

Aquatic Monitoring Plan, Pictured Rocks National Lakeshore 2004

Lora M. Loope

Science and Natural Resources Division
Pictured Rocks National Lakeshore
Munising, Michigan

INTRODUCTION

Pictured Rocks National Lakeshore (PIRO) is situated along the southern shore of Lake Superior between the towns of Munising and Grand Marais in Alger County, Michigan. The lakeshore is unique in the National Park Service because it is composed of both federally owned land (Fee Zone) and an Inland Buffer Zone owned by corporate, state, federal, and private entities. The Inland Buffer Zone (IBZ) was designated to protect the watersheds that originate outside the publicly owned land, while allowing timber harvesting and housing development (the latter limited by zoning). The IBZ includes 37,849 acres, of which 2,177.86 acres have been purchased by the National Park Service since the park was established. The publicly owned Fee Zone is 33,548 acres in area. The lakeshore also includes the surface water of Lake Superior one-quarter mile perpendicular from shore.

Physical Origins of Lakes and Stream Channels

The watersheds of the lakeshore are defined largely by the Cambrian Sandstone that underlies much of the park and by various Pleistocene glacial and post-glacial Holocene natural occurrences. The Cambrian Sandstone influences the chemistry of the ground water and the gradient of the surface water flow. The watershed divide between Lakes Superior and Michigan is quite close to the Lake Superior shoreline in Alger County. The watersheds are relatively short: the main branch of the Lakeshore's longest stream, the Miners River, is approximately 12 miles (38.3 km) long. Except for the Hurricane River and Sullivan Creek, the streams have relatively steep gradients. Most contain numerous riffles and they drop at knickpoints (waterfalls) over the Cambrian Sandstone bedrock. Except for Mosquito River, all streams, including Miners River, are second order streams (having tributaries that themselves do not have tributaries), while Mosquito River is a third order stream (having tributaries that themselves have unbranched tributaries).

Flowing meltwater cut channels as the glacier receded from the central Upper Peninsula about 9,600 years before present (BP). One meltwater channel occupied the southern edge of Beaver Basin where Hyde Lake, Sevenmile Lake, and Sevenmile Creek are located (Blewett, 1994; Carey, 1993; Schwenner, 2003). Another meltwater channel occupied what is now Hurricane River, Rhody Creek, Grand Sable Lake, and Sable Creek. It flowed west to east (Blewett, 1994). Currently these are two watersheds, the Hurricane River watershed and the Sable watershed. At some point the eastern flowing stream was pirated, and what is now Hurricane River reversed the direction of its flow. A similar process took place on lower Mosquito River and Chapel Creek. A meltwater channel flowed west to east, occupying what is now the 2.5 km stretch of Mosquito River upstream from the mouth, the tributary beaver pond, the confined portion of Chapel Creek (upstream from Chapel Lake), Chapel Lake, and Chapel Creek (Blewett, 1994; Hughes, 1968). The lower portion of Mosquito River now flows in the opposite direction than it did when it was incised by glacial meltwater. In the process it captured the greater portion of the watershed that is now the Mosquito River (upstream from the Mosquito Falls area).

Kettle (closed basin) lakes formed when blocks of ice broke off from the glacier, became surrounded and partially buried by meltwater debris, and then melted. Legion, Section 36, and the Shoe Lakes are kettle lakes located very near the watershed divide (Lewin, 1991). Kingston Lake is another kettle lake that formed in a glacial outwash plain (Carey, 1993; Blewett, 1994; Schwenner, 2003)).

Much later, during the Nipissing high water periods about 6,000 years BP, the level of Lake Superior rose to a level 14m higher than it is today. This Nipissing high stage of Lake Superior inundated Miners and Beaver Basins, as well as Sand Point. Miners Lake, Little Beaver Lake, Beaver Lake, and Trappers Lake were all created when the water of Lake Superior receded and waves deposited beach ridges.

Grand Sable Lake and the current channel of Sable Creek are the result of dune dams that formed about 5,000-6,000 years ago and blocked the ancestral channel, creating the lake and rerouting the creek downstream from Grand Sable Lake several times (Loope *et al.*, 2001).

General Biological and Physical Characteristics of Lakes and Streams

The buffering capacity and other inorganic chemical constituents of the flowing (lotic) and standing (lentic) waters of Pictured Rocks National Lakeshore are determined in large part by the soils through which they pass before entering the streams. The Kalkaska sand and the Rubicon sand comprise the greatest percentage of the soils of Pictured Rocks National Lakeshore. Various loamy sands; sandy loams; Chippeny muck; and Carbondale, Lupton, and Rifle soils are also common (Carey, 1993; Schwenner, 2003).

The watersheds that are perched above bedrock are very responsive to heavy and/or prolonged rainfall (Boyle, 1999) and to annual snowmelt in April (Stottlemeyer and Rutkowski, 1990). Discharge can double in a matter of hours in response to a heavy rain (PIRO data files), and seasonal variation can be a factor of 10 (Handy and Twenter, 1985).

Many streams and some lakes in the lakeshore are described as “brown water” (dystrophic). They contain relatively high amounts of dissolved humic acids (dissolved organic carbon) that originate from the decay of organic matter in swamps in the headwaters.

Freshwater unionids (mussel) are *not* present in the rivers and streams of Pictured Rocks National Lakeshore, although Nichols *et al.* (2000) expected to find them in these flowing waters. Native mussels, however, *are* present in many, but not all, of the lakes: Grand Sable, Kingston, Trappers, Beaver, Little Beaver, and Chapel Lakes (Nichols *et al.*, 2002).

Handy and Twenter (1985) of the US Geological Survey reported the results of dozens of water quality parameters: metals, organo-chlorides, nutrients, etc. The only parameter that exceeded US Environmental Protection Agency standards was color (platinum-cobalt units) from Chapel Lake and Grand Sable Lake. Color is a secondary (aesthetic) standard.

DESCRIPTIONS OF WATERSHEDS

Numerous watersheds within Pictured Rocks National Lakeshore have small areas and discharges into Lake Superior. Some are intermittent from year to year (e.g., Bridal Veil Falls watershed), although there may be permanent standing water behind beaver impoundments in headwater areas. There are numerous small (approximately 85ha), unnamed watersheds that usually have perennial flow and have no beaver impoundments or other standing water habitats. The watershed area of most of these small creeks lie entirely within the Fee Zone of Pictured Rocks National Lakeshore. These watersheds are not described further in this plan; however, should potential threats arise, amendments can be made to the Aquatic Monitoring Plan to include them.

Munising Falls watershed at the western end of Pictured Rocks National Lakeshore is just 502 ha (Handy and Twenter, 1985). Not only is the watershed area small, but the stream length is short, heading in marshy areas both within and outside the lakeshore boundary. Handy and Twenter (1985) measured discharge for Munising Falls Creek from 1979-1981 and found a minimum of $0.028 \text{ m}^3\text{sec}^{-1}$ in August 1981 and a maximum of $0.119 \text{ m}^3\text{sec}^{-1}$ in June 1979. Dissolved nitrate was 0.43 mgL^{-1} in August 1979, the only unusually high value for the parameters measured by Handy and Twenter (1985).

Sand Point watershed includes headwaters on top of the escarpment that flow seasonally to the lowlands of Sand Point. Three main beaver ponds and surrounding wetlands comprise the lowland portion of the catchment that drains to Lake Superior via two outlets. One is on the southwest end of Sand Point swimming beach. The other is near the escarpment on the northeast part of Sand Point. Levels of the ponds vary seasonally as input flow changes and as beavers establish different dams from time to time.

Miners watershed encompasses an area of 7,044 ha according to Handy and Twenter (1985) and 6,863 ha according to Michigan DNR Watershed Council (2000). It is a brown water system, high in dissolved humic acids. The headwaters of the Miners River are low gradient swamps outside the IBZ. The middle section of the river and the downstream section in Miners Basin, however, are confined. The confined

section is wide and supports shrubby wetlands and cedar swamps. Miners Lake is in Miners Basin and is a shallow (4m deep), brown water lake with a surface area reported as 4.6 ha (Kamke, 1987) and 5.26 ha (Humphreys and Colby, 1965). The lake does not stratify completely (Boyle, 1999), and is essentially a wide place along the Miners River. The lake is fed by another stream from the east and by a ground water rivulet from the higher bedrock to the west. Without this direct, cold water input, the lake might not stratify at all. Kamke (1987) compared the Trophic State Index of the four largest lakes in Pictured Rocks National Lakeshore and determined that the trophic status of Miners Lake was the highest of the four (Grand Sable, Chapel, Beaver, and Miners Lakes). The littoral zone is dominated by emergent and submerged aquatic macrophytes. There is a lamprey control dam along the river between Miners Lake and Lake Superior, and sea lamprey (*Petromyzon marinus*) spawn downstream from the dam. Annual populations of sea lamprey in the lower Miners River are monitored by the US Fish and Wildlife Service, Lamprey Control Division, headquartered in Marquette, MI annually from late May through early July with field assistance by PIRO staff. The discharge at the mouth of Miners River ranges from a minimum of $0.356 \text{ m}^3\text{sec}^{-1}$ in August to $3.030 \text{ m}^3\text{sec}^{-1}$ in April (Handy and Twenter, 1985).

Mosquito watershed is 3,418 ha in area by calculations of Handy and Twenter (1985) and 3600 ha by Michigan DNR Watershed Council digitized calculations (2000). The minimum discharge in August 1981 of the Mosquito River is $0.107 \text{ m}^3\text{sec}^{-1}$ and the maximum in early June 1979 is $1.087 \text{ m}^3\text{sec}^{-1}$ where it enters Lake Superior (Handy and Twenter, 1985). There are two major beaver ponds on each of the main tributaries, but these are the only lentic habitats in the watershed. The river flows over bedrock in several places along the stream course, including Mosquito Falls. Riffles, glides, and pools provide diverse benthic habitats.

Chapel watershed has an area of 2,188 ha according to Handy and Twenter (1985) and 2,486 ha according to Michigan DNR Watershed Council (2000). It includes Chapel Creek, Section 34 Creek, and Chapel Lake. Section 34 Creek contributes on average $0.128 \text{ m}^3\text{sec}^{-1}$ discharge into Chapel Lake (PIRO data files). Chapel Creek discharged a minimum of $0.059 \text{ m}^3\text{sec}^{-1}$ in August 1981 and a maximum of $0.609 \text{ m}^3\text{sec}^{-1}$ in April 1981 into Lake Superior (Handy and Twenter, 1985). The lake is a brown water, meromictic lake that

is 43m deep. Only the upper 18m of water turns over twice a year; the deeper water is denser and is separated by a chemocline from the overlying waters (Kamke, 1987). The lake has a surface area of 23.88 – 30.51 ha (Humphreys and Colby, 1965; Limnetics, Inc., 1970; and Kamke, 1987) with an elongated shoreline. An aquatic macrophyte listed as Threatened in Michigan, *Myriophyllum farwellii*, is present in Chapel Lake (Crispin *et al.*, 1984). Chapel Lake is also home to opossum shrimp, *Mysis relicta*, found only in a few deep, cold, oligotrophic lakes in northern states and provinces east of the Great Plains (Pennak, 1989). Bryozooan colonies are found attached to submersed logs along the steep banks of the southern basin. Freshwater mussels are present in the lake, but species diversity and age classes have not been studied to date. The northern half of the lake is ≤ 3 m deep (Kamke, 1987) and supports emergent and submersed aquatic macrophytes. The level of the lake is determined in small part by beaver dam at the north end of the lake. It appears that beavers have created dams at various locations over the centuries along the stream channel that flows through the wetland to the north of the lake. Thus, the water level and the size of the lake can vary depending on beaver activity. The deeper, southern part of the lake is probably affected only in minor ways by this activity, however.

Little Chapel watershed occupies a former glacial meltwater channel (Blewett, 1994) and is 1.4 mi² (363 ha) in area (Michigan DNR Watershed Council, 2000). Little Chapel Lake is fed by a creek from the west and drains to Lake Superior at the west end of Chapel Beach (Loope, 1998). The discharge to Lake Superior is limited, for the most part, to spring run-off. A rocky bluff on the south side of the lake testifies to the wave action during the high water level of Lake Superior (termed Lake Nipissing) approximately 6,000 BP (Farrand and Drexler, 1985). The lake occupies an area of 2.4 ha according to Humphreys and Colby (1965). Little is currently known about the lake and its watershed. In part this is due to the logistics of boat accessibility to the lake. Before Pictured Rocks National Lakeshore was established there was a road to the lake, but access has been by foot only for three decades. The only chemical and biological data are from a single set of samples collected in October 1970 by Limnetics, Inc. (1970).

Legion Lake, Section 36 Lake, and the Shoe Lakes, besides being closed basin kettle lakes with separate watersheds, are acidic ($\text{pH} \leq 5$) (Lewin, 1991). Reconstruction of pH of Legion Lake by identification of

diatom remains (frustules) in the sediments was attempted, but there were few diatoms in any of the sediment core samples. Silica levels in the lake water are low, and it is likely that diatom frustules dissolve upon death of the cell and the silica is reused for the next generation. It is unlikely, however, that the lake was anthropogenically acidified (Lewin, 1991). The 72 ha catchment of Legion Lake contains glacially derived outwash sands that are very low in cation exchange capacity (Lewin, 1991). Because Legion Lake and the other kettle lakes in the area sit high on the watershed divide, the soils of their catchment basins may have been leached of most of their base cations in the last 9,500 years. Analyses of the sediment cores from Legion Lake indicated that deposition rates of lead and sulfur since the 1880's have been abnormally high compared to other lakes in the region; copper and zinc were also deposited in higher concentrations since the 1880's (Lewin, 1991). Fish stocking of Legion Lake by the Michigan Department of Natural Resources ended in the early 1990's, and currently the chief predators are likely dragonfly (Odonata) larvae (Lewin, 1991) and predacious diving beetle (Dytiscidae) larvae (PIRO data files).

Beaver watershed area has been computed by Doepke (1972) as 2,694 ha, by Handy and Twenter (1985) as 3,962 ha, and as 3,030 ha by Michigan DNR Watershed Council (2000). It contains Little Beaver Lake (16.1 ha) and its tributaries: Arsenault Creek, Little Beaver Creek, and Bills Creek, as well as Beaver Lake (310 ha) and the East and West Branches of Lowney Creek (Doepke, 1972).

Little Beaver Lake is a brown water lake whose hypolimnion becomes anoxic in mid to late summer (Doepke, 1972; PIRO data files) and has a basin exchange time of 0.3 years (Doepke, 1972). The exotic aquatic macrophyte, *Potamogeton crispus*, was present in Little Beaver Lake in 1972 (Doepke, 1972). A Michigan Special Concern aquatic plant, *Callitriche hermaphroditica*, is found in Little Beaver Lake (Crispin, *et al.*, 1984).

Beaver Lake, however, has a basin exchange time of 2.9 years (Doepke, 1972) but its water transparency values indicate that dissolved organic carbon is much less than in Little Beaver Lake (PIRO data files). The fetch of Beaver Lake is approximately parallel to the prevailing winds. This feature, combined with its shallowness (maximum depth = 10m, mean depth = 5.6m) makes it possible for the lake to turn over even

in the summer, providing there are very strong winds. Even without significant winds the lake does not stratify completely every summer (Doepke, 1972; Boyle, 1999). An aquatic macrophyte listed as Special Concern in Michigan, *Myriophyllum alterniflorum*, is present in Beaver Lake (Crispin *et al.*, 1984). Five species of freshwater mussels are found in both Little Beaver Lake and Beaver Lake (Nichols, *et al.*, 2000). Basketball-sized freshwater sponges in Beaver Lake are unique to the lakeshore (Nichols *et al.*, 2000). Beaver Lake is also home to an exotic zooplankter called the spiny water flea (*Bythotrephes cederstroemi*), introduced sometime since 1987, and undoubtedly affecting food web dynamics among native species (Loope, 1998). Sea lamprey (*Petromyzon marinus*) move through Beaver Creek, Beaver Lake and Lowney Creek to the dam of the trout pond, built when the land was owned by the Wisconsin Gas Company as a retreat for its executives. Handy and Twenter (1985) measured the discharge of Beaver Creek in 1981, recording a minimum of $0.518 \text{ m}^3\text{sec}^{-1}$ in August and a maximum of $1.127 \text{ m}^3\text{sec}^{-1}$ in April.

Spray watershed, like most, heads in alder/willow wetlands. Its area was calculated by Handy and Twenter (1985) as 1,846 ha and by Michigan DNR Watershed Council (2000) as 1,580 ha. It flows at a low gradient 5.63 km to Spray Falls along the Pictured Rocks cliffs, where it makes a dramatic entrance into Lake Superior (Limnetics, 1970). Its discharge is very nearly the same at an upstream site as it is near Spray Falls (5 month average = $0.168 \text{ m}^3\text{sec}^{-1}$) which suggests that there is little water added to the stream along its course by groundwater seepage or very small tributaries (PIRO data files). Handy and Twenter (1985) recorded a minimum discharge of $0.096 \text{ m}^3\text{sec}^{-1}$ in August 1981 and a maximum of $0.390 \text{ m}^3\text{sec}^{-1}$ in October 1981.

Sevenmile watershed is located in Beaver Basin to the south and east of the “hardwood island”, so called because it remained above the high water level of the Nipissing stage of Lake Superior about 6,000 BP. The watershed includes Hyde Lake, Sevenmile Lake and Sevenmile Creek and comprises 2,103 ha (Handy and Twenter, 1985). For the most part the stream gradient is low. Handy and Twenter (1985) found that the discharge of Sevenmile Creek varied between a minimum of $0.439 \text{ m}^3\text{sec}^{-1}$ in August 1981 and a maximum of $0.694 \text{ m}^3\text{sec}^{-1}$ in October of the same year. The substrate of the creek is mostly sand except near the mouth when cobble/gravel and bedrock substrates are prevalent.

Kingston Lake, formed as a kettle lake in a broad, glacial outwash plain (Blewett, 1994), however, is not acidic. The surface area of the lake is 250 acres (101.2 ha) and its maximum depth is 32 feet (9.75m) (Humphreys and Colby, 1965). Four species of freshwater mussels are found in Kingston Lake (Nichols *et al.*, 2000). With a shallow, gradually sloping nearshore zone, one can notice that the lake level of Kingston Lake varies noticeably from wet to dry summers.

Twelvemile Bog is an area approximately 6 ha (Futyma, 1990) that is situated adjacent to Lake Superior less than a half a kilometer east of Twelvemile Beach Campground and Picnic Area. It is comprised of four shallow basins, some of which flow into one another during periods of high water, but itself is a closed basin. The bogs lie 40 to 50 feet above Lake Superior. Pollen analysis of a sediment core material from the bog revealed that the wetland has become increasingly acidic (peaty) since its inception following the Nipissing high water period (4,000-5,000 years before present) (Futyma, 1990). The earliest pollen indicates that sedges, grasses, and cattails were common, and as the centuries passed black spruce, tamarack, leatherleaf, Labrador tea, sedges, and Sphagnum have come to dominate the bog community (Futyma, 1990). Pines have been common on the surrounding lands continually, although the beginning of European settlement is detectable in the pollen record as white pine pollen decreased in abundance and ragweed pollen increased (Futyma, 1990).

An unnamed closed basin, dystrophic (brown water) pond between the Twelvemile Bog catchment and Sullivan Creek is approximately 6 ha in area. Its maximum depth is 2 m and a benthic algal mat lies above the unconsolidated surface sediments. Water from an adjacent cedar swamp to the east-southeast trickles into the pond at least part of the time. A beaver lodge is situated in the northeast part of the pond.

Sullivan watershed encompasses 1,885 ha (Handy and Twenter, 1985). Sullivan Creek headwaters are open beaver ponds and sedge meadows. Downstream the creek flows through mixed, old hemlock and cedar woods at a low gradient. The minimum discharge of $0.068 \text{ m}^3\text{sec}^{-1}$ was measured by in August 1981, and the maximum discharge of $0.210 \text{ m}^3\text{sec}^{-1}$ in June 1979 (Handy and Twenter, 1985).

Hurricane watershed is a low gradient stream that now flows in the opposite direction from the water that originally cut the channel as the glacier retreated. The headwater area [3,548 ha (Handy and Twenter, 1985)] is composed of open sedge meadows and alder thickets. In 1996 there were two renewed beaver dams along the course of the river; their occurrence appears variable spatially and temporally, and they provide the only standing water habitat in the watershed. Hurricane Falls is located within a few hundred meters of the mouth of the river. Limnetics, Inc. (1970) calculated the length of the river as 5.63 km. Handy and Twenter (1985) measured the discharge of Hurricane River and reported that the minimum occurred in August 1981 ($0.269 \text{ m}^3\text{sec}^{-1}$) and the maximum occurred in April 1981 ($0.844 \text{ m}^3\text{sec}^{-1}$). A three year average discharge (1994-96) of Hurricane River into Lake Superior is $0.444 \text{ m}^3\text{sec}^{-1}$ (PIRO data files). The river has considerably more sand substrate than the Mosquito River, in direct relationship to its gradient (Boyle, 1999).

The Sable watershed area has been computed by Doepke (1972) as 3,263 ha, by Handy and Twenter (1985) as 5,024 ha, and by Michigan DNR Watershed Council (2000) as 4,713 ha. The watershed consists of Grand Sable Lake, which is fed by Rhody, DeMull, and Towes Creeks, and Sable Creek. The lake has a surface area of 255 ha and discharges to Lake Superior via Sable Creek which is 3.62 km in length (Limnetics, 1970). The basin exchange time of Grand Sable Lake is 3.7 years (Doepke, 1972). A few quiet bays foster aquatic macrophyte communities that are more diverse and abundant than those along the more exposed shoreline. The aquatic macrophyte, *Callitriche hermaphroditica*, is listed as Special Concern in Michigan and is found in Grand Sable Lake (Crispin *et al.*, 1984). *Myriophyllum alterniflorum*, another aquatic macrophyte, is listed as Special Concern (Doepke, 1972). The low density and poor recruitment of mussels in Grand Sable Lake is noteworthy as well (Nichols, *et al.*, 2001). The discharge of Sable Creek was measured by Handy and Twenter (1985), and they found a minimum discharge of $0.079 \text{ m}^3\text{sec}^{-1}$ in August 1979 and a maximum of $1.246 \text{ m}^3\text{sec}^{-1}$ in April 1981. (The latter must have been a major snowmelt event.)

The following monitoring plan addresses the only the parts of the watersheds that exhibit permanent standing or flowing water.

MANAGEMENT OBJECTIVES

The Organic Act of 1916 charges the National Park Service with the responsibility to “. . . conserve the scenery and the natural and historic objects 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.”

The NPS Management Policy (NPS, 1988) further states that the NPS seeks to preserve and protect entire ecosystems, including “aquatic biological resources and the quality and quantity of surface water”.

National Park Service Natural Resources Management Guidelines (NPS, 1991) state that non-point source pollution should be included in monitoring. In addition, “consistent with the rights of others, the Park Service will maintain a continuous vigilance by observing and monitoring upstream diversions, adjacent uses, and groundwater withdrawals and their effects on the occurrence, quantity, and quality of water necessary for the continued preservation of park biota and ecosystems” and actions will be taken to protect the quality of water flowing through parks. And, “(t)he intensity of use will be regulated in certain areas and at certain times determined to be necessary based on water quality monitoring studies.” The goals of the NPS, as stated in the Natural Resources Management Guidelines (NPS, 1991) are to:

- a) eliminate human-induced impacts on aquatic habitats,
- b) limit effects and mitigate damage if impacts are unavoidable, and
- c) maintain and restore aquatic habitats to protect their ecological and aesthetic character and dependent animal and plant communities.

Two documents guide aquatic management decisions at the park level: the enabling legislation and the 1981 General Management Plan. Section 9 of the enabling legislation for Pictured Rocks National Lakeshore (Eighty-ninth Congress, 1966) states:

“The area hereinafter described in subsection (b) of this section is hereby established as an inland buffer zone in order to stabilize and protect the existing character and uses of the lands, waters, and streams, and providing for the fullest economic utilization of the renewable resources through sustained yield timber management and other resource management compatible with the purposes of this Act.”

Management Objectives from the 1981 Pictured Rocks National Lakeshore General Management Plan

(Pictured Rocks National Lakeshore, 1981) include the following:

- a) Identify and protect the significant natural and cultural features and the scenery throughout the lakeshore in such manner that they will not be diminished.
- b) Coordinate the identification and management of significant natural and cultural features of the lakeshore with the resources of the Upper Peninsula and other Great Lakes NPS areas.
- c) Manage the inland buffer zone in accordance with the legislation in order to stabilize and protect its character.
- d) Identify and monitor visitor use impacts on significant ecosystems and cultural resources, and control visitor activities so that adverse impacts on these resources will be minimized.

(The General Management Plan is currently under revision and will be finalized in 2002. It should be consulted for updates to the aforementioned Management Objectives.)

GOALS

The goal of this aquatic monitoring plan is to propose actions that aim to protect the water quality and native aquatic communities of Pictured Rocks National Lakeshore. Specifically, the plan seeks to:

1. Identify known stressors to the aquatic environments of Pictured Rocks National Lakeshore and recommend indicators that assess those stressors (Gibbs, *et al.*, 1999; Noon *et al.*, 1999).
2. Provide methods for sampling indicators of these extrinsic changes in water quality and biological communities, keeping cost-effectiveness in mind (Noon *et al.*, 1999).
3. Define statistical analyses that measure changes due to stressors and changes in status of protected, native populations (state listed species)(Gibbs, *et al.*, 1999; Noon *et al.*, 1999).
4. Determine levels of change of indicators that warrant management actions (Noon *et al.*, 1999).
5. Establish timetable for communicating results to management. [Successful monitoring plans also contain action plans to recommend to those in positions of management (Gibbs, *et al.*, 1999; Noon *et al.*, 1999). However, at least for the present, management recommendations shall not appear in this plan at the request of the Chief of Science, Pictured Rocks National Lakeshore.]

DISTURBANCES

NATURAL DISTURBANCES

Natural disturbances at Pictured Rocks National Lakeshore are the result of weather, lake level changes of Lake Superior, disease, or are related to cyclic patterns in populations. Weather disturbances may be either seasonal changes or storm events and affect water quality. Successional changes in the biota may occur following these events (Noon, *et al.*, 1999). Cyclic variations in population structure, particularly of zooplankton, are not uncommon. Not all changes to water quality and species abundances should cause concern.

Relatively high discharge occurs during and after annual snowmelt (Stottlemeyer and Rutkowski, 1990). One significant effect of this annual event is the pulse of atmospheric deposition of dissolved organic carbon (DOC), NO_3^- and SO_4^{2-} , among others (Toczydlowski and Stottlemeyer, 2001; Stottlemeyer and Rutkowski, 1990). These affect not only the stream biota but are transported to the lake(s), if existent, in the watershed. DOC is highly correlated to light transmission in lake water (Toczydlowski and Stottlemeyer, 2001). Light transmission affects primary production and how a lake stratifies in summer. Stratification determines the vertical boundaries of phytoplankton, zooplankton, and vertebrate activity.

During and immediately after heavy rainfall, the discharge values (volume of water/time) of the streams of Pictured Rocks National Lakeshore can easily double (PIRO data files). There are rainfall events, on average, every three to five years significant enough that the water level of streams rises to bankfull limits. These events scour pools, carry fine substrates downstream, and alter the dimensions and locations of riffles where cobbles and gravels are deposited, as well as alter the dimensions and locations of depositional areas of fine substrates.

High winds associated with strong storms can fell trees, especially those exposed near banks or shorelines. If a tree falls across a stream, it alters the movement of water around it, usually creating a pool downstream, followed by a glide. Incident light may be temporarily increased at the localized area of the stream, because the shading provided by the standing tree is removed. The presence of the trunk in the stream (either partly or wholly submerged) increases the habitat available for periphyton (attached algae) and for

macroinvertebrates. High winds generate strong waves that pound lake shorelines, uprooting aquatic macrophytes.

ANTHROPOGENICALLY INDUCED DISTURBANCES

Anthropogenically induced disturbances are the result of some human action and are of particular interest because they are the ones to which park management can respond (Noon, *et al.*, 1999). It is the changes that result from these disturbances that this plan seeks to identify and monitor, because they are the ones that the park has responsibility to prevent or mitigate.

The most significant extrinsic stressors to water quality of the inland waters of Pictured Rocks National Lakeshore are exotic species; atmospheric deposition of contaminants (e.g., heavy metals, organochlorides, acid deposition); and global climate change; and the sedimentation of streams and their tributaries at unpaved road crossings.

Less significant anthropogenically induced disturbances may include: water quality degradation from backcountry campgrounds and/or septic systems; point source fuel emissions from personal water craft; and the potential for unsound logging or home building practices in the IBZ to affect soil erosion, incident light, and water chemistry. These latter stressors have not been assessed, and should be considered **potential** stressors, until supporting data indicate otherwise.

Exotic Species

Exotic species pose a threat to native aquatic communities and species diversity of Pictured Rocks National Lakeshore. These species include round goby, Eurasian ruffe, white perch, three spine stickleback, sea lamprey, rusty crayfish, zebra mussel, quagga mussel, Asian clam, Daphnia lumholtzi spiny water flea, hooked water flea, Eurasian milfoil, European frog-bit, flowering rush, and purple loosestrife. The first four are not addressed in this document because fish are not part of this monitoring plan. Other exotic fish have been intentionally introduced for sport fishing purposes (e.g., coho salmon, brown trout, rainbow trout, pink salmon, and the hybrid splake). Refer to current fisheries surveys by the Biology Department, Northern Michigan University (Jill Leonard, Ph.D.); U.S. Fish and Wildlife Service, Ashland, WI (Lee

Newman and Henry Quinlan); and U. S. Geological Survey, Lake Superior Research Station, Ashland, WI (Mike Hoff); and Michigan Department of Natural Resources, District Office, Newberry, MI (Steve Scott).

Sea lamprey

Sea lamprey (*Petromyzon marinus*), a primitive cyclostome native to the Atlantic Ocean, entered Lake Superior in the early 1940's (Smith *et al.*, 1974). This non-native lamprey is a parasite on fish in its adult stage. Adult lamprey in the Great Lakes migrate into tributary streams in the late spring and early summer when the stream temperature is at least 13°C to spawn on gravel beds. Larvae (ammocetes) emerge from eggs and remain in the sand/silt stream substrate from 3-17 years before maturation, when they swim downstream to the lake (Loope, W., 1983). Spawning has been documented in Munising Falls Creek, Miners River, Beaver Creek and the tributary streams of Beaver Lake, Sevenmile Creek, Sullivans Creek, Hurricane River, and Sable Creek for several decades (Smith *et al.*, 1974). Sea lampreys have been monitored in Miners River and Beaver Creek since 1953 and in the Hurricane River since 1954. Chemical treatment with a lampricide (granular Bayer 73) began in 1958 on the Mosquito River; in 1959 on the Miners River, Beaver Creek, Sevenmile Creek and Sullivans Creek; and in 1964 on Munising Falls Creek by the U.S. Fish and Wildlife Service, Marquette, MI (Smith *et al.*, 1974). Treatment continued every 4-6 years through 1970. Sharp declines in the abundance of sea lamprey spawning migrants were noted in 1962 on Lake Superior tributaries (Smith *et al.*, 1974). A lamprey control dam was constructed on the Miners River between Miners Lake and Lake Superior at the bridge crossing in about 1977 (NPS file). Granular Bayluscide (3.2%) was applied to Beaver Lake (76 lbs.) and Little Beaver Lake (76 lbs.) in 1996. Bayluscide was last applied to Miners Lake in 1994 (NPS file). The U.S. Fish and Wildlife Service applied lampricide (TFM) to the Miners River at the bridge in Miners Basin in June 1992 and June 1998.

Rusty crayfish

Rusty crayfish (*Orconectes rusticus*) can inhabit lakes, ponds, and streams (including pools and riffles) that have rocks and/or logs as cover (Gunderson, 2000). Rusty crayfish are native to the Ohio River Basin and were probably introduced to Wisconsin about 1960 by non-resident fisherpersons using them as bait (Gunderson, 2000).

Juvenile rusty crayfish feed heavily on larval mayflies, stoneflies, midges, and side swimmers (Momot, 1984). Adults are opportunistic feeders, ingesting aquatic plants, benthic invertebrates, detritus, fish eggs, and small fish. Lodge and Lorman (1987) found that rusty crayfish feed heavily on aquatic macrophytes. This herbivory decreases species diversity of algae, protists, invertebrates, and reduces cover and food for zooplankton, young fish, including panfish and forage fish, and water fowl (Lodge and Lorman, 1987). It is estimated that because of a higher metabolic rate, rusty crayfish consume twice the food of the similar sized *Orconectes virilis*, a native crayfish (Momot, 1992).

Native crayfish often exhibit population declines due to the aggressive behavior of this exotic (Capelli, 1982). Rusty crayfish compete with juvenile game fish and forage fish for the same food, and evidence suggests that bluegill, smallmouth bass, and largemouth bass, and northern pike decline after rusty crayfish have become established (Gunderson, 2000). Gunderson (2000) also contends that some unscrupulous bait dealers may intentionally introduce this non-native crayfish into bodies of water for their own commercial bait harvest.

Zebra Mussel, Quagga Mussel, Asian Clam

Zebra mussels (*Dreissenia polymorpha*) and quagga mussels (*Dreissenia bugensis*) cause catastrophic decline of native mussels. The rapid expansion of the ranges of these two species in North America is due to their ability to grow and reproduce in a wide range of environmental conditions (Nichols, 1993). These exotic mussels up to 15mm in length are very mobile, attach to the shells of other mussel species, and interfere with activities such as feeding, respiration and burrowing (Nichols *et al.*, 2000). Adults are omnivores, feeding on algae, zooplankton, their own young, and detritus but can survive up to 11 months without food under laboratory conditions at 4°C. Reproduction begins at water temperatures of 12°C (Nichols, 1993). Larvae (veligers) are planktonic and tolerate the same temperatures as adults. The veligers settle on filamentous material before undergoing metamorphosis, and then move to a hard substrate; without the proper substrate, the veligers will die (Nichols, 1993). Recent evidence (late spring 2001) from Otter Lake at Sleeping Bear Dunes National Lakeshore, MI indicate that young adults will

attach to aquatic macrophytes and Odonate nymphs, at least in newly invaded waters (Steve Yancho, pers. comm.).

Zebra mussels are present in South Bay, commonly called Munising Bay, although it is not known whether they reproduce. Don Kinnunen of the Sea Grant (Michigan State Extension) office in Marquette, MI (pers. comm, 2001) stated that zebra mussels are found at the Kimberly-Clark coal unloading site, probably introduced by the freighter that delivers coal. Pete Lindquist, who dives in Lake Superior, said that zebra mussels were attached to the tugboat that was sunk in South Bay for the benefit of recreational divers in 1998. Before the tugboat was sunk, it was docked at the City Dock. Mr. Lindquist has checked the dock and no zebra mussels have been found on the dock in the two years since the tug was sunk. He stated that last year (2000) the sunken tug had a few living zebra mussels on it, but that most had died. He will continue to check their status (pers. comm., 2001).

Quagga mussels (*Dreissenia bugensis*) were found in the lower Great Lakes in the early 1990's and are known from Saginaw Bay. Like zebra mussels, they cause catastrophic decline of native mussels and have a lower water temperature tolerance (4 -20°C)(Snyder *et al.*, 1997). This closely related species to the zebra mussel survives on *soft* substrates and at greater depths than zebra mussels (Dermott and Kerec, 1997).

Asian clams (*Corbicula fluminea*) have been found in the Portage Canal at Houghton, MI in effluent water from Upper Peninsula Power Company (Ward and Hodgson, 1997). These freshwater bivalves grow to the size of a nickel and are yellowish-gold or light brown with thick, distinctively ridged shells. They thrive in running water with sand or gravel substrates, and are pollution intolerant (Balcom, 1994).

Daphnia lumholtzi

Daphnia lumholtzi is a zooplankter native to Africa, Asia, and Australia and was first noticed in North America in 1990 (Stockel and Charlebois, 2001). *Daphnia lumholtzi* feeds on algae and suspended detritus and have longer spines than native species of *Daphnia*. Larval and juvenile fish have difficulty consuming

it for this reason. With less predation pressure on it than on native species with smaller spines, it outcompetes native species. *Daphnia lumholtzi* populations are most abundant in mid summer when asexual reproductive rates are high and water temperatures are 20-30°C. However, females with eggs have been collected in the Illinois River at lower temperatures (3-10°C)(Stockel and Charlebois, 2001). Fish that spawn late (e.g., bass, sunfish) and whose larval and young-of-the-year stages feed when *Daphnia lumholtzi* are most abundant will most likely be affected. It is not known if the spiny water flea preys on *Daphnia lumholtzi* or not (Stockel and Charlebois, 2001). As of fall 2000, *Daphnia lumholtzi* was known to be in the Illinois River 10 miles upstream from Lake Michigan (Stockel and Charlebois, 2001).

Spiny water flea

The spiny water flea (*Bythotrephes cederstroemi*), commonly called BC, is a large zooplankter (cladoceran) native to freshwater, oligotrophic lakes of Eurasia. It was first observed in Lake Huron in 1984, in Lake Superior in 1987 (Cullis and Johnson, 1988), and in Beaver Lake in 1997. Throughout the summer females reproduce parthenogenically (cloning) and it isn't until autumn when, due to environmental conditions, males are produced. Sexual reproduction then yields resting or over-wintering eggs that are capable of withstanding desiccation and/or cold for a long period of time (Sprules *et al.*, 1990). These eggs are carried in a pouch by the female and can survive passage through the digestive tract of fish. Live bait fish, thus, are vectors for the dispersal of the spiny water flea. Over-wintering eggs lie in the sediments of a lake until conditions are suitable for hatching, and adults exhibit the ability to alter their physiology to adapt to different environmental conditions of lakes (Garton and Berg, 1990).

In Lake Michigan the presence of *Bythotrephes* was correlated to reduced abundance of three species of native zooplankters (Lehman and Caceres, 1993). In addition, due to its long spine, *Bythotrephes* is rejected as prey by small (≤ 2.5 inch) perch. By competitive advantage, this exotic reduces the palatable prey for its predators, while being unattractive as prey itself.

The vectors for introduction to new lakes are boating gear like lines (to which the barbs of the spines attach), anchors (that carry lake sediment with over-wintering eggs), and bilge water. Live fish bait, if released into a new body of water, can also carry viable eggs. The lakes that have the greatest recreational

and economic value as prime fishing lakes are also the most vulnerable to ecosystem disruption by *Bythotrephes*, because this exotic is most likely transferred by the gear and/or live bait of fisherpersons (Jarnigan, 1998).

Hooked water flea

The hooked water flea (*Cercopagis pengoi*) is native to the Caspian Sea and is very similar in size, life history, and habits to the spiny water flea, but instead of a straight caudal spine, that of the hooked water flea is curved at the end. In September 1999 it was found in Grand Traverse Bay in Lake Michigan (MacIsaac, 1999).

Eurasian watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*) is an aquatic macrophyte that was introduced to North America in the 1940's (Sea Grant, 2001). It can be spread by boats and waterbirds. In shallow water this species forms dense growth, reducing light penetration, out-competing native aquatic macrophytes and reducing biodiversity (Weeks and Andrascik, 1998).

European frogbit

European frogbit (*Hydrocharis morsus-ranae*) is a monocot in the Hydrocharitaceae family that is native to Eurasia. It escaped from cultivation in Canada in the 1930's (Daniels, 2000). It is a free-floating aquatic macrophyte with leathery, heart-shaped leaves and long roots that grows in quiet water in marshes, lakes, and rivers along banks and shorelines. Small white flowers bloom occasionally throughout the growing season. Plants form a thick mat of intertwined roots at the water's surface and can reproduce vegetatively. Currently the exotic is thriving in Lake St. Clair marshes and Detroit River (Daniels, 2000). The plant significantly reduces light penetration species diversity with its dense growth at the surface (Daniels, 2000).

Flowering rush

Flowering rush (*Botumus umbellatus*) is a plant native to Eurasia whose growth habits may be as an emergent or as a true aquatic (submersed) in the littoral regions of lakes. Its dense growth crowds out

native vegetation like *Juncus*. Flowers are pink umbels found on emergent plants about 3 feet above the water level. Stems in cross-section are triangular shaped (Michigan Sea Grant College Program).

Purple loosestrife

Purple loosestrife (*Lythrum salicaria*) is plant native to Eurasia that arrived in North America in the early 1880's (Stackpoole, 1997) and is found in the most counties of Michigan's Lower Peninsula and in some Upper Peninsula counties, including nearby Schoolcraft Co. It aggressively invades wetlands, stream edges and banks, usually growing where cattails and sedges are found. Seeds will germinate in water, but subsequent growth is greater in moist soil. Purple loosestrife out competes native plants; reduces shelter and food for native wildlife such as water fowl, frogs and toads, salamanders, and some fish with its dense growth; and impedes water flow (Stackpoole, 1997).

Atmospheric deposition of contaminants

The wind pattern in the upper mid-west Lewin circulates air from the Ohio industrial belt clockwise to Iowa and Minnesota and eastward across the Lake Superior to Ontario. These winds carry suspended particulates onto which water molecules attach. Contaminants like SO_4^{2-} , NO_3^- , copper, lead, and herbicides and pesticides fall with precipitation and are eventually carried through streams and into lake sediments (Thurman and Cromwell, 2000). In some cases, dissolved metals in the hypolimnion react with the surficial sediments. The Michigan State DNR conducted tests for the presence of mercury in lake sediments and fish tissue between 1987 and 1990. Their results showed 0.08 mg/kg Hg in the surficial sediments of Grand Sable Lake (average of Michigan lakes without municipal or industrial discharges = 0.157 mg/kg)(Michigan DNR, 1991). The level of mercury was higher than in the deeper sediments, however. Northern pike tissue from Grand Sable Lake was, on average, 0.74 mg/kg Hg, which is above the consumption advisory level of 0.5 mg/kg (Michigan DNR, 1991). Tests were conducted for a suite of other metals in the surface sediments and they all were at relatively low concentrations (Michigan DNR, 1991). Lewin (1991) examined sediment cores extracted from the sediments of Legion Lake and measured higher levels of copper, calcium, sulfur, zinc, and lead in sediments deposited since the 1880's than in older sediments.

Global Climate Change

Direct impacts of global climate change in the Great Lakes ecosystem may be increased air and water temperatures. Indirect effects of global climate change may include an increase or decrease in regional precipitation, decreased discharge of rivers, less snowfall and snowpack accumulation, higher evapo-transpiration, and a reduction in lake levels and connecting channel flows. In turn, water temperature changes affect the frequency and timing of lake turnover, amount of dissolved oxygen, and fish community composition (Mortsch and Quinn, 1996) and duration of ice on temperate lakes (Anderson, *et al.*, 1996).

Water quality degradation from backcountry campgrounds and septic systems

Backcountry use at Pictured Rocks National Lakeshore includes those who take day hikes and those who camp overnight. All add some human waste to the soil, which in the escarpment portions of the lakeshore, is a rather thin layer overlying bedrock. Backcountry statistics on human visitation are available for overnight stays and are reported in units of “people nights”. From 1976 to 1983 the number of people nights increased from 7,550 to a peak of approximately 15,000 (PIRO, 1993). Since 1983 backcountry people nights have lessened and leveled off in the 9,000 – 11,000 range (PIRO, 1996). Several backcountry campsites in Pictured Rocks National Lakeshore are located along rivers: Mosquito, Chapel, Beaver Creek, and Sevenmile. Two lesser used backcountry campgrounds, Trappers and Beaver Lake, are near lakes. Mosquito and Chapel campgrounds have outhouses provided for camper use, but the others do not. Nitrogenous waste, caffeine, and pharmaceuticals (e.g., progesterones found in birth control pills) can make their way into nearby rivers. Elevated levels of nitrogen can cause increased algal growth. Caffeine and hormones can affect the development of aquatic life. Jim Ellis of the USGS Water Quality Division in Escanaba, MI (pers. comm.) stated that caffeine and pharmaceuticals would very probably be undetectable at these sites.

Nearly all permanent or seasonal housing in the IBZ and outside the lakeshore have septic systems. (A few houses in the Munising area are on Munising water supply.) The only indication of an elevated level of a nutrient in water samples taken between 1979 – 1981 was the dissolved nitrogen measurement from

Munising Falls Creek in August of 1979, the month of lowest discharge (Handy and Twenter, 1985). The value of 0.43 mgL^{-1} is, however, below the 10 mgL^{-1} drinking water standard (U.S. Environmental Protection Agency, 2001). Samples from May and October were similar to other streams.

Water quality degradation due to fossil fuels

Motorboats, and to some extent snowmobiles, are used on Little Beaver Lake, Beaver Lake, and Grand Sable Lake. It is estimated that 10-20% of oil and gas used by two stroke engines is discharged into the environment (Weeks and Andrascik, 1998).

Leaching of soil chemicals due to erosion after logging

Mullen (1988) found that logging guidelines in the Inland Buffer Zone of Pictured Rocks National Lakeshore were sufficient in maintaining chemical water quality of the streams. He measured stream water chemistry and soil leachates both before and after logging activity in a hardwood forest along the Mosquito River and at a control station site. Selective cutting occurred to within 30 m of the river. He detected no significant differences in stream water or soil water analyses after logging.

Based on the research mentioned above, monitoring of water chemistry parameters does not need to be tied to logging activity within 30 m of streams.

Sedimentation of streams

Sedimentation of streams at Pictured Rocks National Lakeshore are predicted to come from three erosional events: after fire, after logging, and after road grading or rain at road or trail crossings. Erosion can also occur naturally in the Lakeshore, especially in the confined stream reaches where the soil is very sandy. There are places along the Miners River in Miners Basin where erosion occurs after windfall of a large tree along the stream bank. The substrate of the stream is largely sand as well, given its history during the Lake Nipissing high water level.

Undetermined and/or multiple stressors

Unionids (bivalve mussels) are filter feeders that process a large volume of water. They remove much suspended particulate matter from the water column. As primary consumers, they feed primarily on algae, bacteria, and suspended detrital particles. Freshwater mussels protect and provide a food source for the larvae of many aquatic invertebrates (Nichols and Garling, 2000). However, seventy-one percent of 270 native North American freshwater unionid species are extinct, endangered, threatened, or of special concern, and unionid relocation efforts by and large fail (Nichols and Garling, 2000). Freshwater unionids of Pictured Rocks National Lakeshore have been surveyed by Nichols *et al.* (2000). Unionids were not found in the streams and rivers, but only in certain lakes (i.e., Chapel, Little Beaver, Beaver, Trappers, Kingston, and Grand Sable Lakes). These data are needed from the following inland lakes only: Beaver Lake, Chapel Lake, Grand Sable Lake, Kingston Lake, Little Beaver Lake, and Trappers Lake. It is unknown whether unionids occur in Little Chapel Lake. Streams and rivers at PIRO are not home to unionid species (Nichols *et al.*, 2000).

Frogs and toads (anurans) are amphibians, and although some species spend part of their life cycles on land, all Michigan species require water for breeding. Leopard frog populations, for unexplained reasons, have declined in Wisconsin since 1975 (Hine *et al.*, 1981), and there is general concern in the state of Michigan about anuran populations. The Michigan Department of Natural Resources Wildlife Division established a Frog and Toad Survey in 1996. Pictured Rocks National Lakeshore established a survey route (Michigan DNR route #298), and PIRO staff from the Ranger Division and Science and Natural Resources read the 10 sites on the transect on their personal time in 1996 and 1997. Date, temperature, and wind requirements made it difficult to find appropriate dates to conduct the surveys at PIRO. The results of transect surveys were not done between 1997 and 2000, however, the survey was re-instigated in 2001, eased by the relaxed date and temperature requirements of MDNR.

MONITORING PLAN

Global ClimateChange

Pictured Rocks National Lakeshore can not by itself have a significant effect on global climate change.

However, the lakeshore can measure physical qualities of its streams and lakes that may assist in monitoring the occurrence on a larger scale.

Mortsch and Quinn (1996) identify direct and indirect parameters affecting aquatic habitats that can be monitored. They hypothesize that there will be a decrease in riverine runoff; measuring stream discharge on a regular monthly basis is feasible. Boyle et al. (1999) established upstream and downstream permanent, discharge sampling sites on the Miners, Mosquito, and Hurricane Rivers. Three years of baseline data (1994-1996) from these sites exists. Since the streams are very responsive to storm events, it is recommended that discharge data not be gathered the day of or following a significant rainfall.

A. Monitoring plan for stream discharge

1. Locations: mouths of Miners River, Mosquito River, Chapel Creek, Hurricane River, and Sable Creek. Use permanent stations and add station to Sable Creek.
2. Frequency: once monthly during the middle of the month, May through September or October. During April access may be restricted due to snowy or muddy roads and trails. Discharge is usually high at this time of year because of the pulse of snowmelt. Safety should be the first consideration with fast-flowing, high water level.
3. Materials:
 - Flowmeter (PIRO currently owns a Marsh-McBirney Model 2000 “Flo-Mate”)
 - D batteries
 - discharge datasheets on waterproof paper
 - clipboard, metric tape measure
 - 2 staffs for walking in streams
 - waders
4. Cost:
 - D batteries ~ \$4, purchase as needed
 - 2.5 lb. box Rite-in the-Rain waterproof paper @ \$20.95, purchase as needed
 - replacement 30m fiberglass, metric tape measure @ \$26.50, purchase as needed
 - Total cost: \$4 - \$50, depending on need during particular year
5. Methods: establish discharge site between Sable Falls and mouth of creek. During mid month from May – September take discharge readings with flowmeter at established downstream sites utilized in study by Boyle *et al.* (1999). Consult Marsh-McBirney, Inc. Flow-mate Model 2000 Portable Water Flowmeter Instruction Manual for operating instructions. Care should be taken to take discharge data on days when there has not been significant rain on the preceding days; if it is impractical to avoid days following rain, note recent precipitation on datasheet. Record stream edge, water depth, and water velocity readings on datasheet (see sample datasheet in Appendix C). Data will be entered into Excel worksheet in PIRO Natural Resources database in folder named Q2xxx (yyyy) and in STORET.

Mortsch and Quinn (1996) also suggest that higher water temperatures will likely result from global climate change. Late July epilimnion temperatures and epilimnial depth can be recorded for Grand Sable Lake and Beaver Lake, as well as water transparency.

B. Monitoring epilimnial development

1. Locations: Grand Sable Lake and Beaver Lake
2. Frequency: once a summer, in late July, for each lake
3. Materials:
 - Standard solutions for pH, specific conductivity
 - Dissolved oxygen membrane and KCl solution kit
 - Yellow Springs Instrument Co. (YSI) Model 6820 Sonde, 610-DM Data Logger, uploading cables to computer, and recharging cables
 - Field notebook of water proof paper
 - clipboard
 - Barometer (at lab or office) set to absolute barometric pressure
 - Bathymetric map of each lake
 - Canoe or boat with anchor and 100 ft of line
 - GPS unit (optional)
 - Thermometer
 - Secchi Disk
 - Boat
 - Personal flotation devices
 - Waders
4. Costs:
 - Rite-in-the-Rain waterproof notebooks (4.5" x 7"), as needed @ \$3.15
 - YSI dissolved oxygen membrane and KCl solution kit @ \$15, as needed
YSI, Inc.
1725 Brannum Ln.
Yellow Springs, OH 45387
Phone 1-800-897-4151
 - Dissolved Oxygen Probe. Replace every 3-4 yrs. @ \$500
 - pHydron buffer capsule kit solutions buffer preservative @ \$18.37 from Fisher Scientific, as needed
 - pH storage solution 1.3 lb. @\$8 from Ben Meadows, as needed
 - barometer (one available for use at PIRO currently)
5. Methods:
 - See that barometer is set to absolute barometric pressure. This can be done by taking the barometer to the Negaunee office of the National Weather Service. (phone: 906 475-5212). Have a meteorologist read their barometer that is set to absolute barometric pressure and set PIRO's barometer to match. The elevation at their station is several hundred feet higher than at PIRO headquarters, so setting the instrument must be done at the NOAA office.
 - Prepare standard solutions according to accompanying instructions for pH and specific conductivity
 - Recharge YSI battery for 24-48 hours using cable provided with instrument; calibrate YSI the morning of field work, entering current absolute barometric pressure

- change membrane on dissolved oxygen probe if bubble appears underneath membrane or if test readings are above 103% saturation
- calibrate other parameters as desired (pH and specific conductivity, because those data will be measured and recorded automatically with temperature and dissolved oxygen) against standard solutions
- enter absolute barometric pressure into YSI datalogger 610 DM on morning of field work. To convert inches of mercury (the unit of measurement found on most barometers) to millimeters of mercury, multiply the barometric pressure reading by 25.4. Enter this number into the datalogger and in one's field notes.
- turn on YSI 5 minutes before using instrument
- hold sonde just above water level (or in boat) and enter depth as 0 (zero)
- Establish lake file in datalogger
- Lower sonde until black ring is at surface and wait for parameters to equilibrate. On data logger press "A" for "add", then press the "enter" button. Repeat for each meter of depth. Record total site depth in field notebook from lowest reading obtained on sonde. (Note: depth calibrates the slowest of all the parameters.) Check datalogger lake file to make sure that there are data from each meter of depth before winding cable and leaving site.
- Record field observations in notebook. See sample in Appendix D.
- At office or lab, download data to YSI program on computer.
- Determine lower boundaries of epilimnion and metalimnion (depth in meters) from data, as well as Secchi disc depth and record in Excel file folder labeled with lake name.

Several decades of dates of ice-off for South Bay, commonly called Munising Bay, are available. As part of long term climate change monitoring, date of ice-off each year will be recorded. Date will be entered into Excel worksheet named Ice-off, file South Bay.

Additional ice-off data will be recorded from Grand Sable Lake, because of its accessibility in spring.

Request cooperation of Grand Marais ranger(s) for this observation. Record date of full ice-off (>90% surface area) in Excel folder named Ice-Off.

Satellite images are also available on the internet. The following website addresses may provide the resolution needed to decipher dates of ice-off on other inland lakes:

www.rap.ncar.edu/weather/satellite
www.crh.noaa.gov/mqt/index.htm
www.ssec.wisc.edu/data/index.html

To date, the pixel resolution is not great enough to determine ice-off on the small inland lakes, but the resolution may increase in time.

Water quality degradation from backcountry campgrounds and septic systems

Monitoring for nutrients (nitrogen, phosphorus) will be targeted at locations where the potential exists for detecting components of human waste from backcountry campgrounds and IBZ septic systems. Although

caffeine and pharmaceuticals can be detected in wastewater and have an affect on aquatic organisms, Jim Ellis of the U.S. Geological Survey Water Resources Division in Escanaba, MI (pers. comm., 2001) suggested that caffeine, progesterones, and steroids would likely be undetectable along the rivers of Pictured Rocks National Lakeshore.

A. Monitoring for nutrients

1. Locations: Munising Falls Creek (above falls), Miners River at H-58 road crossing, mouth of the Mosquito River, mouth of Chapel Creek, mouth of Beaver Creek, mouth of Sevenmile Creek, and Hurricane River near federal fee zone boundary.
2. Frequency: every 10 years
3. Materials
 - Contract with U.S. Geological Survey, Escanaba, MI (Jim Ellis, pers. comm.). See cost estimate below.
4. Cost estimate: \$8.2K which includes
 - 8 hrs field preparation
 - 4 days, 2 people (72 hours per diem) collecting at **9** sites
 - lab analytical costs for nutrients
 - supplies and shipping
 - quality control, quality assurance sampling and analyses
 - for an additional \$750, PIRO could receive suspended sediment analyses from 9 sites
 - for an additional \$500, PIRO could receive bacterial analyses from 9 sites
 - for an additional \$40 per site, PIRO could receive chloride analyses (indicates input from human waste and/or septic systems processing water softener chemicals)
 - for an additional \$3K, PIRO could receive trace metal analyses
 - for an additional \$150 per site, PIRO can receive caffeine analyses (likely undetectable, however)
 - possible cooperative monies (partnering incentive) available through USGS
5. Methods: U.S.G.S. standard protocols with standard, approved quality assurance and quality control protocols. Water samples are sent to U.S.G.S. national lab in Denver for analyses by field investigators. Bacterial tests done in U.S.G.S. lab in Escanaba.

Atmospheric deposition of contaminants

Monitoring for atmospheric deposition of contaminants will target copper, sulfur, lead, mercury (Lewin, 1991; Michigan DNR, 1991), and other contaminants identified by Whitman *et al.* (in prep.) that become entrained in the sediments of lakes.

1. Locations: Legion Lake, Grand Sable Lake, and Beaver Lake
2. Frequency: every 15 years
3. Materials:
 - Ekman dredge
 - Non-metal spoon
 - Glass jars supplied by contracted laboratory
 - Cooler, ice packs for field

- Boat, oars
 - Personal floatation devices
 - Cooler, ice packs for mailing, sometimes provided by contracted laboratory
 - Overnight mailing costs ~\$24 per cooler, prepared for mailing from day's sampling
4. Cost (estimates from Severn Trent Lab, Inc. Arvada, CO)
- Sediment analyses for Cu, Hg, Pb; 3 @ \$105 each = \$315
 - Sediment analyses for S; 3 @ \$22 each = \$66
 - Sediment analyses for organics vary from \$110 (organochloride pesticides), \$225 (TCL semivolatile organics), to \$550 (dioxins/furans and atrazine) for each sample

Sea Lamprey

Sea lamprey monitoring and mitigation will follow the Lamprey Control Plan, Pictured Rocks National Lakeshore (Loope, 1983), which recommends coordination with the U.S. Fish and Wildlife Service Sea Lamprey Control Division in Marquette, MI. See Appendix A. Data and analyses from the Fish and Wildlife Service that concern population estimates and trends will be filed in the office of the Supervisor, Science and Natural Resource Division.

Zebra mussel, quagga mussel, and Asian clam

The zebra mussel, quagga mussel, or Asian clam are not known to exist in any of the bodies of water within Pictured Rocks National Lakeshore, although their introduction is possible at any time. Particularly vulnerable are Grand Sable Lake, Little Beaver and Beaver Lake, because they are accessible by motor boat. Two monitoring approaches, one for adults and one for larvae, will determine presence or absence of these exotics.

Education is a major key to the prevention of exotic mussel introduction. Posters with recommendations from the Sea Grant Program for wise stewardship of lakes by boaters and fisherpersons shall be designed and placed at campground kiosks and at boat launch bulletin boards with assistance of the Interpretive Division. Every winter the park will submit an article for publication in *The Superior Wildlands*, a newspaper for visitors to the public lands of the central Upper Peninsula.

- A. Monitoring for the presence of adult zebra and quagga mussels
1. Locations: Grand Sable Lake Boat launch site, Little Beaver Lake boat launch site, channel between Little Beaver Lake and Beaver Lake where boat scrapes bottom, mouth of Miners River, mouth of Mosquito River, and mouth of Hurricane River.
 2. Frequency: monitor every month, May through September
 3. Materials: 6 bricks (approximately 2.5"x8.25"x3") and braided, nylon line (3/8"), waders

4. Cost:

- 6 bricks @ \$.40 = \$2.40 (Newberry Redi-Mix Inc., Newberry, MI)
- 100 ft. twisted 3/8" nylon line (rope) to attach bricks to dock, log, etc. @ \$.35/ft = \$35 (Denman's Hardware, Munising, MI).
- plastic kitchen jars (e.g., peanut butter jars) or zip lock bags @ \$2.60 per box
- Total cost: \$40

5. Methods: each May secure line to a brick and if possible attach to dock, foot bridge, or natural material that is immobile. Check monthly for presence of adult zebra mussels. Not all individuals have the characteristic stripes, so also look for their distinctive byssal threads (see Sea Grant Zebra Mussel Watch card). If adult zebra mussels are detected, all specimens will be collected and frozen as soon as possible to kill them, as zebra mussels can live outside water for days. Examine soft substrate for quagga mussels.

B. Monitoring for larval (veliger) zebra and quagga mussels

1. Locations: Grand Sable Lake and Beaver Lake. Choose 3 locations at each lake where the water depth is greater than 18 ft. (5.5 m)(Great Lakes Sea Grant Network, 1996).
2. Frequency: For Beaver Lake collect water samples twice a summer, first between June 20-30 and second between July 15-25. For Grand Sable Lake collect water samples twice a summer, first between July 1-10 and second between July 25-August 5 (Great Lakes Sea Grant Network, 1996).

3. Materials:

- laminate a copy of the bathymetric map of each lake @ \$1 each = \$2
- zebra mussel veliger sampling kit assembled by Michigan Sea Grant Program. Free.
- 2 – 10 fl. oz. jars of isopropyl alcohol @ \$1 = \$2, annually
- cooler, ice pacs (already owned), and quart sized plastic zip lock bags @ \$2.50
- Tape for sealing sample jars, postage and handling costs of mailing 4 samples annually @ ~\$5 = \$20.
- Total cost: \$27

4. Methods:

- follow protocols provided by the Great Lakes Sea Grant Network (1996). See below. Preserve in isopropyl alcohol.
- Mail filtered water samples. Pay attention to instructions for mailing hazardous materials (flammable alcohol). Send samples and map of each lake to :
Sea Grant Citizen ZM Monitoring Program
Michigan Sea Grant
334 Natural Resources Bldg.
Michigan State University
East Lansing, MI 48824-1222
- Or examine samples in-house using microscope with magnification of 40x-100x, using the taxonomic key for larvae identification by Nichols and Black (1994).

C. Prevention of their spread by National Park Service personnel. See decontamination protocols in Appendix B.

Undetermined and/or multiple stressors

Unionid mussels

Toxin contamination/accumulation should be monitored because of the filter feeding activity of mussels.

Monitoring schedule: every 10 years in Beaver, Little Beaver, and Kingston Lakes. If otter populations increase in Beaver Lake, then unionid monitoring should follow as soon as possible (Nichols *et al.*, 2000).

Chapel recommendations not determined yet (Nichols, 2000).

Decontamination procedures should be followed by research crews when moving between lakes (see Appendix B).

Anurans

Frog and toad populations should continue to be monitored along the established Michigan DNR route #298. The US Geological Survey North American Amphibian Monitoring Program (NAAMP) has begun implementation of nationwide survey standards. Although the methods differ slightly from the MDNR survey methods, Pictured Rocks National Lakeshore will follow the new guidelines in 2002.

- A. Locations: Transect Route #298 includes a total of 10 sites:
 - #1) Sand Point Road where spring comes out of bluff;
 - #2) southernmost point of boardwalk;
 - #3) trail bridge at base of bluff at Sand Point;
 - #4) 100 m in on the Becker Road from H-58;
 - #5) maintenance complex;
 - #6) along Miners Castle Road at creek crossing before the turnoff to Miners Falls Road;
 - #7) Miners Castle parking lot;
 - #8) Miners River near lamprey control dam;
 - #9) east end of Miners Beach; and
 - #10) along H-58 near the intersection with Indiantown Road, where the road crosses the headwaters of the Miners River.
- B. Frequency: transect is “read” 3 times on 3 days as follows:
 - 1. April or May when late evening temperature is above 45°F and wind speed is less than 8 mph
 - 2. May or June when late evening temperature is above 55°F and wind speed is less than 8 mph
 - 3. June or July when late evening temperature is above 65°F and wind speed is less than 8 mph
- C. Materials
 - 1. Standard frog and toad survey forms provided by MDNR. Free
 - 2. Tape recording of frog and toad calls. \$8 each for additional copies. Available from

MDNR Wildlife Division
Natural Heritage Program
PO Box 30180
Lansing, MI 48909
- 3. Hours: 1 person @ 2.5 hours per survey X 3 surveys = 7.5 nighttime hours
- D. Methods
 - 1. Conduct surveys after dark according to date, temperature, and wind categories.
 - 2. Stops must always start with site #1 and continue in numerical order.
 - 3. Record Sky Code for beginning and ending of survey.
 - a. Sky Code 0: clear or a few clouds.
 - b. Sky Code 1: partly cloudy or variable.
 - c. Sky Code 2: drizzle
 - 4. Record Wind Code for beginning and ending of survey.
 - a. Wind Code 0: less than 1 mph. Smoke rises vertically.
 - b. Wind Code 1: 1-3 mph. Wind direction shown by smoke drift.
 - c. Wind Code 2: 4-7 mph. Wind felt on face; leaves rustle.

- d. Wind Code 3: 8-12 mph. Leaves and small twigs in constant motion; wind extends light flag.
- e. Wind Code 4: 13-18 mph. Raises dust and loose paper; small branches are moved.
- 5. Listen for 5 minutes at each site and record a call index of 1, 2, or 3.
 - a. Call Index 1: individuals can be counted, there is space between calls.
 - b. Call Index 2: calls of individuals can be distinguished but there is some overlapping of calls (intermediate between “1” and “3”).
 - c. Call Index 3: Full chorus. Calls are constant, continuous, and overlapping.
- 6. Air temperature must be recorded at each site.
- 7. Only one observer per datasheet is allowed – a second observer can submit data on the same route and it will be used for observer variation studies.
- 8. After third transect is run, photocopy field data sheet for park file. Enter data into EXCEL spreadsheet for anuran surveys, and send original paper copy to Lori Sargent at MDNR at address listed above.

Aquatic Macrophytes

There will be two purposes for monitoring aquatic macrophytes at Pictured Rocks National Lakeshore: to search for the presence of exotic macrophytes and to determine the status of three Michigan threatened and special concern species.

Three species of aquatic macrophytes have been found in the inland waters of Pictured Rocks National Lakeshore. *Myriophyllum alterniflorum* is known from Beaver Lake, *Myriophyllum farwellii* is known from Chapel Lake, and *Callitriche hermaphroditica* is known from Little Beaver Lake and Grand Sable Lake (Crispin *et al.*, 1984).

- A. Monitor presence of state listed aquatic macrophytes
 - 1. Locations: Beaver Lake, Little Beaver Lake and Grand Sable Lake. See Appendix E for maps that indicate the locations of these populations.
 - 2. Frequency: Annually in August every 5 years
 - 3. Materials:
 - Voss, E. G. 1972, 1985, and 1996 volumes of *Michigan Flora*
 - Fassett, N. C. 1957. A manual of aquatic plants. With revision appendix by E. C. Ogden. University of Wisconsin Press. 405pp.
 - Waders
 - Canoe, paddles, personal flotation devices
 - Diving mask @ ~\$20
 - Quadrat, 1x1m, constructed of buoyant material, 1@ ~\$30
 - Plant press, newspapers, blotter paper for pressing specimens
 - 4. Cost: ~\$50
 - 5. Methods:
 - Search areas identified on maps prepared by Crispin *et al.*, 1984) in Appendix E
 - When located, determine UTM coordinates with GPS unit

- Establish permanent plot by triangulation from natural markers on land and by noting UTM coordinates and water depth.
 - Establish five 1 x 1 m quadrats at each site on the maps in Appendix E in which the listed plant is growing
 - Within each quadrat identify species and percent cover. In water to deep too wade, gather data from canoe using diving mask for better visibility. Record taxa present in very small amounts as 0.5%. Cover estimates may exceed 100% because plants may occupy different strata (Meeker and Wilcox, 1989).
 - Set aside field time to search for other populations of these state listed species.
- B. Monitoring for non-native aquatic macrophytes
1. Locations: Little Beaver Lake, Beaver Lake, the channel between the two, Grand Sable Lake, and hiking trails to Mosquito River, Mosquito Falls, and Chapel Beach.
 2. Frequency: annually in late July, August, and September
 3. Materials
 - Plastic garbage bags
 - Collapsible shovel, net for floating aquatics
 - Various Sea Grant publications distributed widely for the identification of non-native aquatic macrophytes.
 4. Cost: none
 5. Methods:
 - search highly traveled areas like moist trail side areas, as well as boat launch areas, waters downwind of them and popular nearshore fishing areas
 - take all of plant, being careful to gather all of root and not to spread seeds.

Spiny water flea

Bythotrephes cederstroemi presence is known to affect zooplankton community composition once introduced to a new body of water (Lehman, 1991; Lehman and Caceres, 1993; Lehman and Branstrator, 1995). Zooplankton populations of Beaver Lake shall be monitored to determine the presence and date of emergence of this exotic.

Location: Beaver Lake and any other lake found to have an exotic zooplankter

1. Frequency; every month, May to September
2. Materials and cost:
 - Compound microscope, magnification up to 100x @ ~ \$1,500
 - Hensen-Stempel pipette @ \$53 from Wildco.
 - Sedgwick-Rafter cell @ \$68 from Wildco and cover slip
 - Standard microscope slides and cover slips, \$26.52 + \$15.32 = \$41.84

Management action: Each year post signs both facing the water and the access drive that remind fisherpersons to leave unused bait on shore, and to check bilge areas and lines for *Bythotrephes cederstroemi* and *Cercopagis pengoi*.

Sedimentation of streams

Alternative 1: Baseline sedimentation rates can be collected by U.S. Geological Survey Water Resources Division in conjunction with sampling for nutrients (see above).

1. Locations: Miners River within Miners Basin lamprey control dam and foot bridge near the mouth and Beaver Creek between Beaver Lake and Lake Superior.
2. Frequency: once for baseline data, thereafter only after fire in Miners Basin or near Beaver Creek.
3. Materials: U.S. Geological Survey equipment. Results reported in mgL⁻¹.
4. Cost: \$750 for nine sites when other water quality work is being done.
5. Methods: U.S.G.S. standard protocols.

Alternative 2: Conduct Wolman pebble counts at sites specified in Boyle *et al.* (1999).

Bibliography

- American Public Health Association (APHA). 1989. Standard methods for the examination of water and wastewater. Greenberg, A.E., ed. American Public Health Association, Washington, D.C.
- Anderson, W. L., D. M. Robertson, and J. J. Magnuson. 1996. Evidence of recent warming and El Niño-related variations in ice breakup of Wisconsin lakes. *Limnol. Oceanogr.* 41(5):815-821.
- Balcom, N. C. 1994. Aquatic immigrants of the northeast, No. 4: Asian clam, *Corbicula fluminea*. Connecticut Sea Grant College Program. 1pp.
- Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish. Second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.
- Barnhisel, D. R. 1991. Zooplankton spine induces aversion in small fish predators. *Oecologia* 88:444-450.
- Blewett, W. L. 1994. Late Wisconsin history of Pictured Rocks National Lakeshore and vicinity. Pictured Rocks Resource Report PIRO 94-01. Pictured Rocks National Lakeshore, Munising, MI. 8pp.
- Boyle, T. P., R. G. Waltermire, and G. W. Gustina. 1999. Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: An ecologically based inventory and estimation of the effects of land use practices. Mid-continent Ecological Science Center, USGS-BRD, Fort Collins, CO. 45 pp + appendices.
- Bricker, O. P. and M. A. Ruggiero. 1998. Toward a national program for monitoring environmental resources. *Ecol. Appl.* 8(2):326-329.
- Carey, L. M. 1993. Soil Survey of Pictured Rocks National Lakeshore. U.S. Department of Agriculture, Soil Conservation Service. Marquette, MI. 182pp + appendices.

- Capelli, G. M. 1982. Displacement of northern Wisconsin crayfish by *Orconectes rusticus*. *Limnol. Oceanogr.* 27:741-745.
- Crispin, S. R., V. L. Dunevitz, D. Katz, and K. A. Chapman. 1984. A survey for endangered, threatened, and special concern plant species in Pictured Rocks National Lakeshore, Michigan. Michigan Natural Features Inventory. Lansing, MI. 9pp. + appendices.
- Cullis, K. I. and G. E. Johnson. 1988. First evidence of the cladoceran *Bythotrephes cederstroemi* Schoedler in Lake Superior. *J. Great Lakes Res.* 14:524-525.
- Daniels, J. 2000. European frogbit: What is it? Should we be worried? Michigan Sea Grant College Program. *Upwellings* 22(4).
- Dermott, R. and D. Kerec. 1997. Changes to the deepwater benthos of eastern Lake Erie since the invasion of *Dreissena*: 1979-1993. *Can. J. Fish. Aquat. Sci.* 54:922-930.
- Doepke, P. A. 1972. Alger County lakes study. Report to local agencies. Northern Michigan University. Marquette, MI. 68 pp.
- Ellis, J. 2001. Personal communication. U.S. Geological Survey, Water Resources Division. Escanaba, MI.
- Eighty-ninth Congress, U.S. House of Representatives 8678. 1966. Public Law 89-668: An Act to establish in the State of Michigan the Pictured Rocks National Lakeshore, and for other purposes. October 15, 1966. GPO 65-139. 4pp.
- Farrand, W. R. and C. W. Drexler. 1985. Late Wisconsinan and Holocene history of the Lake Superior Basin. In Carrow, T. F. and T. E. Calkin, eds. Quaternary evolution of the Great Lakes. Geological Association of Canada Special Paper No. 30.
- Futyma, R. P. 1990?. Fossil Pollen Stratigraphy of Twelvemile Bog, Pictured Rocks National Lakeshore, Michigan. Biological Survey, New York State Museum. Albany, NY. 7pp. + appendix.
- Garton, D. W. and D. J. Berg. 1990. Occurrence of *Bythotrephes cederstroemi* (Schoedler 1877) in Lake Superior, with evidence of demographic variation within the Great Lakes. *J. Great Lakes Res.* 16(1):148-152.
- Gibbs, J. P., H L. Snell, and C. E. Causton. 1999. Effective monitoring for adaptive wildlife management: Jassby, A. D. and T. M. Powell. 1990. Detecting changes in ecological time series. *Ecology* 71(6):2044-2052.
- Great Lakes Sea Grant Network. 1996. Detecting Zebra Mussels: Monitoring Procedures for Citizens and Sample Timing. Michigan State University Extension. Lansing, MI. 12 pp.
- Gruhn, W. 1976. The Trout Streams of Michigan No. 24: The Miners River. Michigan Department of Natural Resources, Fisheries Division. Tech. Report No. 76-11. 3pp.
- Gunderson, J. 2000. Rusty crayfish factsheet. Minnesota Sea Grant, University of Minnesota. Minneapolis, MN. <http://www.seagrants.mn.edu/exotics/rusty.html>
- Handy, A. H. and F. R. Twenter. 1985. Water resources of Pictured Rocks National Lakeshore, Michigan. U.S. Geological Survey, Water-Resources Investigations Report 85-4103. Lansing, MI. 41pp.
- Hine, R.L., B. L. Les, and B. R. Hellmich. 1981. Leopard frog populations and mortality in Wisconsin. Wisconsin Department of Natural Resources Tech. Bull. No. 122. 39pp.

- Hughes, J. D. 1968. Unpublished materials for the section on geology of Pictured Rocks National Lakeshore Master Plan. 8pp.
- Humphreys, C. R. and J. Colby. 1965. Michigan lakes and ponds: Agricultural Experiment Station, Michigan State University. Lansing, MI.
- Jarnigan, S. T. 1998. Direct and indirect estimates of death rates and predator-mediated dispersal of *Bythotrephes cederstroemi*. Ph.D. dissertation in Biological Sciences. Michigan Technological University. Houghton, MI. 155pp.
- Jassby, A. D. and T. M. Powell. 1990. Detecting changes in ecological time series. *Ecology* 71(6):2044-2052.
- Kamke, K. K. 1987. Limnology of our lakes in Pictured Rocks National Lakeshore. M.S. thesis. University of Wisconsin-Stevens Point. 153 pp.
- Kinnunen, R. E. 2001. Personal communication. March 29, 2001. Michigan State University Extension District Sea Grant Agent. Marquette, MI.
- Lehman, J. T. 1991. Causes and consequences of cladoceran dynamics in Lake Michigan: implications of species invasion by *Bythotrephes*. *J. Great Lakes Res.* 17(4):437-445.
- Lehman, J. T. and D. K. Branstrator. 1995. A model for growth, development, and diet selection by the invertebrate predator *Bythotrephes cederstroemi*. *J. Great Lakes Res.* 21(4):610-619.
- Lehman, J. T. and C. E. Caceres. 1993. Food-web responses to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan. *Limnol. and Oceanogr.* 38(4):879-891.
- Lewin, J. C. 1991. Acidification mechanisms in a small, clear-water, low pH seepage lake, Upper Peninsula of Michigan. M.S. thesis. Michigan Technological University. 100 pp.
- Lindquist, P. 2001. Personal conversation. April 3, 2001. Munising, MI.
- Limnetics, Inc. 1970. A preliminary survey of the environmental quality of the Pictured Rocks National Lakeshore and Recreational Area, Alger County, Michigan. Limnetics, Inc., Milwaukee, WI. 131 pp + appendices.
- Loope, L. M. 1998. A review of the limnology of six small inland lakes in Pictured Rocks National Lakeshore. Report to the agency. Munising, MI. 74pp. + appendices.
- Loope, W. L., J. B. Anderton, T. G. Fisher, H. M. Joll, and W. L. Blewett. 2001. Landscape-level impacts of late Holocene lake level change along the southeastern shore of Lake Superior. Annual meeting of the North Central Section, Geological Society of America, Abstracts and Program 33(4):A11.
- Loope, W. L. 1983. Lamprey Control Plan, Pictured Rocks National Lakeshore. Agency document. Pictured Rocks National Lakeshore. Munising, MI. 8pp.
- MacIsaac, H. 1999. <http://www.greatlakes.net/lists/glin-announce/1999-09/msg00023.html>
- Meeker, J. E. and D. A. Wilcox. 1989. Comparison of aquatic macrophyte communities in regulated and unregulated lakes, Voyageurs National Park and Boundary Water Canoe Area, Minnesota. Research/Resources Management Report MWR-16, National Park Service, Omaha, NE, and contribution 739 of the National Fisheries Research Center - Great Lakes, Ann Arbor, MI. 39pp.
- Meeker, J. E. 2000. Personal communication 07/24/2000. Northland College, Ashland, WI.

- Michigan Department of Natural Resources. 1976. Draft Memorandum of Understanding between the National Park Service and the Michigan Department of Natural Resources to Construct a Sea Lamprey Barrier and Fish Passage Facility on the Miners River, Alger County. Lansing, MI. 22pp.
- Michigan DNR, Surface Water Quality Division. 1991. Assessment of mercury contamination in selected Michigan Lakes, 1987-1990: Historical trends, environmental correlates, and potential sources. Lansing, MI. 18pp. + appendices.
- Michigan DNR Watershed Council. 2000. Geographic Information Systems database. Lansing, MI.
- Michigan Sea Grant College Program. A field guide to aquatic exotic plants and animals. Lansing, MI. 4pp.
- Momot, W. T. 1984. Crayfish production: a reflection of community energetics. *J. Crustacean Biol.* 4:35-54.
- Mortsch, L. D. and R. H. Quinn. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies. *Limnol. and Oceanogr.* 41(5):903-911.
- Mulder, B. S.; B. R. Noon; T. A. Spies; M. G. Raphael; C. J. Palmer; A. R. Olsen; G. H. Reeves; and H. H. Welch. 1999. The strategy and design of the effectiveness monitoring program for the northwest forest plan. U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-437. Portland, OR. 48pp.
- Mullen, Gregory. 1988. An evaluation of standard timber harvest practices on stream dynamics in the Pictured Rocks National Lakeshore Inland Buffer Zone. Thesis for Master of Science degree. Department of Forestry. Michigan Technological University, Houghton, MI. 46pp + appendix.
- National Park Service, Pictured Rocks National Lakeshore file entitled "Exotic Species: Sea Lamprey" contains letters and reports from the Michigan DNR and U.S. Fish and Wildlife Service about sea lamprey management at Pictured Rocks National Lakeshore. PIRO Headquarters, Munising, MI.
- National Park Service. 1988. Management Policies. Office of Policy, NPS. Washington, D. C.
- National Park Service. 1991. Natural Resources Management Guidelines. NPS-77. Washington, D.C. 609pp + appendices.
- Nichols, S. J. 1993. Appendix A: Life history and ecological requirements of the Zebra Mussel – North American Experience through 1992. *In: Reid, D. F. et al. Zebra-Mussel-Specific Containment Protocols.* NOAA Great Lakes Environmental Research Laboratory Contribution No. 890. http://www.nsgo.seagrant.org/research/nonindigenous/Zebra_Mussel_Research_Protocol.html. p. 24-27.
- Nichols, S. J. and M. G. Black. 1994. Identification of larvae: the zebra mussel (*Dreissena polymorpha*), quagga mussel (*Dreissena rostriformis bugensis*), and Asian clam (*Corbicula fluminea*). *Can. J. Zool.* 72:406-417.
- Nichols, S. J.; E. Crawford; J. Amberg; G. Kennedy; G. Black; J. Allen. 2000. Status of freshwater unionid populations at Pictured Rocks National Lakeshore– 1999-2000 (DRAFT). Report to the agency. U.S. Geological Survey, Great Lakes Science Center. Ann Arbor, MI. 55pp. + appendices.
- Nichols, S. J. and D. Garling. 2000. Food-web dynamics and trophic-level interactions in a multispecies community of freshwater unionids. *Can. J. Zool.* 78:871-882.
- Noon, B. R. T. A. Spies, and M. G. Raphael. 1999. Conceptual Basis for Designing an Effectiveness Monitoring Program. pp 21-48. *In: Mulder, B. S., B. R. Noon, T. A. Spies, M. G. Raphael, C. J. Palmer,*

- A. R. Olsen, G. H. Reeves, and H. H. Welsh. 1999 The strategy and design of the effectiveness monitoring program for the northwest forest plan. General Technical Report PNW-GTR-437. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.
- Pennak, R. W. 1989. Fresh-water Invertebrates of the United States, 3rd Ed. John Wiley & Sons, Inc. New York, NY. 628pp.
- Pictured Rocks National Lakeshore. 1981. General Management Plan. Denver Service Center, National Park Service, Denver, CO. NPS 1711A. 79pp.
- Pictured Rocks National Lakeshore. 1993. Backcountry management plan - Pictured Rocks National Lakeshore. Munising, MI.
- Pictured Rocks National Lakeshore. 1996. Statement for management - Pictured Rocks National Lakeshore - 1996. Munising, MI. 33pp.
- Pictured Rocks National Lakeshore. Various dates. Data files. Munising, MI.
- Reid, D. F., J. Bidwell, J. Carlton, L. Johnson, E. Marsden, and S. J. Nichols. 1993. Zebra-Mussel-Specific Containment Protocols. NOAA Great Lakes Environmental Research Laboratory Contribution No. 890. http://www.nsgo.seagrant.org/research/nonindigenous/Zebra_Mussel_Research_Protocol.html. 24pp. + appendix.
- Sea Grant Minnesota website. 2001. <http://www.seagrant.umn.edu/exotics>
- Smith, B. R., J. J. Tibbles, and B. G. H. Johnson. 1974. Control of the Sea Lamprey (*Petromyzon marinus*) in Lake Superior, 1953-1970. Technical Report No. 26. Great Lakes Fishery Commission. Ann Arbor, MI. 60pp.
- Snyder, F. L., M. B. Hilgendorf, and D. W. Garton. 1997. Zebra mussels in North America. OHSU-FS-045. Ohio Sea Grant College Program. 4pp.
- Stackpoole, S. 1997. Purple loosestrife in Michigan. Bulletin E-2632, Michigan Sea Grant. MICHU-SG-97-501. 6pp.
- Sprules, W. G.; H. P. Riessen; and E. H. Jin. 1990. Dynamics of the *Bythotrephes* invasion of the St. Lawrence Great Lakes. J. Great Lakes Res. 16(3):346-351.
- Stockel, J. A. and P. M. Charlebois. 2001. *Daphnia lumholtzi*: The next Great Lakes Exotic? Illinois-Indiana Sea Grant College Program, Illinois Natural History Survey, Dept. of Nat. Res. And Env. Sci. UIUC. <http://www.miseagrant.org/pubs/online/msg99-500.html>
- Stottlmyer, R. and D. Rutkowski. 1990. Multi-year trends in snowpack ion accumulation and loss, Northern Michigan. Water Resources Research 26(4):721-737.
- Stow, C. A.; S. R. Carpenter; K. E. Webster and T. M. Frost. 1998. Long-term environmental monitoring: some perspectives from lakes. Ecol. Appl. 8(2):269-276.
- Thurman, E. M. and A. E. Cromwell. 2000. Atmospheric transport, deposition, and fate of triazine herbicides and their metabolites in pristine areas at Isle Royale National Park. Environm. Sci. and Techn. 34:3079-3085.
- Toczydlowski, D. and R. Stottlmyer. 2001. Factors affecting nitrogen budget in a boreal ecosystem, Isle Royale National Park (abstr.). Lake Superior Parks Research Conference. March 27-28, 2001. Michigan Technological University. Houghton, MI.

U.S. Environmental Protection Agency. 2001. Current drinking water standards.
<http://www.epa.gov/safewater/mcl.html>

Ward, J. L. and J. R. Hodgson. 1997. The presence of the Asian clam *Corbicula sp.*, from Lake Superior. J. Freshwater Ecol. 12(1):167-169.

Weeks, D. P. and R. J. Andrascik. 1998. Voyageurs National Park, Minnesota, Water Resources Scoping Report. Technical Report NPS/NRWRS/NRTR-98/201. Water Resources Division, National Park Service, Department of the Interior. Denver, CO. 51pp.

Yancho, Steve. 2001. Morning Report, Ranger Bulletin Board. National Park Service CC:Mail. 15 June 2001.

Additional References relating to aquatic environments (updated March 2004)

Armichardy, D. and J. B. K. Leonard. 2002. Beaver Basin fish survey report – 2001. Northern Michigan University. Marquette, MI. 25 + figures.

Armichardy, D. and J. B. K. Leonard. 2003. Seasonal movements of resident and Lake Superior anadromous fishes in the Beaver Lakes basin, Pictured Rocks National Lakeshore, MI, USA. Northern Michigan University. Marquette, MI. 10pp.

Glime, J. M. 2002. Bryophytes of the Pictured Rocks National Lakeshore, Alger Co., Michigan. Michigan Botanist 41(2):31-45.

Newman, L. 2003. Inventory of nearshore fish and mud puppy (Amphibian) in Lake Superior, Pictured Rocks National Lakeshore. US Fish and Wildlife Service. Ashland, WI. 15pp + appendices.

Newman, L. E.; R. B. DeBois; and T. N. Halpern. 2003. A brook trout rehabilitation plan for Lake Superior. In fish-community objectives for Lake Superior. 2003-03 Misc. Publ. Great Lakes Fisheries Commission. www.glfc.org/pubs/SpecialPubs/Sp03_1.pdf (as of 11/13/2003).

Nichols, S. J.; E. Crawford; J. Amberg; G. Kennedy; G. Black; J. Allen. 2002. Status of freshwater Unionid populations at Pictured Rocks National Lakeshore – 1999-2000. US Geological Survey, Great Lakes Science Center. Ann Arbor, MI. 153pp.

Schwenner, C. 2003. Soil Survey of Alger County, Michigan, Interim Report - May 2003. Vol. 1-3. Natural Resources Conservation Service. Marquette, MI.