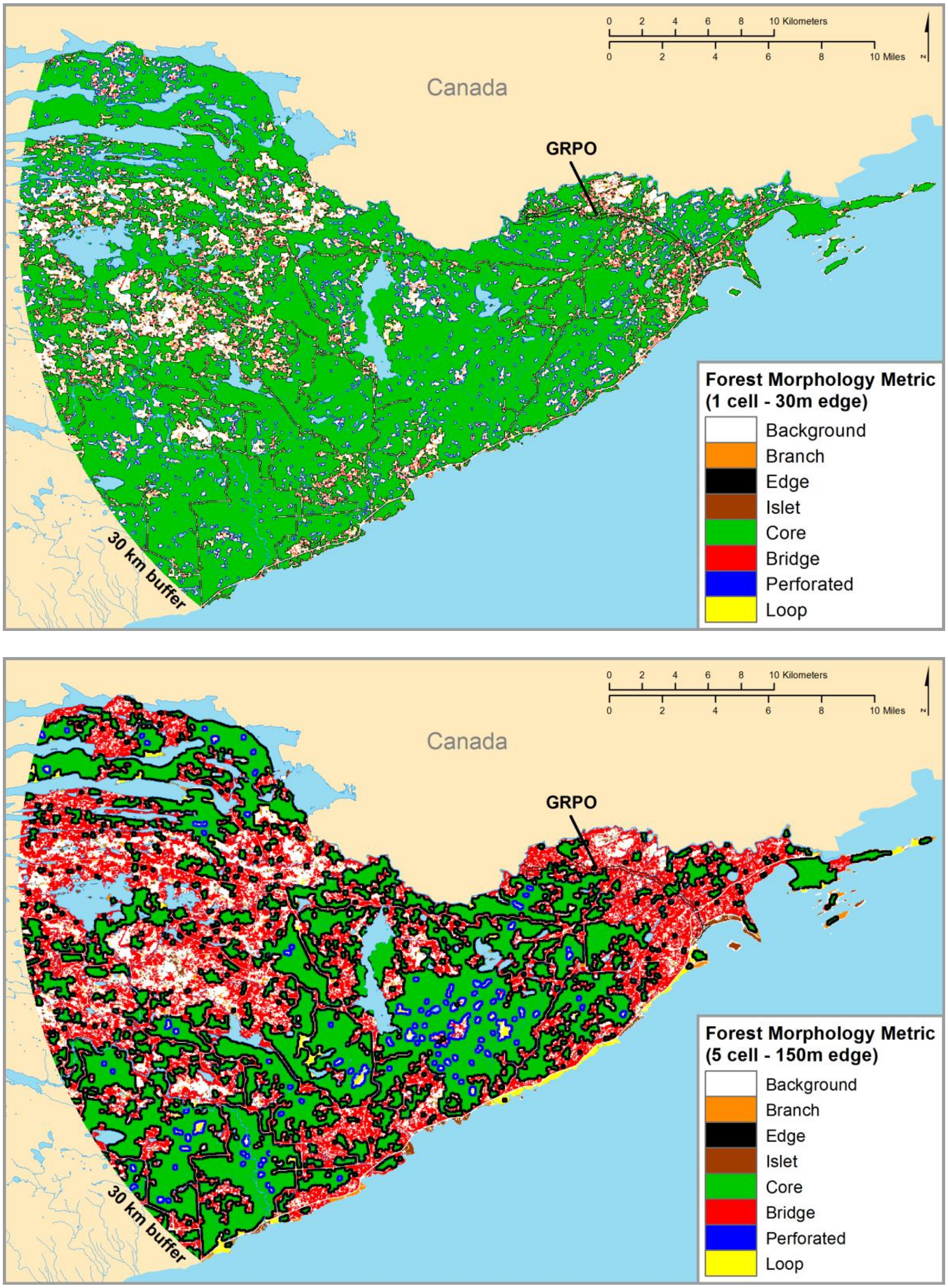


Figure 12. Landscape morphology metrics for a 30 km buffer surrounding Grand Portage National Monument at the one cell (30 m edge) and five cell (150 m edge) scales.

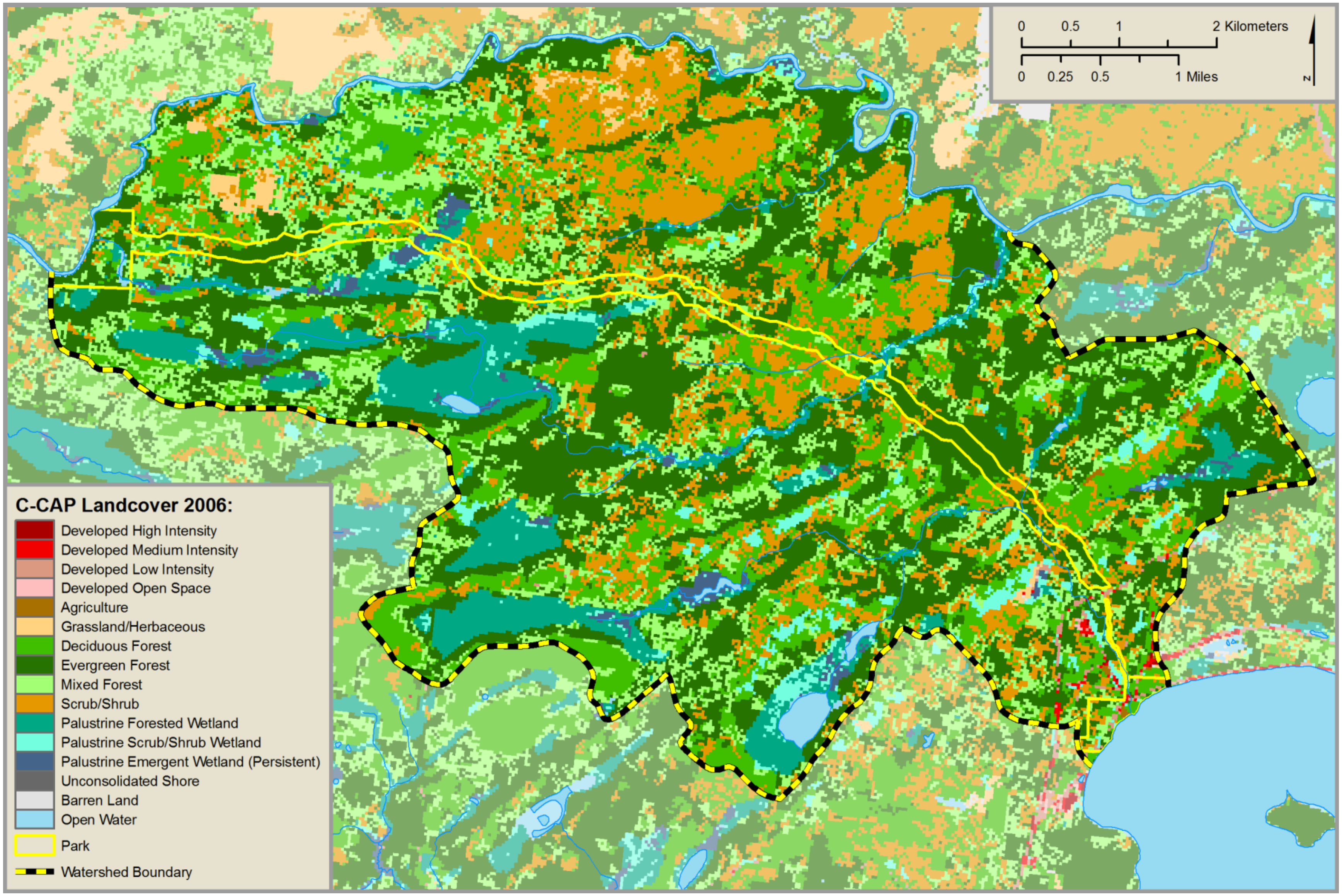


Figure 13. C-CAP landcover map for the vicinity of Grand Portage National Monument.

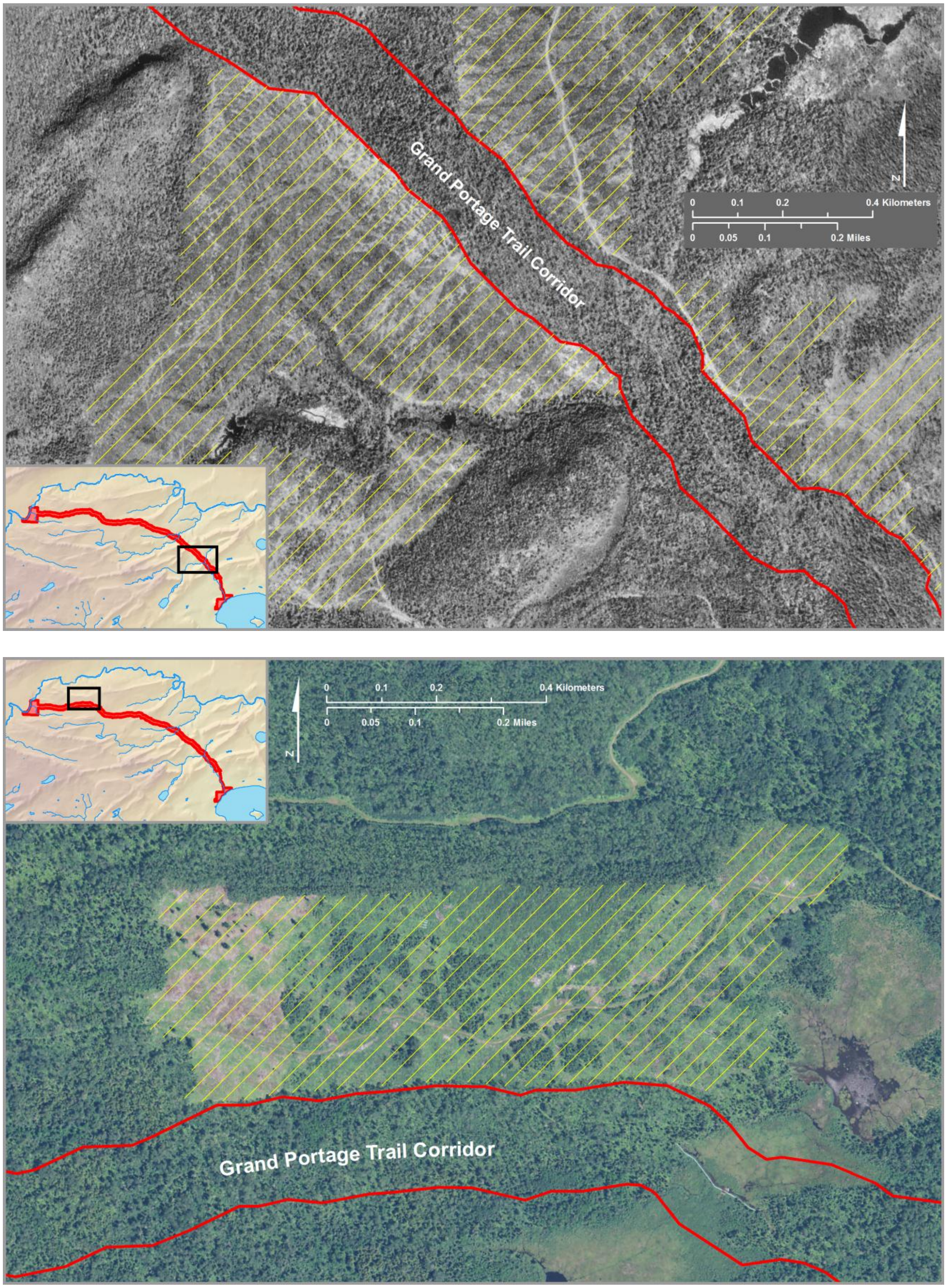


Figure 14. Air photos showing harvesting (shaded areas) along the Grand Portage Trail corridor just prior to 1991 (above) and between 2003 and 2010 (below).

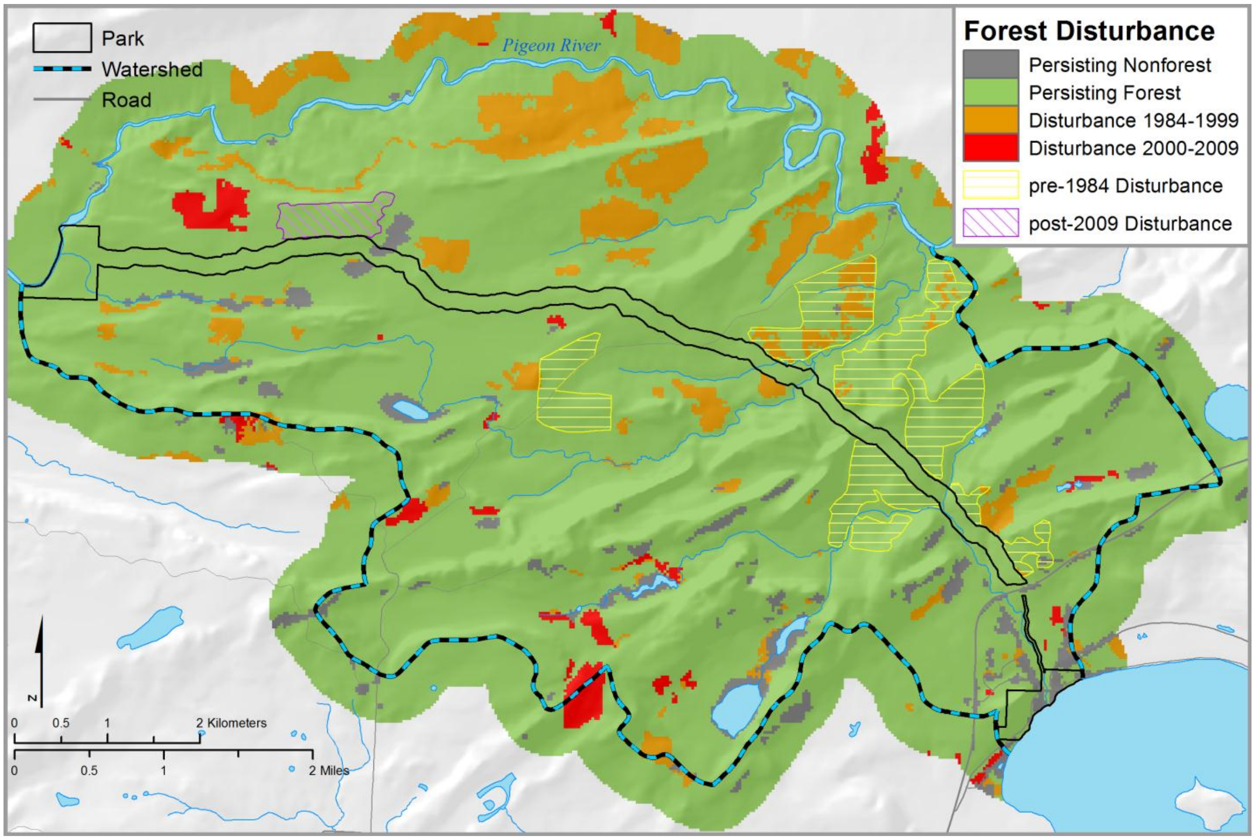


Figure 15. Forest disturbance results from the USFS VCT, with an overlay of pre-1984 and post-2009 disturbances based on aerial photo analysis.

4.1.4 Road Density

<u>Description</u>

An extensive body of literature has documented the effects of roads on both terrestrial and aquatic environments. Gross et al. (2009) cited comprehensive reviews by Spellerberg (1998), Ercelawn (2000), Trombulak and Frissell (2000), and Forman et al. (2002) and stated that “Even in areas where human population densities are relatively low and landscapes are perceived as natural, the impacts of roads are pervasive and may extend hundreds to thousands of meters from the roadside.”

Roads have a wide variety of ecological effects, ranging from altered hydrology, increased erosion, habitat segregation, migration barriers, and direct mortality (Forman and Alexander 1998). For mammals, noise may be more important than collisions due to its effect on behavior. A full evaluation of the effect of roads must include the ‘road-effect zone’, not just the road and associated altered habitat (Forman and Alexander 1998). For large mammals in woodland areas, this typically extends 100-200 m out from the road. Physical and biological effects of roads are summarized in Table 11.

Table 11. Pervasive effects of roads relative to natural resources, park visitors, and park operations (from Gross et al. 2009).

Physical Effects	Biological Effects
Alter temperature, humidity, and other climate attributes	Collisions between animals and cars
Increase rate and amount of water runoff	Physical barrier to movement
Alter surface and ground water flows	Habitat loss
Alter rates of sediment and nutrient dispersal	Habitat fragmentation
Runoff of chemicals applied to road surface	Behavioral avoidance of disturbances
Alter geological and soil substrates	Corridor for invasive species
Increase production and propagation of noise	Indirect effects like poaching, fire ignition, trash
Alter light	Noise interference with species communication
Physical barrier to many species	Habitat alteration

<u>Data and Methods</u>

The road network for GRPO (Figure 16) is based on a 1:24,000 scale DLG road layer downloaded from the NPS data server (Budde 1999). We found it to be more detailed and accurate than the ESRI layer (used by NPScape) or the limited Minnesota Department of Transportation layer. Some roads were added/edited based on 2003 NAIP air photos. We reclassified a number of DLG "trails," such as the one we toured between Hwy 61 and old 61, as minor roads since we felt this was a better interpretation relative to road density metrics. "Trails" that were readily discernible on the air photos as road-like are shown as roads.

Road metrics were calculated according to methods delineated in the NPScape Phase 2 Road Metrics Processing SOP (NPS 2010c). The SOP defines major roads as the FCC classes for primary, state, and county roads (A10-A38). Hwy 61 and local county roads were therefore considered the major roads for our metrics, with an additional major road traversing the watershed from northeast to southwest and some major roads in Grand Portage defined in consultation with GRPO staff. We did not use a weighted road calculation as outlined in NPScape where the length of major roads was multiplied by 3 for better comparison to literature values. Trails were not used for the metric calculation.

Laurian et al. (2008) monitored moose movement by capturing adult moose and attaching radio collars on 47 individuals over a 3-year period. The locations used by the collared animals were overlain on 1:20,000 digital maps to determine proximity to roads suitable for motor vehicle travel. The study was conducted in a wildlife reserve in Quebec. The moose density had increased in recent years and was estimated at 0.22 moose km^{-2}. The road densities in the region were determined to be 0.06 km km^{-2} for highways and 0.16 km km^{-2} for forest roads. The forests in the region were described as "typical of the boreal region" with balsam fir and black spruce dominating the uplands.

Rempel et al. (1997) used Landsat cover data and 16 years of aerial surveys to document moose use in five regions of Ontario. The regions differed in type of disturbance (fire versus harvesting), road density, and hunter access.

Joyce and Mahoney (2001) examined historic records of moose-vehicle collisions in Newfoundland to determine if time of day, season, road condition, visibility, or moose gender influenced the likelihood of a collision.

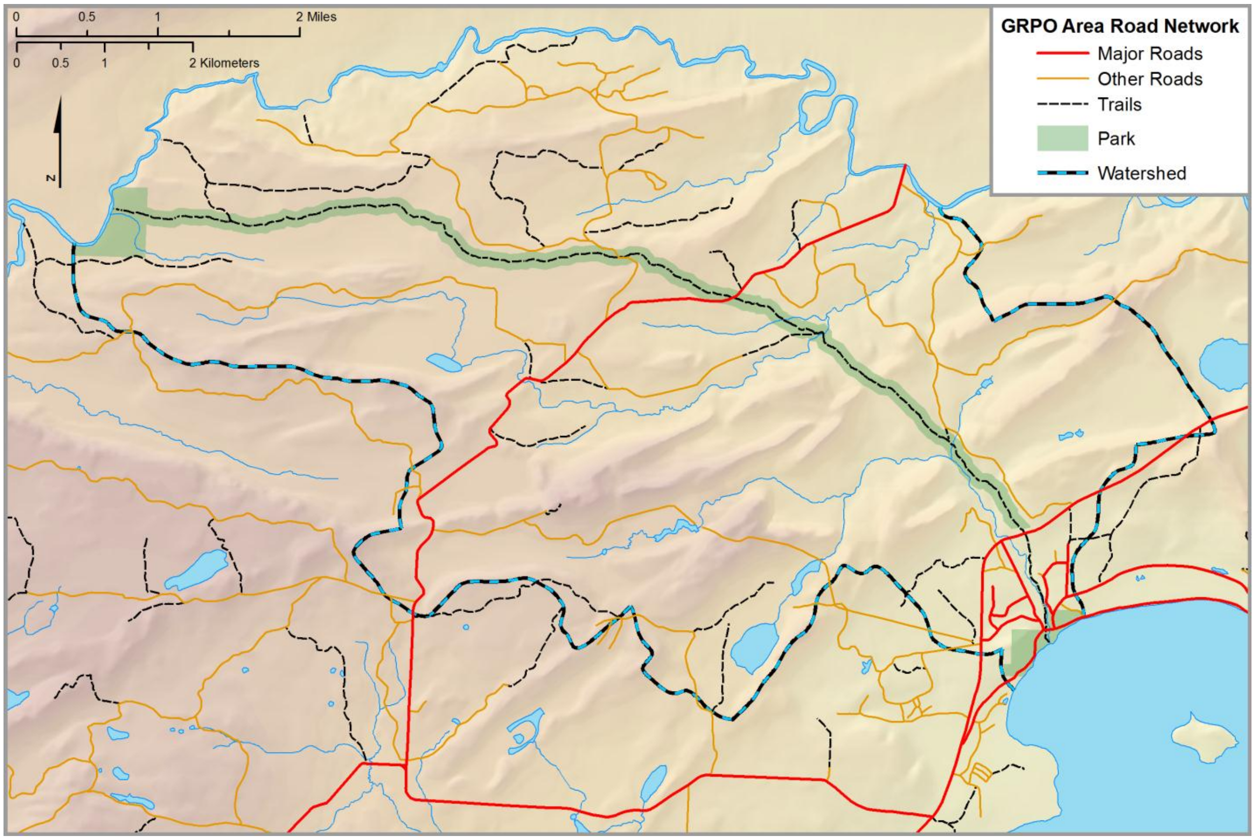


Figure 16. Road network in Grand Portage National Monument.

Peek et al. (1976) combined aerial surveys and ground censuses to determine habitat selection by moose over a 3-year period in the Boundary Waters Canoe Area.

Moen et al. (2010) analyzed data collected from a radio collar study tracking 12 Canada lynx between 2003 and 2009.

Mladenoff et al. (1995) used data collected by radio collaring gray wolves to establish predictors of preferred habitat in northern Wisconsin and the upper peninsula of Michigan; road density had the greatest explanatory effect. Further work on the model (Mladenoff et al. 1999) indicated that it applied well in the larger Great Lakes region, including Minnesota.

Reference Condition

For moose, the reference condition is the existence of areas at least 10 km^2 in size that are at least 500 m from roads. For gray wolves, the reference condition is the existence of areas with a road density of <0.45 km km^2. These reference conditions are based on observations of the presence or absence of these species under varying road density conditions and reported in the peer-reviewed literature. This represents a “least disturbed condition” (Stoddard et al. 2006).

Condition and Trend

The majority of the land within the GRPO watershed (77%) is within 500 m of a road and so does not meet the habitat requirements documented for moose in Quebec (Laurian et al.

2008) (Figure 17), so we rate this condition as of moderate concern, with an unchanging trend. Because there are no local studies, our degree of confidence in this assessment is fair.

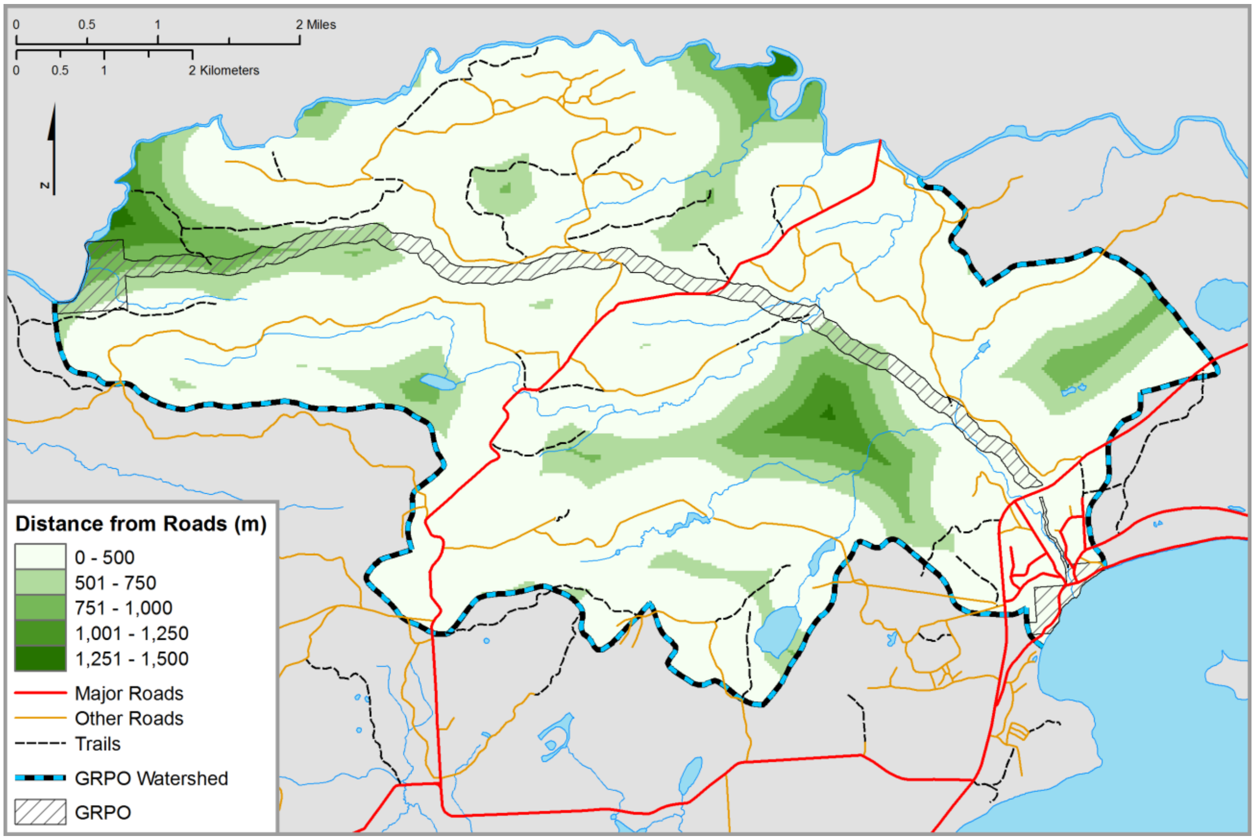


Figure 17. Distance of lands within the Grand Portage National Monument watershed from roads.

Movement of collared moose in Quebec indicated strong avoidance of all types of roads, but their behavior was affected more by highways (Laurian et al. 2008). This is consistent with the review of Forman and Alexander (1998), which stated that large and mid-sized mammals are especially susceptible to two-lane, high-speed roads. Though animals generally stayed 500 m or more away from roads, 20% of the moose made visits within 50 m of highways. These occurred primarily in spring and summer. Laurian et al. (2008) interpret their results to indicate that moose interact with roads at two scales: at a coarse scale they avoid roads, but at a local scale they may preferentially use road right-of-ways to address a dietary need. As documented in other studies (e.g., Leblond et al. 2007), Laurian et al. (2008) found significantly higher levels of sodium in the vegetation near roads compared to that farther away.

Seventy percent or more of recorded moose-vehicle collisions occurred between dusk and dawn and between June and October (Joyce and Mahoney 2001). Part of the reason for the seasonal pattern is that moose use a much smaller home range in winter than summer (Cederlund and Okarma 1988), and the habitats they most use also shift, with greater use of upland conifer forests (Peek et al. 1976).

Moose make fairly extensive use of recently disturbed areas for foraging (Peek et al. 1976, Rempel et al. 1997, Lenarz et al. 2011). In general, population growth is enhanced equally by recent fire or harvesting, but when road density goes up substantially, the population can be repressed by increased hunter use (Rempel et al. 1997).

These results should be applied with caution in northeastern Minnesota, because most came from other regions. The landscape context of each study is pertinent; the annual home range of 29 moose in northeastern Minnesota was 32.8 km^2 (Lenarz et al. 2011), but adult females in Sweden averaged 12.6 km^2 (Cederlund and Okarma 1988). Populations of moose in rural and more wild areas do not always respond the same to roads as moose in more urban settings, and benefits other than sodium can be provided by roads (Laurian et al. 2008). Over time, a population/species may change its tolerance of humans and human-generated habitat features. We currently lack context-specific data to establish minimum road-density thresholds for moose in northeastern Minnesota; however, the levels noted in Quebec (Laurian et al. 2008) are a reasonable first approximation.

Using the NPScape Road Metrics SOP (NPS 2010c), the average density of roads within the GRPO watershed is 1.2 km km^{-2}. Only approximately 27% of the land within the GRPO watershed has a road density of ≤0.23 km km^{-2}, which has been cited as the territory core use area for the gray wolf (Mladenoff et al. 1995) (Figure 18). Approximately 32% of the land has a road density of ≤0.45 km km^{-2}, which Mladenoff et al. (1995) reported as the threshold beyond which “few portions of any pack territory are located.” Thus, we rank the condition of the GRPO watershed for gray wolf territory as of moderate concern, with an unchanging trend. Our level of confidence in this assessment is good.

Mladenoff et al. (1995) noted that the existence of roads is not in itself problematic for wolves, but that road density serves as an index to human contact, which has meant “high levels of legal, illegal, and accidental killing of wolves.” They noted that wolves had moved into territory formerly thought to be marginal in northern Minnesota, for example, where road densities exceeded 0.7 km km^{-2}. Where wolves were “present and tolerated by humans,” adequate prey density appeared to be the major limiting factor for wolves. Similarly, Merrill (2000) reported on an area in central Minnesota where wolves were breeding successfully in an area with a road density of 1.42 km km^{-2}. Still, Mladenoff et al. (1995) cited areas of low human contact as important to recovering or colonizing wolf populations. Potvin et al. (2005) predicted a road density threshold of 0.7 km km^{-2} along with a deer density threshold of 2.3-5.8 deer km^{-2} for successful wolf occupation of areas in upper Michigan.

In a study of variables predicting lynx occurrence in the eastern United States, Hoving et al. (2005) observed that the direction of the effect of road density with lynx occurrence switched between positive and negative associations in 19 logistic regression models and was inconclusive. However, among the top six models, three showed a positive association with roads and none showed a negative association. Moen et al. (2010) found that when lynx made

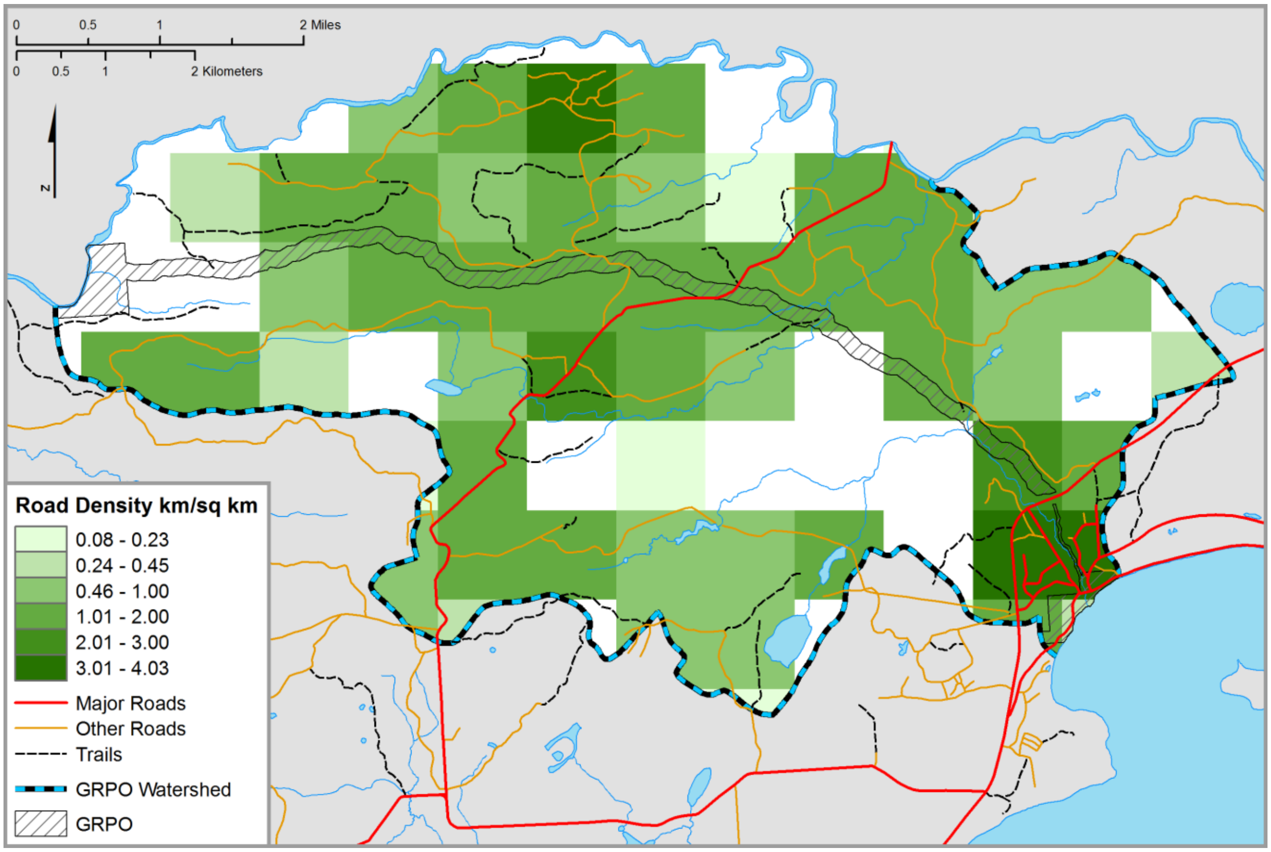


Figure 18. Road density in the Grand Portage National Monument watershed.

long-distance movements through roaded areas of the Superior National Forest, over 2/3 of their locations were within 200 m of a road, trail, or other linear feature. When traveling near paved roads, lynx tended to stay within 15 m of the road. Lynx also tended to stay within 200 m of roads within their home ranges. The authors attributed this finding to the "energetic efficiency" of moving along a road rather than through a forest. They suggested that the road and trail network increased the connectivity of parts of the forest and enabled lynx to travel farther distances. They also noted the risk of lynx mortality due to increased human contact along roads, although none occurred during their study. Based on this work, we did not establish a reference condition for road density for lynx.

Sources of Expertise

NPScape website, Bill Monahan, Lisa Nelson, Dave Mechenich, James Cook.

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4.2 Biotic Condition

In the EPA-SAB framework, biotic condition includes structural and compositional aspects of the biota below the landscape level at the organizational levels of ecosystems or communities, species and populations, individual organisms, and genes (USEPA 2002). We will discuss the biotic condition of the terrestrial and inland aquatic ecosystems, focusing on species composition, regeneration, and invasive species for terrestrial systems and invasive species and indices of biotic integrity for aquatic systems. At the species and population level, we will focus on the focal species of moose, beaver, and coaster brook trout.

4.2.1 Southern Boreal Forest

Description

The Southern Boreal Forest (SBF) is a region of the boreal forest that is transitional between the northern hardwood-conifer forest to the south and the boreal forest proper to the north (Vankat 1979 in White and Host 2003). The SBF in extreme northeastern Minnesota has been classified as largely in the “mesic birch-aspen-spruce-fir” forest type (White and Host 2000), based on current vegetation. Using the trees recorded during the General Land Office (GLO) survey, Marschner (1946) recognized two forest types: mixed white and red pine primarily in the Swamp River Till Plain and aspen-birch-conifer in the North Shore Till Plain. This is relevant because many other studies in this region also recognized only these two forest types. Consequently, the majority of the descriptive information available cannot be applied to an association, as defined in Hop et al. (2010), but generally will match up at the ‘Group’ level.

Data and Methods

A recent classification effort that followed the National Vegetation Classification Standards (NatureServe 2009) identified 20 natural/semi-natural associations in GRPO (Hop et al. 2010). These associations should be considered tentative and approximate because of a) the narrow, linear shape of the unit, b) the very limited field data utilized to determine how many associations occur in GRPO (23 plots installed and 20 associations identified), c) the difficulties in applying the standard methods of analyses due to the small sample size, and d) the need to extrapolate from work done at Voyageurs National Park (VOYA) and ISRO. These limitations were fully recognized by Hop et al. (2010). It should be noted that the mapping team visited and gathered descriptive information at 146 locations, so the basis for the floristic descriptions is much more extensive than that for the structural and abundance data. The guideline was 3-5 locations per association type.

The GLKN (Sanders 2008) established 20 permanent inventory locations at GRPO in 2007, with the purpose of establishing baseline information; the objectives were largely focused on woody vegetation (Sanders 2008, p. 1). These plots were located so as to provide “spatial balance” (presumably well distributed) throughout the park. At each plot, the forest habitat type was determined using the Kotar classification system. This system differs from other classification systems in that it groups areas based on anticipated climax forest type, rather than current type. For the monitoring in 2007, all plots were classified as the “white spruce-balsam fir-paper birch type.” As part of this effort, 30 1-m^2 quadrats were installed per vegetation plot, for a total of 600 quadrats. Herb-layer presence of all species within each quadrat was noted.

MacLean and Gucciardo (2005) reported the results of re-measurements in 2004 at four permanent vegetation plots that were sampled in 1986. Though there were methodological limitations to the study, the results showing the major patterns of the tree component (stems > 6 cm diameter at breast height [DBH]) are useful.

In 2000-2002, White and Host (2003) conducted a study to document the historic disturbance regimes of GRPO. The initial step was to map the cover types along the corridor using 1:15,840 color photos from 1999 after digitizing and rectifying to a resolution of 1 m. They used this cover type map to locate old-growth and mixed hardwood-conifer stands most likely to contain fire scars and trees suitable for tree ring analysis. Increment cores were taken from several large conifers and sometimes down woody material at each site (n=14). In addition to fire scar and tree age data, the authors used various historic and current data sources to characterize the 1600-1900 fire regime in GRPO. These sources included a) GLO bearing trees and line notes, b) fire history information from the BWCAW, c) regional level disturbance models, and d) soils, landform, and climate data.

Overview of Vegetation at GRPO

White and Host (2003) determined that 64% of the forests along the corridor in 1999 were of the “aspen-birch type.” An additional 26% were “spruce-fir.” These types were strictly overstory-composition based and do not match up directly with the associations described below. These data appear to overstate slightly the dominance of the Southern Boreal Forest biome, broadly defined; however, they confirm that the character of the landscape is largely shaped by this group of forest types.

The vegetation classification at GRPO documented 11 associations in the Forest and Woodland Class, one shrub-dominated upland association, and three associations in the Nonvascular and Sparse Vascular Rock Vegetation Class (Table 12). It is important to note that Hop et al. (2010) provide a reasonably complete floristic description of the communities (associations) currently in the Monument. However, when these descriptions are compared to the so-called “Global Summary,” substantial differences are often noted. This is true for composition and structure as well as the “Environment” in which each may occur. These differences partially (or perhaps entirely) indicate the extent to which a particular association could vary and still be the same general community type.

The White Spruce- Balsam Fir Forest Group strongly dominates (69%) the lands within GRPO (Table 12, Figure 19). The overstory of the associations in this group contains various amounts of white spruce, aspen, paper birch, balsam fir, and white pine. The next most common Group (8%) is the Northern and Central Alkaline Conifer and Hardwood Swamp Group. Two associations are noted: Black Ash-Mixed Hardwood-Conifer Swamp and Aspen-Balsam Poplar Lowland Forest. The former has black ash as the dominant but may contain a wide variety of broadleaved and evergreen species in different mixtures and abundances; this is the community type that historically contained most of the white cedar in GRPO. Quaking aspen and balsam poplar are clear dominants in the latter association. Paper birch and mountain ash may be secondary canopy species, as well as balsam fir and white spruce, but conifers are less well represented overall than in the black ash association. Only two other Groups occupy > 5% of the area; in decreasing order, they are the Northern Hardwood-Hemlock-White Pine Forest Group and the White Pine-Red Pine-Jack Pine-Oak Forest and Woodland Group.

The one association in the Shrubland and Grassland Class is in the Eastern North America Boreal Hazelnut-Serviceberry Rocky Shrubland Group; the Association has the same name. This group is characterized by some combination of three dominant shrub species (beaked hazelnut [*Corylus cornuta*], serviceberry [*Amelanchier* sp.], and chokecherry [*Prunus virginiana*]) and a strong graminoid herbaceous layer. The association occupies < 0.5% of the area.

Only one of the three associations in the Great Lakes Cliff and Shore Group was inventoried during the classification fieldwork, and thus only general ‘global’ descriptions are available for two at this time. These Cliff and Shore Group associations occur on talus slopes and near shorelines where there is a lot of cobble and/or gravel. Hence, these associations have very sparse vegetative cover due to very high levels (often > 90%) of rock on the surface. This group occurs on < 0.5% of the land within GRPO.

Description of White Spruce-Balsam Fir Forest Group at GRPO

This Group occupies ~69% of the GRPO lands and contains three associations (see above). The dominant overstory species in each is aspen, balsam fir, and aspen, respectively, and canopy cover is very similar (50-60%). Paper birch and balsam fir are present in at least modest quantities in all three. Mountain maple (*Acer spicatum*) occurs in the tall shrub layer in all three associations and also forms a sparse (20%) sub-canopy layer in the spruce-fir/mountain maple association. Eastern white pine occurs sporadically as an emergent [super-dominant, > 35 m tall] tree in the mountain maple association. The extent of the herbaceous layer is greater (90% cover) in the aspen-birch/conifer association than the other two (70%) (see Hop et al. 2010 for additional composition details).

Table 12. Vegetation map classification names, frequencies of occurrence in plots, and areas for Grand Portage National Monument (Hop et al. 2010).

Class and Group Name	Association Name	Frequency	Area (ha)	% of Total
Forest and Woodland Class		**387**	**269.4**	**92.3%**
Northern Hardwood – Hemlock – White Pine Forest Group		32	19.4	6.6%
	White-cedar – Boreal Conifer Mesic Forest			
White Pine - Red Pine - Jack Pine - Oak Forest and Woodland Group		26	15.3	5.2%
	White Pine/Mountain Maple Mesic Forest			
Northern and Central Hardwood and Conifer Ruderal Forest Group		1	0.2	0.1%
Northern and Central Conifer and Hardwood Plantation Group		4	1.0	0.3%
Northern and Central Alkaline Conifer and Hardwood Swamp Group		57	23.2	8.0%
	Black Ash – Mixed Hardwood Swamp			
	Aspen – Balsam Poplar Lowland Forest			
Northern and Central Shrub Swamp Group		20	6.7	2.3%
	Gray Alder Swamp			
Jack Pine - Black Spruce Forest Group		3	2.1	0.7%
	Jack Pine – Aspen/Bush-honeysuckle Forest			
	Jack Pine/Balsam Fir Forest			
Jack Pine - Northern Pin Oak Rocky Woodland Group		3	0.9	0.3%
	Boreal Pine Rocky Woodland			
White Spruce - Balsam Fir Forest Group		241	200.5	68.7%
	Spruce-Fir-Aspen Forest			
	Spruce-Fir/Mountain Maple Forest			
	Aspen-Birch/Boreal Conifer Forest			
Shrubland and Grassland Class		**19**	**7.8**	**2.7%**
Eastern Ruderal Shrubland and Grassland Group		4	2.3	0.8%
Eastern North American Boreal Shrubland and Grassland Group		3	0.7	0.2%
	Boreal Hazelnut-Serviceberry Rocky Shrubland			
Eastern North American Freshwater Marsh Group		3	1.0	0.3%
	Water Horsetail-Spikerush Marsh			
Eastern North American Wet Meadow Group		9	3.8	1.3%
	Bluejoint Wet Meadow			
	Northern Sedge Wet Meadow			
Aquatic Vegetation Class		**4**	**1.0**	**0.3%**
Eastern North American Freshwater Aquatic Vegetation Group		4	1.0	0.3%
	Northern Water-lily Aquatic Wetland			
	Midwest Pondweed Submerged Aquatic Wetland			
Nonvascular and Sparse Vascular Rock Vegetation Class		**3**	**1.1**	**0.4%**
Great Lakes Cliff and Shore Group		3	1.1	0.4%
	Great Lakes Basalt-Diabase Cobble-Gravel Shore			
	Northern Non-Carbonate Dry Talus Vegetation			
	Northern Non-Carbonate Moist Talus Vegetation			
	NVCS Subtotal	**413**	**279.2**	**95.7%**
Developed Vegetation Cultural Class				
Developed Area		7	7.4	2.5%
	NVCS Cultural Subtotal	**7**	**7.4**	**2.5%**
Non-NVCS Units				
Open Water		3	5.2	1.8%
	Non-NVCS Subtotal	**3**	**5.2**	**1.8%**
	Grand Total	**423**	**291.8**	**100.0%**

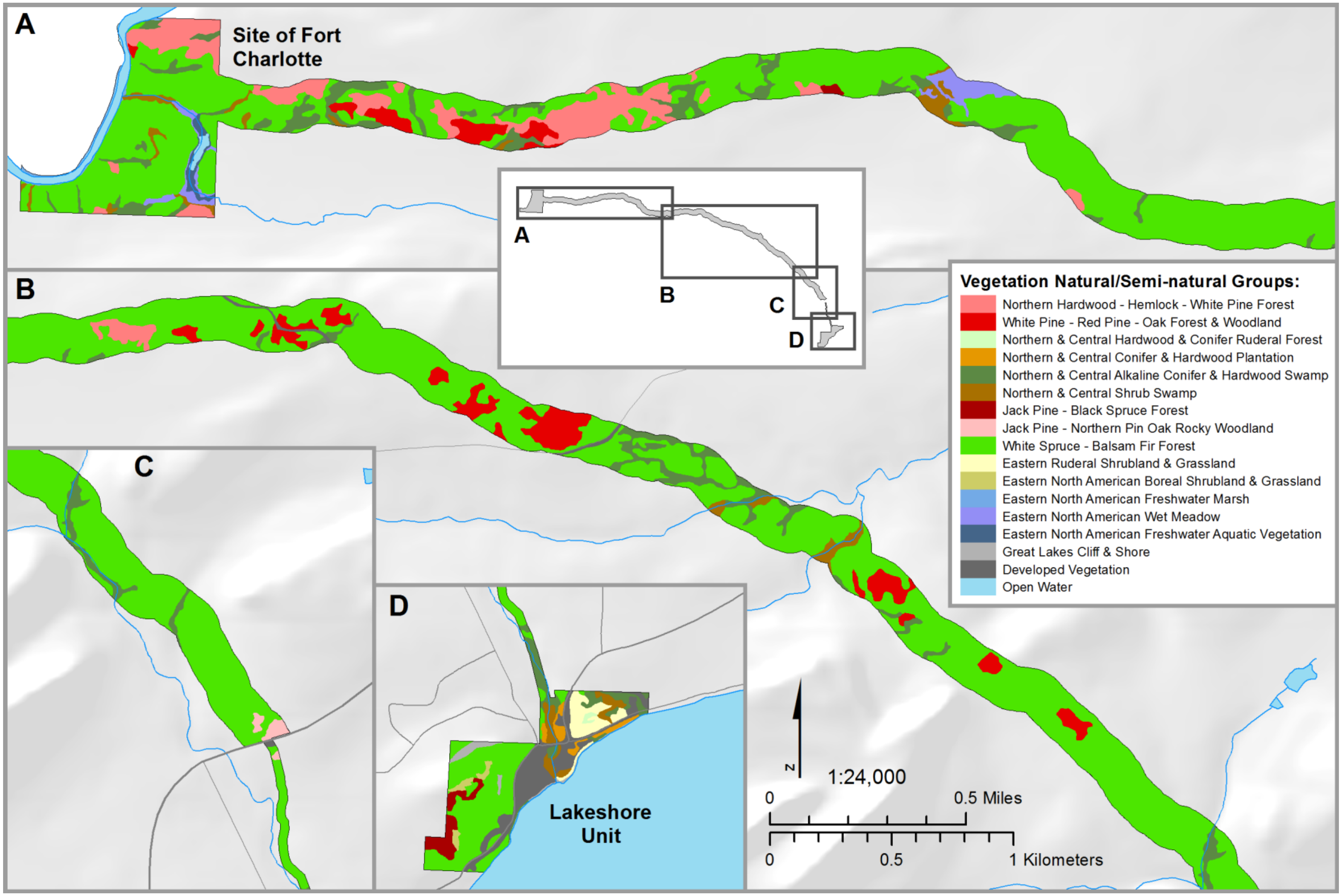

Figure 19. Vegetation of Grand Portage National Monument (Hop et al. 2010).

Sanders (2008) found balsam fir to have the greatest densities (727 ha^{-1}) of all woody species, with mountain maple (266 ha^{-1}) and quaking aspen (232 ha^{-1}) a distant second and third, respectively. Seventy-five percent of the balsam fir were < 10 cm DBH, reflecting their recent recruitment into these forests; in contrast, white pine was uncommon (13 ha^{-1}), and all were > 17.5 cm DBH.

The composition and relative densities among the sapling size class (< 2.6 cm DBH) are informative because this represents the most likely dominants in the community type that will replace the current one. Mountain maple (3,733 stems ha^{-1}) will become the dominant of the tall shrub layer, and balsam fir (2,633 stems ha^{-1}) will assume dominance of the overstory (Sanders 2008). Quaking aspen was the only other potential canopy species with a density > 1,000 ha^{-1}). Three other broad-leaved species (paper birch, black ash, and mountain ash (*Sorbus decora*) occurred at densities > 100/ha. No white cedar saplings were documented, and white spruce and white pine were present at densities of ≤ 50 stems ha^{-1}.

The age structure of this Group was documented by White and Host (2003) during their investigation of the disturbance history. In approximately 2/3 of the corridor, there is an abundance of aspen in the > 75 year age classes, reflecting the severe disturbances of the late 1800s. On more mesic sites, white spruce and/or fir dominated (~ 26% of the area), and a little over half (56%) were in the 75-100 year age class. About 1/5 (22%) of the stems were in the 25-50 and 100-125 year age classes. The maximum age recorded was 150 years or less at 11 of 14 points; most maxima were 100 ± 10 (Fig. 11, White and Host 2003). Two white cedar were found that exceeded 200 years, and in a few "protected" (not specified how) portions of the landscape, white cedar and pine formed a late successional old-growth community. These communities consistently contained cedar at least 140 years old, and due to cedar's susceptibility to fire, its presence was taken as evidence of lack of recent fire. The trend toward greater representation of white cedar in the absence of fire is consistent with the conclusions of Drake et al. (2011) (below).

At all four locations examined by MacLean and Gucciardo (2005), balsam fir increased dramatically (more than fourfold), whereas aspen and paper birch exhibited small declines at three locations and a large drop at the fourth. The woody stems 1.25-6 cm were quite dynamic over the 18 year period, with major gains by balsam fir at two locations. Fir declined substantially at one, whereas hazelnut and alder declined at all four.

Other Forest Associations

There are three other associations that are noteworthy: one (White cedar-Boreal Conifer Mesic Forest) dominated by northern white cedar, a White Pine/Mountain Maple Mesic Forest type, and a Jack Pine/Balsam Fir association. These three share many of the woody species that are common in the White Spruce-Balsam Fir Group (paper birch, white spruce, and balsam fir), thus indicating the close affinity among most of the upland forest types.

Swamp and Marsh Groups

Among the Forest and Shrubland Classes, two of the associations are lowland forests (Black Ash-Mixed Hardwood Swamp and Aspen-Balsam Poplar Lowland Forest) and one is shrub-dominated (Gray Alder Swamp). These three associations typically occur in floodplains and areas flooded by beaver activity.

The Black Ash-Mixed Hardwood Swamp is defined by black ash contributing at least 50% of the cover in the upper stratum. At GRPO, there is generally 50-60% canopy cover, and the canopy height ranges from 15-35 m. Balsam fir is often a co-dominant in the canopy and sub-canopy and is typically mixed with white spruce, balsam poplar, and/or quaking aspen. There are usually both tall and short shrub layers with approximately 30% cover each. Though several species may occur in each, the species with strong affinity for wetter conditions are red-osier dogwood and American cranberry (*Viburnum opulus*). This community occurs on poorly drained sites, typically with a clay loam soil, and has 81-93% leaf litter cover.

The Aspen-Balsam Poplar Lowland Forest in GRPO is found on a well-drained clay loam site that floods seasonally. The level of canopy cover and canopy height are similar to the black ash type, but with overstory dominance by both aspen and balsam poplar. The sub-canopy is moderately sparse and made up of balsam fir, mountain ash, and paper birch. The tall shrub layer is well developed (~50%) and dominated by mountain maple. The short shrub layer is moderately sparse (~20%) and includes red-osier dogwood, northern bush honeysuckle (*Diervilla lonicera*), white meadowsweet (*Spirea alba*), and American cranberry. Non-vascular moss cover is important here and in the closely related black ash type. The forest floor is 90% covered by leaf litter.

The Gray Alder Swamp in GRPO has a moderately to very dense (70-90% cover) tall shrub layer dominated by speckled alder and lesser amounts of state-threatened black hawthorn, black ash, willow, and American cranberry. Soils range from poorly drained to moderately well-drained clay and clay loam and have 87-93% leaf litter cover.

For further descriptions of these communities, the reader is referred to Appendix B of Hop et al. (2010).

<u>Reference Conditions</u>

Portage Trail

The dynamic nature of the vegetation due to weather and disturbance clearly establishes that there is no single reference condition, from an ecological point of view. The concept of historic range of variability (Landres et al. 1999) is highly applicable to this landscape (White and Host 2003), and the vegetative conditions during the fur trade era are simply one set among many that existed in the recent past. However, since the relative abundance of forest types at GRPO appears to be significantly outside its normal range of variation, based on the lack or very minimal amount of eastern white pine, tamarack, and northern white cedar, we rate its condition as of moderate concern, with a declining trend. This assessment is based on "historic condition" (Stoddard et al. 2006), and our level of confidence in this ranking is good.

Reviews of the boreal biome (Bonan and Shugart 1989, Johnson 1992), and for the SBF in particular, have concluded that several successional pathways are possible. This is true even for a single set of environmental conditions and from the same starting point (Bergeron and Dubuc 1989, Drake et al. 2011). Though a strong majority of the tree species that are part of the entire sere (which often spans 300+ years) are present within the first 50 years (Bergeron and Dubuc 1989), the successional sequence can proceed one of several ways. On mesic sites, and on some dry-mesic (Jack pine – aspen pioneer forest type) sites, succession will slowly move toward a mix of northern white cedar and boreal conifers. This takes hundreds of years, and often the process is interrupted by one or more severe disturbances (wind, insects, or fire) (Heinselman 1981, Bonan and Shugart 1989, Frelich 2002, White and Host 2003).

The suggestion by Drake et al. (2011) that aspen would be more common than paper birch in the intermediate stage on mesic sites is debatable. Other studies in nearby areas document that moderate severity disturbances occur frequently in the SBF (Frelich and Reich 1995, Kneeshaw and Bergeron 1998). These events create large canopy gaps and allow species such as paper birch (Frelich and Reich 1995), and under specific conditions, aspen and white pine, to persist in the community for a much longer time. Paper birch is not simply a pioneer species in this system; it is commonly a part of one or more intermediate stages (Heinselman 1973, Frelich and Reich 1995, Frelich 2002). These disturbances also release understory and midstory stems, most commonly balsam fir, and increase recruitment of those species to the canopy (Kneeshaw and Bergeron 1998). The inventories and species lists compiled by Hop et al. (2010) noted that paper birch is commonly found in the sub-canopy. The assessment by Friedman et al. (2001–see 'Conditions and Trends') supports a leading role for paper birch. It appears that subtle site differences, proximity of seed source, and recent disturbance history determine whether quaking aspen or paper birch is more common.

The most xeric sites at GRPO capable of supporting a tree component often have Jack pine as the dominant species; aspen can be a co-dominant if the soil is deeper or more moisture is available. Balsam fir is usually able to invade these sites when partial shade is established. If the site is not exceptionally harsh, Drake et al. (2011) hypothesized that the Jack pine/balsam fir type will form a relatively stable, late-successional community. The successional process proceeds much more slowly on these sites (Bergeron and Dubuc 1989, Drake et al. 2011); thus, it is more difficult to determine how the latter portion of the sere(s) might play out.

The precise mix of species at a particular point on the landscape is constrained by the site conditions, but only to a modest degree. As noted earlier, the recent disturbance events will play a strong role – and these are variable over time and across the landscape. The magnitude of forest floor disturbance (e.g., fire vs. wind or insects) is of equal importance to the extent of canopy destruction (Nguyen-Xuan et al. 2000). The general pattern is for more true pioneer species (all life forms) to establish as the extent of forest floor removal increases (Nguyen-Xuan et al. 2000). More variability in the assemblages that occur and the successional pathway followed is created by proximity of seed sources, differences in dispersal capacity among species, fire tolerance, shade tolerance, and longevity (Bergeron and Dubuc 1989, Bonan and Shugart 1989, Asselin et al. 2001). Many of these regeneration processes interact with short-term weather patterns. The net sum of all these influences is modest-to-large differences in relative abundance, and to some extent composition, among sites that share similar soils. This is the basis for viewing 'reference condition' as ***a range*** of conditions.

Several of the reports mentioned above provide species lists of the herbaceous layer (Sanders 2008, Hop et al. 2010) or a list of abundances by time period (MacLean and Gucciardo 2005). Two of these have serious limitations due to very limited sample size (MacLean and Gucciardo 2005, Hop et al. 2010). The Sanders (2008) report is potentially very useful in that it provides measures of frequency at four spatial scales (quadrat, transect, plot, monument) and thus a measure of the variation in species occurrence. These data could be further used to document richness and diversity at the spatial scales and to derive or refine classification efforts. The most important limitation of this data set is that presumably all plots were placed in the 'white spruce balsam fir-paper birch' community type.

<u>Condition and Trends</u>
White and Host (2003) concluded that the majority of forests at GRPO should be, based on GLO data, multi-aged, mature, and conifer-dominated. Their assessment of GLO data versus current conditions led to the conclusions that there is more young forest dominated by broadleaved species today than in the mid-to-late 1800s, and that eastern white pine, white cedar, balsam fir, white spruce, and perhaps tamarack are underrepresented.

An assessment by Friedman et al. (2001) of the 'North Shore Highlands' physiographic province, also based on GLO records, concluded that paper birch, balsam fir, and spruce (without distinction between white and black spruce) were the three most abundant taxa in this region; each contributed 18-19.3% of the witness trees noted at section corners. The next three most abundant species were white pine, white cedar, and tamarack, contributing 10.9%, 10.0%, and 9.1 %, respectively. This is a landscape level perspective but should match the GRPO area reasonably well.

A compilation of data from three sources representing two time periods supports the suggestions of Friedman et al. (2001). For white spruce, tamarack, aspen, and white pine, all three assessments concur. However, my assessment (Table 13) and that of Friedman et al. (2001) differ from White and Host (2003) for paper birch and balsam fir. Birch has maintained its relative abundance (on the landscape) or declined (at GRPO) over the past ~ 150 years, whereas balsam fir is equally abundant (on the landscape) or more numerous (at GRPO) now than in the recent past.

White and Host (2003) concluded that a major shift from aspen and birch to balsam fir is occurring in much of GRPO; Sanders (2008) indicates that it has already occurred; this represents a major change in balsam fir density since the early 1900s.

Tree Regeneration
A number of plant species are currently much less common at GRPO than they were in pre-European settlement times. This may be due largely, or in part, to one or more reproductive barriers (Cornett et al. 1998). Consequently, the reproductive capacity and requirements, up to establishment of seedling-size individuals, are reviewed for eastern white pine, eastern hemlock, yellow birch, northern white cedar, and tamarack.

Eastern white pine
Seed Production and Dispersal: The species can start to produce flowers as young as age five if the tree is open-grown. The species is monoecious; however, for the first few years, only female flowers may be produced. Under more typical forest conditions, flower production will start between the ages of 20-30 years. Flowering occurs between May and June in the northern part of its range (Wendel and Smith 1990). Unlike most angiosperms, the reproductive cycle in the pines lasts two growing seasons or 16 months from pollination to seed maturation (Wendel and Smith 1990). A population of white pine will typically have average-to-above-average seed crops every 3-5 years. The seeds mature in early fall and are dispersed through late fall. Dispersal distances

Table 13. Relative abundance of tree species in the North Shore Highlands province (mid-1800s and 1990) and in permanent plots at Grand Portage National Monument in 2007. The GLKN calculation was based on density to make it as comparable to the others as possible. Numbers in bold indicate large changes among time periods.

Tree Species	% Abundance by Time Period		
	Mid-1800s (GLO records)	1990 (FIA data)*	2007 (GLKN data)
Ash	1.3%	5.5%	2.4%
Elm	0.2%	0.2%	<0.1%
Aspen	5.6%	**20.7%**	**19.2%**
Balsam Poplar	0.3%	3.7%	<0.1%
Paper Birch	18.7%	20.1%	**9.0%**
Red Maple	0.1%	2.1%	0.3%
Sugar Maple	2.2%	**9.3%**	**<0.1%**
Basswood	0.5%	0.9%	0%
Yellow Birch	3.1%	**1.5%**	**0%**
Red Oak	0.1%	0.2%	0%
White Pine	10.1%	**1.1%**	**1.1%**
Red Pine	0.6%	1.0%	0%
Jack Pine	0.6%	0.3%	0%
White Spruce	11.5%	**3.5**%	**5.1%**
Balsam Fir	15.0%	15.2%	**60.4%**
Black Spruce	5.9%	4.5%	**0.8**%
Tamarack	11.6%	**1.3%**	**0%**
Northern White Cedar	9.6%	8.6%	**1.2**%

*data taken from the Minnesota North Shore subsection forest resource management plan

of white pines are relatively high; the seed can travel up to 60 m within an intact forest and up to 210 m if the seed tree is in the open. Though wind is clearly the most important dispersal mode, it is not rare to find animals involved in this important process. Squirrels, mice, and voles all cache white pine seeds. When these caches are not used, they can be a ready source of new germinants (Abbott and Quink 1970). However, these seed predators can also significantly reduce white pine regeneration (Cornett et al. 1998). Stratification is required for seed germination, and the requirement is easily met over the winter; consequently, there is very limited germination during the second growing season and none thereafter.

Germination and Establishment: The substrates most suitable to successful germination are moist mineral soil, moss mats, or areas with low-to-intermediate short grass cover (Carey 1993a, Dovciak et al. 2003). Cornett et al. (1998) determined that reduction of the understory (competition) increased the early survival of white pine. In areas of moderate to heavy shade, germination is likely to be successful in pine litter, on lichen, or patches of very thin or thick short-grass cover (Carey 1993a). In Minnesota, seedling density was positively influenced by increasing amounts of overstory basal area in mixed species forests (Dovciak et al. 2003). The physiology and tolerances of the species allow it to effectively colonize disturbed areas. Seedlings are likely to successfully establish under partial shade of aspen, birch, or other pioneer species and need at least 20% full sunlight for longer term (in the range of 3-10 year) survival (Wendel and Smith 1990). For seeds that land in an area with a ground layer, the vegetation has contrasting effects on the seed and the seedling. The layer, by providing cover, usually results in increased rates of seed predation and seedling herbivory by small rodents. In contrast, there is a higher rate of seedling emergence (after accounting for higher losses to predation) and survival.

Site Conditions: Eastern white pine is not an exacting species and is found across the full soil moisture spectrum and on almost every soil type. In the northern part of the Lake States, white pine is usually found on soils derived from basalt, gabbro, diabase, or granite (Wendel and Smith 1990). It is also found in all successional stages. However, within a region, the sites and stages are generally a subset of this characterization for the species as a whole. Northeastern Minnesota is close to the northwestern limit (natural range) of the species, so it can establish in thinner and more coarse-textured soil and in topographic positions that receive more solar radiation. In the southern boreal forest, the species can succeed aspen, but is often replaced by balsam fir, white spruce, and paper birch if the disturbance regime does not match its requirements and control some competitors.

Eastern hemlock (Tsuga canadensis)
Seed Production and Dispersal: Hemlock, another monoecious tree, will start to flower and produce seed at approximately 20-30 years if it is in a dominant canopy condition. Seed production will be delayed approximately 20 years if the tree is partially shaded (i.e., shorter than the upper canopy layer). Due to the great longevity of the species, seed production can continue past age 450 (Godman and Lancaster 1990). Pollen production begins shortly after the new leaves start to form, and fertilization occurs about six weeks later. The cones are fully mature by late August to early September. The peak of seed dissemination is October, but the process continues through the winter. Rarely will initial seed dispersal carry the seed more than one tree height from the parent. At northern latitudes, seed may exhibit secondary dispersal across a snow crust (Mladenoff and Stearns 1993). No caching of seed by rodents has been reported. Godman and Lancaster (1990) rated hemlock as one of the most frequent seed producers, and abundant crops occur every three years of a five-year cycle (Carey 1993b). However, the species has a low viability rate, often less than 25%, so the abundance of viable seed is low in many years (Mladenoff and Stearns 1993). There has not been any report of delayed emergence for eastern hemlock; this may reflect the fact that the seed has only ‘partial dormancy’, and this inhibition can be broken by light. Nonetheless, seed germination is enhanced by cold stratification.

Germination and Establishment: Pollen, seeds, and seedlings of hemlock are especially susceptible to desiccation. The species will germinate on a variety of substrates, but adequate, consistent, but not excessive moisture is critical. Germination will occur between 7-18°C but is best at 15^{o}C. It takes the seed of hemlock 45-60 days to germinate once temperatures are above the minimum, and hence the new seedlings of this species emerge much later than those of most co-occurring species such as white cedar (Erdmann and Godman 1987). Successful regeneration has occurred on well-rotted wood, mineral soil, mineral soil mixed with humus, well decomposed litter, moss, and tip-up mounds (Godman and Lancaster 1990, Carey 1993b). It will rarely be successful in fresh or only minimally decomposed litter (Mladenoff and Stearns 1993). The emerging seedling easily dries out in its first year due to very limited root growth and is so small that it can be buried by annual litter fall (Mladenoff and Stearns 1993). This also explains its lack of success in recent, severely disturbed areas. However, mineral soil exposed by low intensity surface fires can be a suitable seedbed if overhead shade is present (Mladenoff and Stearns 1993). Carey (1993b) stated that the species cannot tolerate full sun until the seedlings are 1-1.5 m tall. The species is highly shade-tolerant, and thus seedlings can survive at 5% full sunlight, but regeneration is most abundant when there is at least a partial canopy and hemlock dominates (Carey 1993b, Rooney et al. 2000).

Site Conditions: The abiotic conditions of the sites on which hemlock thrives can vary by soil type and topographic position, but consistent moisture and good drainage are required (Carey 1993b). In the northern part of its range, it is more likely to be on sites that are a little drier or have thinner soils (Rogers 1978), but the species also occurs at the margin of swamps. The soils are almost always acid to very acid, but a few are near neutral. In the Lake States region, the species grows on sandy loams, loamy sands, and silt loams, often with coarse rocky material in the upper profile (Godman and Lancaster 1990).

Yellow birch (Betula alleghaniensis)
Seed Production and Dispersal: Under forest conditions, yellow birch will start to produce notable amounts of seed at about age 40, though seeds have been produced by 7-year-old, open-grown saplings (Sullivan 1994). Average to above-average seed crops occur at 1 to 4 year intervals, and the intervening years yield very little seed. Based on a 26-year record from northeastern Wisconsin, 38% of the years the species had a good crop or bumper crop (Godman and Mattson 1976). Maximum seed production occurs at ages of 70-80. Seed viability is generally high, but it varies from year to year. Pistillate flowers appear in mid to late May, and the seeds develop by late July or August. The seed is very, very small, and more than 400,000 ha^{-1} can fall in a bumper crop. Dispersal by wind begins in earnest with the onset of cold weather in October but continues through the winter (Erdmann 1990), and some may disperse during the following spring (Tubbs 1969). The typical dispersal distance ranges from 2-4 times tree height, but this species also exhibits some secondary dispersal along a snow crust; dispersal via this means up to 400 m has been reported (Erdmann 1990). The seeds have internal (innate) dormancy and thus require cold, moist stratification; this is true because the inhibitor is water soluble.

Germination and Establishment: Germination is better on mineral soil than on litter, duff, or moss (Perala and Alm 1990) but is best on moist mineral soil enhanced with humus (Sullivan 1994). Other suitable substrates include moss-covered logs, well decayed wood, and the tops of tip-up mounds. Some shade improves seedling survival, and they can survive in full sunlight only if growing on mineral soil (Perala and Alm 1990). The mortality rate of very young seedlings is often quite high (up to 97%) (Sullivan 1994). The success of new germinants is higher in disturbed areas such as skid roads (Perala and Alm 1990). Seedlings fare better in areas with some overhead light, under conifers rather than broad-leaved species, and where the litter and mineral soil layers are lightly mixed.

Site Conditions: This species often co-occurs with hemlock in the Lake States. Although it does not have exacting soil requirements, it grows best on sites that are moist and well-drained. It can survive in poorly-drained micro-sites, though, and thus may become more common in stands with this condition (Tubbs 1969). Most typically it occurs on loams and sandy loams, though it has been found in muck soils. Yellow birch occurs on sites with the soil pH ranging from 4-8 (Sullivan 1994). Because of its shallow roots, it is a rather moisture-sensitive species, so it is more common on north-to-eastern slopes in hilly terrain (Erdmann 1990).

Northern white cedar
Seed Production and Dispersal: Northern white cedar may begin producing cones by age six, but it does not produce large quantities until age 30 or older, and maximum production is after age 75 (Carey 1993c). Good-to above-average seed crops occur at 2-5 year intervals, with fair crops between. Pollen is formed and dispersed from late April until early June, and the seeds/cones are mature by late August to mid-September. Seed dispersal begins at this time and is largely complete by November, though a few seeds will drop during the winter. The seed has two lateral wings and is disseminated by wind 40-60 m from the parent tree.

Germination and Establishment: The seed has minimal internal dormancy which is broken while the seeds are on the ground during the winter; hence, there does not appear to be any delayed germination in this species (Johnston 1990a). The species requires warmer temperatures than the other species discussed, with highest germination rates near 29°C. Therefore, some seed may not germinate until July or early August. Northern white cedar will germinate on a wide variety of moist substrates, but seedling establishment is more exacting (Johnston 1990a). This is due, in part, to its very slow growth rate; seedlings rarely attain a height greater than 7.5 cm the first year (Johnston 1990a). There must be constant moisture and warm temperatures; accordingly, in undisturbed forests, well-decayed wood and stumps accounted for >70% of extant seedlings (Johnston 1990a). Disturbed areas can also represent suitable conditions for seedling establishment. These include mineral soils exposed in burned areas and moss mats in skid trails. In a controlled environment study, limited moisture restricted percent emergence on all substrates to <20%; at moderate moisture levels, birch litter and cedar litter supported the highest and lowest emergence rates, approximately 62% and 9%, respectively (Cornett et al. 2000). First year survival was high and not different on all substrates at moderate and high moisture levels; however, at low moisture, birch litter, cedar litter, and mineral soil had significantly greater survival than logs of either species (Cornett et al. 2000).

Site Conditions: Northern white cedar grows on both upland and lowland sites; across its range it is found on a surprising range of sites (Johnston 1990a), given its association with swamps (rich fens) in the Lake States region. It can grow on both organic and mineral soils and grows best on limestone-derived, nearly-neutral, well-drained soils. Most cedar-dominated forests are found in swamps and floodplains where there is a consistent flow of mineral-rich water. These sites typically have a moderately high amount of well-decomposed organic peat (up to 1.8 m deep) (Carey 1993c). In the northern part of its range, this species becomes more of a late-succession, upland species and thus is largely confined to typical upland soil types such as calcareous clays. If the soil is nutrient poor, northern white cedar may be restricted to seepage areas. Despite the important role of moisture in its establishment, it is found on sandstone bluffs, trap rock outcrops, and limestone cliffs (Johnston 1990a).

Tamarack (Eastern larch) (Larix laricina)

Seed Production and Dispersal: Cone production begins at approximately 12-15 years of age for open-grown trees and at 35-40 years under forest conditions (Johnston 1990b, Uchytil 1991). Maximum production occurs around age 75. The less competition a tree is experiencing, the more cones it will produce, and a single vigorous tree can produce up to 20,000 cones. Average or better seed crops occur every 3-6 years, with some seed produced in the intervening years. A healthy forest can produce 1,200,000-3,000,000 seeds ha^{-1} (Johnston 1990b). The species is monoecious and bears its cones at the same time as needles emerge in the spring (typically late April to mid-May in the Lake States).

Seed dispersal occurs in the fall in a concentrated time period; in a Minnesota study 98% of the seed fell between September 1 and October 31. The few that may remain can disperse over an extended period (Uchytil 1991). Wind is the primary dispersal mode, though red squirrels may distribute a few. The maximum dispersal distance is usually two times the tree height. Seed viability ranges from 30-60%.

Very significant proportions of the seed crop are often lost to predation. In Minnesota, small mammals consumed one-half of the crop. In a New Brunswick study, insects destroyed 25-88% of the seed produced (Johnston 1990b, Uchytil 1991).

Germination and Establishment: Germination is not influenced by radiation or the pH of the substrate, but it is by temperature; it peaks at 18-21°C (Johnston 1990b). Moist mineral soil, organic soil, and sphagnum moss are the better seedbeds; the latter is especially important in open, swampy habitats. Though tamarack often occurs on sites that are saturated part of the year, the young seedlings cannot endure more than 1-3 weeks of partial submersion. They also cannot live more than 2-3 years under shade. Under optimal light and moisture conditions, the seedlings reach a height of 18-23 cm in one year. The primary agents of mortality for young tamarack are damping-off fungi, drought, and submersion (Johnston 1990b).

Site Conditions: The species is most commonly found on cold, wet to moist, poorly drained sites, including swamps, bogs, and stream and lake margins. It can tolerate a wide range of soil conditions, but is most common on moist organic soil, especially nutrient poor, acid peatlands. It does well on well-decomposed woody peat (Johnston 1990b). In Minnesota, tamarack grows on a wide variety of organic soils and is generally an indicator of weakly minerotrophic sites (pH 4.3-5.8). Despite its association with wet sites, the species grows best on well-drained, loamy soils along lakes, streams, and seeps.

Sources of Expertise

White and Host (2003), Sanders (2008), Drake et al. (2011), James Cook.

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4.2.2 Climate Change and the Southern Boreal Forest

Projected Impacts on Plants

Plants and plant communities may be affected by climate change in myriad ways that involve a large number of interacting conditions and biotic interactions, as constrained by the local site conditions and genetic variation of each species. These effects will include very basic, cellular level processes; whole plant processes; interactions between plants (e.g., competition), between plants and their mutualists, and between plants, insects, and pathogens. Climate change often alters the frequency and severity of disturbances and community-wide processes and characteristics. In the earlier stages of carbon dioxide (CO_2)-induced warming, the photosynthetic rate and water use efficiency is expected to increase, and thus plant growth may increase (Aber et al. 2001). This will probably not be a universal response; species near the southern end of their range and those closely adapted to mesic site conditions will most likely be stressed by the increased temperatures (Davis et al. 2000). In all likelihood the increase in productivity will be short-lived as temperatures continue to rise and drought becomes more common or severe (Dale et al. 2001).

Another well-established response to climate change is phenology. An increase in temperature over the past 100 years (primarily 1910-1945 and 1976 to date) has altered the timing of important life history stages of many species (reviewed in Walther et al. 2002). For example, a broad-scale assessment of initiation of spring growth in North America found that it has occurred 1.2-2.0 days earlier per decade for the past 35-63 years (Walther et al. 2002). Following warm, wet winters, nine of 13 European species bloomed earlier by 13-26 days, and one-third bloomed 13-19 days longer (Post and Stenseth 1999); however, woody plants were less sensitive than herbaceous species to climatic variability. A greater impact on spring stages of life history has been noted as opposed to late summer or fall (Walther et al. 2002). Shifts of this magnitude, which will probably continue through the 21st century, could profoundly affect other taxa that key in on a particular stage of the life cycle of plants. Obvious examples include nectar-gathering insects and folivores that feed on new leaves and shoots. These are examples of cascading, or indirect, effects of climate change. Physiologic and phenologic adjustments will continue until climate change exceeds the tolerance of the species and its capacity to adapt (Davis et al. 2005). Alternatively, the species may migrate to an area with a more favorable climate (Davis et al. 2005).

At the community scale, it is highly probable that at least a few community types as we currently know them will 'disassemble' and reform in different combinations, or into a similar and recognizable community. Others will disappear from the landscape, and species that currently do not commonly associate will do so in the future (Hansen et al. 2001, Williams et al. 2007). This will result in communities that are novel (*sensu* Williams et al. 2007), without a current or prior analog. It is highly unlikely that communities will migrate as a unit because of differences among species (in reality, populations) in genotypic variation, generation time, dispersal mode and capacity, phenotypic plasticity, and subtle differences in physiologic tolerances. Imposed on top of this may be impacts of novel insect and fungal pests and differences among species in the need for mutualists. This multitude of drivers makes prediction difficult and, thus, there will be groups of species occurring together that are unanticipated. Management efforts will then be dealing with novel entities or assemblages with unknown levels of temporal stability.

Predicted responses for common tree species (below) highlight the probable magnitude of the impact, as well as what is likely to happen for some other life forms and species. However, it would be dangerous to extrapolate from one or a few species in an assemblage to all of the species; the dendro-chronologic and pollen records clearly show that co-occurring species can respond in very different ways to decade- and century-long climatic change (Villalba et al. 1994, Villalba and Veblen 1998, Black and Abrams 2005).

Two key components to the response by a species (or population) are how quickly it can adapt, if at all, and how rapidly it can disperse or migrate (Davis et al. 2005, McKenney et al. 2007). The capacity to adapt increases with greater population-level genetic variation and effective population size, a mating system that is partially or entirely out-crossing but does not rely on a specialized pollinator, and a larger range size. It is anticipated that adaptation will vary tremendously among life forms and significantly among species within a life form (Dale et al. 2001, Davis et al. 2005). Herbaceous species should adapt more quickly than trees and insects more quickly than most plants; this is primarily a function of life cycle length. However, annual plants and short-lived species are more sensitive than longer-lived species to temperature fluctuation (Morris et al. 2008).

The second component is migration. Based on the pollen record, we know that species, even within a life form, migrate at very different rates (e.g., Graumlich and Davis 1993) at the scale of millennia. The primary question is whether a species will be able to disperse rapidly enough to match the rates of change in temperature and precipitation regimes (Williams et al. 2007).

Hansen et al. (2001) predicted the impacts of climate change on forest types and major tree species in the conterminous U.S.. The future distribution of trees and forest types was based on changes in hydrology, light, nutrients, and plant response to increased CO_2. Predictions that might apply to GRPO include that suitable habitat for both spruce-fir and aspen-birch forests will decrease by >90%; species now at GRPO that would lose 90% of their range within the U.S. include quaking aspen, northern white cedar, balsam fir, and paper birch. These are continent-wide predictions, and they should not be applied directly to GRPO because the moderating effects of Lake Superior (Davis et al. 2000) are not accounted for. Currie (2001) predicted the long-term change in richness (number of species within a community) of trees under a scenario of doubling of CO_2 and found that short-term changes are likely to be negative, but tree richness will increase in cooler climates and mountainous areas.

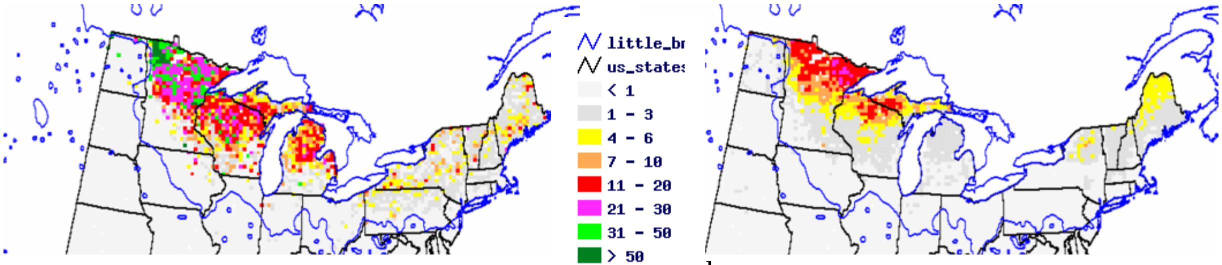
A more recent and ongoing assessment of tree response provides the most reliable estimates to-date (McKenney et al. 2007, Prasad et al. 2007 and ongoing). These authors examined the predicted range response of 134 tree species in the conterminous U.S. using the concept of climate envelope. The assumption behind this is simply that the climatic boundaries of a species today probably indicate the conditions it can endure in the future.

Using this approach (which ignores many possible interactions that may manifest and influence where a species thrives in the future), McKenney et al. (2007) determined that within the conterminous U.S., 72 species would show a decrease in the size of their range. Many of the more northerly distributed species will increase dramatically in Canada (and this is the general expectation for the boreal forest type in the U.S.). The authors ranked species based on the magnitudes of the reduction in the size of the climate envelope assuming no dispersal and the northward shift in the latitude of the climate envelope. No GRPO species were in the top 20% of the first category, and only two somewhat common species (eastern white pine and mountain maple) were in the top 20% of the second (range shift). The extent of the northern range shift varies depending on which GCM model is used and the migration rate of a species. For example, eastern white pine could have its range move northward as little as 3.4 degrees of latitude or as much as 8.2 degrees.

Probably the most accurate predictions are contained in the recently updated 'tree atlas and predicted range shifts' provided by Prasad et al. (www.nrs.fs.fed.us/atlas). This tool provides comparisons based on 3 GCMs and two emissions scenarios.

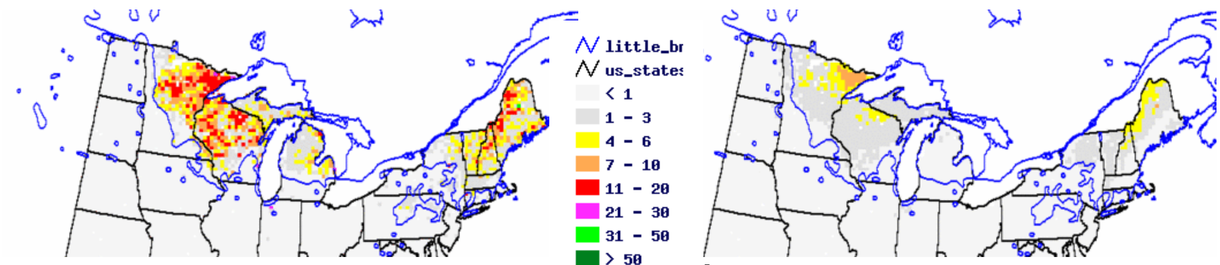
For Figure 20 to Figure 23, the importance value (IV) for each tree species was calculated using the formula

$$IV(x) = 50*BA(x) / BA(\text{all species}) + 50*NS(x) / NS(\text{all species})$$



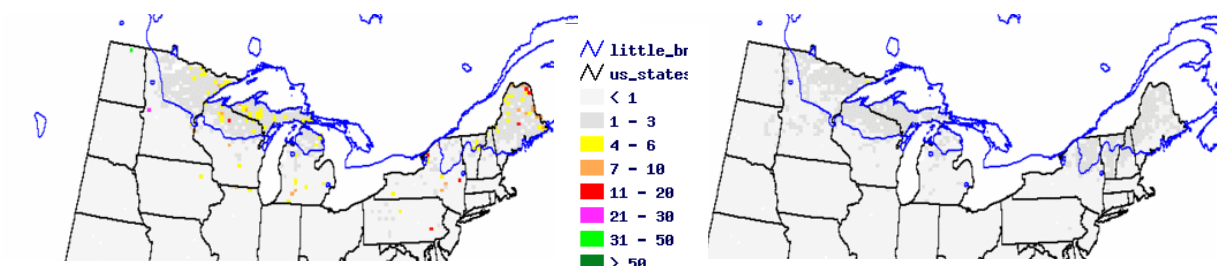
a. b.

Figure 20. Importance value of quaking aspen under a) the current Forest Inventory Analysis (FIA) and b) the Hadley low emission climate change scenario (from Prasad et al. 2007).



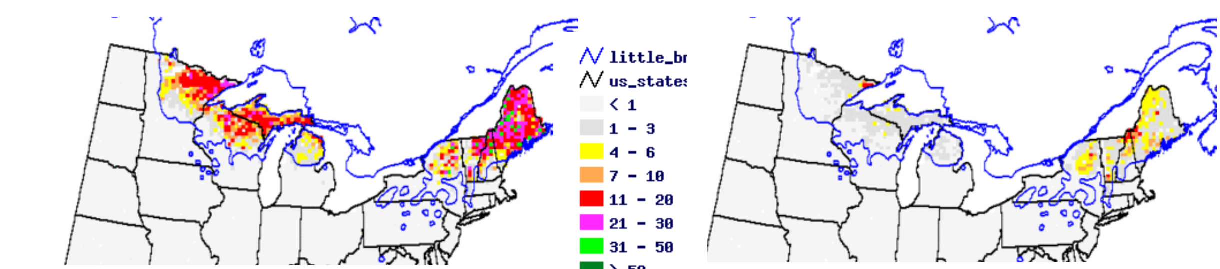
a. b.

Figure 21. Importance value of paper birch under a) the current FIA and b) the Hadley low emission climate change scenario (from Prasad et al. 2007).



a. b.

Figure 22. Importance value of white spruce under a) the current FIA and b) the Hadley low emission climate change scenario (from Prasad et al. 2007).



a. b.

Figure 23. Importance value of balsam fir under a) the current FIA and b) the Hadley low emission climate change scenario (from Prasad et al. 2007).

where x is a particular species on a plot, BA is basal area, and NS is number of stems (summed for overstory and understory trees). In monotypic stands, the IV would reach the maximum of 100. The figures also display Little's ranges, which are based on a series of maps of tree species ranges published from 1971-1977 based on botanical lists, forest surveys, field notes, and herbarium specimens (republished by Prasad and Iverson 2003).

Using the Hadley model and a low emission scenario, the predictions for the dominant species at GRPO varied tremendously. Quaking aspen (Figure 20) shows very limited range contraction in Minnesota. Paper birch (Figure 21) and white spruce (Figure 22) maintain their presence over approximately the same area as currently, but their importance values go down substantially. Balsam fir (Figure 23) exhibits a very large loss of range and in the Midwest will persist only in far northeastern Minnesota. The spatial scale of the data fed into these predictions is too coarse to use them as predictions for specific forests at GRPO. However, they probably provide a reasonably clear indication of the relative magnitude of impact that will occur over the next 50 years.

The projected changes in climate, particularly temperature, may also lead to new tree species migrating in a north-northeasterly direction and arriving at GRPO and the surrounding landscape. Those most likely to make this range shift are associated with the Northern and Central Hardwood Forest Group. Using the tree atlas site referenced above, the projected shift of all tree species in these two broad groups was examined. A list was generated for all species for which the projection had an "intermediate" or "high" level of reliability and showed a substantial gain for the average of the three "low carbon" scenarios. This group was qualitatively divided into 'modest' and 'large' sub-groups based on the magnitude of the projected increase in Importance Value (Table 14). These should not be viewed as actual predictions of which novel species will arrive at GRPO due to the coarse-scale nature of the predictions. However, they provide an index of how much the tree composition could change, and alert managers to some of the species they may be working with later in the 21st century.

Table 14. Tree species that may show modest or large increases at GRPO under "low-carbon" climate change scenarios.

Modest Projected Increases		Large Projected Increases	
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
slippery elm	*Ulmus rubra*	eastern red cedar	*Juniperus virginiana*
American elm	*Ulmus americana*	hackberry	*Celtis occidentalis*
shagbark hickory	*Carya ovata*	black walnut	*Juglans nigra*
American basswood	*Tilia americana*	black cherry	*Prunus serotina*
boxelder	*Acer negundo*	white oak	*Quercus alba*
red maple	*Acer rubrum*	bur oak	*Quercus macrocarpa*
silver maple	*Acer saccharinum*	northern red oak	*Quercus rubra*
eastern hophornbeam	*Ostrya virginiana*		
black oak	*Quercus velutina*		

Winter soil temperatures decreased as air temperatures warmed from 1951-2000 in the Great Lakes region (Isard et al. 2007). This is probably a function of warmer winter air temperatures leading to less and more variable snow pack, and is another example of the interactions that will manifest in the future. A decrease in soil temperature would work to delay the onset of plant growth in the spring and thus minimize some of the phenologic changes noted earlier. In turn, this could mean a shorter growing season, which could offset the increased productivity related to higher CO_2. Conversely, a decrease in ice cover on Lake Superior could lead to more lake-effect snow (Davis et al. 2000), which could result in warmer wintertime soil temperatures (Isard and Schaetzl 1995, Isard et al. 2007).

Projected Impacts on Animal Communities

The richness of birds and mammals is tied closely to temperature but only weakly to precipitation (Hansen et al. 2001), and thus in North America the greatest levels of vertebrate richness is in moderately warm areas. Therefore, if animals can disperse to northeastern Minnesota, the richness of these two groups may increase by a magnitude similar to the prediction (11-100%) for the upper montane areas of the U.S. (Currie 2001). It should be noted that these predictions are based solely on temperature and precipitation by season, and thus do not account for all of the indirect influences (see below for moose) that could come into play. Nonetheless, they establish a benchmark from which to plan.

As noted for plants, phenologic shifts have been noted for animals. Earlier arrival of migrant birds and butterflies and early nesting has been noted in many species (Walther et al. 2002). In addition, climate change may not affect all currently linked processes at the same rate, leading to asynchrony between the time of flowering and pollinator activity, or the arrival of migratory birds and the availability of their prey (Kling et al. 2003).

Post and Stenseth (1999) examined long-term trends in fecundity, body mass, and population size of 16 populations of six ungulate species and related these characteristics to the North Atlantic Oscillation (NAO). The NAO is a large-scale alternation in atmospheric pressure between Iceland and the Azores, and has direct and strong impacts on climatic variation and temperature over the span of years and decades. Hence, it functions similarly to the El Nino Southern Oscillation in the Pacific. Some important demographic responses (body mass, fecundity) varied between mainland and maritime populations. Moose density on ISRO declined two years after warm, wet winters, and moose populations in Scandinavia exhibited significant changes in calf, yearling, and adult female mass with changes in winter characteristics. The population in Norway, which inhabits an area with a more maritime climate, had heavier yearling moose following a warmer-than-average winter. Though these two outcomes work in opposite directions, the prevailing indication is that warmer winters lead to reduced moose density.

LaSorte and Thompson (2007) estimated the poleward movement of 254 winter avifauna of North America from 1975 to 2004. The center of occurrence shifted 0.45 km yr^{-1}, and the northern boundary changed 1.48 km yr^{-1}. Thus, many bird species would likely disappear from GRPO, but other more southern species might increase.

Similar to the tree atlas referenced above, a bird atlas has been prepared to predict the effect of various climate change scenarios on bird populations in the eastern U.S. (http://www.nrs.fs.fed.us/atlas/bird/bird_atlas.html) (Matthews et al. 2007). However, a recent publication by these authors (Matthews et al. 2011) led us not to attempt a similar analysis for GRPO birds. The authors' model did predict a 10%+ increase in habitat for 61-79 species and a decrease of similar magnitude for 38-52 species. However, they concluded that refugia are likely to persist for many species predicted to decline (because the birds are rarely tied to a single tree species) and that fine-scale research is needed to understand how climate change may affect the needs of a specific species.

Overall Impacts at GRPO

An analysis performed by Davis et al. (2000) for six western Great Lakes parks (but not GRPO) noted that they are "important reservoirs of biologic diversity in a landscape that has been altered by logging, mineral extraction, agriculture, and urbanization." The accumulated pollen record over the Holocene suggests that proximity to Lake Superior may buffer the regional level effects of temperature changes, at least temporarily. This could result in several refugia, possibly including GRPO, for plants and animals that cannot survive farther inland. However, that same location may jeopardize plants and animals because it is more subject to precipitation extremes than inland sites (Davis et al. 2000).

Given current climate change scenarios, biologically significant changes will likely occur in plant species ranges, species abundance, community composition, and many ecosystem properties. Novel assemblages may form, creating many challenges because we will not know the outcome of interactions like competition, nor will we know the successional pathways some communities will take. Species' capacity for, and method of, dispersal will play a key role. Under current climate change projections, it is almost certain that some species that are at or near the southern limit of their range will disappear. Concurrently, an unknown (probably smaller) number of novel plant species but more insects will expand northward and appear at GRPO. Species that are scattered and uncommon (not limited to threatened or endangered species), that have limited genetic variation, or rely on specialized pollinators will be more vulnerable to local extinction. It is likely that mammalian richness will decrease, but avian richness will not. It is unknown how important groups like amphibians and fungi will respond, but clearly there will be important ecologic alterations as the climatic regime changes.

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4.2.3 Moose

Description

Moose (Figure 24) are the largest herbivores in the boreal forest. A moose eats about three metric tons of leaves and twigs each year (Dybas 2009). Moose in turn are important prey for carnivores like wolves. Moose are at the center of Ojibwe culture, according to Norman Deschampe, chairman of the Grand Portage Band (Dybas 2009).

Figure 24. Moose. Photo taken by M. Riederer in Cook County, Minnesota and posted to the website Moose in Minnesota: Investigating moose populations in northern Minnesota (http://www.nrri.umn.edu/moose/).

The 2003 General Management Plan for GRPO stated that moose “appear to be plentiful” in the context of serving as a food source for the gray wolf (NPS 2003). However, moose populations on the Grand Portage Reservation declined about two percent annually from 1990-2007 and about 64 percent since 2005 (Dybas 2009).

Minnesota moose are considered to be at "the very southern edge of the North American range for their subspecies" (MDNR 2011), and a warming climate has been suspected as a factor in their decline. However, in the 2000s, moose in North Dakota were noted to be moving west and south into areas that were not only traditionally considered too warm for moose, but also consisted of agricultural fields and prairie not previously considered prime moose habitat (http://www.nrri.umn.edu/moose/information/NDmoose.html). Thus, all the factors relative to moose success or decline in northeastern Minnesota may not yet be understood.

Data and Methods

Lenarz et al. (2009, 2010, 2011) conducted moose population modeling research through radiocollaring and aerial surveys, mainly in the Superior National Forest of northeast Minnesota. The annual home range of moose averaged 32.8 km^2, with a range of 9-88 km^2 (Lenarz et al. 2011). Brown (2011) examined moose population trends in Ontario.

The MDNR (2011) has completed a Minnesota Moose Research and Management Plan that focuses on the northeastern Minnesota moose population and discusses harvest, predation, research projects and needs, moose-deer relationships, habitat management, and social dimensions of moose management.

Reference Condition

Two appropriate reference conditions for the moose population at GRPO are survival rate and stochastic growth rate. Studies summarized by Lenarz et al. (2010) from Alaska and Canada "without exception" estimated annual adult moose non-hunting mortality at 8-12%. A stable moose population has a long-term stochastic growth rate of at least 1. These reference conditions are "minimally disturbed conditions" or "the condition…in the absence of significant human disturbance" (Stoddard et al. 2006).

Condition and Trend

Several sources indicate that the moose population in northeastern Minnesota is in decline. Lenarz et al. (2010) modeled a long-term stochastic growth rate of 0.85, based on annual age-specific matrices, and a mean annual mortality rate of 21%. Additional modeling showed that annual finite rates of increase for the moose population varied from 0.67-0.98 from 2002-2008. The authors noted that such a decline was not observed in concurrent aerial surveys, but that a change of 20% may be needed to detect a statistically significant change in population size by aerial survey. Therefore, the condition of moose at GRPO is rated as of moderate concern, with a declining trend. Since the study was conducted in the Superior National Forest south and west of GRPO, the degree of confidence is rated fair.

In the study conducted mostly in the Superior National Forest (Lenarz et al. 2009), the fate of the moose three to six years after capture was that 85 (73%) had died; five assumed from capture mortality, 15 by hunting, two by poaching, eight in vehicle collisions, five by wolf predation, one of bacterial meningitis, and 49 of unknown causes. Contact was lost with another three animals.

Studies that have examined moose mortality factors have consistently found temperature to be important. However, since temperature effects may be either cumulative or immediate, the outcome of a warmer or colder year or season is not obvious and not necessarily consistent. Previous research indicated that temperatures greater than 15°C in the summer or -7°C in the winter can cause stress (Dybas 2009). Models applied to the observed nonanthropogenic mortality in northeastern Minnesota showed that seasonal and annual moose survival was negatively correlated with the frequency and magnitude by which temperatures exceeded an upper heat stress threshold (Lenarz et al. 2009, 2010, Brown 2011).

Lenarz et al. (2009) found that the temperature range in January explained 78% of the variability in survival the following spring and fall. Above-average temperatures in late spring also appeared to be important in explaining declines in moose short-term survival in fall. Murray et al. (2006, in Lenarz et al. 2009) noted that cumulative heat stress translated to body condition deterioration leading to general malnutrition, immunosuppression, and increased moose mortality in northwestern Minnesota. In contrast, Brown (2011) found that an index of heat stress was positively related to moose recruitment on the southern periphery of range in Ontario and suggested that cold climate effects were more limiting to moose. Herfindal et al. (2006) found warmer than average winter temperatures to be generally positive for moose because they increase access to food by reducing snow pack and reduce the energetic demand of body temperature regulation. However, a warm period in winter could have the immediate effect of forming a layer of ice on top of the snow and restricting access to the food supply.

A study by Herfindal et al. (2006) in Norway highlighted some of the ways in which temperature change from year to year affected plant development and thus affected moose body mass. The role of diet, which interacts with weather, was highlighted by a study in Alaska also. These authors concluded that percent nitrogen and digestible protein, which is affected by the concentration of tannin, had a pronounced effect on body mass and represented a nutritional constraint on moose (McArt et al. 2009). This constraint is greater the higher the proportion of woody browse in the diet. This group of studies indicates that the relationship between weather, moose health, and moose population density is complex. Brown (2011) suggested that the differences among studies could be due to the scale at which climate was measured, the precise level of heat stress indices (though still above critical temperatures), or differences in availability of or behavior regarding shelter. It needs to be recognized that a weather shift can have several effects, and each of these can have separate impacts on moose.

Competition from white-tailed deer (*Odocoileus virginianus*) has also been cited as a factor in moose population declines. Deer act as a reservoir for several parasites fatal to moose, such as meningeal worm (*Parelaphostrongylus tenuis*) and liver fluke (*Fascioloides magna*) (Murray et al. 2006). However, Lenarz et al. (2010) reported a declining population of approximately 4 deer km^{-2} within the study area, and suggested that deer were not a major stressor.

An appropriate population of moose at GRPO is unclear because data are poor for historic moose populations. Hoffman et al. (2006) stated that at the time of European settlement, moose occurred in northeastern Minnesota, and by the early 1900s their population was lower than in presettlement times. Because of concerns about the size of the population, Minnesota closed its moose hunting season in 1922 and did not reopen it until 1971. The MDNR, in a 2011 management plan, gave population size estimates only as far back as 1983 (Figure 25). A change

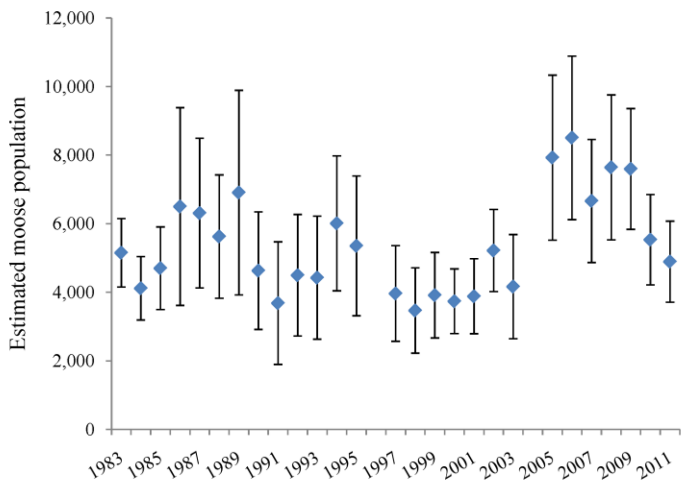

Figure 25. Estimated moose populations for northeastern Minnesota, 1983-2011 (from MDNR 2011).

Note: Beginning in 2004, the MDNR began using helicopters on the survey and corrected visibility bias using a "sightability model." Estimates prior to 2004 are not directly comparable with the new survey techniques.

in population monitoring method in 2004 creates further difficulty in comparing today's populations to those even in the recent past. However, based on several lines of evidence (high mortality among adult radiocollared moose, low recruitment rates of calves, and reports of declining moose observations and hunter success rates), MDNR (2011) indicates "a likely problem."

Based on research in Ontario, Brown (2011) suggested that in a predation-dominated system, moose density may stabilize at an equilibrium of approximately 0.2-0.4 moose km^{-2}. Brown's work also has management implications, as it suggested that the ratio of bulls to cows declines with increased road density (likely because of the relationship to hunting). It also found that the moose population growth rate was positively correlated to mixed deciduous habitat abundant in forage; however, an upper limit is placed on its value by the importance of conifers as shelter habitat for moose from both predators and severe winter weather.

A study by Ron Moen of the University of Minnesota – Duluth Natural Resources Research Institute is currently underway on the Reservation to determine habitats used and moose activity in response to weather events and throughout the course of the year (http://www.nrri.umn.edu/moose/research/grandportage.html).

Sources of Expertise
Lenarz et al. 2009, 2010; James Cook.

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4.2.4 Beaver

Description

GRPO is the earliest fur trade site in the NPS, and its fur trading history is "integrally related to Native Americans in the past and present" (NPS 2003). Beaver (*Castor canadensis*) are considered a "critical story element" in the long-range interpretive plan for GRPO because of their importance in the fur trade (NPS 2005). The presence of beaver at GRPO today is considered particularly important so that the visitor can interpret their intrinsic value and draw a contrast to the extrinsic value they had as a commodity in the historic period which GRPO preserves and interprets.

Beaver are the largest North American rodents and have the "ability to alter their physical environment more than any other animal" (Johnston and Naiman 1987). The dams erected by a colony temporarily create new shallow, flooded wetland habitat in and adjacent to the stream channel. One or more of these may represent novel habitats that do not occur in the absence of the ‘landscape engineering’ by beaver (Donkor 2007). These dams catch sediment (up to 6,500 m^3 per dam), moderate some floods, alter hydrology, and change channel morphology. In low-order streams such as those in GRPO, they allow large accumulations of detritus and nutrients and alter biogeochemical pathways such as denitrification by creating substantial shifts to anaerobic cycles (Naiman et al. 1986). After the dams are breached, rather extensive sedge meadow typically forms.

Smith and Peterson (1988) documented the ecologic significance of beaver-created ponds and swamps in GRPO, including the creation of habitats for mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), and otter (*Lontra canadensis*). Their literature review also documented benefits to water and land birds and large ungulates such as white-tailed deer and moose. Allen et al. (1987) convened moose experts at a habitat suitability index modeling workshop for the Lake Superior region and reported that wetlands with dense vegetative cover near the water’s edge or irregularly shaped wetlands provide high quality habitat for calving moose.

The effects directly or indirectly associated with dams are typically short lived (< 10 years) because most colony sites are not used consistently for extended periods of time (Fryxell 2001). The species has a moderately high reproductive and dispersal capacity (Payne 1984, Donkor 2007), and can readily move to different areas or expand its range. Thus, the specific areas directly impacted change over a relatively short time frame. A literature review by ECONorthwest (2011) reported a range of occupation of “a couple of years to many decades, and in some instances, centuries” and used 10 years as an average. In contrast, effects related to the utilization of trees can last for many decades and even exceed 100 years.

Because beaver can fell relatively large, sometimes mature trees (Figure 26), they have profound effects on riparian community structure and composition (Johnston and Naiman 1990).

Figure 26. Photograph of beaver in Grand Portage National Monument taken by Moen and Moore (2011) using a remote camera.

Utilization of woody plants by beaver is concentrated in a small area; for streams, the beaver do not commonly forage more than 50-70 m from the water's edge. Within this zone, tree basal area can be reduced up to 43% over a six year period. In one study, about two-thirds of all stems cut were <5 cm, but the average size of aspen used was 12 cm, and the largest was 43.5 cm (Johnston and Naiman 1990).

Beaver show strong preference for deciduous species, especially aspen, willow, and birch, and avoid conifers. Alder may be selected (Donkor and Fryxell 2000) or avoided (Johnston and Naiman 1990). This selective foraging shifts the woody plant composition toward conifers, non-palatable hardwoods, and shrubs. The woody species that recruit within the foraging zone of beaver are also influenced by abiotic conditions, of which soil moisture seems to be the most important (Donkor 2007). The 'preferred' browse species (e.g., alder and willow) do not always recruit at the lowest rates near the ponds, and conifers (e.g., red pine and balsam fir) do not always recruit equally from pond edge to the edge of the foraging zone (Donkor 2007). The net effect of soil moisture and foraging patterns is to see the highest number of woody species at an intermediate distance (Donkor and Fryxell 2000). Recent studies (cited in Moen and Moore 2011) have shown that roots and stems of aquatic plants can be an alternative food for beaver. However, over decades, the long-term effect of beaver activity is to make the habitat decidedly sub-optimal for the species.

Predation also affects the dynamics of the beaver population. Shelton (2004) reported that in ISRO, wolves preyed heavily upon the beaver population, and Mech (1966) found that 7-17% of wolf scat in ISRO contained evidence of beaver. Shelton and Peterson (1983) reported that beaver are an especially important food source for wolves in early spring, when they have young pups but moose calves have not yet been born. Moen and Moore (2011) summarized existing studies to conclude that in the presence of wolves, beaver tend to forage no more than 50 m from shore; they found that in the Boardwalk beaver colony, foraging distances averaged about 30 m in 1987 and from 2008-2010.

Data and Methods

A survey of basic population characteristics and habitat conditions for beavers was conducted for both GRPO and the adjacent reservation lands in 1987 (Smith and Peterson 1988). Its objectives were to determine beaver density and distribution in GRPO, determine colony size and composition, obtain physical measurements of beavers, assess the relative quality of vegetation and aquatic habitat, examine ecosystem effects, and estimate dispersal and movements.

From 2008-2010, Moen and Moore (2011) conducted a study of the Boardwalk beaver colony (the only colony active in GRPO at that time). Population estimates were made by various methods, and the quality of nearby food resources was evaluated. The authors also examined aerial photos taken in 1940, 1974, 1983, 1986, 1991, 2003, 2006, 2008 and 2009 and created a table of the locations of past and present beaver activity.

Reference Condition

Estimates of historic beaver density vary by more than an order of magnitude. Naiman and Melillo (1984) reviewed past studies and reported that prior to the arrival of Europeans, beaver density was about 4 beaver km^{-2}, and remained similar in "remote regions" of North America in 1984. Carlos and Lewis (2010) estimated a "biological optimum" beaver population of 0.3

Figure 27. Location of Fort Churchill and Fort Albany in Ontario relative to Grand Portage National Monument (Carlos and Lewis 2010).

beaver km^{-2} in the Fort Churchill, Manitoba area, located on Hudson Bay (Figure 27) consisting of "northern boreal forest and tundra." They estimated the maximum beaver density for Fort Albany, Ontario to be 0.6 km^{-2} and reported it to be "similar to that found by contemporary land-use studies for that region of Ontario." (The MDNR [2011] reports a beaver density of 0.4 river km^{-1} in its range, a number not directly comparable to the others). Pre-European settlement beaver population estimates have not been made for GRPO, and beaver populations naturally fluctuate because of their own ability to deplete their preferred food sources near streams. We have chosen modern reported population density of beaver on the Grand Portage Reservation and in other National Parks in the Lake Superior region as the reference condition. This range for population density is 1.4-5.1 beaver km^{-2} (Smith and Peterson 1988) and is a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006).

<u>Condition and Trend</u>

The most recent beaver population estimate for GRPO is 1.1-1.5 beaver km^{-2} (Table 15) and falls at or slightly below the reference condition of 1.4-5.1 beaver km^{-2}. We rank the condition as good, with a stable to slightly improving trend. Because of the age of the population data (1988) and a lack of assessment of whether beaver are present in all appropriate habitats in GRPO, we rank the level of confidence in this ranking as fair.

Table 15. Beaver population density at Grand Portage National Monument compared to the Grand Portage Reservation and other parks in the Great Lakes region.

Location	Density		
	Colonies km^{-2}	Beaver/colony	Beaver km^{-2}
GRPO	0.3[a]	3.5[a] or 5.0[b]	1.1[c] or 1.5[c]
Grand Portage Reservation	0.3[a]	4.7[a]	1.4[c]
ISRO	0.7[a] and 0.3[a]	6.3[a]	4.4[c] and 1.9[c]
APIS	0.4[a]	-	-
VOYA	0.9[a]	5.7[a]	5.1[c]
Northern Ontario	-	-	0.6[d]
"Remote regions of North America"	-	-	4[e]

[a]Smith and Peterson 1988, [b]Moen and Moore 2011, [c]calculated, [d]Carlos and Lewis 2010, [e]Naiman and Melillo 1984

In 1988, Smith and Peterson (1988) reported that beaver population trends in GRPO were consistent with those observed elsewhere in northeastern Minnesota. Beaver were scarce in the region at the turn of the 20^{th} century because of the fur trade followed by logging, but their numbers began to increase in the 1930s as aspen and birch grew in to replace the large conifers that had been logged. In the early 1950s, a tularemia-like disease caused a large beaver die-off (Stenlund 1953), followed by a recovery.

In 1987, Smith and Peterson (1988) found four colonies in GRPO. These were on Poplar Creek, a Poplar Creek tributary, in the Boardwalk colony on Snow Creek (which they called the Grand Portage colony), and at Fort Charlotte. They also found three more colonies on the Reservation outside GRPO. They reported a decline in population that had begun in the 1970s as a result of aspen depletion, and concluded that "… a population increase is not expected – unless fire or logging regenerates aspen and other seral species…" The population density of beaver in GRPO was 0.3 colonies km^{-2}, with an average of 3.5 beaver/colony, or 1.1 beaver km^{-2} (Smith and Peterson 1988). Moen and Moore (2011) suggested that the average would have been closer to 5 beaver/colony (1.5 beaver km^{-2}) if two colonies that were not fully established had been excluded.

Moen and Moore (2011) reported that an aerial survey conducted in 2008 showed more active beaver ponds in GRPO and on the Reservation (13) than at the time of Smith and Peterson's (1988) survey on foot (10), although presence of water is not a perfect indicator of beaver occupancy. They further concluded that based on trapping and camera surveys, beaver continue to use the Boardwalk ponds at GRPO. Based on review of aerial photos and Smith and Peterson's (1988) report, they concluded that the Poplar Creek colonies found in 1987 were no longer active (since the ponds are dry) and may not have a secure future without aspen regeneration. The Pigeon River and Snow Creek colonies are probably sources of beaver for GRPO for the foreseeable future (Moen and Moore 2011).

Sources of Expertise

Smith and Peterson (1988), Moen and Moore (2011), James Cook, Christine Mechenich.

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4.2.5 Terrestrial Exotic Plant Species

Description

The introduction of terrestrial alien species probably began with the arrival of European settlers (DiTomaso 2000). It was not unusual for immigrants to bring useful plants or seeds with them from their native lands. Collectively, exotic plants represent an important ecologic threat (Ehrenfeld 2003, Heneghan et al. 2006). In the recent past, eastern North America has experienced a rapidly increasing number of exotic plant populations. Effects have been widespread and have included, at a minimum, alteration of community structure (Heneghan et al. 2006); reduction of native richness (Rooney et al. 2004); alteration of ecosystem process such as decomposition, mineralization, and primary productivity (Ehrenfeld 2003, Heneghan et al. 2006); and altered fire regimes (Brooks et al. 2004). However, most exotics do not have any appreciable ecologic effects, and among those that do, some have minor impacts. Only a small proportion of non-native species are invasive. The National Invasive Species Council (http://www.invasivespecies.gov/) was established in 1999 by Executive Order 13112, which defines invasive species as "…an alien (or non-native) species whose introduction does, or is likely to cause economic or environmental harm or harm to human health".

Many, although not all, of the problem exotic species are especially adept at invading recently disturbed areas. The list of exotic invasives in Table 16 illustrates this – note how many species are found along trails and in the vicinity of the forts. Canada thistle (*Cirsium arvense*) is an example and is quite problematic; it is considered a noxious weed in 43 states, including Minnesota and Wisconsin (Czarapata 2005). A study in the BWCAW showed the importance of portage trails to the spread of invasives (Dickens et al. 2005), and in the Pacific Northwest streams and low-use roads are corridors for exotics and can serve as a refuge for these species (Parendes and Jones 2000). Even in largely unfragmented landscapes and mature forests, more subtle human manipulation of the landscape and accidental introduction can lead to steady increases in the number and dominance of exotics in the flora (Martin et al. 2009). This was recently documented for a 50-year period in upland forests of northern Wisconsin (Rooney et al. 2004), where the increase by exotics led to an 18.5% decrease in native species density at a 20 m^2 scale. Even the establishment of a park by no means guards land against further exotic invasion. A recent study of a small (19 km^2) newly established national park in Quebec found that the proportion of exotics increased from 16% to 25% in just 21 years (1984-2005) (Lavoie and Saint-Louis 2008).

For forests in the region, exotic taxa of serious concern are garlic mustard (*Alliaria petiolata*), the alien buckthorns (*Rhamnus* sp.), Oriental bittersweet (*Celastrus orbiculatus*), Japanese knotweed (*Fallopia japonica*), Norway maple (*Acer platanoides*), and the honeysuckles (*Lonicera* spp.) (Woods 1993, Czarapata 2005, Martin et al. 2009). These species can invade intact communities and reduce the number and/or diversity of native species. The buckthorns can thrive in richer soils and thus could invade birch, aspen, or northern hardwood forests. Garlic mustard and buckthorn are European species that have coevolved with earthworms and have been noted by Frelich and Reich (2009) as a concern for the nearby BWCAW.

Plant and animal exotics received the highest ranking of 46 Vital Signs compiled by the GLKN (Route and Elias 2007).

Data and Methods
Recent reports on GRPO vegetation (Sanders 2008, Hop et al. 2010) were reviewed for listings of invasive species, as was the 2010 field data (https://irma.nps.gov/App/Reference/Profile/2165721) and report (NPS 2010) of the NPS Great Lakes Exotic Plant Management Team.

Reference Conditions
Less than 10% of the GRPO watershed should be infested with populations of terrestrial invasive species that could necessitate treatment (Potyondy and Geier 2011). This is a "least disturbed condition," or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend


Nineteen invasive plant species were identified in a 2010 survey at GRPO (Table 16) (NPS 2010). The gross infested area, or area that contained any invasive plants, was 65 ha (23%). The infested area, which was calculated by multiplying the gross infested area by the midpoint of the percent cover class for the invasive species, was 2.6 ha (0.9%), indicating that many of the infested areas are sparsely occupied by invasives. Control measures were recommended for several species. We rank the condition of terrestrial invasive plants at GRPO as of moderate concern, with an uncertain trend, and our level of confidence in this assessment is good.

The invasive species covering the greatest area in GRPO were plantain (*Plantago major*), cow vetch (*Vicia cracca*), and dandelion (*Taraxacum officinale*) (Table 16). Control measures were recommended for reed canary grass (*Phalaris arundinacea*) along the eastern end of the Trail, in the front country, and in monotypic patches at Fort Charlotte; tansy (*Tanacetum vulgare*) in the front country and meadow; bird's foot trefoil (*Lotus corniculatus*) in the front country; and cow vetch in the meadow. It was also noted that bull thistle (*Cirsium vulgare*) and Canada thistle are noxious species in Minnesota, and their control is required by law. Some invasives are performing the function of controlling erosion on the Trail.

No non-native shrub species were noted in Sanders (2008), Hop et al. (2010), or NPS (2010), and the latter considered the threat of invasion by horticultural shrubs to be low because of the low level of contemporary landscaping in the vicinity. However, Hop et al. (2010) did note the presence of several herbaceous invasives, including ox-eye daisy (*Leucanthemum vulgare*), hawkweeds (*Hieracium* spp.), and Canada bluegrass (*Poa compressa*).

Table 16. Invasive plant species found in Grand Portage National Monument during a 2010 survey (NPS 2010).

Scientific Name	Common Name	Areas Infested	Gross Infested Area (ha)	Infested Area (ha)
Achillea millefolium	Yarrow	East Trail, West Trail, Front Country	4.5	<0.1
Arctium minus	Burdock	Fort Charlotte	<0.1	<0.1
Brassicaceae	Mustards	Front Country	<0.1	<0.1
Carum carvi	Caraway	East Trail, West Trail, Front Country, Front Country Meadow	6.9	0.1
Cirsium arvense	Canada thistle	Fort Charlotte, Front Country Meadow	6.1	0.2
Cirsium vulgare	Bull thistle	East Trail, Fort Charlotte, Front Country, Poplar Creek	2.6	0.1
Hieracium vulgatum	Yellow hawkweed	East Trail, West Trail, Front Country	4.5	0.1
Leucanthemum vulgare	Ox-eye daisy	East Trail, West Trail, Front Country	4.5	0.1
Lotus corniculatus	Bird's foot trefoil	Front Country, Front Country Meadow	0.9	<0.1
Melilotus officinalis	Yellow sweet clover	Front Country	<0.1	<0.1
Phalaris arundinacea	Reed canary grass	East Trail, Fort Charlotte, Front Country, Poplar Creek	2.4	0.1
Plantago major	Plantain	East Trail, West Trail, Front Country	4.5	0.6
Ranunculus acris	Tall buttercup	East Trail, West Trail, Front Country	4.5	0.1
Tanacetum vulgare	Tansy	East Trail, Front Country, Front Country Meadow, Stockade	4.6	0.1
Taraxacum officinale	Dandelion	East Trail, West Trail, Front Country, Front Country Meadow	6.9	0.3
Trifolium	Clover	Front Country Meadow	0.4	<0.1
Trifolium pratense	Red clover	East Trail, West Trail, Front Country	4.5	0.1
Trifolium repens	White clover	East Trail, West Trail, Front Country	4.5	0.1
Vicia cracca	Cow vetch	Front Country Meadow	2.8	0.4
Total			65.1	2.6

A group of invasive species that could affect the terrestrial plant communities of GRPO is the earthworms. The scientific consensus is that there are no native earthworms in the forests of the western Great Lakes Region because they have not migrated back since the retreat of the Wisconsin glacier (Hendrix and Bohlen 2002). However, due to human migration and commerce (e.g., use of worms as fish bait and for composting), at least 45 exotic species have been introduced to North America. The most common exotics are from Europe, and they have spread substantially over the past few decades (Bohlen et al. 2004).

Earthworms are placed into three broad major ecological groups (epigeic, endogeic, and anecic) based on their burrowing habits. Those that live and feed only at the surface, and sometimes only in the litter layer, are called epigeic. Earthworms that live and feed in the mineral soil are called endogeic. Those that burrow very deeply (down to 2 m) but feed on fresh surface litter are called anecic. Earthworms that live and feed in the litter layer and the top few inches of mineral soil are sometimes referred to as epi-endogeic (Great Lakes Worm Watch 2011).

Typically, the members of the first group to invade a site are smaller, stay in the litter layer, and have a minimal impact on the system. The second and third waves, or stages, include larger species that move between the litter/duff layer and mineral soil or burrow deeper into the soil (Frelich et al. 2006, Hale et al. 2006). However, the dominant species near an earthworm-free area is likely to invade first (Frelich et al. 2006). Most authors believe that the larger the number of species, the greater the magnitude of impacts (e.g., Wironen and Moore 2006).

The most numerous and problematic earthworms are members of the family Lumbricidae (Hendrix and Bohlen 2002, Shartell et al. 2012). As early as the 1960s, it was noted that these species have significant impact on soil properties in areas devoid of native species (Hendrix and Bohlen 2002), changing soil structure, seedbeds, microbial biomass, nutrient cycles, and the hydrologic cycle (Groffman et al. 2004, Frelich and Reich 2009). *Lumbricus terrestris* may burrow 25 cm or more into the soil and take entire leaves down its burrows. Both *L. terrestris* (in the anecic group) and *L. rubellus* (in the epi-endogeic group) have very notable impacts on litter depth, soil carbon and soil nitrogen (Bohlen et al. 2004), and understory composition (Hale et al. 2005, 2006).

Recently, some far-reaching implications of earthworms for the composition and function of northern hardwood forests in the northern parts of the Great Lakes region have been identified (Hale et al. 2006, Corio et al. 2009, Nuzzo et al. 2009). In the Chippewa National Forest of northern Minnesota, invaded areas typically had reduced understory species richness, reduced recruitment of sugar maple saplings, and increasing amounts of Pennsylvania sedge (*Carex pensylvanica*) (Hale et al. 2006). In the Northeast, it was found that the sharp reduction of the litter layer was contributing to the decline of woodland salamanders (Maerz et al. 2009).

Frelich and Reich (2009) reported that *L. rubellus* was capable of consuming the forest floor duff layer in all forest types in the Quetico-Superior ecoregion of North America (in which GRPO is included) except for spruce, Jack pine, and red pine forests. Frelich et al. (2006) stipulated that a high carbon-to-nitrogen ratio in the organic layer and low soil pH effectively screened out most soil-dwelling species. Hale and Host (2005) found five exotic earthworms commonly occurring in the aspen-fir forest type of VOYA; *Lumbricus* and *Dendrobaena* (a common epigeic) were the two most abundant genera in their samples. Numbers of *L. terrestris* adults were three times higher in the northern hardwood forests of Pictured Rocks National Lakeshore than in the VOYA aspen-fir forest, but the opposite trend was true for *L. rubellus*. The presence of *L. terrestris* was correlated with the distance to human development.

Shartell et al. (2012) found that in the Great Lakes region, four stand level variables were associated with increased earthworm biomass: high soil pH, high basal area of earthworm-preferred species, high percent anthropogenic cover, and low conifer dominance. Proximity to agricultural areas plus the four stand-level variables influenced earthworm community composition. However, only epi-endogeic species were significantly associated with anthropogenic land cover, and earthworm community diversity was greatest in areas with a variety of natural land cover components.

A 2009 survey in GRPO showed a high frequency of earthworm presence at sites along the trail corridor in GRPO (Figure 28) (unpublished data of Dr. Cindy Hale provided in an email by Brandon Seitz, NPS, 10/31/2012). This inventory documented that four species were present. The biomass per square meter was low compared to other invaded sites (e.g., Wironen and Moore 2006, Holdsworth et al. 2007), but it raises moderately serious concerns because *L. rubellus* or *Lumbricus* spp. was the dominant taxon at every location. *D. octaedra* was also typically present, and thus the dominant species in GRPO mirror those in VOYA and PIRO. Based on these results, any sites at GRPO with a significant broad-leaved tree component, or with near neutral soil pH, are likely to have increased invasion in the near future.

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Great Lakes Exotic Plant Management Team, Dr. Cindy Hale, James Cook.

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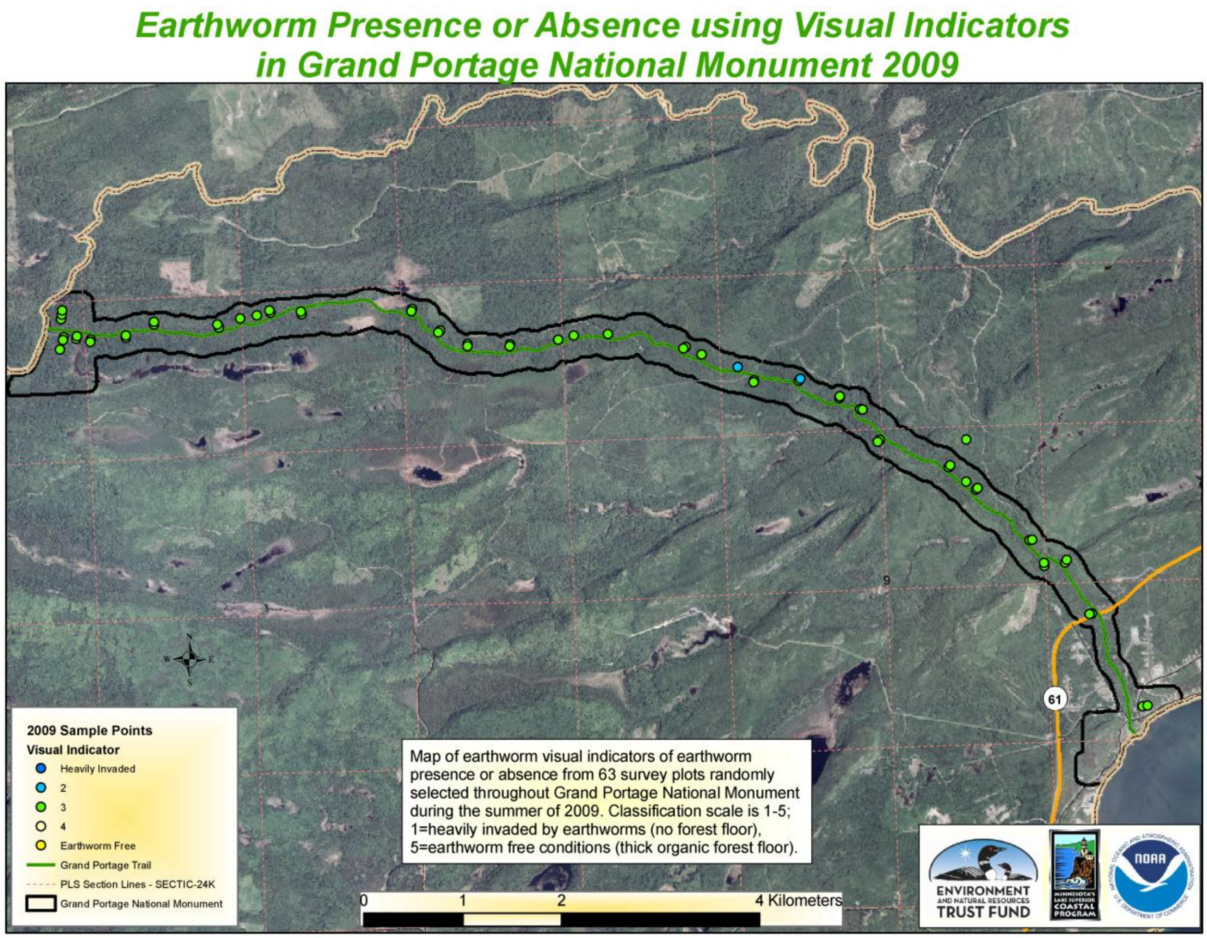

Figure 28. Earthworm presence or absence using visual indicators in Grand Portage National Monument, 2009 (from the work of Dr. Cindy Hale and provided by Brandon Seitz 10/31/2012).

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4.2.6 Coaster Brook Trout

Description

Lake trout (*Salvelinus namaycush*) and brook trout are the only two trout species endemic to Lake Superior (Newman and Dubois 1997). While brook trout typically inhabit cold-water streams, a distinct form of brook trout is native to Lake Superior. This form of brook trout is typically referred to as a "coaster" brook trout due to its preference for shoreline habitat. There are two forms of coaster brook trout; an adfluvial form that forages in Lake Superior and reproduces in streams and a lacustrine form that spends its entire life in Lake Superior (Huckins et al. 2008). Coaster brook trout are distinct from other brook trout due to a larger size and distinct coloring (Figure 29) and are prized for their size, beauty, and taste (Newman 2000).

Once prevalent in Lake Superior, most coaster brook trout populations have been extirpated because of overexploitation, habitat loss, and competition with introduced salmonids (Newman 2000). The evolutionary (Behnke 1994) and recreational significance of coaster brook trout has generated interest in the conservation and restoration of the Lake Superior population. Efforts have been made to reintroduce coaster brook trout and to monitor extant populations in Lake Superior. The reintroduction and management of coaster brook trout in Grand Portage Creek in GRPO is part of the overall rehabilitation plan for coaster brook trout in Lake Superior (Newman et al. 2003). Currently, GRPO harbors a coaster brook trout population in Grand Portage Creek that was successfully reintroduced by a joint effort between the Grand Portage Band and the U.S. Fish and Wildlife Service (USFWS) (Wiland et al. 2006).

Data and Methods

Federal, state, and tribal reports were used to determine the status and trend of coaster brook trout in GRPO. Federal and Minnesota reports were used to determine the broad-scale status and trend of coaster brook trout in Lake Superior. Specific data and reports for the Grand Portage Reservation were used when possible to determine the status and trend of coaster brook trout in GPRO. Salient data included, but were not limited to, population monitoring, reproductive condition, and morphometric data.

Figure 29. A coaster brook trout (from Wiland et al. 2006).

The USFWS works in a joint effort with state and tribal agencies in managing Lake Superior coaster brook trout. Therefore, USFWS reports were also included in this assessment. The "Status of Brook Trout in Lake Superior" (Newman and Dubois 1997) was used as an early account on the conservation status of coaster brook trout. Newman (2000) gave a detailed account of coaster brook trout reintroduction efforts to Grand Portage Bay. Finally, USFWS journal entries were used to assess the current population trend of coaster brook trout in GRPO.

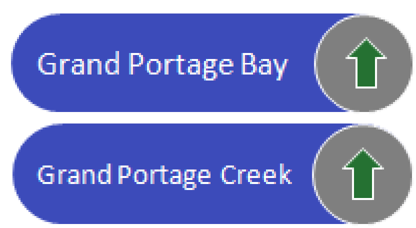
The MDNR also conducts population monitoring for coaster brook trout along the Minnesota shoreline of Lake Superior. The most recent publication of this data was by Ward (2008). This report was used as a general indicator of the overall status of coaster brook trout around the Minnesota shoreline of Lake Superior.

The management of coaster brook trout in GRPO is the responsibility of the Grand Portage Band's Natural Resources Management (GPBNRM) Department. The management goals and strategies for coaster brook trout in GRPO are specified in the Band's fisheries management plan, "A Coaster Brook Trout Rehabilitation Plan for the Grand Portage Reservation 2006-2016" (Moore et al. 2006). The overall goal for Lake Superior is the establishment of self-sustaining coaster brook trout populations in as many original native habitats as possible; within the Grand Portage Reservation this includes the Pigeon River and Hollow Rock and Grand Portage Creeks. Management goals specified that each stream's population should consist of 5 or more year classes (ages 0 to 4) and a minimum of 30 pairs of adult spawning brook trout. The goal for the total harvest of coaster brook trout from Lake Superior and anadromous habitats was set at 200 adult individuals.

The GPBNRM surveys the Grand Portage area each spring and fall to maintain data on the status of the local coaster brook trout population. The total brook trout habitat of each stream is electrofished, and all coaster brook trout are counted, measured, marked, and returned to the stream. These data were used in part to assess the condition and trend of coaster brook trout in GRPO.

<u>Reference Condition</u>
The metric for the reference condition for coaster brook trout in GRPO is taken from the Band's management goals. The population of coaster brook trout in Grand Portage Creek should consist of 5 or more year classes (ages 0 to 4) and a minimum of 30 pairs of adult spawning brook trout. This reference condition represents a "least disturbed condition," or "the best of today's existing conditions" (Stoddard et al. 2006).

<u>Condition and Trend</u>
The condition of the coaster brook trout population (as determined by the reference condition) in Grand Portage Creek and Grand Portage Bay is unknown, but the trend appears to be improving. Since limited numeric data were available to us, the degree of confidence in the assessment is moderate.



The contemporary distribution of native coaster brook trout has been greatly reduced from the historic range (Newman and Dubois 1997, Carlson 2003) (Figure 30). Historic data is largely anecdotal but indicates that much of the Lake Superior shoreline once supported a robust population of coaster brook trout (Newman and Dubois 1997). The Grand Portage Reservation once supported several coaster brook trout populations, including plentiful populations in Hollow Rock and Grand Portage Creeks and the Reservation and Pigeon Rivers (Moore et al. 2006). Development and logging activities negatively affected the flow and temperature profiles of these streams, and combined with overexploitation from 1850 to 1950, led to the extirpation of coaster brook trout from Grand Portage in the 1950s (Moore et al. 2006). Unfortunately, these causes, along with pressures from introduced aquatic species have also eliminated the coaster brook trout from most of their native range throughout Lake Superior (Newman and Dubois 1997). The only remaining native populations of coaster brook trout include several remnant populations around Nipigon and Thunder Bay, Canada; ISRO and the Salmon-Trout River, Michigan; and the Batchawana Bay, Canada area of eastern Lake Superior (Newman and Dubois 1997).

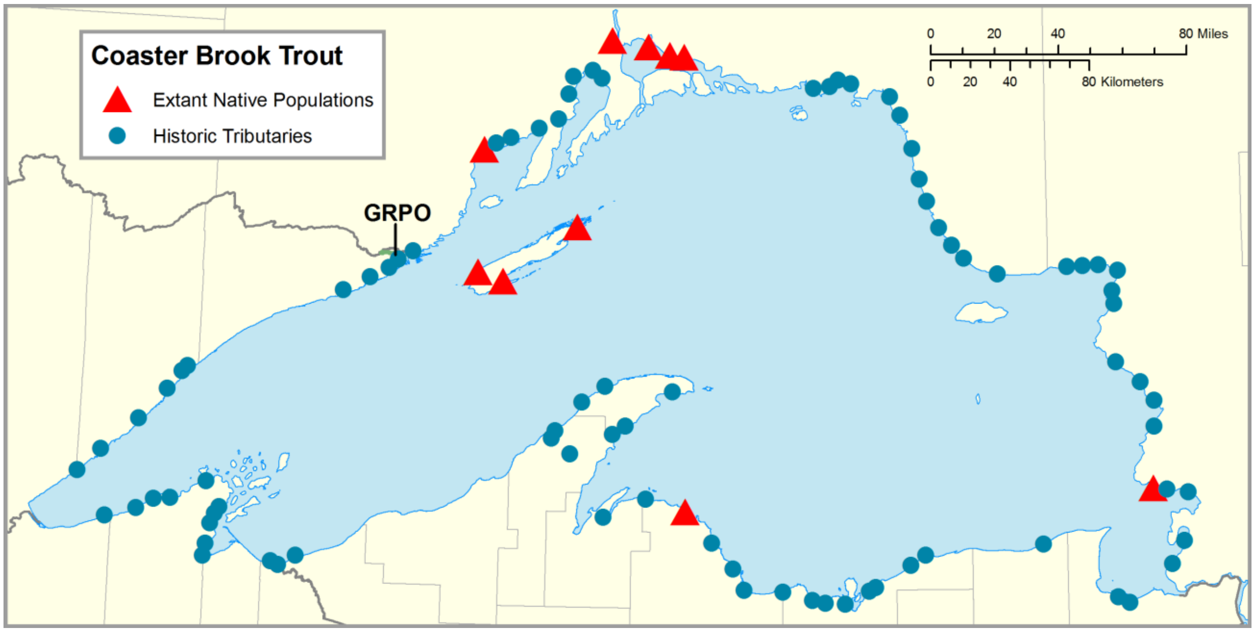


Figure 30. A comparison of historic coaster brook trout spawning populations and extant native populations (Newman et al. 2003 after Carlson 2003).

Population trends for coaster brook trout on the Minnesota shoreline of Lake Superior are monitored by the MDNR (Figure 31) (Ward 2008). These population trends have generally been positive (Figure 32). Several streams show an increasing population size, while others show fluctuating but reasonably large populations and one stream (Spruce) shows a consistently decreasing population. Another encouraging sign was the noticeable improvement in the size and age structures of coaster brook trout populations (Figure 33 and Figure 34, respectively). Coaster brook trout typically reach sexual maturity around age 3, and female fecundity is size-dependent (Newman and Dubois 1997). Therefore, it is necessary to have a diverse size and age structure to ensure a viable population. The increase in the size and age diversity of coaster brook trout indicates an overall improvement in the reproductive health of Minnesota coaster brook trout populations.

Coaster brook trout were reintroduced to GRPO and the Grand Portage Reservation by a joint effort between the Grand Portage Band and the USFWS (Wiland et al. 2006). Three streams, Grand Portage Creek, Little Lake Creek, and Hollow Rock Creek, were originally selected as reintroduction sites. Significant efforts were made to mitigate the difficulties limiting the success of other reintroduction efforts (Newman 2000). For example, previous reintroductions typically stocked fingerlings or yearling brook trout and resulted in low adult return rates and no natural reproduction (Smith and Moyle 1944). To maximize early acclimation and natal imprinting to the introduced location, the Grand Portage reintroduction focused on stocking the earliest life stage of coaster brook trout possible, typically 'eyed' eggs (where the developing fry is visible) or early stage fry.

Figure 31. Streams monitored for coaster brook trout populations by the Minnesota Department of Natural Resources (after Ward 2008).

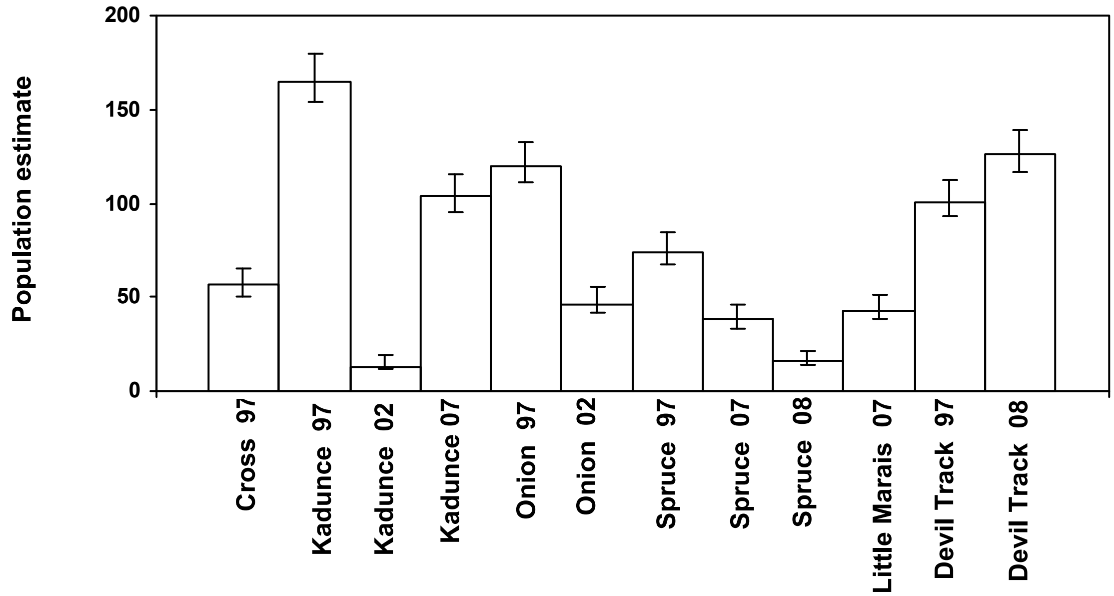


Figure 32. Population estimates for coaster brook trout at several standardized locations along the Minnesota shoreline of Lake Superior (from Ward 2008). Stream locations are listed horizontally along the bottom followed by the year the survey was conducted.

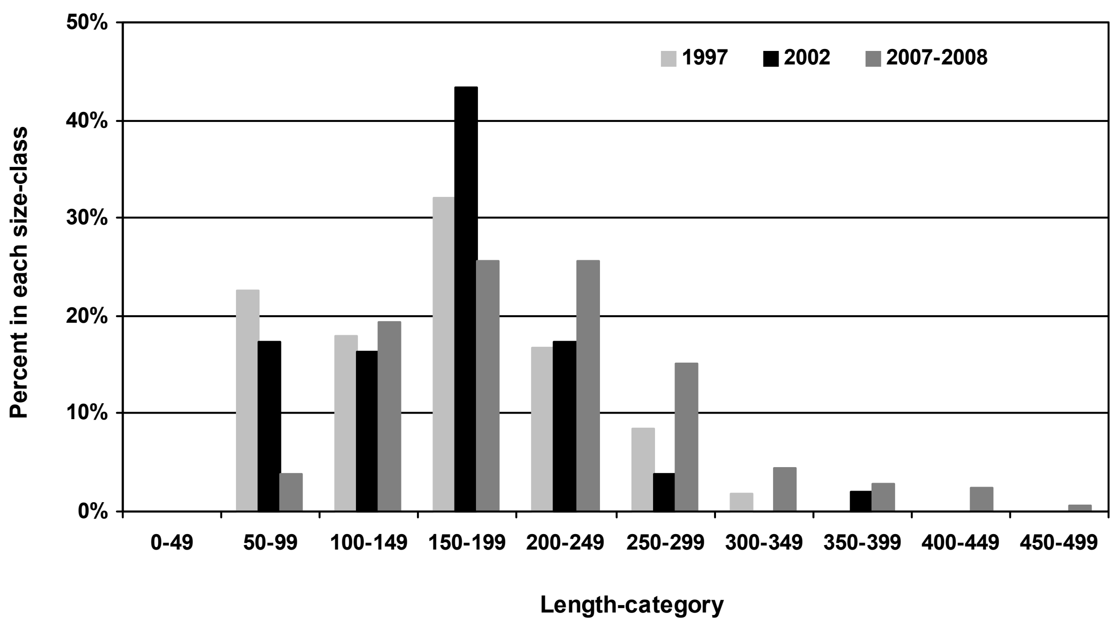


Figure 33. Size structure of coaster brook trout populations along the Minnesota shoreline of Lake Superior (from Ward 2008). Fish lengths (mm) are binned by 50 mm intervals.

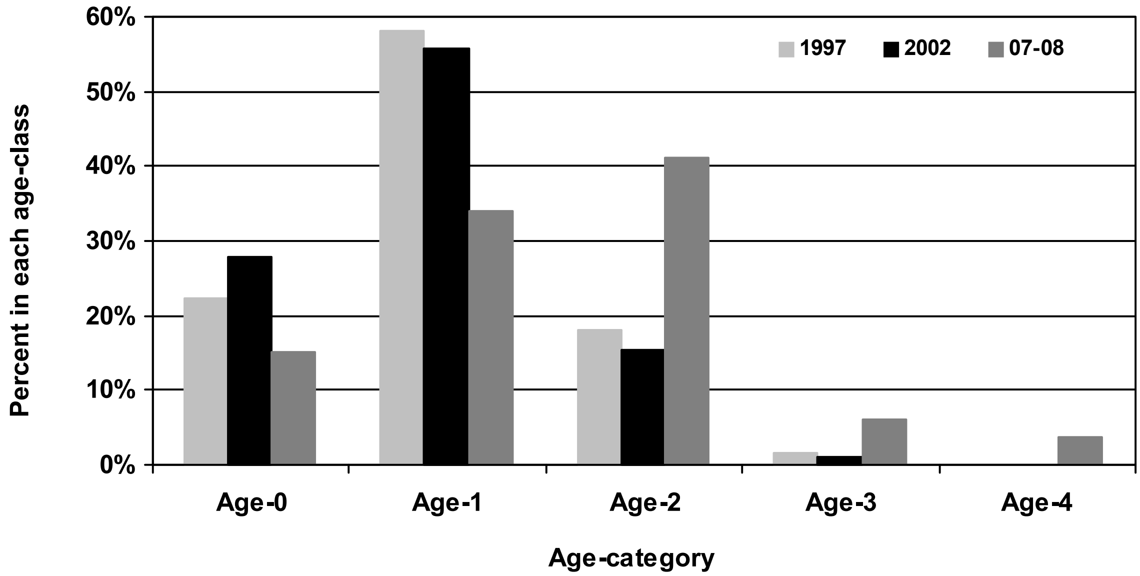


Figure 34. Age structure of coaster brook trout populations along the Minnesota shoreline of Lake Superior (Ward 2008).

Substantial attention was also paid to finding the most appropriate strain of coaster brook trout to use in stocking Grand Portage. Most brook trout populations differ in small but characteristic ways due to genetic isolation. When these differences are great enough, a population or group of populations are considered a strain; this can sometimes represent local adaptations or favorable characteristics of the population.

At first, the most appropriate strain of coaster brook trout available to reintroduce was the Nipigon strain (Moore et al. 2006). Brook trout were stocked in GRPO and the Grand Portage Reservation annually from 1992-2002 using only this strain (Newman 2000). However, in 2003, the project transitioned to using two Isle Royale strains, the Tobin Harbor and Big Siskiwit strains, which became available. This project successfully established a breeding population of coaster brook trout which has been monitored by the GPBNRM since its inception. In 2010, approximately 114,000 fry were stocked in Grand Portage Creek, the Reservation River, Grand Portage Marina, Hollow Rock Creek, and the Pigeon River, all of which are located on tribal community lands. An additional 52,000 fry were provided to the Grand Portage Band's hatchery for later stocking as fingerlings or yearlings (Edwards 2010).

There was a significant increase in the total Pigeon Bay coaster brook trout population from 2006 to 2010 (Figure 35). This indicates that the coaster brook trout stocked into this area are surviving and possibly reproducing. Stocked brook trout of fingerling size or larger are generally marked by a fin clip, and when population surveys are done, fish are examined for this mark to determine if they are of hatchery or natural origin. There was a general increase in the number of unclipped fish caught at Pigeon Bay; however, this trend was not significant. It appears that the coaster brook trout population is increasingly composed of hatchery-reared fish; however, these fish are likely to naturally reproduce and contribute to the natural coaster brook trout population as monitoring continues for a sufficient time to allow for sexual maturation and recruitment.

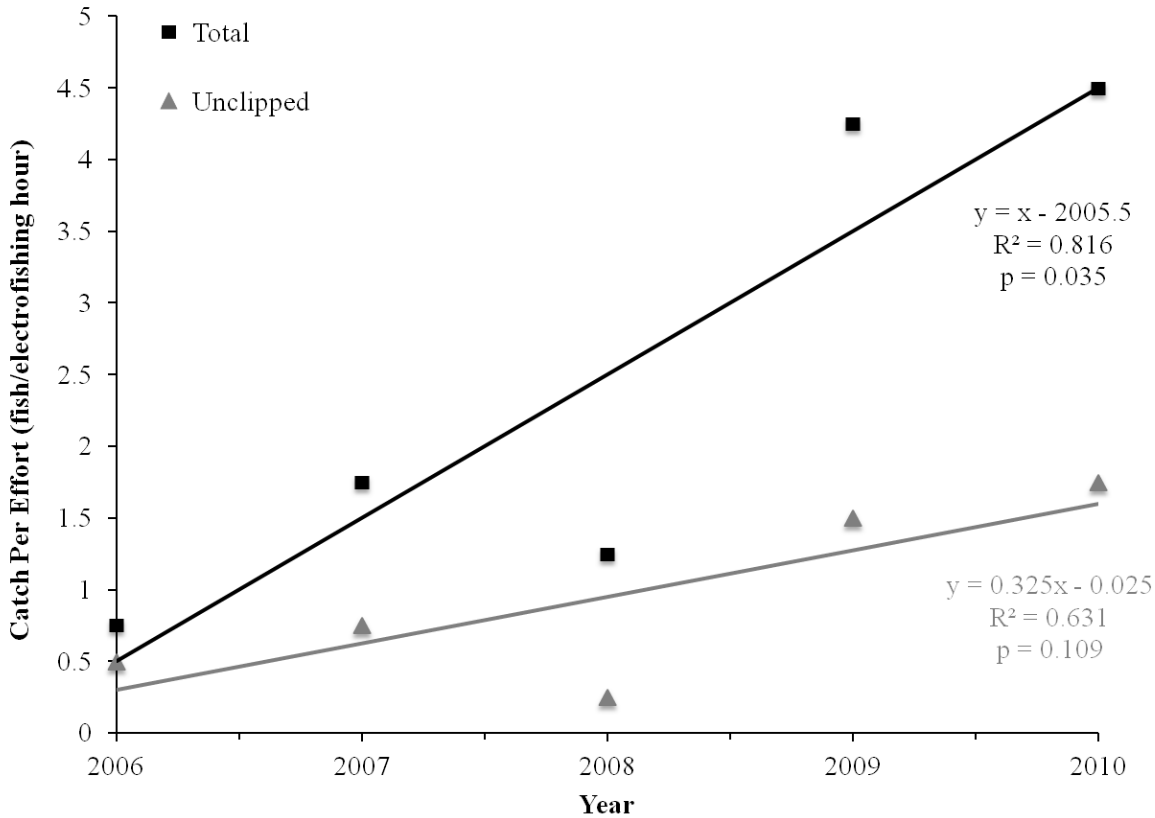


Figure 35. Coaster brook trout monitoring data for Pigeon Bay, Grand Portage, Minnesota. Data were collected by the Grand Portage Tribal Department of Natural Resources. Graph provided by Seth Moore, GPBNRM. Catch per effort (CPUE) is used as an index of population abundance. Unclipped refers to the unmarked fish CPUE (likely representing natural reproduction) and total refers to the total CPUE of coaster brook trout.

A genetic analysis done in 2007-2009 indicated nearly 100% of unclipped fish were of the Isle Royale strains (Seth Moore, GPBNRM, written communication, 3-5-2012). These unclipped fish may be pure crosses of Isle Royale strain fish resulting from natural reproduction of stocked fish. Or, they may have been stocked at small sizes (fry) when fin clipping is impractical. Fry are marked by oxytetracyline which is undetectable without killing the fish and extracting otoliths. Future analysis could be conducted to determine if the introduced coaster brook trout populations are recruiting and contributing to a self-sustaining population.

There was an apparent increase in the coaster brook trout recruitment in Grand Portage Creek from 1991-2009 as measured by young-of-year (YOY) and yearling densities (Figure 36 and Figure 37), although these trends were not statistically significant. This indicates that the reintroduced coaster brook trout may be successfully reproducing and surviving to age 1, which could lead to an increase in the adult population. However, numbers of fry and YOY can be highly variable from year to year, and data on the adult population of Grand Portage Creek are not presented in this assessment. Interestingly, three coaster brook trout marked as originating from Grand Portage have been recovered from Kadunce, Spruce, and Silver Creeks (Figure 31) during MDNR monitoring (Ward 2008). Thus, rehabilitating the Grand Portage population may

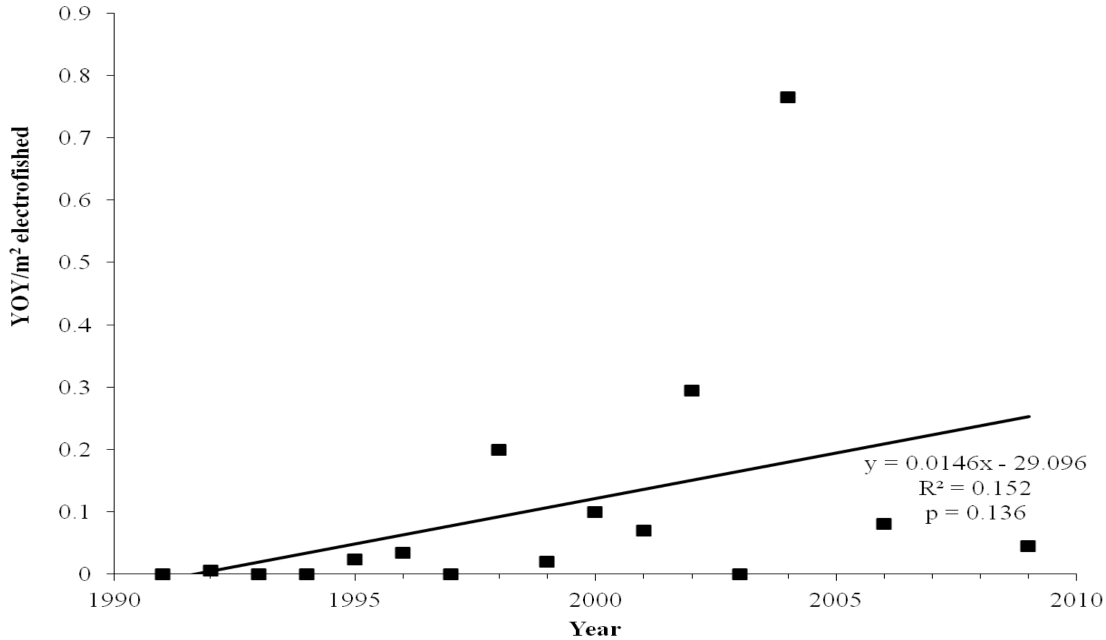


Figure 36. Coaster brook trout reproduction as measured by young-of-year (YOY) in Grand Portage Creek from 1991-2009. Data were collected by the Grand Portage Tribal Department of Natural Resources. Graph provided by Seth Moore, GPBNRM. Measurement was number of fish caught per square meter of stream electrofished.

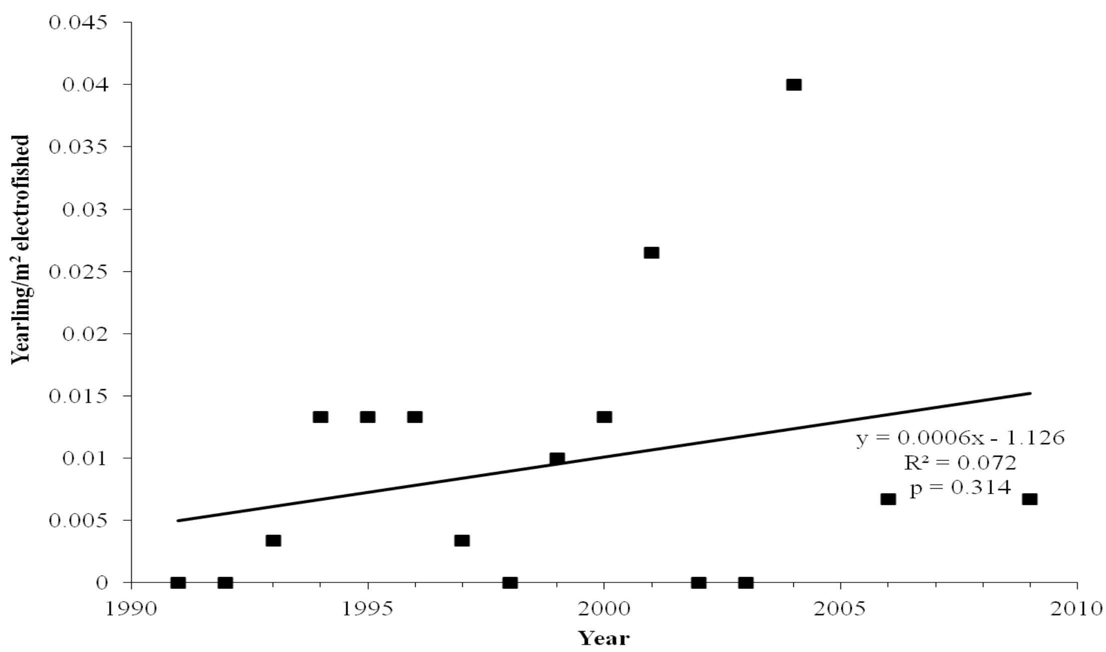


Figure 37. Coaster brook trout reproduction as measured by yearlings in Grand Portage Creek from 1991-2009. Data were collected by the Grand Portage Tribal Department of Natural Resources. Graph provided by Seth Moore, GPBNRM. Measurement was number of fish caught per square meter of stream electrofished.

be helping the reestablishment of coaster brook trout populations along other sections of the Minnesota shoreline.

While size data are not presented here, it is likely that the size structure of Grand Portage coaster brook trout follows the positive trends of other Minnesota populations. Harvest data were also unavailable, but the Grand Portage Band maintains a strict coaster brook trout regulation with a daily bag limit of one fish and a minimum size limit of 20 inches (510 mm) (Moore et al. 2006). The intent of this regulation was to allow coasters the opportunity to spawn twice before they are harvested, and given the size structure present in Minnesota (Figure 33), likely results in very low levels of exploitation.

Coaster brook trout show several positive trends, including an increase in the size and age structure of populations in Minnesota, natural reproduction, and increasing population abundance in Lake Superior waters near GRPO. However, the Band has indicated that not all the criteria they outlined in their plan have yet been met (Seth Moore, personal communication, GPBNRM, 3-5-2012). Specific population sizes, structure, and age structure will continue to be monitored by GPBNRM through their annual assessment protocols.

Sources of Expertise
L. E. Newman, USFWS; M. Ward, MDNR; J. Glase, NPS; S. Moore, Grand Portage Band; Trout Unlimited; and M. D. Waterhouse.

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4.2.7 Aquatic Macroinvertebrates

Description

Aquatic macroinvertebrates are an important, if often overlooked, contributing community of most ecosystems. In addition to their obvious role as food sources for fish, herptiles, and birds, aquatic macroinvertebrates are important processors of organic matter. Aquatic macroinvertebrates can be used to infer and monitor the environmental condition of the stream and contributing watershed provided the ecological requirements of resident taxa are known. This biological monitoring can supplement physical and chemical testing to more adequately assess water resource quality (Stroom and Richards 2000, Brady and Breneman 2008).

Aquatic macroinvertebrates are ideally suited to environmental condition assessments for several reasons. They are common in most streams, easy to collect, relatively immobile, easy to identify, and many taxa have life cycles of a year or greater (Hilsenhoff 1977). Their immobility causes them to be continually exposed to environmental conditions and stressors (Barbour et al. 1999); hence, aquatic macroinvertebrates function as *in situ* environmental barometers.

Community-level bioassessments should incorporate several classes of metrics, as different metrics describe different aspects of the community and may provide differing insights to the ecological stressors influencing the community. Suites of metrics calculated on a dataset spanning multiple years can provide inference to trends in environmental condition of the streams sampled.

Richness measures describe the number of distinctly different taxa in a sample. Richness can also be expressed as the number of taxa contained in select groups, as in the sensitive Ephemeroptera-Plecoptera-Trichoptera (EPT) group. Richness measures compared across samples should be viewed with caution if the same proportion of sample was not processed for each sample in the comparison. If dissimilar sample portions were processed, more directly comparable richness measures may be developed based on taxa density or number of taxa per portion of sample processed (Barbour and Gerritsen 1996). It is generally held that richness observations decrease in face of increasing environmental perturbation (Plafkin et al. 1989, Barbour et al. 1999). Stroom and Richards (2000) reported a small amount of overlap, but overall good separation, of their richness measure between reference and disturbed streams. Richness was higher for reference streams than for disturbed streams. Bode (1986) presented EPT taxa richness values for classifying impact in New York streams (Table 17).

Table 17. EPT taxa richness values for classifying stream disturbance (Bode 1986).

EPT Richness	Disturbance Level
>10	Non-impacted
6-10	Slightly impacted
2-5	Moderately impacted
0-1	Severely impacted

Enumerations range from counts of all organisms collected to relative abundances of different taxonomic groups. Counts often exhibit high natural variability, respond to perturbations inconsistently, and are difficult to interpret, especially from qualitative samples. Relative abundances provide information on the makeup of the community assemblage and the contributions of individual taxa populations to the total fauna (Barbour et al. 1999). Healthy assemblages will exhibit relatively consistent proportional representations of trophic function and habitat traits even as individual abundances vary. Individual abundances also contribute information to the stability of a community. Communities dominated by few taxa are considered less stable than communities in which dominance is spread across many taxa.

Diversity indices represent a measure of the distribution of individuals between the taxa present in a sample. A community represented by many taxa of even distribution is considered more natural, and more resilient to minor perturbations, than a simple community dominated by few taxa. Diversity values are not directly relatable to environmental quality; however, higher diversity values are indicative of stable environmental conditions. The Shannon Diversity index (H’), which is often mistakenly called the Shannon-Wiener index (Magurran 1988) is the most commonly applied index (Lillie et al. 2003). H’ values usually range from 1.2-4.5, with higher values representing higher diversity.

Biotic indices (BI) are indices of organic pollution. They are incorporated into national protocols for rapid bioassessment (Plafkin et al. 1989). Biotic indices use pre-established water quality tolerance values for taxa (Rosenberg et al. 2008). Biotic index scores range from 0-10, with 0 representing excellent water quality and 10 representing very poor water quality (Table 18). The Hilsenhoff Biotic Index (HBI) (Hilsenhoff 1977, 1982, 1987, 1998) and Family-level Biotic Index (FBI) (Hilsenhoff 1988) represent the average weighted pollution tolerance values of all arthropods in a sample, excluding taxonomies for which no pollution tolerance values have been assigned. HBI 10-Max (Hilsenhoff 1998) is calculated using only ten individuals of each taxon represented by more than ten individuals in the original sample. HBI 10-Max has been shown to reduce variability in resulting BI values and can be used throughout the year (Hilsenhoff 1998). Mean Pollution Tolerance Value (MPTV) (Lillie and Schlesser 1994) is an arithmetic average of the assigned pollution tolerance value for each taxon in the sample. HBI 10-Max and MPTV tend to reduce variability of their resultant values and may be less susceptible to temporal changes and sample sizes than the HBI (Lillie et al. 2003).

Table 18. Water quality ratings for HBI and FBI values (Hilsenhoff 1987, 1988).

HBI value (Hilsenhoff 1987)	FBI Value (Hilsenhoff 1988)	Water Quality Rating	Degree of Organic Pollution
≤ 3.50	≤ 3.75	Excellent	Unlikely
3.51-4.50	3.76-4.25	Very Good	Possible Slight
4.51-5.50	4.26-5.00	Good	Some
5.51-6.50	5.01-5.75	Fair	Fairly Significant
6.51-7.50	5.76-6.50	Fairly Poor	Significant
7.51-8.50	6.51-7.25	Poor	Very Significant
8.51-10.00	7.26-10.00	Very Poor	Severe

Functional feeding group measures examine general modes of food acquisition based on an organism's principal feeding mechanism. These measures are reported as relative composition by feeding class among total individuals in a sample. Metrics calculated on functional feeding classes are useful in characterizing the food base of a community, providing insight to organic particle source, size, and transport.

Multimetric indices use more than one measurement to describe environmental condition. A macroinvertebrate-based Index of Biotic Integrity (mIBI) uses macroinvertebrate metrics to detect human influence by weighting environmental variables among multiple spatial scales to characterize human influence in a way relevant to the biota and quantifying the relative influence of environmental variables among multiple spatial scales (Weigel 2003). mIBI values range from 0-10, with lower values indicating poorer water quality and higher scores indicating better water quality (Table 19).

Table 19. Water quality ratings for mIBI values (Weigel 2003)

mIBI Value	Condition
< 2	Very Poor
2-3.9	Poor
4-5.9	Fair
6-7.9	Good
> 7.9	Excellent

<u>Data and Methods</u>

Aquatic macroinvertebrate samples were collected approximately biannually from 2000-2011 on Grand Portage Creek and Poplar Creek (Figure 38). Excel® datasets reporting taxonomies and enumerations from these samples were provided by M. Watkins, Water Quality Specialist, Grand Portage Band (Watkins 2012).

Datasets were examined for overall integrity. Vertebrate listings were removed. Taxonomies presumed incorrect were flagged. M. Watkins (personal communication) followed up and corrected one taxonomy listing (*Stenonema bipunctata* = *Arthroplea bipunctata* Mc Dunnough). After examining the taxonomies reported across all years, listings presenting either *Stenonema* Traver or *Macdunnoa persimplex* McDunnough were presumed to be *Maccaffertium* Bednarik and changed. Taxonomies were updated to reflect current concepts. Trophic function, habitat, and habit attributes were checked against summary tables in Merritt et al. (2008).

Metrics were calculated for each collection event (creek by date) using DNRBUG Ver. 8.11 (UWSP ABL 2007). Terrestrial or riparian taxonomies were not included during metric calculations. The coefficient of variation (CV) was used to determine variability of the metrics because it is unit-independent and allows comparison of measures with different values (Elliot 1977). Cahow (1995) categorized CV values as having low variability (CV $\leq$ .169), moderate variability (CV .170-.299) or high variability (CV $\geq$ .300). Initial analyses showed widely-varying values for each metric (Table 20 and Table 21).

Watkins (conference call 22 March 2012) indicated macroinvertebrate sampling methodology changed between 2005 and 2007 collections. The data for each creek were then split into subsets (pre-2006 and post-2006) by methodology of sampling. The CV values of these data subsets suggested the variability in metric values was due in large part to sampling methodology. The variability of the pre-2006 data subset was larger than the variability of the entire data set, while the variability of the post-2006 data sets was much smaller than the variability of the entire data set (Table 20 and Table 21). Further discussion of condition and trend will be done with the post-2006 data.

While displaying high variability, the pre-2006 data subset was populated by many of the same taxa, in similar proportions, as the post-2006 data subset. The specimens in the pre-2006 data subset were generally indicative of good water quality, and their relative abundance suggested the ecological condition of the GRPO landscape was relatively stable during the entire timeframe of aquatic macroinvertebrate collections.

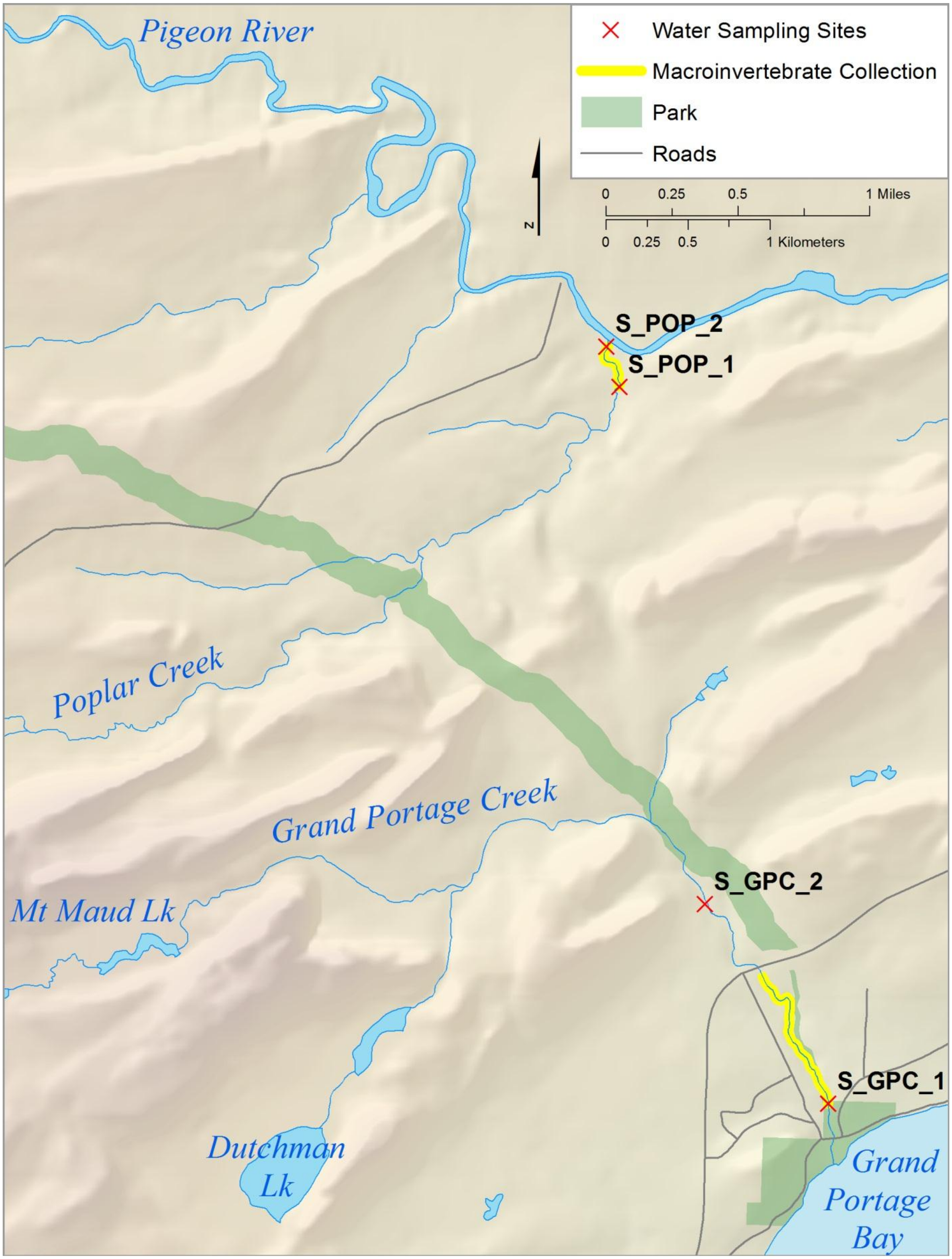


Figure 38. Location of stream reaches where macroinvertebrate samples were collected on Grand Portage and Poplar Creeks.

Table 20. Metrics for macroinvertebrate samples, Grand Portage Creek, 2000-2011, 2000-2005, and 2007-2011.

DATE		SR	GR	GR_ EPT	HBI	HBI_ COUNT	HBI10	HBI10_ COUNT	HBI_EPT_ COUNT	FBI	FBI_ COUNT	FBI_EPT_ COUNT	BIOINDEX INSECTS ONLY
2000-09-07		10	10	50	2.83	53	3.83	24	74	3.68	374	96	2.83
2001-09-13		15	15	33	0.06	450	1.00	26	99	3.65	556	99	0.06
2003-09-22		28	26	42	3.00	279	2.35	71	96	3.44	290	93	2.99
2005-09-08		11	11	55	0.59	110	1.17	30	96	3.20	188	98	0.59
2007-09-24		18	18	39	2.72	107	2.82	45	91	3.71	233	92	2.72
2009-07-29		24	23	48	1.99	255	2.94	83	92	2.79	277	91	1.99
2011-09-30		25	24	79	2.15	407	1.73	106	99	3.48	413	99	2.15
	AVG	18.7	18.1	49.4	1.906	237.3	2.263	55.0	92.4	3.421	333.0	95.4	1.903
	SD	7.1	6.4	15.0	1.150	154.5	1.027	32.1	8.7	0.329	125.0	3.4	1.147
	CV	0.38	0.35	0.30	0.60	0.65	0.45	0.58	0.09	0.10	0.38	0.04	0.60
2000-09-07		10	10	50	2.83	53	3.83	24	74	3.68	374	96	2.83
2001-09-13		15	15	33	0.06	450	1.00	26	99	3.65	556	99	0.06
2003-09-22		28	26	42	3.00	279	2.35	71	96	3.44	290	93	2.99
2005-09-08		11	11	55	0.59	110	1.17	30	96	3.20	188	98	0.59
	AVG	16.0	15.5	45.0	1.621	223.0	2.09	37.8	91.3	3.492	352.0	96.5	1.616
	SD	8.3	7.3	9.6	1.514	179.2	1.31	22.3	11.6	0.221	155.8	2.6	1.509
	CV	0.52	0.47	0.21	0.93	0.80	0.63	0.59	0.13	0.06	0.44	0.03	0.93
2007-09-24		18	18	39	2.72	107	2.82	45	91	3.71	233	92	2.72
2009-07-29		24	23	48	1.99	255	2.94	83	92	2.79	277	91	1.99
2011-09-30		25	24	79	2.15	407	1.73	106	99	3.48	413	99	2.15
	AVG	22.3	21.7	55.3	2.286	256.3	2.496	78.0	94.0	3.327	307.7	94.0	2.286
	SD	3.8	3.2	21.0	0.384	150.0	0.669	30.8	4.4	0.479	93.8	4.4	0.384
	CV	0.17	0.15	0.38	0.17	0.59	0.27	0.39	0.05	0.14	0.30	0.05	0.17

SR=species richness, GR=generic richness, GR_EPT=generic richness for the EPT group, HBI= Hilsenhoff Biotic Index, HBI_Count=count for the Hilsenhoff Biotic Index, HBI10= Hilsenhoff 10-Max Biotic Index, HBI10_Count= count for the Hilsenhoff 10-Max Biotic Index, HBI_EPT_COUNT=count for the Hilsenhoff Biotic Index for the EPT group, FBI=Family-level Biotic Index, FBI_Count=count for the Family-level Biotic Index, FBI_EPT_COUNT= count for the Family-level Biotic Index for the EPT group, BIOINDEX=biotic index, AVG=average, SD=standard deviation, CV=coefficient of variation

Table 20. Metrics for macroinvertebrate samples, Grand Portage Creek, 2000-2011, 2000-2005, and 2007-2011. (continued)

DATE		COUNT	% COUNT_ EPT	EPT_ COUNT	EPT_ GENERA	DIV	TOLVAL	mIBI	%POET	POET INDEX	% DNC	TFM COUNT
2000-09-07		384	94	360	5	2.20	4.25	5.16	94.5	5	3.6	384
2001-09-13		570	96	550	5	1.38	3.17	6.66	96.7	5	0.9	569
2003-09-22		311	87	271	11	2.24	3.44	7.05	91.6	10	0.3	310
2005-09-08		196	94	184	6	2.26	1.50	4.52	94.1	7	0.0	196
2007-09-24		273	79	215	7	2.68	3.56	6.16	82.4	7	2.6	266
2009-07-29		294	85	251	11	3.20	3.07	5.21	93.2	12	0.3	293
2011-09-30		417	98	410	19	2.56	2.43	9.66	97.2	12	0.2	417
	AVG	349.3	90.4	320.1	9.1	2.359	3.060	6.347	92.81	8.3	1.13	347.9
	SD	121.3	6.9	128.6	5.0	0.556	0.881	1.713	4.98	3.0	1.40	121.9
	CV	0.35	0.08	0.40	0.55	0.24	0.29	0.27	0.05	0.37	1.24	0.35
2000-09-07		384	94	360	5	2.20	4.25	5.16	94.5	5	3.6	384
2001-09-13		570	96	550	5	1.38	3.17	6.66	96.7	5	0.9	569
2003-09-22		311	87	271	11	2.24	3.44	7.05	91.6	10	0.3	310
2005-09-08		196	94	184	6	2.26	1.50	4.52	94.1	7	0.0	196
	AVG	365.3	92.8	341.3	6.8	2.019	3.090	5.850	94.23	6.8	1.20	364.8
	SD	156.9	3.9	156.6	2.9	0.424	1.155	1.203	2.09	2.4	1.64	156.6
	CV	0.43	0.04	0.46	0.43	0.21	0.37	0.21	0.02	0.35	1.37	0.43
2007-09-24		273	79	215	7	2.68	3.56	6.16	82.4	7	2.6	266
2009-07-29		294	85	251	11	3.20	3.07	5.21	93.2	12	0.3	293
2011-09-30		417	98	410	19	2.56	2.43	9.66	97.2	12	0.2	417
	AVG	328.0	87.3	292.0	12.3	2.812	3.019	7.009	90.93	10.3	1.03	325.3
	SD	77.8	9.7	103.8	6.1	0.344	0.565	2.341	7.66	2.9	1.36	80.5
	CV	0.24	0.11	0.36	0.50	0.12	0.19	0.33	0.08	0.28	1.31	0.25

COUNT=number of macroinvertebrates, % COUNT_EPT=% of macroinvertebrates in the EPT group; EPT_COUNT=number of macroinvertebrates in the EPT group, EPT_GENERA=number of macroinvertebrate genera in the EPT group, DIV=Shannon diversity index (H'), TOLVAL=tolerance value, mIBI= macroinvertebrate-based Index of Biotic Integrity, %POET=% of species in the Odonata and EPT groups, POET INDEX= an index for the POET metric, % DNC=% Diptera non-Chironomidae, TFM COUNT=number of species to which a trophic function metric has been assigned, AVG=average, SD=standard deviation, CV=coefficient of variation

Table 20. Metrics for macroinvertebrate samples, Grand Portage Creek, 2000-2011, 2000-2005, and 2007-2011. (continued)

DATE		% SCR	% FIL	% SHR	% GAT	% COL	SCR /FIL	SCR/ GAT	SCR /COL	TFM GEN	% SCR G	% FILG	% SHR G	% GAT G	% COL G	SCR/ FIL G	SCR/ GAT G	SCR/ COL G
2000-09-07		17	73	2	5	79	23	314	22	10	20	20	10	30	50	100	67	40
2001-09-13		2	90	1	1	91	2	180	2	14	7	21	7	14	36	33	50	20
2003-09-22		5	64	1	7	71	9	74	8	25	8	12	12	28	40	67	29	20
2005-09-08		11	71	0	2	73	16	550	15	11	36	18	0	18	36	200	200	100
2007-09-24		19	47	2	14	61	41	138	31	17	6	18	6	29	47	33	20	13
2009-07-29		4	38	42	3	42	10	110	9	24	13	25	17	17	42	50	75	30
2011-09-30		11	71	3	6	78	15	163	14	24	25	21	13	21	42	120	120	60
	AVG	9.9	64.9	7.3	5.4	70.7	16.6	218.4	14.4	17.9	16.4	19.3	9.3	22.4	41.9	86.1	80.1	40.4
	SD	6.5	17.4	15.3	4.4	15.6	12.6	164.7	9.6	6.5	11.2	4.0	5.5	6.5	5.2	60.0	62.3	30.6
	CV	0.66	0.27	2.11	0.80	0.22	0.76	0.75	0.67	0.36	0.68	0.21	0.60	0.29	0.13	0.70	0.78	0.76
2000-09-07		17	73	2	5	79	23	314	22	10	20	20	10	30	50	100	67	40
2001-09-13		2	90	1	1	91	2	180	2	14	7	21	7	14	36	33	50	20
2003-09-22		5	64	1	7	71	9	74	8	25	8	12	12	28	40	67	29	20
2005-09-08		11	71	0	2	73	16	550	15	11	36	18	0	18	36	200	200	100
	AVG	8.8	74.5	1.0	3.8	78.5	12.5	279.5	11.8	15.0	17.8	17.8	7.3	22.5	40.5	100.0	86.5	45.0
	SD	6.7	11.0	0.8	2.8	9.0	9.0	205.3	8.7	6.9	13.5	4.0	5.3	7.7	6.6	72.1	77.2	37.9
	CV	0.76	0.15	0.82	0.73	0.11	0.72	0.73	0.74	0.46	0.76	0.23	0.72	0.34	0.16	0.72	0.89	0.84
2007-09-24		19	47	2	14	61	41	138	31	17	6	18	6	29	47	33	20	13
2009-07-29		4	38	42	3	42	10	110	9	24	13	25	17	17	42	50	75	30
2011-09-30		11	71	3	6	78	15	163	14	24	25	21	13	21	42	120	120	60
	AVG	11.3	52.0	15.7	7.7	60.3	22.0	137.0	18.0	21.7	14.7	21.3	12.0	22.3	43.7	67.7	71.7	34.3
	SD	7.5	17.1	22.8	5.7	18.0	16.6	26.5	11.5	4.0	9.6	3.5	5.6	6.1	2.9	46.1	50.1	23.8
	CV	0.66	0.33	1.46	0.74	0.30	0.76	0.19	0.64	0.19	0.66	0.16	0.46	0.27	0.07	0.68	0.70	0.69

% SCR, % FIL, % SHR, % GAT, % COL=% of species in TFM that are scrapers, filterers, shredders, gatherers, or collectors, respectively;
SCR/FIL, SCR/GAT, SCR/COL=ratio of scrapers to filterers, gatherers, or collectors, respectively (a value of 100 represents a 1:1 ratio),
TFM GEN= number of genera with a trophic function metric assigned,
% SCR G, % FIL G, % SHR G, % GAT G, % COL G==% of genera in TFM that are scrapers, filterers, shredders, gatherers, or collectors, respectively; SCR/FIL G, SCR/GAT G, SCR/COL G, = ratio of genera of scrapers to filterers, gatherers, or collectors, respectively (a value of 100 represents a 1:1 ratio),
AVG=average, SD=standard deviation, CV=coefficient of variation

Table 21. Metrics for macroinvertebrate samples, Poplar Creek, 2001-2011, 2001-2005, and 2007-2011.

DATE		SR	GR	GR_ EPT	HBI	HBI_ COUNT	HBI10	HBI10_ COUNT	HBI_EPT_ COUNT	FBI	FBI_ COUNT	FBI_EPT_ COUNT	BIOINDEX INSECTS ONLY
2001-09-18		12	12	42	0.39	96	1.54	24	91	3.50	199	95	0.39
2003-09-30		42	40	43	4.20	319	4.52	152	77	3.79	378	66	4.19
2005-09-15		11	10	40	3.13	104	3.64	25	95	3.64	164	97	3.13
2007-10-12		39	25	12	3.50	58	3.59	39	34	3.87	61	34	3.42
2009-09-17		25	22	73	3.63	280	3.31	98	98	3.52	287	97	3.61
2011-07-25		46	45	44	3.13	321	3.13	142	91	3.73	349	88	3.11
	AVG	29.2	25.7	42.3	2.995	196.3	3.289	80.0	81.0	3.675	239.7	79.5	2.974
	SD	15.4	14.3	19.3	1.339	122.7	0.980	58.6	24.1	0.147	120.5	25.2	1.329
	CV	0.53	0.56	0.46	0.45	0.63	0.30	0.73	0.30	0.04	0.50	0.32	0.45
2001-09-18		12	12	42	0.39	96	1.54	24	91	3.50	199	95	0.39
2003-09-30		42	40	43	4.20	319	4.52	152	77	3.79	378	66	4.19
2005-09-15		11	10	40	3.13	104	3.64	25	95	3.64	164	97	3.13
	AVG	21.7	20.7	41.7	2.571	173.0	3.234	67.0	87.7	3.644	247.0	86.0	2.567
	SD	17.6	16.8	1.5	1.969	126.5	1.530	73.6	9.5	0.143	114.8	17.3	1.964
	CV	0.81	0.81	0.04	0.77	0.73	0.47	1.10	0.11	0.04	0.46	0.20	0.76
2007-10-12		39	25	12	3.50	58	3.59	39	34	3.87	61	34	3.42
2009-09-17		25	22	73	3.63	280	3.31	98	98	3.52	287	97	3.61
2011-07-25		46	45	44	3.13	321	3.13	142	91	3.73	349	88	3.11
	AVG	36.7	30.7	43.0	3.418	219.7	3.343	93.0	74.3	3.705	232.3	73.0	3.381
	SD	10.7	12.5	30.5	0.259	141.5	0.230	51.7	35.1	0.176	151.6	34.1	0.250
	CV	0.29	0.41	0.71	0.08	0.64	0.07	0.56	0.47	0.05	0.65	0.47	0.07

SR=species richness, GR=generic richness, GR_EPT=generic richness for the EPT group, HBI= Hilsenhoff Biotic Index, HBI_Count=count for the Hilsenhoff Biotic Index, HBI10= Hilsenhoff 10-Max Biotic Index, HBI10_Count= count for the Hilsenhoff 10-Max Biotic Index, HBI_EPT_COUNT=count for the Hilsenhoff Biotic Index for the EPT group, FBI=Family-level Biotic Index, FBI_Count=count for the Family-level Biotic Index, FBI_EPT_COUNT= count for the Family-level Biotic Index for the EPT group, BIOINDEX=biotic index, AVG=average, SD=standard deviation, CV=coefficient of variation.

Table 21. Metrics for macroinvertebrate samples, Poplar Creek, 2001-2011, 2001-2005, and 2007-2011. (continued).

DATE		COUNT	% COUNT_ EPT	EPT_ COUNT	EPT_ GENERA	DIV	TOLVAL	mIBI	%POET	POET INDEX	% DNC	TFM COUNT
2001-09-18		215	88	190	5	2.47	2.80	4.99	92.1	6	0.5	214
2003-09-30		394	63	250	17	4.13	4.68	9.38	75.0	12	0.5	391
2005-09-15		172	92	159	4	2.23	3.83	1.08	93.7	5	0.0	172
2007-10-12		264	8	21	3	3.01	5.00	3.28	21.2	6	0.3	259
2009-09-17		294	95	278	16	3.14	3.10	8.61	94.6	8	1.0	294
2011-07-25		376	82	307	20	4.23	3.21	8.83	79.5	15	2.9	373
	AVG	285.8	71.3	200.8	10.8	3.203	3.770	6.027	76.02	8.7	0.87	283.8
	SD	87.6	33.0	103.8	7.6	0.828	0.900	3.432	28.05	4.0	1.05	86.6
	CV	0.31	0.46	0.52	0.70	0.26	0.24	0.57	0.37	0.46	1.21	0.31
2001-09-18		215	88	190	5	2.47	2.80	4.99	92.1	6	0.5	214
2003-09-30		394	63	250	17	4.13	4.68	9.38	75.0	12	0.5	391
2005-09-15		172	92	159	4	2.23	3.83	1.08	93.7	5	0.0	172
	AVG	260.3	81.0	199.7	8.7	2.946	3.770	5.148	86.93	7.7	0.33	259.0
	SD	117.7	15.7	46.3	7.2	1.034	0.940	4.152	10.37	3.8	0.29	116.2
	CV	0.45	0.19	0.23	0.83	0.35	0.25	0.81	0.12	0.49	0.87	0.45
2007-10-12		264	8	21	3	3.01	5.00	3.28	21.2	6	0.3	259
2009-09-17		294	95	278	16	3.14	3.10	8.61	94.6	8	1.0	294
2011-07-25		376	82	307	20	4.23	3.21	8.83	79.5	15	2.9	373
	AVG	311.3	61.7	202.0	13.0	3.459	3.769	6.906	65.10	9.7	1.40	308.7
	SD	58.0	46.9	157.4	8.9	0.670	1.067	3.145	38.76	4.7	1.35	58.4
	CV	0.19	0.76	0.78	0.68	0.19	0.28	0.46	0.60	0.49	0.96	0.19

COUNT=number of macroinvertebrates, % COUNT_EPT=% of macroinvertebrates in the EPT group; EPT_COUNT=number of macroinvertebrates in the EPT group, EPT_GENERA=number of macroinvertebrate genera in the EPT group, DIV=Shannon diversity index (H'), TOLVAL=tolerance value, mIBI= macroinvertebrate-based Index of Biotic Integrity, %POET=% of species in the Odonata and EPT groups, POET INDEX= an index for the POET metric, % DNC=% Diptera non-Chironomidae, TFM COUNT=number of species to which a trophic function metric has been assigned, AVG=average, SD=standard deviation, CV=coefficient of variation

Table 21. Metrics for macroinvertebrate samples, Poplar Creek, 2001-2011, 2001-2005, and 2007-2011. (continued).

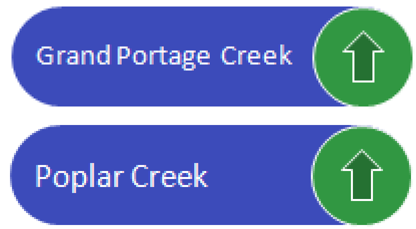
DATE		% SCR	% FIL	% SHR	% GAT	% COL	SCR /FIL	SCR/ GAT	SCR/ COL	TFM GEN	% SCR G	% FILG	% SHR G	% GAT G	% COL G	SCR/ FIL G	SCR/ GAT G	SCR/ COL G
2001-09-18		13	65	0	12	77	20	108	17	11	9	18	0	27	45	50	33	20
2003-09-30		14	39	1	25	64	37	57	22	39	10	18	8	38	56	57	27	18
2005-09-15		29	63	0	3	66	46	1000	44	10	10	30	0	10	40	33	100	25
2007-10-12		0	0	3	10	10	0	0	0	24	0	0	8	33	33	0	0	0
2009-09-17		20	61	1	13	73	33	159	27	22	18	32	5	32	64	57	57	29
2011-07-25		18	46	7	25	71	39	73	25	44	9	18	14	30	48	50	31	19
	AVG	15.7	45.7	2.0	14.7	60.2	35.0	232.8	22.5	25.0	9.3	19.3	5.8	28.3	47.7	49.4	41.3	18.5
	SD	9.6	24.7	2.7	8.7	25.0	9.6	379.5	14.3	14.1	5.7	11.4	5.4	9.7	11.1	9.8	34.0	10.0
	CV	0.61	0.54	1.34	0.60	0.42	0.27	1.63	0.64	0.56	0.61	0.59	0.92	0.34	0.23	0.20	0.82	0.54
2001-09-18		13	65	0	12	77	20	108	17	11	9	18	0	27	45	50	33	20
2003-09-30		14	39	1	25	64	37	57	22	39	10	18	8	38	56	57	27	18
2005-09-15		29	63	0	3	66	46	1000	44	10	10	30	0	10	40	33	100	25
	AVG	18.7	55.7	0.3	13.3	69.0	34.3	388.3	27.7	20.0	9.7	22.0	2.7	25.0	47.0	46.7	53.3	21.0
	SD	9.0	14.5	0.6	11.1	7.0	13.2	530.3	14.4	16.5	0.6	6.9	4.6	14.1	8.2	12.3	40.5	3.6
	CV	0.48	0.26	1.73	0.83	0.10	0.38	1.37	0.52	0.82	0.06	0.31	1.73	0.56	0.17	0.26	0.76	0.17
2007-10-12		0	0	3	10	10	0	0	0	24	0	0	8	33	33	0	0	0
2009-09-17		20	61	1	13	73	33	159	27	22	18	32	5	32	64	57	57	29
2011-07-25		18	46	7	25	71	39	73	25	44	9	18	14	30	48	50	31	19
	AVG	12.7	35.7	3.7	16.0	51.3	36.0	77.3	17.3	30.0	9.0	16.7	9.0	31.7	48.3	53.5	29.3	16.0
	SD	11.0	31.8	3.1	7.9	35.8	4.2	79.6	15.0	12.2	9.0	16.0	4.6	1.5	15.5	4.9	28.5	14.7
	CV	0.87	0.89	0.83	0.50	0.70	0.12	1.03	0.87	0.41	1.00	0.96	0.51	0.05	0.32	0.09	0.97	0.92

% SCR, % FIL, % SHR, % GAT, % COL=% of species in TFM that are scrapers, filterers, shredders, gatherers, or collectors, respectively; SCR/FIL, SCR/GAT, SCR/COL=ratio of scrapers to filterers, gatherers, or collectors, respectively (a value of 100 represents a 1:1 ratio),
TFM GEN= number of genera with a trophic function metric assigned,
% SCR G, % FIL G, % SHR G, % GAT G, % COL G==% of genera in TFM that are scrapers, filterers, shredders, gatherers, or collectors, respectively; SCR/FIL G, SCR/GAT G, SCR/COL G, = ratio of genera of scrapers to filterers, gatherers, or collectors, respectively (a value of 100 represents a 1:1 ratio),
AVG=average, SD=standard deviation, CV=coefficient of variation

Reference Conditions

The reference conditions chosen for Grand Portage and Poplar Creeks are as follows: HBI $\leq$ 4.00, TAXA richness $\geq$ 20, EPT generic richness $\geq$ 10, H' > 2.50, and clinger habit dominating $\geq$ 40%. These represent a "minimally disturbed condition," or "the condition of a system in the absence of significant human disturbance" (Stoddard et al. 2006).

Condition and Trend



Examination of recent aquatic macroinvertebrate data from Grand Portage Creek and Poplar Creek (Watkins 2012) indicated stable – improving conditions. Considering average scores for samples collected from 2007-2011, Grand Portage Creek and Poplar Creek both received "excellent" scores on the HBI (2.3 and 3.4, respectively); taxa richness scores of 22 and 37, respectively; a "non-impacted" score on the EPT generic richness metric (55 and 43, respectively); and H' scores of 2.8 and 3.5, respectively. Of 40 metrics calculated for Grand Portage Creek, 13 (33%) were improving, 13 (33%) were steady, four (10%) were increasing, three (8%) were decreasing, and seven (18%) were irrelevant for this analysis. For Poplar Creek, 12 (30%) were improving, two (5%) were improving to steady, 12 (30%) were steady, six (15%) were increasing, one (3%) was decreasing, and seven (18%) were irrelevant for this analysis. Most metric values, compared from 2007-2011, increased in quality rating over time (Table 22 and Table 23). We rate the condition of the macroinvertebrate communities in these streams as good, with an improving trend. Some of this quality increase was certainly due to 2007 being a regional drought year (B. Seitz, email communication, 22 March 2012), resulting in low flow situations throughout the region, as shown in a hydrograph for the nearby Pigeon River (Figure 39). Surface runoff is the main factor controlling stream flow in the Lake Superior watershed (MPCA 1975), and stream flows are highly variable. Some reported maximum/minimum streamflow events exhibited magnitudes of 2-3. These harsh physical conditions can lead to highly variable macroinvertebrate communities, even in healthy unimpacted watersheds.

Low flow situations alter stream habitats in several ways. Reduction of stream flow may dewater habitats and eliminate refugia such as pools and under-bank areas. Reduction in current velocity may lead to a decrease in suspended particles, an increase in particle deposition, an increase in embeddedness, and loss of interstitial space. Macroinvertebrate responses to these alterations may include displacement of rheophilic taxa to less-than-optimal habitats, causing clustered distributions; displacement of clinging taxa; displacement of bank-side taxa to mid-stream habitats; and short-term changes to trophic function measures based on changes to delivery of organic particles.

Macroinvertebrate sampling was performed during these low flow situations, and the resultant taxonomic listings for 2007 collections display changes to the community attributable to low

Table 22. Assessment of macroinvertebrate metrics for Grand Portage Creek, 2007-2011.

DATE	SR	GR	GR_ EPT	HBI	HBI_ COUNT	HBI10	HBI10_ COUNT	HBI_EPT_ COUNT	FBI	FBI_ COUNT	FBI_EPT_ COUNT	BIOINDEX INSECTS ONLY
2007-09-24	18	18	39	2.72	107	2.82	45	91	3.71	233	92	2.72
2009-07-29	24	23	48	1.99	255	2.94	83	92	2.79	277	91	1.99
2011-09-30	25	24	79	2.15	407	1.73	106	99	3.48	413	99	2.15
AVG	22.3	21.7	55.3	2.286	256.3	2.496	78.0	94.0	3.327	307.7	94.0	2.286
SD	3.8	3.2	21.0	0.384	150.0	0.669	30.8	4.4	0.479	93.8	4.4	0.384
CV	0.17	0.15	0.38	0.17	0.59	0.27	0.39	0.05	0.14	0.30	0.05	0.17
TREND	impr	impr	impr	impr	irr	impr	irr	steady	steady	irr	steady	impr

DATE	COUNT	% COUNT_ EPT	EPT_ COUNT	EPT_ GENERA	DIV	TOLVAL	mIBI	%POET	POET INDEX	% DNC	TFM COUNT
2007-09-24	273	79	215	7	2.68	3.56	6.16	82.4	7	2.6	266
2009-07-29	294	85	251	11	3.20	3.07	5.21	93.2	12	0.3	293
2011-09-30	417	98	410	19	2.56	2.43	9.66	97.2	12	0.2	417
AVG	328.0	87.3	292.0	12.3	2.812	3.019	7.009	90.93	10.3	1.03	325.3
SD	77.8	9.7	103.8	6.1	0.344	0.565	2.341	7.66	2.9	1.36	80.5
CV	0.24	0.11	0.36	0.50	0.12	0.19	0.33	0.08	0.28	1.31	0.25
TREND	irr	impr	irr	impr	steady	impr	impr	impr	steady	impr	irr

DATE	% SCR	% FIL	% SHR	% GAT	% COL	SCR /FIL	SCR/ GAT	SCR /COL	TFM GEN	% SCR G	% FIL G	% SHR G	% GAT G	% COL G	SCR/ FIL G	SCR/ GAT G	SCR/ COL G
2007-09-24	19	47	2	14	61	41	138	31	17	6	18	6	29	47	33	20	13
2009-07-29	4	38	42	3	42	10	110	9	24	13	25	17	17	42	50	75	30
2011-09-30	11	71	3	6	78	15	163	14	24	25	21	13	21	42	120	120	60
AVG	11.3	52.0	15.7	7.7	60.3	22.0	137.0	18.0	21.7	14.7	21.3	12.0	22.3	43.7	67.7	71.7	34.3
SD	7.5	17.1	22.8	5.7	18.0	16.6	26.5	11.5	4.0	9.6	3.5	5.6	6.1	2.9	46.1	50.1	23.8
CV	0.66	0.33	1.46	0.74	0.30	0.76	0.19	0.64	0.19	0.66	0.16	0.46	0.27	0.07	0.68	0.70	0.69
TREND	steady	incr	steady	decr	steady	decr	steady	decr	irr	impr	steady	steady	steady	steady	incr	incr	incr

CV: green=low variability, yellow=moderate variability, red=high variability
TREND: impr=improving, incr=increasing, decr=decreasing, irr=irrelevant

Table 23. Assessment of macroinvertebrate metrics for Poplar Creek, 2007-2011.

DATE		SR	GR	GR_ EPT	HBI	HBI_ COUNT	HBI10	HBI10_ COUNT	HBI_EPT_ COUNT	FBI	FBI_ COUNT	FBI_EPT_ COUNT	BIOINDEX INSECTS ONLY
2007-10-12		39	25	12	3.50	58	3.59	39	34	3.87	61	34	3.42
2009-09-17		25	22	73	3.63	280	3.31	98	98	3.52	287	97	3.61
2011-07-25		46	45	44	3.13	321	3.13	142	91	3.73	349	88	3.11
	AVG	36.7	30.7	43.0	3.418	219.7	3.343	93.0	74.3	3.705	232.3	73.0	3.381
	SD	10.7	12.5	30.5	0.259	141.5	0.230	51.7	35.1	0.176	151.6	34.1	0.250
	CV	0.29	0.41	0.71	0.08	0.64	0.07	0.56	0.47	0.05	0.65	0.47	0.07
	TREND	impr	impr	steady	impr-steady	irr	impr	irr	impr	steady	irr	impr	impr-steady

DATE		COUNT	% COUNT_ EPT	EPT_ COUNT	EPT_ GENERA	DIV	TOLVAL	mIBI	%POET	POET INDEX	% DNC	TFM COUNT
2007-10-12		264	8	21	3	3.01	5.00	3.28	21.2	6	0.3	259
2009-09-17		294	95	278	16	3.14	3.10	8.61	94.6	8	1.0	294
2011-07-25		376	82	307	20	4.23	3.21	8.83	79.5	15	2.9	373
	AVG	311.3	61.7	202.0	13.0	3.459	3.769	6.906	65.10	9.7	1.40	308.7
	SD	58.0	46.9	157.4	8.9	0.670	1.067	3.145	38.76	4.7	1.35	58.4
	CV	0.19	0.76	0.78	0.68	0.19	0.28	0.46	0.60	0.49	0.96	0.19
	TREND	irr	impr	irr	impr	impr	impr	impr	steady	impr	decr	irr

DATE		% SCR	% FIL	% SHR	% GAT	% COL	SCR /FIL	SCR/ GAT	SCR/ COL	TFM GEN	% SCR G	% FILG	% SHR G	% GAT G	% COL G	SCR/ FIL G	SCR/ GAT G	SCR/ COL G
2007-10-12		0	0	3	10	10	0	0	0	24	0	0	8	33	33	0	0	0
2009-09-17		20	61	1	13	73	33	159	27	22	18	32	5	32	64	57	57	29
2011-07-25		18	46	7	25	71	39	73	25	44	9	18	14	30	48	50	31	19
	AVG	12.7	35.7	3.7	16.0	51.3	36.0	77.3	17.3	30.0	9.0	16.7	9.0	31.7	48.3	53.5	29.3	16.0
	SD	11.0	31.8	3.1	7.9	35.8	4.2	79.6	15.0	12.2	9.0	16.0	4.6	1.5	15.5	4.9	28.5	14.7
	CV	0.87	0.89	0.83	0.50	0.70	0.12	1.03	0.87	0.41	1.00	0.96	0.51	0.05	0.32	0.09	0.97	0.92
	TREND	incr	incr	incr	incr	incr	incr	steady	steady	irr	steady	steady	incr	steady	steady	steady	steady	steady

CV: green=low variability, yellow=moderate variability, red=high variability

TREND: impr=improving, impr-steady=improving to steady, incr=increasing, decr=decreasing, irr=irrelevant

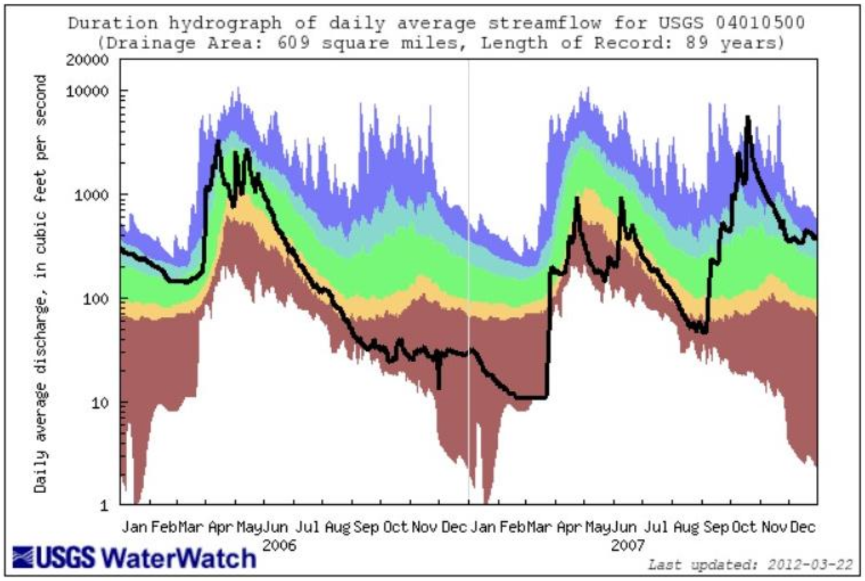


Figure 39. Hydrograph for the Pigeon River at Middle Falls near Grand Portage, Minnesota, showing low-flow conditions from August, 2006 to April, 2007 (picture from waterdata.usgs.gov/nwis).

flow conditions. Low flow situations in the Grand Portage Creek 2007 collections were noted by the one-time appearance and high relative abundance (19%) of the mayfly *Arthroplea bipunctata*. This larva inhabits streamside pools and depositional areas of slow woodland streams and feeds on deposited fine particulate organic matter by creating vortices with its specialized maxillary palpi, filtering out the resultant suspended organic matter. The highest abundance of snails in any Grand Portage Creek collection, especially slow-water specialists in the families Physidae and Planorbidae, also occurred in 2007.

Low flow situations in Poplar Creek 2007 were noted by only one rheophilic (fast-moving water) taxon, *Leptophlebia* Westwood (Ephemeroptera: Leptophlebiidae), being present among the 39 unique taxa in the sample. Additionally, the high abundance (66%) of Corixidae (Hemiptera), a swimming group, suggest low current velocity and lack of bankside refugia at the time of sample collection, an observation reinforced by the occurrence of six swimming Coleoptera taxa, four climbing/sprawling Odonata taxa, and snails in the families Physidae and Planorbidae.

These observations suggest the low flow regimes of 2007 altered available stream habitats, macroinvertebrate food resources, current velocities, and resultant macroinvertebrate community assemblage. Using 2007 data in the formation of reference conditions for the streams of GRPO is not advised.

Collections from 2009 and 2011 contained many rheophilic taxa and were predominated by clinging forms (Figure 40).

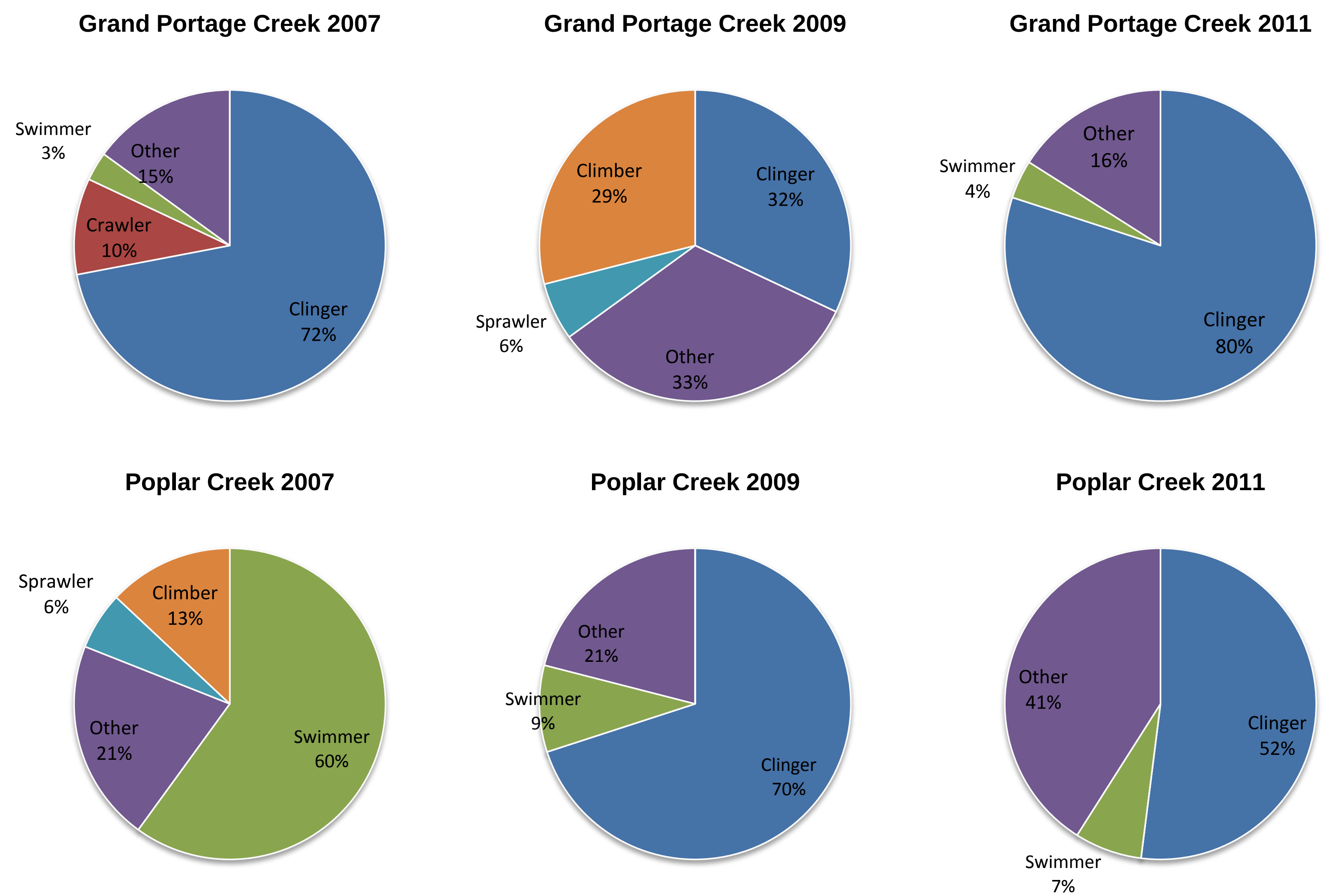


Figure 40. Life habit of five top taxa found in samples collected from Grand Portage and Poplar Creeks, 2007-2009.

Weighted average biotic index (HBI, FBI) values exhibited improving or stable trends from 2007-2011 (Table 22 and Table 23). BIs intended to reduce variability in the calculated value (HBI10, MPTV) displayed improving trends. Some of the improving trend is due to recovery of stream macroinvertebrate community from the low flow conditions of 2007. Future BI values should stabilize near the values calculated from 2009 and 2011 collections.

The m-Index of Biotic Integrity values were lowest in 2007 and 2009 (Table 22 and Table 23), increasing to excellent values in the last year of sampling. Low Chironomidae abundance, high numbers of intolerant taxa, and low abundance of depositional taxa drove IBI values up in the last year. The mIBI may have validity in classifying condition of GRPO streams, as the wide range of values returned provide great discriminatory power in spite of the metric's high variability.

The predominance of filter feeders in most samples (Figure 41) except the 2007 Poplar Creek low flow sample suggest that delivery and transport of fine particulate organic matter (FPOM) is important to maintaining the macroinvertebrate communities of the streams in GRPO. Probable sources of FPOM are natural processing of coarse particulate organic matter (CPOM) and release of FPOM from human-made and beaver impoundments.

EPT values suggest slight to moderate impact (Table 20 and Table 21) during 2007 and no impact in 2009 and 2011 collections.

This data set for these streams in GRPO should be viewed as a baseline data set. The metric values from years 2007-2011, especially 2009 and 2011, should be considered as defining the reference condition values.

<u>Sources of Expertise</u>

Jeffrey J. Dimick, Laboratory Supervisor, Aquatic Biomonitoring Laboratory, University of Wisconsin – Stevens Point, 26 years practical experience processing biomonitoring samples and interpreting results for Wisconsin Department of Natural Resources, United States Geological Survey, United States Environmental Protection Agency, NPO's/NGO's; Margaret Watkins.

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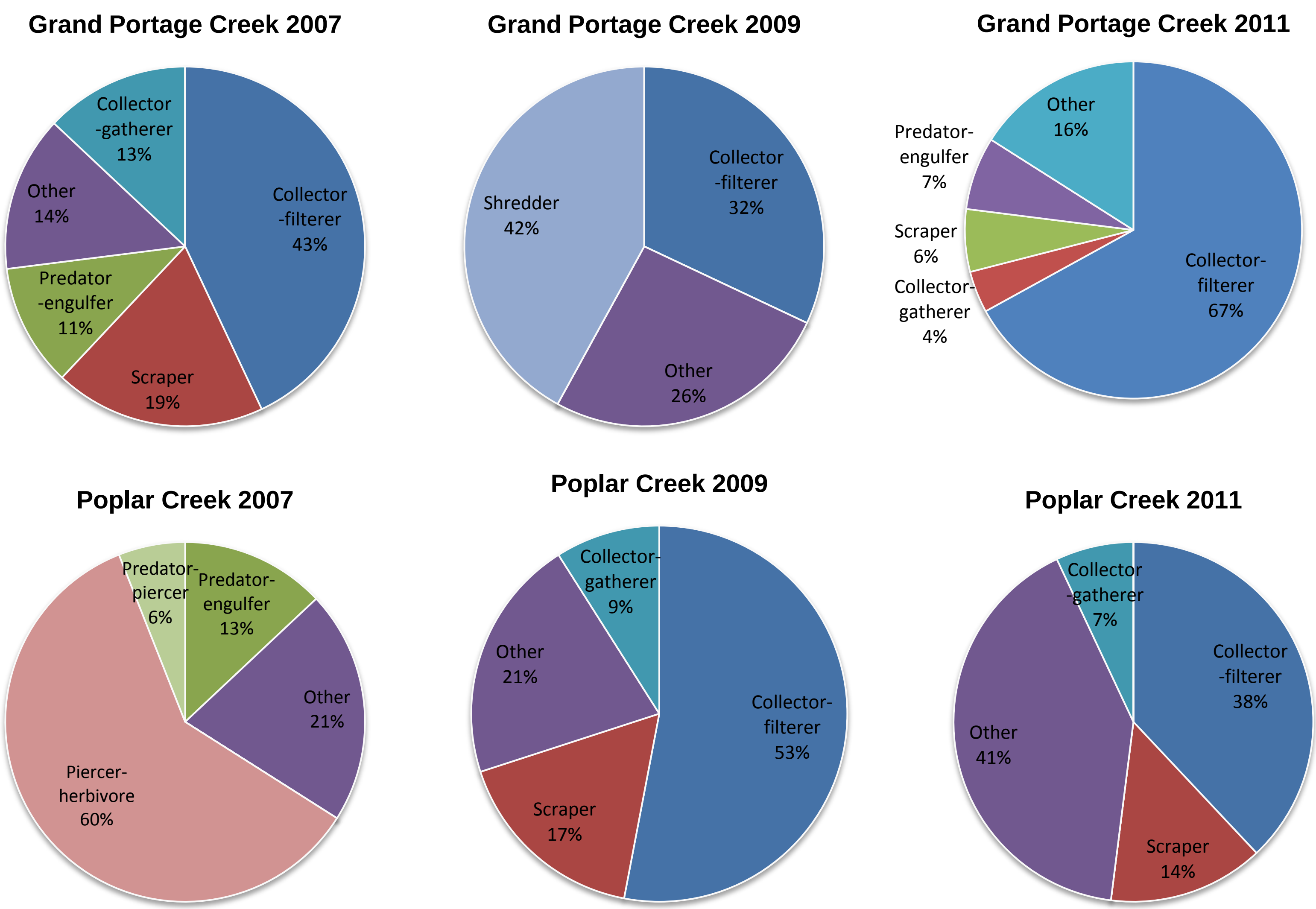

Figure 41. Trophic function of five top taxa found in samples collected from Grand Portage and Poplar Creeks, 2007-2011.

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4.2.8 Aquatic Non-Native and Invasive Species

Description

As of February, 2009, 88 non-native aquatic species have been found in Lake Superior (Lake Superior Work Group 2010). Non-native species interact with the environment in unpredictable ways, and at least ten percent of non-native species are considered to be invasive and negatively affect ecosystem health (Environment Canada and USEPA 2009). Invasive species are the second-leading cause of loss of biodiversity and species extinction in aquatic environments worldwide (USEPA 2008). The Lake Superior Aquatic Invasive Species Complete Prevention Plan (Lake Superior Work Group 2010) indicates the importance of preventing the spread of AIS out of Lake Superior into inland waters.

Data and Methods

The Great Lakes Indian Fish and Wildlife Commission (GLIFWC) has maps of aquatic invasive species (AIS) at http://maps.glifwc.org/.

A 2007 report (Quinlan et al. 2007) assessed the threat of AIS in GLKN parks, including GRPO, and produced a list of species most important to monitor.

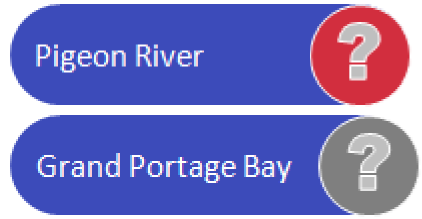
The biennial State of the Great Lakes Conference (http://www.epa.gov/solec/) provides updated information on the condition of each of the Great Lakes relative to invasive species.

Reference Condition

Non-native aquatic species should not be present in numbers that are detrimental to the functioning of natural aquatic ecosystems. This represents a "historic condition" (Stoddard et al. 2006).

Condition and Trend

The Grand Portage Band (Moore et al. 2006) has reported the presence of "great numbers" of rusty crayfish (*Orconectes rusticus*) that have displaced most native crayfish in the Pigeon River watershed. We rate the condition of the Pigeon River for aquatic invasive species as of significant concern, with an uncertain trend; our confidence in this assessment is good. The Great Lakes Indian Fish and Wildlife Commission (GLIFWC) has noted the presence of the plant purple loosestrife (*Lythrum salicaria*) in Grand Portage Bay (http://maps.glifwc.org/). The extent of the purple loosestrife invasion is unknown. We rate the condition of Grand Portage Bay as unknown for aquatic invasive species, with an uncertain trend, and our confidence in this assessment is fair. It should be noted here that neither Grand Portage Bay nor the Pigeon River are under the jurisdiction of NPS.



The rusty crayfish has been confirmed in five North Shore counties in Minnesota, including Cook County (USGS 2012). They are probably spread by anglers who use them as fishing bait, although it is illegal to sell them as bait or aquarium pets in Minnesota. They inhabit lakes, ponds, and streams (including pools and riffles) and prefer areas that have rocks and/or logs as cover (Gunderson 2008). Their major ecologic effects include displacing native crayfish, reducing volume and diversity of aquatic plants, decreasing the density and variety of invertebrates, and reducing some fish populations (Gunderson 2008 and citations therein).

Rainbow smelt (*Osmerus mordax*) are reported from both Grand Portage Bay (http://maps.glifwc.org/) and Pigeon Bay (Moore et al. 2006). These fish, although non-native, are an important prey fish in Lake Superior (Gorman 2012), so their presence is not necessarily a reason for concern. Rainbow smelt were abundant during the 1930s, 1940s, and 1950s (Horns et al. 2003), but their numbers have been greatly reduced by lake trout predation (Bronte et al. 2003). Their biomass fluctuated but declined during 1978-2011 (Figure 42) and from 2008-2011 was only 7-11% of the peak 1978 level (Gorman 2012).

Purple loosestrife is native to Eurasia and was transported to North America in the early 1800s, most likely in the ballast of ships, and was later distributed as an ornamental (Stackpoole 1997). Currently, there are approximately 2,000 purple loosestrife infestations in Minnesota, and they occur in 77 of Minnesota's 87 counties, the majority (70%) in lakes, rivers, or wetlands (MDNR 2012). This species is an aggressive plant that prefers wetlands, stream edges, and banks, along with cattails and sedges. Purple loosestrife can have a devastating effect on native plants and animals because it can reduce shelter and niche space and food for native wildlife such as waterfowl, frogs and toads, salamanders, and some fish with its dense growth and resulting obstruction of normal water flow (Stackpoole 1997).

The Grand Portage Band (Moore et al. 2006) has reported the presence of the threespine stickleback (*Gasterosteus aculeatus*) and sea lamprey (*Petromyzon marinus*) wounding rates on fish of up to 20% in Pigeon Bay. The threespine stickleback has been known in Lake Superior since at least 1994. Threespine stickleback feed on a variety of fauna, including zooplankton, oligochaete worms, macroinvertebrates (insect larvae), small fish, fish eggs, crustaceans, adult aquatic insects, and drowned aerial insects. Their known impacts are that they compete with native sticklebacks for food and space and prey on other fishes' eggs (Quinlan et al. 2007).

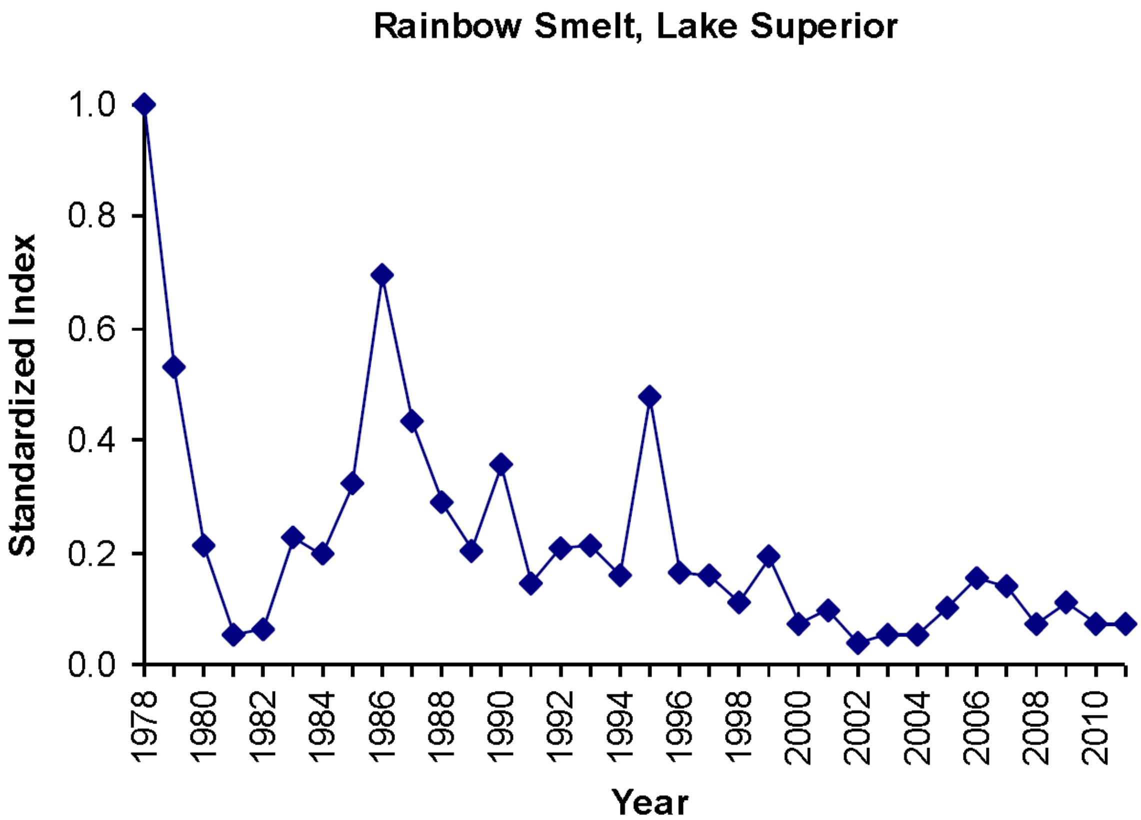


Figure 42. Standardized indices of biomass for age-1 and older rainbow smelt in Lake Superior, 1978-2011 (from Gorman 2012).

Sea lampreys, by feeding on the body fluids and blood of fish, have significantly reduced the large native predator fish populations which comprise the top levels of the food web in the Great Lakes (Quinlan et al. 2007). Their abundance in the mid-2000s was only 17% of their abundance before 1958, when control measures were instituted. However, the Lake Superior Technical Committee set a target mean sea lamprey marking rate of 5 marks per 100 lake trout >533 mm, and the 2001-2005 rate of 9.5 marks exceeded that target (Steeves et al. 2010), as did the Grand Portage Band's reported rate for Pigeon Bay.

In 2007, the USFWS published recommendations for AIS monitoring in each of the GLKN parks (Quinlan et al. 2007). For GRPO, the top five species recommended for monitoring were the rusty crayfish, ruffe (*Gymnocephalus cernuus*), zebra mussel (*Dreissena polymorpha*), quagga mussel (*D. bugensis*), and white perch (*Morone americana*).

Sources of Expertise
USGS Nonindigenous Aquatic Species Database, Quinlan et al. 2007, Chris Mechenich.

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4.2.9 VHSv

Description

Viral Hemorrhagic Septicemia virus (VHSv) is a deadly fish pathogen first detected in North America in 1988 among pacific salmonids in Washington State (Meyers and Winton 1995). This virus was first thought to have been introduced from Europe, where VHSv has been a known issue in salmon aquaculture since the 1950s. However, genetic analysis indicated VHSv found in North America is of a unique genotype. The isolate, or unique genetic type, of VHSv found in the Great Lakes is most similar to VHSv found along the Atlantic coast of North America (Winton et al. 2008). It is likely that VHSv was introduced to the Great Lakes via transport in ballast water or in infected migratory fishes (Elsayed et al. 2006).

The symptoms of VHSv differ over the course of the infection and by the species infected (Kipp and Ricciardi 2012). During the early stages of infection some mortality can occur, and the nervous system of the fish can be affected, causing twitching of the body and erratic swimming behavior. The infected fish becomes lethargic, dark, and anemic, with bulging eyes. Internal organs are affected, and widespread hemorrhaging occurs (McAllister 1990). Other carriers show no symptoms at all. Mortality rates are high, between 20% and 80% depending on environmental conditions, and any surviving fish can carry the virus throughout the rest of its life (Kipp and Ricciardi 2012)

Unfortunately, the introduction of VHSv into the Great Lakes has led to widespread occurrences of VHSv in many native and introduced fish species (Figure 43). The first occurred in 2005 and caused significant mortality of freshwater drum (*Aplodinotus grunniens*) in the Bay of Quinte, Lake Ontario (NPS and Grand Portage Band 2008). By 2007, the four lower Great Lakes had reports of VHSv; it was detected in Lake Superior at APIS in 2009 and in Superior Bay and near Skanee, Michigan and Paradise, Michigan in 2010 (NPS and Grand Portage Band 2008, USGS 2012).

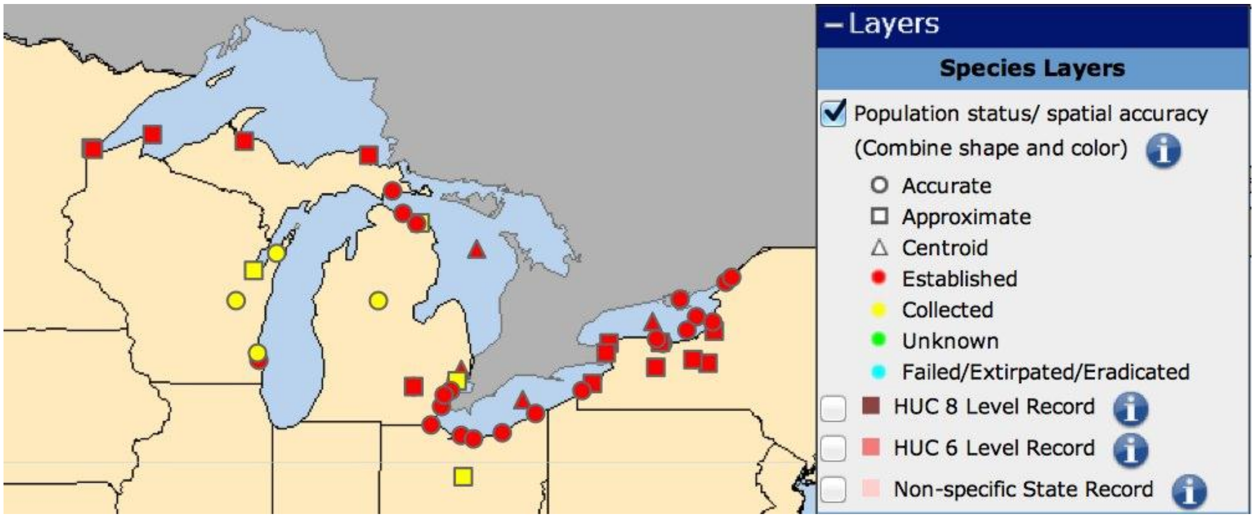

Figure 43. Known VHS occurrences in the Great Lakes as of February 2012 (from USGS 2012).

Many of the native and introduced fishes of the Great Lakes are vulnerable to VHSv (Table 24). The U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS) lists 28 species that are carriers of or are susceptible to VHSv in the Great Lakes (NPS and Grand Portage Band 2008), and significant fish mortalities have been reported in many of these fish species. In a research review, McAllister (1990) also lists brook trout among the vulnerable species (NPS and Grand Portage Band 2008). With the spread of VHSv to Lake Superior, fish species inhabiting GRPO are at risk.

Table 24. Native and introduced fish species in the Great Lakes listed by APHIS as being affected by VHSv (NPS and Grand Portage Band 2008).

Black crappie	Bluegill	Bluntnose minnow	Brown bullhead
Brown trout	Burbot	Channel catfish	Chinook salmon
Emerald shiner	Freshwater drum	Gizzard shad	Lake whitefish
Largemouth bass	Muskellunge	Shorthead redhorse	Northern Pike
Pumpkinseed	Rainbow trout	Rock bass	Round goby
Silver redhorse	Smallmouth bass	Spottail shiner	Trout-Perch
Walleye	White bass	White perch	Yellow perch

Data and Methods

Due to the severity of the VHSv threat, the NPS and Grand Portage Band have worked together to develop the "Emergency Prevention and Response Plan for Viral Hemorrhagic Septicemia" (NPS and Grand Portage Band 2008). This plan was published in 2008 and focuses on preventing contamination, detecting, and responding to the introduction of VHSv in the four NPS units located in Lake Superior and on the Grand Portage Reservation.

Reference Conditions

VHSv should not be detected in Grand Portage Bay or any GRPO inland waters. This represents a "historic condition" (Stoddard et al. 2006).

Condition and Trend

VHSv is not present in GRPO or Grand Portage Bay, but the future spread of this disease is uncertain. Our level of confidence in this assessment is good. Currently, measures implemented to control the spread of VHSv include extensive fish sampling to detect the presence of VHSv, public outreach to reduce behavior that may contribute to the spread of VHSv, research on how to best disinfect fish eggs to prevent hatcheries spreading VHSv, research on sport-fish susceptibility to VHSv, and measures to increase monitoring of hatcheries for VHSv.

While these steps to prevent the spread of VHSv have been put in place, many risks remain. Current risk factors include aquaculture, ballast water, commercial and subsistence fishing, movement/migration of fish and wildlife, and water-based recreational activities (NPS and Grand Portage Band 2008). These threats impact GRPO in unique ways. One of the most notable is the presence of coaster brook trout in GRPO; this is an important fish species to protect and may be vulnerable to VHSv infection. Second, sport fishing on the Reservation is managed by the Grand Portage Natural Resources Management Department, so to be effective, VHSv prevention must come from joint management between the Band and GRPO. The Band operates two commercial marinas around GRPO that could be potential vectors for the spread of VHSv. Increased public outreach could help educate the public and reduce the spread of VHSv. APIS has the capacity to produce high quality metal signs and has offered to do so at cost to help the Band meet their communication goal. GRPO is planning to offer watercraft inspection and decontamination training in partnership with Minnesota Sea Grant and USFWS in May, 2012.

It is important that effective steps are taken to prevent the further spread of VHSv in Lake Superior. Once introduced to a water body it has the potential to cause massive biological damage and is nearly impossible to eradicate.

Sources of Expertise

NPS and Grand Portage Band 2008, Matthew Waterhouse.

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4.2.10 Didymosphenia geminata (Didymo)

Description

Didymosphenia geminata (didymo) is a species of diatom native to cold nutrient-poor North American freshwater systems (Spaulding and Elwell 2007). Diatoms are a major group of single-celled algae that produce a silica cell wall and are found in nearly every marine and freshwater system (Spaulding and Elwell 2007). They are major primary producers in most aquatic systems and can be an integral portion of both benthic and planktonic food webs. Species in the genus *Didymosphenia* possess a raphe which allows the cell to move on surfaces and a porefield which allows the stalk to attach to rocks, plants, or other submerged substrates (Figure 44).

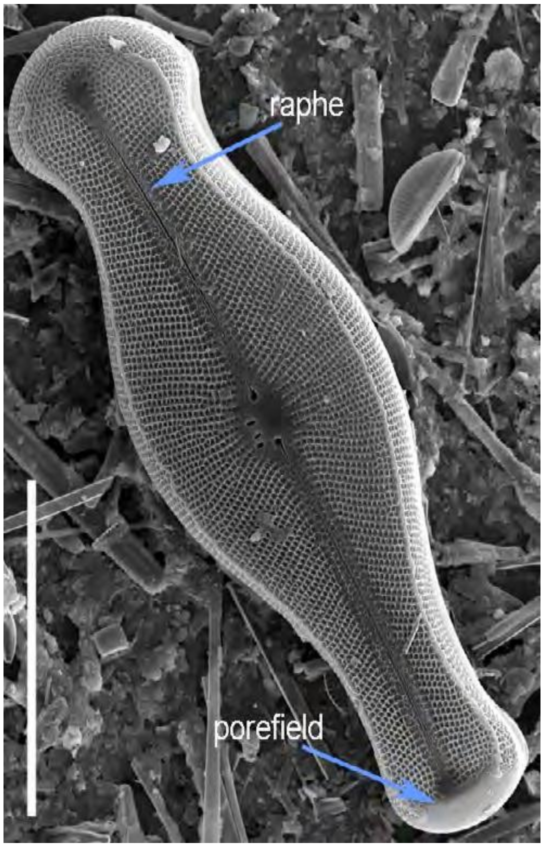

Figure 44. Scanning electron micrograph of a didymo cell showing the raphe and porefield; scale bar is 50 µm (from Spaulding and Elwell 2007**,** photograph by Sarah Spaulding).

A general lack of historic reports and voucher specimens of didymo in North American makes it difficult to determine its historic range (Spaulding and Elwell 2007). Early accounts indicated that didymo was limited to cold nutrient-poor waters and was probably only present in Virginia (Patrick and Reimer 1975) and some rivers in the western United States (Bahls 2004), although Moen (2009) quotes experts who list it as a native diatom in Lake Superior. In recent years, the range of didymo has greatly expanded, and it has become a nuisance in the United States (Figure 45) (Pryfogle et al. 1997, Holderman and Hardy 2004, Shelby 2006) and also in Europe and New Zealand (Figure 46). Didymo can grow in thick slimy masses that have inspired the nickname of "rock snot" (Figure 47).

Although didymo is not considered an invasive species in the United States, its blooms are considered a nuisance and unsightly (Spaulding and Elwell 2007). They also have the potential to be costly; because of the economic importance of natural resources, approximately $120 billion is spent on control and eradication of invasive and nuisance species in the United States each year (Pimentel et al. 2005).

<u>Reference Condition</u>

Didymo should not be present in numbers great enough to cause nuisance conditions. This represents a "historic condition" (Stoddard et al. 2006).

<u>Condition and Trend</u>

Didymo is present in Lake Superior at the mouth of the Knife River north of Duluth and so far has not caused significant algae blooms (Hemphill 2010). Furthermore, the presence of didymo in Lake Superior is considered a sign of good water quality, since it generally grows in cold, clear water. Interestingly, little is known about why didymo causes major issues, including blooms and food chain disruptions, in many places where it is introduced, but not in Lake Superior (Hemphill 2010). We rate the condition of GRPO waters for didymo as good, with an uncertain trend.

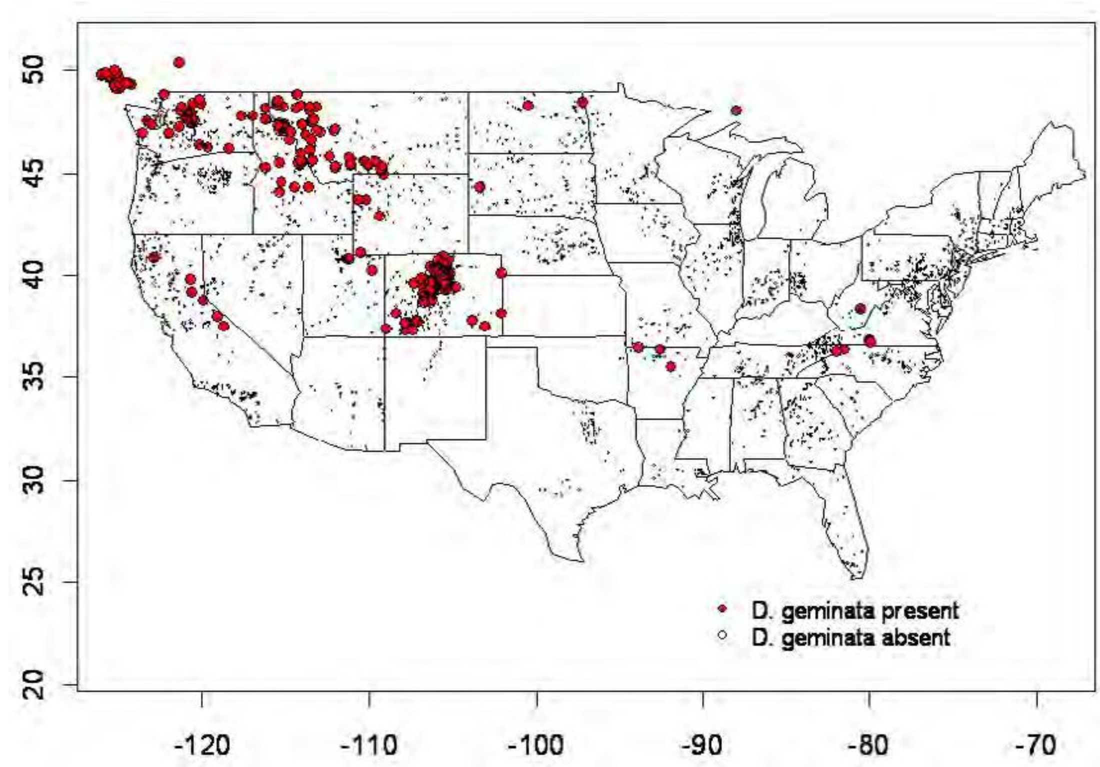

Figure 45. Confirmed presence of didymo in the United States. Records are based on USGS National Water Quality Assessment, the USEPA Environmental Monitoring and Assessment Program, and samples from other studies (from Spaulding and Elwell 2007).

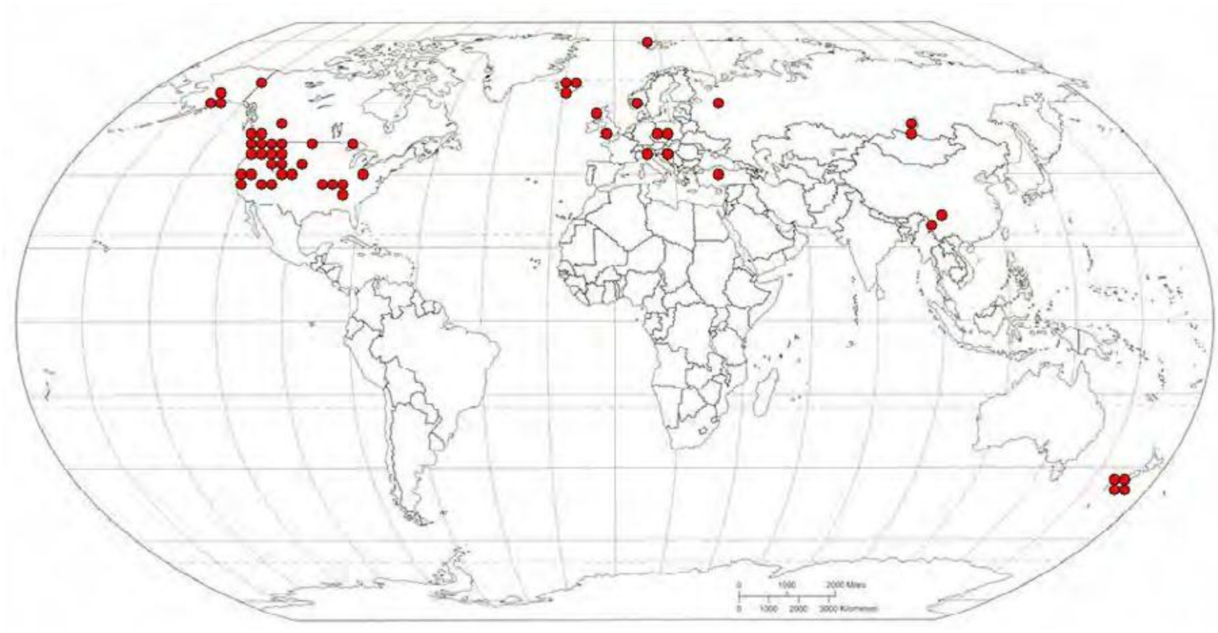

Figure 46. Worldwide distribution of didymo; dots represent approximate geographic locations of confirmed reports of didymo (from Spaulding and Elwell 2007)

Figure 47. Didymo mass (from Moen 2009).

Precautions could be taken to limit the spread of didymo from Lake Superior to surrounding water bodies where it may become an aquatic nuisance. Didymo cells are able to survive out of water for up to 40 days in cold, damp, dark conditions (Kilroy 2005). Fishing equipment such as boot tops; neoprene waders, especially felt-sole waders; and watercraft are likely the largest vector for spreading didymo (Spaulding and Elwell 2007). Raising public awareness through education and outreach and encouraging the cleaning of gear before traveling between water bodies would likely reduce the spread of didymo as well as other aquatic nuisance species.

Sources of Expertise
Hemphill 2010, Matthew Waterhouse.

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4.2.11 Organic Contaminants in Fish

Description

Although Lake Superior is the coldest and cleanest of the Great Lakes and has the least development within its watershed, it is contaminated with many organic compounds. To address this and many other issues regarding Lake Superior, the federal governments of Canada and the United States, the province of Ontario, and the states of Michigan, Minnesota, and Wisconsin have developed an agreement and an administrative framework known as the Lake Superior Binational Program (LSBP). The LSBP has initiated a Zero Discharge Demonstration Program to end the use of nine critical pollutants in industrial processes and products (Table 25) and prevent their release in the Lake Superior basin by 2020 (LSBP 2008). Although progress has been made, concentrations of PCBs, HCB, dieldrin, and toxaphene in Lake Superior water still remained above one or more “yardstick values” established by states or the province of Ontario as of 2005 (LSBP 2008).

Table 25. Pollutants targeted for zero discharge and zero emission in the Lake Superior basin (LSBP 2008).

2,3,7,8-TCDD dioxin	Dichlorodiphenyltrichloroethane (DDT) and its metabolites	Aldrin/dieldrin
Chlordane	Hexachlorobenzene (HCB)	Mercury
Octachlorostyrene	Polychlorinated biphenyls (PCBs)	Toxaphene

Another set of chemicals (polycyclic aromatic hydrocarbons [PAHs], alpha-hexachlorocyclohexane [α-HCH], cadmium, heptachlor and its breakdown product heptachlor epoxide, and another set of dioxins and furans) is on a "critical pollutant lakewide remediation" list, while a third set of chemicals (mostly heavy metals) is on a "local remediation" list (LSBP 2008).

In 2012, the status of Lake Superior for toxic chemicals in offshore waters was fair, with an unchanging trend (USEPA and Environment Canada 2012a). However, the longer-term trend is that certain persistent toxic compounds have decreased since the 1970s (LSBP 2011). Compared to the other Great Lakes, concentrations of most organic compounds are lowest in Lake Superior, but several compounds that can be transported through the atmosphere (α-HCH, lindane, g-chlordane, a- and b-endosulfan, and endrin) are found at the highest concentrations in Lake Superior. Factors that contribute to this include the lake's large surface area (82,100 km^2) in contact with the atmosphere, its cold waters, its depth (149 m on average), and its long retention time (191 years) (statistics from MDEQ 2012).

The atmospheric transport of organic substances to Lake Superior occurs both locally and over significant distances. Volatilization of the pesticide chlordane from soils in the southern U.S. is the predominant source of chlordane to the Great Lakes (Hafner and Hites 2003) even though chlordane has been banned in the U.S. since 1988. Similarly, soils in the cotton-growing region of the SE U.S. account for 59% of the toxaphene deposited in Lake Superior even though it was banned in 1982 with residual use allowed only until 1986 (Ma et al. 2005). Midwestern agricultural soils and urban areas continue to emit significant quantities of DDT (Bidleman et al. 2006), although continuing use in Mexico and Central America is another potential DDT source. Hafner and Hites (2003) reported that the major source of PCBs to the IADN monitoring site at Eagle Harbor, Michigan was the Chicago area. Fluorene, one of the PAHs (products of incomplete combustion of fossil fuels), arrives at Eagle Harbor mainly from a SW source region reaching from Michigan through Iowa and North Dakota (Hafner and Hites 2003).

Substances of emerging concern for the Great Lakes include flame retardants, fluorinated surfactants, personal care products (including triclosan and benzalkonium chloride), pharmaceuticals (steroids, hormones, caffeine, and cotinine), detergents, plasticizers, pesticides, and short-chain chlorinated paraffins. Of these, the first two categories have been most intensively studied in Lake Superior. In 2008, the flame retardants called polybrominated diphenyl ethers (PBDEs) were increasing in fish tissue and sediment in Lake Superior. Fluorinated surfactants, specifically perfluorinated alkyl acids, are now the predominant halogenated organic contaminants in Lake Superior waters (LSBP 2008); these are members of the group of compounds called PFCs (perfluorinated compounds or perfluorochemicals) which we will discuss below.

One concern about the presence of organic contaminants in Lake Superior water is that they may enter the food chain and accumulate in the biota. In 2012, the status of Lake Superior for contaminants in whole fish was fair, with a deteriorating trend (USEPA and Environment Canada 2012b), but the trend was based on increasing mercury levels in fish. In contrast, whole fish were of good status and an improving trend for DDT and its metabolites, mirex, and dieldrin, and of fair status and an improving trend for PCBs and toxaphene. Whole fish were of good status with an unchanging trend for cis- and trans-chlordane (USEPA and Environment Canada 2012b). The status of Lake Superior for contaminants in waterbirds was good, with significant declines in DDE (a metabolite of DDT), total PCBs and TCDD (a dioxin) both since the 1970s and in the 2000s, but no change in PBDE over the short term (USEPA and Environment Canada 2012c).

Data and Methods

In 2009, fish were collected from six national park units in the western Great Lakes region, including GRPO (Wiener et al. 2012, in review). Nine composite samples of fish axial muscle tissue were created from fish collected at four stream sites (Hollow Rock Creek, Reservation River, Grand Portage Creek, and Poplar Creek) on the Grand Portage Reservation; portions of the latter two are within GRPO. The fish species were creek chub (*Semotilus atromaculatus*) from Poplar Creek and rainbow trout (*Oncorhynchus mykiss*) from the other creeks. Samples were analyzed for DDT and its metabolites, nine PFCs, total PBDEs, total PCBs, and total lead.

Reference Condition

DDT is an organochlorine insecticide which was banned in the U.S. in 1972. The target for DDT and its metabolites in the Great Lakes Water Quality Annex (GLWQA) is 1,000 ng g^{-1} wet weight (ww) in whole fish; this target was established for the protection of fish-consuming aquatic birds (Table 26) (IJC 1989).

Table 26. Reference conditions and detected concentrations for organic contaminants in fish tissue in Grand Portage National Monument and on the Grand Portage Reservation.

Analyte	Reference Condition (ng g^{-1} ww)	Concentration in Lake Superior whole fish 2006-2009 (ng g^{-1} ww)	Concentration in GRPO composite samples of fish axial muscle tissue 2009 (ng g^{-1} ww)
DDT and metabolites	1,000	40-90	<10
Total PCBs	100	210-370	0.84-9.3
PFOS	40*	4.8**	2.0
TetraBDEs	88	~15-75	1.5-1.9***
PentaBDEs	1.0	~5-60	1.0-1.2***

*human fish consumption standard; standard for wildlife protection not yet determined
**in 2001; more recent data not available
***between limit of detection (LOD) and limit of quantitation (LOQ)

PCBs are synthetic organic compounds that make good insulating materials because they do not burn easily. They were widely used as coolants and lubricants in transformers, capacitors, and other electrical equipment until their manufacture ceased in the U.S. in 1977. The target for total PCBs in the GLWQA is 100 ng g^{-1} ww in whole fish; this target was established for the protection of birds and animals that consume fish (Table 26) (IJC 1989).

PFCs are synthetic organic compounds with unique properties that make them useful in many consumer products, most notably fire-fighting foam, stain protection, and non-stick surfaces (Chou et al. 2009). They “are globally distributed, environmentally persistent, bioaccumulative, and potentially harmful” (Giesy and Kannan 2002). PFOS (perfluoro-1-octanesulfonate) is the primary PFC found in fish and other biota (Monson et al. 2010). In 2002, PFOS was voluntarily phased-out of production, but its use continues in both the U.S. and Canada because of specific use exemptions (USEPA and Environment Canada 2012b). A reference condition for PFOS or PFCs based on the protection of wildlife has not yet been established. A reference condition of 40 ng g^{-1} has been established by the Minnesota Department of Health (MDH) as the maximum level of PFOS in fish tissue that does not require the issuance of a fish consumption advisory (Table 26) (MDH 2008).

PBDEs are released into the environment from their manufacture and use as flame retardants in thermoplastics in a wide range of products (WHO 1994). The congeners of PBDE are named according to the number of bromine atoms they contain, which can vary from one to ten. A phase-out of penta- and octaBDEs began in 2004, and decaBDEs were scheduled for phase-out in 2012 (USEPA and Environment Canada 2012b). Environment Canada has determined that tetra-, penta-, and hexaBDEs are highly bioaccumulative and has established Federal Environmental Quality Guidelines (FEQGs) of 88, 1.0, and 420 ng g^{-1} ww in fish tissue, respectively, to protect wildlife consumers of fish (Table 26) (Environment Canada 2010).

These reference conditions represent "least disturbed conditions," or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

DDT and metabolites

The concentrations of DDT and its metabolites DDD and DDE have continuously declined in top predator fish in Lake Superior since 1972, with median values of 40-90 ng g^{-1} ww (Canada and U.S., respectively) in 292 whole fish samples from 2006-2009. The condition of the Great Lakes for DDT and its metabolites in whole fish is rated as good, with an improving trend (USEPA and Environment Canada 2012b). In GRPO, no detectable DDT or metabolites (<10 ng g^{-1}) were found in composite samples of fish axial muscle tissue in 2009 (Wiener et al. 2012). We rate the condition of GRPO for DDT and its metabolites as good based on sampling in the park, and the trend as improving based on the conditions in Lake Superior. Our confidence in this assessment is good.

Total PCBs

Total PCB concentrations in top predator fish in Lake Superior have continuously declined since 1977; however, median concentrations were 210-370 ng g^{-1} ww (Canada and U.S., respectively) in 359 whole fish samples from 2006-2009. The condition of the Great Lakes for PCBs in whole fish is rated as fair, with an improving trend (USEPA and Environment Canada 2012b). At GRPO, concentrations of individual congeners of PCBs were 0.84-3.6 ng g^{-1} ww for composite samples of rainbow trout axial muscle tissue in Grand Portage Creek, Hollow Rock Creek, and Reservation River in 2009, with a maximum concentration of total PCBs of 9.3 ng g^{-1} ww in Hollow Rock Creek (Wiener et al. 2012). We rate the condition of GRPO for total PCBs as good based on sampling in the park, and the trend as improving based on the conditions in Lake Superior. Our confidence in this assessment is good.

PFOS and other PFCs

Data for PFOS and other PFCs in Lake Superior are not recent; samples of lake trout collected in 2001 contained 13 ± 1 ng g^{-1} ww total PFCs and 4.8 ± 0.4 ng g^{-1} ww PFOS (Furdui et al. 2007). Trend data for PFCs or PFOS in whole fish in the Great Lakes are not available. At GRPO, concentrations of PFCs were 0.50-2.5 ng g^{-1} ww for composite samples of axial muscle tissue of creek chubs from Poplar Creek and rainbow trout from Grand Portage Creek, Hollow Rock Creek, and Reservation River in 2009 (Wiener et al. 2012). PFOS was detected at all four sampling sites, with a maximum concentration of 2.0 ng g^{-1} ww for rainbow trout in the Reservation River. We rate the condition of GRPO for PFOS and other PFCs as of moderate concern, since PFCs are bioaccumulative (Kannan et al. 2005) and a reference condition for effects on wildlife has not been established. The trend is uncertain. Our confidence in this assessment is fair.

PBDEs

Concentrations of BDE-47 (a tetraBDE) ranged from approximately 15-75 ng g^{-1} ww in whole lake trout and walleye (*Sander vitreus*) in Lake Superior in 2009. For the sum of BDE-99 and BDE-100 (pentaBDEs), the range was approximately 5-60 ng g^{-1} ww (data interpolated from graphic in USEPA and Environment Canada 2012b). In the Great Lakes, the majority of tetraBDE concentrations are below the FEQG, but all measured pentaBDE concentrations are "well above" the FEQG (USEPA and Environment Canada 2012b). Concentrations of PBDEs in Lake Superior appear to be declining since the early 2000s, but the decline is not statistically significant. The condition of Lake Superior for PBDEs is rated fair, with a stable trend (USEPA and Environment Canada 2012b). On the Grand Portage Reservation, concentrations of BDE-47 were 1.5-1.9 ng g^{-1} ww for composite samples of axial muscle tissue of rainbow trout from Hollow Rock Creek in 2009, below the FEQG of 88 ng g^{-1} ww (Wiener et al. 2012). However, concentrations of BDE-99 at the same location were 1.0-1.2 ng g^{-1} ww, at or above the FEQG of 1.0 ng g^{-1} ww. Because the limit of quantitation for BDE-99 is 3.3 ng g^{-1} ww, the concentration of BDE-99 in the fish tissue cannot be stated with certainty. Despite this, we rate the condition of GRPO for PBDEs as of moderate concern, with an uncertain trend. Our level of confidence in this assessment is fair.

Sources of Expertise

Christine Mechenich, Wiener et al. 2012, USEPA and Environment Canada 2012.

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4.3 Chemical and Physical Characteristics

The EPA-SAB framework subdivides chemical and physical characteristics into the categories of nutrient concentrations, trace inorganic and organic chemicals, other chemical parameters, and physical parameters (USEPA 2002a). It allows for either reporting the categories separately by environmental medium or displaying integrated information from all environmental compartments (air, water, soil, and sediment). We have chosen to subdivide this section into air, inland waters, and Grand Portage Bay, and to include a special section on mercury.

4.3.1 Air

Description

Air quality is a broad term that includes all compounds, particles, aerosols, gases, and metals in the atmosphere. These substances are considered air pollutants when they enter at rates that clearly exceed the background rates and when they have the potential to affect ecosystem structure, function, or composition. They may originate locally or travel long distances from their sources. Air pollution may affect GRPO resources through atmospheric deposition of contaminants, nutrient enrichment, or vegetation damage, and may affect human uses of the park by limiting visibility and harming human health.

GRPO is a Class II air quality area geographically positioned among the federally-designated Class I areas of VOYA, BWCAW, and ISRO (GRPO 2004). Class I air quality areas are provided with the highest degree of protection under the USEPA Clean Air Act (CAA) and its amendments. Class II areas have higher ceilings on additional pollution over baseline concentrations, allowing for moderate development. Major new and modified air pollution sources with the potential to affect a Class II area must analyze their impacts on the area's ambient air quality, climate and meteorology, terrain, soils and vegetation, and visibility. NPS managers can participate in reviews of a variety of state, federal, and local activities that might affect air quality in these areas (http://www.nature.nps.gov/air/regs/psd.cfm).

Air Quality and Air Quality Related Values (AQRV) are Vital Signs for GRPO and all other parks in the GLKN (Route and Elias 2007). In the prioritized list of Vital Signs for GLKN, air contaminants were ranked 27th of 46 (3.0 on a 5-point scale), and AQRV were ranked 36th of 46 (2.6 on a 5-point scale) (Route and Elias 2007).

The USEPA collects monitoring data and establishes concentration limits for six common air pollutants called criteria pollutants; these are carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), and lead (Pb) (USEPA 2009a). In order to track the sources of criteria pollutants, USEPA collects emissions data from regulated facilities for CO, SO_2, PM, and three 'precursor/promoters' of criteria air pollutants: volatile organic compounds (VOC), nitrogen oxides (NO_x), and ammonia (NH_3) (USEPA 2009a). USEPA also tracks Pb emissions, but reports them as hazardous air pollutants instead of criteria pollutants (USEPA 2009a). Thousands of metric tons of criteria pollutants are emitted from regulated facilities, nonpoint sources, and mobile sources in the vicinity of GRPO each year (Figure 48, Table 27).

The NPS Air Resources Division (ARD) assesses the current condition of air quality in NPS units in the categories of $O_{3;}$ wet deposition of NH_3, nitrate (NO_3^-), and sulfate (SO_4^{2-}); and visibility (as PM) (NPS 2010a), all of which are, or are related to, the USEPA criteria pollutants. Ozone affects human health and harms vegetation. Wet deposition affects ecological health through acidification and fertilization of soil and surface waters, and visibility affects how well and how far visitors can see (NPS 2010b).

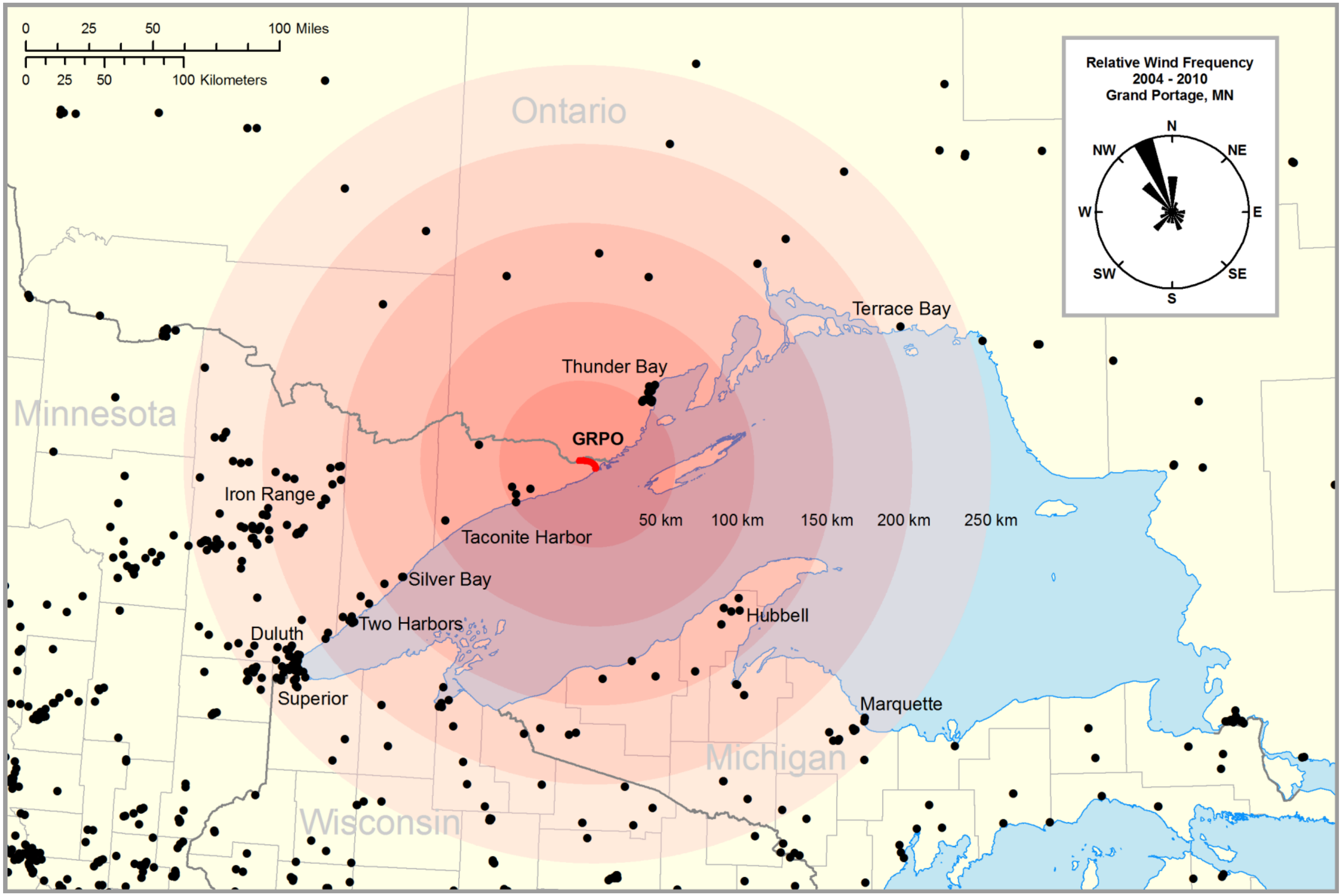

Figure 48. Regulated facilities that emit criteria air pollutants within 250 km of Grand Portage National Monument (Environment Canada 2009, USEPA 2009a).

Table 27. Criteria pollutant emissions for regulated facilities within 250 km and nonpoint and mobile sources in Cook County, Minnesota near Grand Portage National Monument (Environment Canada 2009, USEPA 2002b, 2009c, 2011a).

Locations	Year	Pollutant emissions in metric tons per year (MT yr^{-1})						
Regulated Facilities		NO_x	NH_3	SO_2	$PM_{2.5}$	PM_{10}	CO	VOC
Terrace Bay, Canada	2007	805	185	1,186	995	1,271	3,096	271
Thunder Bay, Canada area	2007	2,563	11	3,703	221	333	5,057	1,098
Iron Range, MN	2002	31,806	22	8,119	459	10,638	1,580	224
Duluth-Superior, MN/WI area	2002	2,864	121	2,814	614	1,651	4,856	706
Hubbell, MI area	2002	35	162	12	<1	1	1	41
Marquette, MI area	2002	17,796	3	17,812	980	1,266	1,066	242
Other	2002 and 2007	11,289	33	10,013	267	1,043	3,141	651
Total regulated facilities		67,158	536	43,659	3,537	16,204	18,798	3,233
Nonpoint and Mobile Sources								
Cook County, MN	2002	2,804	100	251	410	1,570	6,819	1,275

Data and Methods

Data for criteria air pollutant emissions within 250 km of GRPO were downloaded from the USEPA AirData website (http://www.epa.gov/air/data/index.html) and the Environment Canada website (http://www.ec.gc.ca/inrp-npri/). The U.S. data are from 2002 and the Canadian data are from 2007. Additional data for northeast Minnesota were obtained from the Minnesota Pollution Control Agency (MPCA) from their Regional Haze Plan website (http://www.pca.state.mn.us/index.php/air/air-quality-and-pollutants/general-air-quality/state-implementation-plan/minnesota-regional-haze-plan.html). The 250 km radius, which includes the western half of Michigan's Upper Peninsula, part of northern Wisconsin, and the Iron Range of Minnesota, was chosen to facilitate comparison with an earlier study done for ISRO and VOYA, which are in the same region, by Swackhamer and Hornbuckle (2004). Air quality data for GRPO were acquired from the NPS air quality estimate tables (http://www.nature.nps.gov/air/maps/airatlas/IM_materials.cfm) as recommended in the Guidance for Evaluating Air Quality in Natural Resource Condition Assessments (NPS 2010c).

Wind rose climatology was found for Grand Portage, Minnesota at the Western Regional Climate Center RAWS US Climate archive (http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?sdMGPO). From November to February, winds are predominantly from the north – northwest. However, from March to October, winds are from the north – northwest only at night, and are from the southeast – southwest during the day. The wind rose on the air monitoring station and air emissions maps reflects the average wind direction for the year and may not match well with emissions if they are timed to certain seasons or times of day.

Air monitoring sites in the GRPO vicinity include a HazeCam operated by the Midwest Regional Planning Organization at the Grand Portage Reservation. The camera looks out at ISRO and provides local particulate monitoring and meteorologic data (www.mwhazecam.net). A National Atmospheric Deposition Program (NADP) National Trends Network (NTN) site (http://nadp.sws.uiuc.edu/) that monitors wet deposition is located at Hovland, Minnesota, 19 km

SW of GRPO. Other NTN sites are located at Fernberg in the BWCAW, 124 km W of GRPO; Wolf Ridge, 124 km SW of GRPO; and Chassell, Michigan, 128 km SSE of GRPO (Figure 49).

Eagle Harbor, Michigan, 121 km SE of GRPO, and the BWCAW have Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites where fine aerosols, particulate matter less than 10 microns in size (PM_{10}), and light extinction and scattering are measured (IMPROVE Network 2004). The Eagle Harbor site also features a camera for qualitative observation. Also at Eagle Harbor, an Integrated Atmospheric Deposition Network (IADN) station operated by the USEPA and Environment Canada monitors organic compounds such as polychlorinated biphenyls (PCBs), organochlorine pesticides, and polyaromatic hydrocarbons (PAHs) (IADN 2002). BWCAW also has a NTN site, a NADP Mercury Deposition Network (MDN) site, and an ozone monitor operated by the Minnesota Pollution Control Agency. The nearest dry deposition site operated by the Clean Air Status and Trends Network (CASTNet) is at VOYA, 228 km W of GRPO (Figure 49).

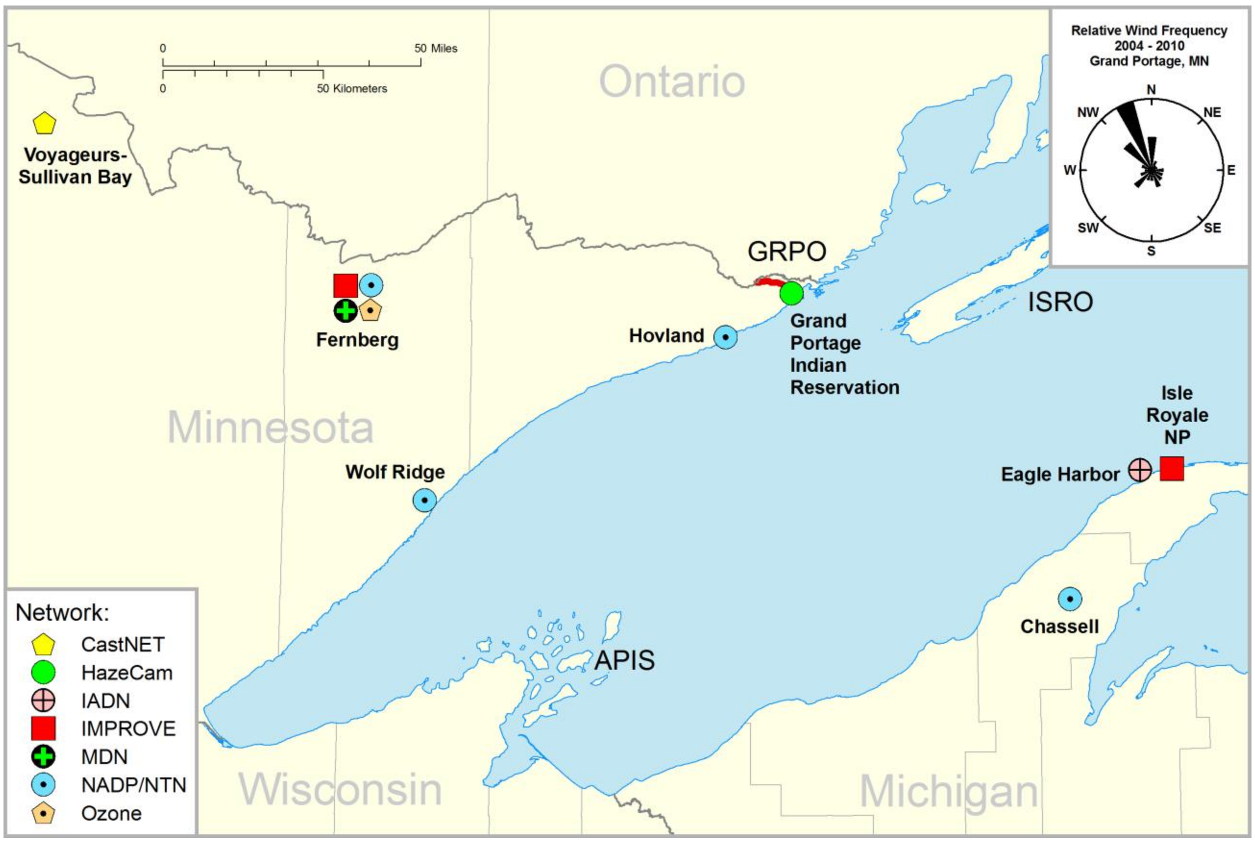

Figure 49. Air monitoring sites operated by state and federal agencies in the vicinity of Grand Portage National Monument.

<u>Reference Condition</u>

For ozone, the metric is the annual 4th highest daily maximum 8-hour ozone concentration (The metric used by EPA is the *3-year average* of the annual 4th highest daily maximum 8-hour ozone concentration). For visibility, the metric is the difference between the mean of the visibility observations falling within the range of the 40th through 60th percentiles and the estimated values that would be observed under natural conditions. This metric is called the ‘Group 50 visibility minus natural conditions' and is expressed in deciviews, a unitless measure of light extinction (Malm 1999). For wet deposition of nitrogen (N) and sulfur (S), the metric is expressed in kilograms per hectare per year. Values that represent 'Good' condition (Table 28) were used as the reference condition, also as specified in NPS 2010c. These reference condition represent "least disturbed conditions," or "the best of today's existing conditions" (Stoddard et al. 2006).

<u>Condition and Trend</u>

Air quality at GRPO is a significant concern for wet deposition of total nitrogen. It is of moderate concern for ozone, wet deposition of total sulfur, and visibility (Table 28) (NPS 2011). This assessment is based on NPS ARD data and has a high level of confidence.

Wet deposition of nitrogen

Ozone, wet deposition of total sulfur, and visibility

Air quality trends are not directly available for GRPO, but they are available for two Class I airsheds in the vicinity, ISRO and VOYA. For ISRO, an improving trend ($p= 0.04$) for visibility on clear days, and an improving trend of possible significance ($p= 0.09$) for wet nitrate deposition were measured from 1999-2008. No significant trends were measured for ISRO for visibility or wet nitrate or sulfur deposition from 2004-2008 (NPS 2010b). For VOYA, an improving trend of possible significance ($p= 0.13$) for visibility on clear days was measured from 1999-2008. No significant trends were measured for visibility or ozone for VOYA from 2004-2008 (NPS 2010b). Therefore, it is likely that there are no significant trends for GRPO air quality from 2004-2008. Since ARD did not evaluate trends for GRPO, this assessment is based on proximity and has a moderate level of confidence.

In the following sections, the significance and sources of ozone, visibility, and total sulfur and nitrogen deposition will be further discussed.

Ozone

Ozone is a compound of three oxygen atoms (O_3). In the stratosphere, ozone protects life on Earth from harmful ultraviolet radiation, but at ground level, it is the primary constituent of smog. Breathing ozone can trigger a variety of human health problems such as chest pain, coughing, throat irritation, and congestion and can worsen bronchitis, emphysema, and asthma (USEPA 2003). Ground-level ozone also damages vegetation and ecosystems (USEPA 2003).

Table 28. Air quality conditions for ozone, wet deposition, and visibility in Grand Portage National Monument (NPS 2011).

Parameter	Date Range	Metric/Value	Condition	Condition Range
Ozone		4th highest 8 hr (ppb)*		
	1999-2003	68.7	Moderate	Significant Concern: ≥ 76 Moderate: 61-75 Good: ≤ 60
	2001-2005	66.5	Moderate	
	2003-2007	64.5	Moderate	
	2004-2008	64.1	Moderate	
	2005-2009	63.6	Moderate	
Visibility		Group 50 Visibility minus Natural Conditions (deciviews)		
	2001-2005	3.8	Moderate	Significant concern:>8 Moderate: 2-8 Good: <2
	2003-2007	5.4	Moderate	
	2004-2008	5.26	Moderate	
	2005-2009	4.7	Moderate	
Wet Deposition – Total N		Kg/ha/year		
	2001-2005	3.78	Significant Concern	Significant concern:>3 Moderate: 1-3 Good: <1
	2003-2007	4.22	Significant Concern	
	2004-2008	3.86	Significant Concern	
	2005-2009	4.16	Significant Concern	
Wet Deposition – Total S		Kg/ha/year		
	2001-2005	2.18	Moderate	Significant concern:>3 Moderate: 1-3 Good: <1
	2003-2007	2.40	Moderate	
	2004-2008	2.28	Moderate	
	2005-2009	2.47	Moderate	

*In January 2010, EPA proposed but did not ultimately implement a reduction in the ozone standard from 75 ppb to a level within the range of 60-70 ppb; this decision will be reviewed in 2013 (USEPA 2011b).

Five-year averages of annual 4th highest daily maximum 8-hour ozone concentrations for GRPO range from 63.6 for 2005-2009 to 68.7 ppb for 1999-2003 (Table 28). These readings fall within the ‘moderate’ category as defined by NPS ARD (NPS 2011). An assessment of the risk of foliar injury from ozone in GRPO and other GLKN parks listed six plant species sensitive to ozone, but it concluded that GRPO was at low risk of foliar injury from ozone because of low exposure levels (GLKN 2004).

Ground-level ozone (hereafter, ozone) is not emitted directly into the air. It is created by chemical reactions between VOC and NO_x in the presence of sunlight. Ozone levels are generally higher in summer because of the combination of high temperatures and strong sunlight.

Industrial emissions, electric utilities emissions, motor vehicle exhausts, gasoline vapors, and chemical solvents are some of the major sources of VOC and NO_x (USEPA 2003).

In the GRPO vicinity, major sources of VOC are regulated facilities at Thunder Bay, Canada (1,098 MT yr^{-1}) (Figure 50) and nonpoint and mobile sources in Cook County, including off-highway non-road gasoline vehicles (502 MT yr^{-1}), light-duty gas vehicles and motorcycles (115 MT yr^{-1}), light-duty gas trucks (100 MT yr^{-1}), and residential wood burning (78 MT yr^{-1}) (Table 27) (Environment Canada 2009, USEPA 2009a, 2011a).

In 2002, major sources of NO_x included regulated facilities on the Iron Range of Minnesota (31,806 MT yr^{-1}); at Marquette, Michigan (17,796 MT yr^{-1}); and at Thunder Bay, Canada (2,563 MT yr^{-1} [2007 data]) (Figure 51); and marine vessels in Cook County (2,296 MT yr^{-1}) (Table 27) (Environment Canada 2009, USEPA 2009a, 2011a). Corbett and Fischbeck (2000) estimated that cargo movement on the Great Lakes produced NO_x emissions of 5-10 MT km^{-1}.

The Minnesota Regional Haze State Implementation Plan (MPCA 2009) contains a Northeast Minnesota Plan to reduce emissions of SO_2 and NO_x from large sources (those that emit >91 MT yr^{-1} of either pollutant) by 20% by 2012 and 30% by 2018 from a 2002 baseline. In 2009, the Northshore Mining Company facility at Silver Bay emitted 2,709 MT NO_x and the Minnesota Power electrical generating facility at Taconite Harbor emitted 1,510 MT; these were reductions of 24% and 28%, respectively, from 2002 (MPCA 2011) (Table 29).

Table 29. Comparison of 2002 and 2009 NOx emissions for large regulated facilities in northeast Minnesota within 250 km of Grand Portage National Monument. (Negative reductions are increases). (MPCA 2011).

Facility	City		NO_x	
		2002 (MT yr^{-1})	2009 (MT yr^{-1})	% reduction
U.S. Steel Corp - Minntac	Mt. Iron	13,539	5,410	60
Hibbing Taconite Co	Hibbing	5,627	893	84
U.S. Steel Corp - Keewatin Taconite	Keewatin	5,488	42	99
Northshore Mining Company - Silver Bay	Silver Bay	3,548	2,709	24
Arcelor Mittal Mining Co	Virginia	2,952	1,641	44
Minnesota Power Inc - Taconite Harbor	Taconite Harbor	2,095	1,510	28
Minnesota Power Inc - Laskin Energy	Hoyt Lakes	1,974	590	70
United Taconite LLC - Fairlane Plant	Forbes	1,607	1,785	-11
Sappi Cloquet LLC	Cloquet	1,085	1,010	7
Minnesota Power Inc - ML Hibbard	Duluth	376	582	-55
Duluth Steam Cooperative Association	Duluth	298	347	-16
Virginia Dept of Public Utilities	Virginia	297	348	-17
Hibbing Public Utilities	Hibbing	257	625	-143
Hill Biomass Inc	Cook	203	0	100
Georgia-Pacific Duluth Hardboard	Duluth	62	43	31

Figure 50. Emissions of volatile organic compounds (VOC) from regulated facilities within 250 km of Grand Portage National Monument (Environment Canada 2009, USEPA 2009a).

Figure 51. Emissions of nitrous oxides (NO_x) from regulated facilities within 250 km of Grand Portage National Monument (Environment Canada 2009, USEPA 2009a).

Visibility

Visibility is a measurement of how well and at what distance visitors to the park can see the park's natural features. One measure of visibility in GRPO is how well visitors can see the stockade or Lake Superior from the scenic overlook on Mount Rose. Using the metric called Group 50 visibility minus natural conditions and measured in deciviews, visibility concerns at GRPO are moderate and ranged from 3.8 from 2001-2005 to 5.4 from 2003-2007 (Table 28).

Particulate matter pollution, especially particles with diameters of 2.5 microns or less, ($PM_{2.5}$) is the major cause of reduced visibility, also called haze (Malm 1999, USEPA 2006). One study found that at BWCAW, ammonium sulfate was the largest contributor to $PM_{2.5}$ except at $PM_{2.5}$ concentrations above the 95^{th} percentile. On these haziest days, organic carbon from fires became the largest constituent. Other constituents of $PM_{2.5}$ at BWCAW, in order of significance, are nitrate, elemental carbon, and soil dust (MACTEC 2004).

Within 250 km of GRPO, major sources of $PM_{2.5}$ are regulated facilities at Terrace Bay, Canada, (995 MT yr^{-1}), Marquette, Michigan (980 MT yr^{-1}), and the Duluth/Superior area (614 MT yr^{-1}) (Figure 52, Table 27). Major mobile and nonpoint sources in Cook County include fires (miscellaneous combustion, 108 MT yr^{-1}; residential wood burning, 41 MT yr^{-1}; and open burning, 41 MT yr^{-1}), fugitive dust (124 MT yr^{-1}), and marine vessels (71 MT yr^{-1}) (Table 27) (USEPA 2011a).

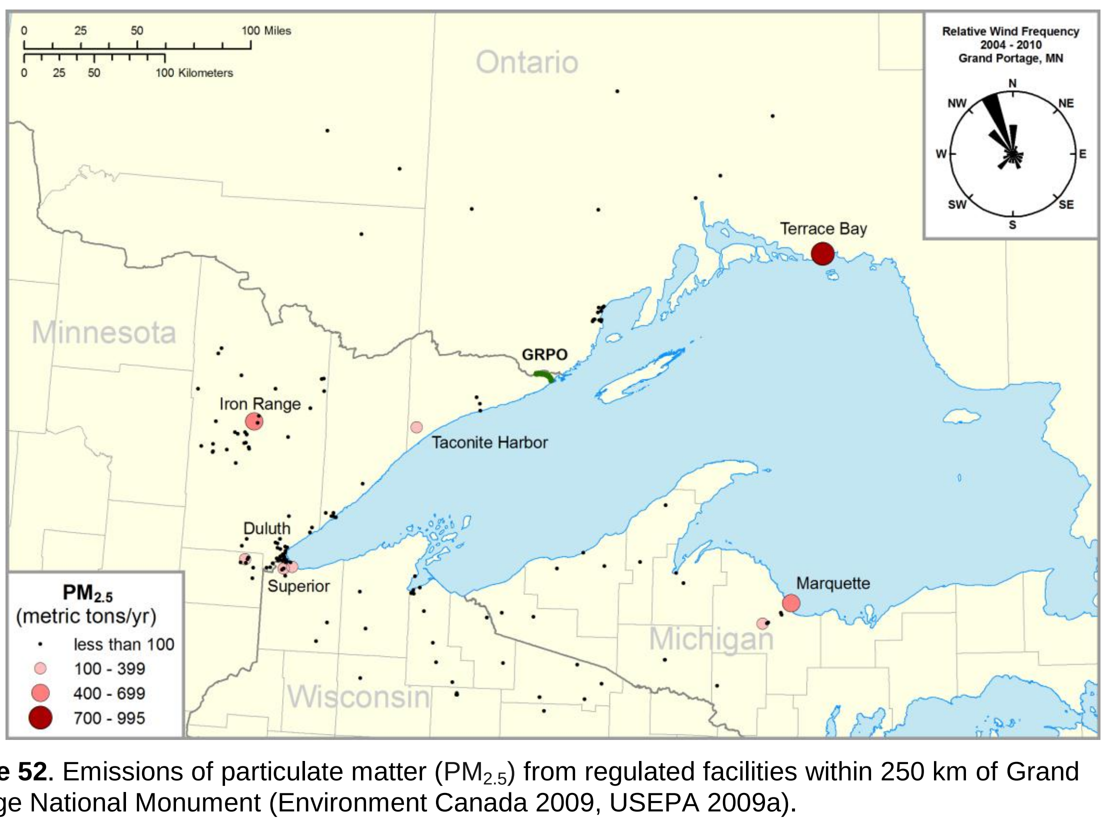

Figure 52. Emissions of particulate matter ($PM_{2.5}$) from regulated facilities within 250 km of Grand Portage National Monument (Environment Canada 2009, USEPA 2009a).

Wet Deposition – Sulfur and Wet Deposition – Nitrogen
Wet deposition of total S is considered by NPS ARD to be moderate for GRPO, with a range of 2.18 kg ha^{-1} yr^{-1} from 2001-2005 to 2.40 kg ha^{-1} yr^{-1} for 2003-2007. Wet deposition of total N is considered to be of significant concern for GRPO, with values ranging from 3.78 kg ha^{-1} yr^{-1} from 2001-2005 to 4.22 kg ha^{-1} yr^{-1} from 2003-2007 (Table 28) (NPS 2011). The potential effects of wet deposition of nitrogen and sulfur include acidification of ecosystems, both aquatic and terrestrial, and addition of nutrients that can lead to eutrophication.

Deposition results from emissions of SO_2 and NO_x, which also have consequences for human health. These gases create a variety of respiratory problems in people, and they react with other components in the atmosphere to create fine particles that create additional respiratory problems (USEPA 2011c, d). Sulfates also contribute greatly to visibility reductions at high relative humidity levels (Malm 1999).

Emissions of SO_2 from regulated facilities in the U.S. and Canada within 250 km of GRPO are 43,659 MT yr^{-1} (Canadian data from 2007 and U.S. data from 2002) (Table 27) (Environment Canada 2009, USEPA 2009a). The largest source of SO_2 is a power plant at Marquette, Michigan, but significant nearby sources include the Northshore Mining Company facility at Silver Bay and the Minnesota Power electrical generating facility at Taconite Harbor (USEPA 2009a, MPCA 2011) (Figure 53).

Atmospheric SO_4^{2-} deposition at nearby ISRO exhibited a downward trend from 1985-2005 (Drevnick et al. 2007). Similarly, in New England, the region with the longest deposition record in North America, a decline in SO_4^{2-} input has been documented since the 1970s (Hedin et al. 1994, Likens et al. 1996). This decline extended as far west as Minnesota. Driscoll et al. (2001) reported that a decrease in SO_4^{2-} wet deposition in the eastern U.S. has resulted from the Clean Air Act Amendments (CAAA) of 1990.

The Minnesota Regional Haze State Implementation Plan (MPCA 2009) contains a Northeast Minnesota Plan to reduce emissions of SO_2 and NO_x from large sources (those that emit >91 MT yr^{-1} of either pollutant) by 20% by 2012 and 30% by 2018. In 2009, the Northshore Mining Company facility at Silver Bay emitted 1,593 MT SO_2 and the Minnesota Power electrical generating facility at Taconite Harbor emitted 3,231 MT; these were a reduction of 23% and an increase of 14%, respectively, from 2002 (MPCA 2011) (Table 30).

Of the 251 MT yr^{-1} of SO_2 emissions attributed to mobile and nonpoint sources in Cook County, 204 MT yr^{-1} come from marine vessels. The USEPA has made rule changes in recent years to reduce emissions from diesel boats and ships; allowable levels of sulfur in fuel used in marine vessels were reduced by 99% in 2007, which also resulted in a decrease in PM emissions (USEPA 2009b). USEPA rules in 2008 and 2010 reduced allowable sulfur emissions from marine diesel engines (USEPA 2009b, c). However, Great Lakes ships received exemptions from the rules, allowing them to purchase the lowest sulfur fuel available if fuel that met the sulfur standard was not available, creating an economic hardship relief provision, and exempting existing steamships operating on the Great Lakes from international fuel sulfur standards (USEPA 2009c).

Figure 53. Emissions of sulfur dioxide from regulated facilities within 250 km of Grand Portage National Monument (Environment Canada 2009, USEPA 2009a).

Sources of nitrogen emissions were described in the previous discussion of ozone. Although the 1990 CAAA decreased sulfur deposition in the eastern US, the same effect was not observed for nitrogen deposition (Driscoll et al. 2001).

Table 30. Comparison of 2002 and 2009 SO2 emissions for large regulated facilities in northeast Minnesota within 250 km of Grand Portage National Monument. (Negative reductions are increases). (MPCA 2011).

Facility	City		SO_2	
		2002 ($MT\ yr^{-1}$)	2009 ($MT\ yr^{-1}$)	% reduction
United Taconite LLC - Fairlane Plant	Forbes	2,923	2,663	9%
Minnesota Power Inc - Taconite Harbor	Taconite Harbor	2,823	3,231	-14%
Northshore Mining Company - Silver Bay	Silver Bay	2,078	1,593	23%
U.S. Steel Corp – Minntac	Mt. Iron	1,765	524	70%
Minnesota Power Inc - Laskin Energy	Hoyt Lakes	1,459	1,138	22%
U.S. Steel Corp - Keewatin Taconite	Keewatin	639	42	93%
Hibbing Taconite Co	Hibbing	538	86	84%
Virginia Dept of Public Utilities	Virginia	350	581	-66%
Georgia-Pacific Duluth Hardboard	Duluth	279	54	80%
Duluth Steam Cooperative Association	Duluth	259	366	-41%
Hibbing Public Utilities	Hibbing	233	918	-294%
Sappi Cloquet LLC	Cloquet	172	162	6%
Arcelor Mittal Mining Co	Virginia	141	50	65%
Minnesota Power Inc - ML Hibbard	Duluth	120	321	-168%
Hill Biomass Inc	Cook	18	0	100%

Wet deposition of reactive forms of sulfur and nitrogen that form or can form acids when in contact with water is part of the subset of air pollution known as acid deposition. Acid deposition specifically includes gases, particles, rain, snow, clouds, and fog that are composed of sulfuric acid, nitric acid (HNO_3), and ammonium (NH_4^+), derived from SO_2, NO_x, and NH_3, respectively.

Dry deposition of total nitrogen is also a consideration for GRPO. Wet deposition may include HNO_3, NO_3^-, and NH_4^+, while dry deposition includes HNO_3, particulate NO_3^-, particulate NH_4^+, and NH_3 (NAPAP 2005). Of total nitrogen deposition at VOYA (the closest CASTNet site to GRPO) from 2007-2009, 87% was wet deposition and 13% was dry deposition (USEPA 2011e); deposition proportions at GRPO might be expected to be similar.

In a ranking of all national parks by quintile, GRPO is considered to be at moderate risk from acidic deposition. This ranking is based on three factors: a low pollutant exposure, a high ecosystem sensitivity, and a moderate degree of park protection (not ranked high because of a lack of areas included as Class I or wilderness) (Sullivan et al. 2011a).

The effect of acid precipitation on aquatic ecosystems is determined largely by the ability of the water and watershed soil to neutralize the acid deposition they receive. Generally, small watersheds with shallow soils and few alkaline minerals are most sensitive to acidification. Low pH levels and higher aluminum levels that result from acidification hinder fish reproduction and decrease fish sizes and population densities (NAPAP 2005). Watersheds that contain alkaline minerals such as limestone, or those with well-developed riparian zones, generally have a greater capacity to neutralize acids. Lake Superior and GRPO streams have alkalinities over the threshold value (Sheffy 1984, Shaw et al. 2004) of 25 mg L^{-1} as $CaCO_3$ and so are not considered particularly vulnerable to acid precipitation.

The effects of acid precipitation on upland and forest ecosystems include direct and indirect impacts on plants, changes in forest floor and/or soil chemistry, and altered rates of mineral and nutrient accumulation and loss (Ohman and Grigal 1990, Aber et al. 1998, 2003). The possible direct effects on plants (e.g., reducing the integrity of the epidermis) are well-known (McLaughlin 1985), and are all negative, with the possible exception of a fertilization effect. The indirect effects on plants derive largely from changes in chemistry of the system and include nutritional, toxic, and altered symbiosis effects (Hedin et al. 1994, Aber et al. 1998, Friedland and Miller 1999, Zaccherio and Finzi 2007).

Buffering capacity in forest soils is largely a function of four factors: a) surface horizon texture and depth, b) B-horizon texture and depth, c) total cation exchange capacity and base saturation, and d) abundance of fungi and bacteria in the upper soil profile (Johnson et al. 1983, Aber et al. 1998). Generally, buffering capacity is low in systems with coarse, acid soils; soils low in organic matter (OM); and soils that are shallow. Since the dominant soils at GRPO, which originated from clayey tills, are moderately deep and fine textured (Gafvert 2009), their buffering capacity is moderately high. Less common soil types formed from igneous bedrock and are shallow to moderately deep, very stony, and relatively coarse-textured. Soil pH values range from 3.5 in sandy and loamy soils to 9.0 in clayey soils. The two most common soil types in GRPO, the Portwing-Herbster complex and Cornucopia silt loam, have pH values ranging from 4.5 near the surface to 9.0 in deeper clay layers (Gafvert 2009). Soil pH data for specific forest types are not available for GRPO, but values from ISRO are probably representative. At one site in the interior of the main island, the soil pH under spruce was 4.4-4.5 and slightly higher (4.6-5.0) in the deciduous forest (Stottlemyer and Toczydlowski 1999).

In a ranking of all national parks by quintile, GRPO is considered to be at very low risk from atmospheric nutrient N enrichment. This ranking is based on three factors: a low pollutant exposure, a low ecosystem sensitivity, and a moderate degree of park protection (lack of areas included as Class I or wilderness) (Sullivan et al. 2011b).

A compilation of many studies in the northeast (Aber et al. 2003) concluded that an increase in nitrate leaching is likely to occur if the N deposition rate exceeds approximately 8 kg ha^{-1} yr^{-1} for an extended period of time. However, the magnitude of the effect was highly variable among sites; it was hypothesized that this variability is due to the large number of factors (plant composition, soil type, land use, hydrology, and climate) that affect leaching (Pardo et al. 2010). Increased nitrate leaching is one of the probable indicators that N saturation has occurred (Aber et al. 2003, Pardo et al. 2010). The complexity of the situation is highlighted by the fact that very large differences between evergreen and broadleaved species often occur (Stottlemyer and Hanson 1989, Reich et al. 1997, Ollinger et al. 2002) and that N deposition rates are only weakly related to nitrogen cycling processes (Pardo et al. 2010).

However, in susceptible systems, N saturation can occur at low deposition rates if the input is elevated over a long enough period of time (Aber et al. 2003). In the Engelmann spruce forest type of central Colorado, litter quality (assessed by many indicators) and potential net mineralization were affected at deposition rates of 3-5 kg N ha^{-1} yr^{-1} (Rueth and Baron 2002), within the range of the deposition rates found at GRPO. Old-growth conifer forests in Colorado responded differently to deposition based on the size of the nitrogen pools and carbon to nitrogen (C:N) ratio. A low level of fertilization did not affect soil processes, but foliar N levels and the amount of N in the organic horizon increased (Rueth et al. 2003). The higher deposition rate (3.2-5.5 kg N ha^{-1} yr^{-1}) caused an increase in mineralization and N in the soil fraction. A large-scale, longitudinal study of 161 spruce-fir forests across the NE U.S. suggested that effects will show up at a deposition rate of 6-8 kg N ha^{-1} yr^{-1}. A study in Alaska with white spruce found many of the same effects from approximately 30 years of increased deposition (Lilleskov et al. 2001). One very striking result from the Alaska study was the responsiveness of the ectomycorrhizal fungal community, which was ten times richer at the upper end of the depositional gradient. The synthesis by Pardo et al. (2010) for the "northern forest eco-region" determined that the ectomycorrhizal community and lichen community had the lowest thresholds (4-7 kg ha^{-1} yr^{-1}) to nitrogen.

Because streams and rivers integrate the deposition on land and deposition directly to the aquatic system, the N concentration in water has been suggested as a suitable sentinel of N deposition problems (Williamson et al. 2008). However, other components of the system (such as foliar N concentration or the fungal community discussed above) may change prior to this and thus provide an earlier 'warning.' Furthermore, just as certain soil types are more susceptible, so are different species of trees. Yellow birch and quaking aspen are among the "sensitive" species identified by Pardo et al. (2010); this group shows reduced growth or survivorship at deposition rates above 3 kg ha^{-1} yr^{-1}.

Nitrogen is the prime limiting nutrient in the boreal forest types (Bonan and Shugart 1989), so N deposition might appear to be beneficial. However, the acidification that accompanies N and S deposition can lead to the loss of cations which are important nutrients. Nutrient deficiency is particularly likely for any upland ecosystem that has low base saturation, which is common on acidic sites. However, cation loss occurs even on soils with high buffering capacity. The effect is cumulative and continues even after acid deposition is mitigated. In New England, large quantities of calcium (Ca^{2+}) and magnesium (Mg^{2+}) have been lost from the soil (Likens et al. 1996, Friedland and Miller 1999) even after nitrate and sulfate inputs were reduced and the pH of precipitation increased (Likens et al. 1996).

The boreal system also may have low resilience to chemical stressors. Stottlemyer and Hanson (1989) determined that the concentrations of SO_4^{2-}, Ca^{2+}, and Mg^{2+} were higher in soil solution than in precipitation, and SO_4^{2-} had a flux 2-3 times that of other nutrients under conifers. These findings demonstrate how acid deposition could affect a terrestrial system by setting the stage for accelerated loss of cations. The hydrogen ions associated with SO_4^{2-} replace other cations on the soil exchange sites (Tomlinson 2003), and then the cations are leached if water moves down through the soil profile. A second undesirable effect that might manifest from N deposition is simplification of composition. That is, a subset of species is favored under the changed nutrient conditions and is able to outcompete other species. Simplification has not been documented in a boreal forest, but it has been demonstrated in some forest fertilization trials (Rainey et al. 1999).

A nitrogen deposition study is currenly in progress for GRPO to explore the potential role of N in some recent biological changes observed in GLKN boreal lakes. The study uses N stable isotope data from sediment cores to determine historic N trajectories in GLKN lakes, relate them to measured N deposition and concentration data, and evaluate relationships between N and diatom communities (Brenda Moraska Lafrancois, Aquatic Ecologist, NPS, personal communication, 1/2/2013)

Sources of Expertise

USEPA air quality website (http://www.epa.gov/air), NPS ARD, David Pohlman, James Cook, Christine Mechenich.

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4.3.2 Water Quality of Inland Waters

Description

Lakes and streams are important natural features in northeastern Minnesota, and their protection is of management interest for both the Grand Portage Band and GRPO (Lafrancois et al. 2009). The water quality of Reservation lakes is considered to be in good condition, in part due to the relatively undisturbed second growth northern hardwood and boreal forests (Winterstein 2002). Overall, Reservation lakes and streams tend to be dilute, with intermediate nutrient levels, low transparency, and high dissolved organic carbon concentrations, with water chemistry and groundwater inputs that are influenced by local geologic features. Streams show more seasonal variation than lakes, being strongly influenced by hydrologic patterns (Winterstein 2002, Lafrancois et al. 2009).

The NRCA focused on three lakes and three streams that are wholly or in part within the GRPO watershed. These are Chevans Lake, Dutchman Lake, Mt. Maud Lake, Grand Portage Creek, Pigeon River, and Poplar Creek. These water bodies have the most consistent water quality data and sampling sites.

It is important here to define some terms related to water quality conditions. USEPA establishes water quality “criteria,” scientific assessments of ecological and human health effects, under the Clean Water Act. It recommends these criteria to states and tribes so they can establish water quality “standards,” which provide a basis for them to control discharges of pollutants (USEPA 2001). “Reference conditions” as used by USEPA (2000, 2001) and Heiskary and Wilson (2005) refer to a ranking process in which water quality data from water bodies in an ecoregion are ordered in a database; the value representing the 25^{th} percentile is called the “reference condition” and is considered to represent an undisturbed condition for that ecoregion. Therefore, for a parameter whose harmful effects increase with concentration, the value for that parameter would be expected to be less than the reference condition in 25% of the water bodies and more than the reference condition in 75% of the water bodies. Our use of the term “reference condition” may encompass a standard, criterion, or reference condition, and we specify this in the discussion of each parameter.

Data and Methods

Several studies have addressed the surface water quality of inland lakes and streams at GRPO. In 1997, Boyle and Richmond assembled baseline data for the future management of aquatic natural resources in Poplar Creek and Grand Portage Creek in GRPO. The baseline data included physical, chemical, and biological attributes of the two creeks. Parameters were selected because of their biological importance and their potential response to changes in land use or dam construction that was proposed at the time.

In 1999, an inventory and analysis of water quality data presented the results of surface-water-quality data retrievals for GRPO from six USEPA national databases: (1) Storage and Retrieval (STORET) water quality database management system, (2) River Reach File (RF3), (3) Industrial Facilities Discharge (IFD), (4) Drinking Water Supplies (DRINKS), (5) Water Gages (GAGES), and (6) Water Impoundments (DAMS). Several of the identified monitoring stations represented either one-time or intensive single-year sampling efforts by the collecting agencies. At the time of the report, no stations within the park boundary yielded longer-term records for important water quality parameters. This study did not include data from the Grand Portage Band. From available data, water quality appears to have been generally good, with some impacts from human activities. Potential anthropogenic sources of contamination included municipal wastewater discharges, stormwater runoff, mining operations, watercraft traffic, recreational use, logging activities, and atmospheric deposition (NPS 1999).

A 2005 NPS report (Lafrancois and Glase 2005) catalogued these as well as earlier studies and concluded that GRPO water resource information was limited, and basic and descriptive in nature, but that the information that did exist was fairly current and thorough.

In 1999, the Grand Portage Band began intensively monitoring water quality in 15 lakes and eight streams in preparation for the development of nutrient criteria. In 2009, Lafrancois et al. (2009) published the report "Water Quality Conditions and Patterns on the Grand Portage Reservation and Grand Portage National Monument, Minnesota." The data collected from 1999-2006 were used to develop local nutrient criteria for Reservation waters and additional monitoring activities for Grand Portage Creek through the GLKN. Two water quality datasets were used for the analyses conducted in the report. The first included data from 15 lakes and eight streams within the Reservation. Water quality specialists from Grand Portage Trust Lands sampled each lake or stream monthly, from May through October for lakes and from April or May through October for streams, every other year from 1999-2006. Basic chemical and physical parameters (i.e., pH, dissolved oxygen, specific conductance, and Secchi depth or stream transparency) were measured in the field on each sampling date; pH was also measured directly by the analytical laboratory. To circumvent issues associated with skewed data distribution and to account for inter-annual variability, existing water quality conditions were characterized for the entire 1999-2006 monitoring period using median values. The second dataset contained environmental data from 59 lakes in Minnesota's Northern Lakes and Forests Ecoregion (NLF). Data for these lakes were compiled by staff from the MPCA, the St. Croix Watershed Research Station, the Natural Resources Research Institute-Ely Field Station, and Ramstack et al. (2003).

For this report, 1996-2006 median water quality values were taken from Lafrancois et al. (2009) for Chevans Lake, Dutchman Lake, Mt. Maud Lake, Grand Portage Creek, Pigeon River, and Poplar Creek. The NPS core water quality variables of specific conductance, pH, dissolved oxygen, and water clarity and the advanced water quality variables of alkalinity, chloride, nutrients, and chlorophyll-*a* were used for comparisons. Lafrancois et al. (2009) compared these variables from each water body to available reference standards that included USEPA reference conditions referring to the 25th percentile value for lakes and streams of Ecoregion VIII, Subecoregion 50 (USEPA 2000, 2001); Minnesota reference conditions referring to the 25th percentile value for 32 lakes in the NLF (Heiskary and Wilson 2005); and state and federal standards and criteria compiled from the USEPA (1976, 1986, 2006) and the Minnesota Pollution Control Agency (MPCA 2009).

Lafrancois et al. (2009) then proposed reference conditions similar to those for Ecoregion VIII, Subregion 50 or the NLF ecoregion based only on data from Reservation lakes and streams. Two scenarios were developed using percentiles of data distributions among 15 Reservation lakes and eight streams. The “strict” scenario assumes that Reservation lakes and streams are a mixture of human-impacted and less-impacted sites and uses the 25^{th} percentile as a criterion. The “less strict” scenario assumes that Reservation watersheds are minimally impacted relative to other parts of the NLF ecoregion and represent reference conditions in themselves, and so uses the 75^{th} percentile as a criterion.

Our analysis of inland water quality condition relies heavily on the work of Lafrancois et al. (2009). In addition, spreadsheets containing water quality data for the six water bodies from 1999-2011 were provided by M. Watkins, Water Quality Specialist, Grand Portage Band (Watkins 2012) and used in trend analysis.

The Mann-Kendall test was used to examine trends in all the water quality parameters for each lake and stream, using the method of Helsel and Hirsch (2002). The non-parametric Mann-Kendall test determines whether *y* values trend to increase or decrease with time. The test requires at least ten observations for the normal approximation to be appropriate. Only observations from July and August of each sample year were chosen to eliminate variations due to seasonality, while still having enough observations to run the test. A significance level of 0.05 was chosen. The statistical program Minitab® 15.1.1.0 was used to run the Mann-Kendall test.

A map showing the locations of water quality sampling sites in the GRPO watershed is included as Figure 54. Discussion of individual parameters follows.

Specific Conductance
Specific conductance is the measure of the capacity of water to conduct an electric current. Its magnitude is largely controlled by watershed geology, with the size of the watershed relative to the water body also an important factor (Elias et al. 2008). Increases in specific conductance may indicate polluted runoff, which could contain excess nutrients, organic matter, pathogenic microbes, heavy metals, and organic contaminants. If waters are soft, these contaminants can be a major stressor to salmonids, shoreline and nearshore plants, and other aquatic organisms (Elias et al. 2008).

<u>Reference Condition</u>
There is no numeric reference condition for specific conductance, since it is watershed-dependent; it is monitored for possible changes rather than its absolute value. We chose a reference condition of a lack of trend in specific conductance values over the period of record. This represents a “minimally disturbed condition” (Stoddard et al. 2006).

<u>Condition and Trend</u>

In the GRPO watershed, median stream specific conductance was 118.3 µmhos cm^{-1} from 1996-2006. The Pigeon River had the lowest median of 80.7 µmhos cm^{-1} (Lafrancois et al. 2009). Lakes in the GRPO watershed were dilute when compared to the streams (Lafrancois et al. 2009). Dutchman Lake had the lowest median specific conductance, 45 µmhos cm^{-1}, and Mt. Maud Lake had the highest, 62 µmhos cm^{-1}. We rank the condition of surface waters in the GRPO watershed for specific conductance as good based on trend analysis, which shows no trend over the period 1999-2011. Our level of confidence in this assessment is good.

pH

The pH value is the negative logarithm of the hydrogen ion (H+) activity in the water. It is important as a determinant of the solubility and biological availability of nutrients essential for

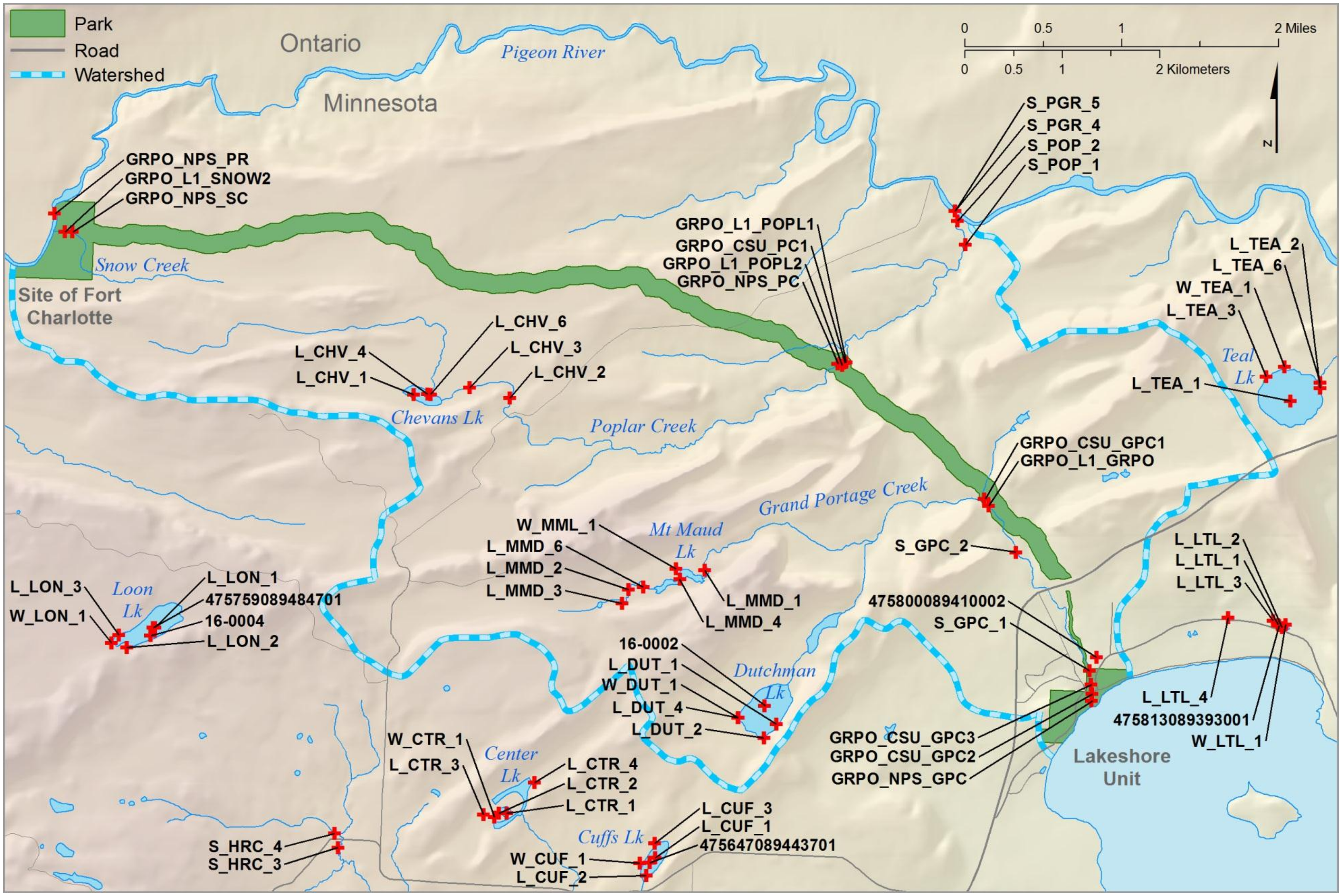

Figure 54. Locations of water sampling sites within the Grand Portage National Monument watershed.

growth as well as potentially toxic heavy metals (Elias et al. 2008). Aquatic macroinvertebrates and some salmonids can be adversely affected at certain stages of their life cycles when pH is above 9.0 or below 6.5 (Elias et al. 2008).

Reference Condition

Our chosen reference condition for lakes and streams in the GRPO watershed is a biological criterion and standard for freshwater life that indicates an optimal pH range of 6.5-9.0 (USEPA 1976, 1986, 2006, MPCA 2009). This represents a “least disturbed condition” (Stoddard et al. 2006).

Condition and Trend

Streams in the GRPO watershed had a median pH of 7.4, with a range of medians from 7.1 in Poplar Creek to 7.6 in Grand Portage Creek (Lafrancois et al. 2009), and are all within the range of 6.5-9.0 for freshwater life. Reservation lakes were circumneutral to slightly acidic (Lafrancois et al. 2009), and the median pH of lakes in the GRPO watershed ranged from 6.60 in Chevans Lake to 6.80 in Dutchman Lake. Although median pH values in GRPO lakes are below the 25th percentile for the NLF (pH value 7.2) (Heiskary and Wilson 2005), they are all within the standards for biological life, and their pH values are likely natural in origin. Therefore, we rate the condition of surface waters in GRPO for pH as good. No trend for pH was observed for any water body in the watershed from 1999-2011. Our level of confidence in this assessment is good.

Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen in solution in water. The atmosphere is the largest source of DO, although phytoplankton and macrophytes produce DO during photosynthesis. Respiration by animals, plants, and microbes consumes DO (Elias et al. 2008). The MPCA water quality standard for DO is based on the maintenance of a healthy community of fish and associated aquatic life (MPCA 2009).

Reference Condition

Our chosen reference condition is the MPCA (2009) standard for DO of 5 mg L^{-1} as a daily minimum. This represents a “least disturbed condition” (Stoddard et al. 2006).

Condition and Trend

Reservation streams and lakes tend to have low to moderate DO concentrations (Lafrancois et al. 2009). Within the GRPO watershed, median stream DO concentrations ranged from 8.79-10.16 mg L^{-1}, well above the state minimum standard. Median DO concentrations in Chevans Lake and Mt. Maud Lake were below the minimum state standard, while Dutchman Lake met the standard with a median DO level of 7.52 mg L^{-1} (Figure 55). Chevans Lake and Mt. Maud Lake are humic lakes with high levels of dissolved organic carbon (DOC) and color; such lakes naturally tend toward low oxygen levels (Lafrancois et al. 2009 and citations therein). We therefore rate the condition of surface waters in the GRPO watershed for DO as good. No trend for DO was observed for any water body in the watershed from 1999-2011. Our level of confidence in this assessment is good.

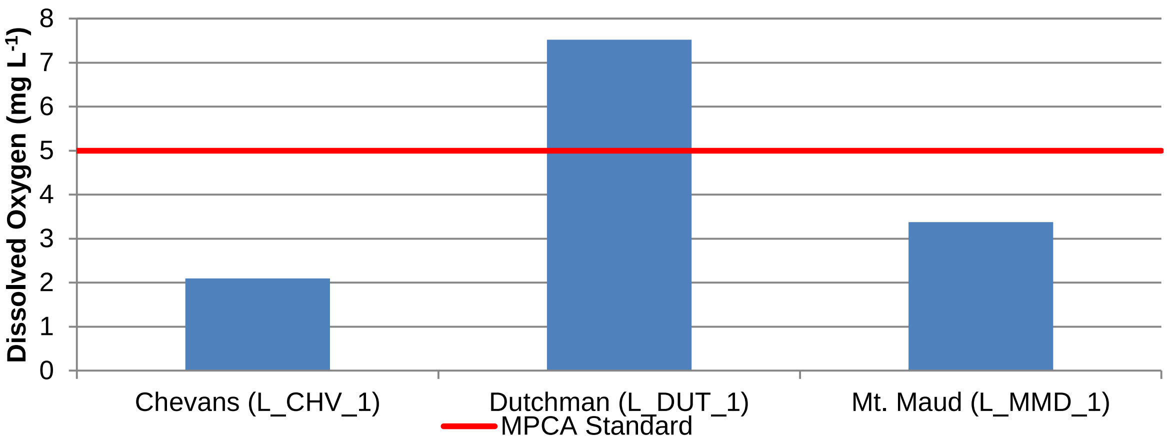

Figure 55. Median dissolved oxygen content of lakes in the Grand Portage National Monument watershed, 1999-2006.

Alkalinity

Alkalinity is a measure of the ability of a water body to buffer, or resist, a change in pH. Lakes in far northeastern Minnesota are generally low in alkalinity because of the low calcium and magnesium content of the underlying bedrock, making them sensitive to atmospheric acid deposition (Omernik et al. 1988).

<u>Reference Condition</u>

Our chosen reference condition is the USEPA criterion of 20 mg L^{-1} as $CaCO_3$ for the protection of aquatic life "except where natural conditions are less" (USEPA 1986). This represents a "least disturbed condition" (Stoddard et al. 2006).

<u>Condition and Trend</u>

Streams and lakes within the GRPO watershed met the reference condition for alkalinity, with median values ranging from 20 mg L^{-1} as $CaCO_3$ in Chevans Lake to 65 mg L^{-1} as $CaCO_3$ in Poplar Creek, with the exception of Dutchman Lake, whose median alkalinity was 16 mg L^{-1} as $CaCO_3$ from 1999-2006 (Lafrancois et al. 2009). However, since alkalinity values are naturally low in the region, we rate the condition of streams and lakes in the GRPO watershed for alkalinity as good. The Pigeon River showed a significant upward trend for July and August alkalinity from 1999-2011 (Figure 56). Since this trend does not negatively affect water quality, we rate the overall trend in GRPO as stable. Our level of confidence in this assessment is good.

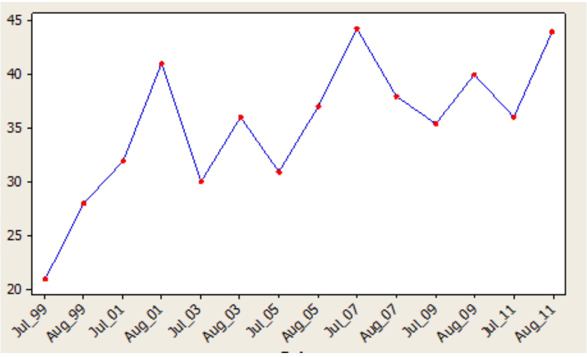

Figure 56. Time series plot of July and August alkalinity from 1999-2011 for the Pigeon River in the Grand Portage National Monument watershed.

Chloride
Chloride is often used as a tracer of wastewater plumes and an indicator of road salt runoff into surface waters (Elias et al. 2008). Winterstein (2002) found elevated levels of chloride (up to 1,410 mg L^{-1}) in a well water sample taken on the Reservation, which he attributed to dissolution of minerals from the rock matrix or discharge of brine from the underlying Precambrian bedrock.

<u>Reference Condition</u>
Our chosen reference condition for chloride is the MPCA standard of 230 mg L^{-1} for chronic exposure for aquatic life (MPCA 2009). This represents a “least disturbed condition” (Stoddard et al. 2006).

<u>Condition and Trend</u>

All lakes and streams in the GRPO watershed met the MPCA standard, with median values ranging from 1.2 mg L^{-1} in Chevans and Dutchman Lakes to 5.5 mg L^{-1} in Grand Portage Creek from 1999-2006 (Lafrancois et al. 2009). The authors noted, however, that the Grand Portage Creek median was the second highest among Reservation streams and recommended continued monitoring to check for a trend that could be related to the use of road salt on nearby roads and highways. We rate the condition of streams and lakes in the GRPO watershed for chloride as good, with an unknown future trend because of the need for further monitoring of Grand Portage Creek. No trend for chloride was observed in any water body in the GRPO watershed from 1999-2011. Our confidence in this assessment is good.

Parameters Related to the Development of Nutrient Criteria
For parameters related to the development of nutrient criteria (water clarity, total phosphorus, total nitrogen, nitrate + nitrite nitrogen, and chlorophyll *a*), we use MPCA standards as reference conditions when they exist. We also use the “less strict” reference conditions proposed by Lafrancois et al. (2009) for the Reservation, which assume that most water bodies (those from the first to the 75^{th} percentile) on the Reservation are unaffected by human activities.

Water Clarity (Transparency)
Although not a mandated parameter, the GLKN has included a measure of water clarity (Secchi depth and/or transparency tube depth) in the core suite of parameters because of its fundamental importance to whole-lake ecology and its ease of measurement (Elias et al. 2008). Water clarity is a surrogate for light penetration, which is an important regulator of rate of primary production and plant species composition, including the balance between phytoplankton and macrophyte production in shallow lakes. Water clarity is also important in the public’s perception of the aesthetic quality of water bodies. Secchi depth can also be an effective indicator of non-algal suspended sediment loading from agricultural and urban runoff and from shoreline erosion (Elias et al. 2008).

For streams, the less strict reference condition for water clarity proposed by Lafrancois et al. (2009), which assumes that most Reservation waters represent reference conditions, is 0.92 m, while the strict reference condition, which assumes that Reservation waters are a mix of impacted and less impacted sites, is 1.2 m (Table 31). The MPCA standard is 2.0 m (MPCA 2009).

Table 31. Water bodies in the Grand Portage National Monument watershed that meet standards or reference conditions for water quality parameters related to nutrient criteria development.

	Water bodies in the GRPO watershed that:				
	Meet MPCA standard (lakes only)	**Are in best 25% for USEPA ecoregion**	**Are in best 25% for Northern Lakes and Forests subecoregion (lakes only)**	**Are in best 75% for Reservation (“less strict scenario”)**	**Are in best 25% for Reservation (“strict scenario”)**
Water Clarity	None >2.0 m	None >4.2 m (lakes only)	None >2.4 m	Grand Portage Creek >0.92 m Mt. Maud Lake >0.77 m	Grand Portage Creek >1.2 m No lakes >1.2 m
Total Phosphorus	Chevans Lake and Dutchman Lake <0.03 mg L^{-1}	No streams <0.012 mg L^{-1} No lakes <0.010 mg L^{-1}	None <0.014 mg L^{-1}	Grand Portage Creek and Pigeon River <0.031 mg L^{-1} Chevans Lake and Dutchman Lake <0.027 mg L^{-1}	No streams <0.022 mg L^{-1} No lakes <0.012 mg L^{-1}
Total Nitrogen	N/A	No streams <0.36 mg L^{-1} No lakes <0.32 mg L^{-1}	N/A	Grand Portage Creek, Poplar Creek, and Pigeon River <0.80 mg L^{-1} No lakes <0.93 mg L^{-1}	Pigeon River <0.55 mg L^{-1} No lakes <0.70 mg L^{-1}
Chlorophyll-*a*	Chevans Lake, Dutchman Lake, and Mt. Maud Lake <9.0 µg L^{-1}	Grand Portage Creek <0.6 µg L^{-1} Mt. Maud Lake <2.46 µg L^{-1}	Chevans Lake and Mt. Maud Lake <4.00 µg L^{-1}	Grand Portage Creek and Pigeon River <1.08 µg L^{-1} Chevans Lake and Mt. Maud Lake <3.75 µg L^{-1}	Grand Portage Creek <0.5 µg L^{-1} Mt. Maud Lake <2.00 µg L^{-1}

For lakes, the less strict reference condition proposed by Lafrancois et al. (2009) is 0.77 m, while the strict reference condition is 1.2 m (Table 31). The USEPA reference condition (25^{th} percentile) for the ecoregion for water clarity is 4.2 m (USEPA 2000), while the MPCA minimum standard is 2.0 m (MPCA 2009). The NLF reference condition (25^{th} percentile) is 2.4 m (Heiskary and Wilson 2005).

Reference Condition
Our chosen reference condition for stream water clarity is the less strict reference condition of 0.92 m (Lafrancois et al. 2009). This represents a “minimally disturbed condition” (Stoddard et al. 2006). For lakes, our chosen reference condition is the MPCA minimum standard of 2.0 m (MPCA 2009). This represents a “least disturbed condition” (Stoddard et al. 2006).

Condition and Trend

Median water clarity was less than 1.3 m in all Reservation streams (Lafrancois et al. 2009). Of streams within the GRPO watershed, only Grand Portage Creek met the less strict reference condition (Figure 57). Therefore, Poplar Creek and the Pigeon River are less clear than 75% of streams on the Reservation. Secchi depths also tended to be low in Reservation lakes, with an average depth of 1.30 m (Lafrancois et al. 2009). No lakes in the GRPO watershed met the minimum MPCA standard of 2.0 m. Mt. Maud Lake met the less strict reference condition, indicating that it is in the best 75% of Reservation lakes (Figure 58). Water clarity has a negative relationship to DOC and color in both the streams and lakes of the Reservation (Lafrancois et al. 2009), which likely explains the failure of water bodies in GRPO to meet reference conditions for water clarity. We rate the condition of GRPO streams and lakes for water clarity as good. No trend for water clarity was observed for any water body in the watershed from 1999-2011. Our confidence in this assessment is good.

Nutrients (Nitrogen and Phosphorus)
Nitrogen and phosphorus are the two most important nutrients regulating phytoplankton and aquatic macrophyte growth in lakes and streams. Excessive nutrient inputs can lead to excessive algal growth and eutrophication and are the most important threat to lakes in the upper Midwest (Elias et al. 2008 and citations therein). Nutrients enter bodies of water primarily through surface and subsurface runoff and groundwater, but in less productive systems, such as those on the Reservation, atmospheric deposition may also be an important source.

In the natural annual cycles of lakes, bioavailable forms of phosphorus and nitrogen are typically highest in spring because of runoff from snowmelt and the mixing of nutrients from the bottom during spring turnover. Concentrations usually decline in the epilimnion during summer stratification as the nutrients are taken up by algae and eventually transported to the hypolimnion (Elias et al. 2008).

Total Phosphorus (TP)
For streams, the less strict reference condition for TP proposed by Lafrancois et al. (2009), which assumes that most Reservation waters represent reference conditions, is 0.031 mg L^{-1}, while the strict reference condition, which assumes that Reservation waters are a mix of impacted and less impacted sites, is 0.022 mg L^{-1} (Table 31). The USEPA reference condition for the subecoregion is 0.012 mg L^{-1} (USEPA 2001). The MPCA maximum standard is 0.030 mg L^{-1} (MPCA 2009).

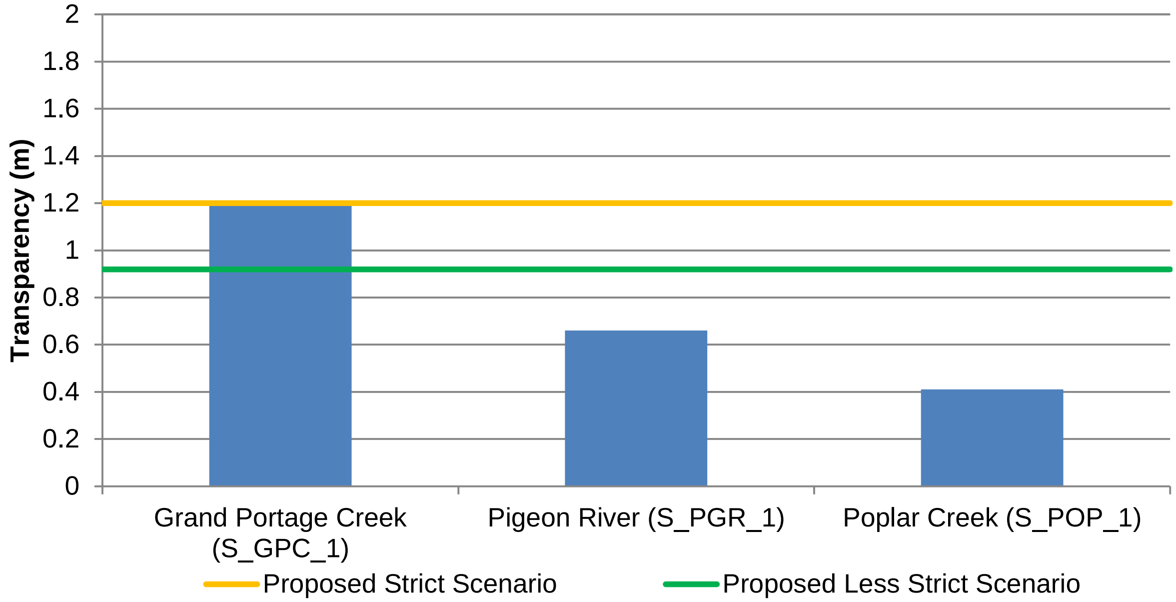

Figure 57. Median transparency values for streams in the Grand Portage National Monument watershed, 1999-2006.

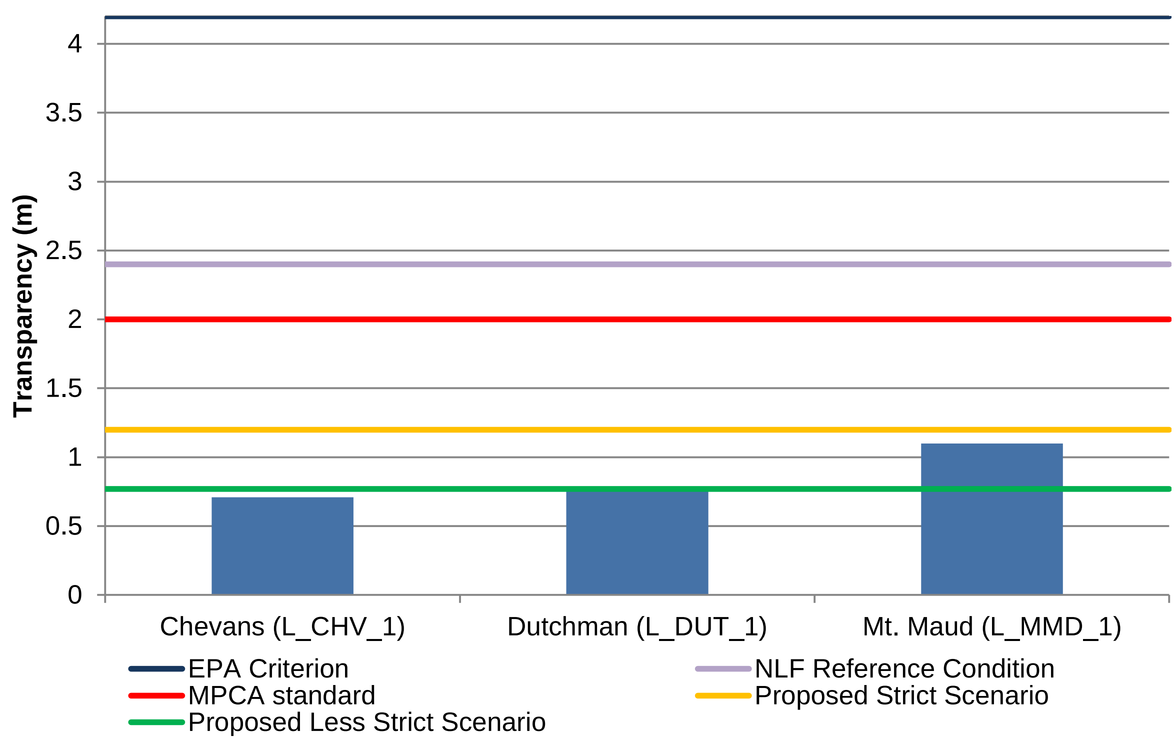

Figure 58. Median transparency values for lakes in the Grand Portage National Monument watershed, 1999-2006.

For lakes, the less strict reference condition proposed by Lafrancois et al. (2009) for TP is 0.027 mg L^{-1}, while the strict reference condition is 0.012 mg L^{-1} (Table 31). The USEPA reference condition for TP is 0.010 mg L^{-1} (USEPA 2000), while the MPCA maximum standard is 0.030 mg L^{-1} (MPCA 2009). The NLF reference condition (25^{th} percentile) is 0.014 mg L^{-1} (Heiskary and Wilson 2005).

<u>Reference Condition</u>
Our chosen reference condition for median stream TP is the less strict reference condition of 0.031 mg L^{-1} (Lafrancois et al. 2009). This represents a “minimally disturbed condition” (Stoddard et al. 2006). For lakes, our chosen reference condition is the MPCA maximum standard of 0.030 mg L^{-1} (MPCA 2009). This represents a “least disturbed condition” (Stoddard et al. 2006).

<u>Condition and Trend</u>


Median TP was 0.028 mg L^{-1} and 0.022 mg L^{-1} in Reservation streams and lakes, respectively, from 1996-2006 (Lafrancois et al. 2009). In the GRPO watershed, the median TP values in Poplar Creek (Figure 59) and Mt. Maud Lake (Figure 60) exceeded the proposed less strict reference condition of Lafrancois et al. (2009), indicating that their TP values are in the upper 25% of Reservation water bodies. The median TP value for Mt. Maud Lake also exceeded the MPCA maximum standard of 0.030 mg L^{-1}

In Reservation lakes, TP is positively correlated with chlorophyll-*a*, DOC, and color; it is correlated with these and total suspended solids (TSS) in Reservation streams. Lafrancois et al. (2009) attribute elevated TP values to the humic, dystrophic nature of the water bodies and not to anthropogenic enrichment. Therefore, we rate the condition of GRPO inland waters for TP as good. No trend for TP was observed for any water body in the watershed from 1999-2011. Our confidence in this assessment is good.

Total Nitrogen (TN)
For streams, the less strict reference condition for TN proposed by Lafrancois et al. (2009), which assumes that most Reservation waters represent reference conditions, is 0.80 mg L^{-1}, while the strict reference condition, which assumes that Reservation waters are a mix of impacted and less impacted sites, is 0.55 mg L^{-1} (Table 31). The USEPA reference condition for the subecoregion is 0.360 mg L^{-1} (USEPA 2001). There is no MPCA maximum standard for TN.

For lakes, the less strict reference condition proposed by Lafrancois et al. (2009) for TN is 0.93 mg L^{-1}, while the strict reference condition is 0.70 mg L^{-1} (Table 31). The USEPA reference condition for TN is 0.32 mg L^{-1} (USEPA 2000). There is no MPCA maximum standard for TN.

<u>Reference Condition</u>
In the absence of a standard or criterion for TN, we have chosen the less strict reference values of 0.80 mg L^{-1} for Reservation streams and 0.93 mg L^{-1} for Reservation lakes (Lafrancois et al. 2009). These represent “minimally disturbed conditions” (Stoddard et al. 2006).

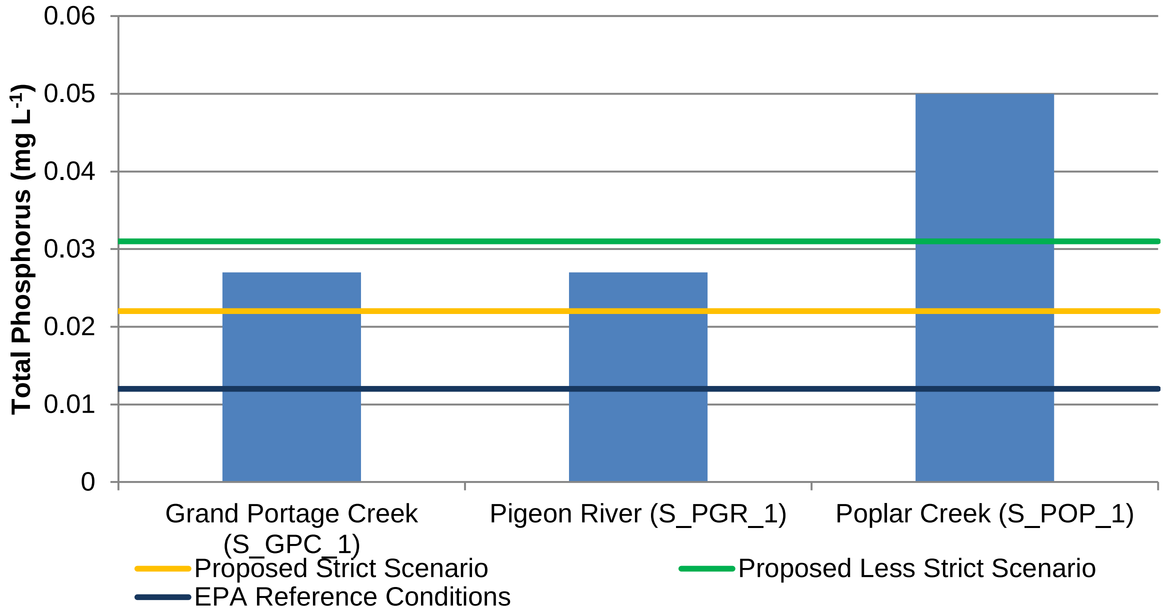

Figure 59. Median total phosphorus values for streams in the Grand Portage National Monument watershed, 1999-2006.

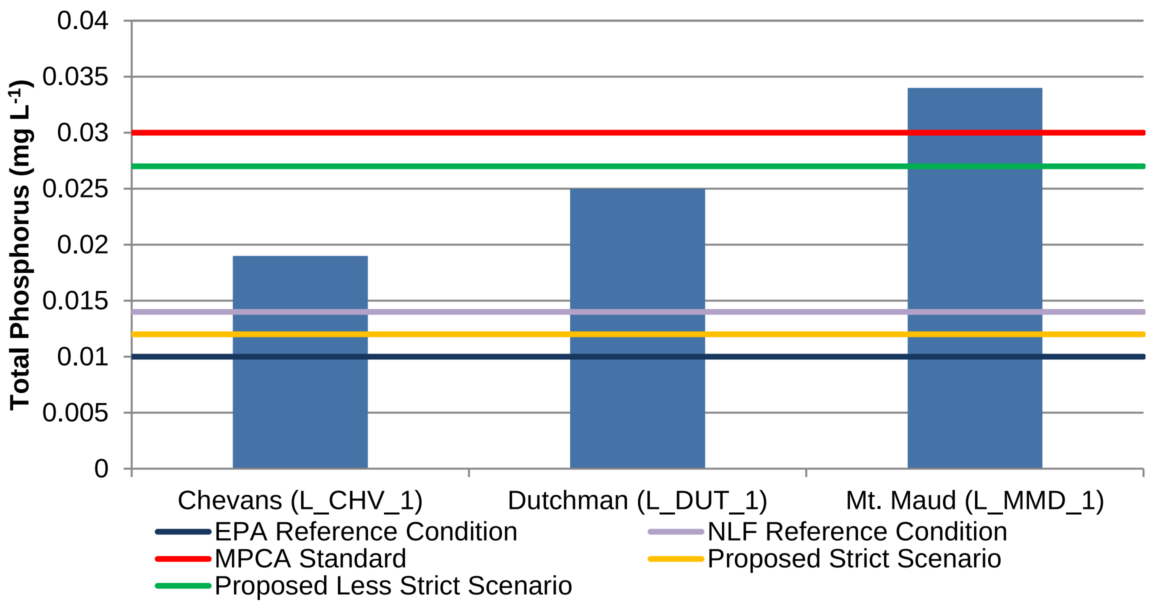

Figure 60. Median total phosphorus levels for lakes in the Grand Portage National Monument watershed, 1999-2006.

Condition and Trend

Median TN was 0.65 mg L^{-1} and 0.81 mg L^{-1} in Reservation streams and lakes, respectively, from 1996-2006 (Lafrancois et al. 2009). In the GRPO watershed, all three streams had median TN values less than or equal to the less strict reference condition of Lafrancois et al. (2009) for TN, placing them in the best 75% of Reservation streams for TN (Figure 62). All three lakes had median TN values greater than the less strict reference condition for TN, placing them in the upper 25% of Reservation lakes for TN (Figure 63). As with TP, Lafrancois et al. (2009) found that TN was positively correlated with DOC and color in Reservation streams and lakes. Also as with TP, they attributed elevated TN values to dystrophic conditions rather that anthropogenic enrichment. However, they recommended future monitoring of TN and nitrate+nitrite-nitrogen to rule out atmospheric deposition as a significant source.

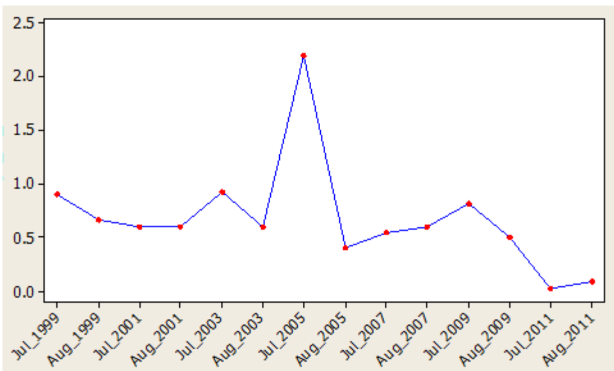

Figure 61. Time series plot of July and August total nitrogen from 1999-2011 for Grand Portage Creek in the Grand Portage National Monument watershed.

Grand Portage Creek showed a significant downward trend for July and August TN from 1999-2011 (Figure 61). However, this is insufficient evidence to negate the possible effects of atmospheric deposition, since no trend was observed in the other water bodies in the watershed. We rate the condition of GRPO inland waters for TN as good, with an uncertain trend.

It can also be noted here that Mt. Maud Lake had a significant downward trend for total kjeldahl nitrogen (a subset of TN which omits nitrate+nitrite nitrogen). This is likely a positive development related to the lake’s recovery from the disturbance created during its initial construction.

Nitrate+Nitrite-Nitrogen (NO_3+NO_2-N)

Reference Condition

The USEPA reference condition for the subecoregion is 0.030 mg L^{-1} for streams (USEPA 2001) and 0.003 mg L^{-1} for lakes (USEPA 2000). There are no NLF reference conditions, applicable MPCA standards, or proposed Reservation reference conditions for NO_3+NO_2-N. Therefore, we chose the USEPA reference conditions as our reference conditions; these are “minimally disturbed conditions” (Stoddard et al. 2006).

Condition and Trend

The median NO_3+NO_2-N concentrations in Reservation lakes and streams were near or below laboratory detection limits, which were higher than reference condition values (Lafrancois et al. 2009). Therefore, neither condition nor trend can be accurately assessed.

In Wallace Lake on nearby ISRO, both dissolved organic nitrogen and NO_3-N have increased sharply since the 1990s despite little change in atmospheric N deposition, according to unpublished data from a 2009 annual report by Stottlemyer and Toczydlowski (Brenda Moraska

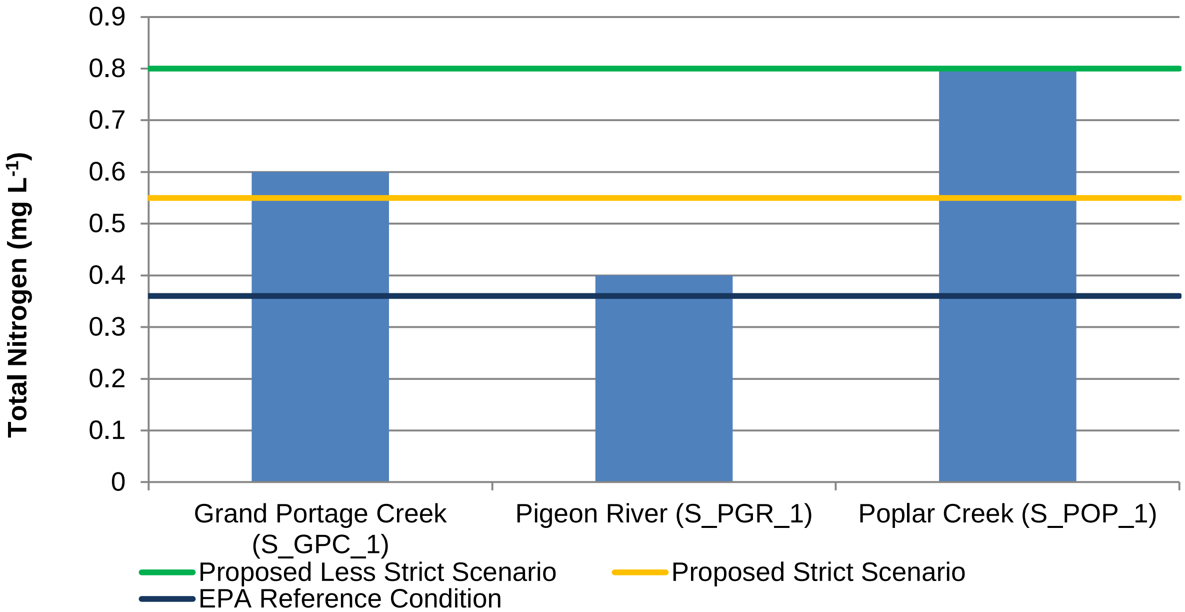

Figure 62. Median total nitrogen values for streams in the Grand Portage National Monument watershed, 1999-2006.

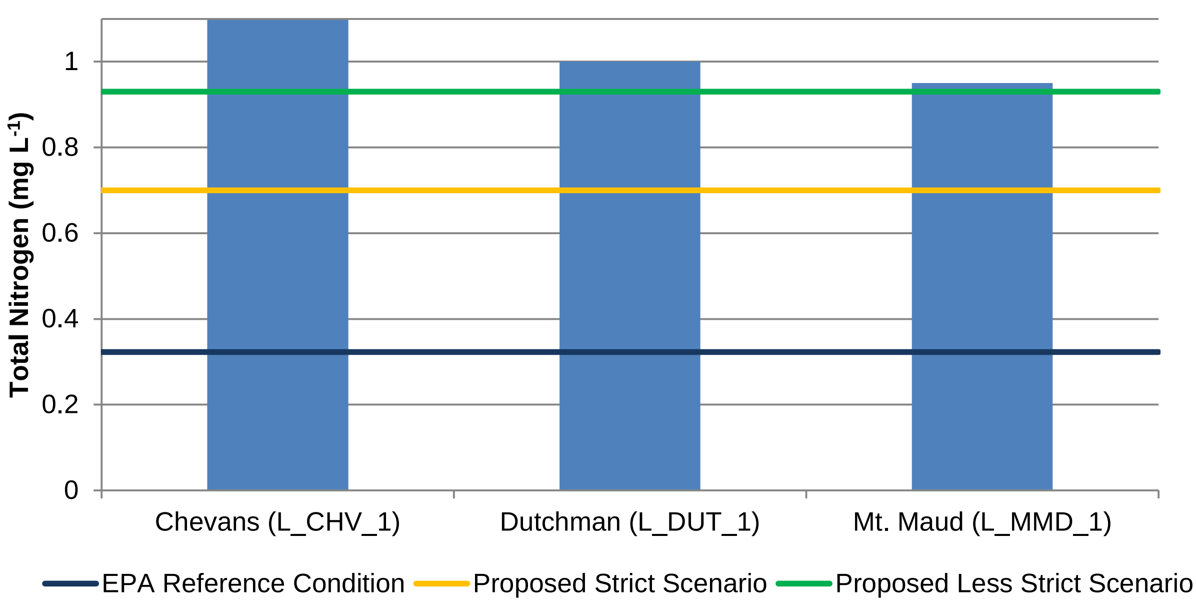

Figure 63. Median total nitrogen concentrations for lakes in the Grand Portage National Monument watershed, 1999-2006.

Lafrancois, Aquatic Ecologist, NPS, personal communication, 1/2/2013). This finding reinforces the need for the Band to continue monitoring N species, including NO_3-N, even though levels are often below detection at present.

Chlorophyll-a

Chlorophyll-*a* is the primary photosynthetic pigment in all green plants including phytoplankton and is nearly universally accepted as a measure of algal biomass in the open waters of lakes (Elias et al. 2008). However, some inaccuracy arises because different algal groups have different proportions of chlorophyll-*a* versus other pigments, and the mix of species may affect management decisions for lakes (Elias et al. 2008). Consistent and directional trends in chlorophyll-*a* concentrations are good indicators of change in a lake's tropic status (Elias et al. 2008 and citations therein).

For streams, the less strict reference condition for chlorophyll-*a* proposed by Lafrancois et al. (2009), which assumes that most Reservation waters represent reference conditions, is 1.08 µg L^{-1}, while the strict reference condition, which assumes that Reservation waters are a mix of impacted and less impacted sites, is 0.50 µg L^{-1} (Table 31). The USEPA reference condition for the subecoregion is 0.60 µg L^{-1} for the spectrophotometric method of analysis (USEPA 2001).

For lakes, the less strict reference condition for chlorophyll-*a* proposed by Lafrancois et al. (2009) is 3.75 µg L^{-1}, while the strict reference condition is 2.00 µg L^{-1} (Table 31). The USEPA reference condition for the subecoregion is 2.46 µg L^{-1} for the spectrophotometric method of analysis (USEPA 2000). The MPCA maximum standard for chlorophyll-*a* for NLF lakes is 9.00 µg L^{-1} (MPCA 2009). The NLF reference condition (25^{th} percentile) is 4.00 µg L^{-1} (Heiskary and Wilson 2005).

Reference Condition

Our chosen reference condition for chlorophyll-*a* for streams is the less strict reference condition of 1.08 µg L (Lafrancois et al. 2009). This represents a "minimally disturbed condition" (Stoddard et al. 2006). For lakes, our chosen reference condition is the MPCA maximum standard of 9.0 µg L (MPCA 2009). This represents a "least disturbed condition" (Stoddard et al. 2006).

Condition and Trend

Median chlorophyll-*a* concentrations were uniformly low (<2 µg L^{-1}) in Reservation streams from 1999-2006 (Lafrancois et al. 2009). Within the GRPO watershed, Poplar Creek (Figure 64) and Dutchman Lake (Figure 65) exceeded the proposed less strict reference condition of Lafrancois et al. (2009), placing them in the upper 25% of Reservation streams and lakes for chlorophyll-*a*. All lakes in the GRPO watershed easily met the MPCA chlorophyll-*a* maximum standard when median values from 1999-2006 were considered.

However, Mt. Maud Lake has had August chlorophyll-*a* values of 16 and 24 µg L^{-1} in 2010 and 2011, respectively, and trend analysis shows a significant upward trend from 1999-2011 (Figure 66). At the same time, the Pigeon River shows a significant downward trend. We rate the condition of GRPO lakes and streams for chlorophyll-*a* as uncertain, with an unclear trend, and our confidence in this assessment is fair.

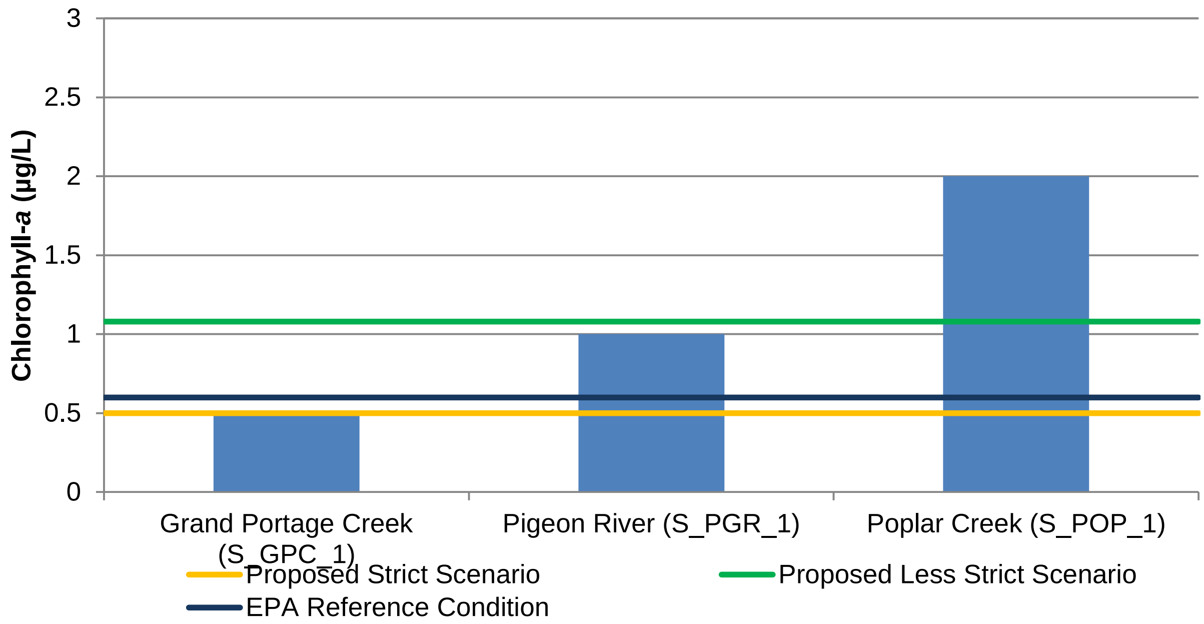

Figure 64. Median chlorophyll-*a* concentrations for streams in the Grand Portage National Monument watershed, 1999-2006.

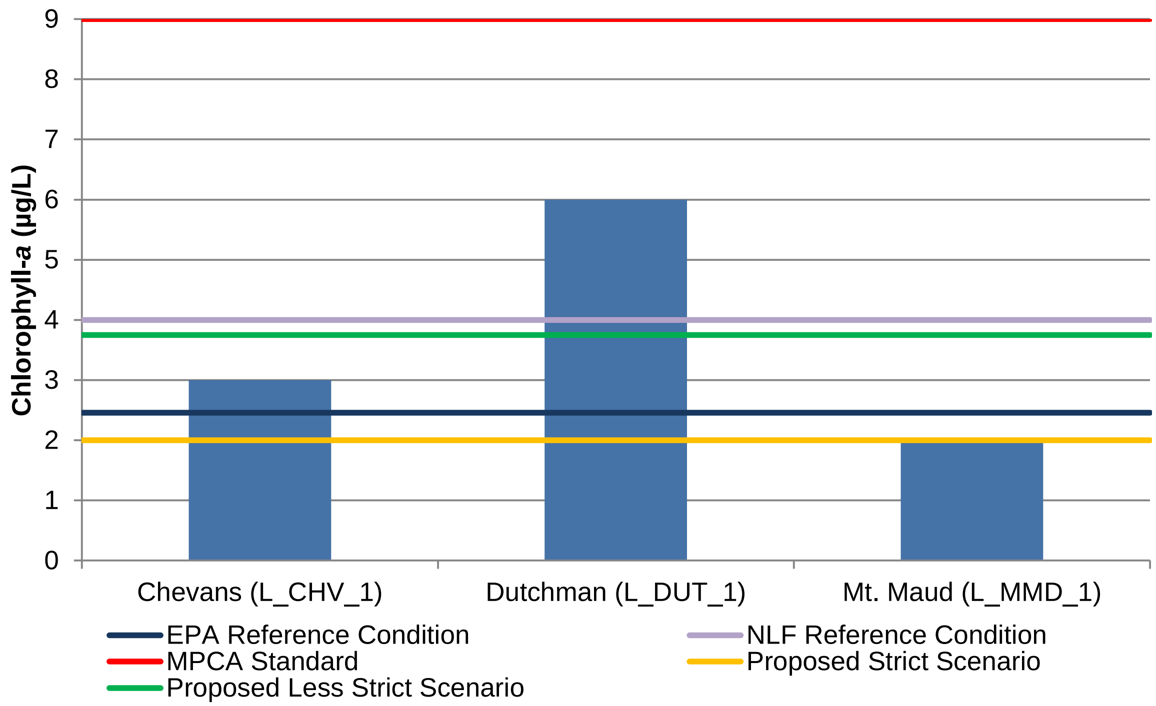

Figure 65. Median chlorophyll-*a* concentrations for lakes in the Grand Portage National Monument watershed, 1999-2006.

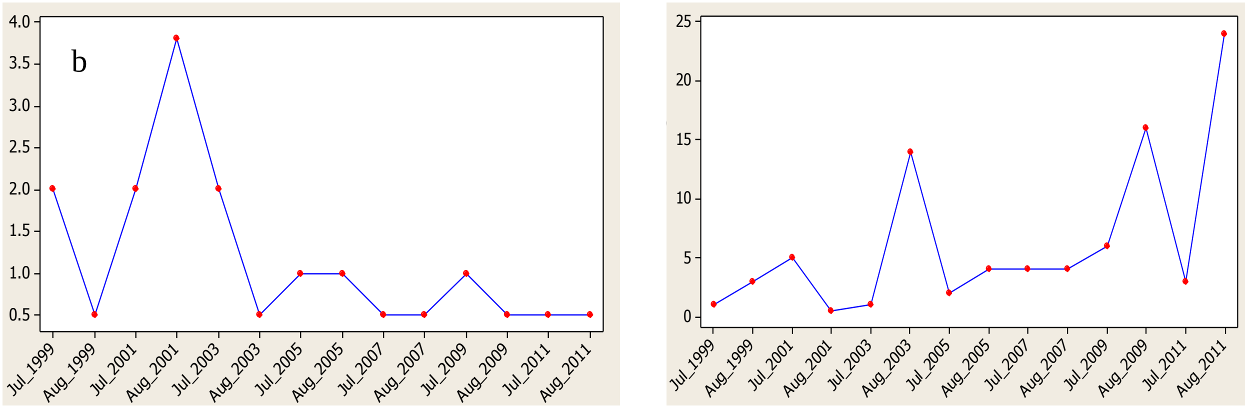

Figure 66. Time series plot of July and August chlorophyll *a* from 1999-2011 for a) Mt. Maud Lake and b) the Pigeon River in the Grand Portage National Monument watershed (note differences in y scales).

<u>Sources of Expertise</u>

Elias et al. 2008; Lafrancois et al. 2009; Margaret Watkins; Dr. Katherine Clancy, UWSP; Jen McNelly; Christine Mechenich.

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4.3.3 Water Quality of Grand Portage Bay

Description

Although Grand Portage Bay waters are not under the jurisdiction of NPS, water quality in the Bay is of interest to GRPO managers. Grand Portage Bay waters are generally less than 4 m deep and so are in the nearshore zone, which is separated from the offshore zone in Lake Superior at approximately the 10-m depth contour (Bennett 1978).

Data and Methods

The Baseline Water Quality Data Inventory and Analysis report for GRPO (NPS 1999) listed 10 water quality monitoring sites in Grand Portage Bay; of these, five had no data, four had sediment data, and one had coliform data. Known past and present sampling sites in Grand Portage Bay are shown in Figure 67. Ruhl (1997) assessed water quality in Grand Portage Bay in the summers of 1994-1996; those points are labeled with his original numbering (e.g., 475757089394001) as well as the designations the Band uses as it continues to monitor them (e.g., LS_PT_5) in Figure 67.

In the Bay, the Grand Portage Band monitors ten sites (GPBay 1, 1.5, 2, 2.5, and 3-8) for coliform bacteria, seven sites (LS_NPS_1-7) for nonpoint pollution, and eight open water sites (LS_PT_1-8). One of these sites (LS_NPS_5) is at the GRPO dock. Data for these sites was available in the USEPA STORET/WQX system (http://www.epa.gov/storet/) for 2006-2011; these data were used for the analyses in this section. Parameters considered were DO, turbidity, *E. coli*, and TP.

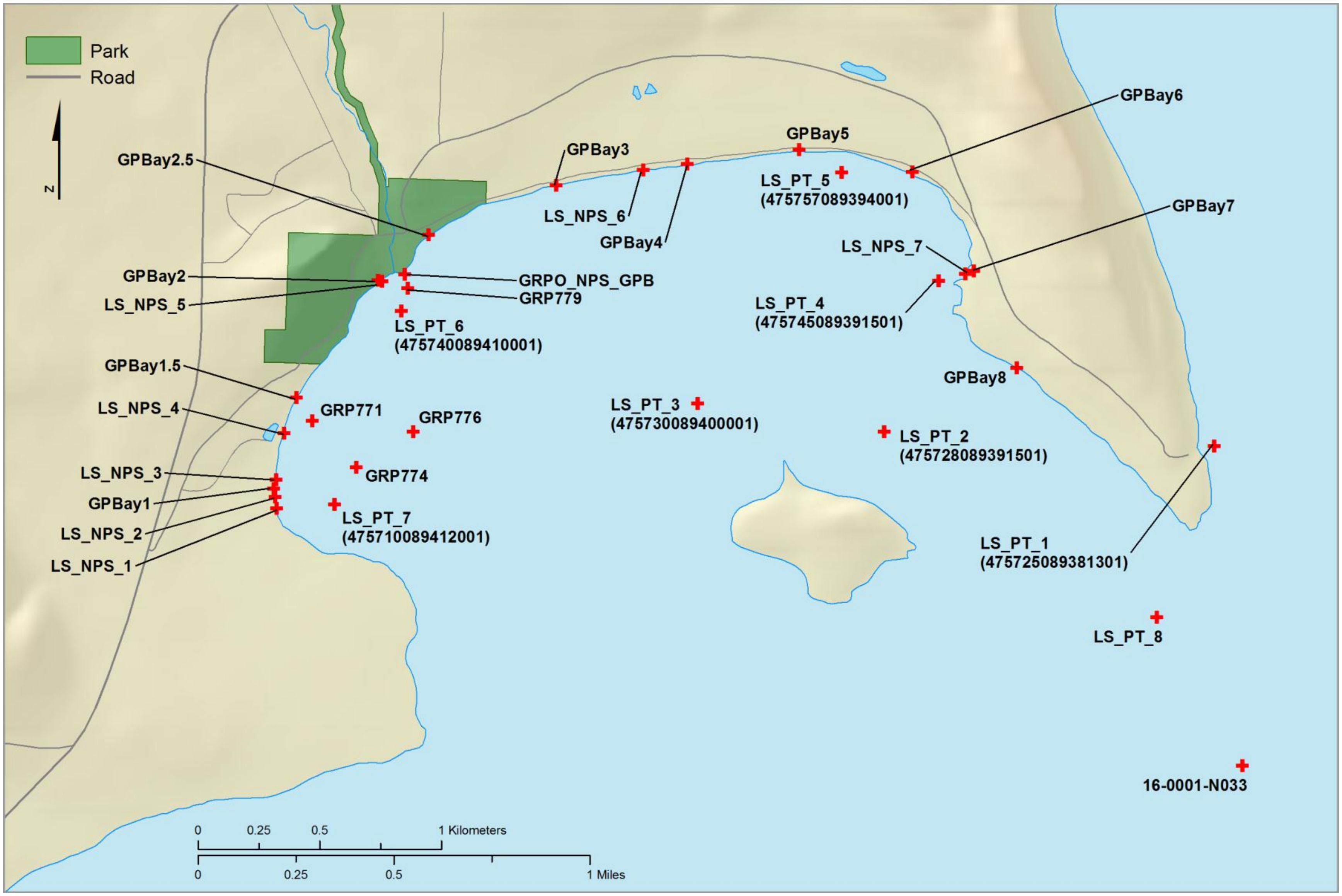

Figure 67. Historic and current water quality and fish tissue monitoring sites on Grand Portage Bay (NPS 1999 and http://www.epa.gov/storet/).

Reference Condition

For DO, the MPCA standard for Lake Superior waters is a daily minimum value of 7 mg L^{-1} (MPCA 2012). The Grand Portage Band standard for Grand Portage Bay is a minimum daily mean concentration of 9.0 mg L^{-1} when and where early life stages of cold water fish occur and 6.0 mg L^{-1} for all other cold water aquatic life stages (Grand Portage Band 2006).

For turbidity, the MPCA standard for Lake Superior is 10 NTU (nephelometric turbidity units) (MPCA 2012). The Grand Portage Band standard for Grand Portage Bay is a narrative standard tating that "turbidity attributable to other than natural causes must not exceed 5 NTU over natural conditions as defined by Tribal monitoring data" (Grand Portage Band 2006).

For *E. coli*, the Grand Portage Band has adopted the USEPA standard of a single sample maximum of 235 CFU (colony-forming units) per 100 ml and a monthly geometric mean of 126 CFU per 100 ml (Grand Portage Band 2006).

For total phosphorus, the USEPA and Environment Canada have set an endpoint of 0.005 mg L^{-1} (5 µg L^{-1}) to maintain the lake's oligotrophic state (USEPA and Environment Canada 2007, Dove and Warren 2011). The MPCA standard for Lake Superior waters is 0.012 mg L^{-1} (12 µg L^{-1}) (MPCA 2012).

These reference conditions represent "least disturbed conditions," or the best of today's existing conditions (Stoddard et al. 2006).

Condition and Trend

For DO, the average of 1,535 measurements taken at the eight open water sites (LS_PT_1-8) from 2007-2010 was 12.39 mg L^{-1}, with a range of 7.20-16.66 mg L^{-1}. At the GRPO dock, the average of 20 samples from 2008-2010 was 10.92 mg L^{-1}, with a range of 8.84-13.06 mg L^{-1}. These measurements were taken during the day and do not assess diel fluctuation. However, we anticipate that these sites meet the reference condition, and we rate the condition of Grand Portage Bay for DO as good, with a stable trend. Our confidence in this assessment is fair because of the lack of diel data.

Lake Superior is renowned for the clarity of its waters. Turbidity is a measure of water clarity, and turbidity values for the eight open water sites in Grand Portage Bay are low (water clarity is high). Of 1,431 measurements taken from 2006-2011, 999 (70%) were less than 1 NTU, and 92% met the MPCA standard of 10 NTU. However, the situation for the seven nonpoint pollution monitoring sites (LS_NPS_1-7) is different. For 127 measurements taken from 2006-2011, only 46% met the MPCA standard, and several values were 3,000 NTU in early September, 2007. Because it appears that nonpoint pollution sources periodically contribute significant amounts of turbidity to Grand Portage Bay, (likely related to storm events), we rate the condition for turbidity of moderate concern, with an unknown trend. Our confidence in this assessment is fair.

E. coli are bacteria that indicate the possible presence of disease-causing microbes originating from sewage or other fecal pollution. They are used as an indicator of the safety of surface water for recreational contact. Swimmers in water contaminated with disease-causing microbes may contract diseases of the gastrointestinal tract, eyes, ears, skin, and upper respiratory tract (USEPA 2011a). Sources of *E. coli* may include stormwater runoff, sewage treatment plant malfunctions or overflows, and pet and wildlife waste on or near beaches (USEPA 2011a). For *E. coli*, the Grand Portage Band monitors eight beach sites (GP_Bay1-8) weekly during the swimming season and seven nonpoint pollution sites during annual monitoring.

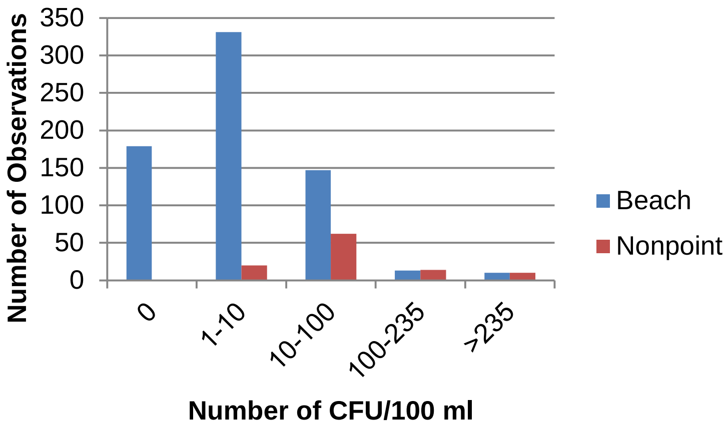

Figure 68. Number of E. coli CFU for open water and nonpoint pollution sites in Grand Portage Bay, 2006-2010.

Only 1.5% of the 680 samples taken from the beach sites exceeded the 235 CFU standard (Figure 68); half of those occurred at GP_Bay1. For the nonpoint pollution sites, 9.4% of the 106 samples exceeded the standard. Clearly, nonpoint source pollution contributes *E. coli* to Grand Portage Bay. Since most samples are well below the standard for *E. coli*, we rank the condition of Grand Portage Bay as good, with a stable trend. Our confidence in this assessment is fair, since we have not conducted an in-depth investigation of the sources and spatial variation of the *E. coli* contamination in Grand Portage Bay.

For TP, five of the eight open water sites in Grand Portage Bay had average concentrations equal to or greater than the USEPA and Environment Canada endpoint of 0.005 mg L^{-1} (Figure 69). All seven of the nonpoint pollution sites had minimum concentrations equal to or greater than this endpoint (Figure 70). All but one of the open water sites had an average concentration less than the MPCA standard of 0.012 mg L^{-1}. Only one of the nonpoint pollution sites had a minimum concentration that met this standard. For comparison, an analysis of 207 Lake Superior nearshore samples collected from 2002-2007 showed an average TP concentration of 0.00643 mg L^{-1}, with a range of 0.00190-0.01921 mg L^{-1} (Kelly 2008). We rate the condition of Grand Portage Bay for TP of moderate concern, with an unknown trend; our confidence in this assessment is fair. The spatial distribution of average TP concentrations in Grand Portage Bay is presented in Figure 71.

Trophic state is another indicator of water quality; it is based on the total weight of living biologic material at a specific location and time (Carlson and Simpson 1996). Carlson's trophic state indices (TSIs) use algal biomass as the basis for trophic state classification. Three variables (chlorophyll pigments, Secchi depth, and TP) independently estimate algal biomass, with

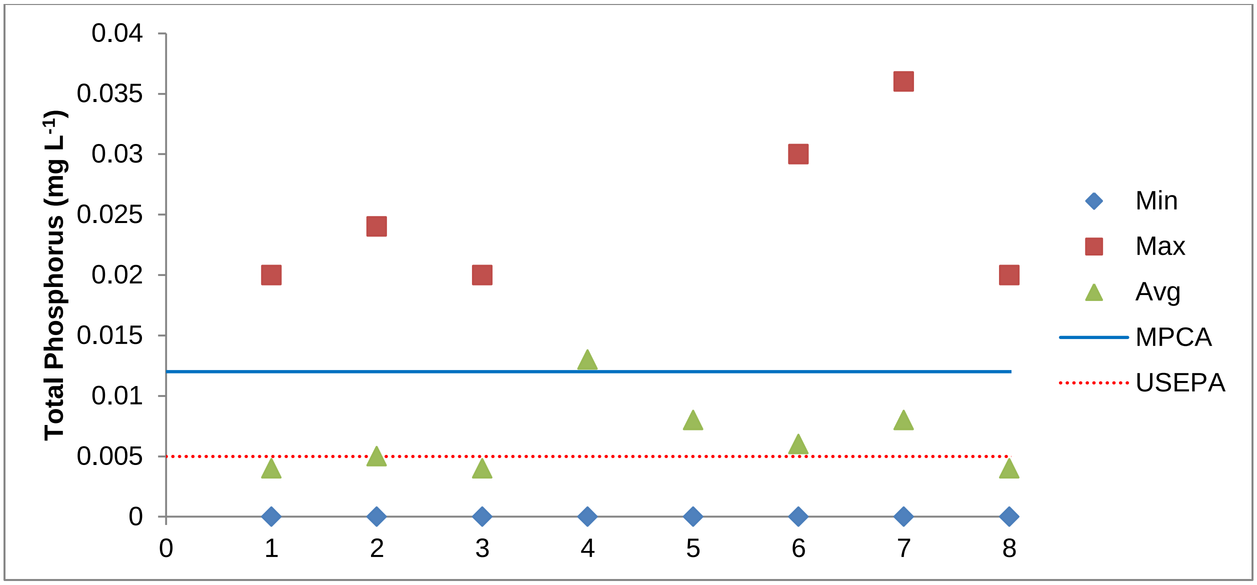

Figure 69. Total phosphorus concentrations at eight open water sites in Grand Portage Bay (LS_PT_1 to LS_PT_8) from 2006-2011, compared to the MPCA standard and USEPA/Environment Canada endpoint.

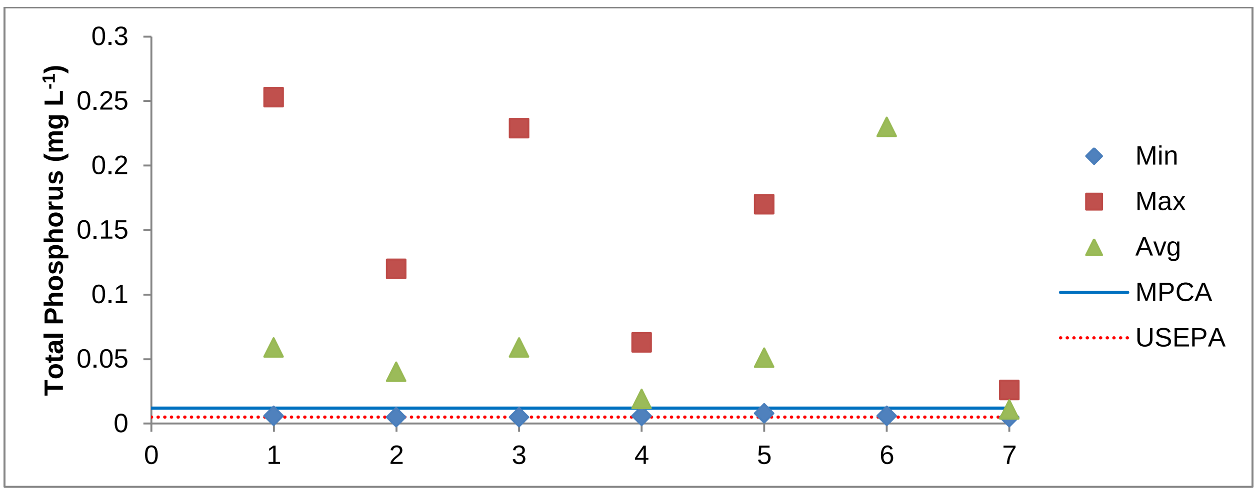

Figure 70. Total phosphorus concentrations at seven nonpoint sites affecting Grand Portage Bay (LS_NPS_1 to LS_NPS_7) from 2006-2011, compared to the MPCA standard and USEPA/Environment Canada endpoint. (The maximum concentration of 1.86 mg L^{-1} for site LS_NPS_6 is not shown.)

chlorophyll being the best predictor (Carlson 1977). Carlson TSIs for TP were calculated for the eight open water sites (n=120) and for the GRPO dock site (LS_NPS_5, n=16) for 2006-2011. As might be expected, the index predicted oligotrophic conditions for the Bay, but conditions ranged from mesotrophic to hypereutrophic at the dock (Figure 72). Data were not available to calculate TSIs based on chlorophyll pigments or Secchi depth.

In addition to runoff from nonpoint pollution sources, an additional source of nutrients, *E. coli*, and/or turbidity might be the sewage treatment system that serves GRPO and Grand Portage and discharges into Grand Portage Bay. A factsheet describing the permit issued by the USEPA (USEPA 2011b) indicates that the treatment system consists of a four-cell stabilization lagoon.

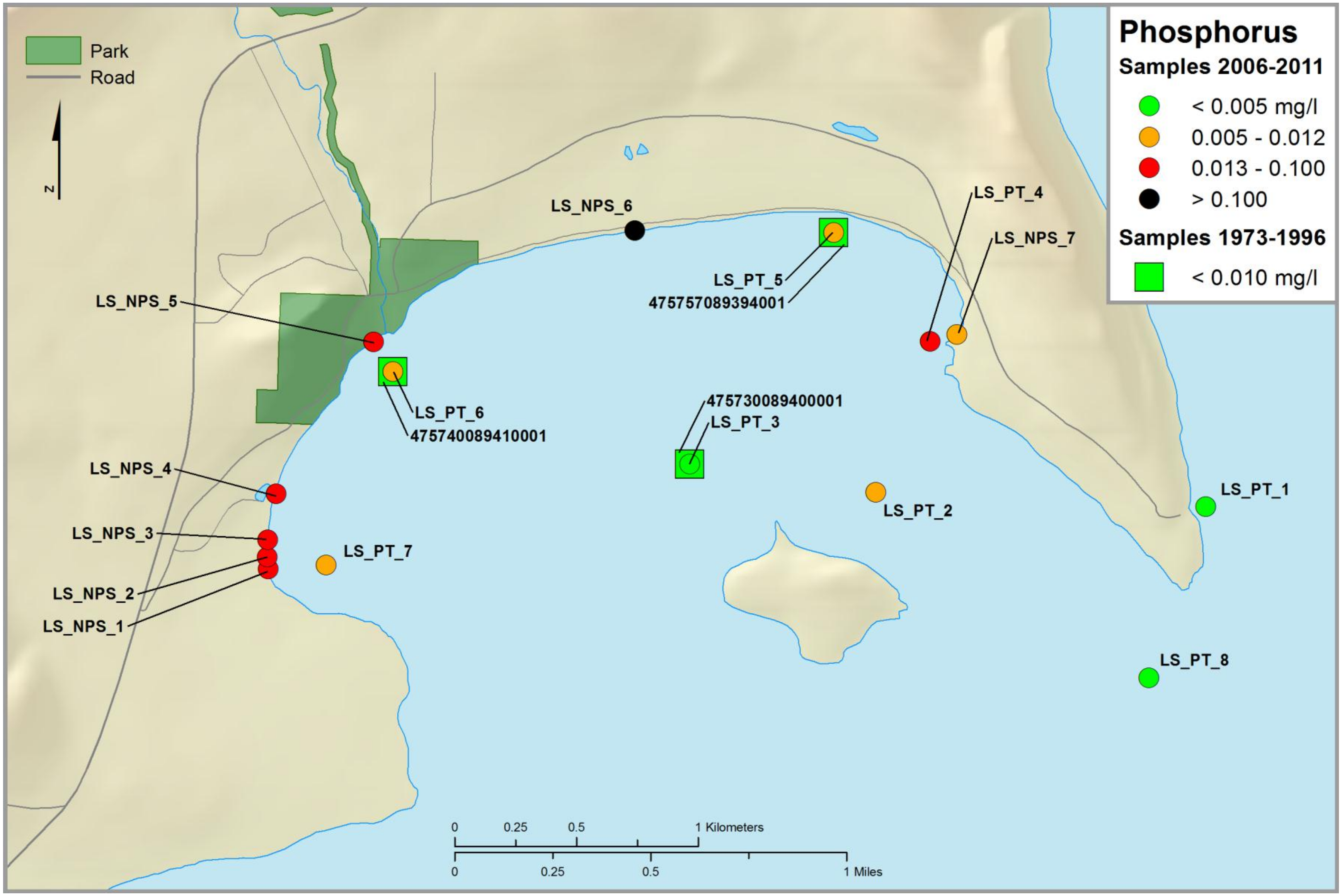

Figure 71. Average total phosphorus values for sites on Grand Portage Bay.

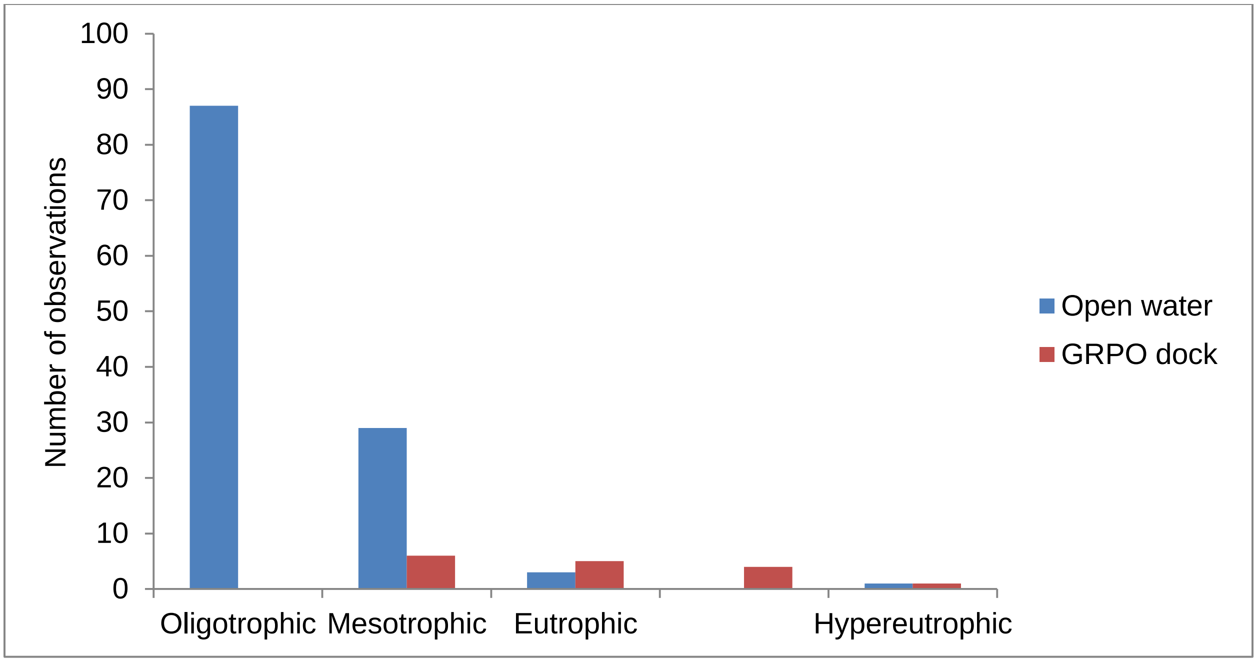

Figure 72. Carlson's trophic state index (TSI) based on total phosphorus for Grand Portage Bay and the Grand Portage National Monument dock.

The three cells that provide primary treatment (settling of solids) are 0.6, 0.8, and 1.8 ha; the fourth cell provides secondary treatment (biological treatment) and is 1.5 ha. Tertiary treatment is provided by adding alum to remove phosphorus. The ponds are designed for an average influent flow of 280 m^3 day^{-1} and allow for 210 days of storage.

The limits for discharge of regulated parameters are listed in Table 32. Under the system's previous permit, the allowable TP discharge was a 30-day average of 1.0 mg L^{-1}. The renewed permit issued July 14, 2011 reduced the allowable TP discharge to an 30-day average of 0.5 mg L^{-1} and a daily maximum of 1.0 mg L^{-1} and stated that "effluent monitoring data indicate that the facility can meet the new limits" (USEPA 2011b). The system exceeded its allowable TP discharge twice in 2011; the USEPA ECHO (Enforcement and Compliance History Online) website (http://www.epa-echo.gov/cgi-bin/get1cReport.cgi?tool=echo&IDNumber=110011114203) lists reported quarterly TP discharges of 1.12 mg L^{-1} on May 31, 2011 and 1.09 mg L^{-1} on September 30, 2011. Also on May 31, 2011, the system reported quarterly removal of 83.8% of total suspended solids instead of the 85% required at that time.

Table 32. Discharge limits effective July 14, 2011 for the Grand Portage Reservation wastewater treatment plant under USEPA permit MN-0025887-5.

Parameter	30-Day Average	7-Day Average	Daily Minimum	Daily Maximum
BOD5	25 mg/L	40 mg/L		
Total Suspended Solids	30 mg/L	45 mg/L		
Total Phosphorus	0.5 mg/L			1.0 mg/L
Total Mercury	4.7 ng/L			
pH	NA	NA	6.0 S.U.	9.0 S.U.
E. Coli	126 *E. coli*/100 ml	NA	NA	235 *E. coli*/100 ml

Sources of Expertise
USEPA, Margaret Watkins, Christine Mechenich.

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4.3.4 Mercury

Description

Mercury is a persistent, bioaccumulative toxic pollutant with harmful health consequences for both humans and animals. Although it is naturally occurring, human activities have facilitated its spread throughout the environment. Most of the mercury that is found in Minnesota's lakes, rivers, and fish is deposited from the atmosphere (MPCA 2010). An MPCA (2008) report projected that in 2010, 1,191 kg of mercury would be emitted to the atmosphere in Minnesota; 46% from energy production, 32% from taconite production, and 22% from "purposeful use" of mercury. However, because mercury can be carried long distances by the wind, about 90% of the mercury deposited from the air in Minnesota comes from other states and countries, and about 90% of Minnesota's mercury emissions are deposited on other states and countries (MPCA 2010).

Both the USEPA and MPCA track mercury emissions in Minnesota, and results vary from year to year, both because of improvements at the facilities and because production is not constant. Air emissions within 250 km of GRPO are shown in Figure 73.

Sources of mercury air emissions nearest to GRPO are at Taconite Harbor (22.0 kg yr^{-1}), Silver Bay (4.7 kg yr^{-1}), and Thunder Bay (3.7 kg yr^{-1}). The largest sources in the region are the taconite processing facilities on the Iron Range (Table 33).

Mercury occurs in three forms in the atmosphere: 1) the gas-phase elemental form (Hg[0]), 2) a gaseous inorganic form (Hg[II]) formed in photochemical reactions, and 3) the particulate form (Hg[P]). Ninety-five percent of the total in the atmosphere is in the elemental form (Grigal 2002), but the inorganic form is more soluble and is the dominant form in precipitation. In aquatic ecosystems, particularly in anaerobic environments such as wetlands and lake sediments, microbes transform deposited inorganic mercury into methylmercury (MeHg), which biomagnifies in food webs, resulting in high concentrations in fish (Drevnick et al. 2007 and citations therein). In Lake Superior, a small amount (< 6%) of the total mercury deposited is MeHg; this occurs mainly during low-volume rain events where it is "washed out" of the atmosphere. Sources of this MeHg may include lake-effect cloud and fog, nearby wetlands, or upwelling of deep waters from the lake (Hall et al. 2005).

Figure 73. Mercury emissions to the air within 250 km of Grand Portage National Monument.

Data and Methods

Mercury air emissions data were obtained and mapped from the following sources: Environment Canada (2009) (Canadian data); USEPA (2010) (Toxic Release Inventory TRI Basic Data files for Minnesota, Wisconsin, and Michigan for 2010); MPCA (2008) (Taconite Processing emissions for 2005) (Table 33). A specific value for Northshore Mining – Silver Bay was developed in consultation with Anne Jackson of MPCA (email, February 6, 2012).

Data for mercury in precipitation at the MDN station at Fernberg, 124 km W of GRPO were downloaded from http://nadp.sws.uiuc.edu/nadpdata/mdnRequest.asp?site=MN18.

GRPO has an ongoing project that began in 2008 to assess mercury in water, seston, sediment, fish, and larval dragonflies. A summary of this current unpublished research was provided by James Wiener of UW-La Crosse (Wiener 2012). In 2009, a soil geochemical survey of the Portage Trail was conducted by USGS. A data summary of this investigation and the mercury findings in a 2001 bedrock mapping project were provided by Laurel Woodruff.

A large body of research has recently been published about mercury. The February, 2012 special issue of the journal *Environmental Pollution* was titled Mercury in the Laurentian Great Lakes Region, and the October, 2011 special issue of the journal *Ecotoxicology* was titled Mercury in the Great Lakes Region.

Table 33. Mercury emissions within 250 km of Grand Portage National Monument.

Year	Facility	Location	State/ Province	kg Hg
Energy Generating Facilities (22.3%)				
2009	Ontario Power-Thunder Bay Generating Station	Thunder Bay	ON	3.7
2009	Ontario Power-Atikokan Generating Station	Atikokan	ON	8.8
2010	Sappi Cloquet LLC	Cloquet	MN	2.1
2010	Taconite Harbor Energy Center	Schroeder	MN	22.0
2010	Virginia Public Utilities	Virginia	MN	4.7
2010	Laskin Energy Center	Hoyt Lakes	MN	7.5
2010	Hibbing Public Utilities Commission	Hibbing	MN	6.3
2005	Minnesota Power Inc.-M L Hibbard Plant	Duluth	MN	2.8
2010	White Pine Electric Power LLC	White Pine	MI	0.1
2010	Presque Isle Power Plant	Marquette	MI	11.4
2010	Marquette Board Of Light & Power	Marquette	MI	8.2
2010	Murphy Oil USA, Inc.	Superior	WI	0.8
2010	Flambeau River Papers	Park Falls	WI	0.8
2010	Graymont (Wi) Inc.	Superior	WI	2.4
2010	Xcel Energy Bay Front Plant	Ashland	WI	12.8
Energy Generation and Taconite Production				
2005	Northshore Mining- Silver Bay	Silver Bay	MN	4.7
Taconite Production (76.6%)				
2005	U.S. Steel Corp - Minntac	Iron Range	MN	84.0
2005	United Taconite LLC - Thunderbird Mine	Iron Range	MN	0.5
2005	Northshore Mining - Babbitt	Iron Range	MN	0.1
2005	Hibbing Taconite Co.	Iron Range	MN	103.0
2005	Ispat Inland Steel Mining - Minorca	Iron Range	MN	15.1
2005	U.S. Steel - Keewatin Taconite	Iron Range	MN	62.0
2005	United Taconite LLC - Fairlane Plant	Iron Range	MN	60.6
			Total	424.5

<u>Reference Condition</u>

A modeling study in Sweden indicates that in humic lakes in the boreal ecosystem, the maximum mercury concentration in precipitation to maintain the regional mean mercury concentrations in 1-kg northern pike (*Esox lucius* L.) below 0.5 mg kg^{-1} fresh weight is approximately 2 ng L^{-1} (Meili et al. 2003). The authors also suggested that 2 ng L^{-1} or less may be the global pre-industrial level of mercury in precipitation. Thus, this reference condition represents both a "historic condition" and a "least disturbed condition" (Stoddard et al. 2006).

In northern Minnesota, soil geochemical surveys have shown that shallow soils have mercury concentrations up to 0.4 ppm (parts per million), while the B or C horizons of soils have lower concentrations, typically about 0.03 ppm (Woodruff and Cannon 2010). In the western Lake Superior region, bedrock and deep soil samples often have mercury levels below the detection limit of 0.02 ppm (Woodruff 2012). The reference condition of 0.03 ppm represents a "historic condition" for deep soils (Stoddard et al. 2006). The MPCA (1999) has established a Soil Reference Value of 0.7 ppm as a risk screening criterion for whether contaminated soils are suitable for residential use.

The USEPA (2002) has established a tissue residue criterion for MeHg of 0.30 mg kg^{-1} for fish intended for human consumption. Minnesota has established a statewide fish tissue criterion of 0.2 mg kg^{-1} for mercury and places water bodies that do not meet this criterion on the impaired waters list (MPCA 2009). The USEPA has developed a surface water quality criterion for total mercury of 1.3 ng L^{-1} for wildlife to "…protect mammals and birds from adverse impacts from that chemical due to consumption of food and/or water from the Great Lakes System" (USEPA 1995). The Grand Portage Band has adopted this wildlife criterion and also established an aquatic life criterion of 0.908 ng L^{-1} for aquatic life and a human health criterion for subsistence fishing of 0.196 ng L^{-1} for Grand Portage Bay (Grand Portage Band 2006, Margaret Watkins, Water Quality Specialist, Grand Portage Band, emails 2/28/13 and 4/2/13). Wiener (2012) reported that Depew et al. (2012) had estimated 40 ng g^{-1} w.w. in prey fish as a dietary threshold for reproductive effects of mercury on piscivorous fish. These reference conditions are "best attainable conditions," or the condition that today's sites might achieve if they were better managed (Stoddard et al. 2006). Reference conditions for mercury are summarized in Table 34.

Table 34. Reference conditions used in evaluating mercury contamination at Grand Portage National Monument.

Medium	Source	Reference condition	Units	Equivalents (ppm)
Precipitation	Meili et al. 2003	2	ng L^{-1}	0.000002
Deep soils	Woodruff and Cannon 2010	0.03	ppm	0.03
Contaminated soils	MPCA 1999	0.7	ppm	0.7
Fish tissue (MeHg)	USEPA 2002	0.30	mg kg^{-1}	0.30
Fish tissue	MPCA 2009	0.2	mg kg^{-1}	0.2
Prey fish tissue	Depew et al. 2012	40	ng g^{-1}	0.04
Surface water (wildlife)	USEPA 1995	0.13	ng L^{-1}	0.00000013
Surface water (aquatic life)	Grand Portage Band 2006	0.908	ng L^{-1}	0.000000908
Surface water (fish consumption)	Grand Portage Band 2006	0.196	ng L^{-1}	0.000000196

<u>Condition and Trend</u>

Precipitation

Mercury concentrations in precipitation at GRPO are of significant concern. Some evidence suggests an improving trend, but our current assessment is that the trend is unchanging. Because the nearest precipitation monitoring station for mercury is at Fernberg, Minnesota (MN 18), 124 km west of GRPO, our level of confidence in the assessment is fair.

Mercury concentrations in precipitation at Fernberg consistently exceed the reference condition of 2 ng L^{-1} (Figure 74). Of 552 weekly samples for which data were recorded from 1996-2011, only 21 (3.8%) met the reference criterion; 447 (81%) were up to an order of magnitude higher, in the 2-20 ng L^{-1} range.

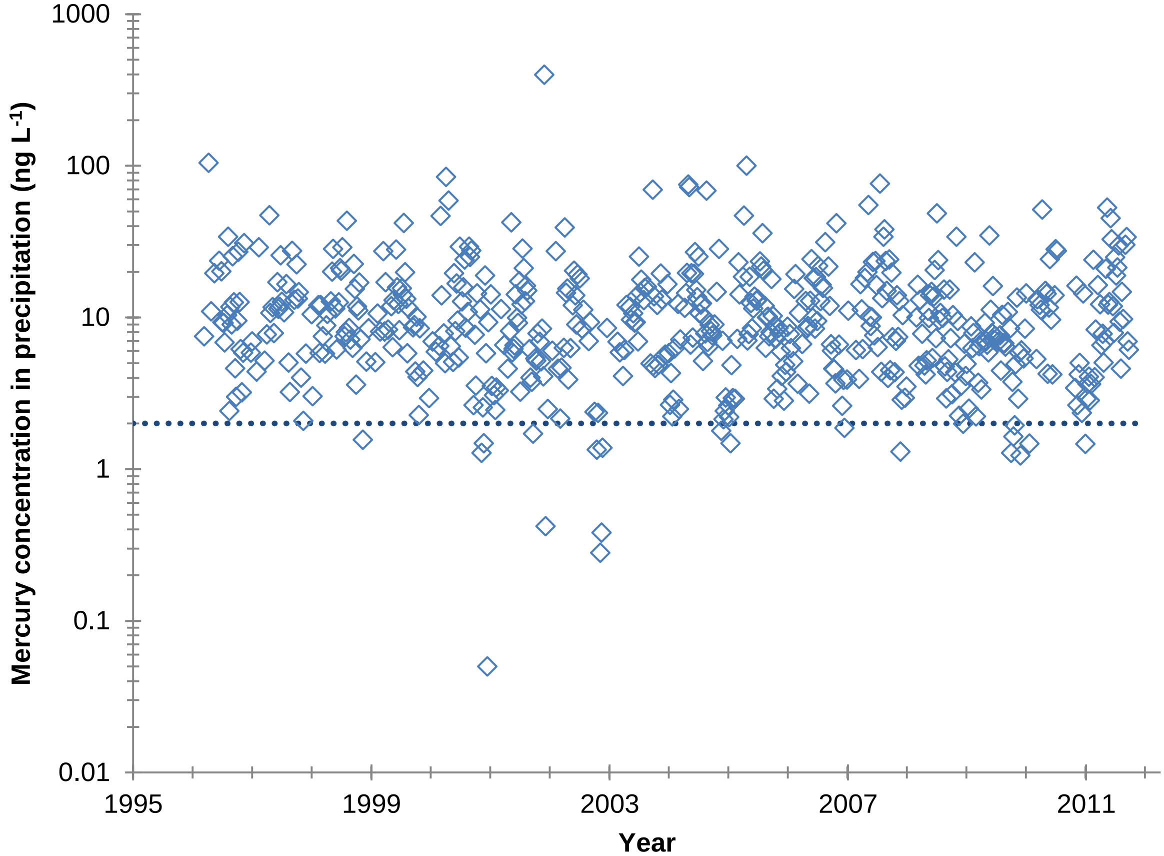


Figure 74. Total mercury in precipitation, weekly sampling, Fernberg, Minnesota. (Note that the data are plotted on a logarithmic scale for ease of viewing).

Risch et al. (2012a), using data from Fernberg as well as other MDN stations in the Great Lakes basin, estimated a net change in annual average mercury concentration in precipitation in the range of -2.0 to -1.1 ng L^{-1} for the GRPO vicinity, but an increase of 0.1 to 1.0 ng L^{-1} on the Iron Range to the west from 2002-2008. We calculated annual averages for the Fernberg data from 1996-2011 (Figure 75); although levels appear to be declining, the trend was not significant (p=0.103).

Soil

Mercury concentrations in the C horizons of GRPO soils at three sites exceed the reference condition of 0.02 ppm for bedrock and deep soils in the western Lake Superior region. We rate the finding of elevated levels of mercury in some GRPO soils as of moderate concern. No information is available on trend, but given the nature of mercury enrichment processes, it is unlikely that these values are changing significantly. Our confidence in this assessment is good.

Surface soils in the western Great Lakes region are often enriched with mercury up to 0.3-0.4 ppm Hg, generally attributed to wet and dry deposition of atmospheric deposition to the ground

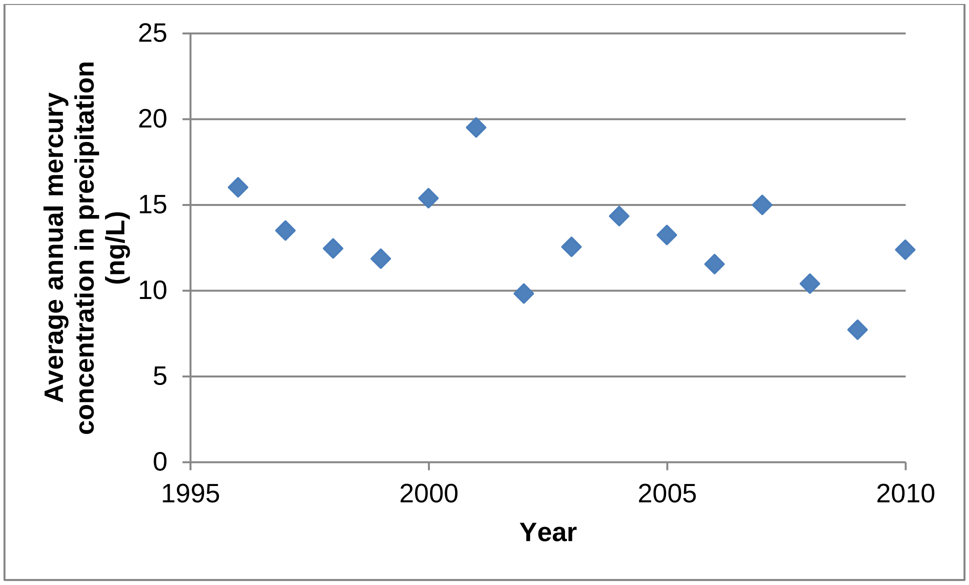


Figure 75. Annual average mercury concentration in precipitation, Fernberg, Minnesota, 1996-2010. Trend not significant; p=0.103.

surface as well as litterfall and throughfall from the forest canopy. Mercury generally decreases with depth in the soil profile. Mercury readily adheres to most forms of organic matter; for thisreason, the concentration of mercury in the organic horizon on the forest floor is six times that of the mineral soil, though the total mass in the mineral soil is five times higher (Nater and Grigal 1992). Hg(0) and Hg(II) are the more common forms in the soil, and both forms go into solution and adhere to soil adsorption sites (Grigal 2003). Under certain conditions, it is converted to the MeHg form, with MeHg being only about 0.6% of the total.

The 2009 soil geochemical survey of the Portage Trail showed most mercury values to be consistent with those at VOYA and ISRO, considering variations in bedrock and glacial type (Woodruff 2012). Surface soils met the reference condition of 0.4 ppm. Sixteen of 19 sites in GRPO had a typical distribution of mercury, decreasing with depth (Woodruff 2012).

However, the remaining three sites were anomalous, showing “significantly” higher mercury at depth (Table 35). Sites GP-13 and GP-14 are located at either end of the Portage Trail, where human activities were concentrated during the fur trade era, while GP-11 is a forested site approximately 3.2 km from the western end of the trail.

Table 35. Anomalous mercury concentrations at depth for three soil samples in Grand Portage National Monument (Woodruff 2012).

	GP-11 Depth (cm)	Concentration (ppm)	GP-13 Depth (cm)	Concentration (ppm)	GP-14 Depth (cm)	Concentration (ppm)
A Horizon	0-9	0.06	0-5	0.07	0-10	0.20
C Horizon	70-80	0.12	70-80	0.15	30-35	0.33

Woodruff (2012) states that "the occurrence of high mercury at depth must have an anthropogenic source." In an email (1/13/2012), Brandon Seitz provided a history of mercury use at Grand Portage, noting that an inventory of trade goods at Grand Portage in June, 1797 included 48 kg of mercuric sulfide (vermillion) and at least 0.5 kg "mercurial ointment." Mercurial materials were likely traded across Grand Portage for several decades, and the amount of mercuric sulfide traded over time likely exceeded 968 kg. Vermillion was mixed with grease and applied to the skin as a decorative paint, and was also used to dye clothing and the paddle tips of those who reached "the height of land," or the summit of the Laurentian Divide separating the watersheds of the Atlantic and Arctic oceans. An archaeologist excavated a small amount of vermillion at Fort Charlotte (email, Brandon Seitz, NPS, 1/13/2012). More investigation would be necessary to determine the extent of such anthropogenic mercury contamination at GRPO.

Vegetation

The review of inputs and outputs by Grigal (2002) concluded that less than 10% of the mercury in plants is from the soil. The roots of plants act as a natural barrier to mercury and an adsorption site, and thus there is limited uptake (Grigal 2003). The gas-phase elemental form adsorbs to leaf surfaces and enters the plant through open stomates. It binds to mesophyll tissues readily and is easily oxidized, and thus 'captured,' in the leaves. Consequently, litterfall is the dominant flux between the atmosphere and the terrestrial system, and is the primary pathway by which mercury gets to the soil subsystem. This fact explains why characteristics of the surface are an important part of the movement of mercury; the length of the growing season, the longevity of leaves, and the amount of leaf surface area all play a critical role in determining how much mercury is deposited on an annual basis.

Risch et al. (2012b) found that for the MDN station at the Marcell Experimental Forest (MN 16), 278 km from GRPO, litterfall dry deposition of mercury was 3.8 ± 0.4 µg m^2 yr^{-1} compared to wet deposition of 6.7 ± 3.1 µg m^2 yr^{-1} from 2007-2009. Litterfall dry deposition of mercury for aspen-birch and white-red-Jack pine forest types in their study area of 15 sites in the eastern U.S. (including Minnesota) was 6.8 and 7.7 µg m^2 yr^{-1}, respectively. Though Hg(0) is the most abundant form, approximately 0.6-1.5% of the mercury in litterfall is MeHg (Grigal 2002, Risch et al. 2012b).

Published values indicate that the concentration of both total mercury and MeHg in "plants" is: herbs < trees + shrubs < aquatic macrophytes < sphagnum moss < mosses < lichens < fungi (Moore et al. 1995). In Ontario, the lowest concentrations of total mercury and MeHg were found in the leaves of trees and shrubs. Thus, herbivores that feed on forbs or upland woody plants get a very low dose of mercury. Though top predators often have higher concentrations than herbivores, there appears to be little biomagnification in terrestrial food chains (Grigal 2002). In a study of deer mice on ISRO, mercury concentrations were "not remarkably high compared to heavily polluted sites," but the authors expressed concern about both biomagnification and the (then) unknown source of the mercury (Vucetich et al. 2001).

Although the concentration of MeHg is greater in aquatic macrophytes than in upland herbs, trees, and shrubs, there is unlikely to be a 'bio-concentrating' mechanism involving the rooted aquatic macrophytes. This is true primarily because these plants are herbaceous and die back annually. This is also our expectation because MeHg probably is only 1% or less of the mercury load in deposition (Grigal 2002). Third, non-woody plants, as a life form, make up a small to very small portion of moose diet, even in summer (Shipley 2010). Fourth, the concentration of Me(Hg) is low in aquatic plants compared to *Sphagnum*, mosses, and lichens (Moore et al. 1995). However, the amount of the basin in a wetland condition will probably exert a detectable positive effect on the amount of MeHg in the system (Chasar et al. 2009). Current work in progress at GRPO through partnership with Michigan Technological University will provide further insight into this question.

Because most of GRPO is terrestrial and largely forested, the majority of the total mercury load passes through the forest ecosystem, and a strong majority of incoming mercury stays in the terrestrial system for some period of time. Studies have shown that between 5% and 25% of deposited mercury will reach associated lakes (Grigal 2002). Thus, the land is an important contributor to the mercury status of water bodies.

Streams

Concentrations of total mercury in three GRPO streams (Snow Creek beaver pond in upper reaches and lower reaches, Poplar Creek south branch, and Grand Portage Creek lower reach) ranged from 6.5-9.3 ng L^{-1} and averaged 7.8 ng L^{-1} in 2010 (Wiener 2012). These levels exceed both the reference criterion of 1.3 ng L^{-1} for the protection of wildlife in the Great Lakes basin (USEPA 1995) and the reference criterion of 0.196 ng L^{-1} for surface waters producing fish for human consumption (Grand Portage Band 2006). We rate this condition as of significant concern. Historic data were not found, so a trend could not be established. Our confidence in this assessment is good.

The concentrations of total mercury and MeHg in GRPO streams are "substantially higher" than those typically found in lakes and streams in the western Great Lakes region (Wiener 2012). For example, Roy et al. (2009) reported a range of 1.26-3.43 ng L^{-1} total mercury in five streams in coniferous watersheds in the Laurentian region of the Canadian Shield of Quebec, lower than the range of 6.5-9.3 ng L^{-1} found in GRPO. Wiener (2012) further described GRPO streams and basins as "mercury-sensitive ecosystems" in which environmental conditions are favorable for the conversion of deposited inorganic mercury to the MeHg that readily accumulates in lotic food webs. In GRPO, MeHg accounted on average for 19% of total mercury in filtered stream water (Rolfhus et al. 2011).

Wetlands are important sites of MeHg production, and water and biota in wetland-influenced streams can contain high levels of MeHg (Wiener 2012 and citations therein). St. Louis et al. (1994) found that in the Experimental Lakes Area of northwestern Ontario, yields of MeHg were 26-79 times higher from wetland portions of watersheds than from purely upland areas. Roy et al. (2009) studied the influence of beaver ponds, one type of wetland, on stream water chemistry for total mercury, MeHg and various other parameters. The range of MeHg values they reported at the outlets of five beaver ponds in coniferous watersheds (0.53-4.53 ng L^{-1}) was similar to that observed by Wiener (2012) in GRPO streams (0.55-2.3 ng L^{-1}). This finding appears to agree with the work of Driscoll et al. (1998), who reported that the areal rate of MeHg production for an older beaver impoundment in the state of New York was comparable to rates reported for wetlands, at the low end of the range reported for lakes, and well below values reported for flooded terrestrial areas.

Methylation efficiency of beaver ponds was found by Roy et al. (2009) to decrease with age (from 55 ± 18% for “recent” ponds to 20 ± 9% for “old” ponds). Pond outlets located above 450 m in altitude in predominantly coniferous sites with acidic waters had higher MeHg and total mercury concentrations than those in lower mixed forest zones. Beaver ponds were sites of high microbial activity that led to significant increases in DOC, TP, particulate phosphorus, TN, and NH_4^+, but significant depletions of DO, NO_2-NO_3^--N, SO_4^{2-}, and chloride (Roy et al. 2009).

Similarly, total mercury concentrations increased after Mt. Maud Lake flooded newly-impounded lands on the Grand Portage Reservation (Margaret Watkins, Water Quality Specialist, Grand Portage Band, personal communication 3/22/12). Stokes and Wren (1987) conducted a literature review of mercury concentrations in impoundments and concluded that the source was soils and vegetation in the flooded areas.

Sulfate availability influences mercury methylation, and sulfate-reducing bacteria are the organisms responsible for the methylation of mercury (Grigal 2003, Drevnick et al. 2007). These microbes are most abundant under anoxic conditions and in places where carbon accumulates. This explains why the wetland area around a lake is a critical determinant of mercury concentration in lakes, and why rates of MeHg production are higher in beaver pond sediments than in lake sediments (Driscoll et al. 1998, Grigal 2003). Drevnick et al. (2007) reported that at ISRO, mercury accumulation in fish has been controlled by the deposition and cycling of sulfur for the last century. Thus, acid rain reduction programs that reduce sulfur deposition have had the unexpected benefit of reducing MeHg contamination of fish at ISRO and in other sulfur-limited environments, including boreal lakes. The authors warned that a significant increase in atmospheric sulfur loading (such as that proposed by some to slow climate change) could reverse this positive effect (Drevnick et al. 2007). The extent to which GRPO surface waters are sulfur-limited has not yet been quantified.

Aquatic Organisms Other than Game Fish

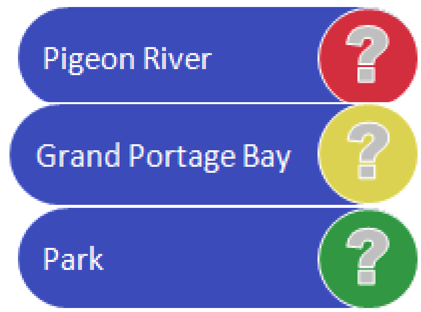
Mean concentrations of mercury in prey fish tissue in GRPO in 2010 ranged from 43 ng g^{-1} for creek chub (*Semotilus atromaculatus*) in Poplar Creek to >100 ng g^{-1} for longnose dace (*Rhinichthys cataractae*) and blacknose dace (*Rhinichthys atratulus*) in Poplar Creek, with the maximum concentration in individual fish of 242 ng g^{-1} in blacknose dace (Wiener 2012). These mean concentrations exceed the reference condition of 40 ng g^{-1} for the protection of piscivorous fish (Depew et al. 2012). We rate this condition as of significant concern. Historic data were not found, so a trend could not be established. Our confidence in this assessment is good.

Wiener (2012) also reported concentrations of total mercury and MeHg in larval dragonflies two to three times greater at GRPO than at other Great Lakes national parks. The percent MeHg was greater at GRPO than at the other five parks (Table 36). This finding may be particularly significant for passerine songbirds and other invertivorous birds (Wiener 2012). In the northeastern US, current environmental loads of mercury have the potential to significantly reduce reproductive success in several songbird species of conservation concern (Evers et al. 2012); the extent to which this might constitute an impairment at GRPO has not been determined.

Table 36. Mean total mercury (Hg), methylmercury (MeHg), and percent MeHg in larval dragonflies sampled from six park units during 2008-2009. Mean values were calculated from data for all species from each park unit. Sample size (n) indicates the number of dragonflies analyzed individually for both total mercury and MeHg (Wiener 2012).

Park unit	n	MeHg (ng g^{-1} dry weight)	Total Hg (ng g^{-1} dry weight)	Percent MeHg
GRPO	59	145	151	95
INDU	16	53	66	91
ISRO	139	57	73	74
PIRO	101	63	92	73
SLBE	119	51	64	77
VOYA	117	98	119	85

Game Fish



Mercury concentrations in 20 rainbow trout (*Oncorhynchus mykiss*) fillets collected in 2009 from Poplar, Grand Portage, and Snow Creeks in the GRPO watershed, as well as the Reservation River and Hollow Rock Creek, contained <0.1 mg kg^{-1} mercury (GLKN 2010), meeting the reference criteria of 0.2 and 0.3 mg kg^{-1} set by the MPCA in 2008 (Preimesberger and Maschwitz 2011) and the USEPA in 2001 (USEPA 2002), respectively. Based on the MDH fish consumption guidelines, brook trout in Grand Portage Creek are estimated to contain ≤0.05 mg kg^{-1} mercury. Walleye and northern pike in the Pigeon River are estimated to contain 0.05-0.22 and 0.22-0.95 mg kg^{-1} mercury, respectively. Pigeon River northern pike exceed the reference condition of 0.2 mg kg^{-1} (Table 37); this result is of particular concern because of the high level of subsistence fishing in the Pigeon River by native people.

Lake Superior is on Minnesota's 303(d) list in part because of the levels of mercury found in fish tissue (MPCA 2011). In Lake Superior, Chinook salmon (*Oncorhynchus tshawytscha*) >76 cm, lake trout >58 cm, and siscowet lake trout (*Salvelinus namaycush siscowet*) exceed the reference condition of 0.2 mg kg^{-1} set by the MPCA (MDH 2008, 2010, MPCA 2011, Preimesberger and Maschwitz 2011). The Grand Portage Band (2010) reported that fish tissue concentrations of mercury have been recorded in the range of 0.06-0.11 mg kg^{-1} for herring (*Coregonus artedi*) and 0.100-0.508 mg kg^{-1} for lake trout but did not indicate the time period or the proportion of samples that exceeded the reference condition (Table 37).

We rank the condition of the sampled game fish for mercury as good for Grand Portage Creek, Poplar Creek and Snow Creek; of significant concern for the Pigeon River; and of moderate concern for Grand Portage Bay since the MDH Lake Superior data were not specific to Grand Portage Bay. No trend data were available, but our level of confidence in the condition assessment is good for all but Grand Portage Bay, which is fair.

A review of mercury in selected fish species in the Great Lakes region from 2000-2008 (Evers et al. 2011) indicates that in inland waters, predators such as northern pike, largemouth bass (*Micropterus salmoides*), walleye, smallmouth bass (*M. dolomieu*), and muskellunge have the

Table 37. Mercury levels in game fish in streams of the Grand Portage National Monument and Lake Superior.

Stream	Fish Species	Mercury ($mg\ kg^{-1}$)	Source
Poplar, Grand Portage, and Snow Creeks	Rainbow trout	<0.1	GLKN 2010
Grand Portage Creek	Brook trout	≤0.05	MDH 2010
Pigeon River	Walleye	0.05-0.22	MDH 2010
Pigeon River	Northern pike	0.22-0.95	MDH 2010
Lake Superior	Chinook salmon >76 cm, lake trout >58 cm, and siscowet lake trout	>0.2	MDH 2008, 2010, MPCA 2011
Lake Superior	Herring	0.06-0.11	Grand Portage Band 2010
Lake Superior	Lake trout	0.100-0.508	Grand Portage Band 2010

highest levels of mercury (Figure 76). In Great Lakes waters, only walleye, northern pike, and largemouth bass were found to exceed the USEPA human health criterion.

An indirect indicator of the mercury content of fish in the GRPO vicinity is found in the Grand Portage Band's application for a variance from water quality standards for the discharge from the Grand Portage Reservation Wastewater Treatment Plant (Grand Portage Band 2010). Band members participate in a traditional cultural practice of subsistence netting in Grand Portage Bay, and subsistence fishers and their families consume "large amounts" of fish. The variance request states that "…the most significant source of mercury in the effluent is the mercury that is in the tissue of the fish that the tribal members are harvesting and consuming from waters of the Reservation including Lake Superior" (Grand Portage Band 2010). The request states that the Band is unaware of any alternative or enhanced treatment method that could further reduce the mercury concentration of their treated wastewater, which has had a maximum concentration of 4.7 ng L^{-1}, lower than some of the ambient mercury measurements for the receiving waters of Grand Portage Bay (<0.1-11.6 ng L^{-1} from 2003-2009).

McGoldrick et al. (2011) rank the condition of Lake Superior for mercury in whole fish as fair, with a deteriorating trend, noting that although total mercury concentrations in top predator fish are below the Great Lakes Water Quality Agreement target of 0.5 mg kg^{-1} ww (a standard set for the protection of wildlife consuming the fish), they have returned to levels observed in the 1980s and appear to be increasing (Figure 77). Monson et al. (2011) noted that researchers in the Canadian arctic have found increasing mercury concentrations in fish and attributed them to a warming climate (Carrie et al. 2010, Kirk et al. 2011 in Monson et al. 2011). Monson et al. (2011) also suggested changes in the aquatic food web caused by invasive species as a possible contributing factor to changing growth rates, and thus, changing mercury concentrations in fish.

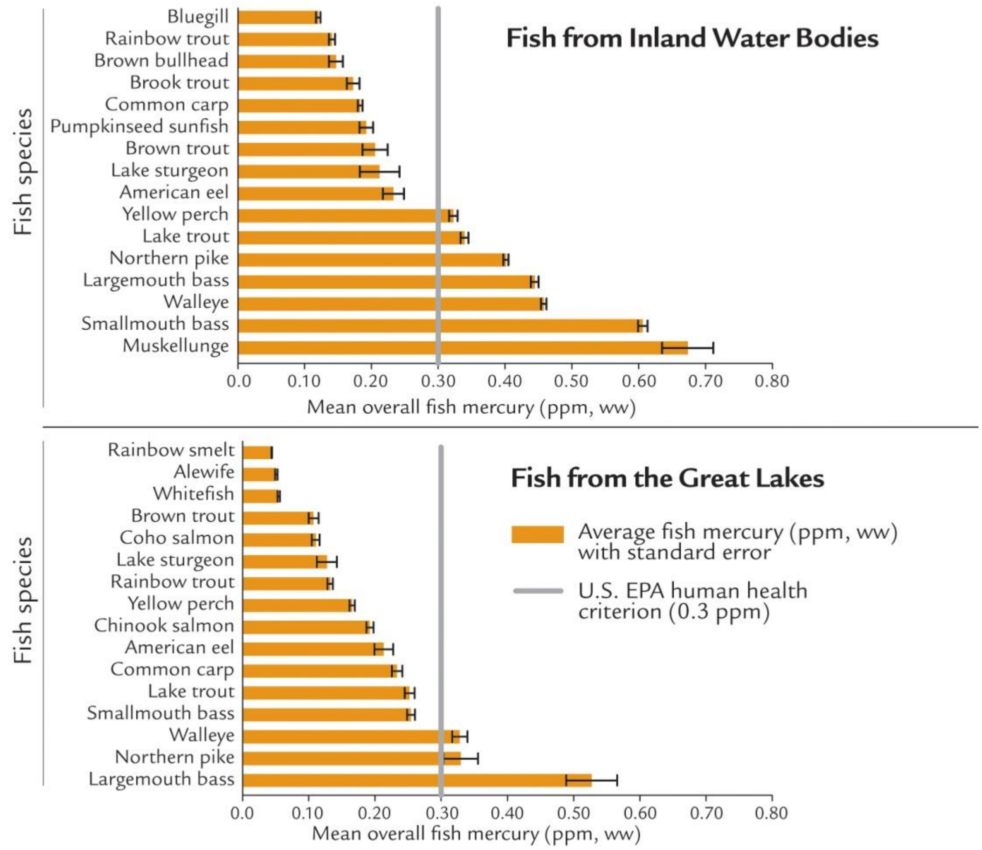


Figure 76. Mercury in selected fish species in the Great Lakes region (Evers et al. 2011; graphic obtained at http://www.briloon.org/mercuryconnections/greatlakes/graphics).

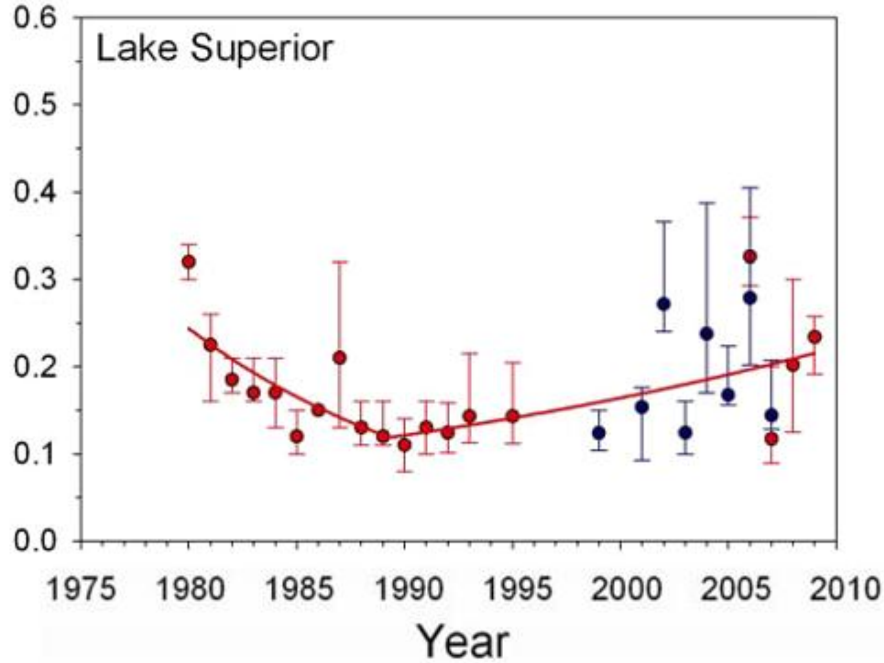


Figure 77. Total mercury levels in mg kg^{-1} wet weight in top predator fish (whole fish) in Lake Superior, 1980-2010. Red circles are Environment Canada data, and blue circles are USEPA data. The solid red line indicates the results of 2-segment linear piecewise regression. Graph copied from McGoldrick et al. (2011).

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Jim Wiener, Laurel Woodruff, Bill Route, Chris Mechenich, James Cook.

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4.3.5 Organic Contaminants in Sediments - Grand Portage Bay

<u>Description</u>

In 2009, a single sample was collected off the GRPO dock in Grand Portage Bay and analyzed for dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs). Dioxins and furans are produced as unintentional by-products of industrial processes, including smelting, chlorine bleaching of paper pulp, and the manufacturing of some herbicides and pesticides, and uncontrolled waste incineration (ATSDR 2012). Dioxins and furans are classes of chlorodibenzodioxins and chlorodibenzofurans with different numbers and positions of chlorine substitution on aromatic rings. The toxicity of individual dioxins and furans varies. Some are highly toxic, and can cause reproductive and developmental problems, damage to the immune system, interference with hormones, and cancer. They reach Lake Superior primarily through atmospheric deposition (Shen et al. 2009). Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals built from two or more benzene rings. PAHs can be found in natural substances, such as in coal tars, and can also be formed during incomplete combustion processes. Releases to the environment from industrial sources, such as waste disposal or leakage from wood preservation facilities, do occur. PAHs are a human toxin with various health effects including cancer.

<u>Data and Methods</u>

A single sample of sediment was taken off the Grand Portage dock and analyzed for dioxins, furans, (Table 38) and PAHs. We used Canadian Sediment Quality guideline tables (CCME 2002) to generate a summed toxic equivalents score (TEQ) for dioxins and furans. This method multiplies a toxicity factor for individual members of the dioxin and furan classes (which balances the toxic effect of the members of the chemical class) by their concentration and then sums to give an overall toxicity score. Only one PAH was detected, fluoranthene.

<u>Reference Condition</u>

The toxic equivalents score for sediment at the GRPO dock should be zero, and the concentration of PAHs should be below the detection limit; this represents a "historic condition" (Stoddard et al. 2006).

<u>Condition and Trend</u>

The suite of detected dioxin and furan compounds is similar to that found in other Lake Superior locales (Shen et al. 2009), and was dominated by OCDD, a relatively nontoxic dioxin. TEQs of furans and dioxins equaled 12.3 ng kg^{-1}. This level is greater than the Canadian Sediment Quality guideline threshold effect level (TEL) of 0.85 ng kg^{-1} (CCME 2002), a level below which adverse biological effects are expected to occur rarely (CCME 1999). It is, however, below the probable effect level (PEL) of 21.5 ng kg^{-1} (CCME 2002), a level above which adverse biological effects are expected to occur frequently (CCME 1999). Therefore, we rate the condition as of moderate concern. The trend is unknown.

The PAH fluoranthene was detected at 0.18 ng kg^{-1}, well below its Interim Sediment Quality Guideline of 111 µg kg^{-1} (111,000 ng kg^{-1}) and its PEL of 2,355 µg kg^{-1} (2,355,000 ng kg^{-1}) (CCME 1999). Therefore, we rate the condition as good, with an unknown trend.

Table 38. Concentration and toxicity scores for dioxins and furans detected in Grand Portage Bay off the Grand Portage National Monument dock.

Chemical name	**Concentration ($ng\ kg^{-1}$)**	**Toxicity equivalency factor**	**Toxicity score**
1,2,3,6,7,8-HxCDF (hexafuran)	5.9	0.1	
Total HxCDF	29	0.1	2.9
1,2,3,4,7,8-HxCDD (hexadioxin)	9.8	0.1	
Total HxCDD	28	0.1	2.8
1,2,3,4,6,7,8-HpCDF (heptafuran)	60	0.01	
Total HpCDF	150	0.01	1.5
OCDF (octafuran)	140	0.0003	0.042
1,2,3,4,6,7,8-HpCDD (heptadioxin)	300	0.01	
Total HpCDD	440	0.01	4.4
OCDD (octadioxin)	2300	0.0003	0.69
Total Furan / Dioxin Toxicity Score			12.332

Sources of Expertise
George Kraft, CCME.

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4.4 Ecological Processes

The EPA-SAB framework lists energy flow and material flow as the two primary subdivisions of ecological processes (USEPA 2002). The categories of energy flow and material flow, and their respective subcategories, describe how an ecosystem is functioning, and if followed over time, how it is developing. Within GRPO, these flows might be measured within terrestrial or aquatic systems. Adequately characterizing these flows requires the development of energy and material budgets rather than just monitoring of concentrations. Process measurements have inherently higher variability than static measurements and are more costly to obtain, so they are used less often in environmental reporting (USEPA 2002).

Energy flow is the movement of carbon into, among compartments within, and out of a system. In terrestrial systems, all carbon comes from carbon dioxide in the atmosphere and enters the system via the primary producers. Thus, carbon is rarely a limiting factor to a terrestrial ecosystem. In contrast, for streams and rivers, a significant portion of the carbon used is allochthonous; that is, the organic matter originated in the surrounding terrestrial ecosystems (Allan and Castillo 2007). Therefore, vegetative cover and land use in the riparian zone, and sometimes the floodplain, have a pronounced influence on productivity in streams and rivers.

Because a substantial amount of the carbon fixed by primary producers is used internally (well over 50% in a mature forest (Barnes et al. 1998), primary production is divided into gross [GPP] and net primary production [NPP]). To measure the activity of all organisms (i.e., to add in the heterotrophs) net ecosystem production and growth efficiency can be determined. In forests such as those at GRPO, the rates of GPP and NPP follow predictable trajectories with age (Barnes et al. 1998, Cain et al. 2008), if there is no major disturbance. However, the specific rates of GPP and NPP, and the inflection points along the curves, vary among forest and soil types within a climatic region. A severe disturbance will re-start the trajectory but will not lead to a novel trajectory. Though human actions alter GPP and NPP, it is rare for one of these actions to result in a truly unique trajectory (though it has occurred due to radiation, heavy metal concentrations from mine tailings, and severe over-grazing, for example).

The information needed to put together an energy flow budget is extensive, time consuming to collect, and quite costly to obtain (Cain et al. 2008). To use such ecosystem characteristics to gauge ‘health’ would require detailed, highly accurate, site specific measurements over an extended period of time. Thus, it is highly unlikely that such an investment would produce information, or an indicator, that is better than others that are more readily obtainable.

The flow of materials (nitrogen, phosphorus, and other essential minerals) into, through, and out of a system is more complex and less well understood than primary production. In streams, productivity is influenced by nutrient concentrations, particularly phosphorus and nitrogen, but in low-order streams in forested areas such as GRPO, light limitation may be more important (Giller and Malmqvist 2002). For terrestrial systems, nitrogen is more commonly the limiting nutrient; however, all essential minerals potentially are.

The process carried out by a specific trophic level or functional group of a system is clearly known, but how long a given quantity of carbon or molecule of a nutrient stays in that trophic level is quite variable and not easy to predict. The difficulty is especially acute for all below-ground processes. This is true because of the difficulty of measuring processes accurately in situ; the vast, but unknown, number of organisms involved in decomposition; and the rapid changes in fine roots, microorganisms, and invertebrates in the soil (Cain et al. 2008). Thus, the situation for material flow is virtually identical to energy flow – a useful assessment would require a large commitment of time and money to produce the level of accuracy and sensitivity needed.

There are a few situations where the ‘flow’ of nutrients into and/or out of a system is itself the source of impairment. The most well-known and widespread is the eutrophication of aquatic systems. Similarly, high levels of atmospheric deposition of acid-causing compounds (sulfur and nitrogen), or simply excessive amounts of nitrogen can alter the typical functioning of terrestrial systems.

The GLKN has identified four monitoring categories related to ecosystem processes (Route and Elias 2007). These are succession, trophic relations, nutrient dynamics, and primary productivity. They are 22nd, 26th, 39th, and 42nd, respectively, in the list of 46 vital signs (see Table 5). Only succession is currently scheduled for the development of a monitoring protocol.

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4.5 Hydrology and Geomorphology

The EPA-SAB framework considers hydrology and geomorphology an essential ecological attribute because it reflects "the dynamic interplay of water flow and landforms" (USEPA 2002). For a river such as Grand Portage Creek, water flow patterns and the interactions of water, riverbed, and riparian areas influence the natural diversity of habitats and species. Sediment and other material transport patterns are critical to a variety of underwater, riparian, and wetland habitats. For Grand Portage Bay, the dynamic structural characteristics of the shoreline influence not only the quality and diversity of habitats but also the structural integrity of the built environment of the Depot itself.

4.5.1 Geomorphology of Grand Portage Bay

Description

Grand Portage Bay is a shallow, sheltered bay that is a prominent feature in the history of GRPO. Its present shore is comprised of uncompacted raised beach material that varies in size from fine sands to cobbles (Phillips 2001). An area of large boulders marks the area once referred to as Premier's Point at Grand Portage Creek. Today, most of the bay landward of Grand Portage Island is less than 4 m deep (Figure 78), but a variety of natural factors has changed its depth and the configuration of its shoreline on time scales ranging from years to thousands of years. Our understanding of the recent geologic past of GRPO dates back to just before 10,500 years before present (BP), when the Marquette advance of the glacier destroyed much of the evidence of what had existed before it. However, scientists have found evidence that water levels in Early Lake

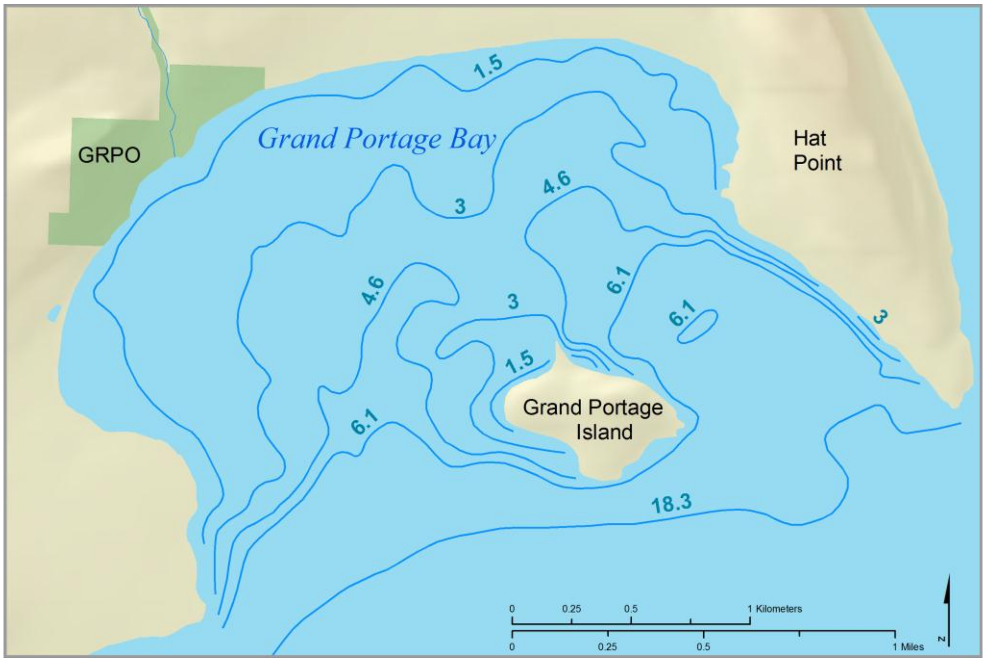

Figure 78. Bathymetry of Grand Portage Bay, Minnesota.

Minong, a predecessor to Lake Superior before the Marquette advance, were as high as 439 m above mean sea level (AMSL). All of GRPO was then under water (Phillips 2003). GRPO began to emerge during the Low Lake Duluth phase, 393 m AMSL. At GRPO today, several ancient Lake Superior shorelines can be seen; the Lake Minong (217.9 m), Nipissing (193.9 m), Algoma (189.3 m), and Sault (185.9 m) levels AMSL (Phillips 2001, Rosenthal 2011) (Figure 79). In addition, the Houghton shoreline (177.4 m AMSL) extends bayward from the present shoreline to the south side of Grand Portage Island; during this lake level stand, the island and mainland were connected.

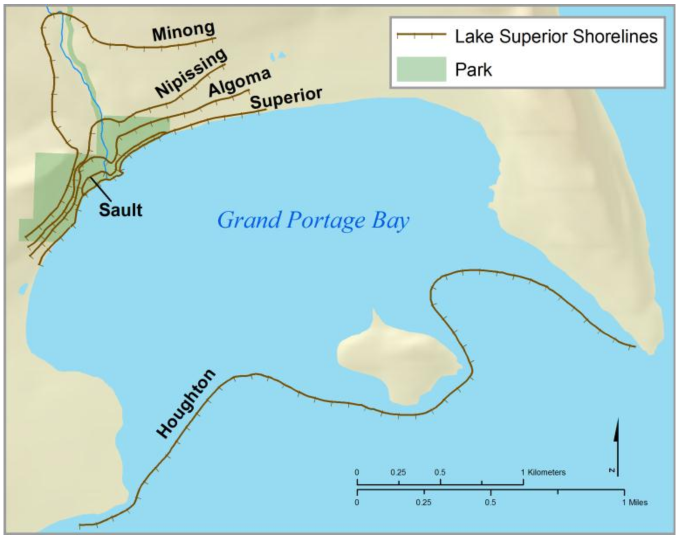

Figure 79. Historic shorelines of Lake Superior in the vicinity of Grand Portage National Monument (after Rosenthal 2011).

The modern 'average' water level of Lake Superior (and thus of the bay) is 183.4 m AMSL. Changes in Lake Superior water levels have been limited since 1914 by a control structure at the lake's mouth. In the 55 years of preregulation data, water levels had a range of 1.10 m, from 182.76 m in February 1866 to 183.86 m in August 1876. As regulated, the mean annual variability is 0.30 m, with a 1.19 m range from 182.72 m in April 1926 to 183.91 m in October 1985 (Wilcox et al. 2007, USACE 2012).

Water levels in all the Great Lakes except Lake Ontario dropped sharply from 1997-1999 and have remained at relatively low levels since then (NOAA 2009). Lake Superior set new record lows in August and September, 2007 of 183.01 m and 183.02 m, respectively (USACE 2012). These declines are "of concern" because they appear consistent with climate change projections (NOAA 2009).

Climate change is already affecting chemical, biological, and physical aspects of the Great Lakes (Boyer et al. 2006). The Great Lakes are forecast to have a reduced ice cover season, declining lake levels, and reduced inputs related to lowered groundwater levels and stream baseflows, but increased inputs related to higher runoff during extreme precipitation events, all as a result of climate change (IJC 2003). When two atmospheric climate change models, or General Circulation Models (called CGCM1 and HadCM2) were run for the Great Lakes region, air temperature increases were 5.4°C and 2.9°C, respectively, by 2090. Changes in mean annual runoff varied between the models from -13% to +4%, respectively, by 2090, and mean annual evaporation varied from +39% to +19%. As a result, Lake Superior levels varied from -0.42 m to +0.11 m by 2090 (Lofgren et al. 2002). Of 12 scenarios run with 10 models, only one showed a net water gain.

Austin and Colman (2007) have shown that in Lake Superior, summer water temperatures are increasing more rapidly than regional air temperatures. They attribute this to declining winter ice cover and a lengthening period of stratification, and they use the work of numerous authors to predict "a significant impact on the ecology of the upper Great Lakes at all trophic levels." Allan et al. (2012), in an analysis of environmental stressors affecting the Great Lakes, have mapped the GRPO vicinity of Lake Superior with relatively high stress levels for both summer water temperature warming and decreasing winter ice cover.

Lake Superior would be a terminal lake (a lake without an outlet) if precipitation dropped 60% or more from the present, or if air temperature increased 13°C above the present, or some combination of the two (Croley and Lewis 2006). One such combination would be a 25% precipitation decrease combined with a 5ºC mean temperature increase (Lewis et al. 2008). Lewis et al. (2008) demonstrated that the Great Lakes experienced such a low period during which they lacked connecting channels during the early Holocene dry period (approximately 8,770 years BP).

Lake Superior is famous for its unpredictable weather and severe storms; these along with the numerous cliffs and reefs have contributed to 350 shipwrecks since European settlement (Minnesota Sea Grant 2005). GRPO is sheltered from the effects of many such storms, but those that arise from the southeast and east, though infrequent, may be effective in causing erosion and damage (Phillips 2001). For example, a November, 1986 storm damaged rock revetment placed to protect the stockade and tore off the end portion of the dock (Phillips 2001).

Of more concern at GRPO is change in the historic configuration of the shoreline. Phillips (2001) examined historic data and maps to attempt to establish the configuration of the Grand Portage Bay shoreline during the fur trade era, especially in the area just east of Grand Portage Creek known as Premier's Point. This point of land was mentioned in contemporary accounts of the fur trading period, but Phillips (2001) believes that it was never very prominent, no more than 6-9 m beyond the general line of the shore. It was reportedly "destroyed" in a great storm in 1905.

Phillips (2001) stated, "That progressive shoreline erosion of the sand and gravel margin of Grand Portage Bay has taken place in historical time would seem obvious." In this section, we will examine risk factors and trends that affect the future Grand Portage Bay shoreline.

<u>Data and Methods</u>

Phillips (2001) reviewed the geology of the Grand Portage Bay area; prehistoric and historic Lake Superior water levels; variations caused by weather, climate, and human activities; historic documents showing the configuration of the bay; and modern-day accounts of erosion to create a history of water level and shoreline change for GRPO.

Pendleton et al. (2007) assessed the potential for lake level changes to produce coastal change in three Great Lakes National Lakeshores (Sleeping Bear Dunes, Indiana Dunes, and Apostle Islands). Pendleton et al. (2010) analyzed the results of this and other studies to determine which coastal change variables were most important in determining vulnerability to lake level change, and provided a table by which the change potential for other coastal sites could be assessed.

Lake level data for Lake Superior are found at the U.S Army Corps of Engineering (USACE)–Detroit district website http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/historicdata/greatlakeshydrographs/. Shoreline recession rates were taken from Phillips (2001) and Pope et al. (1999).

Reference Condition

In his 2001 report, Phillips stated "the erosion and retreat of lakeshores is a fundamental process, which is an entirely natural part of lacustrine history. It becomes inconvenient and even hazardous when human structures are built adjacent to the shore." Because of the historic value of structures on the Grand Portage Bay shoreline, the recession rate for the Grand Portage Bay shoreline should remain within the natural historic range of values of 0.07-0.29 m yr^{-1}. This represents a "historic condition" (Stoddard et al. 2006).

Condition and Trend

The current shoreline recession rate of Grand Portage Bay appears to be within its historic range, but the reference condition probably cannot be adequately assessed over short time frames. Pope et al. (1999) point out that over a time period of 50 years, the average recession rate for a shoreline may be the result of a relatively few extreme events. As noted above, extreme events did occur at GRPO in 1905 and 1986. The following discussion will examine factors that could affect the future trend of shoreline recession.

Phillips (2001) reported that the "most likely causes of chronic shoreline erosion" on the Minnesota North Shore were differential isostatic tilting and the infrequent but very effective incidence of storms and storm-related water level rises from the southeast and east. Differential isostatic tilting refers to the fact that the Lake Superior basin is rising in elevation as a result of rebound after having been compressed by the weight of ice during the glacial period. However, the northeastern part of the basin is rising faster than the southwestern part; the net effect is that the south and west shores (including GRPO, which is just slightly south of the 'hinge line') are being progressively submerged. Phillips (2001) further suggested that shore ice, although sometimes an erosive agent in its own right when it is pushed or rafted, is more often a protective barrier against wave erosion in winter and spring, sometimes into May.

Pendleton et al. (2010) reported that the four most important factors in coastal vulnerability to lake-level change related to climate change were geomorphology, regional coastal slope, relative lake level change rate, and mean significant wave height. Phillips (2001) provided most of the metrics needed to assess the vulnerability of GRPO (Table 39). These variables will be discussed individually below.

Geomorphology

The sandy to cobbly nature of the GRPO shoreline (Phillips 2001) makes it more vulnerable than shorelines that consist of rocky cliffs, placing it in the 'high' to 'very high' category.

Shoreline Change

Using contemporary writings of the fur trade era, Phillips (2001) estimated a recession rate of 0.07 m yr^{-1} for GRPO from 1793-2001. The estimated modern recession rate for Minnesota's North Shore ranges from 0.1-0.29 m yr^{-1} , with all but one segment less than 0.2 m yr^{-1} (Pope et al. 1999). These measurements place GRPO vulnerability in the 'moderate' category.

Regional Coastal Slope

We estimated a regional coastal slope of >1.2% using data from NGDC (1999), placing GRPO vulnerability in the 'very low' category.

Table 39. Variables rated important in assessing coastal vulnerability to lake-level change and values taken from the literature for Grand Portage National Monument (after Pendleton et al. 2010).

Variable	Value for GRPO	Source	Vulnerability Ranking
*Geomorphology	Cobble beaches, sand beaches	Phillips 2001	4.5 High to Very High
Shoreline change (m yr^{-1})	-1.0 to 1.0	Phillips 2001	3 Moderate
*Regional coastal slope (%)	>1.2	NGDC 1999	1 Very Low
*Relative lake-level change rate (mm yr^{-1})	0.1 to 3.0	Phillips 2001, Pendleton et al. 2007	2 Low
*Mean significant wave height (m)	0.86 to 1.05	Phillips 2001	3 Moderate
Mean annual ice cover (days)	30 to 105	Bolsenga et al. 1988	3.5 Moderate to High

*most important

Mean Lake Level Change Rate
Pendleton et al. (2007) cited the Great Lakes Environmental Research Laboratory (GLERL 2006) to assign a change rate of +0.4 mm yr^{-1} to Lake Superior. Phillips (2001) reported that since GRPO is south of the ‘hinge line’ it experiences a differential isostatic tilting that results in a lake level rise of 0.3 mm yr^{-1}. Together, these changes place GRPO in the ‘low’ vulnerability category. If climate change resulted in a lower lake level, wave erosion at GRPO would likely be reduced. However, it would also increase the gradient and possibly the erosive capacity of Grand Portage Creek; this will be discussed in the next section.

Mean Significant Wave Height
Phillips (2001) cites monthly wave statistics for western Lake Superior to assign a mean annual significant wave height of 0.9 m for GRPO, with a low monthly mean of 0.3 m in September and a high monthly mean of 1.3 m from November through January. The annual mean places GRPO vulnerability in the ‘moderate’ category; the monthly means >1.25 m place GRPO vulnerability from November through January in the ‘very high’ category. However, Phillips (2001) shows that most “effective” waves for erosion on the North Shore are from an easterly direction and occur in April and May, when mean significant wave heights are 0.9 m and 0.7 m respectively. Wind-driven wave heights may increase in the future; Desai et al. (2009) showed that surface winds over Lake Superior are increasing 5% per decade since 1985 and that this increase exceeds that of wind speeds over land.

Mean Annual Ice Cover
Bolsenga et al. (1988) reported an average ice cover duration for Grand Portage Bay of 68 days, with a range of 49-90 days. This places GRPO vulnerability in the ‘moderate’ to ‘high’ category. Allan et al. (2012) placed GRPO in a moderately high stress category for decreasing winter ice cover.

In summary, factors that might increase shoreline erosion at GRPO in the future include extreme precipitation events, reduced shelf ice cover, or an increase in the gradient of Grand Portage Creek that might result from climate change. Factors that might decrease shoreline erosion at GRPO include a lower lake level and subsequently reduced ice pushed up on shore.

4.5.2 Hydrology and Geomorphology of Grand Portage Creek

<u>Description</u>

Grand Portage Creek enters Grand Portage Bay near the eastern edge of the historic North West Company trading post in GRPO. It is a fast-flowing, high gradient stream in its lower reaches. Its width varies from 3-15 m, and it is generally less than 0.5 m deep (Moore et al. 2006).

The Grand Portage Creek watershed is approximately 18.8 km^2, (Elias in progress), and the stream is 5.6 km long (Fitzpatrick and Seitz 2011). With its two tributaries, Dutchman Creek and Mt. Maud Creek, its length is 10.8 km (Elias in progress). Approximately 1 km of the creek's length occurs within GRPO (Figure 80).

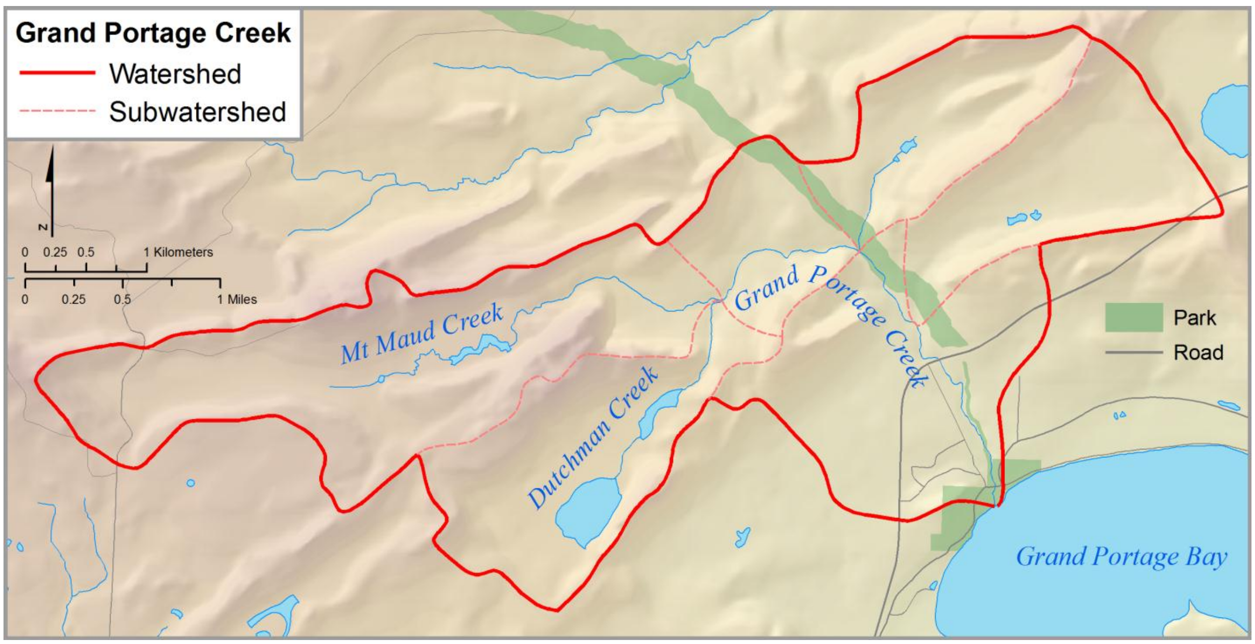

Figure 80. Grand Portage Creek and its watershed.

Grand Portage Creek is significant to both the natural and cultural resources of GRPO. The Grand Portage Band is reintroducing coaster brook trout in its lower reaches. It has satisfactory water quality and a macroinvertebrate population that is monitored by the Band (Elias in progress). It is also the site of a prehistoric Ojibwe village, a likely Ojibwe grave site, and a historic stone bridge built by the Civilian Conservation Corps Indian Division in 1936 (Fitzpatrick and Seitz 2011). Its two major tributaries have run-of-the-river impoundments for the production of wild rice. The impoundment on Mt. Maud Creek is managed principally for wild rice and had 2.2 ha of rice beds in 2008 (Grand Portage Trust Lands 2008). In 2011, 200 kg of rice were seeded into the impoundment on Dutchman Creek (Schmidt 2011).

The average annual flow rate of Grand Portage Creek has been reported as 0.05 $m^3 sec^{-1}$ (Moore et al. 2006) and 0.1 $m^3 sec^{-1}$ (Newman et al. 2003). Martin (2008) estimated flood flows from 4.0

$m^3 sec^{-1}$ with a recurrence interval of two years up to 34.0 $m^3 sec^{-1}$ with a 500-year recurrence interval. He suggested that the impoundments were unlikely to exert substantial influence on the downstream channel, although they have probably had some effect on peak flows and hydrograph duration.

The lower main stem of the creek has experienced increased bank erosion and lateral migration over the last decade, threatening cultural resources and historic landmarks (Fitzpatrick and Seitz 2011). A comprehensive watershed geomorphic assessment, with five major focus areas (alluvial sedimentation history; geomorphic evolution; mapping into geomorphically similar reaches; establishing and benchmarking reference reaches; and establishing flood frequency, discharge and return intervals) has been proposed for FY 13 (Fitzpatrick and Seitz 2011). This study will also examine possible base level changes associated with fluctuations in the water level of Lake Superior as one of the possible causes for increased erosion.

In summer 2012, a GeoCorps member (Kilgore 2012) conducted a rapid geomorphic assessment and a longitudinal profile survey, collected cores, and established benchmarks in the lower 1.6 km of Grand Portage Creek. Her report concluded that the creek appears to have naturally shifted throughout its floodplain over time, but has also more recently experienced instability in some areas due to land use changes and crossing construction. The most unstable areas of the creek were located near bridges and buildings.

<u>Data and Methods</u>

Phillips (2003) described the glacial and post-glacial history of GRPO, including a description of the various Lake Superior shorelines still visible in the park (Figure 79). Rosenthal (2011) produced a map of those as well as the step and tread terraces of Grand Portage Creek.

Martin (2008) and Martin and Seitz (2009) conducted a field assessment of the stability of eroding reaches of the creek and recommended options for treatment.

Elias (in progress) summarized basic hydrologic data for the creek; Fitzpatrick and Seitz (2011) summarized existing knowledge in a grant proposal for a watershed geomorphic assessment.

<u>Condition and Trend</u>

Grand Portage Creek is currently experiencing an apparently increased amount of bank erosion and lateral migration, leading us to rank its condition as of moderate concern, with a fair degree of certainty. However, the reason for this increased erosion is unclear. Fitzpatrick and Seitz (2011) suggest “changes in the watershed’s forest cover and precipitation patterns, base level changes associated with fluctuations in the water level of Lake Superior, or human modifications to the creek” as possible causes. Without a clear understanding of cause, the trend cannot be assessed. However, it should be noted that as mentioned above, Lake Superior water levels may trend lower over time, and this would lead to instability in the pattern and profile of Grand Portage Creek.

4.5.3 Hydrology of the Pigeon River

Description

The Pigeon River, a provisional fundamental resource in GRPO, flows past historic Fort Charlotte and is responsible for the location of the Portage Trail. The river flows 98 km from its origin at South Fowl Lake at the edge of the BWCAW to Pigeon Bay on Lake Superior. Its drainage basin is 1,550 km^2 (Slack et al. 1993). It forms the border between the United States and Canada and, as previously noted, it is managed by various tribal, state, provincial, and national entities. A 120 m buffer along the shoreline on the Canadian side is managed as part of the LaVerendrye Provincial Park, but intense logging occurs on the lands beyond the buffer in the Hinterland General Use Area (Figure 81).

The USGS has maintained a gaging station on the Pigeon River at Middle Falls since 1921. It is located on the Reservation, on the river's right bank, 120 m upstream from the falls. Annual mean flow at this location was 13.9 m^3 sec^{-1} from 1921-2010, with the lowest annual mean of 3.9 m^3 sec^{-1} in 2007 and the highest annual mean of 23.8 m^3 sec^{-1} in 1971 (Figure 82). The maximum peak flow recorded was 303 m^3 sec^{-1} on May 5, 1934.

Data and Methods

Land use designations were obtained from the Crown Land Use Policy Atlas of the Ontario Ministry of Natural Resources at http://crownlanduseatlas.mnr.gov.on.ca/clupa.html.

Historic flow data for the Pigeon River at Middle Falls were obtained from http://nwis.waterdata.usgs.gov/nwis/uv/?site_no=04010500&agency_cd=USGS.

Reference Condition

The annual and monthly mean flows of the Pigeon River should remain within the historic range of variation. This reference condition represents a "historic condition" (Stoddard et al. 2006).

Condition and Trend

With an 89-year period of record, the Pigeon River at Middle Falls had its two lowest flow years in 2007 (3.9 m^3 sec^{-1}) and 2010 (4.4 m^3 sec^{-1}). Its lowest monthly mean flows for April and August were set in 2010, while its lowest monthly mean flows for March and September were in 2007 and 2006, respectively. The lowest monthly mean flows for May, June, and October – February were all set in 1977. In addition, Lafrancois et al. (2009) noted that for the period 1999-2006, there was an apparent shift in the stream hydrograph toward earlier snowmelt and peak spring discharge and a reduction in late summer discharge compared to the averages for the entire period of record (1921-2007), but a statistical analysis was not conducted (Figure 83). We rate the hydrologic condition of the Pigeon River as of moderate concern and uncertain trend. Our confidence in this assessment is fair.

Sources of Expertise

USGS, Lafrancois et al. (2009), Chris Mechenich.

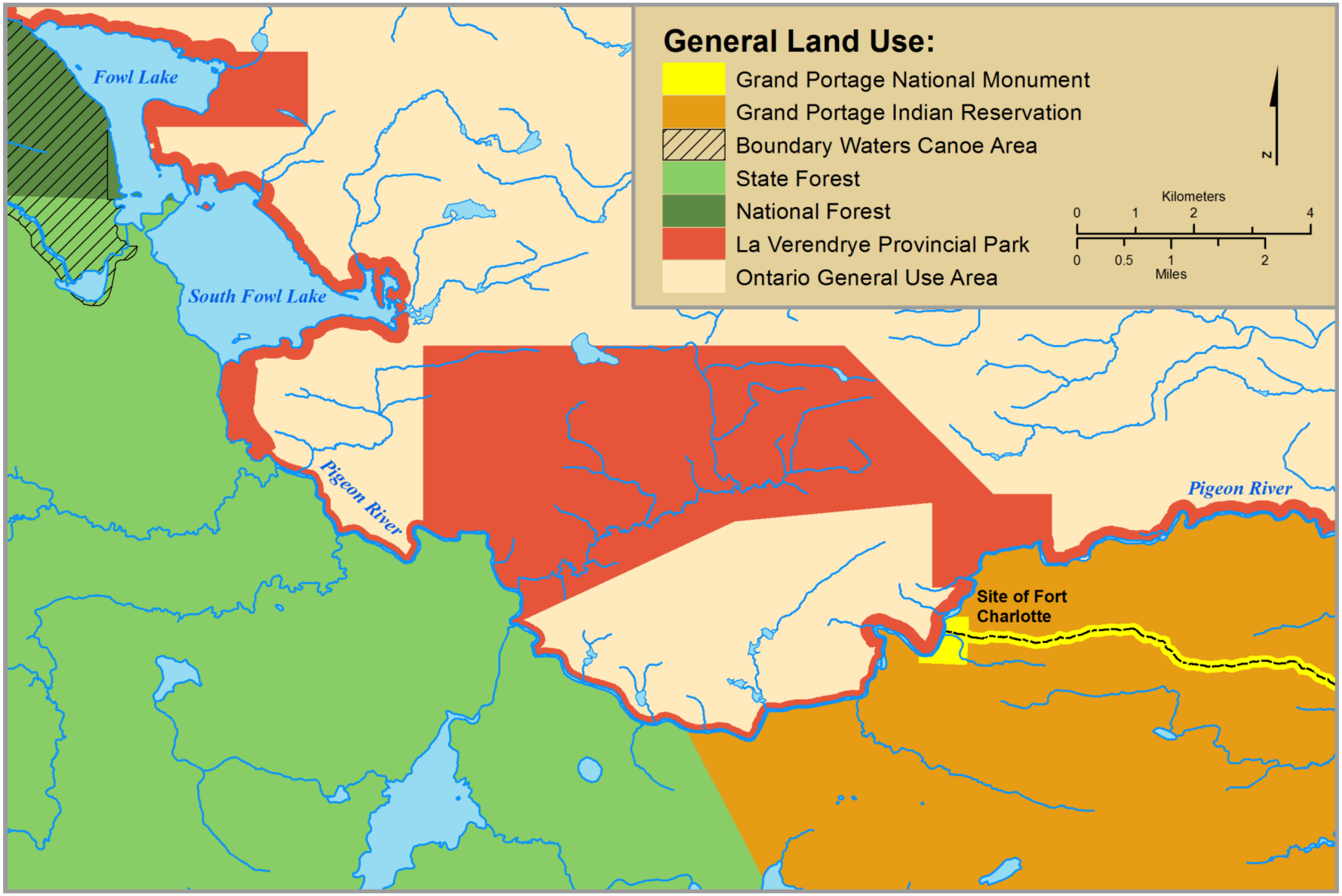

Figure 81. Land use designations along the Pigeon River in Ontario and Minnesota.

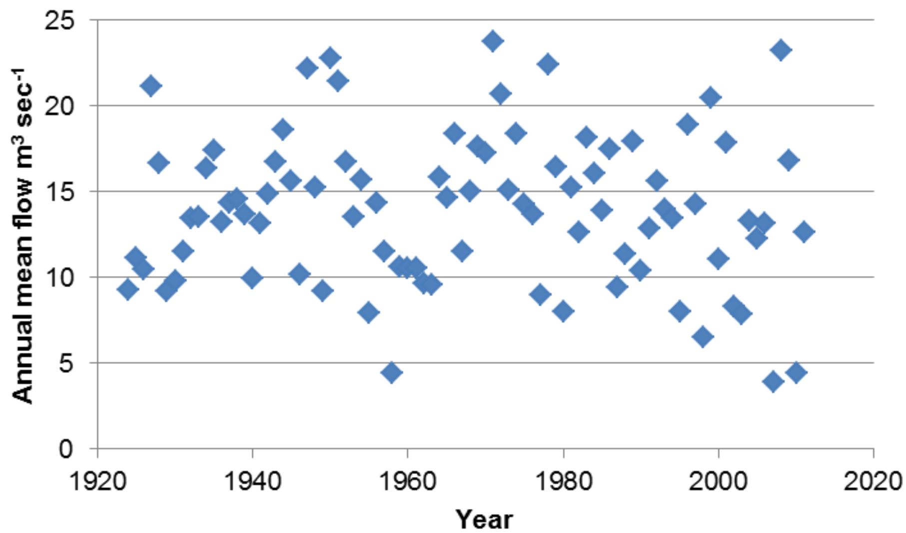

Figure 82. Annual mean flow of the Pigeon River near Grand Portage National Monument.

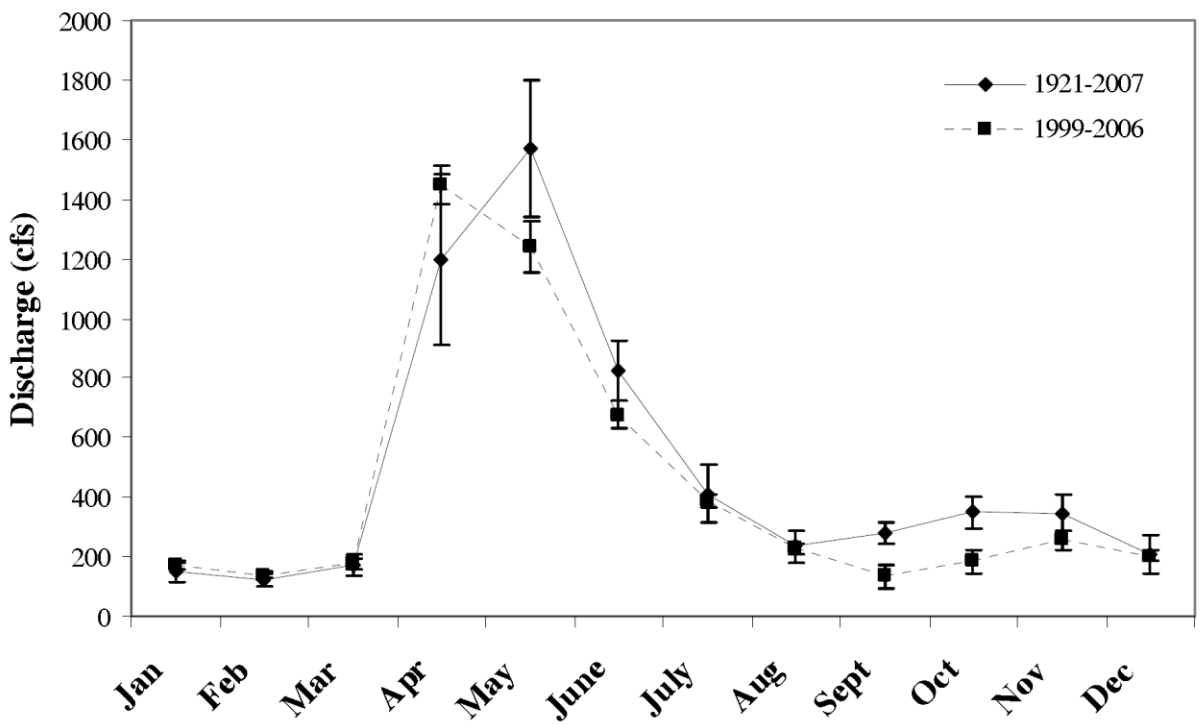

Figure 83. Annual stream hydrograph for the USGS Pigeon River gauging station (from Lafrancois et al. 2009).

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4.6 Natural Disturbance Regimes

Description

The ecologic units within a landscape, from smallest to largest in spatial extent, are individual organisms, populations, communities, cluster of contiguous communities, and finally watersheds/ecosystems. To fully understand the dynamics of an individual, population, or community, it is necessary to look at the effects and constraints at larger spatial scales, for the reasons explained below.

The ecologic character of a landscape is largely determined by climate, current disturbance regime (DR), topography, and parent material (Barnes et al. 1998, Wimberly and Spies 2001). These dominant structuring forces operate primarily at large spatial scales in a hierarchical fashion. Thus, these can be viewed as top-down influences in that they set the range of ecologic units that may occur. Within this framework, differences manifest at smaller scales due to features such as topography, aspect, and small scale disturbances, and due to the autecology of individual species (Schwartz et al. 2003).

Among the dominant structuring forces, disturbances are the most variable in space, time, areal extent, and impact (Sousa 1984, Hong and Mladenoff 1999, Frelich 2002). Disturbances interact with climate (e.g., drought), parent materials (e.g., soil texture and depth), and physiographic features (e.g., aspect and depth to water table) to affect, directly and indirectly, plant composition and community structure. When a landscape is impacted by large, severe disturbances at short or intermediate intervals, many characteristics of the landscape are tied to the occurrence of these disturbances. This is true because a severe disturbance drastically changes the biotic conditions and sets in motion a series of changes that play out over hundreds of years (Halpern and Franklin 1990).

Though we can characterize the typical case or condition for a landscape or community and quantify the range of conditions, variation in weather, climate, and disturbance produce a substantial level of unpredictability about future conditions (Baker 1989). Because of the known constraints of climate, physiography, and soils, we generally know the range of conditions and landscape arrangements that might occur (the historic range of variability), but cannot say with certainty what the precise configuration will be at a particular point in time.

The combined effects of these dominant forces produce a specific group and arrangement of ecological communities at a point in time (sometimes called a 'mosaic'), and disturbance and/or climate significantly influence how they change over time. Over longer periods of time, a southern boreal landscape such as GRPO may or may not exhibit constancy in the types and amounts of communities present due to the so-called 'shifting mosaic steady state' (Baker 1989, Hong and Mladenoff 1999, Frelich 2002). The different communities across a landscape vary in size, structure, shape, and composition (Hong and Mladenoff 1999, Frelich 2002), and these characteristics affect many biotic conditions (e.g., habitat types) and processes such as nest predation. The arrangement of the communities and connectivity between habitats – which is critical to dispersal – also changes over time due to disturbance (Cissel et al. 1999) and occasionally due to climate.

All types of disturbance, their frequency, intensity (which describes the disturbance itself), and extent, may collectively describe the DR of a region (Frelich 2002), but this picture may still be incomplete. In some cases, the seasonality and duration of a type of disturbance may determine its role in structuring the landscape (White 1979, Sousa 1984). To understand the adaptations plants and animals may have to disturbance, the variability of frequency, intensity, and seasonality are also critical (Sousa 1984, Gauthier et al. 1996).

For example, Frelich (2002) estimated that the average fire size in the southern boreal forest was 4,000 ha in pre-settlement times. But this does not mean that 4,000 ha burned every year or at a set interval. Fire occurrence varies tremendously among years due to weather and climate and over longer time frames due to climate and changes in fuel properties. The variation in year-to-year fire occurrence and size are well illustrated by the 376 year fire history of the BWCA (Heinselman 1973).

Thus, disturbance regimes change naturally on the scale of hundreds to thousands of years (Heinselman 1973, Niklasson and Granstrom 2000, Bergeron et al. 2004), and some components (especially fire) can be altered by human action (Heinselman 1973). A substantial change in the DR can affect the relative abundance of species and community types, the average patch size and shape, connectivity across the landscape, and successional trends (Turner et al. 1997).

The scale of impact of a single disturbance ranges from a single tree to 90,700 ha in a fire in the BWCAW (Heinselman 1973) or to 20,000,000 ha in an eastern spruce budworm outbreak in eastern Canada (Attiwell 1994). For regions such as the southern boreal forest that have large, severe (this describes the magnitude of impact) disturbances as a prominent part of the DR, the pattern of vegetation composition and structure and successional pathways are closely linked to disturbance frequency (De Groot et al. 2003, Bergeron et al. 2004, Schoennagel et al. 2004).

The DR of the southern boreal forest includes three common types of disturbance: fire, wind, and herbivory (Frelich 2002). Though fire is the dominant disturbance type (Heinselman 1973, Reich et al. 2001), the other two must be carefully considered to understand the dynamics and variability of the vegetation in northeastern Minnesota (Frelich 2002).

<u>Data and Methods</u>

White and Host (2003) studied natural disturbance regimes in GRPO with the objectives of characterizing the historic fire regime, making inferences about natural variability of vegetation composition and structure along the corridor, characterizing vegetation composition and age structure, examining changes from the fur trade era, and recommending future management options and research needs related to GRPO forest ecosystem management. Their work joined a large body of published literature on DR in the southern boreal forest (e.g., Heinselman 1973, Viereck 1983, Bergeron 1991, Frelich and Reich 1995, Frelich 2002, Arseneault and Sirois 2004).

The USFS Forest Health Monitoring Program publishes an annual Forest Health Highlights publication for Minnesota; these include information on weather-related forest damage (such as severe ice or wind storms) and insect infestations. Annual reports from 1994-2010 are available at http://fhm.fs.fed.us/fhh/ncregion.shtml.

4.6.1 Fire

Much has been written about the fire regime in the vicinity of GRPO. Based on General Land Office (GLO) survey notes, White and Host (2003) estimated significantly different fire regimes among subsections of the Northern Superior Uplands section of Minnesota, with a much longer rotation period for the North Shore Highlands subsection than the Border Lakes subsection; this was ascribed to differences in soil texture and lightning occurrence. For four community types, based on section corners, White and Host (2003) calculated fire rotation periods of 140-500 years (Table 40). Values from BWCAW, which is within the Border Lakes subsection, are provided for comparison.

Table 40. Comparison of reported fire return intervals for Grand Portage National Monument and Boundary Waters Canoe Area.

	Fire Rotation Periods (years)	
Forest Type	**GRPO (White and Host 2003)**	**BWCAW (Heinselman 1973)**
Mesic white pine-red pine	375	---
Mesic birch-aspen-spruce-fir	500	---
Dry mesic white pine-red pine	190	150-250
Dry mesic Jack pine-black spruce	140	50-100

Though the intervals between fires were longer in the vicinity of GRPO than in BWCAW, fire occurred frequently enough that this disturbance type had a major role in determining landscape composition, arrangement, and community structure (White and Host 2003). In the BWCAW from 1727-1926, more than 80% of all acreage that experienced fires burned during major fire years (defined as those years that affected 24,300+ ha of the landscape) (Heinselman 1973). Thus, the primary impacts of fire come from the more infrequent but severe events that influence thousands of hectares. These types of fires occur primarily under drought-like conditions, usually in July and August (Heinselman 1973). Most of the fires at GRPO (historically) were probably of a similar severity.

4.6.2 Wind

High severity wind events (e.g., severe thunderstorms, straight line winds, downbursts, and tornadoes) are not common in this landscape, but impact thousands of hectares when they occur. They have major impacts on structure and development of communities, at an extent similar to stand-replacing fires (Frelich 2002). The rotation period for this type of event in the Upper Great

Lakes region has been estimated at 1,000+ years (Canham and Loucks 1984, Whitney 1986, White and Host 2003). However, it may be considerably shorter due to the temporary and imprecise signal they leave behind. In recent times a number of very large scale, severe storms have struck the area (Table 41).

Table 41. Dates and locations of large-scale wind disturbances in the vicinity of Grand Portage National Monument.

Date	Location	Size (ha)	Reference
October, 1949	Northern Wisconsin, upper peninsula of Michigan	6,100,000	Stoeckeler and Arbogast 1955
July, 1995	Northern Minnesota	4,000+	Palik and Robl 1999
July, 1999	Northern Minnesota (mainly BWCAW)	158,000	Fraver et al. 2011

4.6.3 Herbivory

Insects that defoliate and potentially kill the overstory are the other important component of the DR in northeastern Minnesota (e.g., Frelich and Reich 1995). White-tailed deer and moose have minor impacts in this landscape. The herbivores that have the most widespread impact in northeastern Minnesota are the forest tent caterpillar (FTC) (*Malacosoma disstria*) and eastern spruce budworm (ESB) (*Choristoneura fumiferana*). Both species reach epidemic levels from time to time, but impact totally different tree species. The FTC prefers aspen but will feed on many broad-leaved species (Duncan and Hodson 1958). In contrast, for ESB, balsam fir is the preferred host (Morin et al. 2007), and white spruce is readily eaten (Taylor and MacLean 2009).

Based on tree composition in the mid-1800s, ESB would have been the more important species at that time. In contrast, the increase in aspen and birch since the European settlement period has elevated FTC to the spot of 'top' herbivore. This is shown by the extensive defoliation that occurred in northeastern Minnesota in 1951-52 (Duncan and Hodson 1958). Su et al. (1996) reported for 25 stands in New Brunswick that defoliation of balsam fir by ESB decreased significantly and steadily as the proportion of broad-leaved species in the canopy increased. Thus, in the mixed composition forests in and around GRPO, the overall impact of this insect is lower than reported for other regions of the southern boreal forest (e.g., Taylor and MacLean 2009). However, Minnesota has had recent outbreaks – more than 30,000 ha were defoliated in 2002, mainly in northeast Minnesota (USFS 2003). Since 2005, the extent of damage by FTC increased steadily in the state, but virtually all occurred in the central part. The ESB has also been very active lately with >44,000 ha defoliated in 2010-2011, but a strong majority occurred in St. Louis County. The trends since the mid-20th century suggest that these two aggressive insect defoliators are less-frequent disturbance agents in far northeastern Minnesota. A potentially new threat to the deciduous component of the forests in and around GRPO is the gypsy moth (*Lymantria dispar*). More than 900 moths were trapped in Cook County in 2011, mostly along the lakeshore (http://fhm.fs.fed.us/fhh/ncregion.shtml).

There has been considerable speculation about the potential effects of climate change on forest disturbances. The most common characterization has been that the disturbances will increase in severity, and in some regions, in frequency (Ayres and Lombardero 2000, Dale et al. 2001, Swanston et al. 2011). The level of insect and pathogenic activity and the occurrence of fires are closely tied to temperature regime and precipitation patterns. Consequently, most of North America is expected to experience more acreage burned (Dale et al. 2001). However, the amount and timing of precipitation could lead to less fire activity, despite an increase in temperature (Dale et al. 2001). The impact of climate change on insect population levels is more difficult to predict, but most are anticipated to result in large impacts (Ayres and Lombardero 2000). The large increase in area impacted by the mountain pine beetle in British Columbia may be indicative of the magnitude of changes to come (Kurz et al. 2008).

4.6.4 Small-scale Disturbances

As a forest matures, the trees in the canopy become susceptible to damage and mortality from small-scale phenomena such as wind, ice, insects, and disease. In the BWCAW, Frelich and Reich (1995) estimated the openings created by these events are typically 10-30 m across. In northwestern Quebec, the percent of forest in openings ranged from 7% in a 50-year old aspen-dominated forest to 40% in a 200+ year old balsam fir-dominated type (Kneeshaw and Bergeron 1998). Though both studies are extrapolations, they give a general indication of the likely extent of this moderately important component of the DR in GRPO.

In summary, the DR of the landscape around GRPO has four major components (fire, wind, herbivory, and small-scale disturbances), each of which is variable across community types and over time. High-severity fires and wind events play a major role in shaping the landscape, with fires being more frequent. Each occurrence levels the existing forest and produces a pioneer community which will gradually transition into other community types over time. Low-severity fires were a part of this landscape; they were rare in the more mesic parts of the landscape, but would have occurred with some frequency in pine-dominated areas. All forest types, once a canopy has formed, experience small-scale disturbances ('gap' size) at a relatively predictable level that increases with age. These are the result of wind, insects, and disease, probably in that order of importance. At times when extensive areas become dominated by the fir-spruce or aspen forest type, the appropriate insect herbivore would become a more prominent part of the DR by increasing the amount of tree mortality it caused, primarily in the overstory.

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Chapter 5 Discussion

Grand Portage National Monument was established by a 1958 act of Congress that gave equal weight to preserving the “unique historic values” and conserving “the scenery and the natural and historic objects and the wildlife therin.” Within the Resources Trust lands of the monument, the long, narrow corridor of the Portage Trail has required both thoughtful attention to land management and close cooperation with the land managers of the surrounding Grand Portage Indian Reservation.

GRPO is located in an area of growing population both on and off the Reservation. The population of the Reservation has increased as the Band has increased its prosperity, its influence, and the services it provides to its residents. The non-Reservation population of Cook County is more elderly than the general population of Minnesota. Visitation to GRPO has varied by decade, but is generally increasing, averaging 63,000 yr^{-1} in the 1960s, 52,000 yr^{-1} in the 1970s, 49,000 yr^{-1} in the 1980s, 69,000 yr^{-1} in the 1990s, and 76,000 yr^{-1} in the 2000s, with a record attendance from 1961-2010 of 113,996 in 2010.

5.1 Landscape Condition

Landscape condition for GRPO was assessed in the categories of land cover, impervious surfaces, landscape pattern and structure, and road density. Land cover was in good condition and stable, as defined by the lack of major changes in C-CAP program data over five-year increments. Data were insufficient to assess a trend. Within the Grand Portage Creek watershed, the condition relative to impervious surfaces was good; the watershed had 0.3-0.6% impervious surface, less than the maximum 4% recommended for the protection of coaster brook trout. However, since the mouth of the watershed is in one of the growth areas of Grand Portage, the trend is uncertain.

The landscape pattern and structure at GRPO is of moderate concern based on qualitative analysis using air photos and the USFS disturbance map. Habitat in GRPO can change abruptly at its boundary because of forest harvesting and logging roads on the surrounding Reservation. The trend in this condition is uncertain. The condition of the landscape is of moderate concern for road density; the majority of the land in the GRPO watershed is within 500 m of a road and so does not meet the habitat requirements documented for moose in a study in Quebec, and only 23% of the land in the GRPO watershed has a low enough road density to be considered territory core use area for the gray wolf.

The GLKN program to analyze natural or human-related disturbances using aerial photography and satellite images should help analyze and track landscape condition and should be completed.

5.2 Biotic Condition

The condition of the southern boreal forest at GRPO is of moderate concern and declining, since the relative abundance of tree species appears to be significantly outside its normal range of variation. Current climate change scenarios make likely biologically significant changes in plant species ranges, species abundance, community composition, and other ecosystem properties. The moose population is similarly of moderate concern and in decline. Beaver, a “critical story element” for GRPO, are in good condition, with a stable to slightly improving trend. Terrestrial invasive species are of moderate concern, with an uncertain trend. Nineteen invasive plant species were identified in a 2010 survey at GRPO.

In aquatic habitats, insufficient detail on the distribution of year classes prevented an accurate assessment of the coaster brook trout population; however, the trend appears to be improving. The aquatic macroinvertebrate population in streams is in good and stable to improving condition, based on detailed sampling conducted by the Band. Outside GRPO boundaries, the Pigeon River is of significant concern because of a large population of invasive rusty crayfish, and Grand Portage Bay is of unknown condition because of a possible invasion of invasive purple loosestrife; the trend for both these is unknown. VHSv is a fish virus that might affect future fish populations at GRPO, and *Didymosphenia geminata*, a diatom species, may present future problems with nuisance blooms, but the current condition of GRPO for both these is good.

Fish in GRPO have been assessed for a variety of organic chemical contaminants. DDT and its metabolites have been decreasing in fish in Lake Superior and were not found in fish sampling in GRPO in 2006-2009. PCBs were found in GRPO fish during that time period, but at levels far below the GLWQA targets. The condition of GRPO for both these organic chemical groups is good, with an apparent improving trend based on improvements noted in Lake Superior. However, for two other groups of organic chemicals, PFOS and other PFCs, and PBDEs, levels in GRPO are of moderate concern, with an uncertain trend.

5.3 Chemical and Physical Characteristics

Air quality for GRPO is of significant concern for wet deposition of total nitrogen and of moderate concern for ozone, wet deposition of total sulfur, and visibility. The nearby Class I airsheds of VOYA and ISRO did not show significant air quality trends from 2004-2008, so we judge GRPO to also have no significant trends for these parameters over this time period.

For water quality parameters in GRPO inland waters, the condition is good and the trend is stable for specific conductance, pH, dissolved oxygen, water clarity, alkalinity, and total phosphorus. The condition is good but the trend is uncertain for chloride and total nitrogen because of inputs from road salt and the atmosphere, respectively. The data for nitrate and nitrite nitrogen were inadequate to assess either the condition or the trend. Water quality monitoring by both the Band and the GLKN appears appropriate and should be continued.

In Grand Portage Bay, which borders but is outside the jurisdiction of GRPO, the condition is good and the trend is stable for dissolved oxygen and *E. coli* bacteria, and of moderate concern with an uncertain trend for total phosphorus and water clarity.

Mercury deposition from the atmosphere is a major concern at GRPO. Over 400 kg of mercury are emitted by regulated sources within 250 km of GRPO each year. Mercury in precipitation is of significant concern, with an uncertain trend. Mercury likely of anthropogenic origin has been detected in deep soils at three sites in GRPO; this condition is of moderate concern, but its magnitude is not likely changing. Mercury concentrations in stream water and aquatic organisms in GRPO exceed reference conditions for the protection of wildlife and are of significant concern. Data are insufficient to determine a trend. In game fish, mercury concentrations in GRPO streams are good, but those in Grand Portage Bay are of moderate concern and those in the Pigeon River are of significant concern for the health of consumers, especially native subsistence fishers; trends are uncertain, but there is some evidence that mercury levels in Lake Superior fish are increasing. Adverse reproductive effects on invertivorous songbirds from mercury contamination in the food chain have been noted in the northeastern U.S. and, given the mercury levels in larval dragonflies at GRPO, the possibility of impairment at GRPO should be evaluated.

Organic contaminants were found in a water sample collected off the GRPO dock in 2009; these are similar to those found at other Lake Superior locations and are of moderate concern, with an unknown trend.

5.4 Ecological Processes

Energy flow and material flow, the two primary categories of ecological processes, are of great importance in ecosystems but are costly and time consuming to measure. No specific assessments were found for these in GRPO. The GLKN lists four monitoring categories related to ecosystem processes (succession, trophic relations, nutrient dynamics, and primary productivity), but only succession is currently scheduled for the development of a monitoring protocol.

5.5 Hydrology and Geomorphology

The current shoreline recession rate of Grand Portage Bay appears to be within its historic range and therefore in good condition, but the trend is unknown. Extreme events such as storms can quickly change a shoreline. Reduced shelf ice cover or an increase in the gradient of Grand Portage Creek could change the shoreline more gradually over time. On the other hand, climate-change-induced lowering of lake levels or reduced ice push could decrease the average shoreline recession rate.

Grand Portage Creek is experiencing an apparently increased amount of bank erosion and lateral migration, leading us to rank its condition as of moderate concern. A USGS study currently being conducted at GRPO should provide more information on trend. The hydrologic condition of the Pigeon River is rated as of moderate concern and declining; data suggest that the stream hydrograph is shifting toward earlier snowmelt and peak spring discharge and a reduction in late summer discharge.

5.6 Natural Disturbance Regimes

The major components of the natural disturbance regime at GRPO are fire, wind, herbivory, and small-scale disturbances. Reference conditions were not established for these. However, high-severity fires and wind disturbances are a natural part of the GRPO landscape. Fires have rotation periods of 140 years for dry mesic Jack pine-black spruce forests to 500 years for mesic birch-aspen-spruce-fir forests at GRPO. The rotation period for high severity wind events in the upper Great Lakes is estimated at 1,000 years or more, but very large, severe storms struck in the GRPO vicinity in 1949, 1995, and 1999.

Herbivory from white-tailed deer and moose produces minor impacts in the GRPO landscape; the greater threat comes from insects such as forest tent caterpillar and eastern spruce budworm, which can defoliate and potentially kill the overstory. The gypsy moth is a potential new threat to the deciduous forests of GRPO. Small-scale disturbances, such as wind, ice, insects, and disease that create openings of 10-30 m in the canopy, are a moderately important component of the disturbance regime in GRPO.

A summary of the condition of the resources we evaluated at GRPO is included as Table 42.

Table 42. Condition and trend for resources, stressors, and features in Grand Portage National Monument.

Group	Resource, Stressor, or Feature Evaluated	Condition	Trend	Symbol and Location
Landscape Condition	Land Cover	Good	Uncertain	Park
	Impervious Surfaces	Good	Uncertain	Grand Portage Creek
	Landscape Pattern and Structure	Moderate concern	Uncertain	Portage Trail
	Road Density – Moose and Gray Wolf	Moderate concern	Unchanging	Park
Biotic Condition	Southern Boreal Forest	Moderate concern	Declining	Portage Trail
	Moose	Moderate concern	Declining	Park
	Beaver	Good	Stable to slightly improving	Park
	Terrestrial Exotic Plant Species	Moderate concern	Uncertain	Park
	Coaster Brook Trout – Grand Portage Creek	Unknown	Improving	Grand Portage Creek
	Coaster Brook Trout – Grand Portage Bay	Unknown	Improving	Grand Portage Bay

Table 42. Condition and trend for resources, stressors, and features in Grand Portage National Monument. (continued)

Group	Resource, Stressor, or Feature Evaluated	Condition	Trend	Symbol and Location
Biotic Condition (continued)	Aquatic Macroinvertebrates – Grand Portage Creek	Good	Improving	Grand Portage Creek
	Aquatic Macroinvertebrates – Poplar Creek	Good	Improving	Poplar Creek
	Aquatic Non-Native and Invasive Species – Pigeon River	Significant concern	Uncertain	Pigeon River
	Aquatic Non-Native and Invasive Species – Grand Portage Bay	Unknown	Uncertain	Grand Portage Bay
	VHSv	Good	Uncertain	Park
	Didymosphenia geminata (Didymo)	Good	Uncertain	Park
	Organic Contaminants in Fish - DDT and Metabolites and Total PCBs	Good	Improving	Park
	Organic Contaminants in Fish - PFOS and other PFCs and PBDEs	Moderate concern	Uncertain	Park
Chemical and Physical Condition	Air – Wet Deposition of Total Nitrogen	Significant concern	No significant trend	Park
	Air – Wet Deposition of Total Sulfur, Ozone, and Visibility	Moderate concern	No significant trend	Park

Table 42. Condition and trend for resources, stressors, and features in Grand Portage National Monument. (continued).

Group	Resource, Stressor, or Feature Evaluated	Condition	Trend	Symbol and Location
Chemical and Physical Condition (continued)	Water Quality of Inland Waters – Specific Conductance, pH, Dissolved Oxygen, Alkalinity, Water Clarity, and Total Phosphorus	Good	Stable	Park
	Water Quality of Inland Waters – Chloride and Total Nitrogen	Good	Uncertain	Park
	Water Quality of Inland Waters - Nitrate and Nitrite Nitrogen and Chlorophyll *a*	Uncertain	Uncertain	Park
	Water Quality of Grand Portage Bay – Dissolved Oxygen and *E. coli*	Good	Stable	Grand Portage Bay
	Water Quality of Grand Portage Bay – Turbidity and Total Phosphorus	Moderate concern	Uncertain	Grand Portage Bay
	Mercury – Precipitation	Significant concern	Unchanging	Park
	Mercury – Soil	Moderate concern	Stable	Park
	Mercury – Streams and Aquatic Organisms other than Game Fish	Significant concern	Uncertain	Park
	Mercury – Game Fish – Pigeon River	Significant concern	Uncertain	Pigeon River
	Mercury – Game Fish – Grand Portage Bay	Moderate concern	Uncertain	Grand Portage Bay

Table 42. Condition and trend for resources, stressors, and features in Grand Portage National Monument. (continued).

Group	Resource, Stressor, or Feature Evaluated	Condition	Trend	Symbol and Location
Chemical and Physical Condition (continued)	Mercury – Game Fish – Grand Portage, Poplar, and Snow Creeks	Good	Uncertain	Park
	Organic Contaminants in Sediments – Grand Portage Bay	Moderate concern	Unknown	Grand Portage Bay
Hydrology and Geomorphology	Geomorphology of Grand Portage Bay	Good	Stable	Grand Portage Bay
	Hydrology and Geomorphology of Grand Portage Creek	Moderate concern	Uncertain	Grand Portage Creek
	Hydrology of the Pigeon River	Moderate concern	Uncertain	Pigeon River

Appendix A. GIS layers, datasets for base maps, and summary/analysis files.

All maps and associated geoprocessing were done with the ArcGIS 10 software by Environmental Systems Research Institute, Inc., Redlands, CA (2010). Maps are generally displayed in the NAD 1983 UTM Zone 16N coordinate system (NPScape metric maps are USA Contiguous Albers Equal Area Conic USGS version). Spatial data, other than NPScape metrics related files, obtained in other datums or coordinate systems were re-projected using ArcGIS.

All GIS datasets are contained in the GRPO.gdb geodatabase along with associated metadata. The geodatabase, map document files, layer definition files, and png/pdf versions of the report figures were packaged on a DVD submitted with the report. Map documents use relative pathnames to data sources and therefore should open properly if kept in the same directory as the geodatabase.

References for specific map content are included in the map caption or are described in the report text that refers to the figure. All base map layers and metadata are included in the geodatabase but are generally not referenced in the report. These layers include:

Park boundary and features:

National Park Service. 2011. Current Administrative Boundaries of National Park System Units (queried for GRPO). Available at http://irma.nps.gov/App/Reference/Profile/2192761. (accessed June 29, 2011).

Grand Portage Natural Resources GIS Lab. 2000. Grand Portage Trail. Available at http://irmafiles.nps.gov/Reference/Holding/359036/gptrail.e00. (accessed July 27, 2011).

Grand Portage Natural Resources GIS Lab. 2000. Mount Rose Trail. Available at http://irma.nps.gov/App/Reference/Profile/1023059. (accessed July 26, 2011).

Grand Portage Natural Resources GIS Lab. 2000. Historic Buildings in the Grand Portage National Monument. Available at http://irmafiles.nps.gov/Reference/Holding/359057/histbdg.e00. (accessed July 26, 2011).

Grand Portage Natural Resources GIS Lab. 2000. Linear Structures in the Grand Portage National Monument. Available at http://irmafiles.nps.gov/Reference/Holding/359059/linestru.e00. (accessed July 25, 2011).

Elevation background and hillshading:

U.S. Geological Survey. 2009. 1-Arc Second National Elevation Dataset. Available at http://nationalmap.gov/viewer.html. (accessed http://seamless.usgs.gov Sept 6, 2011).

General roads:

Minnesota DNR – MIS Bureau. 2002. DOT Basemap Roads – All Types. Available at http://deli.dnr.state.mn.us. (accessed July 26, 2011).

Surface water features:

U.S. Geological Survey. 2011. NHDFlowline/NHDArea/NHDWaterbody. Available at http://nhd.usgs.gov/data.html. (accessed July 5, 2011).

The DVD also includes a subdirectory with these Excel spreadsheets that summarize various GIS analyses or provide source information such as water quality and flow data.

Road Metrics

Forest Density

Forest Morphology

CCAP Summary

NPS System Area Perimeter

Air Monitoring Sites

Air Summary with Hg

Soils Summary

Veg Summary

Air Hg

Grand Portage Bay Phosphorus

Fernberg Precip

Pigeon River Flows

GPNM_tables_appendices

Water quality data and trends folder

Appendix B. Minnesota endangered, threatened, and special concern species in Grand Portage National Monument (NPS 2011c).

Category	Family	Common Name	Scientific Name	Minnesota Status	Occurrence	Abundance
Vascular Plant	Orchidaceae	Auricled twayblade	*Listera auriculata*	Endangered	Present in Park	Rare
Bird	Falconidae	Peregrine falcon	*Falco peregrinus*	Threatened	Present in Park	Uncommon
Bird	Laridae	Common tern	*Sterna hirundo*	Threatened	Present in Park	Occasional
Bird	Podicipedidae	Horned grebe	*Podiceps auritus*	Threatened	Present in Park	Occasional
Vascular Plant	Cyperaceae	Elk sedge, Garber's sedge	*Carex garberi*	Threatened	Present in Park	Rare
Vascular Plant	Cyperaceae	Bright green spikerush	*Eleocharis olivacea*	Threatened	Present in Park	Rare
Vascular Plant	Ophioglossaceae	Common moonwort, moonwort, moonwort grapefern	*Botrychium lunaria*	Threatened	Present in Park	Rare
Vascular Plant	Dryopteridaceae	Smooth cliff fern	*Woodsia glabella*	Threatened	Present in Park	Uncommon
Bird	Accipitridae	Bald eagle	*Haliaeetus leucocephalus*	Special Concern	Present in Park	Common
Insect	Limnephilidae	A caddisfly	*Asynarchus rossi*	Special Concern	Present in Park	Uncommon
Mammal	Canidae	Gray wolf, wolf	*Canis lupus*	Special Concern	Present in Park	Common
Mammal	Mustelidae	Least weasel	*Mustela nivalis*	Special Concern	Present in Park	Occasional
Mammal	Vespertilionidae	Northern long-eared bat, northern myotis	*Myotis septentrionalis*	Special Concern	Present in Park	Uncommon
Vascular Plant	Apiaceae	Blunt-fruited sweet cicely	*Osmorhiza depauperata*	Special Concern	Present in Park	Rare
Vascular Plant	Brassicaceae	Rock whitlow grass	*Draba arabisans*	Special Concern	Present in Park	Rare
Vascular Plant	Caryophyllaceae	Longstalk starwort, long-stalk starwort	*Stellaria longipes*	Special Concern	Present in Park	Uncommon
Vascular Plant	Portulacaceae	Carolina springbeauty	*Claytonia caroliniana*	Special Concern	Present in Park	Uncommon
Vascular Plant	Poaceae	Wavy hairgrass	*Deschampsia flexuosa*	Special Concern	Present in Park	Rare

Appendix B. Minnesota endangered, threatened, and special concern species in Grand Portage National Monument (NPS 2011c) (continued).

Category	Family	Common Name	Scientific Name	Minnesota Status	Occurrence	Abundance
Vascular Plant	Adoxaceae	Muskroot	*Adoxa moschatellina*	Special Concern	Present in Park	Rare
Vascular Plant	Pyrolaceae	Snowline shinleaf, snowline wintergreen	*Pyrola minor*	Special Concern	Present in Park	Unknown
Vascular Plant	Ophioglossaceae	Little grapefern	*Botrychium simplex*	Special Concern	Present in Park	Rare
Vascular Plant	Cupressaceae	Creeping juniper	*Juniperus horizontalis*	Special Concern	Present in Park	Rare
Vascular Plant	Salicaceae	Satiny willow	*Salix pellita*	Special Concern	Present in Park	Rare
Vascular Plant	Scrophulariaceae	Hudson Bay eyebright	*Euphrasia hudsoniana*	Special Concern	Present in Park	Rare
Vascular Plant	Apiaceae	Mountain sweetroot, sweet cicely, sweetcicely	*Osmorhiza berteroi*	Endangered	Probably Present	NA
Vascular Plant	Dryopteridaceae	Braun's hollyfern	*Polystichum braunii*	Endangered	Probably Present	NA
Bird	Strigidae	Short-eared owl	*Asio flammeus*	Special Concern	Probably Present	NA
Reptile	Chelydridae	Common snapping turtle, snapping turtle	*Chelydra serpentina*	Special Concern	Probably Present	NA
Vascular Plant	Orchidaceae	Broadleaf twayblade, broad-lip twayblade, broadlipped listera	*Listera convallarioides*	Special Concern	Probably Present	NA
Vascular Plant	Polygonaceae	Alpine bistort, serpent-grass, viviparous bistort	*Polygonum viviparum*	Special Concern	Probably Present	NA
Vascular Plant	Dryopteridaceae	Alpine woodsia, northern woodsia	*Woodsia alpina*	Special Concern	Probably Present	NA
Vascular Plant	Brassicaceae	Norwegian draba	*Draba norvegica*	Endangered	Unconfirmed	NA
Vascular Plant	Cyperaceae	Pale sedge	*Carex pallescens*	Endangered	Unconfirmed	NA

Appendix B. Minnesota endangered, threatened, and special concern species in Grand Portage National Monument (NPS 2011c) (continued).

Category	Family	Common Name	Scientific Name	Minnesota Status	Occurrence	Abundance
Vascular Plant	Liliaceae	Scotch false asphodel	*Tofieldia pusilla*	Endangered	Unconfirmed	NA
Vascular Plant	Ophioglossaceae	Pale botrychium, pale moonwort	*Botrychium pallidum*	Endangered	Unconfirmed	NA
Vascular Plant	Saxifragaceae	Nodding saxifrage	*Saxifraga cernua*	Endangered	Unconfirmed	NA
Vascular Plant	Selaginellaceae	Club spikemoss, clubmoss, northern spikemoss	*Selaginella selaginoides*	Endangered	Unconfirmed	NA
Vascular Plant	Asteraceae	Longleaf arnica, seep arnica	*Arnica lonchophylla*	Threatened	Unconfirmed	NA
Vascular Plant	Brassicaceae	A holboell rock-cress, second rockcress	*Arabis holboellii* var. *retrofracta*	Threatened	Unconfirmed	NA
Vascular Plant	Brassicaceae	American awlwort, waterawlwort	*Subularia aquatica*	Threatened	Unconfirmed	NA
Vascular Plant	Ericaceae	Bog blueberry	*Vaccinium uliginosum*	Threatened	Unconfirmed	NA
Vascular Plant	Liliaceae	Nodding onion	*Allium cernuum*	Threatened	Unconfirmed	NA
Vascular Plant	Nymphaeaceae	Leiberg's waterlily	*Nymphaea leibergii*	Threatened	Unconfirmed	NA
Vascular Plant	Ophioglossaceae	Rugulose grape-fern, ternate grapefern	*Botrychium rugulosum*	Threatened	Unconfirmed	NA
Vascular Plant	Orchidaceae	Ram's head lady's slipper, ram's-head lady's-slipper	*Cypripedium arietinum*	Threatened	Unconfirmed	NA
Vascular Plant	Aspleniaceae	Maidenhair spleenwort	*Asplenium trichomanes*	Threatened	Unconfirmed	NA
Vascular Plant	Rosaceae	Cloudberry	*Rubus chamaemorus*	Threatened	Unconfirmed	NA

Appendix B. Minnesota endangered, threatened, and special concern species in Grand Portage National Monument (NPS 2011c) (continued).

Category	Family	Common Name	Scientific Name	Minnesota Status	Occurrence	Abundance
Mammal	Felidae	Mountain lion, cougar	*Felis concolor*	Special Concern	Unconfirmed	NA
Vascular Plant	Asteraceae	Elegant groundsel	*Senecio indecorus*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Yellow sedge	*Carex flava*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Michaux's sedge	*Carex michauxiana*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Meadow sedge, northern meadow sedge	*Carex praticola*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Whitescale sedge, white-scale sedge	*Carex xerantica*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Fewflower spikerush, few-flower spikerush, few-flower spike-rush	*Eleocharis quinqueflora*	Special Concern	Unconfirmed	NA
Vascular Plant	Cyperaceae	Brown beaksedge	*Rhynchospora fusca*	Special Concern	Unconfirmed	NA
Vascular Plant	Poaceae	Purple reedgrass	*Calamagrostis purpurascens*	Special Concern	Unconfirmed	NA
Vascular Plant	Poaceae	Bog muhly	*Muhlenbergia uniflora*	Special Concern	Unconfirmed	NA
Vascular Plant	Najadaceae	Slender waternymph	*Najas gracillima*	Special Concern	Unconfirmed	NA
Vascular Plant	Ophioglossaceae	Iowa moonwort, prairie dunewort	*Botrychium campestre*	Special Concern	Unconfirmed	NA
Vascular Plant	Ophioglossaceae	Mingan Island grapefern, Mingan moonwort	*Botrychium minganense*	Special Concern	Unconfirmed	NA

Appendix B. Minnesota endangered, threatened, and special concern species in Grand Portage National Monument (NPS 2011c) (continued).

Category	Family	Common Name	Scientific Name	Minnesota Status	Occurrence	Abundance
Vascular Plant	Orchidaceae	Green woodland orchid, small green wood orchid	*Platanthera clavellata*	Special Concern	Unconfirmed	NA
Vascular Plant	Plantaginaceae	American shoreweed	*Littorella uniflora*	Special Concern	Unconfirmed	NA
Vascular Plant	Ranunculaceae	Lapland buttercup	*Ranunculus lapponicus*	Special Concern	Unconfirmed	NA
Vascular Plant	Lentibulariaceae	Common butterwort	*Pinguicula vulgaris*	Special Concern	Unconfirmed	NA
Vascular Plant	Lentibulariaceae	Lavender bladderwort, northeastern bladderwort	*Utricularia resupinata*	Special Concern	Unconfirmed	NA
Vascular Plant	Hydrophyllaceae	Franklin's phacelia	*Phacelia franklinii*	Special Concern	Unconfirmed	NA
Vascular Plant	Sparganiaceae	Clustered bur-reed, northern bur-reed	*Sparganium glomeratum*	Special Concern	Unconfirmed	NA

Appendix C. A brief description of laws, rules, regulation, and policy governing resource management in National Parks.

The following was prepared by Brandon Seitz and is a brief description of the laws, rules, regulations, and policies governing resource management in National Parks. They are presented here to frame the Natural Resource Condition Assessment (NRCA) within the perspective of legal mandates and precedent for stewardship of natural resources.

FEDERAL LAWS – acts passed by the U.S. Congress and approved by the President. All laws must be consistent with the U.S. Constitution. Federal laws have supremacy over state and local laws. Legislative history (i.e., committee reports, transcripts of congressional debates) clarifies the congressional intent in enacting a law.

1) Organic Act: 16 U.S.C. 1 et seq. (1988), Aug. 25, 1916, ch. 408, 39 Stat. 535

> *...By law, the National Park Service is mandated to "conserve the scenery and the natural and historic object and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."...As amended, the Organic Act allows the Secretary a great deal of latitude in making management decisions, and the courts have consistently upheld this latitude, especially if it is supported by careful study and planning. The Secretary can exclude a use that is detrimental to resources, or allow a use if it is determined to be appropriate...Alternatively, the Secretary can permit a use if it has been clearly proven not to threaten resources. (NPS/NRPO/Nrr-94/15).*

The NRCA may be used as a study to aid in the identification of any resources that are or have the potential to become impaired. The NRCA will be used to inform management decisions.

2) Redwood National Park Act: 16 U.S.C. 79a-79q (1988), 82 Stat. 931, Pub. L. 90-545

> *...By amending the General Authorities Act of 1970, the act reasserted Systemwide the high standard of protection prescribed by Congress in the original Organic Act...External activities at Redwood, namely logging, were the catalyst for this legislation. Congress wanted to strengthen the ability of the Secretary of the Interior to protect park resources from such threats. Part of the amendment's legislative history stated, "The Secretary has an absolute duty, which is not to be compromised, to fulfill the mandate of the 1916 Act to take whatever actions and seek whatever relief as will safeguard the units of the National Park System." Nevertheless, the Redwood Act qualifies the provision that park protection and management "shall not be exercised in derogation of the values and purposes for which these various areas have been established," by adding "except as may have been or shall be directly and specifically provided for by Congress." Thus, specific provisions in a park's enabling legislation allow park managers to permit activities such as hunting and grazing. While the qualification can clearly be interpreted narrowly (i.e., in those situations and within those parks where Congress explicitly authorizes an activity that threatens park resources), because the direction is to the Secretary, it arguably could be interpreted more broadly to include, for example, the multiple-use management on adjacent federal lands that can affect park resources (NPS/NRPO/Nrr-94/15).*

As land use surrounding GRPO has the potential to impact park resources, GRPO has an inherent interest in logging or other resource extraction activities that could leave GRPO resources impaired. As a result, the NRCA may be used as a study to aid in the identification of any resources that are or have the potential to become impaired by external activities. The NRCA will be used to inform management decisions.

3) National Environmental Policy Act: 42 U.S.C. 4321 et seq. (1988), 83 Stat. 852, Pub. L. 91-190

> *...requires the federal government to use all practicable means to preserve important historic, cultural, and natural aspects of our national heritage and "to maintain, whenever possible, an environment which supports diversity and variety of individual choice." It promotes efforts that will "enrich the understanding of ecological systems and ecological resources of the nation" and discusses the role of research in forming the information base from which the cause and effect of environmental changes can be analyzed and monitored...It enables the Park Service to integrate compliance with other legal mandates such as the Endangered Species Act, floodplain and wetland requirements, and Section 106 of the National Historic Preservation Act. It provides a format for public involvement and considering the viewpoints of outsiders. It enables the Park Service to build a record in defense of park resources and policies and clear up confusion about policies in a public forum. NEPA also provides the National Park Service an opportunity to participate in the development and review of other agencies' NEPA documents when lands adjacent to parks are involved or when the National Park Service has review responsibilities as an agency with "jurisdiction" or expertise in recreation, land management, and historic preservation. This type of involvement is an important but underused avenue for addressing external problems that affect parks (NPS/NRPO/Nrr-94/15).*

The NRCA will be used to enrich the understanding of GRPO's ecological systems and ecological resources by facilitating a discussion of the role of research in forming the information base from which the cause and effect of environmental changes can be analyzed and monitored. It may also be used as an aid to determine whether or not any major, future, federal action undertaken by GRPO (such as construction, natural or cultural resource management projects, and/or park plans) has the potential to significantly affect natural resources or ecological processes. The NRCA will be used to inform the environmental compliance planning process established by NEPA.

4) Clean Air Act: 42 U.S.C. 7401-7671q (as amended in 1990), 91 Stat. 685, Pub. L. 101-549

> *Throughout each aspect of the Clean Air Act's (CAA's) structure-its goals, measures, and means-are numerous opportunities to influence a regulatory agency's action to protect the air quality and related values of parks. Examples of regulatory actions that can affect park air quality protection significantly are the determination of national ambient air quality standards, control technology requirements, state implementation measures, and individual source permits. All of the CAA's regulatory actions involve notice to the public of proposed actions and opportunity for comment. Many provisions require consultation with affected federal land managers, and certain provisions give additional influence to the federal land manager's opinion. Generally, the better the National Park Service's*

scientific information on the sources and effects of air pollution affecting parks, the more influential the service can be on proposed regulatory actions. By taking advantage of these opportunities, the park service can ensure that EPA and applicable state agencies consider the special benefits and costs of their regulatory decisions with respect to park air quality and related values (http://www.nature.nps.gov/air/Regs/cleanAir.cfm, 30 December 2011).

a) **42 U.S.C. §§ 7470 - 7492 (CAA §§ 160 - 169B). Prevention of Significant Deterioration (PSD):**

The Clean Air Act's concern for resource protection is not limited to Class I areas. Congress designated all other "clean" air regions of the country [such as GRPO] "Class II." In fact, most of the units of the National Park System are "Class II." ...In Class II areas, the Class II increment ceilings on additional pollution over base-line concentrations allow for moderate development. Class II increments constitute an absolute ceiling on additional pollution in these areas, however, because Congress did not qualify the Class II increment with a variance procedure similar to the adverse impact test for Class I areas. As part of the PSD permit application, major new and modified sources with the potential to affect a park service Class II area must analyze their impacts on the area's ambient air quality, climate and meteorology, terrain, soils and vegetation, and visibility. The Department of the Interior also has encouraged the park service to seek protection of "integral vistas" associated with Class II areas in individual permit and plan proceedings.

Although the act does not create as many resource protection tools for Class II areas as for Class I areas, it nevertheless creates opportunities. The park service can participate in State Implementation Plan proceedings, new source reviews, and other federal, state, and local activities that potentially affect the air quality of these areas. For example, the service can oppose sources that threaten park resources and values, seek more stringent control technology for sources of concern, and recommend special preconstruction and postconstruction monitoring if more information is needed. In proceedings concerning units of the National Park System, the land manager can invoke the strong language of the park system's Organic Act for protection of park purposes and values from adverse air pollution impacts, in addition to the clear mandate of the CAA. Furthermore, as appropriate, the land manager can undertake or encourage efforts to redesignate the area to Class I. (*http://www.nature.nps.gov/air/Regs/psd.cfm*, 30 December 2011)

The NRCA may be used as an aid to assess resources at risk of major new and modified sources of air pollution. The NRCA may be used as an informational tool if the Service were to oppose air pollution sources that threaten park resources and values.

b) **SIPs - State Implementation Plans:**

States comply with Clean Air Act requirements by developing implementation plans to address specific air quality issues. There must be "state implementation plans," (SIPs) for attainment of primary and secondary national ambient air quality standards, (42 U.S.C. § 7410 (CAA § 110)), Prevention of Significant Deterioration (42 U.S.C. § 7471 (CAA § 161)), and for the protection of visibility. States are required to consult with the NPS and *other federal land managers if federal lands might be affected, with more specific consultation requirements for visibility protection plans.* (*http://www.nature.nps.gov/air/Regs/sips.cfm*, 30 December 2011).

The NRCA may be used as an aid to address state implementation plans.

5) Clean Water Act (CWA): 33U.S.C. 1251-1376 (1988), June 30, 1948, ch. 758, 62 Stat. 1155 Section 313 requires the NPS, in implementing its management activities, to

"...comply with all Federal, State, interstate, and local requirements, administrative authority, and process and sanctions respecting the control and abatement of water pollution in the same manner and to the same extent as any non-government entity including the payment of reasonable service charges." (33U.S.C. 1323).

a) Impaired Waters of GRPO

i) CWA Section 305(b), Category 4a: Waters within category 4a have USEPA approved Total Maximum Daily Limits (TMDLs) established for all applicable Water Quality Standards (WQS). The USEPA advises states that all approved TMDLs should be implemented as soon as practicable to ensure the attainment of WQS within the projected time stipulated in the TMDL.
Pigeon River, South Fowl Lake to Pigeon Bay, 2008: Fish Consumption Advisory – Mercury (http://www.nature.nps.gov/water/HIS/, 3 January 2012)
ii) CWA Section 305(b), Category 5: Only waters within category 5 are included in State 303(d) lists. These waters are impaired and do not meet specified designated uses due to the presence of one or more pollutants. Waters remain in category 5 until all violations of WQS and designated uses are addressed by a USEPA approved TMDL and/or some other delisting factor stipulated by the USEPA occurs.

Lake Superior, 2008: Fish Consumption Advisory - Mercury and Polychlorinated Biphenyls (PCBs) (http://www.nature.nps.gov/water/HIS/, 3 January 2012)

6) Endangered Species Act:

Section 7 requires federal agencies to consult with the U.S. Fish and Wildlife Service if their activities may affect listed species (NPS/NRPO/Nrr-94/15).

Section 7 of the Endangered Species Act directs all Federal agencies to use their existing authorities to conserve threatened and endangered species and to ensure that their actions do not jeopardize listed species or destroy or adversely modify critical habitat. Section 7 applies to management of Federal lands as well as other Federal actions that may affect listed species, such as Federal approval of private activities through the issuance of Federal permits, licenses, or other actions (http://inside.nps.gov/regions/custommenu.cfm?lv=3&rgn=1311&id=5351, 04 January 12).

7) National Parks Omnibus Act:

a) 16USC 5911, Sec. 101. Protection, interpretation, and research in National Park System

Recognizing the ever increasing societal pressures being placed upon America's unique natural and cultural resources contained in the National Park System, the Secretary shall continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System (http://www.law.cornell.edu/uscode/html/uscode16/usc_sup_01_16_10_79.html 04 January 2012).

b) 16USC 5932, SEc. 202. Research mandate
The Secretary is authorized and directed to assure that management of units of the National Park System is enhanced by the availability and utilization of a broad program of the highest quality science and information (http://www.law.cornell.edu/uscode/html/uscode16/usc_sup_01_16_10_79.html 04 January 2012).

c) 16USC 5934, Sec. 204. Inventory and monitoring program
The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources. The monitoring program shall be developed in cooperation with other Federal monitoring and information collection efforts to ensure a cost-effective approach (http://www.law.cornell.edu/uscode/html/uscode16/usc_sup_01_16_10_79.html 04 January 2012).

d) 16USC 5936, Sec. 206. Integration of study results into management decisions: *The Secretary shall take such measures as are necessary to assure the full and proper utilization of the results of scientific study for park management decisions. In each case in which an action undertaken by the National Park Service may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in the condition of resources of the National Park System shall be a significant factor in the annual performance evaluation of each superintendent of a unit of the National Park System(http://www.law.cornell.edu/uscode/html/uscode16/usc_sup_01_16_10_79.html 04 January 2012).*

e) 16USC 5937, Sec. 207. Confidentiality of information: *Information concerning the nature and specific location of a National Park System resource which is endangered, threatened, rare, or commercially valuable, of mineral or paleontological objects within units of the National Park System, or of objects of cultural patrimony within units of the National Park System, may be withheld from the public in response to a request under section 552 of title 5, unless the Secretary determines that –*

> *(1) disclosure of the information would further the purposes of the unit of the National Park System in which the resource or object is located and would not create an unreasonable risk of harm, theft, or destruction of the resource or object, including individual organic or inorganic specimens; and*

(2) disclosure is consistent with other applicable laws protecting the resource or object.
(http://www.law.cornell.edu/uscode/html/uscode16/usc_sup_01_16_10_79.html 04 January 2012).

EXECUTIVE ORDERS (EO) – directives from the President to departments and agencies of the executive branch.

1) Protection of Floodplains Executive Order No. 11988: May 24, 1977, 42 F.R. 26951

...Each agency shall provide leadership and shall take action to... restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities...conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning...
(http://water.epa.gov/lawsregs/guidance/wetlands/eo11988.cfm 04 January 2012)

2) Protection of Wetlands Executive Order No. 11990: May 24, l977, 42 F.R. 26961

... Each agency shall provide leadership and shall take action to...preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities for...conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning...
(http://water.epa.gov/lawsregs/guidance/wetlands/eo11990.cfm 04 January 2012)

3) Scientific Integrity, Memorandum of March 9, 2009 for the Heads of Executive Departments and Agencies:

Science and the scientific process must inform and guide decisions of my Administration on a wide range of issues, including improvement of public health, protection of the environment, increased efficiency in the use of energy and other resources, mitigation of the threat of climate change, and protection of national security. The public must be able to trust the science and scientific process informing public policy decisions. Political officials should not suppress or alter scientific or technological findings and conclusions. If scientific and technological information is developed and used by the Federal Government, it should ordinarily be made available to the public. To the extent permitted by law, there should be transparency in the preparation, identification, and use of scientific and technological information in policymaking. The selection of scientists and technology professionals for positions in the executive branch should be based on their scientific and technological knowledge, credentials, experience, and integrity.

By this memorandum, I assign to the Director of the Office of Science and Technology Policy (Director) the responsibility for ensuring the highest level of integrity in all aspects of the executive branch's involvement with scientific and technological processes. The Director shall confer, as appropriate, with the heads of executive departments and agencies, including the Office of Management and Budget and offices and agencies within the Executive Office of the President (collectively, the ''agencies''), and recommend a plan to achieve that goal throughout the executive branch...
(http://www.whitehouse.gov/the-press-office/memorandum-heads-executive-departments-and-agencies-3-9-09,04 January 2012)

FEDERAL REGULATIONS – rules for complying with a federal law developed by the authorized department or agency that also include codification of agency policy. For example, Title 36 Code of Federal Regulation (CFR) Section 1-199 contains general and specific regulations for the management and use of the National Park System (these regulations are augmented by the superintendent's compendium for each unit).

NPS POLICIES - guiding principles or procedures that set the framework and provide direction for management decisions. They may prescribe the process by which decisions are made, how an action is to be accomplished, or the results to be achieved. NPS policies important for natural resource planning and management are:

1.4.5 What Constitutes Impairment of Park Resources and Values

The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts.

An impact to any park resource or value may, but does not necessarily, constitute an impairment. An impact would be more likely to constitute impairment to the extent that it affects a resource or value whose conservation is necessary to fulfill specific purposes identified in the establishing legislation or proclamation of the park, or key to the natural or cultural integrity of the park or to opportunities for enjoyment of the park, or identified in the park's general management plan or other relevant NPS planning documents as being of significance.

An impact would be less likely to constitute an impairment if it is an unavoidable result of an action necessary to preserve or restore the integrity of park resources or values and it cannot be further mitigated. An impact that may, but would not necessarily, lead to impairment may result from visitor activities; NPS administrative activities; or activities undertaken by concessioners, contractors, and others operating in the park. Impairment may also result from sources or activities outside the park. This will be addressed consistent with sections 1.6 and 1.7 on Cooperative Conservation and Civic Engagement. (See Unacceptable Impacts 1.4.7.1)

1.4.7 Decision-making Requirements to Identify and Avoid Impairments

Before approving a proposed action that could lead to an impairment of park resources and values, an NPS decisionmaker must consider the impacts of the proposed action and determine, in writing, that the activity will not lead to an impairment of park resources and values. If there would be an impairment, the action must not be approved.

In making a determination of whether there would be an impairment, an NPS decision-maker must use his or her professional judgment. This means that the decisionmaker must consider any environmental assessments or environmental impact statements required by the National Environmental Policy Act of 1969 (NEPA); consultations required under section 106 of the National Historic Preservation Act (NHPA), relevant scientific and scholarly studies; advice or insights offered by subject matter experts and others who have relevant knowledge or experience; and the results of civic engagement and public involvement activities relating to the decision. The same application of professional judgment applies when reaching conclusions about "unacceptable impacts."

When an NPS decision-maker becomes aware that an ongoing activity might have led or might be leading to an impairment of park resources or values, he or she must investigate and determine if there is or will be an impairment. This investigation and determination may be made independent of, or as part of, a park planning process undertaken for other purposes. If it is determined that there is, or will be, an impairment, the decision-maker must take appropriate action, to the extent possible within the Service's authorities and available resources, to eliminate the impairment. The action must eliminate the impairment as soon as reasonably possible, taking into consideration the nature, duration, magnitude, and other characteristics of the impacts on park resources and values, as well as the requirements of the National Environmental Policy Act, National Historic Preservation Act, the Administrative Procedure Act, and other applicable laws. (See Levels of Park Planning 2.3; Evaluating Impacts on Natural Resources 4.1.3; Planning 5.2; General 8.1; Visitor Use 8.2; General 9.1; Glossary definition of Professional Judgment. Also see Director's Order #12: Conservation Planning, Environmental Impact Analysis, and Decision-making)

1.4.7.1 Unacceptable Impacts

The impact threshold at which impairment occurs is not always readily apparent. Therefore, the Service will apply a standard that offers greater assurance that impairment will not occur. The Service will do this by avoiding impacts that it determines to be unacceptable. These are impacts that fall short of impairment, but are still not acceptable within a particular park's environment. Park managers must not allow uses that would cause unacceptable impacts; they must evaluate existing or proposed uses and determine whether the associated impacts on park resources and values are acceptable.

Virtually every form of human activity that takes place within a park has some degree of effect on park resources or values, but that does not mean the impact is unacceptable or that a particular use must be disallowed. Therefore, for the purposes of these policies, unacceptable impacts are impacts that, individually or cumulatively, would:

- be inconsistent with a park's purposes or values, or
- impede the attainment of a park's desired future conditions for natural and cultural resources as identified through the park's planning process, or
- create an unsafe or unhealthful environment for visitors or employees, or
- diminish opportunities for current or future generations to enjoy, learn about, or be inspired by park resources or values, or unreasonably interfere with:
  - park programs or activities, or
  - an appropriate use, or
  - the atmosphere of peace and tranquility, or the natural soundscape maintained in wilderness and natural, historic, or commemorative locations within the park.

- NPS concessioner or contractor operations or services.

1.4.7.2 Improving Resource Conditions within the Parks

The Service will also strive to ensure that park resources and values are passed on to future generations in a condition that is as good as, or better than, the conditions that exist today. In particular, the Service will strive to restore the integrity of park resources that have been damaged or compromised in the past. Restoration activities will be guided by the natural and cultural resource-specific policies identified in chapters 4 and 5 of these Management Policies. (See Planning for Natural Resource Management 4.1.1; Restoration of Natural Systems 4.1.5; Compensation for Injuries to Natural Resources 4.1.6; Restoration of Native Plant and Animal Species 4.4.2.2; Restoration (of Cultural Landscapes) 5.3.5.2.3; Restoration (of Historic and Prehistoric Structures) 5.3.5.4.3; Restoration (of Museum Collections) 5.3.5.5.2. Also see Director’s Order #12 and Handbook.)

4.1.5 Restoration of Natural Systems

The Service will reestablish natural functions and processes in parks unless otherwise directed by Congress. Landscapes disturbed by natural phenomena, such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires, will be allowed to recover naturally unless manipulation is necessary to protect other park resources, developments, or employee and public safety. Impacts on natural systems resulting from human disturbances include the introduction of exotic species; the contamination of air, water, and soil; changes to hydrologic patterns and sediment transport; the acceleration of erosion and sedimentation; and the disruption of natural processes. The Service will seek to return such disturbed areas to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated. The Service will use the best available technology, within available resources, to restore the biological and physical components of these systems, accelerating both their recovery and the recovery of landscape and biological community structure and function. Efforts may include, for example:

- removal of exotic species
- removal of contaminants and nonhistoric structures or facilities
- restoration of abandoned mineral lands, abandoned or unauthorized roads, areas overgrazed by domestic animals, or disrupted natural waterways and/or shoreline processes
- restoration of areas disturbed by NPS administrative, management, or development activities (such as hazard tree removal, construction, or sand and gravel extraction) or by public use
- restoration of natural soundscapes
- restoration of native plants and animals
- restoration of natural visibility

When park development/facilities are damaged or destroyed and replacement is necessary, the development will be replaced or relocated to promote the restoration of natural resources and processes.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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