# Chapter 6
# Status of Aquatic and Terrestrial Communities and Habitat in the Lake Superior Basin

Lake Superior Lakewide Management Plan
2006

**Table of Contents**

**LIST OF FIGURES**

**LIST OF TABLES**

## I. MISSION, PRINCIPLES AND GOALS

This chapter represents the integration of four chapters from the 2000 Lakewide Management Plan for Lake Superior (LaMP 2000). Those chapters were the Habitat Chapter (formerly Chapter 6), Terrestrial Wildlife Chapter (formerly Chapter 7), Aquatics Chapter (formerly Chapter 8), and Exotic Species Chapter (formerly Chapter 10). These four chapters were integrated to produce this current version, because discussing Lake Superior's resources and basin in four separate places did not acknowledge the integrated ecosystems of the region. This chapter describes these interconnected ecosystems in an integrated way and will contribute to sustainability throughout the region.

When producing a management plan, it is important to start with a vision of the future. Statements regarding the direction of management must be articulated and used to guide the plan. This is particularly true when dealing with ecosystem resources. The Lake Superior vision statement can be found in Chapter 1 of this document, and it articulates a future direction in a very broad based manner. Another statement of future direction from a more resource-oriented perspective can be found in the Ecosystems Mission statement:

### MISSION

*A mission of the Lake Superior Binational Program is to support intact, diverse, healthy, and sustainable ecosystems and the native plant and animal communities that depend upon them.*
When reading this statement, the sense of a "healthy ecosystem" stands out. In fact, in Chapter 1 of the LaMP 2000, a series of objectives is put forth by the various committees of the Lake Superior Work Group. Both the Wildlife and the Aquatics committees reference "healthy ecosystems" in these statements of objectives. This raises the question: what is meant by "healthy ecosystems?"

### Healthy Ecosystems

Ecosystems are comprised of biotic and abiotic components, which interact to support diverse and sustainable communities of plants and animals. Healthy ecosystems are recognized as containing a full complement of species living within them and supporting all the processes that connect the living and non-living portions of the system. It is also important to recognize the role of humans in healthy ecosystems. Humans can have a positive role in the functioning of ecosystems, and they can have a detrimental role. Healthy ecosystems must include benefits that humans can bring to an ecosystem while minimizing detriments.

### Natural Processes Found in a Healthy Ecosystem

For an ecosystem to be considered healthy, the following natural processes must be present and function well:

- Energy flow to all trophic levels historically found in the habitat.
- Nutrients cycle throughout the ecosystem using appropriate pathways.
- Natural disturbances (e.g., fire, wind throw, and floods) take place at appropriate frequencies and over appropriate areas.
- Plant and animal communities are comprised of diverse, native species.
- All indigenous species are present, or, if not present, the habitat exists to rehabilitate or restore extirpated species.
- Native fish, wildlife, and wild plants produce young to result in sustainable populations and remain genetically viable.

- Predator and prey interactions are intact and in balance over the long-term.
- Populations of plants and animals fluctuate in natural cycles relative to one another.
- No populations are so abundant that they impact other populations in a negative, long-term manner.

**Human-Induced Processes**

Human-caused stresses must be managed to recreate a healthy terrestrial wildlife community. Just as some processes must be present in healthy ecosystems, some processes must be eliminated or minimized to ensure that ecosystems remain healthy or can be restored to a healthy state.

- Contaminant levels in plants and animals are sufficiently low so they do not negatively affect the life cycles of species, nor do they negatively affect human health.
- Exotic species of plants and animals, especially those that are harmful or invasive, are either eliminated or are reduced to the point that biodiversity of the native community is not impaired.
- Species of concern, especially threatened or endangered species, are recovered and are no longer in jeopardy.
- Human uses of our natural resources, including timber harvest, agriculture, recreation, mineral extraction, fish and wildlife harvest, energy generation and use, and construction of new dwellings and transportation systems, are done in an ecologically sustainable manner.
- Management practices mimic natural disturbance or are not outside of the range of natural variation of disturbance regimes.

The integrated ecosystem chapter was written from this perspective of healthy ecosystems. The authors used the following principles to guide our writing. As we described the characteristics of the Lake Superior basin and the status and trends of the resources living there, we considered the following principles. The reader will see that many of the notions of healthy ecosystems, both from a natural and anthropogenic perspective, are restated in these principles.

**PRINCIPLES**

- Healthy ecosystems support self-regulating communities comprised of naturally reproducing indigenous species, habitat upon which these species depend, and provide sustainable benefits to society.
- A holistic, ecosystem-based approach is critical to the protection and management of the Lake Superior basin.
- The aquatic environment is interconnected with the wetland, riparian, and terrestrial environments of the Lake Superior basin.
- Native species maintained by natural reproduction provide the greatest potential for sustainability.
- Chemical contamination of fish and wildlife impairs natural reproduction and benefits to society.
- Prevention of additional species introductions and control of existing non-indigenous species will facilitate restoration of a healthy ecosystem.
- An intact ecosystem is resilient and does not require management intervention.

In order to achieve our vision of Lake Superior and in order to preserve, protect, and enhance healthy, sustainable ecosystems, the following goals were established. In many ways, these goals describe the elements we wish to accomplish in the coming years. We believe that if we accomplish these elements, we will achieve the overall vision of Lake Superior.

**GOALS**

- Diverse and healthy native plant and animal communities exist in the Lake Superior basin.
- A program is in place to monitor the abundance, distribution, and health of plant and animal populations and communities in the Lake Superior basin.
- Species at risk or species of concern are recovered if populations are too low, or controlled if populations are too large.
- A system of representative, high-quality habitats is established and these areas are protected.
- No further extirpation of native species occurs in the Lake Superior basin.
- No non-native species will be introduced into the Lake Superior basin.
- An interagency effort to restore and protect critical habitats will be organized and initiated.
- Partnerships among natural resources management agencies, environmental agencies, and non-agency stakeholders are strengthened and broadened.

# II. CHARACTERISTICS OF THE LAKE SUPERIOR BASIN

## 1. PHYSICAL ENVIRONMENT

### 1.1 Geology and Glacial History

**Geology**

Most of the Lake Superior basin is underlain by the Precambrian Canadian Shield (Figure 1), consisting of ancient sedimentary, igneous, and metamorphic rocks. Volcanic rocks, ranging in age from ca. 2.9 to 2.7 billion years ago, along with related sedimentary rocks, form "greenstone" belts.

The Midcontinent Rift extends from southwest of Lake Superior, under the lake, and south through Michigan. During a period of approximately 20 million years (ca. 1,110 to 1,090 million years ago), an estimated 2 million cubic kilometers ($km^3$) of volcanic rocks, predominantly flood basalts, were erupted. Coarse, sedimentary rocks were deposited during hiatuses in eruption activity. Associated, intrusive igneous rocks predominate in northeastern Minnesota, as well as around Lake Nipigon, and extend north of Lake Superior. Rocks of the Midcontinental Rift are only exposed around Lake Superior. Elsewhere, they are overlain by younger sedimentary rocks.

Sedimentary rocks of the Cambrian (570 to 500 million years ago) and Ordovician (500 to 440 million years ago) periods are restricted to the southeastern portion of the Lake Superior basin, near Sault Ste. Marie. They are situated in an area of subsidence in which sandstones, limestones, and other sedimentary rocks accumulated during Paleozoic time (Figure 1).

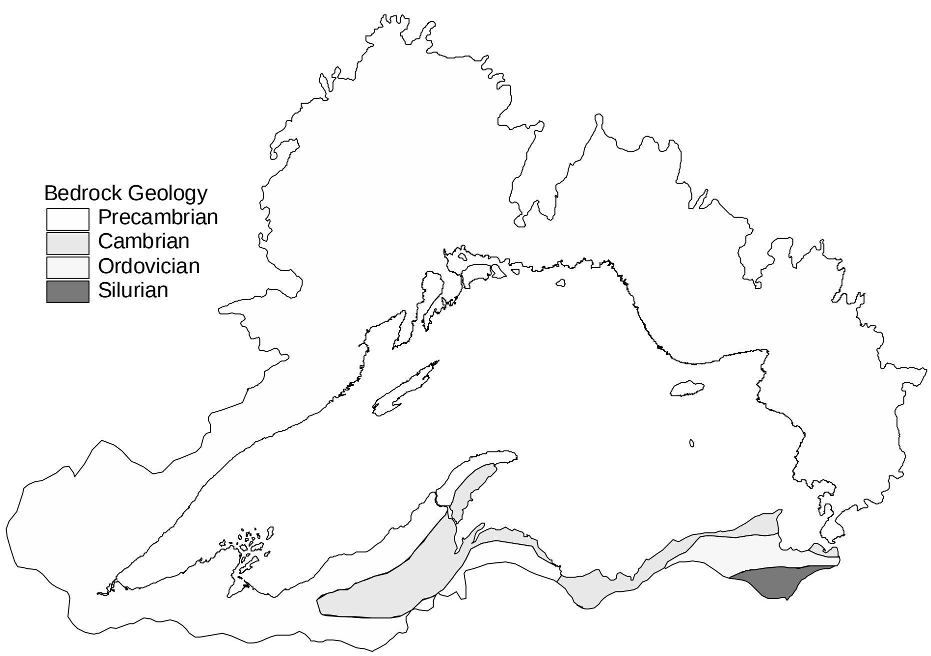


**Figure 1. Generalized geology of the Lake Superior area (Government of Canada and U.S. EPA 1995).**

**Glacial History**
Twenty thousand years ago, the Lake Superior basin was covered by the Laurentide ice sheet. The most recent stage of glaciation, the Wisconsin, began approximately 115 thousand years ago and ended 10 thousand years ago.

Erosion caused by advancing ice produced widespread till deposits of varying thickness, whose composition reflects the eroded source:

- Sandy tills, derived from the erosion of crystalline Precambrian rocks;
- Silty tills, derived from the erosion of Paleozoic carbonate rocks; and
- Clayey tills, derived from the incorporation of proglacial, glaciolacustrine sediments.

Till is less than one meter (m) thick over much of the rocky uplands bordering Lake Superior. However, in bedrock valleys or in areas south of Lake Superior, glacial drift thickness may average 30 to 60 m and may exceed 200 m.

Although the front of the Laurentide ice sheet began its final recession 15 thousand years ago, ice remained in the Lake Superior basin until about 9.5 thousand years ago (Table 1). The ice margin was very lobate in the Great Lakes region in response to topographic controls and ponded water near the ice front. The retreat of ice about 11 thousand years ago was accompanied by the development of proglacial, ice-contact lakes. Lake Duluth and Lake Ontonogan developed on the southwestern and southern flanks of the Superior lobe, respectively. Water from Lake Duluth drained southward via the Brule-St. Croix valley into the Mississippi River valley. Glaciolacustrine sediments (gravel, sand, silt, and clay) were deposited in these fluctuating lake basins as the ice sheet retreated northward. Flowing meltwater produced outwash deposits of stratified sand and gravel.

The Marquette Readvance of the Superior ice lobe 10 thousand years ago filled the Lake Superior basin with ice and extended down to the Grand Marais moraines in northern Michigan. Following the retreat of Marquette ice, glacial Lake Minong developed and eastern outlets for glacial Lake Agassiz developed through Lake Nipigon. The resultant flooding may have triggered the erosion of the drift barrier at the eastern end of the Superior basin, leading to rapid lowering of water levels, culminating in the lowest, Houghton phase ca. 7.5 thousand years ago. Following the rebound of the North Bay outlet, water from the Nipissing Great Lakes flooded into the Superior basin, giving rise to the Nipissing maximum level. Many of the resultant, raised shorelines now preserved around Lake Superior are related to a main, beach-forming event approximately 4.6 thousand years ago. Lake levels subsequently fell to lower levels, such as the Algoma, Sault, and Sub-Sault. The basin was isolated when uplift of the St. Mary's River sill ca. 2.2 thousand years ago isolated the Superior basin, resulting in the Sault and later, Sub-Sault levels that are only represented in the Superior basin. Modern-day levels of Lake Superior, ca.183 m above sea level, were substantially achieved approximately 2 thousand years ago.

Isostatic rebound of ice-depressed land around the basin during progressive deglaciation has led to submergence and emergence on the southern and northern shores of Lake Superior, respectively. Rates of submergence at Duluth, Minnesota have been estimated at 0.21 m per century while emergence rates of approximately 0.27 m per century have been estimated in the Michipicoten area of Ontario.

**Table 1. Post-glacial lake phase names for the Lake Superior basin, with approximate ages (from Geddes and others 1987).**

| **YEARS BEFORE PRESENT** | **LAKE PHASE** | **ELEVATION** (At Marathon, Ontario; In Meters Above Sea Level) |
|---|---|---|
| 0 | (present Lake Superior level) | 183 |
| 1,000 | Sub-Sault | 190 |
| 2,000 | Sault | 197 |
| 3,000 | Algoma | 205 |
| 5,000 | Nipissing | 220 |
| 6,000 | | |
| 7,000 | Houghton | 246 |
| 8,000 | Post-Minong IV<br>(Dorion) III<br>II<br>I | 260<br>270<br>280<br>292 |
| 9,000<br><br>9,500 | Minong III<br>II<br>I | 308<br>315<br>325 |

## 1.2 Soils

Present soil conditions reflect the glacial history (Figure 2). Shallow, well-drained tills cover most of the Ontario basin and northern Minnesota, with local clay and organic deposits. Soils are relatively nutrient-poor, acidic, and rocky.

On the south shore, the Lake Superior Lake Plain extends for approximately 322 kilometers (km) along the lakeshore from Duluth/Superior to the Keweenaw Peninsula. Soils are lacustrine clays and clayey till. Most of the Keweenaw Peninsula is bedrock knob and sandy till.

The eastern part of the U.S. basin is dominated by well-drained ground moraine and lacustrine sand deposits with poorly drained clay in lower areas. Organic soils overly the clay in depressions (McNab and Avers 1994).

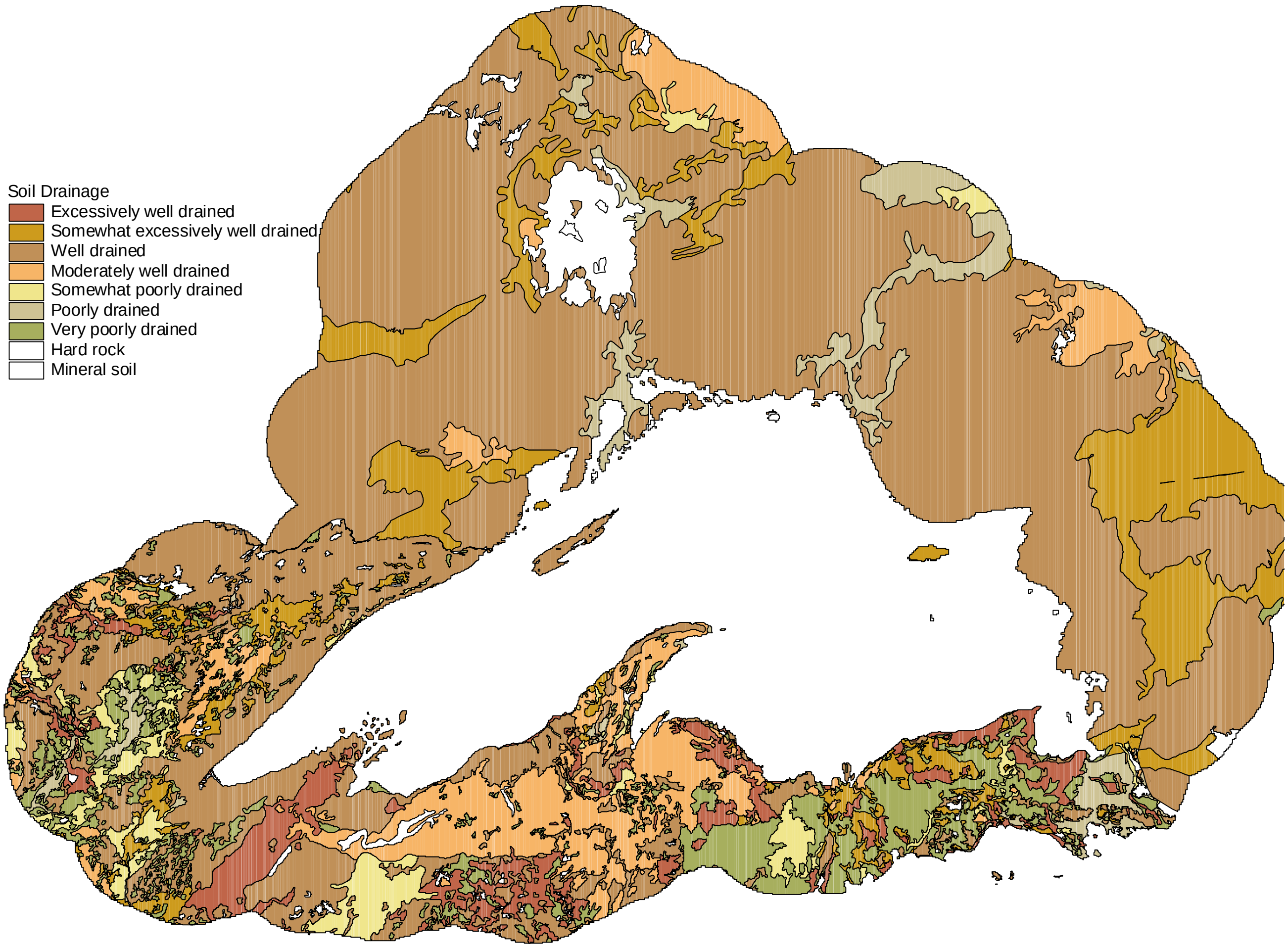


**Figure 2. Soil drainage (Lake Superior Decision Support Systems data).**

## 1.3 Climate

Lake Superior has a strong effect on the climate of Wisconsin, Michigan, and eastern Ontario, but less on Minnesota and the northern part of the basin (Albert 1995). While mean annual temperatures increase steadily from north to south (Figure 3), the lake has a strong effect on climate within a few kilometers of the shore. Shorelines experience cooler summers and milder winters than sites a few kilometers inland. Winter storms tend to be more intense near the lake, but the lake increases stability of the air masses and reduces the intensity of spring and summer storms (Albert 1995).

The wettest areas are immediately east of the lake, north of Sault Ste. Marie, Ontario, and parts of Wisconsin and Michigan where there is a strong lake influence (Figure 4). These areas also have the greatest snow accumulation. Portions of the Michigan Upper Peninsula average 875 centimeters (cm) of snow while Duluth, outside the greatest lake influence, receives only 138 cm (Minnesota Pollution Control Agency (MPCA) 1997).

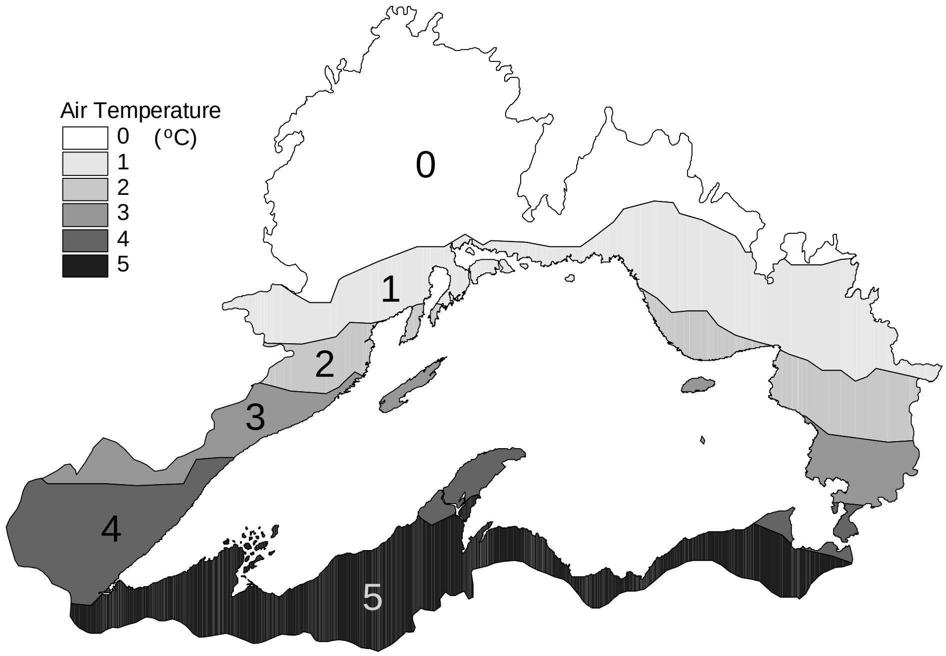


**Figure 3. Mean annual temperatures calculated from monthly values (Lake Superior Decision Support Systems data). The numbers are mean temperatures in degrees Celsius.**

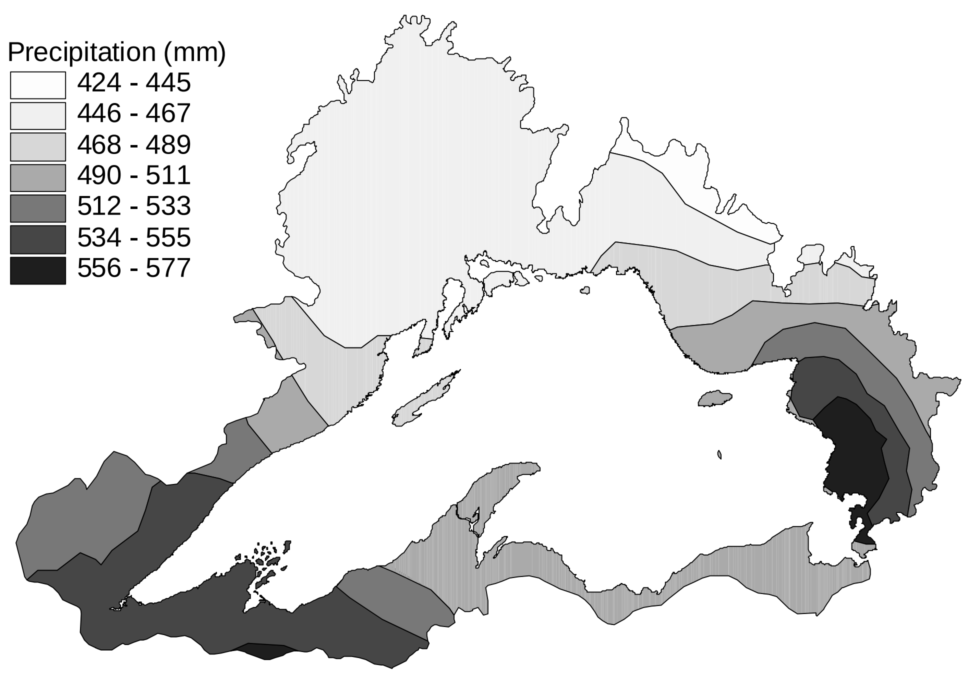


**Figure 4. Growing season precipitation. (Lake Superior Decision Support Systems data).**

## 1.4 Great Lakes Natural Regions and Seascapes

Great Lakes Natural Regions and Seascapes were developed as part of a classification system of enduring features for planning marine protected areas (World Wildlife Fund 1997). Natural regions and seascapes are equivalent to terrestrial ecoprovinces and ecodistricts respectively. Natural regions are delineated on the basis of light penetration and macrotopography. Lake Superior comprises 11 marine natural regions and 20 seascapes (Figure 5). The four benthic natural regions are subdivided into 13 seascapes on the basis of substrate type, slope and water motion (e.g., upwelling, stratification). The Photic Zone Natural Region #1 encompasses the entire benthic euphotic zone of Lake Superior, including significant offshore shoals. The West Slope Natural Region #2 lies on the windward side of the lake and is characterized by low relief at depth of about 150 m. The Central Basin Natural Region #3 is a deep basin (up to 400 m) with upwelling zones. The Southeastern Rise Natural Region #4 is characterized by very irregular bottom topography and depths from 100 to 300 m. The seven pelagic natural regions represent the euphotic (>20 m depth) and dysphotic-aphotic zones overlying the corresponding benthic natural region. Natural Region #1 has only one overly pelagic region (the euphotic zone), whereas the other three benthic natural regions each have two pelagic natural regions. The pelagic natural regions are not further divided so are also effectively seascapes.

Seascapes within the nearshore euphotic zone are defined on the basis of exposure to wave energy (i.e., exposed or protected), which is related to fetch direction and length, the presence or absence of offshore islands, and overall shoreline morphology. Offshore shoals and island shorelines are included with the adjacent mainland at this scale, even though they are often exposed to more wave energy. Seascapes in the offshore natural regions are delineated by water mixing and bottom substrate type (particle size).

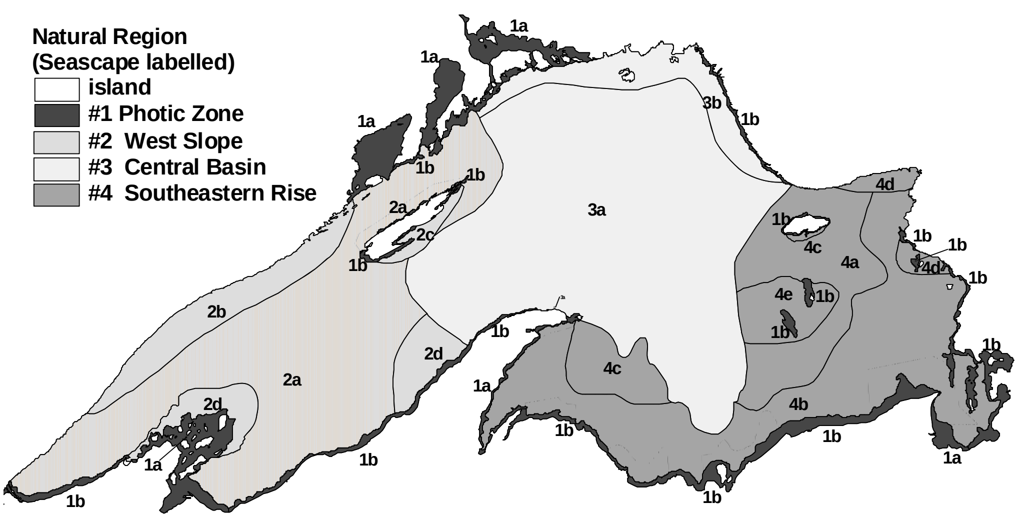


**Figure 5. Seascapes of Lake Superior (World Wildlife Fund Canada 1999).**

### 1.5 Bathymetry And Basin Morphology

Lake Superior averages 147 m in depth with a maximum depth of 406 m. The lake is divided into three main bathymetric basins by the Keweenaw Peninsula, which protrudes approximately 95 km into the lake from the southern shore (Figure 6). The eastern basin is characterized by a series of long, parallel, steep-sided troughs 100 to 300 m in depth which are oriented north-south. The central basin is comprised of very deep (up to 400 m), steep-sided sub-basins bounded on the north by extensive underwater cliffs which fringe a complex series of islands. The western basin encompasses relatively shallower offshore waters and a very deep channel, the Thunder Bay Trough, which separates Isle Royale from the adjacent mainland.

Water depths of less than 100 m are found in a narrow band paralleling the shore, with a rapid fall-off to deeper waters. In addition, water depths of less than 100 m are also found around islands and off shore shoals, especially in eastern Lake Superior. Shoals are numerous along the eastern shore and northern shore, and Superior Shoal is prominent midlake as an extension of the Keweenaw Sill. Along the north shore, the Sibley and Black Bay Peninsulas, and associated islands, delineate three large, sheltered bays, Thunder Bay, Black Bay, and Nipigon Bay.

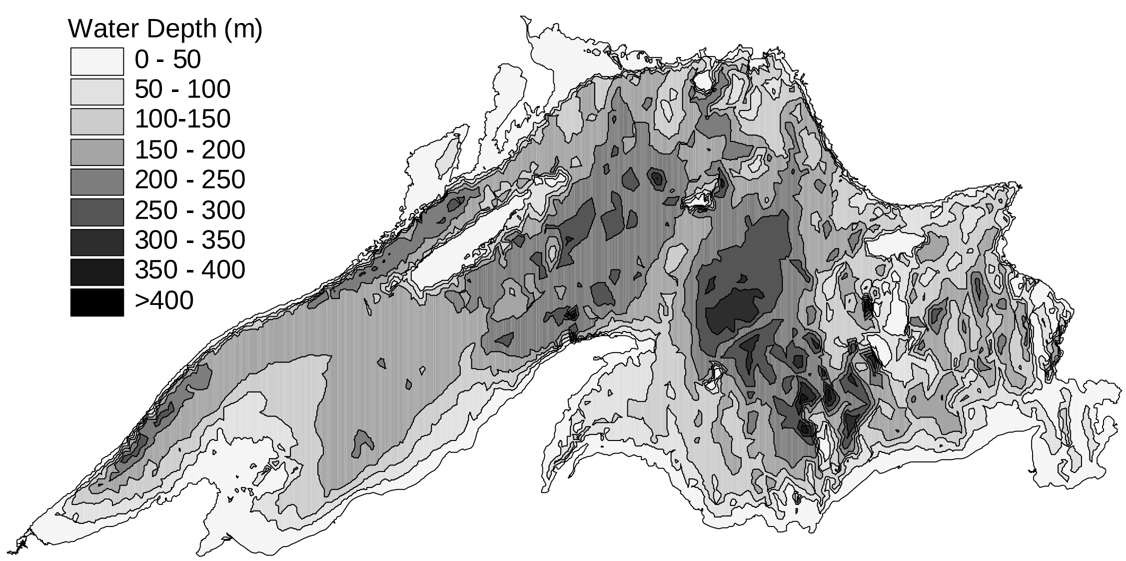


**Figure 6. Lake Superior bathymetry.**

## 1.6 Currents and Circulation

In Lake Superior, epilimnetic and hypolimnetic currents generally flow parallel to the shore in a counter-clockwise direction. There are also smaller gyres south of Isle Royale and around the Superior Shoal that reflect the bottom topography, temperature, and wind conditions of those areas. Currents are stronger along the south shore than elsewhere in the lake and are greatest adjacent to the north side of the Keweenaw Peninsula (Keweenaw Current). Currents are affected by wind conditions and internal pressure caused by density variations and the slope of the thermocline. Less dense, warmer water along the south coast where the thermocline is deeper show higher shoreline currents. Northerly hypolimnetic flows in the eastern portion of the lake may exceed five cm/sec compared to less than one cm/sec near Duluth and the Apostle Islands. The magnitudes of the currents also vary temporally, with the largest currents occurring in September (Lam 1978). Currents also flow during winter when the coldest and least dense water is confined on the periphery of the lake.

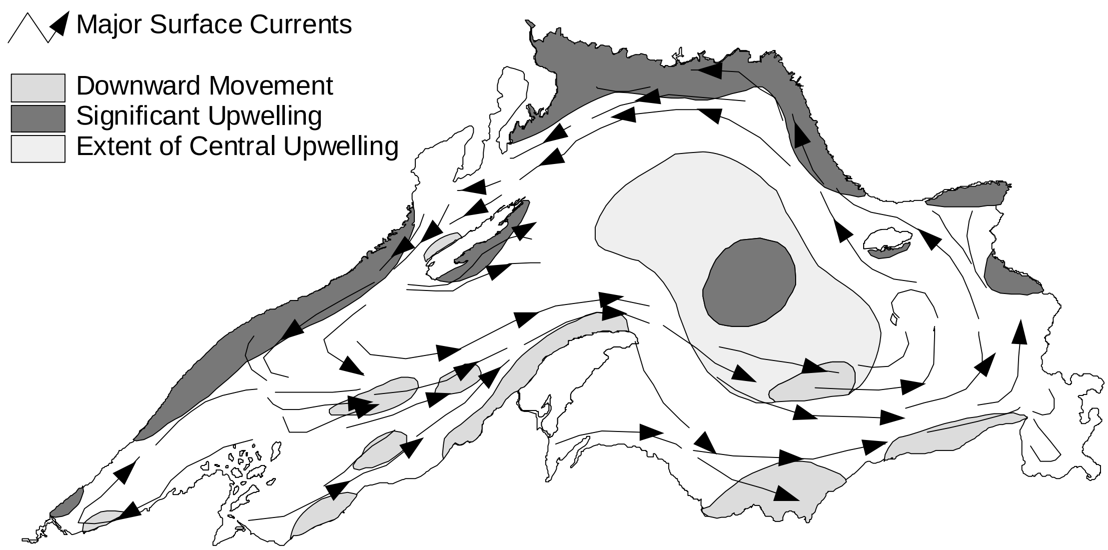


**Figure 7. Major surface currents and upwellings. Downward water movement (cross-hatched), significant areas of upwelling (dark stipple), and extent of central upwelling (light stipple) are shown (after Harrington 1985 and WWF 1999).**

Summer circulation is strongly influenced by the seasonal development and depth of the thermocline. During spring warming, current speeds are relatively constant, low, and uniformly distributed throughout the water column. After stratification, mean current speed rises in the epilimnion (at 10 m depth) and attains maximum values in early September, one or two weeks after surface temperatures peak (Bennet 1978). The thermocline restricts downward transport of heat and momentum from the surface, so current speeds in the hypolimnion decrease slightly because of frictional dissipation and are a seasonal minimum in August. Current speeds and temperatures rise in September due to enhanced vertical mixing which provides a downward flux of heat and momentum. Epilimnetic water temperature and current speeds have a corresponding decline in September and October.

Strong, modeled hypolimnetic currents in the vicinity of Superior Shoal, south of Isle Royale and east of the Apostle Islands, are likely related to upwelling and downwelling (Lam 1978). Upwelling occurs where sub-surface water is brought to the surface of the lake to replace surface water that has been forced to move laterally by wind or the temperature-density pressure gradient. During the summer, surface water tends to flow away from the nearshore upwelling zone along the north shore of Lake Superior and toward the nearshore downwelling zone along the southern shore (Bennet 1978). The general shoreward drift of surface water associated with anti-clockwise flow contributes to upwelling in midlake, as do bottom topography, rapid heating of the water, and winds. Upwelling enhances heat exchange by allowing more heat to enter the water during the summer and more heat to escape during the winter than if no upwelling occurred. Upwelling may bring nutrients and organic matter from the lake bottom and hypolimnium into more biologically active surface waters, which tends to increase productivity. See Figure 7 for major surface currents and upwellings in Lake Superior.

Currents and circulation are significant to the aquatic community because they influence water temperatures, sediment transport, ice cover, distribution of nutrients and oxygen, and dispersal of planktonic organisms.

## 1.7 Water Level Fluctuations

Lake Superior's water levels undergo natural variation at the short-term, seasonal, and year-to-year scales (Edsall and Charlton 1997). Short-term variation takes place over the course of several hours, due to seiche activity (oscillation due to changes in barometric pressure or wind). The amplitude of variation is in the range of a few centimeters or tens of centimeters, but can exceed one meter under extreme conditions (Edsall and Charlton 1997).

Seasonal changes in water levels occur in response to the annual cycle of precipitation and runoff. Lake Superior's levels typically peak in October and recede over the winter, reaching the lowest levels in early spring, followed by a steady rise through the spring and summer.

Year-to-year fluctuations in water level result from year-to-year fluctuations in precipitation and runoff. Table 2 and Figure 8 show the natural water level fluctuations (represented by the 1860-1887 period) compared to current conditions (represented by data from 1900-1986). Lake Superior levels are now higher than they were under natural conditions, but show a smaller range of variation between maximum and minimum values (1.01 m vs. 1.16 m) (Southam and Larsen 1990).

Water level fluctuations are important in maintaining healthy wetlands. Extreme low water levels allow cyclic, regenerative processes, such as oxidation of sediments and germination of submerged seed banks, to occur over a broad width of shoreline. High water levels prevent the encroachment of trees and shrubs in open wetlands (Wilcox and Maynard 1996). Effects of water level fluctuations on fish habitats in the Great Lakes are not well understood (Edsall and Charlton 1997). Effects of water level fluctuations in some basin inland lakes are well known.

**Table 2. Mean water levels (m) under current and natural conditions (adapted from Southam and Larsen 1990).**

| | *Current* | *Natural* | *Difference* |
|---|---|---|---|
| **Mean** | 183.00 | 182.91 | +0.09 |
| **Maximum** | 183.46 | 183.43 | +0.03 |
| **Minimum** | 182.45 | 182.27 | +0.18 |
| **Range** | 1.01 | 1.16 | -0.15 |

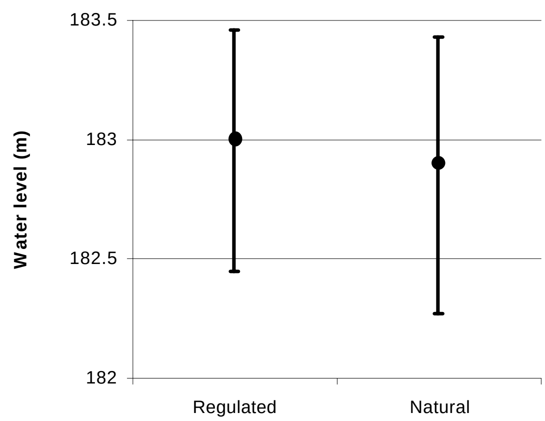


**Figure 8. Annual water level fluctuations in Lake Superior, comparing present and natural values.**

During the period from 1948-1999, the seasonal water level cycle decreased in amplitude by 20 percent (from 40 cm to 32 cm). The change is manifested as a downward trend in summer and autumn lake levels (where levels are typically highest). Summer and autumn trends reflect a large decrease in spring water influx and a nearly compensating influx in late autumn. These changes are primarily the result of trends in runoff and over-lake precipitation and are associated with variations in climate and land surface effects, rather than water level regulation (Lenter 2004).

## 1.8 Sediments

Sedimentation processes are important to aquatic life because they influence water clarity, nutrient availability, and benthic substrates, as well as shoreline habitats such as beaches and dunes. Sediment trap studies along the Keweenaw Peninsula demonstrated that sediment resuspension occurs even at depths of 120 to 220 m (9 to 21 km offshore) and that resuspended sediments contribute 10 to 30 percent of the organic carbon settling flux in offshore traps (Urban et al. 2004).

Lake Superior sediments reflect both glacial and post-glacial processes. Most of the sediments in Lake Superior were deposited approximately 11,000 to 9,200 before present during the last Wisonsinan glaciation (Thomas and Dell 1978). These glaciolacustrine sediments were derived directly from the melting ice front or from meltwater streams flowing into the lake. Till deposited during the last period of glaciation often underlies these glaciolacustrine sediments. The average thickness of glaciolacustrine sediments is approximately 1 m, but can be more than 18 m in northern parts of the lake (Thomas and Dell 1978). Massive red calcareous clays predominate in the lower strata and usually grade upward into red or grey carved calcareous clays. Red clays are derived from red tills from the southwestern portion of the basin, whereas grey clays reflect tills from the northeastern part of the basin exposed later as the glacier retreated. These sediments are comprised mainly of clay minerals, quartz, feldspars, calcite, and dolomite (Dell 1973). The calcite and dolomite are derived from calcareous Paleozoic rocks of the Hudson Bay lowland that were originally deposited as tills around the lake. In late glacial times, sedimentation rates in Lake Superior were so high (up to 13 cm per year) that carbonates were preserved in sediments beneath the top few cm (Thomas and Dell 1978). Unless the sediments are reworked by contemporary processes (e.g., currents), the carbonates remain in equilibrium with interstitial water and are preserved.

Postglacial sediments from deposition within the last 9,200 years overlie glaciolacustrine sediments in most of the lake. Little or no postglacial deposition has occurred in some parts of the lake, especially in nearshore areas, and glacial till or glaciolacustrine sediments are exposed or nearly so. For most of the lake, however, post-glacial deposits average three meters in depth, but may be as much as nine meters in local basin-like depressions (e.g., Thunder Bay Trough). These post-glacial sediments are primarily reddish brown or greyish-brown silty clays in the southern portion of the lake, grading to darker greys in the north. Postglacial sediments in Lake Superior are non-calcareous, even though they are derived from calcareous tills or glaciolacustrine sediments, since modern sedimentation rates are slow enough to allow complete dissolution of calcite and dolomite. Much of the Superior shoreline is rocky and, therefore, contemporary deposition rates average less than two millimeters (mm) per year (Bruland and others 1975). Much of the lacustrine sediment currently being deposited in Lake Superior may be reworked material derived from subaqueous erosion by currents.

Modern surficial sediment distribution in Lake Superior (Figure 9) is related to bathymetry, circulation patterns, and proximity of terrestrial sediment source. Deposition of very fine-grained muds occurs in deeper basins and local topographic depressions, resulting in exceptionally thick deposits in northern portions of the lake. Tills and glaciolacustrine clays are exposed and possibly eroded (Dell 1974) in non-depositional zones that occur around the lake periphery and in areas of high local topographic relief (even if they occur in deep water). Exposed bedrock occurs in a few locations close to shore, in island areas, and in regions of high lake bottom relief. Organic carbon in Lake Superior sediments ranges from only 0.01 to 3.85 percent reflecting the oligotrophic nature of the lake, and is greatest in depositional zones.

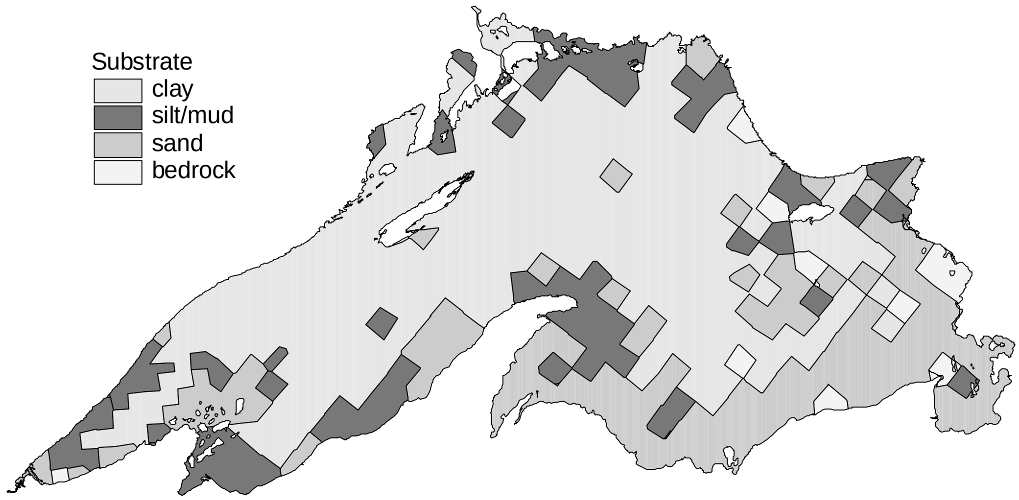


**Figure 9. Surface sediment distribution in Lake Superior (after Thomas and Dell 1978).**

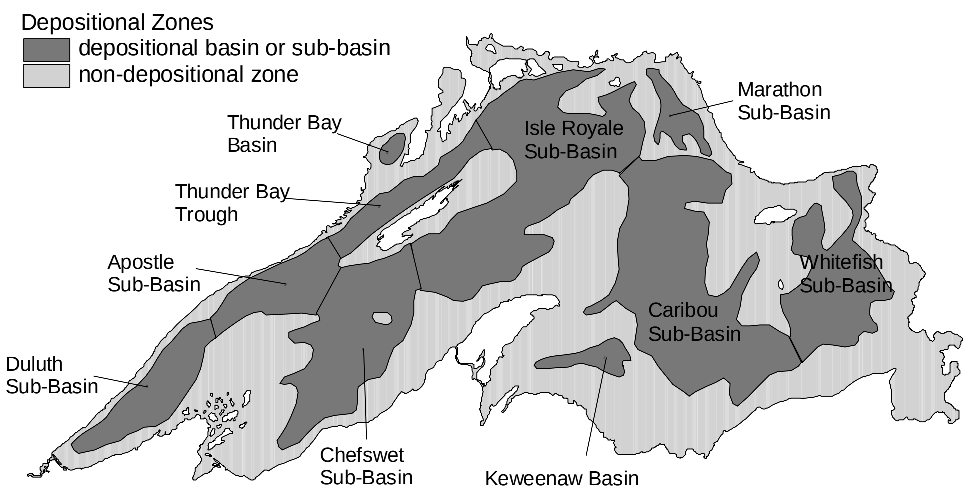


**Figure 10. Depositional basins (shaded) (IJC 1977).**

Modern sedimentation rates are generally half the magnitude of postglacial sedimentation rates and range from 0.1 to 2.0 mm per year. This is equivalent to approximately 6.029 million tonnes of fine sediment annually (Kemp and others 1978). Sedimentation rates vary with proximity to terrestrial source, circulation patterns, and bottom topography. The highest rates are found at locations closest to the edges of depositional basins and sub-basins and at the base of step-sided troughs, and lowest midlake in areas of gentle topography (Figure 10). Shoreline erosion is the largest external source of sediment (Figure 11), with the red-clay district on the western shore of the Keweenaw contributing up to 58 percent of annual inputs (Kemp and others 1978). Due to circulation patterns, suspension and deposition of these particles is likely to remain in the vicinity of the Duluth Sub-basin and western shore of the Keweenaw Peninsula. Approximately 37 percent of the current natural sediment load is deposited in the Duluth Sub-basin, followed by the Chefswet Sub-basin and Keweenaw basin (Kemp and others 1978).

Lake Superior tributaries are the second most important source of sediments with 30 percent of total inputs (IJC 1977). The St. Louis and Ontonagon rivers are the largest American sources, and the Nipigon, Kaministiquia, and Pic rivers are the largest Canadian sources, although much of this settles in Nipigon Bay and Thunder Bay (Kemp and others 1978). Erosion of taconite tailings from Silver Bay, Minnesota accounts for seven percent of the fine-grained sediment input. Although annual loading of airborne particulates is low relative to other sources, these particulates are of great importance because of their high concentrations of toxins and nutrients.

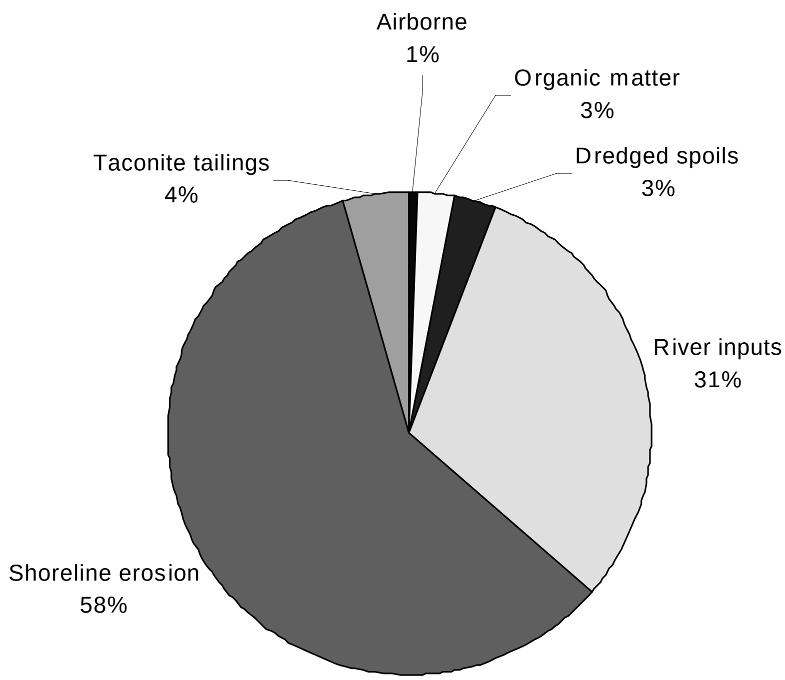


**Figure 11. Estimated quantity of clay and silt-sized sediment inputs to Lake Superior from various sources (adapted from Kemp and others 1978).**

Secchi depths range from 9 to 15 m in midlake and 5 to 11 m in nearshore areas. In southwestern Lake Superior, higher turbidity is due to increased suspended inorganic particulate concentration resulting from high erosion rates after ice break-up, agitation of sediments in the shallower nearshore, and associated sediments in water discharged as runoff from the surrounding basin (Stortz and others 1976). Secchi depths may be a low as 1.5 to 2.8 m under these conditions. Thunder Bay, Nipigon, and Black bays also have reduced water transparency.

## 1.9 Water Temperature

Water temperature is of paramount importance since it affects rates of chemical and biological processes and the thermal regime influences patterns of currents and density structure, as well as vertical and horizontal mixing. Lake Superior has a unique thermal regime due to its size and has the lowest summer surface temperature (13°C) and mean annual lake temperature (3.6°C) of the Great Lakes (Bennet 1978). Lake Superior has a semi-annual alternation between periods of stratification and of extensive vertical mixing typical of dimictic lakes (Figure 12). Although the annual heat income of Lake Superior is the second highest for any lake in the world, winter heat loss is the highest of the Great Lakes, and approximately half is used for spring warming of the lake to the temperature of maximum density (~3.8°C). As a result, the spring convective mixing period is the longest of the Great Lakes, the summer stratification period is the shortest, and the maximum surface temperature in the summer is the lowest. There is great year-to-year variation in the surface temperature of Lake Superior, especially in the summer months. The epilimnion is relatively deep in years when the mean surface temperature is relatively low and vice versa.

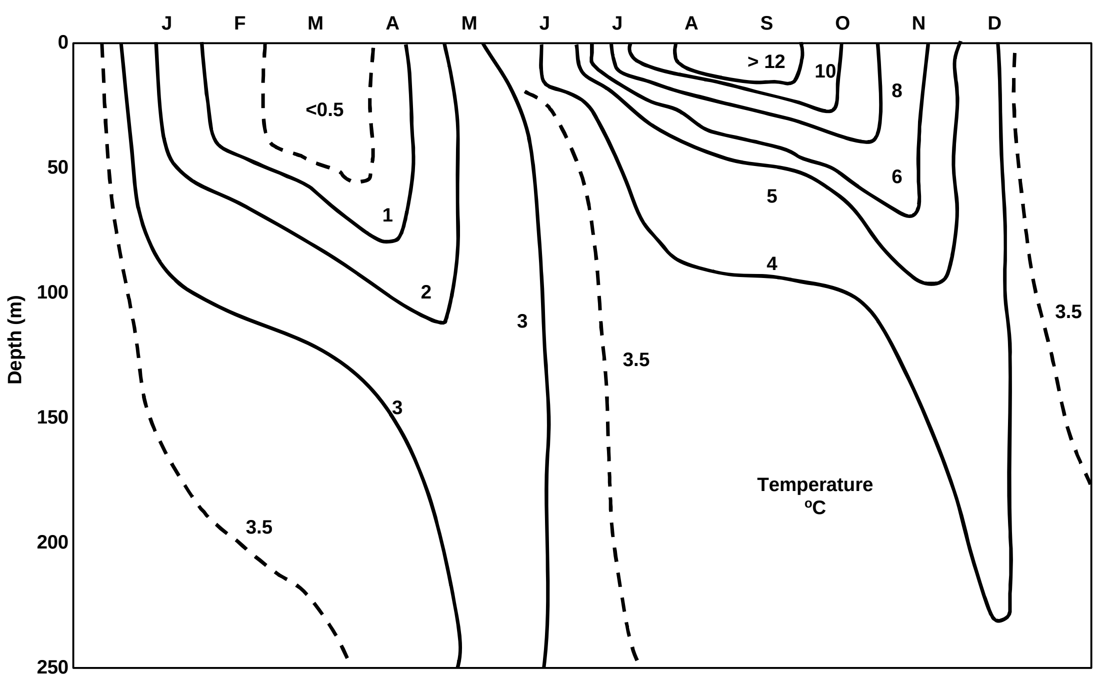


**Figure 12. Seasonal changes in water temperature with depth for Lake Superior (Bennet 1978).**

During winter stratification, the cooler (<1° C) waters of the epilimnion rest on denser, warmer water at a depth of 40 to 60 m. The lowest mean lake temperature of 1.4° C occurs at the beginning of April. Rapid warming from increased spring solar radiation raises surface water temperatures from 0° C at the end of March to 3.0° C by early June. The vigorous convective mixing results in a rapid downward flux of heat from the lake surface and the beginning of heating of the entire lake volume. This extends the epilimnion to a depth of 250 m or more by early June. By mid-July, surface waters have warmed past 4°C across the entire lake (including midlake), and initial summer stratification occurs. Surface temperatures then rise rapidly and the thermocline develops at a depth of approximately 10 m, which effectively reduces further transfer of heat and momentum to the hypolimnion. Surface temperatures continue to rise and reach a maximum of approximately 13° C in September, and mean lake temperature peaks at 5.8° C. Temperatures in the hypolimnion remain fairly constant throughout the summer at about 4° C. Beginning in mid-September, the epilimnion begins to extend downward due to autumnal cooling and enhanced vertical mixing and by the end of summer stratification in late November, the epilimnion has extended to 145 m. Convective mixing develops in November and slows the rate of decrease of surface temperature. By the end of December, surface water temperature has dropped to 3°C, and declines rapidly in January as the lake stratifies.

Horizontal temperature patterns (Figure 13) are due to differences in the local seasonal cycle of heating and cooling of the upper layer. Rapid inshore warming causes the formation of a thermal bar in the spring, which traps less dense warm water until it has reached 4° C. Surface temperature rises relatively rapidly and attains the highest values in Whitefish Bay, while spring warming is slowest and maximum summer temperature is relatively late and low in midlake (Irbe 1991). Coastal upwelling along the northwest coast maintains low temperatures until late June, similar to the midlake condition. As vertical stratification occurs in July, there is rapid warming along the northwest coast from 6° C to 14 to 16° C resulting from the formation and offshore movement of the thermal bar. During the winter, horizontal water temperature patterns are reversed, with cold water on the periphery of the lake, particularly along the south shore, and warm water located along the northwest coast and mid lake (Leshkevich 1975).

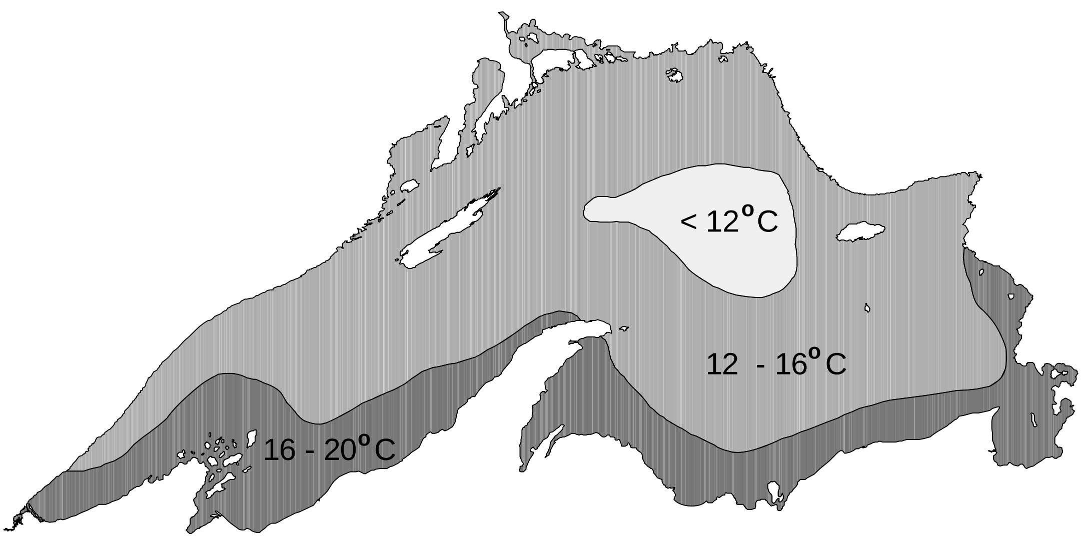


**Figure 13. Mean August surface water temperature for Lake Superior.**

## 1.10 Ice Cover

Ice cover has considerable environmental impacts, such as providing insulation between the atmosphere and relatively warm water, thereby reducing heat loss, evaporation, and the occurrence of lake-effect snowstorms. It may also impact fish reproduction (e.g., burbot) and dispersal of terrestrial mammals to islands (e.g., caribou and wolves on the Slate Islands). During a mild winter, approximately 40 percent of the lake surface is expected to become ice-covered, compared to 60 percent during a normal winter and 95 percent during a severe winter (Rondy 1971). Maximum ice cover normally occurs in late March (Figure 14). At this time, consolidated pack ice occurs in most of the shallow bays and along much of the north shore. Close pack ice (70 to 90 percent cover) exists over the middle portion of the lake and approximately 40 percent of the lake is open water, mainly in the eastern end around Caribou Island. Leads occur off Montreal Shoal, the Apostle Islands, the Keweenaw Peninsula, and between Isle Royale and the Slate Islands. These leads are used by gulls and bald eagles during migration or local movement.

Water circulation has a strong impact upon ice cover. Midlake upwelling that is present during the open-water season is maintained throughout the winter by rapid heat loss. This keeps the central area free of ice, which in turn results in a large integrated winter heat loss (Bennet 1978). The winter upwelling of relatively warm water is responsible for the lack of fast ice along the open part of the northwest shore (Marshall 1968).

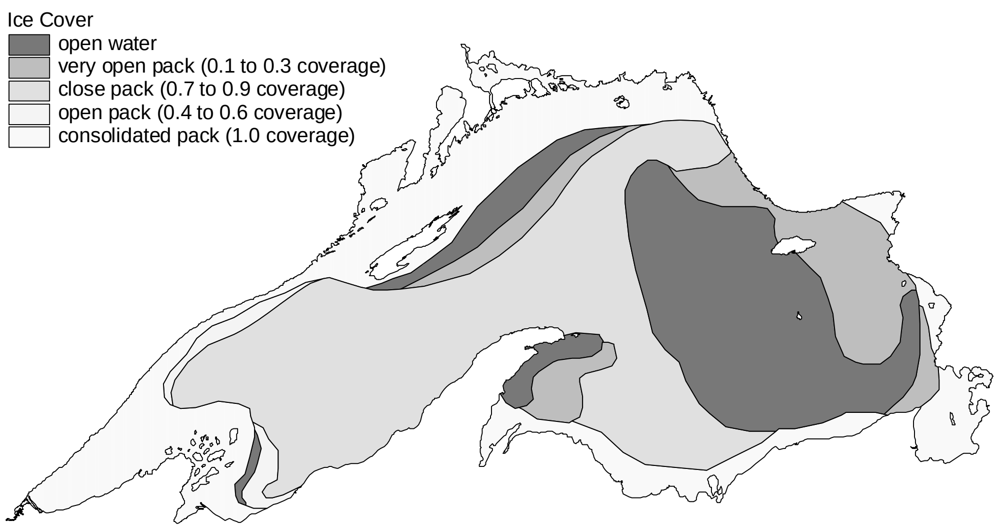


**Figure 14. Normal winter maximum ice cover for Lake Superior (Rondy 1971).**

## 2. SOCIAL ENVIRONMENT

### 2.1 Human Population

The human population of the Lake Superior basin was estimated at 607,121 people in 1996 (Environment Canada and U.S. EPA 1995). Most of the basin is sparsely populated with less than two people per square kilometer ($km^2$) in most of Ontario and the Minnesota north shore. Population density is greater on the south shore of the lake (Figure 15). Centers of population (i.e., cities with greater than 75,000 people) are at Thunder Bay, Duluth/Superior, and Sault Ste. Marie.

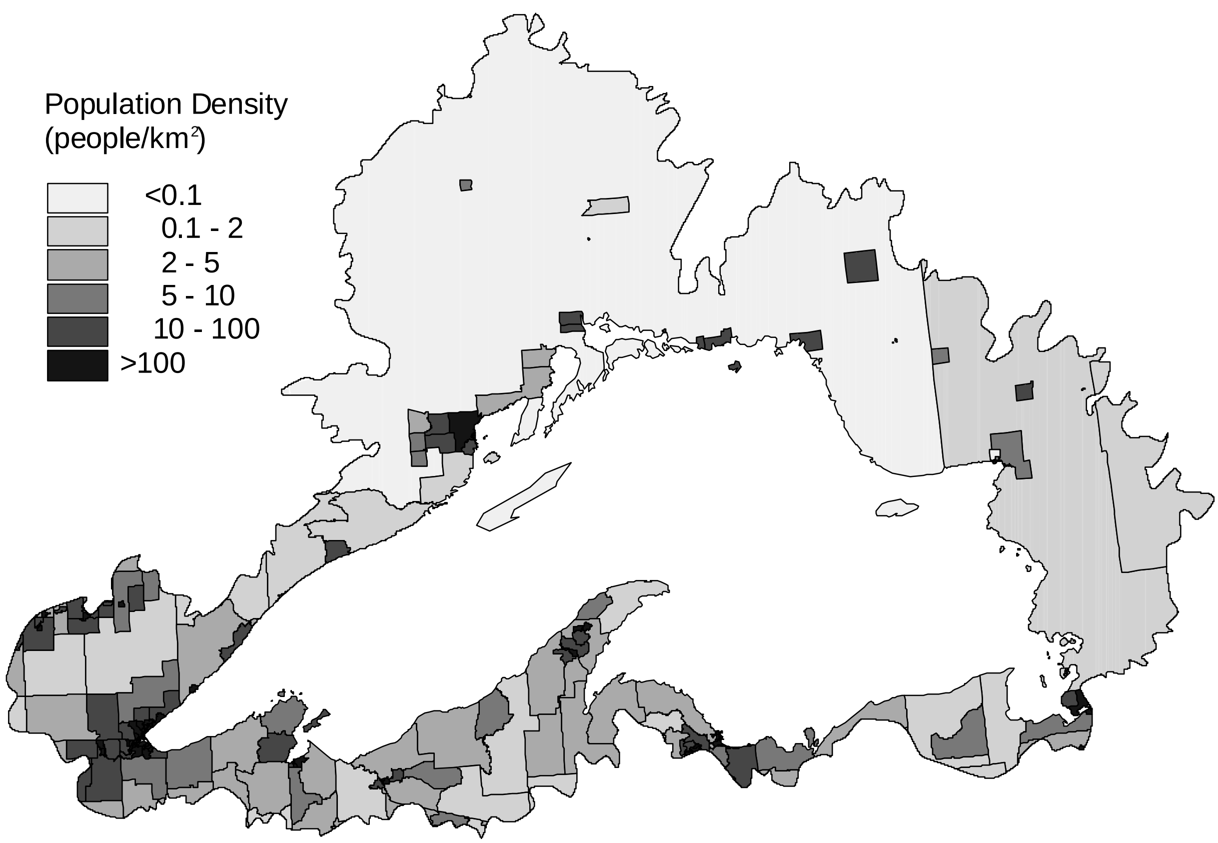


**Figure 15. Population density of the Lake Superior basin in 1996 (people/$km^2$) (Lake Superior Decision Support Systems Data, based on U.S. and Canadian census data). Note that census areas partly overlap the basin and reflect population statistics from outside the basin.**

Most of the basin experienced a small increase in population (zero to five percent) between 1991 and 1996. In contrast, the population of the Great Lakes basin increased by 8.7 percent between 1990 and 2000 (Kling et al. 2003). The greatest population growth was on the Minnesota north shore and adjacent Ontario, the Keweenaw Peninsula and the area west of Sault Ste. Marie, Michigan (Figure 16). The population density in most of these areas remains low, however. Other areas with increasing populations include the Duluth/Superior area and the Bayfield Peninsula. Areas with declining populations include Thunder Bay and other communities dependent on resource-based industries where job numbers have decreased.

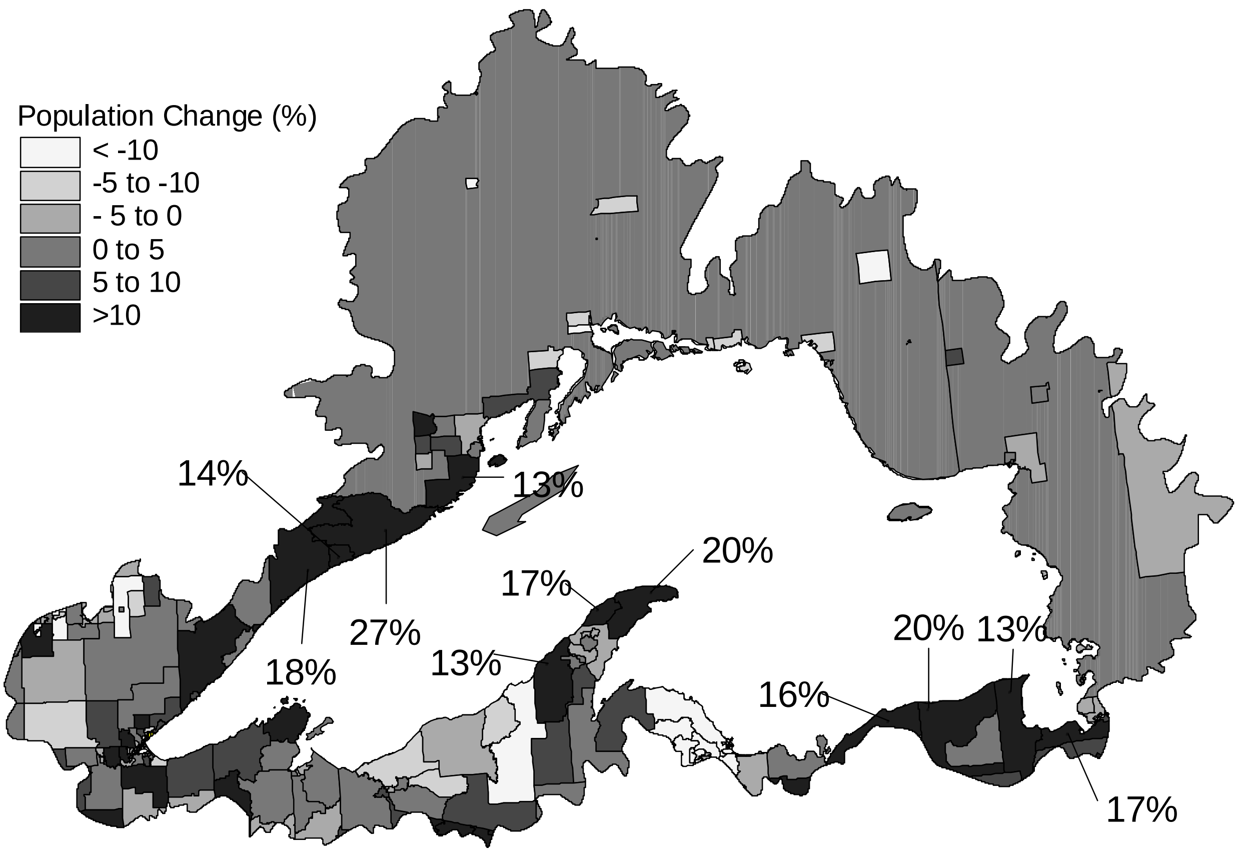


**Figure 16. Population change (percent) between 1991 and 1996 (Lake Superior Decision Support Systems data, based on U.S. and Canadian census data).**

House density (Figure 17) closely parallels population density (Figure 16), but also reflects the number of second homes, especially on the Michigan shore.

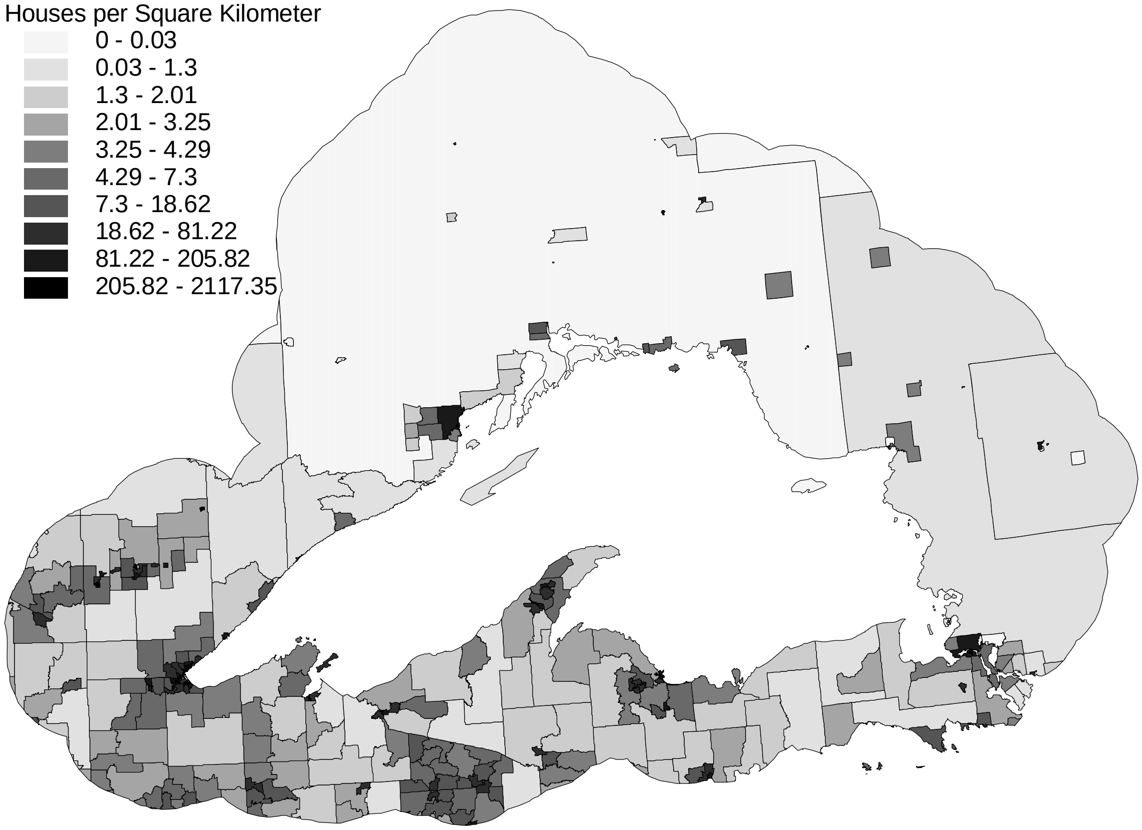


**Figure 17. House density (Lake Superior Decision Support Systems data, based on U.S. and Canadian census data).**

## 2.2 Urban Centers

Urban centers in the Lake Superior basin include Duluth/Superior, Thunder Bay, Sault Ste. Marie, Ashland, Marquette and Houghton (Table 3, Figure 18). About 60 percent of the human population of the basin lives in these cities. As described under *Basin Use and Economics*, the economies of these cities are based mostly on natural resources. Paper and saw mills are present in most of the communities. Shipping of grain, minerals, and manufactured goods also takes place. Universities and colleges, government offices, regional health care, and manufacturing contribute to the economic base.

**Table 3. Urban centers in the Lake Superior basin with populations of greater than 5,000.**

| City | Population | Date of census |
|---|---|---|
| Thunder Bay, Ontario | 121,968 | 2001 |
| Duluth, Minnesota | 86,918 | 2000 |
| Sault Ste. Marie, Ontario | 78,908 | 2001 |
| Superior, Wisconsin | 27,368 | 2000 |
| Marquette, Michigan | 19,661 | 2000 |
| Sault Ste. Marie, Michigan | 16,542 | 2000 |
| Ashland, Wisconsin | 8,620 | 2000 |
| Houghton, Michigan | 7,010 | 2000 |

## 2.3 Political Boundaries

The Lake Superior basin is divided between three states and one province (Table 4, Figure 18). Each of the states is divided into counties (7 in Minnesota, 5 in Wisconsin, and 11 in Michigan). The two districts in Ontario have no elected bodies or land management authority. A number of tribal reservations are also found within the Lake Superior basin including Grand Portage, Fond du Lac, Red Cliff, and Bad River. There are approximately 14 reserves in the Ontario part of the basin under the Robinson-Superior Treaty or Robinson-Huron Treaty.

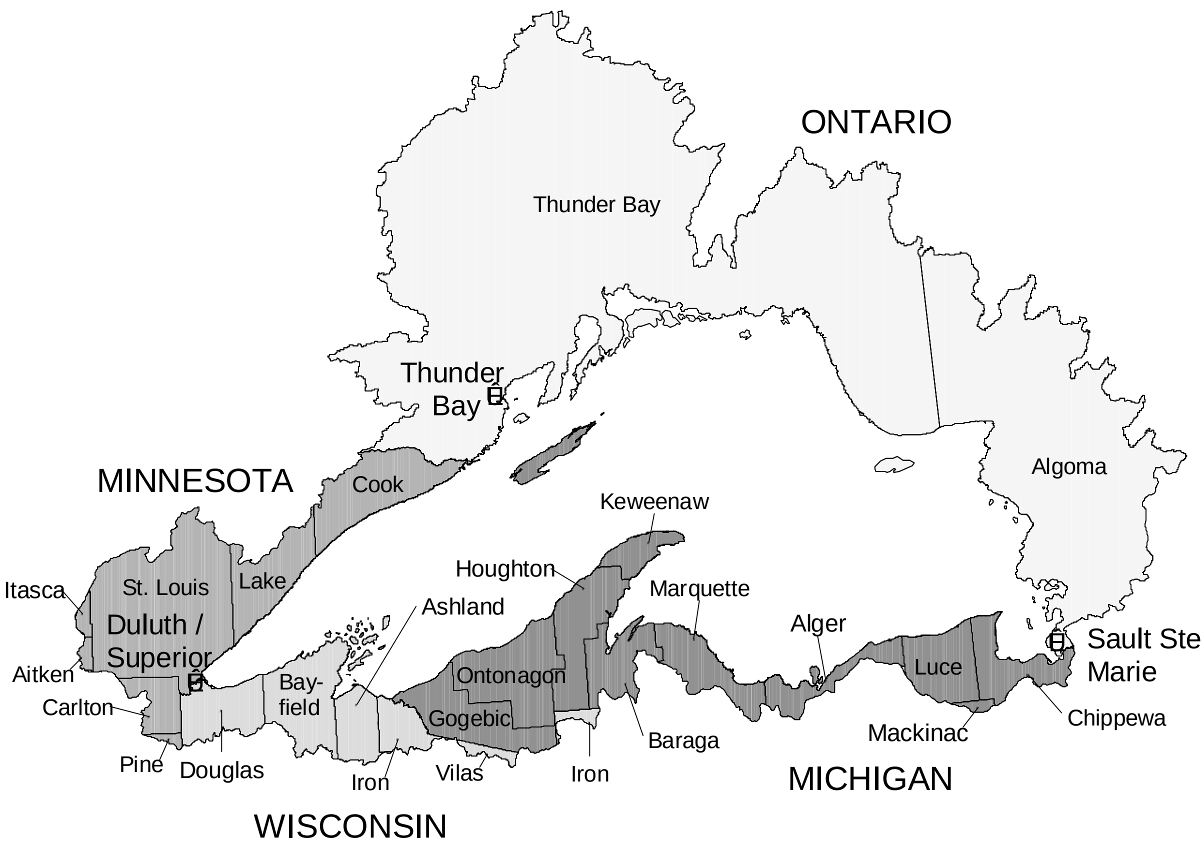


**Figure 18. Counties and districts of the Lake Superior basin.**

## 2.4 Basin Use and Economics

In the U.S., approximately 54 percent of the land base in the basin is privately owned. The remainder is public land held by various agencies of the federal (National Forest Service, National Parks Service), state (Department of Natural Resources), and county governments in Michigan, Minnesota, and Wisconsin (Table 4). Indian Reservations make up 0.6 percent of the land area in the U.S.

In Ontario, about 90 percent of the land is public, held by the Ontario Government as Crown Land and Provincial Parks. The remaining 10 percent is made up of relatively small holdings of farmland, city and rural residential lots, and mining developments (Figure 19, Figure 20). Some large consolidated blocks of land are privately held by railway and forest product companies. Tribal Land and Indian Reservations are included in the 10 percent. Reservations in the basin also contain lands that are not public.

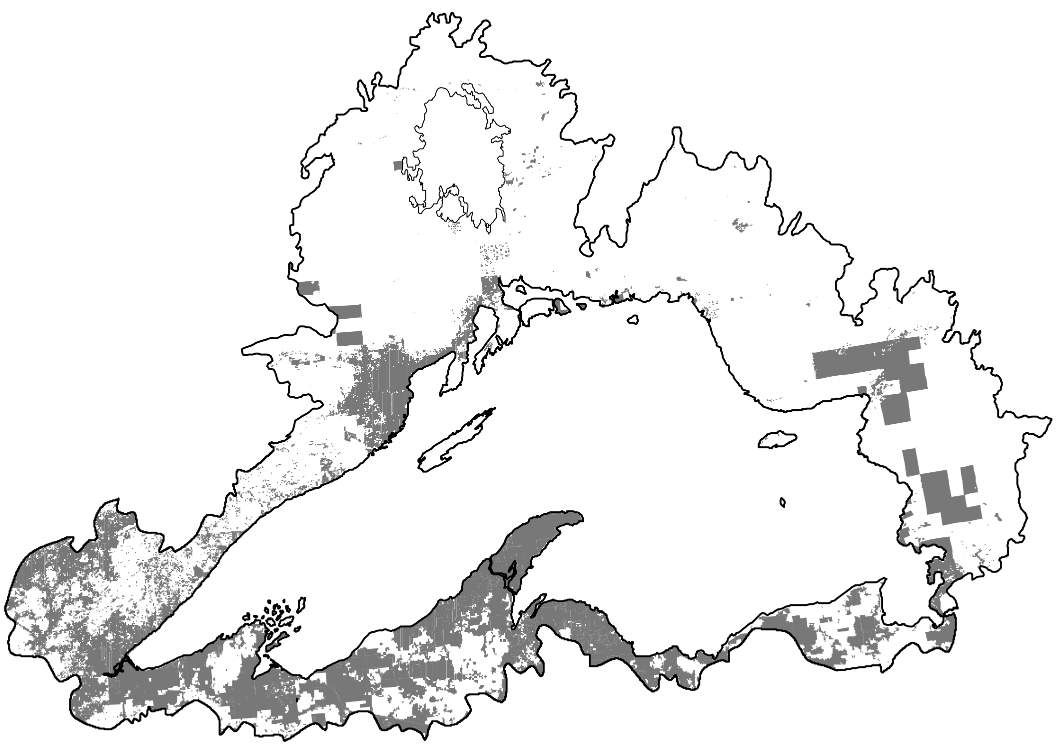

**Figure 19. Private Land (shaded) in the Lake Superior Basin (derived from OMNR and Lake Superior Decision Support Systems data).**

**Table 4. Land ownership (percent) in the Lake Superior basin (derived from OMNR and Lake Superior Decision Support Systems data).**

| Ownership | Ontario | Michigan | Minnesota | Wisconsin | Lake Superior Basin |
|---|---|---|---|---|---|
| County Forest | | 1 | 22 | 19 | 4 |
| National Forest | | 20 | 17 | 15 | 7 |
| National Park | 2 | 3 | <1 | 2 | 2 |
| Other Federal | | <1 | | | <1 |
| Other Private* | 12 | 41 | 38 | 55 | 22 |
| Non-industrial Private Forest | | | <1 | | <1 |
| Private Industrial Forest | | 22 | 3 | 5 | 4 |
| Crown Land / State Forest | 75 | 11 | 13 | 2 | 52 |
| State / Provincial Park | 4 | 2 | 1 | <1 | 3 |
| Conservation Reserve | 6 | | | | 4 |
| State Fish & Wildlife | | | 1 | <1 | <1 |
| Other State | | | 1 | | <1 |
| Tribal | | | 1 | 1 | <1 |
| Army Corps of Engineers | | | <1 | | <1 |
| Bureau of Indian Affairs | | | <1 | | <1 |
| Bureau of Land Management | | | <1 | | <1 |
| Wilderness Area | | | 3 | | 1 |

** includes Patent Land in Ontario*

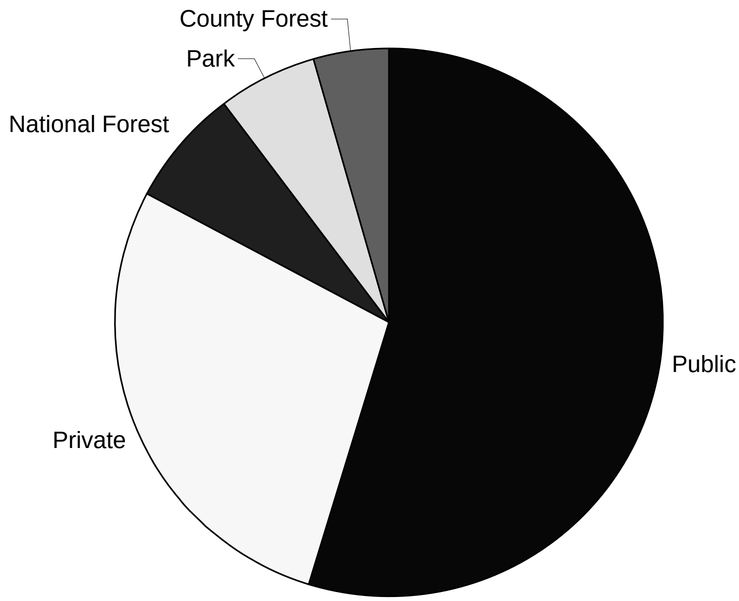


**Figure 20.  Land ownership in the Lake Superior basin.  Most of the public land is in Ontario (see Table 4).**

In general, family and household incomes in Lake Superior counties in the United States are well below the national and state medians (1979 and 1989 data).  In 1990, average monthly mortgage payments within the watershed were considerably below those in the U.S. and the respective states, indicating slow or little economic growth.

The three principal industries in the Lake Superior basin are forestry, mining, and tourism (NWF 1993).

Administration of natural resources in Ontario (including forestry, fish and wildlife, and public lands) is the responsibility of the Ontario Ministry of Natural Resources (OMNR).  Portions of two OMNR Regions and five OMNR Districts are found within the basin.  District offices coordinate the local field delivery of OMNR programs including forest management planning and fish and wildlife inventories and allocation.  Forest management occurs on a number of forest management units under Sustainable Forest Licenses across the commercially harvested Crown forests of Ontario.  Individual Forest Management Plans are prepared by the forest management companies, in conjunction with OMNR staff, every five years.  The two-year planning process involves a great deal of public and stakeholder consultation and is aimed at ensuring that sustainable forest management occurs.  Planning and management follows an ecosystem approach in which timber harvesting attempts to follow natural disturbance patterns (e.g., fire) and retain important wildlife habitat features such as snags and winter habitat.

Fisheries management (i.e., sustainable use, protection, rehabilitation and restoration) is largely OMNR’s responsibility, however, the federal Department of Fisheries and Oceans retains responsibility for fish  habitat under the habitat provisions of the federal Fisheries Act through review and monitoring of activities near water.

Forty-seven percent of the timberland in the U.S. portion of the basin is in public ownership, which includes lands managed by the federal government (U.S. Forest Service), states (Departments of Natural Resources), and counties. The remainder is owned by the forest industry and private landowners. The U.S. Forest Service has a multiple-use mandate and follows a planning process that directly involves the public. State Natural Resources Departments and County Forestry Departments are beginning to encourage public involvement in their forestry planning. All lands, however, are open to recreation. Coordinated regional planning is seldom, if ever, done; however, the Wisconsin and Minnesota Departments of Natural Resources recently initiated a land use planning effort for the northwest sands region (locally referred to as the pine barrens), which is located on the edge of the Lake Superior basin. They are involving interested stakeholders, including towns, counties, landowners, the forest industry, and non-profit organizations.

Since the mid-1800s, mining has had a major impact on the economics and natural resources of the basin. During the 1870s, the Silver Islet mine east of Thunder Bay was the world's most productive silver mine. It closed in the early 1880s. The Keweenaw Peninsula in the Upper Peninsula of Michigan was the world's leading producer of copper during the early 1800s. One of the largest Superfund sites in the country is a result of this copper mining (NWF 1993). Iron ore mining in Minnesota began in 1884 on the Vermilion Range and in 1892 on the Mesabi Range. The eastern portion of the Mesabi Range is within the Lake Superior basin. Mining of taconite, a lower-grade iron ore, continues on the Mesabi Range, and Minnesota remains the largest producer of iron ore and taconite in the United States. In Wisconsin, brownstone was quarried in the late 1800s to early 1900s. Approximately 12 quarries were mined, and the brownstone was exported to large cities in the United States, including Chicago, St. Louis, and Minneapolis/St. Paul. Brownstone buildings remain in the basin in Wisconsin, but brownstone is no longer quarried. Old, unreclaimed quarries dot the landscape. Mining is still one of the other major land uses. Interest in mining and manufacturing is increasing in the basin. In 1984, one of the world's largest gold deposits was found near Marathon, Ontario. Currently, there are four active gold mines in that area. Two smaller gold mines are located near Wawa. A platinum-palladium mine is located approximately 100 km north of Thunder Bay, and zinc/copper mines are located in Manitouwadge and Schreiber. The Schreiber mine is slated for closure. Diamond mining and exploration are underway in the Wawa area. This area is also under development planning for an open pit trap rock mine at Michipicoten Harbour to supply material for road base, construction, and rock wool.

Approximately three-fourths of United States iron ore is produced in Minnesota, totalling about 40 million tons per year (NWF 1993). Most of the ore is shipped to Great Lakes steel mills. One active iron ore mine is located near Ishpeming, Michigan. A large copper mine and smelting operation in Ontonogon in the Upper Peninsula was recently closed. On the Canadian side, the major iron ore-producing mine was located in Wawa. This mine and its associated processing plant produced concentrated ore from 1960 until its closure in May 1998, supplying the Algoma Steel mill in Sault Ste. Marie, which is still in operation.

By the early 1830s, the Great Lakes were opened to international shipping with the completion of several canals that connected all the Great Lakes to the St. Lawrence Seaway. This allowed commodities harvested from the Lake Superior basin to be exported to growing cities farther east. Many cities on Lake Superior had burgeoning shipping industries in the late 1890s and early 1900s, but only a few major shipping docks now remain, including those at Duluth-Superior in the United States and at Thunder Bay, Marathon, and Sault Ste. Marie in Ontario.

Railways created additional accessibility and were important for transport of harvested timber, which was not readily transported by water. Numerous railroad companies and railroad spurs were prevalent in the late 1800s and early 1900s, providing transportation to and from the region.

There are currently five large and two medium-sized pulp and paper operations and four large, two medium, and four small sawmill operations located within the basin on the Ontario side. In addition, there are two veneer mills and two oriented strandboard/particle core board mills within the basin in Ontario. Four pulp and paper mills are found on the U.S. side of the basin, two in Minnesota and two in Michigan. Several mills located outside of the basin draw pulpwood from the basin's forests. A paper mill in Ashland, Wisconsin closed in 1998.

Tourism in the Lake Superior basin is related to outdoor recreation opportunities. The forests, streams, and lakes have attracted outdoor recreation enthusiasts throughout the 20$^{th}$ century. Since the mid-19$^{th}$ century, resorts and lodges have housed visitors from metropolitan areas who come for hunting, fishing, boating, camping, and other outdoor pursuits. Outdoor recreation interest remains high today and is increasing in popularity, especially in areas within driving distance of metropolitan centers, such as Minneapolis /St. Paul. Recreation pursuits have expanded to include skiing, snowmobiling, all-terrain vehicle riding, hiking, bicycling, wildlife watching, sailing, and others. Facilities for these activities have been developed in response to the interest and need. A significant draw is the large percentage of public lands and trails available for public use. Public lands that are set aside as parks include national parks such as Apostle Islands National Lakeshore in Wisconsin and Pictured Rocks National Lakeshore in Michigan, Pukaskwa National Park in Ontario, and state parks and natural areas such as Split Rock Lighthouse State Park in Minnesota. These areas not only provide outdoor recreation opportunities, but they also protect important habitats for wildlife and fish and provide opportunities for natural resource management that are not commodity-based. Local communities that serve as gateways to these protected areas and trails gain economic development opportunities by serving tourists and residents.

## 2.5 Parks and Protected Areas

Approximately 10 percent of the Lake Superior basin is in parks and protected areas (Figure 21). For purposes of this report, protection has been interpreted broadly. Areas included range from Wilderness Class National and Provincial Parks to national forest areas and state parks. There are at least 112 areas ranging in size from Wabakimi Provincial Park (<890,000 hectare (ha), only part of which is within the basin) to Baraga State Park (22 ha) in Michigan.

On the south shore of the Lake, there are two National Lakeshores, a National Park, many State Parks that provide protection for specific sites, and parts of five National Forests that are managed for forestry and recreation, as well as providing some wilderness representation. In addition, part of the Boundary Waters Wilderness Area is within the Superior National Forest (Table 5, Figure 21).

Recently, significant steps have been taken to increase the area under protection around the lake. "Ontario's Living Legacy" has identified many new areas for protection or additions to existing parks. In addition, policies are being put in place to recognize the Great Lakes Heritage Coast. This policy will recognize the “internationally significant natural, cultural, scenic, and recreational values of the Lake Superior shoreline.” The Great Lakes Heritage Coast will apply to Crown lands, waters, lakebeds, Crown islands, and intervening coastal areas between the Pigeon River mouth and the St. Mary’s River at Sault Ste. Marie. The policy does not apply to Indian Reserves or private land.

Lands designated under “Ontario’s Living Legacy” include Provincial Parks, Conservation Reserves, and Enhanced Management Areas, totalling 3,856 $km^2$ of varying degrees of protection.

A proposed National Marine Conservation Area (NMCA) encompasses the waters and federal lands on the north shore of Lake Superior from Thunder Cape to Bottle Point. Negotiation of an NMCA establishment agreement between the Government of Canada and the Province of Ontario is ongoing.

World Wildlife Fund Canada (1999), concludes that there are “…significant gaps in the core protected areas system for the Lake Superior basin in both the terrestrial and aquatic portions in the United States and Canada.” The study indicates that 12 of 29 seascapes have a marginal degree of protection, which includes five areas with at least 10 percent protection. The remaining 24 have less than 5 percent protection.

The Lake Superior Binational Program has developed a map entitled "Important Habitat Conditions in the Lake Superior Basin" (see Addendum 6-H). This map documents a number of sites – some that are protected, some that are not – that contain habitat important for the overall health of the Lake Superior basin.

**Table 5. Parks and protected areas in the U.S. Lake Superior basin.**

| | Michigan | Wisconsin | Minnesota | Total |
|---|---|---|---|---|
| National Parks | 1 | | | 1 |
| National Monument | | | 1 | 1 |
| Wilderness (Forest Service) | | | 1 | 1 |
| National Lakeshore | 1 | 1 | | 2 |
| National Historic Park | 1 | | | 1 |
| National Wildlife Refuge | 1 | 1 | | 2 |
| State Parks | 13 | 4 | 13 | 30 |
| State Wayside | | | 3 | 3 |
| County Parks | | | 2 | 2 |
| Wilderness Area | 1 | | | 1 |

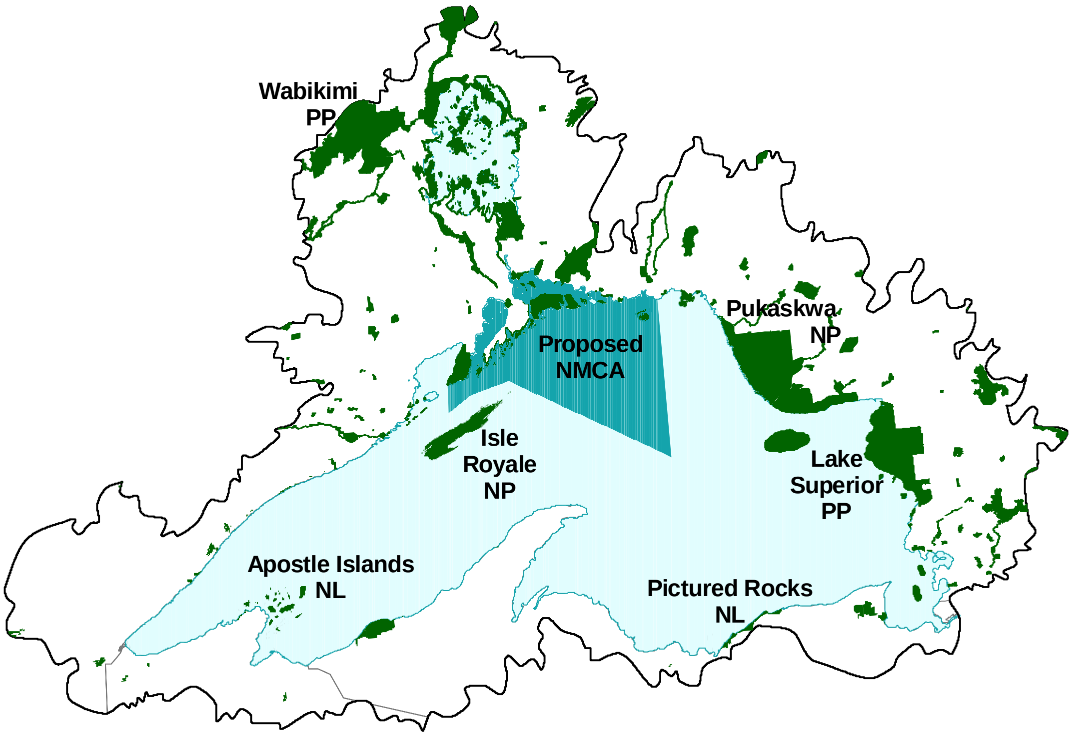


**Figure 21. Parks and protected areas in the Lake Superior basin, including the proposed National Marine Conservation Area (NMCA).**

# 3. LIVING ENVIRONMENT

## 3.1 The Terrestrial Environment

### 3.1.1 Ecological Units

The Lake Superior basin lies in a zone of transition from the mixed deciduous forests in the south to the boreal forest ecosystems of the north. This transition is apparent for many species and ecosystems. The Lake Superior basin represents the northern-most extent for many plant and animal species resident in the United States. It also represents the southern range extent for several other species native to Canada and points north. Because of the complexity of landforms within this region, it is useful to classify the land into ecological units. Often times these classification systems are hierarchical, with smaller units fitting underneath larger units. Different types of land classification systems are applied to the U.S. and the Canadian sides of the basin. Each system is useful and is described below.

Ecological land classifications are based on relationships between vegetation and the physical environment, especially soils, landform, and climate. They define "…useful and functional land units that differ significantly from one another in abiotic characteristics as well as in their related biotic components" (Albert 1995).

The Lake Superior basin is subdivided into 20 land units (called Sections) following the U.S. Ecological Subregions Classification (McNab and Avers 1994) and Ontario's Site Region classification (Hills 1959) (Figure 22). The U.S. system is based on climatic and physiographic features (i.e., bedrock features, glacial landforms, soils, and vegetation) (Albert 1995), while Ontario's classification is based mainly on climatic factors (Hills 1959). Another Canadian land classification, Ecoregions of Ontario (Wickware and Rubec 1989), closely parallels Hills's system, at least within the basin.

The entire Lake Superior basin on the U.S. side is contained in the Laurentian Mixed Forest Province (212), which stretches from New England to northeastern Minnesota. Most of this province has low relief, but rolling hills occur in many places. Lakes, poorly drained depressions, morainic hills, drumlins, eskers, outwash plains, and other glacial features are typical of the area, which was entirely covered by glaciers during parts of the Pleistocene. This province lies between the boreal forest and the broadleaf deciduous forest zones, and is therefore transitional. Part of it consists of mixed stands of a few coniferous species (mainly pine) and a few deciduous species (mainly yellow birch and sugar maple); the rest is a macromosaic of pure deciduous forest in richer soils and pure coniferous forest in poor soils. Mixed stands contain several species of conifer, mainly northern white pine, with an admixture of eastern hemlock.

The Northern Great Lakes Section (212H) makes up most of the eastern part of the U.S. basin. Gently rolling lowland and flat outwash of ground moraine and lacustrine plain predominate, with dune fields near Lake Superior. Local relief is generally less than three meters. Prevailing winds off Lake Superior result in cooler summers and milder winters than Sections to the west. Lake-effect snow and rain is common near Lake Superior. This Section is mainly forested, except the clay lake plains, which are often used for pasture and forage crops. Northern hardwood-fir forests dominate on moraines and stratified ice-contact hills with northern hardwoods on warmer than average sites. Great Lakes pine forests occurred on outwash and lacustrine sands, with jack pine forests occupying outwash and lacustrine sand plains. Conifer bogs occupy low-lying areas (Albert 1995, McNab and Avers 1994).

The Southern Superior Uplands (Section 212J) occupies the middle part of the south shore and consists of bedrock ridges and glacial moraines, lakebeds, outwash channels and plains (Albert 1995). Soils are relatively nutrient-poor, acidic, and rocky. The Lake Superior Lake Plain extends for approximately 322 km along the lakeshore from Duluth / Superior to the Keweenaw Peninsula. Soils are lacustrine clays and clayey till. Most of the Keweenaw Peninsula is a bedrock knob with sandy till. Climate is strongly continental, although considerable lake-effect snowfall occurs across this Section. Northern hardwoods occur on mesic landforms; with pines on drier sites and hemlock and white cedar on wetland landforms. Extensive clearcutting and slash burning in the late $19^{th}$ century have increased the proportion of paper birch and trembling aspens (Albert 1995, McNab and Avers 1994).

The Western Superior Section (212K) encompasses a small part of the western end of the basin. It is mostly poorly drained, flat to slightly rolling ground moraine and plain-pitted outwash, with kettles intermittently overlain by low, undulating ridges (glacial end moraines) and drumlins. Coniferous and deciduous forests dominate. Some jack pine and oak barrens are on the Bayfield peninsula. Logging and agriculture have significantly altered the environment (Albert 1995, McNab and Avers 1994).

The Northern Superior Uplands (Section 212L) constitutes most of the basin within Minnesota. It consists mainly of morainal landforms with shallow soils and low bedrock knobs. There is a prominent escarpment along Superior's shore. Numerous small lakes dominate the northern part of the Section. Climate is slightly drier and cooler than the Southern Superior Uplands, but winter precipitation is less. Forest composition shifts from northern hardwoods in the Southern Superior Uplands to more boreal pines and hardwoods in the Northern Superior Uplands. Dominant vegetation includes mixed pine with aspen-birch, white pine, red pine, jack pine, black spruce, balsam fir, and white cedar, with less common occurrences of northern hardwoods along the shore of Lake Superior. Due to the rugged terrain and cost of constructing transportation corridors, the area has remained relatively undeveloped (Albert 1995, McNab and Avers 1994).

Site Region 4W (Pigeon River), marks the transition between Great Lakes/ St. Lawrence forest and boreal forest. Along Lake Superior, the topography is rugged with shallow soils. West of Thunder Bay, deep, clayey, glacial lacustrine soils exist.

Site Region 3W (Lake Nipigon) and Site Region 3E (Lake Abitibi) contain boreal forests dominated by black spruce, jack pine, trembling aspen, and white birch. Topography is rugged with shallow morainal soils. Near Lake Superior, deep glacial valleys are filled with sandy outwash and varved lacustrine clays.

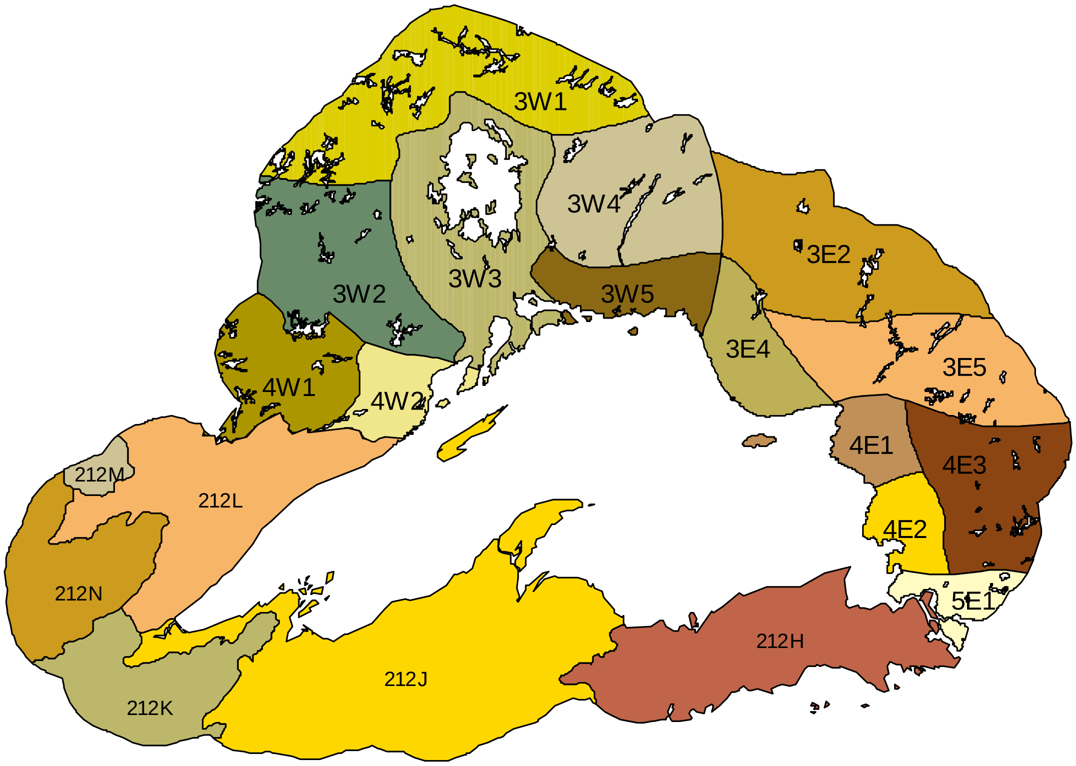


**Figure 22. Ecological land classification of the Lake Superior basin (Hills 1959 and McNab and Avers 1994).**

### 3.1.2 Forested Upland Ecosystems

The majority of the Lake Superior basin (approximately 88 percent) is forested, including conifer, hardwood, and mixed forests (Figure 23 and Figure 24). Early seral hardwoods comprise an additional 1.3 percent of the basin. Non-forested communities (grass and brush) make up only 4.5 percent of the basin. The remainder is inland lakes and rivers, agricultural land, and urban areas.

The character of the forests surrounding Lake Superior changes as one travels from south to north. Within ecological sections (described previously) deciduous, coniferous, or mixed deciduous/coniferous forest types can exist depending on soil fertility and soil moisture. Also, as one moves from the south to the north, the preponderance of conifer species increases, until one reaches the boreal system, in which most of the species are coniferous.

The species composition of forested stands depends on the ecological sections in which it is located, the relative soil fertility and moisture, and the stand's age. As forest stands are disturbed and new forests are regenerated, a predictable series of forest types appear, starting with the early seral stages and progressing to the later seral stages and ultimately to old growth forests. This series of progressions is referred to as succession.

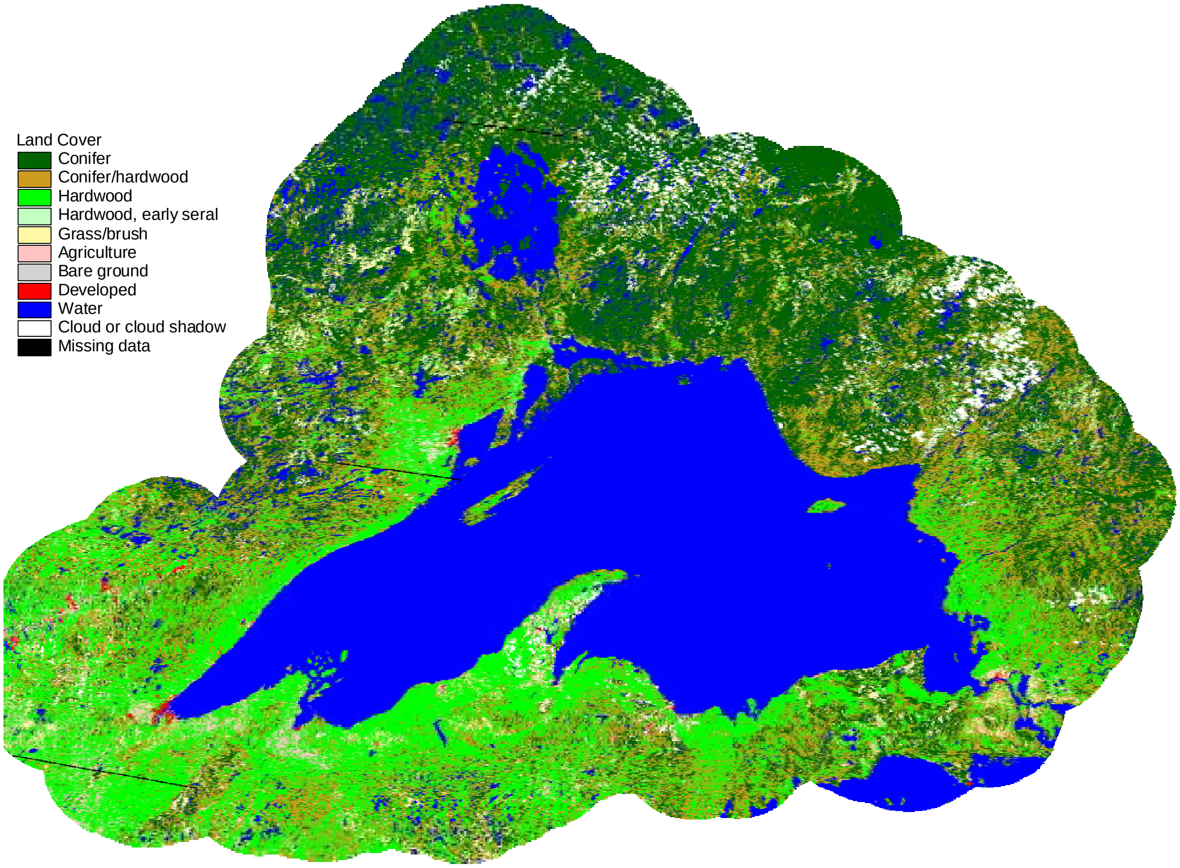


**Figure 23. Land cover classes of the Lake Superior basin (derived from Landsat Thematic Mapper (TM) remote sensing).**

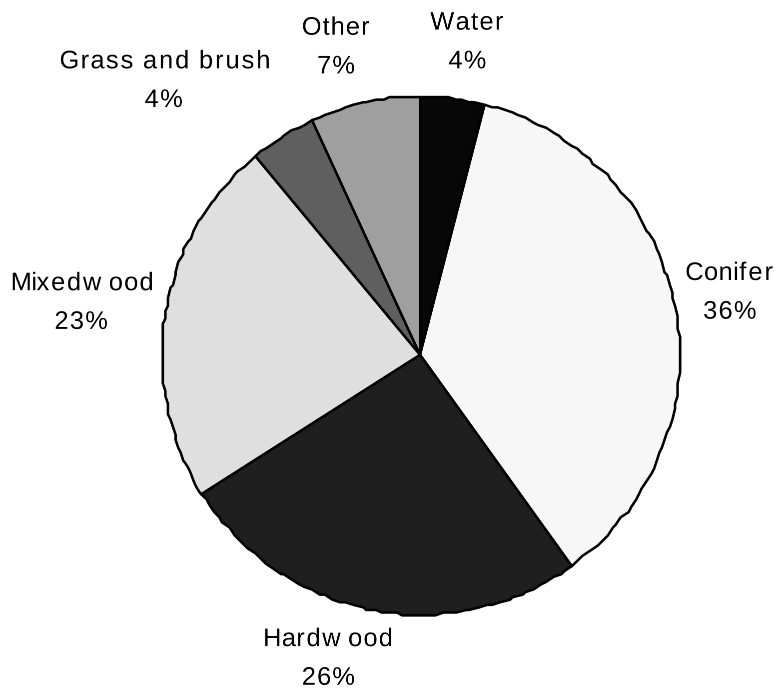


**Figure 24. Land cover classes of Lake Superior basin (excluding the lake itself) (1999).**

***Succession***

Following disturbances of the forests, early successional or seral forests form in most of the forested upland ecosystems within the basin. These forests are typically dominated by pioneer species such as jack pine, white birch, and trembling and big-toothed aspen, depending on site conditions. These seral forests have low to moderate shade tolerance and tend not to be self-replacing.

Succession in the hemlock and hardwood forests of the southern portion of the basin was historically characterized by gap dynamics. These multi-generational forests were dominated by shade-tolerant species such as sugar maple, beech, and hemlock that can reproduce without large canopy openings. Other mid-tolerant species such as yellow birch, green ash, and basswood could reproduce in gaps caused by the death of canopy trees (Frelich 1995).

Succession in the boreal system was generally initiated by large, stand-replacing disturbances. Succession was generally set back every 50 to 100 years by fire in these forests and every 150 to 200 years in red-white pine forests and oak forests (Heinselman 1981). Many of these forests were one-generational, in that many of the first trees to invade after the stand-originating fire lived until the next catastrophic fire (Frelich 1995). As long as intolerant hardwoods and jack pine form vigorous, fully-stocked stands, they restrict the development of shade-tolerant species. However, as canopy openings are created by the death of the short-lived hardwoods, more shade-tolerant species such as white spruce and balsam fir are able to succeed. In the continued absence of fire, shade-tolerant species, particularly balsam fir, will often persist on mesic sites. On more nutrient-poor sites in the boreal forest, black spruce is often the dominant species.

After these early successional stages of shade-intolerant species, such as aspen and birch, comes the mid-successional stages. There is a great deal of variation in the species composition of these mid-successional stages, depending on the location within the basin (boreal vs. Laurentian) and the soil characteristics (moist to dry, fertile to infertile). In deciduous stands of the Laurentian Mixed-Deciduous province, the mid-successional stages are characterized by red oak, basswood, and red maple while the coniferous stands contain red and white pine, white spruce, and balsam fir. In the boreal stands, white spruce and balsam fir stands form on the more productive sites, while black spruce stands form on the more hydric and less productive sites.

If no disturbance occurred on these forested upland areas, succession would lead to a more stable forest type, one that tended to be self-replacing. This is sometimes referred to as the "climax forest." It is usually composed of shade-tolerant species which can regenerate in shady conditions. If this forest type lives long enough without disturbance, it can evolve into a forest with closed canopy, large trees and much forest structure (dead and down woody material, complex canopy structure). These forests are referred to as old growth forests.

***Disturbance***

Three major disturbance regimes naturally occurred in the forests of the Lake Superior basin: fire, disease, and windthrow. In the hemlock and hardwood forests in the U.S. side of the basin, fire was relatively rare and the major disturbances were heavy or catastrophic windstorms and tornadoes that occurred at greater than 1000-year intervals (Frelich 1995). Catastrophic disturbances were relatively small (~100 ha) with an approximate maximum size of 4000 ha (Canham and Loucks 1984). Windstorms could remove 10 to 50 percent of the forest canopy in a given stand every 100 to 300 years (Frelich and Lorimer 1991). In contrast, fire, and to a lesser extent disease, are the most important landscape-level disturbances in the boreal forests and pine forest of the Great Lakes/St. Lawrence Region. Fire is essential to the regeneration dynamics of most boreal forest species, particularly early successional species such as jack pine. A site's long-term cumulative fire history plays an important role in determining present-day vegetation, since some areas are burned more frequently than others (Heinselman 1973). Fire in lowland conifer stands, for example, is less frequent than xeric (extremely dry) sites.

The fire return interval, or fire cycle, is the average period of time between stand-replacing fires in the same stands, assuming all stands in the forest burn once during the interval. The natural fire cycle for Quetico Provincial Park is 78 years (Woods and Day 1977) and approximately 122 years for the Boundary Water Canoe Area Wilderness (BWCAW) (Heinselman 1996). Based on a fire cycle of 70 years, the average annual burn fraction (i.e., the proportion of the total forest that would burn each year on average), was 1.5 percent for boreal forests in Ontario (Ward and Tithecott 1993). Since 1920, fire has burned approximately 1,212,135 ha or 16 percent of the Canadian portion of the basin (on average 0.2 percent per year), most of which is predominantly boreal (Figure 25 and Figure 26).


**Figure 25. Fires in the Canadian portion of the Lake Superior basin 1920-1990.**

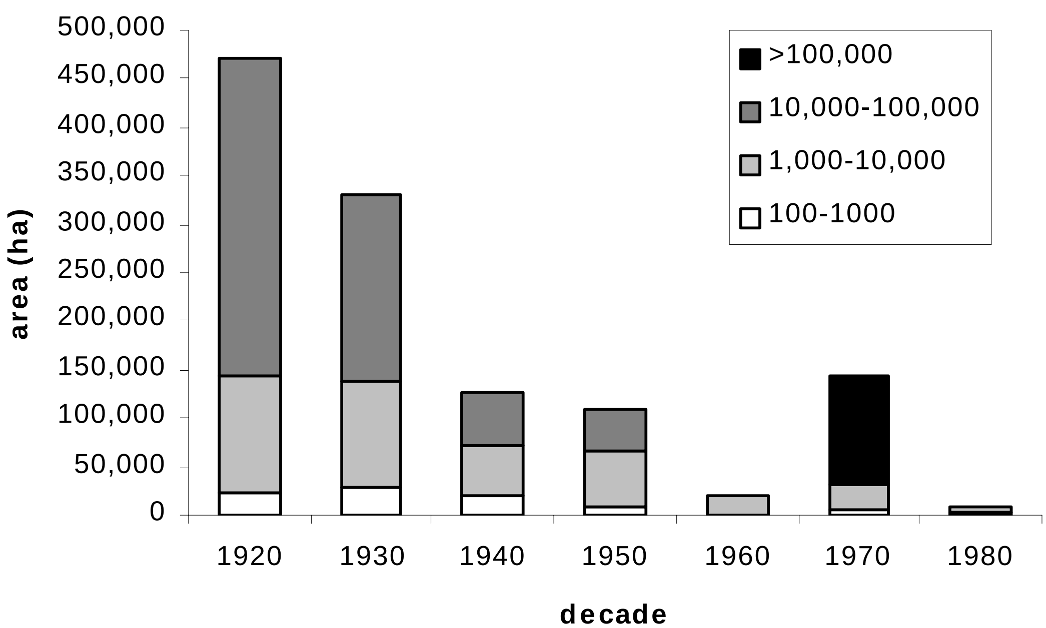


**Figure 26. Area burned by wildfire in the Canadian portion of the Lake Superior basin by fire size class (ha) and decade.**

The area burned in each decade has generally decreased due to more aggressive fire suppression, combined with improved detection and fire-fighting methods. With the exception of some islands, most of the Canadian Lake Superior basin is within the intensive fire management zone of the OMNR, which means that fires are actively suppressed. Despite this, a very large fire burned approximately 111,000 ha west of Lake Nipigon in the 1970s. With that exception, fewer large fires occur than would have occurred historically.

Historically, lightning was the main source of ignition. Lightning is more or less random, but ground strikes are more frequent on high ridges (Heinselman 1996) and lightning-induced fire is often associated with bedrock. First Nations or Native American people were another possible source of fire, but their role in fire cycles in northeastern North America is uncertain (Russell 1983). Habitat manipulation for large game would have been unlikely, since caribou was historically the dominant ungulate and they prefer mature forests. Burning to encourage blueberry production reportedly took place in northern Minnesota (Heinselman 1996).

Spruce budworm is the most important forest pest in the Lake Superior basin in terms of total area infested, length and frequency of outbreaks, as well as volume and numbers of trees killed (Candau and others 1998). It attacks primarily balsam fir, followed by white spruce, and to a lesser extent black spruce. Affected trees will die if exposed to three to five consecutive years of defoliation, and almost all the trees in dense, mature balsam fir stands are killed during uncontrolled outbreaks. Spruce budworm outbreaks are large-scale phenomena and usually consist of many infestations that occur in different localities within the basin at about the same time.

Outbreaks of high budworm densities and heavy defoliation occur every 20 to 100 years and usually last five to 15 years (Blais 1983). During the 18$^{th}$ and 19$^{th}$ centuries, outbreaks have occurred in the Lake Nipigon region at approximately 70-year intervals (Blais 1983, 1985). Lake Nipigon is one of three “hot spots” in Ontario for spruce budworm outbreaks with about 6,600,000 ha being frequently defoliated, i.e., in >1/3 of the years from 1941 to 1998 (Candau and others 1998). Extensive defoliation occurred in this “hot spot” in 1948, 1985, and 1992, with smaller peaks in other years, and an average interval of 38 years between outbreaks. Widespread mortality of balsam fir and white spruce results in a loss of valuable wood, increased risk of fire and windthrow, and associated public safety risks and degraded aesthetics.

Windthrow is relatively common in boreal forests, and is another major natural disturbance in the Lake Superior basin. Shallow-rooting species such as white spruce and white pine are particularly vulnerable (Foster 1988), as are forests heavily affected by spruce budworm. Wide-scale catastrophic windstorms occur infrequently in the basin, but may have significant impacts. Mineral soil exposed following windthrow may be important in boreal forest regeneration dynamics (Jonsson and Dynesius 1993).

### *Old Growth Forest*

“Old growth” has been variously defined and applied, but typically is used to describe forest ecosystems with old trees and their associated plants, animals, and ecological processes. In the Lake Superior basin, old growth usually refers to forests that are dominated by long-lived species including red and white pine, oaks, northern hardwood species, and lowland conifers. The age at which this occurs depends on species composition, site variables, and stand conditions, but typically occurs at approximately 120 years for long-lived species (Frelich and Lorimer 1991, Heinselman 1973). Forests dominated by short-lived species (those that normally live from 60 to 100 years) such as aspen, paper birch, balsam fir, and jack pine are relatively old at age 80 and have been referred to as "old-seral" forests (Frelich 1995).

The age structure of pre-European settlement forests was determined largely by natural disturbance regimes. In the boreal forest, stand-regenerating fires usually occurred every 50 to 200 years (Heinselman 1981), so that old growth was a temporary phenomenon that was usually only attained by oak, and red and white pine stands (Frelich 1995). In contrast, fires were rare in the Great Lake-St. Lawrence Region / Laurentian Mixed Forest Province, and catastrophic windstorms and tornadoes occurred at greater than 1000-year intervals. Many of these forests were multigenerational and old growth conditions could last centuries.

Approximately five to eight percent of the forest in the Great Lakes basin is presently old growth (including old seral forest). Only about one percent of the pre-European settlement primary forest remains in the Lake States, of which more than 90 percent is located outside the Superior basin. Nearly all the primary forest within the U.S. side of the basin is retained in large wildernesses and parks. Very little red and white pine, river bottom northern hardwood, and oak-hickory forests remain. In contrast, it is estimated that 68 percent of pre-European settlement forests in the Lake States were old growth. The proportion of old growth varied among pre-European settlement forest types, with 20 percent of jack pine forests; 45 to 55 percent of red-white pine, spruce-fir-birch, swamp conifer, oak-hickory, and river bottom forests; and 89 percent of northern hardwood forests (Frelich 1995).

The only large, primary upland forests in the U.S. side of the Lake Superior basin are those of the Porcupine Mountains Wilderness State Park (14,164 ha) and the Northshore Highlands (600 ha within the Boundary Waters Canoe Area Wilderness). Porcupine Mountains Wilderness State Park and Pictured Rocks National Lakeshore (400 ha) contain most of the protected northern hardwoods in the basin. Isle Royale National Park has 38 percent of the Lake States' protected old growth spruce-fir. Over 90 percent of the forest in the Porcupine Mountains WSP is older than 120 years, compared to approximately only 10 percent in adjacent commercial forests (Frelich 1995). The Porcupine Mountains is the largest old growth northern hardwood forest in North America and is closest to presettlement condition of any upland forest remnant in the Great Lakes region. Minnesota has 13 old growth sites totalling 1600 to 2000 ha (Kershner 1999). The private Huron Mountain Reserve has 2600 ha of old growth (Kershner 1999). There are protected old-growth forests located on the Apostle Islands National Lakeshore which are older than 350 years. Four islands, each around 120 ha, contain important old-growth stands. They are especially significant because they have not been subjected to deer browse.

Most of the Canadian side of the basin is boreal and predominantly early-seral forest. A Conservation Strategy for Old Growth Forest Ecosystems in Ontario was developed in 1994 by the OMNR (Policy Advisory Committee 1994). Most of the inventory and study of old growth forests on the Canadian Side of the basin has focused on longer-lived red and white pine. Fire suppression has resulted in older ages for some stands, but widespread logging has removed other old growth stands. There are 123 old growth (>120 years) red and white pine stands identified on the Canadian side of the basin covering 3819 ha. Most of these stands are in the southeast or northwest portion of the basin (Figure 27).

**Figure 27. Old growth red and white pine stands in the Ontario Lake Superior basin (OMNR data).**

### 3.1.3 Non-forested Upland Ecosystems

Within the Lake Superior basin upland areas occur which are non-forested. Some of these areas are quite small and remain open due to weather patterns, often referred to as "frost pockets." In these areas, cold temperatures persist late into the spring and prevent trees and shrubs from establishing and growing to maturity. In other areas, landscape-level processes (fire and disease) occur and result in an open savannah called pine barrens.

***Barrens Ecosystems***

Pine barrens are relatively large tracts of land in which frequent fires created a landscape mosaic of large openings, savannas, and forested patches. This landscape mosaic provides habitat for grassland birds and other open habitat species and is known as Pine Barrens. This community is characterized by scattered jack pines (*Pinus banksiana*), or less commonly red pines (*P. resinosa*), sometimes mixed with scrubby Hills and bur oaks (*Quercus ellipsoidalis* and *Q. macrocarpa*), interspersed with openings in which shrubs such as hazelnuts, (*Corylus* spp.) and prairie willow (*Salix humilis*) and herbs dominate. The flora often contains species characteristic of "heaths," such as blueberries (*Vaccinium angustifolium* and *V. myrtilloides*), bearberry (*Arctostaphylos uva-ursi*), American hazelnut (*Corylus americana*), sweet fern (*Comptonia peregrina*), and sand cherry (*Prunus pumila*). Also present are dry sand prairie species such as June grass (*Koeleria macrantha*), little bluestem (*Schizachyrium scoparium*), silky and sky-blue asters (*Aster sericeus* and *A. azureus*), lupine (*Lupinus perennis*), blazing-stars (*Liatris aspera* and *L. cylindracea*), and western sunflower (*Helianthus occidentalis*). Pines may be infrequent, even absent, in some stands in northern Wisconsin and elsewhere because of past logging, altered fire regimes, and an absence of seed sources.

The 930,800 ha of pine barrens in the basin have changed enormously since European settlement. Originally a mosaic of fire dependent communities, today's pine barrens contain only a small fraction of the original acreage of the ecosystem's early seral stages. This open habitat is rated as globally rare.

### 3.1.4 Islands

There are 1,763 islands in Lake Superior, most of which are in Canadian waters (Figure 28). Lake Superior islands represent over 1,672 $km^2$ and 2,265 km of shoreline. They range from small barren rock outcrops to Isle Royale, which is 71 km in length (Figure 29). Most (71 percent) islands are less than 1 ha and represent only 0.2 percent of the total island area. The three largest islands, Isle Royale, St. Ignace I. (in the Black Bay Peninsula Archipelago), and Michipicoten I. represent 62 percent of the total island area. The Apostle Islands National Lakeshore (AINL) protects 21 of the 22 Apostle Islands archipelago. The islands of AINL range in size from 1 to 4,050 ha.

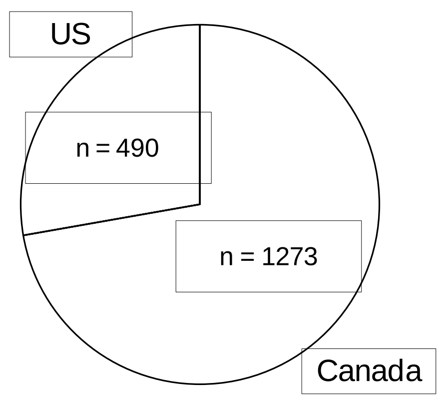


**Figure 28. Lake Superior islands (compiled from U.S. EPA 1994 and Environment Canada 1993).**

Island habitats contribute significantly to the biodiversity of the Lake Superior basin and provide important habitat distinct from most mainland sites. In 1995, a joint U.S.-Canada workshop to assess the State of the Great Lakes Islands, determined that the natural biological diversity of the islands of the Great Lakes is of global significance (Vigmostad 1999). At the 1996 State of the Lakes Ecosystem Conference, islands were also specifically identified as one of seven special ecological community types recognized within the Lake Superior basin (Reid and Holland 1997).

The cold, oligotrophic nature of Lake Superior and the harsh microclimates of exposed shorelines on many islands have created conditions suitable for scattered populations of plants normally only found in arctic or alpine regions. These species were present immediately after the last Wisconsin glaciation and have been able to persist because of these climatic refugia. Many of these plants, known as "arctic-alpine disjuncts," are well-represented in Lake Superior.

Island ecosystems are greatly influenced by their isolation from mainland communities. Their isolation tends to simplify wildlife communities and provide protection from predators (Reid and Holland 1997). Islands often serve as "living laboratories" where studies of the impact of herbivores, predator-prey relationships, evolution and extinction, population dynamics, animal cycles, dispersal, and rapid population growth can be conducted.

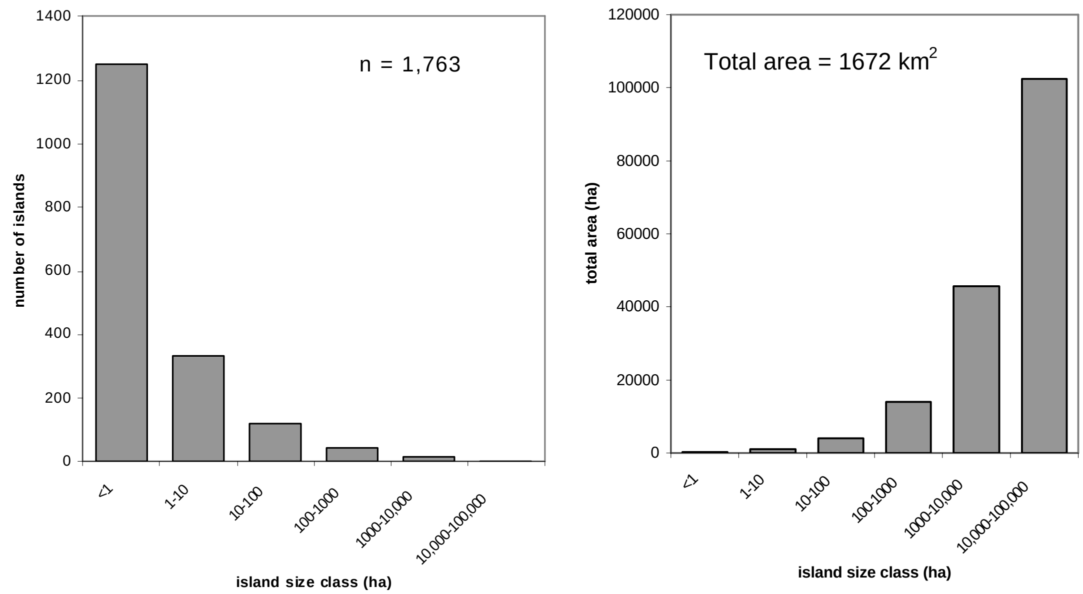


**Figure 29. Lake Superior islands size distribution in terms of number of islands and total area (compiled from U.S. EPA 1994 and Environment Canada 1993).**

Moose commonly calve on small islands and woodland caribou persist (naturally or by reintroduction) on some offshore islands due to the absence of predators. Lake Superior islands provide nesting sites for ring-billed and herring gulls, double-crested cormorants, and great blue herons (Blokpoel and Scharf 1999). Isolated island habitats have few mammals, reducing egg predation for ground nesting birds. Islands also provide stop-over refuges for birds flying over open water at night or form natural extensions to mainlands that follow critical migratory flight corridors.

Many of the islands in Lake Superior are encompassed in protected areas (Figure 30). Lake Superior islands may be particularly suited to serve as biosphere reserves especially in terms of sentinels to detect the long-range transport of toxic materials (Vigmostad 1999). They are under stress, however from increased recreational use particularly sea-kayaking and boating, and human manipulation of lake levels. These isolated islands are sensitive due to the limited potential for recolonizing with mainland species in the event of an extirpation. Islands are by their nature subject to human curiosity and regularly attract human visitation to their shores. Human intrusions can range from recreational visitation by boaters to housing development.

### *Isle Royale*

Isle Royale is the largest island in Lake Superior (555 km$^2$) and is 22 km from the nearest mainland. Climax spruce-fir and yellow birch-sugar maples are the dominant forest cover. Isle Royale is well-known for its long-term studies of predator-prey relationships involving wolves and moose. Caribou were historically present, but white-tailed deer, black bear, raccoons and porcupines are notably absent. Isle Royale is perhaps the best known of the Lake Superior Islands because of its National Park and International Biosphere Reserve designation. It is the only island based national park in the United States and is a federally designated wilderness area (Vigmostad 1996).

### *Apostle Islands*

The 22 Apostle Islands cover over 219 km$^2$ and comprise approximately 291 km of shoreline. Twenty-one of the islands are protected by Apostle Islands National Lakeshore, which is managed by the U.S. National Park Service. Apostle Islands include many important habitats including old-growth forest remnants, a wide variety of coastal features, sandstone cliffs with arctic remnant rare plants, and important habitat for nesting, migratory and colonial birds. The Apostle Islands are comprised of pre-Cambrian sandstone, the remnants of an old braided river channel that created a unique archipelago with almost grid-like spacing. The islands are largely comprised of northern hardwood forest with some pine forests and dune vegetation being found on sand spits and other coastal features. Outer Island has one of the largest remaining virgin hemlock hardwood forests in the Great Lakes region (Vigmostad 1999). This stand has an especially unique understory because it does not have a history of ungulate browsing.

### *Grand Island*

Grand Island lies just offshore in Grand Bay, Lake Superior, near Munising, Michigan, west of the Picture Rocks National Lakeshore. This 55 km$^2$ island is managed by the Hiawatha National Forest as a National Recreation Area, and features sandstone cliffs on the northwest, north and western shorelines.

Outstanding features of this island include a tombolo (connecting sandbar) between two parts of the island and an expansive marsh on Murray Bay. The marsh includes wet meadow, shrub swamp and poor conifer swamp, features a diverse and unusual array of plants. Upland conifers dominate the northern ridges. The upland areas feature some rare plants, habitat for peregrine falcons, and a small, forested Research Natural Area. This is the only large island in Michigan's portion of Lake Superior that consists of sandstone bedrock (adjacent small islands are also sandstone), and second only to Isle Royale in size in Michigan's portion of Lake Superior. Peregrine falcons last nested on the island in 1906 but were reintroduced to the island in 1992.

Grand Island has very high biodiversity significance, primarily because of the excellent quality marsh. The Michigan Natural Areas Council has worked on developing a vegetation monitoring plan for the island in response to impact concerns that may arise from recreational uses.

### *Slate Islands*

The Slates Islands are an archipelago of 58 islands, 13 km from the mainland shoreline near Terrace Bay. They range in size from small barren rocks to Patterson Island at 22 km$^2$. The Slate Islands have exceptionally interesting and significant geology. They are comprised of an array of metamorphic rocks indicative of an ancient volcanic cone or perhaps thought to be the remnants of a crater from a meterorite impact (Snider 1989). The Slate Islands were exposed approximately 3,000 years ago after slowly rebounding from the weight of glaciers.

The Slate Islands provide an example of how isolation from the mainland has affected wildlife communities. The islands support the southern most population of woodland caribou in North America. Caribou are present at extremely high densities (200 to 400 animals) due to the absence of predators. Other large mammals such as moose, deer and wolves have not become established on the Slate Islands (in 1997 two wolves are believed to have reached the island across the ice, but have not persisted). The Slate Is. are also notable for populations of arctic-alpine plants and devil's club, a western disjunct also found on Porphyry Island and Isle Royale. Herring gulls nest on at least seven locations, including the Leadman Islands.

The Slate Islands and surrounding waters within 400 m of shore are protected in the Slate Islands Provincial Park. There is a Canadian Coast Guard lighthouse and outbuilding on federal land on the south shore of Paterson Island.

***Black Bay Peninsula Archipelago***

Over 480 islands form an archipelago along the outer edge of the Black Bay Peninsula and Nipigon Bay along the north shore of Superior. They range from wave-washed rocks to a number of large islands over 1000 ha each including St. Ignace Island (274 $km^2$), Simpson I. (73 $km^2$), Wilson I. (19 $km^2$), Edward I. (16 $km^2$), Fluor I. (14 $km^2$), Vein I. (10 $km^2$) and Copper I. (9 $km^2$). These islands have numerous arctic-alpine communities and colonial nesting waterbirds. The archipelago is largely undisturbed by development and parts have recently been protected as a Provincial Conservation Reserve. The islands are also part of an area currently being considered for establishment of a National Marine Conservation Area.

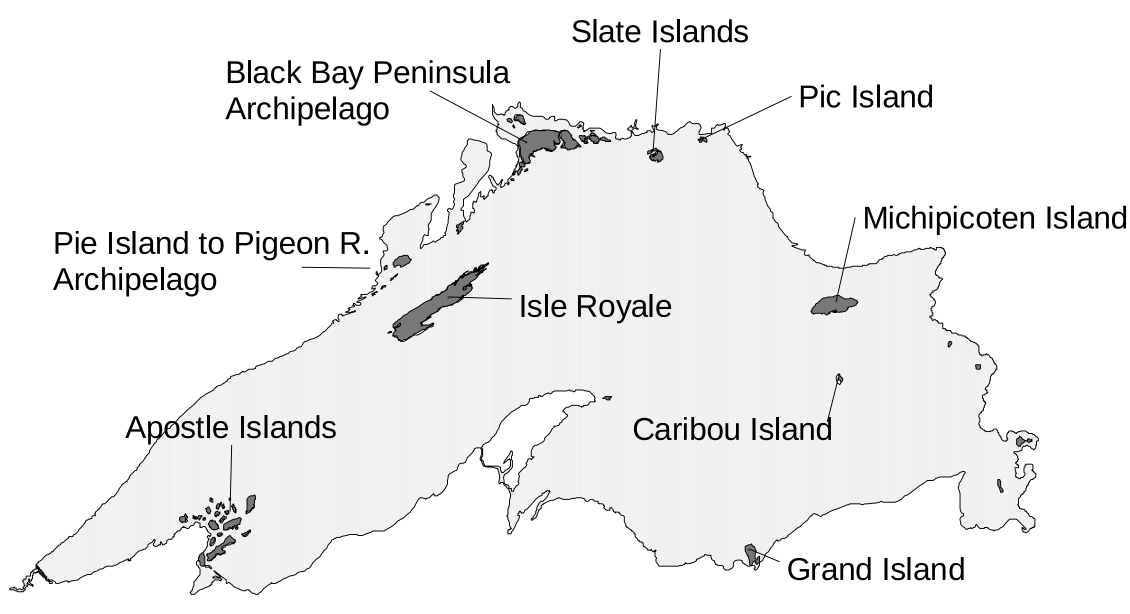


**Figure 30. Major Lake Superior islands.**

### *Michipicoten and Caribou Islands*

Michipicoten is a large island (184 $km^2$) in eastern Lake Superior significant for its introduced woodland caribou population. Caribou Island (12 $km^2$) is due south of Michipicoten Island, approximately 65 km from the mainland and is notable for its isolation and as a rest stop for migrant birds. Michipicoten is a provincial park, and Caribou Island is largely protected from human disturbance by its extreme isolation.

### *Pic Island*

Pic Island is a small island (11 $km^2$) on the north shore of Superior that historically had woodland caribou and still has suitable woodland caribou habitat. Together with three adjacent islands, they have arctic-alpine plants and colonial-nesting birds. They have recently been incorporated into the adjacent Neys Provincial Park.

## 3.1.5 Wildlife

The Lake Superior basin represents a transition zone for wildlife along with vegetation. Lake Superior represents a barrier to dispersal, as does the change in forest composition and climate. No terrestrial vertebrate species are endemic to the Lake Superior basin. Although the term “wildlife” can be defined variously, here it will be used to describe mammals, birds, herptiles, and some invertebrates. See Addendum 7-C for scientific names of non-fish species included throughout this chapter.

### *Mammals*

Fifty-nine species of mammals are native to the Lake Superior basin. Many of these have wide-ranging distributions, but approximately 25 percent are predominantly boreal and 20 percent are species primarily from more southerly deciduous forests (Burt 1975, Dobbyn 1994). In addition to this ecological transition, a social transition exists. Canada (and the Provinces) treat individual species differently than does the U.S. (and the States). For example, the lynx is classified as a Threatened species in the U.S., while classified as a game animal in Canada. This dichotomy of mammal status makes describing the mammal community in the Lake Superior basin complicated.

The mammal community of the Lake Superior basin has been significantly affected by land use change, particularly within the U.S., during the past century. Large carnivores were largely eliminated or greatly reduced in abundance. Some species (e.g., fishers) are making recoveries. Some herbivores have benefited from these land-use changes. Beavers have increased in abundance to the point of causing damage to roads and impacting forested stands. White-tailed deer populations are high in some portions of the southern basin, causing damage to people (e.g., automobile collisions) and forests. A few species, such as coyote, have benefited from habitat change and expanded their ranges and numbers (Hazard 1982, Frelich and Lorimer 1985). It is necessary to place the mammal community in the context of these changes.

*Deer*

White-tailed deer reach the northern extent of their continental range in the Lake Superior basin. Their population densities range from less than two to 15 deer/$km^2$, from northern Ontario to Wisconsin, respectively. Deep snows, cold temperatures, and lack of cover prevent deer from ranging much beyond the northern boundary of the basin. Deer are an important species for several reasons. They are an integral part of forested ecosystems, sometimes referred to as a keystone species. They can have negative impacts on people and forests when they reach over-abundant levels. Deer also provide food for large carnivores such as timber wolves. Deer provide various social benefits, such as hunting and viewing opportunities and the associated economic stimulus.

*Moose*
Moose are more common in the northern part of the basin, become less common to the south, and are relatively common in Ontario and Minnesota. Michigan conducted moose translocation projects to estimate the moose population. Only a handful of moose exist in Wisconsin, with those few animals finding their way to the western part of the state from populations in Minnesota and to the eastern part of the state from moose in the Upper Peninsula of Michigan. Although moose are another large herbivore, they have not been associated with damage complaints, as deer have, because they tend to occupy land removed from human populations. Moose is a big-game species that is hunted over most of the basin.

*Caribou*
Caribou are absent from the south side of the basin, but a few populations occur in Ontario. Woodland caribou population trends are discussed in the *Status and Trends* section of this report.

*Beaver*
Beavers benefited from land use changes in the last century and have recovered from heavy exploitation during the trapping era. They remain a trapped species within the U.S. and Ontario but harvests have declined since the heyday of trapping. Beavers are found throughout the Lake Superior basin occupying the lakes, streams, and wetlands of the region. They are one of the few animals that can alter the habitat to meet its needs. Unfortunately, beaver dams occasionally cause damage to roads and forest lands. Beavers have caused declines in some cool-water fish populations because of their dam building. (Dams back up water, which then warms to a temperature too high for some fish.) On the other hand, beavers create many hectares of wetlands which have benefits to many bird and herptile species.

*Coyote*
Coyotes have benefited from land-use changes and are present at varying densities throughout the basin. They are harvested through hunting and trapping for their fur. With the reductions in wolf populations, coyotes have increased in abundance, occupying areas from which they were once absent. The potential cascading effects of this change have not been investigated.

*Wolves*
Wolves are present at various levels of abundance throughout the Lake Superior basin. They are classified as a game animal and are harvested for their pelts in Ontario. Wolves are a federally listed Threatened species in the U.S., having been recently down-listed from Endangered. Population recovery goals have largely been met and the process is underway to de-list wolves in the U.S. Wolves are a top-level predator and can impact prey populations. They also can cause depredation to some livestock and game farm operations.

*Medium sized carnivores (marten, fisher, bobcat, lynx, , red fox, grey fox, mink, otter, badger)*

Martens and fishers are now present throughout the basin, although they were both extirpated from Wisconsin and Michigan. Populations in these states are the result of reintroduction efforts. They are trapped in Ontario, Minnesota, and Michigan but are classified as state Endangered in Wisconsin, with only a few hundred individuals present. Densities vary among populations in Ontario, Minnesota, and Michigan. Bobcats are more common in the southern portion of the range and become rare to the north. Lynx are just the opposite, being more common in Ontario where they are trapped, and becoming so rare as to be classified as Threatened in the U.S. Red fox, like coyotes, are well established throughout the basin while grey fox is rare in the south basin area and absent from the north. Mink, otters, and badgers are relatively common throughout the basin. The status of many of these species has not been monitored over the years and so population estimates are unavailable.

*Small mammals*
Little has been reported about the small mammal populations (including bats) of the Lake Superior basin, including species that reach the northern part of range, e.g., southern flying squirrel, and species that reach the southern part of range, e.g., northern bog lemming. Many small mammal populations are cyclic and so vary from year to year. No long-term monitoring projects of small mammal populations have been undertaken, so little is known of these species. Some agencies have conducted inventories or other periodic sampling of small mammal populations. Apostle Islands N. L. has surveyed small mammals on 4 of the 22 islands.

***Birds***

The bird species of the Lake Superior basin also reflect a north-south transition. In the northern portion of the basin, boreal species such as the great grey owl, spruce grouse, and three-toed woodpecker are common. Farther south, species typical of the Great Lakes/St. Lawrence and northern hardwood forests, such as rose-breasted grosbeak, scarlet tanager, and red-headed woodpecker are found. Widespread species, such as the American crow, black-capped chickadee, and red-tailed hawk, are found throughout the basin. A few species with western affinities (e.g., yellow-headed blackbird) are found locally.

Of the approximately 200 species of birds that nest in the Lake Superior basin, 130 to 150 species migrate south for the winter (Cadman and others 1987). A smaller number of species (<30) are permanent residents (e.g., most owls, woodpeckers, and grouse). A few species, such as the snowy owl, northern shrike, and common redpoll, breed farther north and are only winter residents in the basin. Although not on a major flyway, relatively large numbers of migrants pass through on the eastern and western sides of Lake Superior. Three well-established, introduced bird species inhabit the basin: rock dove (now reclassified by the American Ornithologists' Union (AOU) as rock pigeon), house sparrow, and European starling. Other introduced species including mute swan, ring-necked pheasant, and house finch have established local populations.

Lake Superior provides important habitat for migratory waterfowl, especially diving ducks. Coastal wetlands also provide important habitat for both breeding and migrating birds. Although Lake Superior is not a center of waterfowl production in North America, large numbers of migratory waterfowl pass over and around the Lake each spring and fall during migration.

*Neotropical migrants*
Neotropical migrants include most of the forest warblers of the region. These birds are sensitive to forest fragmentation and the associated adverse impacts (primarily predation and nest parasitism) of forest edges. Multiple species of neotropical migrants nest in the basin. Some species are showing indications of population decline, while others are either stationary or slightly increasing.

*Colonial nesting birds*
Colonial nesting birds (i.e., gulls, terns, and cormorants) are found throughout the basin at varying levels of abundance. Some of these species are sensitive to environmental perturbations and have undergone large population changes. Cormorants, for example, had been classified as a Threatened species in the U. S. However, due to reduction in mortality factors and increased reproductive success due to pesticide restrictions, cormorants have recovered enough to be de-listed. In some areas of the basin, these birds are seen as a nuisance because of their impacts on some fish populations.

*Birds of prey*
Bald eagles are found throughout the basin. Listed as Endangered for many years in the U.S., their population has recovered sufficiently to be down-listed to Threatened. Bald eagle population trends are discussed in the *Status and Trends* section of this report. Peregrine falcon population trends are also discussed in the *Status and Trends* section of this report.

***Reptiles and Amphibians***

A recent survey of institutional collections, atlas projects, and monitoring efforts found records of 37 species of reptiles and amphibians in the Lake Superior basin (Casper 2002), including seven salamander, 12 frog and toad, six turtle, two lizard, and 10 snake species. An additional 10 species of herptiles occur near the margins of the basin or were erroneously reported. Generally, the abundance and diversity of amphibians and reptiles is dependent on climatic conditions. The short growing season and cold, severe winters limit the number of species that can survive in the Lake Superior basin, especially in the north.

Blue spotted and red-backed salamanders are found throughout the basin (Casper 2002; Cook 1984, Conant and Collins 1991). Common frog and toad species throughout the basin include American toad, spring peeper, green frog, wood frog, and leopard frog. Turtles found throughout the basin include the snapping turtle and the painted turtle. No lizard species are common in the basin. Widely distributed snakes include garter snake, red-bellied snake, and ring-necked snake. Most other species found within the basin are restricted to the south (Casper 2002). The mink frog is a northern species, with the southern border of the basin representing its southern range limit.

Few monitoring programs occur in the region, thus population data are lacking (Casper 2002). Frogs and toads are monitored by some state and local governments or organizations using calling surveys. However, the majority of herptile species remain unstudied and unmonitored.

***Invertebrates***

About 90 percent of the nearly one million species of animals in the world are terrestrial or aquatic invertebrates (animals without backbones). In the Great Lakes region, the larger, more easily seen invertebrates include mollusks, such as snails and clams, and insects. Insects are the most diverse animal group and may have the largest collective biomass of all terrestrial animals.

Within the Lake Superior basin, however, little information exists on status and trends of the insect or other invertebrate populations. The groups are too large to encompass, and taxonomic problems have impeded the development of status and trend information. Although invertebrates can be sensitive to environmental conditions, in a recent review of soil invertebrate species (Mallik 2002) concluded that monitoring of these species would be unduly intensive and would not yield beneficial results. Some have suggested that aquatic invertebrates, such as mussels and clams, can be indicators of water quality, but similar conclusions have not been reached for terrestrial invertebrates.

Some recent research has shown that most earthworm species in the Lake Superior basin are exotics, introduced after the most recent glaciations eliminated earthworms from the region. These non-native earthworms have negative impacts on forest flora. Earthworms increase decomposition rates of the duff on the forest floor. Herbaceous plant species adapted to this forest duff layer (e.g., Canadian shield plants) are adversely impacted by this decomposition.

## 3.2 The Transitional Environment

### 3.2.1 Shorelines

The most comprehensive classification of Lake Superior shorelines are the Environmental Sensitivity Atlases compiled by Environment Canada (1993) and the United States National Oceanic and Atmospheric Administration (U.S. EPA 1994). Although primarily designed to assist in response to oil spills, these Canadian and U.S. atlases also provide data on Lake Superior's shoreline characteristics and features.

This classification system established a number of distinct shoreline habitat types. The U.S. approach to this shoreline classification strategy offered a slightly finer level of detail by providing a greater number of categorized shoreline types. However, both the Canadian and U.S. atlases share a number similar physical themes that, when merged, provide an overview of shoreline habitat for the entire basin. Shoreline types are summarized in Figure 31and Figure 32, and Table 6.

#### *Cliff*

This feature includes bedrock cliffs of various heights comprised of resistant or impermeable bedrock surfaces. This is the most extensive shoreline habitat type of Lake Superior, comprising 32 percent of the shore. Most cliff shores are in Canada, making up the predominant shoreline type on the outer islands and along the eastern shore (Figure 31 and Figure 32). In the U.S., cliffs are common in the Pictured Rocks area, Isle Royale and along the Minnesota north shore. Many rare plant species grow along exposed, shallow soil cliff tops.

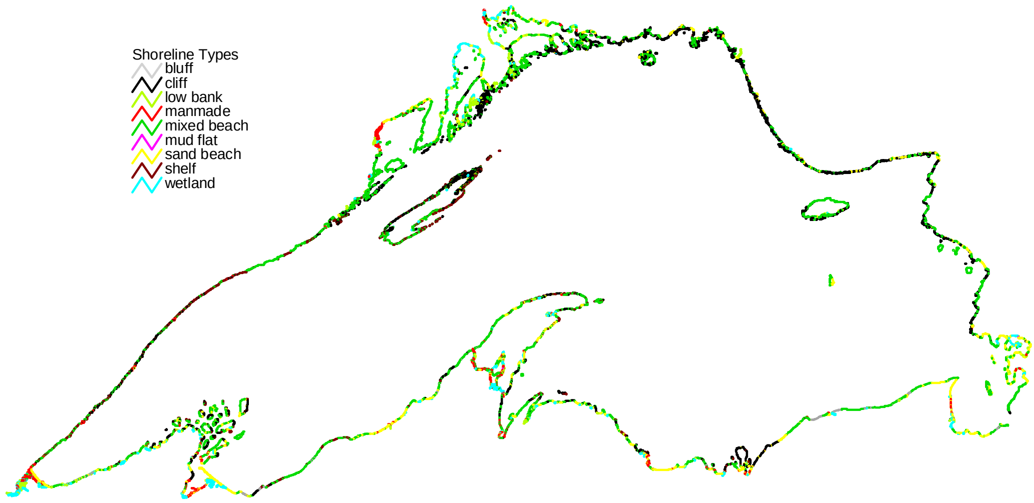


**Figure 31. Lake Superior shoreline types (Environment Canada 1993 and U.S. EPA 1994).**

### *Shelf*

Shelf shoreline consists of flat expanses of bedrock, often extending below water levels. Bedrock shelves are often influenced by wave action. Shelving bedrock shoreline is found mainly in the U.S., particularly on Isle Royale and the Minnesota north shore. Exposure, cool temperatures, and shallow soils provide conditions suitable for arctic-alpine disjunct plant species.

### *Bluff*

Bluffs, or scarps, are unconsolidated soil banks in an erosional state from wind, wave, and surface water action. They represent a source of sand and other mineral soil that is transported and deposited to form sand beaches. Bluffs are uncommon on Lake Superior, making up only one percent of the shoreline.

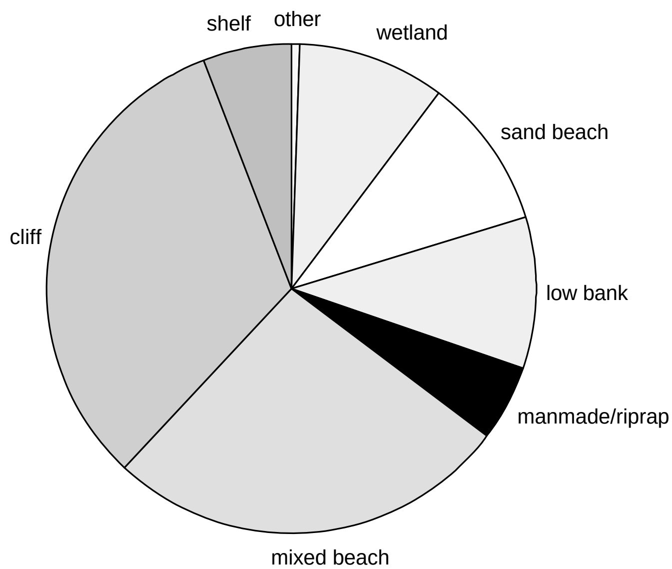


**Figure 32. Lake Superior shoreline types (compiled from U.S. EPA 1994 and Environment Canada).**

**Table 6. Physical features of Lake Superior shoreline (compiled from U.S. EPA 1994 and Environment Canada 1993).**

| Shoreline Type | U.S. | | Canada | | Total | |
|---|---|---|---|---|---|---|
| | km | % | km | % | Km | % |
| Cliff | 607 | 18 | 1,533 | 46 | 2,140 | 32 |
| Bedrock Shelf | 344 | 10 | 36 | 1 | 380 | 6 |
| Bluff | 30 | 1 | 4 | - | 35 | 1 |
| Sand Beach | 409 | 12 | 256 | 8 | 665 | 10 |
| Mixed Beach | 980 | 30 | 797 | 24 | 1,777 | 27 |
| Low Bank | 175 | 5 | 491 | 15 | 666 | 10 |
| Mud Flat | 2 | - | 1 | - | 3 | - |
| Fringing Wetland | 173 | 5 | 154 | 5 | 327 | 5 |
| Extensive Wetland | 294 | 9 | 25 | 1 | 319 | 5 |
| Artificial Structure | 112 | 3 | 22 | 1 | 134 | 2 |
| Riprap | 157 | 5 | 40 | 1 | 197 | 3 |
| **Total** | **3,283** | | **3,359** | | **6,643** | |

### *Sand Beach*

Sand beaches are formed where waves and wind and littoral drift deposit sand particles. Most sand beaches are on the eastern and southern shores of the lake, particularly in sheltered bays where wave action is lessened. Beaches are important areas for migrating shorebirds that feed on a variety of invertebrates. They also provide habitat for a number of rare species dependent on the beach environment. Artificial shoreline structures and the hardening of shorelines can interrupt the process of longshore sediment transport that naturally erodes and replenishes beaches.

### *Mixed Beaches*

Mixed beaches are a combination of sand, gravel, cobbles, and boulders, the proportions of which depend largely on the degree of exposure to wave energy. Cobble and boulder beaches are more common on wave-washed shores and sand/gravel beaches are more common in more sheltered sites. Mixed beaches make up 27 percent of the Lake Superior shoreline. Exposed cobble beaches are largely devoid of vegetation, but in more protected areas they support mosses and lichens. Herbs, graminoids, and woody plants are found above the limit of wave action. The spaces between cobble and other beach materials provide habitat for a variety of terrestrial and aquatic insects. Below the wave wash zones cobble beaches serve as lake trout spawning habitat. Perhaps the most spectacular of this habitat type are the raised cobble beaches resulting from a combination of glacial rebound and receding lake levels. One of the more notable sites for raised cobble beaches is Cobinosh Island near Rossport, Ontario.

### *Low Banks*

Low banks are shorelines with vegetation extending to the waterline. They make up only 10 percent of Lake Superior's shoreline. These are typically found in protected bays where they are sheltered from wind and wave scouring.

### *Mud Flats*

Mud flats are typically found near the mouths of rivers where suspended sediments are deposited upon reaching the waters of Lake Superior. Less than one percent of Lake Superior's shoreline is mud flat.

### *Wetland Shorelines*

Wetland shorelines include fringing wetlands and extensive wetland. Fringing wetlands are marsh communities, characteristically found in shallow water coves protected from wind and waves. They closely border the shore to form a narrow belt of aquatic vegetation. Because urban and cottage sprawl also tend to focus lake front developments in sheltered coves, wetlands tend to be a shoreline habitat particularly susceptible to human impacts. Extensive wetlands are larger (up to one to two km long) and occupy shallow coves with stream outlets. On Lake Superior, marsh communities are the most common type of broad wetland. These two wetland shoreline types make up five percent of the Lake Superior shoreline, with most of the extensive wetlands on the south side of the Lake.

### *Artificial Structures*

This category includes retaining walls, harbour structures, sheet piling, breakwaters, and riprap. This type of shore is usually found in close proximity to urban areas. Riprap is comprised of rock material placed to protect shoreline property. Solid, straight-line artificial structures provide little habitat for terrestrial or aquatic life. In some instances, riprap can enhance fish habitat by providing a suitable spawning substrate, but habitat for plants and animals dependant on soft substrates is lost. Gulls frequently use breakwaters for resting, feeding, and nesting. Collectively, artificial shorelines make up five percent of the Lake Superior shore, mainly in the U.S.

## 3.2.2 Wetlands

Wetlands often form the link between the terrestrial environment and Lake Superior. They provide habitat for fish and wildlife, protect shoreline areas from erosion, buffer runoff following storm peaks, and contribute to the diversity of habitat types in the basin.

Wetlands can be classified in different ways. One of the most widely accepted classifications recognizes five major categories of wetlands. Bogs are peatlands (i.e., wetlands with more than 40 cm of organic soil) where the surface is isolated from contact with mineral rich ground water. They are acidic and nutrient-poor. Fens are peatlands nourished by groundwater flow and are therefore richer than bogs. Swamps are dominated by trees or tall shrubs and have standing or gently moving waters. They have organic or mineral soil. Marshes are flooded by standing or slowly moving water for all or part of the year and are usually associated with lakes or streams. Shallow open water wetlands are also flooded by water, but are dominated by submergent and floating-leaved plants (NWWG 1988).

Wetlands can also be classified by type of aquatic system (lacustrine, riverine, estuarine, palustrine) and site type (e.g., open embayment, barrier beach lagoon, dune and swale complex, etc.) (Chow-Fraser and Albert 1998).

About 15 percent of the U.S. basin is made up of wetland (excluding marshes and shallow water) (Table 7). An alternative estimate of Minnesota's wetland area using National Wetland Inventory (NWI) data puts the total for the basin at 31 percent of the land base (MPCA 1997). Differences in estimates of total wetland area are due to different techniques and definitions of wetlands. Digital NWI data are unavailable for Wisconsin and Michigan.

**Table 7. Wetland area for the U.S. Lake Superior basin (exclusive of open water and deep marsh wetlands) (data from Lake Superior Decision Support Systems).**

| Wetland Class | Total Area ($km^2$) | Percent of Basin |
|---|---|---|
| Michigan | | |
| Forested | 1935 | 10 |
| Non-Forested | 366 | 2 |
| Subtotal | 2301 | **11** |
| Minnesota | | |
| Forested | 3067 | 19 |
| Non-Forested | 312 | 2 |
| Subtotal | 3379 | **21** |
| Wisconsin | | |
| Forested | 699 | 9 |
| Non-Forested | 82 | 1 |
| Subtotal | 781 | **10** |
| **Total U.S.** | **6461** | **15** |

Minnesota's wetlands are mostly bog, fen, and swamp, typically in palustrine environments. Marshes and shallow open water are mostly found on inland lakes and streams (Wright and others 1992, MPCA 1997) (Figure 33).

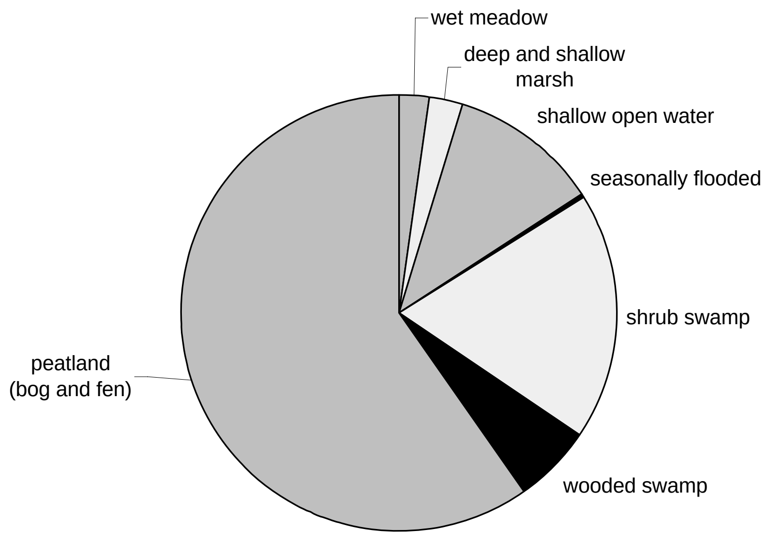


**Figure 33. Proportions of wetland types for the Minnesota Lake Superior basin; "bog" includes bog and fen (MPCA 1997).**

The most heavily concentrated areas of wetland in the U.S. basin are in western Minnesota and eastern Michigan (Figure 34). The St. Louis River watershed is 41 percent wetland, with extensive peatlands in the central watershed (MPCA 1997). Large peatlands in Luce and Chippewa counties in Michigan are also noteworthy (Crum 1988).

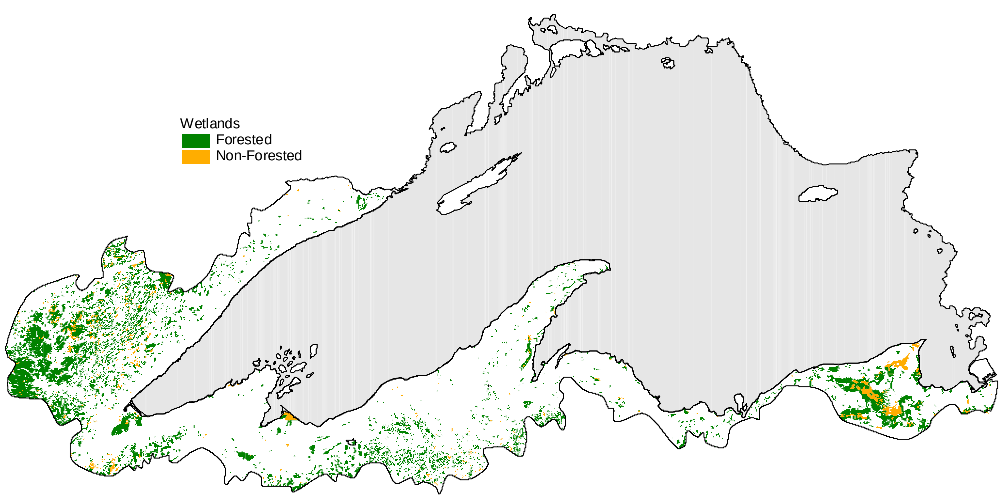


**Figure 34. Forested (green) and non-forested (orange) wetlands in the U.S. Lake Superior basin (Lake Superior Decision Support Systems data).**

Detailed data are unavailable for Ontario, but the area surrounding the basin is estimated at 6 to 25 percent wetland cover by area (Figure 35) (NWWG 1988). Wetlands in Ontario are concentrated in the eastern and western ends of the basin. The Ontario basin is within the "Low Boreal" and "Humid Mid-Boreal" wetland regions, where the most common wetland types are bogs, fens and coniferous swamps.

**Figure 35. Wetlands in the Ontario Lake Superior basin (OMNR data).**

### 3.2.3 Coastal Wetlands

Coastal wetlands make up 10 percent of the Lake Superior shore (Table 7, Figure 36) mostly associated with protected bays, estuaries and barrier beach lagoons (Chow-Fraser and Albert 1998). Lake Superior coastal wetlands consist of small lacustrine marshes dominated by spikerush and hardstem bulrush with richer submergent communities in more sheltered estuaries. Narrow bands of wet meadow with bluejoint grass and sedges and thicket swamp with willows and alder occupy the seasonally-flooded zone. Fens are found above the level of contact with lake water, where organic soil accumulates. Sphagnum moss and ericaceous shrubs are the dominant plants.

In Ontario, coastal wetland development is restricted by high wave energy. Extensive coastal wetlands are confined to Thunder Bay, Black Bay and Nipigon Bay (Figure 36). Fringing wetlands are associated with Black Bay Peninsula and Nipigon Bay. There is very little coastal wetland on the eastern half of the Ontario shore. Ontario's coastal wetlands cover approximately 4,400 ha (Wilcox and Maynard 1996). Because of their scarcity, Ontario's coastal wetlands are very important to fish and wildlife (Maynard and Wilcox 1996). Only about 10 coastal wetlands have been evaluated on Lake Superior, mostly near Thunder Bay and at least 3,500 ha of coastal wetland remains to be evaluated (Wilcox and Maynard 1996).

The U.S. side of the lake has approximately 17,400 ha of coastal wetland (Wilcox and Maynard 1996). Coastal wetland is rare on the Minnesota northshore due to the smooth steep shoreline. The stretch of shoreline from Duluth to Marble Point, Wisconsin has perhaps the most abundant and richest coastal wetlands on Lake Superior. Most are associated with the Lake Superior Clay Plain where estuaries and barrier beaches offer shelter from waves and wind (Epstein and others 1997). Wisconsin's coastal wetlands have been thoroughly inventoried and described (Epstein and others 1997).

Michigan's coastal wetlands are scattered at stream mouths from the Keweenaw Peninsula to Sault Ste. Marie. Extensive dune and swale and barrier beach wetlands are along the sandy shore between Whitefish Bay and Sault Ste. Marie (Chow-Fraser and Albert 1998).

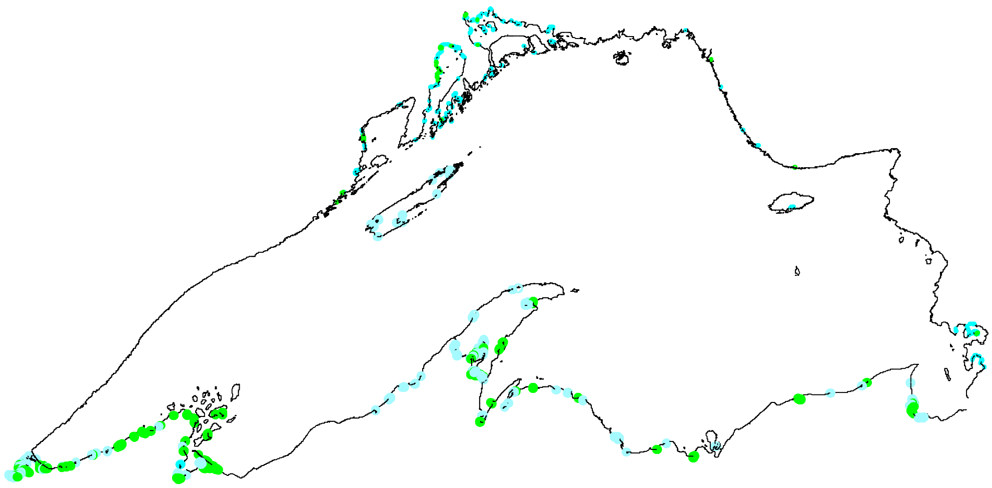

**Figure 36. Lake Superior shoreline wetlands: extensive (green) and fringing (blue) (compiled from U.S. EPA 1994 and Environmental Canada 1993).**

## 3.3 The Aquatic Environment

Four habitat categories have been described for Lake Superior by the Lake Superior Committee (Busiahn 1990). They are offshore habitat in waters deeper than 80 m, nearshore habitat in open waters less than 80 m, embayment and estuary habitat protected from the open lake energy, and tributary habitat utilized by migratory fish. Additionally, aquatic habitat is provided by thousands of inland lakes, ponds, and streams within the Lake Superior watershed.

### 3.3.1 Offshore Habitat

This habitat makes up about 80 percent of the surface area of Lake Superior (Figure 37). Offshore habitat is less productive and diverse than nearshore habitat. The vast majority of this habitat area is dark, due to lack of light penetration to deep water, with a constant temperature of $4^{o}$ C. The substrate is homogeneous, consisting primarily of silt and particulate detritus. The bottom topography is comprised of peaks, valleys and large troughs.

The fish community is relatively simple, composed of a few pelagic and benthic (bottom dwelling) species. The species include three recognized forms of lake trout (lean, siscowet, and humper), burbot, deepwater ciscoes, lake herring, and deepwater sculpins. In addition, non-native Pacific salmon and sea lamprey now utilize this habitat area. This area contains nearly all of the important and critical habitat for siscowets, humpers, chubs, and deepwater sculpins. See Addendum 8-A for further detail on habitat requirements for lake trout, whitefish, lake herring, and walleye.

Limnological conditions were measured at 19 offshore sample stations in spring and summer 1998. Isothermal conditions were present in spring, while summer samples were collected under stable stratified conditions.  In summer stratification, the thermocline, a relatively narrow zone of rapid thermal change that separates warmer epilimnion (upper water layer) from the hypolimnion (cold, deep water) was present at a depth of 23.5 m (Barbiero and Tuchman 2001).  Physical and chemical parameters averaged across all sample stations by season show little seasonal difference.  Epilimnetic temperature increased from $3^{o}$ C to $10^{o}$ C from May to August.  In the offshore zone, alkalinity was 41 mg/L, chloride was 1 to 2 mg/L, total soluble phosphorus ranged from >1 to 3 ug/L, pH remained stable around 8, dissolved silica was just over 1 mg/L, conductivity remained stable at 100 umhos, chlorophyll was around 0.5 ug/L, and nitrogen fluctuated from about 290 to 350 ug/L (Barbiero and Tuchman 2001).

### 3.3.2 Nearshore Habitat

Nearshore open water habitat consists of areas where the water depth is less than 80 m (Busiahn 1990, Lake Superior Technical Committee 1999).  Along with embayments, the nearshore habitat makes up about 20 percent of Lake Superior's surface area.

A subset of the nearshore zone is the area where the thermocline intersects with the lakebed in late summer.  In other words, this is the zone where the entire water column and the substrate are subject to seasonal warming and cooling.  In Lake Superior, this is marked by about the 10 m depth (Edsall and Chalton 1997).

Nearshore waters consist of a narrow band along the north shore, but is generally wider along the south shore (Figure 37).  The most extensive areas of nearshore habitat are at the southeast and southwest ends of the lake.  Nearshore habitat is also found around Isle Royale and other islands and includes offshore shallow waters, such as the Superior Shoal and the Caribou Island Reef complex.

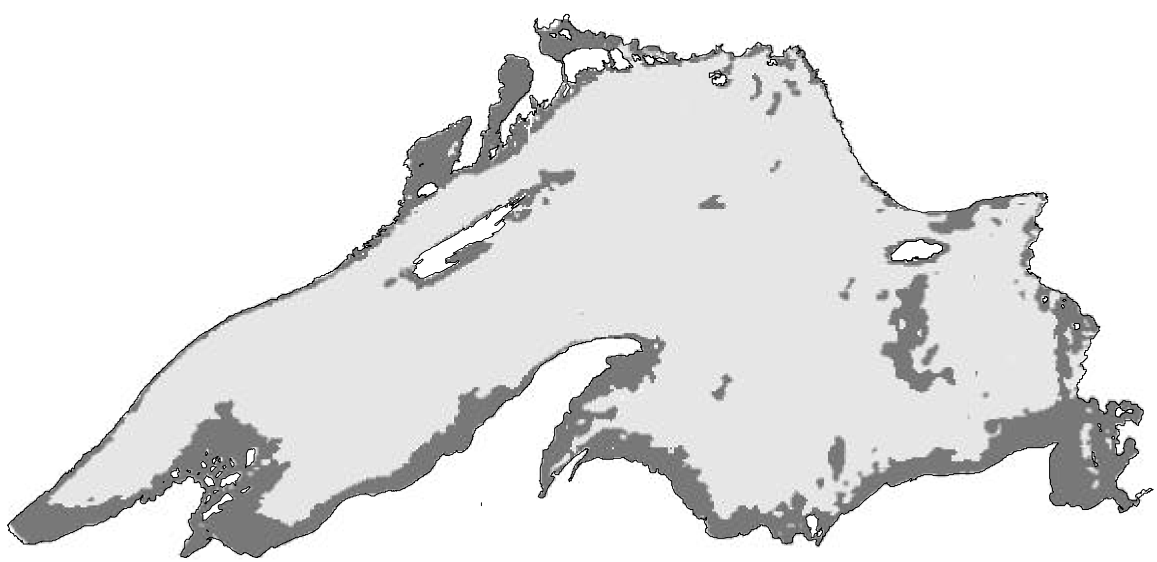

**Figure 37.  Nearshore (dark) and offshore (light) habitats.**

Most of Lake Superior's aquatic plants and animal species use nearshore waters at some stage of their life cycle (Edsall and Charlton 1997).  Nearshore habitats have warmer temperatures and greater diversity of substrate types than offshore areas.  In exposed stretches, waves and currents clean the substrate of sediment, maintaining suitable spawning and nursery habitat for fish species (Figure 38) and providing ideal habitat for aquatic invertebrates typical of riverine habitats (Barton and Hynes 1976). Aquatic vegetation is found in nearshore habitats.

Most of the important and critical habitat for lean lake trout, lake herring, and lake whitefish is found in the nearshore habitat. The nearshore habitat has a greater assemblage of fish species than the offshore habitat. The native fish community is composed mainly of lake trout (both lean and siscowet), burbot, lake herring, lake whitefish, round whitefish, ninespine sticklebacks, trout-perch, pygmy whitefish, and longnose and white suckers. This habitat may also be important to coaster brook trout, however, populations have declined significantly and they are considered extirpated in most nearshore waters. Primary non-native species include Pacific salmon, rainbow and brown trout, rainbow smelt, and sea lamprey.

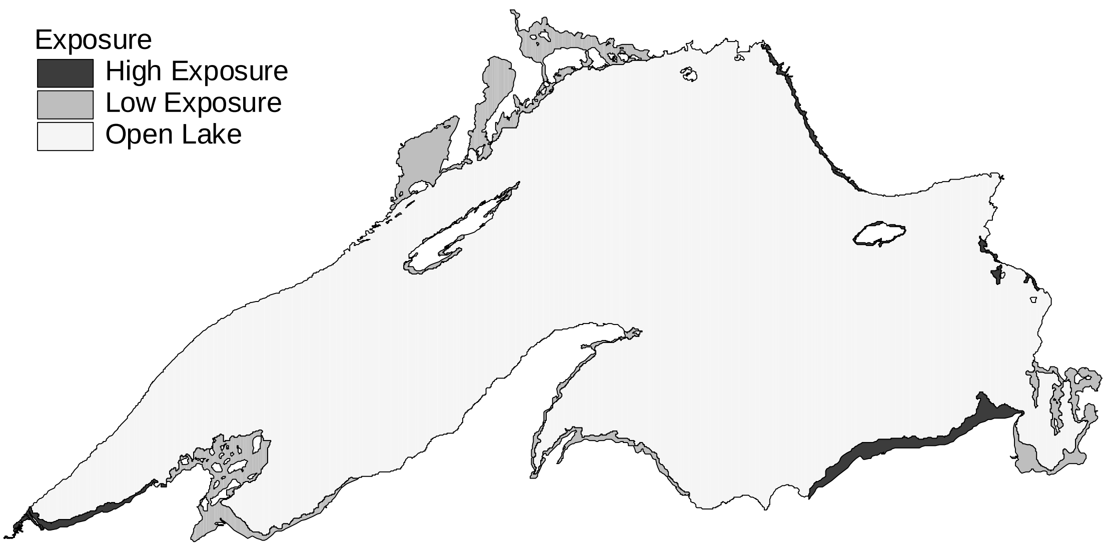


**Figure 38. Wave exposure zones (WWF data).**

### 3.3.3 Embayments

Embayments are a subset of the nearshore habitat that are connected to Lake Superior, but exhibit unique physical properties because they are partially protected from the physical dynamics that occur in the open lake. Embayments can be natural or artificial and include coastal wetlands, bays, harbors, and estuaries that are subject to lake seiche.

Major embayments include Black Bay, Nipigon Bay, Thunder Bay, Batchawana Bay, Goulais Bay, Whitefish Bay, Keweenaw Bay, and Chequamegon Bay.

Fish communities living in the embayment habitat are more complex than in the offshore and nearshore habitats because Lake Superior’s embayments are warmer, more productive, and more physically diverse than the remainder of the lake. Fish living in the embayments include many of the same fish that live in the nearshore habitat, but also warm and cool water fish species such as walleye, smallmouth bass, yellow perch, rock bass, northern pike, lake sturgeon, johnny darters, longnose dace, bullheads, carp, and numerous species of sculpins, shiners, and minnows.

Table 8 shows nearshore areas and bays that have been identified as Aquatic Biodiversity Investment Areas (Koonce and others 1998). These sites are especially productive, support exceptionally high biodiversity, support rare species or habitats and contribute significantly to the integrity of the whole ecosystem (Koonce and others 1998).

**Table 8. Nearshore waters and embayments nominated as Aquatic Biodiversity Investment Areas (adapted from Koonce and others 1998).**

| Site Name | Features | High biodiversity | High productivity | Critical for economically important species | Rare habitat features | Critical for rare species | Critical for endangered species | High habitat diversity |
|---|---|---|---|---|---|---|---|---|
| Allouez Bay | Embayment | X | | X | X | | | |
| Batchewana Bay | Embayment | X | X | | | X | | |
| Big Bay Reef | Nearshore reef, offshore reef | | X | X | | | X | |
| Black Bay | Embayment | X | X | X | | | | |
| Caribou Island Reef Complex | Offshore reef | X | X | | | | | X |
| Eagle River Shoals | Offshore reef | | X | X | X | | | |
| Huron Islands | Offshore reef | | X | X | | | | X |
| Huron River Reef | Nearshore reef | | X | X | X | | | |
| Isle Royale Nearshore Waters | Nearshore reef, embayment | X | | | | X | | X |
| Manitou Island | Nearshore reef | | | X | X | X | | |
| Nipigon Bay | Embayment | X | | X | | X | | |
| Otter Cove | Embayment | X | X | | X | | | |
| St. Louis River | Embayment | | X | | | X | X | |
| Thunder Bay | Embayment, nearshore reef | X | | | X | | | |
| Traverse Island Reef | Offshore reef | | X | X | | | | X |

### 3.3.4 Tributary Streams

Lake Superior has an estimated 1,525 tributaries (840 in the U.S. and 685 in Canada) (Lawrie and Rahrer 1973). These include permanent as well as intermittent streams. There are over 3,300 km of tributaries available to Lake Superior fish. In addition, there are thousands of tributaries that flow into inland lakes or other streams rather than directly into Lake Superior) (Figure 39). Collectively, these streams add up to over 30,000 km of habitat (Figure 40). The largest tributaries are the Nipigon, St. Louis, Kaministiquia, and Pic rivers (Figure 41, Table 10). The length of accessible tributary stream habitat is a limiting factor for Lake Superior's migratory fish populations. Accessible stream length can be limited by natural (e.g., falls) or artificial (e.g., dams, water crossings, excessive water velocities) barriers. Of 118 streams listed in the Brook Trout Rehabiliation Plan for Lake Superior (Newman et. al. 2003), 65 have barriers to fish passage. A discussion of the number and impact of dams is found in the *Status and Trends* section of this report.

On the Canadian side, there is an estimated 1,091 km of stream available to anadromous fishes (Steedman 1992). The U.S. side has an estimated 3,171 km of accessible stream. The method of determining the length probably differs between jurisdictions.

In general terms, many streams are high gradient, cold-water environments supporting brook trout, sculpins, dace and introduced salmonids. Slower-moving, low-gradient streams support cool and warmwater fish communities. Wisconsin has the most exhaustive stream inventory (Turville-Heitz 1999). Most Wisconsin streams that have been classified are coldwater trout streams (Figure 42). Minnesota north shore streams are numerous and short with steep gradients. They are "…deeply entrenched and characterized by swift flows, many rapids and waterfalls, and especially steep gradients in the lower five to eight kilometers before entering Lake Superior…" (MPCA 1997). Streams in the St Louis River watershed have shallower gradients.

Many fish that live in the embayment, nearshore, and offshore habitat types spend part of their life in tributaries. The fish community of tributaries varies greatly based on the water temperature and quantity. Cold water tributaries support brook, lake, brown, and rainbow trout, Pacific salmon juveniles, and mottled sculpin. Cool and warm water tributaries support a large number of species including walleye, yellow perch, northern pike, lake sturgeon, burbot, bullheads, longnose, white and redhorse suckers, darter species, native and sea lamprey, and many species of minnows. Since tributaries provide spawning and nursery habitat, they are the critical habitat for nearly all of the species listed above. Rainbow trout and brook trout are found in more tributaries of Lake Superior than the other major fish species, while lake trout and lake whitefish are found in the fewest number of tributaries. The number of tributaries known to contain important fish species in Lake Superior is described below (Table 9) based on creel surveys, some published literature (Moore and Braem 1965, Goodyear and others 1981 ), and personal communications with area managers and biologists.

**Table 9. Lake Superior tributaries with a record for resident or penadromous fish species.**

| Fish species | Minnesota | Wisconsin | Michigan | Ontario | Total |
|---|---|---|---|---|---|
| Lake trout | 0 | 0 | 3 | 2* | 5 |
| Lake sturgeon | 2 | 3 | 2 | 8 | 13 |
| Pink salmon | 10 | 8 | 65 | 7 | 90 |
| Brown trout | 2 | 76 | 29 | 3 | 110 |
| Chinook salmon | 6 | 15 | 27 | 14 | 62 |
| Coho salmon | 8 | 59 | 56 | 20 | 131 |
| Walleye | 2 | 9 | 29 | 40 | 80 |
| Brook trout | 52 | 90 | 93 | 61 | 254 |
| Rainbow trout | 65 | 74 | 112 | 52 | 270 |

** other tributaries are also used, but confirmed locations are lacking*

**Figure 39. Perennial streams in the Lake Superior basin (Lake Superior Decision Support Systems and OMNR data). Note that stream mapping standards differ between jurisdictions.**

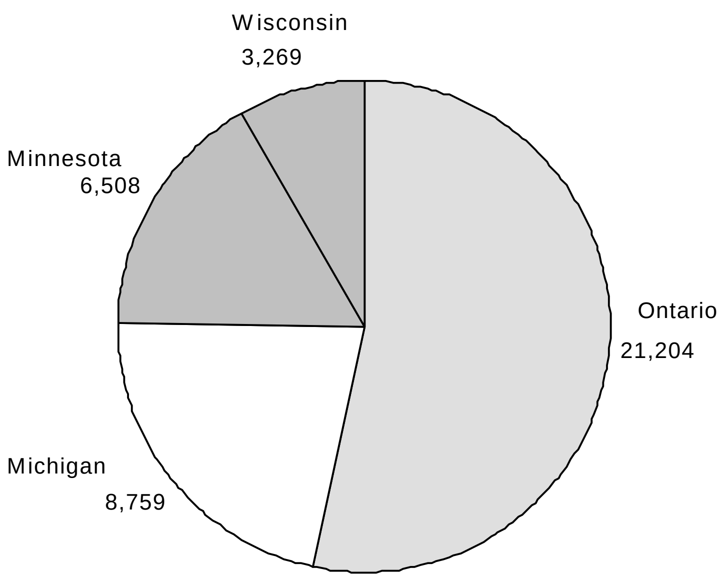


**Figure 40. Perennial stream lengths (km) in the Lake Superior basin (derived from OMNR and Lake Superior Decision Support Systems NRRI data). Note stream mapping standards differ between jurisdictions.**

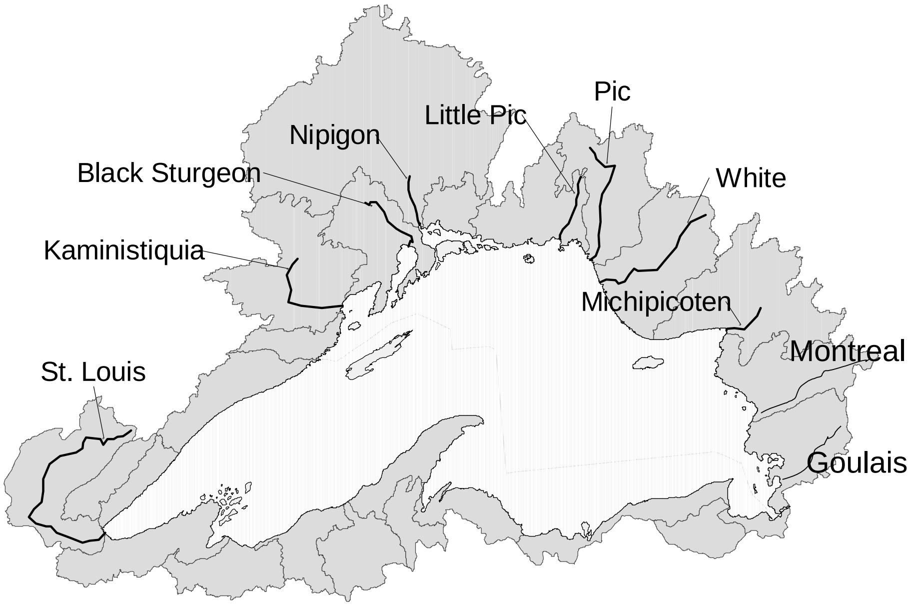


**Figure 41. Major watersheds and rivers (Lake Superior Decision Support Systems data).**

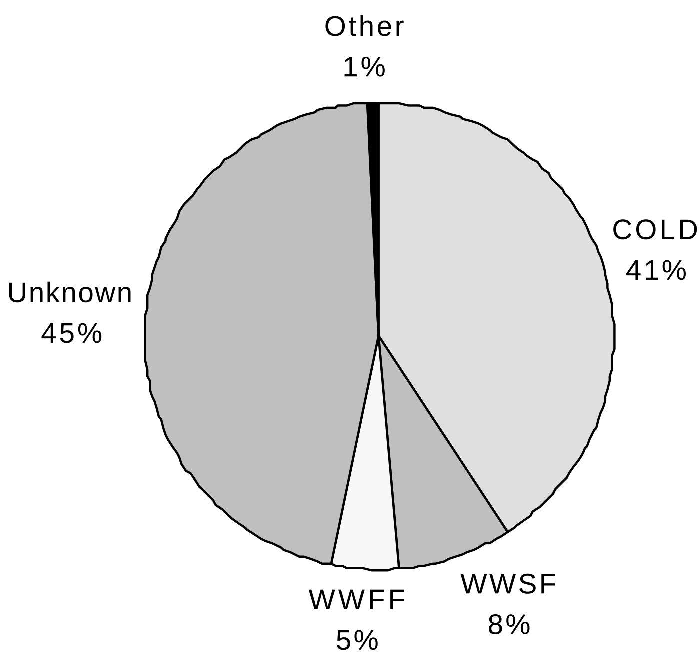


**Figure 42. Classification of Wisconsin streams in the Lake Superior basin. Percent values are the proportion of total stream length in the basin. COLD is cold water fishery including trout stream; WWSF is warm water sport fishery; WWFF is warm water forage fishery; "Other" includes limited forage fishery and limited aquatic life (from Turville-Heitz 1999).**

**Table 10. Some major Lake Superior tributaries (OME 1992, MPCA 1997, OMNR, NRVIS 2003).**

| River | Mean Annual Flow ($m^3/s$) | Length (km) |
|---|---|---|
| Nipigon | 331 | 50 |
| St. Louis | 258* | 288 |
| Pic | 65 | - |
| Kaministiquia | 61 | 93 |
| Montreal | 42 | 70 |
| Michipicoten | 36 | 128 |
| Goulais | 19 | 153 |
| Little Pic | 19 | 158 |
| Black Sturgeon | 19 | 90 |

** approximate value determined downstream from confluence of Cloquet River*

The wide diversity of geology and soils around the basin contribute to a diversity of stream habitats. Due to the steep gradient throughout most of the Lake Superior watershed, discharge tends to fluctuate dramatically related to precipitation and surface water runoff. Discharge is typically greatest during spring due to melting snow and rainfall.

In Ontario, the complex geology of the north shore, north and east of Thunder Bay generates isolated but significant amounts of groundwater discharge into some of the big and small watersheds discharging into Lake Superior. These discharges occur in areas with drifts of glacio-fluvial outwashes, gravel/till moraines, and drifts along the base of escarpments. These deposits in conjunction with steep valley gradients drive significant amounts of groundwater into these watersheds, especially in the last several kilometers before the lake.

Throughout most of the rest of the basin, with the notable exception of tributaries in the central section of Wisconsin, surface water is the primary source of flow. These surface-runoff streams typically experience wide fluctuations in physical and chemical parameters. For example, in the Big Garlic River, Marquette County, Michigan, discharge ranged from 0.3 to 3.3 $m^3$/sec from late spring through winter. Discharge rates are even higher during spring runoff. Temperatures ranged from 0 to 21$^o$ C, conductivity ranged from 40 to 124 micro-mhos, total alkalinity ranged from 14 to 62 ppm, and total hardness ranged from 20 to 66 ppm (Zimmerman 1968).

These fluctuations in stream parameters influence the fish community in a number of ways. Fluctuating discharge and temperature extremes reduce the availability of suitable habitat (e.g., anchor ice) and lead to increased mortality. Stream resident fish and juveniles of migratory fish that require an extended nursery period are adversely affected by the fluctuating conditions. Shrinking habitat forces anadromous juveniles to migrate into Lake Superior at less than optimum size and age. In surface water dominated tributaries, spring spawning migratory fish such as rainbow trout, walleye, and suckers have more reliable access to tributaries than fall spawning fish such as brook and brown trout and the Pacific salmon.

Many Lake Superior tributaries receive some groundwater input, however, groundwater is the predominant source of discharge in tributaries of Wisconsin's Bayfield Peninsula. The high quality, spring-fed streams of this region provide stable flow and constant water temperature, which makes them ideally suited for trout and salmon.

Many of the low gradient tributaries along the south shore of Lake Superior have small coastal estuaries. These estuaries are influenced by both downstream river flow and periodic reverse flow caused by a seiche. Due to their connection to both the riverine and lake environment, these coastal estuaries provide excellent habitat for a wide range of fish and wildlife species.

Western and southeastern Lake Superior tributaries are generally short due to small watershed size (Figure 41). Along the Minnesota shore, stream gradient is steep and flow is heavily dependent upon surface water runoff. These tributaries are harsh environments for salmonine fish in comparison to tributaries around the rest of the lake. Nearly all Minnesota tributaries have natural barriers a short distance upstream from Lake Superior. These barriers limit movement of anadromous fish within tributaries and reduce juvenile salmonine habitat. Minnesota tributaries have very little groundwater intrusion.

Tributaries on the southeastern shore in Michigan are also short, but gradient is generally more gradual. Discharge depends mostly on surface runoff, but numerous streams receive substantial groundwater input. While the north and northeastern shoreline has many small, steep gradient tributaries, most of the large tributaries to Lake Superior are located in Ontario (Table 10). The diverse nature of tributaries along the north shore provides for both cool and coldwater fish communities.

Wisconsin is the only jurisdiction that has a detailed inventory of habitat conditions of streams in the Lake Superior Watershed (Table 11) (Turville-Heitz 1999).

**Table 11. Wisconsin Lake Superior tributaries (from Turville-Heitz 1999).**

| | **Watershed** | **No. Streams** | **Total Stream Length (mi)** | **Watershed Area ($mi^2$)** |
|---|---|---|---|---|
| LS01 | St. Louis and Nemadji rivers | 78 | 284 | 159 |
| LS02 | Black and Upper Nemadji rivers | 52 | 180 | 126 |
| LS03 | Amnicon and Middle rivers | 107 | 384 | 289 |
| LS04 | Bois Brule | 72 | 165 | 195 |
| LS05 | Iron River | 36 | 147 | 218 |
| LS06 | Bayfield Peninsula Northwest | 56 | 172 | 236 |
| LS07 | Bayfield Peninsula Southeast | 56 | 142 | 302 |
| LS08 | Fish Creek | 35 | 115 | 157 |
| LS09 | Lower Bad River | 18 | 129 | 124 |
| LS10 | White River | 67 | 271 | 360 |
| LS11 | Potato River | 46 | 160 | 140 |
| LS12 | Marengo River | 85 | 261 | 218 |
| LS13 | Tyler Forks | 46 | 124 | 79 |
| LS14 | Upper Bad River | 62 | 194 | 135 |
| LS15 | Montreal River | 80 | 264 | 226 |
| LS16 | Presque Isle River | 53 | 91 | 108 |
| | **Total** | **949** | **3083** | **3072** |

### 3.3.5 Inland Lakes

The Lake Superior basin has almost 7,000 inland lakes (Figure 44), covering over 10,000 $km^2$. These lakes range in size from less than 1 ha to Lake Nipigon at 448,000 ha (Table 12). Inland lakes are an important link in the hydrological cycle since much of the water that enters Lake Superior flows through lakes. They contribute to the diversity of aquatic habitats in the basin.

Inland lakes exhibit a wide range of habitat conditions and contain a variety of fish communities. Habitats in these lakes vary from small, shallow winter-kill lakes to deep, cold-water lakes, and as a result of the morphometry of the lakes, fish assemblages vary from warm- to cold-water fish communities.

The morphology and water chemistry of the inland lakes are dictated by the geology of the Lake Superior basin that includes granite, sandstone, and sandy-loam shoals. Most lakes are found on the shallow soils of the Precambrian Shield in Ontario and northern Minnesota (Figure 43). Another concentration of lakes is in the Presque Ile River watershed in Vilas County, Wisconsin and Gogebic County, Michigan.

Inland lakes in Ontario and Minnesota tend to be cool, clear, and low in dissolved solids and nutrients (MPCA 1997). South of Lake Superior, inland lakes tend to be warmer and richer. The number of oligotrophic (nutrient-poor) lakes ranges from 15 to 54 percent in Michigan, Minnesota, and Ontario (Figure 45).

Secchi depth is a measure of lake transparency, reflecting the amount of suspended material and algae in the water. Secchi measurements are available for over 700 lakes in the basin. Over half the lakes in Ontario and Minnesota are in the one to three meter Secchi depth range (Figure 46). Unpolluted lakes show a range of transparencies due to naturally-occurring differences in nutrient availability and turbidity. However, changes in Secchi transparency can indicate a change in the trophic state of a lake due to pollution.

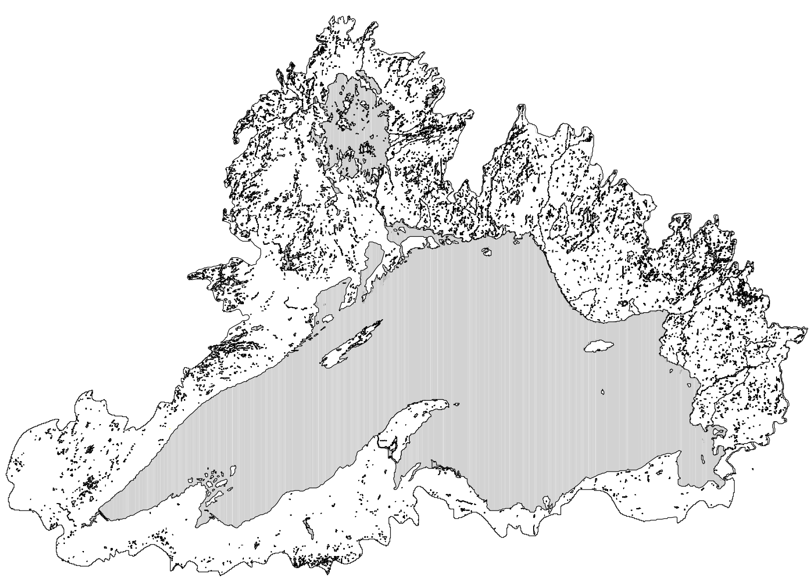

**Figure 43. Inland lakes of the Lake Superior basin (Lake Superior Decision Support Systems and OMNR data).**

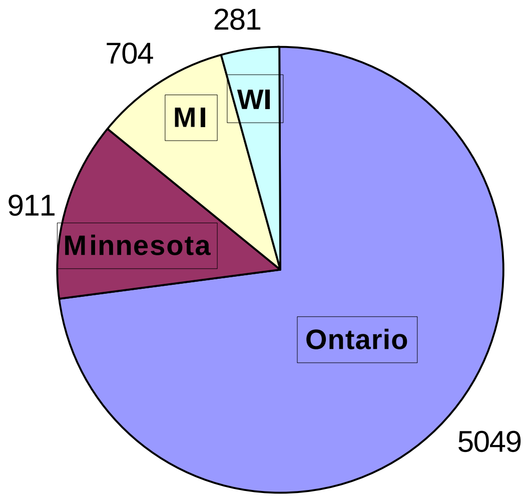


**Figure 44. Inland lakes and reservoirs in the Lake Superior basin (derived from OMNR and NRRI data).**

Fish communities in Ontario and Minnesota are dominated by cool and coldwater species (Figure 47). Oligotrophic lakes often support lake trout, lake herring and lake whitefish, but are relatively species poor. About 100 lakes in the Minnesota North Shore support lake trout (Waters 1987). Some lakes in the southern part of the basin provide warmer and more nutrient-rich habitat than Lake Superior. Warmwater species, such as sunfishes and catfishes, dominate the fish community of these lakes.

**Table 12. Major Inland Lakes (>20 $km^2$) in the Lake Superior Basin.**

| Lake Name | Area ($km^2$) | Max. Depth (m) | Mean Depth (m) | Littoral Area (%) | Trophic Status* | Secchi Depth (m) |
|---|---|---|---|---|---|---|
| Lake Nipigon, ON | 4,481 | 137 | 55 | | Oligotrophic | 6.5 |
| Dog Lake (Thunder Bay), ON | 148 | 117 | 30 | 29 | Oligotrophic | 2.5 |
| Onaman Lake, ON | 108 | 19 | 2 | 97 | Eutrophic | 1 |
| White Otter Lake, ON | 83 | 56 | 22 | 91 | Oligotrophic | 4.8 |
| White Lake, ON | 59 | 49 | 9 | 54 | Eutrophic | 2.7 |
| Shebandowan Lake, ON | 59 | 38 | 8 | | Oligotrophic | 2.9 |
| Lake Gogebic, MI | 52 | - | - | - | - | - |
| Dog Lake, (Wawa) ON | 52 | 75 | 13 | - | Oligotrophic | 4.4 |
| Black Sturgeon Lake, ON | 48 | 49 | 12 | 23 | Oligotrophic | 2.5 |
| Esnagi Lake, ON | 46 | 22 | 5 | 47 | Eutrophic | 3.7 |
| Windermere Lake, ON | 38 | 30 | 8 | | Oligotrophic | 4.8 |
| Wabatongushi Lake, ON | 38 | 53 | 7 | 59 | Eutrophic | 2.9 |
| Obonga Lake, ON | 36 | 72 | 17 | | Oligotrophic | 3 |
| Muskeg Lake, ON | 35 | 12 | 5 | 66 | Eutrophic | 2 |
| Island Reservoir, MN | 34 | 22 | - | - | Eutrophic | 2 |
| Arrow Lake, ON | 33 | 55 | 18 | 23 | Oligotrophic | 4.7 |
| Manitowik Lake, ON | 31 | 119 | 38 | 19 | Oligotrophic | 3.7 |
| McKay Lake, ON | 31 | 49 | 9 | 62 | Eutrophic | 4 |
| Greenwater Lake, ON | 31 | 55 | 18 | 14 | Oligotrophic | 4 |
| Whitefish Lake (Th. Bay), ON | 30 | 6 | 2 | 100 | Eutrophic | 3 |
| Forgan Lake, ON | 30 | 44 | 13 | 35 | Mesotrophic | 4 |

| Lake Name | Area ($km^2$) | Max. Depth (m) | Mean Depth (m) | Littoral Area (%) | Trophic Status* | Secchi Depth (m) |
|---|---|---|---|---|---|---|
| Cedar Lake, ON | 29 | 15 | 6 | 100 | Eutrophic | 2.1 |
| Cliff Lake, ON | 27 | 34 | 9 | 50 | Eutrophic | 4.3 |
| Kagiano Lake, ON | 24 | - | - | - | - | 2 |
| Barbara Lake, ON | 24 | 56 | 10 | | Oligotrophic | 3 |
| Kashabowie Lake, ON | 23 | 35 | 7 | 58 | Oligotrophic | 2.6 |
| Whiteface Reservoir, MN | 23 | 10 | - | - | Eutrophic | 1.2 |
| Holinshead Lake, ON | 23 | 17 | 5 | - | Oligotrophic | 2 |
| Wildgoose Lake, ON | 17 | 16 | 4 | - | Eutrophic | 4 |
| Roslyn Lake, ON | 17 | 45 | 10 | - | Oligotrophic | 4 |
| Loch Lomond, ON | 17 | 71 | 21 | - | Oligotrophic | 4 |
| Brule Lake, MN | 17 | 18 | - | 34 | Oligotrophic | 4.9 |
| Helen Lake, ON | 16 | 61 | 13 | - | Mesotrophic | 3 |

**Trophic status for Ontario lakes is based on morphoedaphic Index (MEI). MEI values between 6 and 7 are mesotrophic, higher are eutrophic, lower are oligotrophic (Leach and Herron 1996). Trophic status for U.S. lakes are determined using the Carlson method.*

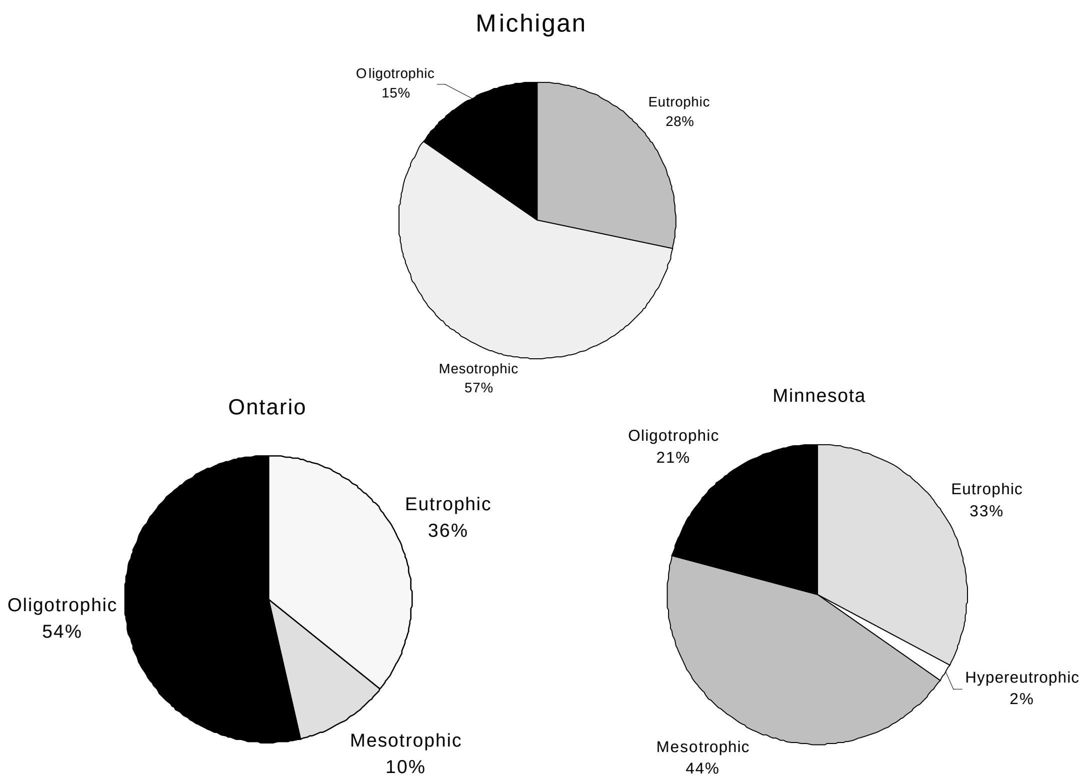


**Figure 45. Trophic status of inland lakes in the Lake Superior basin. (a) Ontario (n= 516), (b) Michigan (n = 78), (c) Minnesota (n = 208). (Data from Ontario Ministry of Natural Resources, Michigan Dept. of Environmental Quality, and Minnesota Pollution Control Agency data.)**

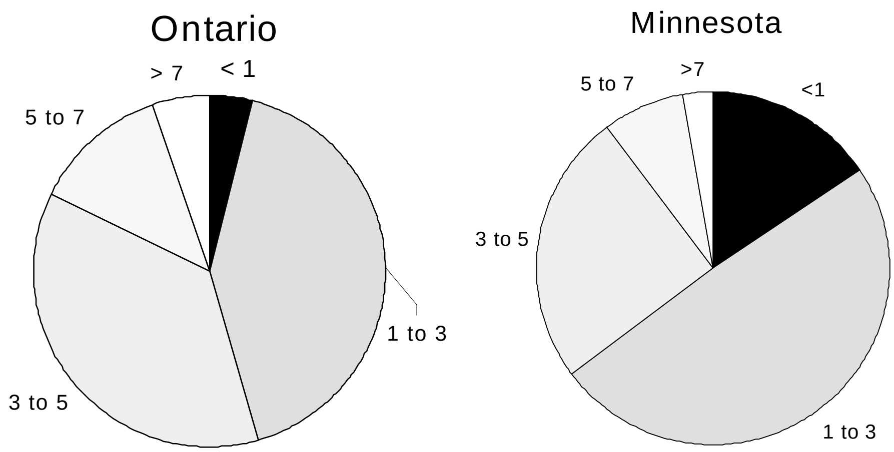


**Figure 46. Secchi depth (m) for 1,128 Ontario and 147 Minnesota lakes within the basin (Ontario Ministry of Natural Resources and MPCA Data).**

***Ontario***

Ontario's portion of the Lake Superior watershed contains numerous inland lakes supporting lake trout, brook trout, walleye, and northern pike fisheries (Figure 47). The majority of the lakes are undeveloped and the shorelines are managed as public lands. Lake Nipigon is the largest inland lake in Ontario's portion of the Lake Superior watershed; with a surface area of 448,060 ha it is approximately one quarter the size of Lake Ontario. Lake Nipigon supports trophy sports fisheries for brook trout and lake trout as well as commercial fisheries for whitefish, lake trout, walleye, and more recently rainbow smelt.

Ontario lake survey data are available from 1,251 lakes within the basin, but there are thousands of unsurveyed lakes. Surveyed lakes tend to be large, accessible, and support sport fishes. Many of the lake survey data are over 20 years old.

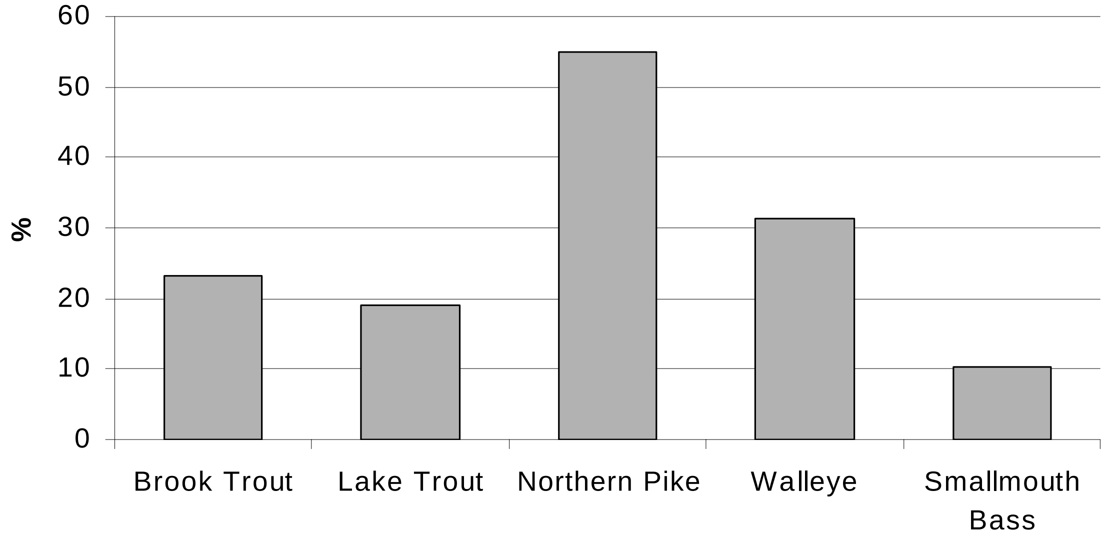


**Figure 47. Major sport fish species in 612 Ontario lakes in the Lake Superior basin (Ontario Ministry of Natural Resources data).**

***Wisconsin***

The soft water seepage lakes are most commonly found in the Wisconsin portion of the Lake Superior basin. These lakes are typically clear, slightly acid, and relatively infertile. The principal fishery resources pursued by anglers in the Wisconsin basin include muskellunge, northern pike, walleye, largemouth and smallmouth bass, and panfish.

Most lakes in the Wisconsin basin have basic, descriptive data. Five Wisconsin lakes in the basin were identified as priority sites from a biodiversity perspective (Epstein and others 1997). These are Anodanta Lake, Bad River Slough, Hoodoo Lake, Rush Lake, and Smith Lake. Most of these lakes have rich invertebrate communities or support rare invertebrate species.

***Michigan***

The MI DNR, U.S. Forest Service, U.S. Fish and Wildlife Service, Bay Mills Indian Community, and Keweenaw Bay Indian Community have assessed many of the 200 to 300 lakes in the Lake Superior drainage of Michigan. Most of these lakes support a cold or cool water fishery. The cold-water lakes have brook trout or rainbow trout as the dominant predator, while the cool-water lakes have walleye, northern pike, or perch as the dominant predator. A few lakes are characterized as warm-water and have a largemouth bass/bluegill fish community. A compliment of various prey species also exists in these lakes, dominated by minnows (cyprinids) and suckers (catostomids).

In general, Michigan inland lakes within the Lake Superior basin receive minimal fishing pressure because of the sparse human population in their region, and their remote locations. A few lakes are storage reservoirs used for hydroelectric power; associated lake level fluctuations negatively impact those fisheries. These lakes include: Gogebic, Prickett, Bond Falls, Victoria, McClure, and Autrain. The storage reservoir known as Silver Lake, located in Marquette County, was lost as a result of dam failure in spring 2003.

***Minnesota***

Minnesota's portion of the Lake Superior watershed contains over 900 inland lakes. These areas are extremely important for both recreation and tourism. Much of the aquatic resource in Minnesota is in very good condition. High quality pristine areas in the watershed include portions of the Boundary Waters Canoe Area, natural heritage lake trout lakes that are supported only by wild populations, state parks, and state and federal forests.

There are five major hydroelectric dams on the St. Louis River system creating two of the largest impoundments in the basin: Island Reservoir and Whiteface Reservoir (MPCA 1997). These are headwater reservoirs that store water during the spring run off and release it to augment low flows at other times of the year. Other impoundments (Two Rivers Reservoir and Whitewater Reservoir) are used for mine processing water and recreation.

### 3.3.6 Nutrients and Oxygen

Lake Superior is an "ultra-oligotrophic" lake on the basis of its very low nutrient availability and cold temperature. Water chemistry is determined by the geology and climate of its drainage basin, anthropogenic inputs, bottom topography, circulation patterns, thermal regime, and biological processes. Most of its watershed is on the nutrient-poor Precambrian shield. Compared to the other Great Lakes, Lake Superior is characterized by high concentrations of total nitrogen and reactive silicate but very low concentrations of total phosphorous, which limits productivity (IJC 1976). Nutrient levels are quite uniform horizontally and vertically in the open lake, with the exception of areas with restricted circulation, notably near Duluth, Thunder Bay, and in Whitefish Bay. Nearshore areas, near Duluth in particular, exhibit generally elevated levels of total phosphorus and silica that are linked to artificial and riverine inputs (Weiler 1978). Locally elevated nutrient concentrations have also been identified in Thunder Bay, the Carp River mouth, and Munising. Nitrate and silica have well-defined seasonal cycles correlated with biological uptake and release. They usually reach a minimum during August and September when phytoplankton biomass peaks. Current nitrate concentrations in Lake Superior are higher than historical levels, and are increasing at approximately 3 μg/L per year (Dobson 1972).

Lake Superior is saturated with dissolved oxygen most of the year. During the spring, convective mixing to nearly 300 m depth brings nearly all of the lake water in contact with the atmosphere (Bennet 1978). Some oxygen depletion can occur locally, but dissolved oxygen levels generally remain over 80 percent (Matheson and Munawar 1978). A small loss of oxygen from the hypolimnion is caused by the oxidation of organic matter that has settled through the thermocline. However, the great depth, large volume of the hypolimnion, low productivity, and persistence of vertical mixing through June means that oxygen depletion is generally not limiting for deep water species.

### 3.3.7 Primary Production – Chlorophyll *a*

Chlorophyll *a* concentrations are a measure of phytoplankton biomass and reflect the levels of nutrients, particularly total nitrogen and phosphorous. In offshore areas, chlorophyll *a* levels seldom exceed 1 μg/L, except in the western end of the lake near Duluth. Higher chlorophyll *a* concentrations are found in nearshore areas, averaging 0.6 to 2.5 μg/L, with Duluth-Superior Harbour showing the highest levels (3.6 μg/L). If greater quantities of phosphorous become available, there is the potential for a significant increase in productivity due to the overabundance of nitrate and reactive silicate in offshore waters (IJC 1976).

Primary production by phytoplankton is strongly related to the depth of the euphotic zone (depth which photosynthetically active radiation penetrates the water surface) (Fee 1971). The euphotic zone averages 20 to 30 m depth in offshore areas, and less than 20 m where water is more turbid in coastal areas near Duluth, Thunder Bay, Nipigon Bay, Black Bay, Marathon, Whitefish Bay, Apostle Is., and the southwest red clay portions of the lake. Near Duluth, the euphotic depth may be only two meters deep. Lake Superior has similar water transparency to Lake Huron, but higher transparency than the other Great Lakes (Schertzer and others 1978).

The deep chlorophyll maximum (DCM), a common feature in summer in the offshore waters of Lake Superior, was observed in the upper hypolimnion between 23 and 35m. Chlorophyll *a* concentrations in the DCM were 1.5 to 2.5 times epilimnetic concentrations and were associated with minimal or no increases in particulate organic carbon concentration. Carbon to phosphorus ratios were consistently lower in the DCM, indicating increased phosphorus content in the phytoplankton. Community structure in the phytoplankton of the DCM was distinguishable from that of the epilimnion, with the most notable difference being a relative reduction in the abundance of Cyclotella species in the DCM (Barbiero and Tuchman 2004).

Lakewide chlorophyll *a* concentration decreases in mid-October due to the decline in solar radiation and decreased water temperatures associated with deep vertical mixing. Seasonally, surface water chlorophyll dynamics were characterized by an increase from late-winter concentrations in late April and early May, a continued increase in the nearshore and a decrease/stabilization at offshore sites from late May through July, a summer minimum in late July and August, and an increase in September and October with the approach to turnover (Auer and Bub 2004).

### 3.3.8 Phytoplankton

The Lake Superior phytoplankton community represents a unique assemblage of approximately 300 species. Over 160 taxa have been been found in the offshore habitat (>80 m) (Barbiero and Tuchman 2001). Nannoplankton (<60 μm) dominate the phytoplankton biomass and primary production, but most surveys have focused on diatoms and other larger plankton (>60μm) (Munawar et al. 1978). Phytoflagellates (cryptomonads, chrysomonads, dinoflagellates) comprise approximately 35 percent of the species, followed by diatoms (31 percent) and Chlorophyta (22 percent).

Lake Superior is divided into six phytoplankton regions based on taxonomic and biophysical data (Munawar and Munawar 1978) (Figure 48). With the exception of the Duluth region, species composition is broadly similar among regions. Common phytoflagellate species typical of oligotrophic lakes (e.g., *Cyclotella* spp. and *Fragilaria crotonensis*) characterize the open lake. There are also a large number of rare species, some of which are indicative of cold, oligotrophic conditions (e.g., *Stelexmonas dichotoma* and *Chrysolykos planctonicus*). The phytoplankton community in the Duluth region has fewer species and is dominated by diatoms, in particular *Melosira ranulata*, which is associated with eutrophication.

In 1998, two non-indigenous phytoplankton species were collected. This is believed to be the first documentation of the centric diatoms, *Thalassiosira baltica* and an organism identified as *Stephanocostis*, in Lake Superior (Barbiero and Tuchman 2001).

Most of the lake has very low (0.1 to 0.2 $g/m^3$) phytoplankton biomass. Biomass is homogeneously distributed with little inshore/offshore differentiation with the exception of Western Lake Superior, which has relatively high biomass concentrations (Munawar and Munawar 1978). Nannoplankton comprise approximately 65 percent of the total phytoplankton, and smaller organisms (<10 µm) account for 32 percent of the biomass. Diatoms and phytoflagellates, especially cryptomonads and chrysomonads, dominate the lakewide phytoplankton biomass. Dinoflagellates, green and blue-green algae contribute little to the total biomass. The Duluth, Thunder Bay, and Whitefish Bay regions are unique environments and show relatively high biomass concentrations during the summer (July to September).

No clear seasonal trends in biomass are apparent for most of the lake, although biomass is lowest when Lake Superior is unstratified (May to June, November to December) and highest from July to September when it is stratified. The overall cold temperature regime of Lake Superior is not conducive to rapid and sudden changes in the phytoplankton community (Munawar and Munawar 1978). Uniform vertical distribution of biomass appears to be typical of offshore conditions in most of the lake although at some offshore stations, phytoflagellate biomass is highest below the thermocline. In temperature-stratified nearshore conditions, there are peaks of diatom and phytoflagellate biomass near 10 m depth. In general, the size and composition of the phytoplankton community has apparently changed little in the past fifty years (Barbiero and Tuchman, in press).

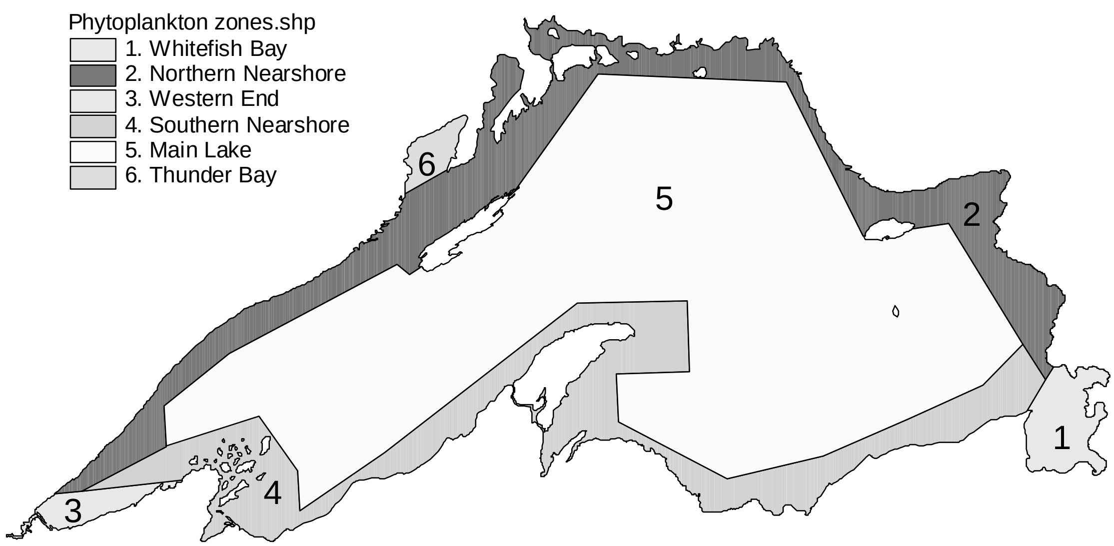


**Figure 48. Phytoplankton zones of Lake Superior based on taxonomic data. (1) Whitefish Bay, (2) Northern Nearshore, (3) Western End, (4) Southern Nearshore, (5) Main Lake, (6) Thunder Bay (Munawar and Munawar 1978).**

### 3.3.9 Zooplankton

Zooplankton distribution and abundance (Table 13) is strongly associated with surface water temperature, and highest concentrations are found inshore, especially in the major embayments. The offshore open water community has low species richness, dominated by large, calanoid copepods found at substantial depths. The summer cladoceran population is small. Overall, abundance is generally low in comparison with the lower Great Lakes, and little variation in abundance is evident throughout the ice-free season.

The lakewide zooplankton community is relatively homogenous in the spring and summer, and offshore as well. During the early summer local clusters appear in many inshore areas, and by early fall the zooplankton community varies in different parts of the lake. Seasonal concentrations peak at 45,000 individuals/$m^3$ in some inshore areas (Whitefish Bay) compared to only about 3000 to 3,500 individuals/$m^3$ in the open lake (Watson and Wilson 1978, Barbiero et al. 2001). Abundance has remained stable in offshore waters for the past 30 years.

The zooplankton community of the open lake is generally dominated by herbivorous filter feeders such as calanoid copepods and cladocera, although low numbers of raptorial cyclopoid copepods that feed on other zooplankton are also present. The zooplankton community of the open lake, and the lakewide average, is dominated by large calanoid copepods such as *Diaptomus sicilis, Limnocalanus macrurus,* and *Senecella calanoides.* The dominant species appear to be present year-round, with a single reproductive pulse during the fall or early winter. Upwellings along the northern shore push warmer inshore water and its entrained zooplankton offshore.

The exotic, spiny water flea, *Bythothrephes longimanus* (formerly *B. cederstroemi*), a predatory cladoceran, was found in modest numbers at most stations across the lake, but accounted for only 0.5 percent of total biomass (Barbiero et al. 2001).

Major embayments and inshore areas along the southern and eastern shore have communities dominated by cladocera and smaller diaptomids. These communities tend to have a bimodal seasonal pattern, with a spring-summer peak dominated by calanoid nauplii and copepodites, and a fall peak of calanoid adults, cladocerans, and cyclopoids. Inshore species gradually extend into the offshore waters during the late summer and early fall and mix with the offshore assemblages. Homogenous lakewide conditions return quickly with the turnover in late fall (Watson and Wilson 1978).

In three ecoregions of western Lake Superior (Duluth-Superior, Apostle Islands, and the open lake), copepods were far more abundant than cladocerans in all ecoregions. Mean zooplankton size was larger in the open lake due to dominance by large calanoid copepods. Zooplankton abundance was three times higher in the Duluth-Superior and Apostle Islands regions than in the open lake due to the large numbers of rotifers. Forage fish abundance and biomass were highest in the Apostle Islands and lowest in the open lake with lake herring, rainbow smelt and deepwater ciscoes comprising over 90 percent of the abundance and biomass. Growth and condition of fish was good, suggesting they were not resource limited. Fish and zooplankton assemblages differed among the three ecoregions of western Lake Superior, due to a combination of physical and limnological factors related to bathymetry and landscape position (Johnson et al. 2004).

Zooplankton biomass distribution patterns in Lake Superior are strongly influenced by the differential heating of surface water, which is in turn influenced by lake morphometry, and upwellings and currents. During the spring and early summer, biomass values are similar across the lake at approximately 4 $mg/m^3$. Inshore biomass peaks at approximately 60 $mg/m^3$ in August and September as cladoceran populations develop. Offshore and lakewide biomass is primarily related to the growth and maturity of large calanoid copepods and peaks approximately one month later at 30 $mg/m^3$. Total biomass nearly doubles from spring to fall in offshore waters (Barbiero et al. 2001), and, overall, biomass increases five-fold between May and September (Watson and Wilson 1978).

**Table 13. Dominant zooplanton species in Lake Superior (Watson and Wilson 1978).**

| Taxa | Numbers (%) | Biomass (%) |
|---|---|---|
| **Calanoid copepods** | | |
| *Diaptomus sicilis* adults | 11 | 20 |
| *Diaptomus ashlandi* adults | 3 | 3 |
| *Diaptomus* spp. copepodites | 18 | 17 |
| *Diaptomus* spp. nauplii | 44 | 7 |
| *Limnocalanus macrurus* | 5 | 32 |
| *Senecella calanoides* | 1 | 5 |
| **Calanoid Total** | **83** | **84** |
| **Cyclopoid copepods** | | |
| *Cyclops bicuspidatus thomasi* adults | 1 | 1 |
| *Cyclops* spp. copepodites | 7 | 2 |
| *Cyclops* spp. nauplii | 5 | 1 |
| **Cyclopoid Total** | **13** | **3** |
| **Cladocerans** | | |
| *Bosmina longirostris* | 1 | <1 |
| *Daphnia galeata mendotae* | 3 | 8 |
| *Holopedium gibberum* | <1 | <1 |
| **Cladoceran Total** | **3** | **8** |
| **Total** | **99** | **95** |

### 3.3.10 Benthic Communities

The benthic community of Lake Superior is dominated by the amphipod *Diporeia hoyi* (formerly known as *Pontoporeia affinis),* followed by the oligochaetes, especially the Enchytraeidae and the lumbriculid worm *Styoldrilus heringianus* (Cook 1975). Molluscs (primarily the sphaeriid pea clam *Pisidium conventus)* and insects (primarily the chironomid *Heterotrissocladius oliveri)* account for less than 10 percent of the total biomass.

The relatively simple benthic community of Lake Superior reflects the low diversity of habitat rather than impaired water quality. Sediment size, depth and therefore temperature are the major factors controlling the distribution of individual species. Sphaeriids and chironomids are associated with shallow water, on sandy and finer substrates respectively. *Diporeia* is most abundant in relatively shallow water (40 to 80 m) compared to the mean depth of Lake Superior (160 m) (Freitag and others 1976; Dermott 1978). Tubificid worms (*Rhyacodrilus)* are associated with relatively shallow water depths and are replaced by *Phallodrilus* in deeper oligotrophic sites having sediments with lower organic matter. *Stylodrilus* and Sphaeriidae were negatively associated with the sediment zinc levels.

In a study along three transects off the Keweenaw Peninsula that each had shelf, slope, and profundal habitat, *Diporeia* (48 percent) was the most abundant invertebrate, with chironomids, oligochaetes and sphaerids representing 21, 19, and 8 percent of the community, respectively. All major groups were most densely distributed in the slope region, with chironomids and oligochaetes exhibiting more fine-scale density differences over the slope. Peaks in the abundance of invertebrate organisms in the slope region of Lake Superior suggest that this area may provide critical habitat, offering an important region for resource acquisition by these and other members of the Lake Superior food web (Auer and Kahn 2004).

A probability-based survey of 27 sites was conducted in 1994 and 2000 to ascertain the status of *Diporeia* in Lake Superior. In 1994, *Diporeia* abundance in the nearshore ranged from 550 to 5,500 /m$^2$ and the Great Lakes Water Quality Agreement objective of 220 to 320 /m$^2$ was met for the entire nearshore. In 2000, abundance ranged from 10 to 2,800 /m$^2$ and the objective was not met in 11 percent of the nearshore area. There was no significant trend in *Diproeia* abundance among years and populations observed at present are higher by a factor of seven than those reported in the 1970s (Scharold et al. 2004).

In deep water communities and much of western Lake Superior, mollusc and insect populations are extremely sparse, and in mid-lake locations with extremely low productivity, only the stenotherms *Diporeia* and *Stylodrilus* are present. The benthic community is richest in terms of abundance and diversity in the area south and east of Michipocoten Island, especially Whitefish Bay (Figure 49), due to shallower mean depth (63 m) and higher algal populations. In contrast to the lakewide mean, oligochaetes were dominant and Sphaeriidae comprise 12 percent of the biomass. Thunder Bay also has a relatively diverse benthic community where Sphaeriidae and Chironomini are more abundant than in the main lake. Benthic abundance and diversity was lowest in the Duluth area and often restricted to *Diporeia,* despite abundant phytoplankton populations (Munawar and Munawar 1978, Rao 1978).


**Figure 49. Benthic biomass diversity. Numbers represent Shannon's diversity index. Higher numbers indicate greater species diversity (Dermott 1978).**

### 3.3.11 Fish Communities

The native fish community of Lake Superior is dominated by lake trout and corregonines (whitefish, lake herring and deepwater ciscoes), as is typical of post-glacial oligotrophic lakes in North America. Approximately 80 fish species belonging to 19 families occur in Lake Superior and its tributaries. Of these, twenty are non-native species that have been deliberately (e.g., chinook salmon, rainbow trout) or accidentally introduced (e.g., ruffe, sea lamprey) since the late 1800s. Commercial and sport fishing pressure, introductions of non-native species, and changes in the physical environment (e.g., logging, dams, mine tailings) have resulted in a fish community somewhat different and less stable than it was in the mid 1800s (Hansen 1994, Paloheimo and Regier 1982). See Addendum 6-F for further detail on the presence of fish species observed during 1953-1996 and Addendum 6-G for fish species names.

Commercial fishing for lake whitefish and lake trout began in the mid 1800s in Lake Superior to provide food for fur trading posts and other settlements (Waters 1987). By the late 1800s, increased human population and improved transportation resulted in intensified fishing effort, and improved boats and gear resulted in a more efficient harvest. Typically, the most accessible stock was fished heavily until the population declined, and then effort switched to another stock or species (Lawrie and Rahrer 1972, Regier and Loftus 1972). Records of depleted stocks date back as early as the 1870s and there was a general pattern of decline for many commercial species between the mid 1940s and early 1970s (Lawrie and Rahrer 1972). Declining populations of lake trout, burbot, whitefish and other species were further decimated during the 1940s and 1950s by sea lamprey (Hansen 1994), which were first recorded from Lake Superior in 1938. During the time of highest sea lamprey abundance, up to 85 percent of fish in commercial catches exhibited sea lamprey wounds (Scott and Crossman 1973). Commercial fish yields from 1979 to 1983 in Lake Superior were significantly lower than historical yields (Table 14) mainly due to the collapse of the lake herring and lake trout, species that have not yet fully recovered lakewide, although lake trout are approaching historical levels in most areas of the lake with the exception of Whitefish Bay. Angling has had less impact on fish populations, but contributed to the decline of some populations of lake trout and brook trout, especially in tributaries, embayments and shallow nearshore waters.

Control of commercial fishing has also contributed to the difference between early and more recent yields. Michigan closed lake trout fishing in 1962 and lake herring fishing in 1974. Although commercial fishing rights have been restored to Native American tribes, there are some Michigan waters of Lake Superior that have been closed even to tribal fishing as described.

Since 1983, lake herring have produced periodic large year classes that have provided pulsed recruitment to the forage base and fishery. However, the boom or bust status of lake herring reproduction is a concern for fishery managers and a project is underway to review the current status of lake herring stocks and evaluate management options. Millions of lake trout were stocked from the 1960s up to the present. The abundance of stocked and wild fish has increased to the point that many lake trout stocks have been restored to pre-crash numbers. In areas of Lake Superior where assessment surveys have shown that lake trout stocks are supported primarily by natural reproduction stocking has been discontinued.

**Table 14. Mean annual fish yield (kg/ha/yr) and percent of total yield for Lake Superior contributed by different species or species groups (from Loftus and others 1987).**

| Species | Early (1913-50) | | Recent (1979-83) | |
|---|---|---|---|---|
| | **Yield** | **%** | **Yield** | **%** |
| Lake herring | 0.651 | 66.4 | 0.139 | 36.6 |
| Other ciscoes and chubs | 0.018 | 1.8 | 0.041 | 10.8 |
| Lake whitefish | 0.048 | 4.9 | 0.080 | 21.1 |
| Lake trout | 0.240[a] | 24.5 | 0.046 | 12.1 |
| Rainbow smelt | 0.000 | 0.0 | 0.041 | 10.8 |
| Other species | 0.021 | 2.1 | 0.028 | 7.4 |
| **Total** | **0.980** | | **0.380** | |

[a]*Based on the years 1920-45 only.*

Historically, the fish community of the main lake was comprised of lake trout, coregonines (whitefishes and ciscoes), burbot, sticklebacks, sculpins, and suckers. Lake trout, and to a lesser extent burbot, were the dominant predators. Today, the predator mix has been expanded by the introduction of non-native salmonines, but lake trout remains the dominant predator. Lake trout made up about 93 percent of the predator biomass in western Lake Superior in the early 1990s (M. Ebener, personal communication). Lake Superior contains three forms of lake trout referred to as leans, sicowets and humpers, but some discrete lean stocks are believed to have disappeared. The main forage of lean lake trout historically was lake herring. Lake herring was largely replaced by non-native rainbow smelt as forage in the1960s and 1970s, but re-emerged as major forage species in the 1980s following a decrease in rainbow smelt and abundance and production of several strong lake herring year classes (Selgeby and others 1994). Coregonines (mainly deepwater ciscoes), burbot, and sculpins are principal forage fish for siscowets.

Lean lake trout, rainbow trout, coho and chinook salmon are most abundant in nearshore waters less than 80 m depth. Brown trout and splake are less widely distributed than other naturalized salmonines. Brook trout were formerly more abundant in nearshore areas but have been reduced by overfishing, competition with introduced species and loss of access to and destruction of spawning habitat in tributaries. Lake whitefish are less pelagic than other coregonines and are most abundant at depths of 20 to 50 m. Rainbow smelt are also abundant in nearshore waters, however, their numbers have declined dramatically over the past 40 years.

The fish community of bays, harbors, and estuaries is comprised mainly of perches (walleye and yellow perch), suckers, sculpins, and minnow species (Table 15). Walleye is most abundant in mesotrophic waters less than 15 m depth, although they may be found deeper. Both walleye and lake sturgeon were formerly more abundant and exist mostly as suppressed localized populations. The recent introduction of exotic ruffe, white bass and round gobies may have profound impacts on these warmwater communities. Approximately 20 species (e.g., catfishes and sunfishes) are restricted to the warmest weedy shallows of protected bays and estuaries. Tributaries are critical spawning and nursery habitat for many species, including walleye, sturgeon, burbot and salmonines. Various minnow species, native lamprey, and the central mudminnow are generally confined to tributary waters.

Shoals and spawning areas for lake whitefish, lake herring, round whitefish, and lake trout are shown in Figure 50.

**Table 15. Principal fish species in the four main habitat zones of Lake Superior. "X" denotes presence of species during different life stages, i.e., adult (A), juvenile (J), and/or spawning (S).**

| **Principal Species** | **Adult Diet** | **Offshore (>80 m deep)** | | | **Nearshore (<80 m deep)** | | | **Bays, Harbours, Estuaries** | | | **Tributaries** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **A** | **J** | **S** | **A** | **J** | **S** | **A** | **J** | **S** | **A** | **J** | **S** |
| sea lamprey | fish | | | | X | | | | | | | X | X |
| lake sturgeon | macroinvertebrates | | | | X | X | | X | X | | | | X |
| pink salmon | fish, macroinvertebrates | X | | | X | | | | | | | X | X |
| coho salmon | fish | X | | | X | | | | | | | X | X |
| chinook salmon | fish | X | | | | | | | | | | X | X |
| rainbow trout | fish | | | | X | | | | | | | X | X |
| brown trout | fish | | X | X | | | | | | | | | |
| brook trout | macroinvert./ fish | | | | X | X | | X | X | X | X | X | X |
| lake trout | fish | X | X | X | X | X | X | X | X | | | | X |
| lake whitefish | macroinvertebrates | | | | X | X | X | | | | | | |
| lake herring | plankton | X | X | | X | X | X | | | | | | |
| Bloater | plankton | X | X | X | | | | | | | | | |
| Kiyi | macroinvertebrates | X | X | X | | | | | | | | | |
| rainbow smelt | plankton | | | | X | X | | X | X | X | | | X |
| Burbot | fish | | | | X | | X | | | X | | | X |
| ninespine stickleback | macroinvertebrates | X | | | X | | | | | | X | | |
| Ruffe | macroinvertebrates | | | | X | | | X | X | X | X | X | X |
| Walleye | fish | | | | X | | | X | X | | | | X |
| slimy sculpin | macroinvertebrates | X | | | | | | | | | X | | |
| deepwater sculpin | macroinvertebrates | X | | | | | | | | | | | |

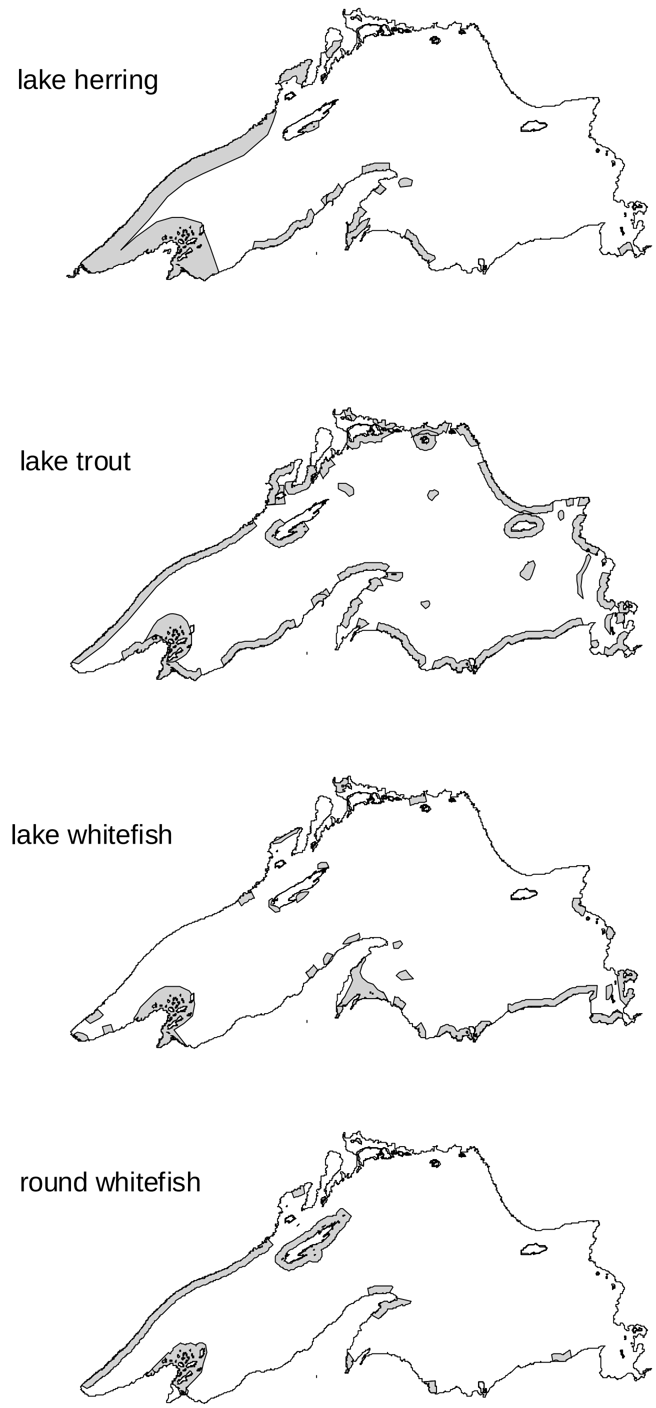


**Figure 50. Spawning habitat for major fish species (from Goodier and others 1981).**

## III. STATUS AND TRENDS OF LAKE SUPERIOR ECOSYSTEMS

## 4. THE TERRESTRIAL ENVIRONMENT

### 4.1 Changes in Forest Composition

On the U.S. side of the basin, the forests were almost entirely cut-over between the mid-1800s and early-1900s. Early logging concentrated on white pine; individual trees could reach 61 m in height and produce slightly over 14 cubic meters ($m^3$)of lumber (TNC 1994). Red pine was harvested to a lesser extent. Early logging practices greatly reduced the seed source for many of the conifer species. In addition, burning of the slash from timber harvest further eliminated reproduction. Hemlock was removed during a later wave of logging when the bark was used for the tanning industry (WI DNR 1995).

After railroads and logging roads were built, hardwoods were harvested by both clearcutting and high-grading (cutting only the most valuable trees). Many hardwood species regenerated, especially sugar maple, beech, basswood, yellow birch, and ash.

Pre-settlement forests on the U.S. side of the basin were predominantly spruce-fir (41 percent) in Minnesota and northern hardwood (39 percent) in Wisconsin and Michigan (Figure 51). Fire-dependent forests of white, red, jack pine combined accounted for 14.8 percent and aspen-birch represented only 1.4 percent. Since logging, pioneer species such as aspen have became more abundant than before settlement (Frelich 1995). For example, in the protected Porcupine Mountains and Sylvania Wilderness northern hardwoods predominate as in historical times, and aspen-birch stands represent only about 1.4 percent of the forest. However, in surrounding commercial forests, approximately 23 percent is aspen-birch dominated (Frelich 1995). Increased browsing of hemlock by deer has contributed recruitment failure and a gradual conversion of hemlock stands to northern hardwoods and spruce-fir where white-tailed deer numbers are well above historic levels (Frelich and Lorimer 1985).

Clearing of presettlement forests not only eliminated the forest ecosystem locally and regionally, but it also created other massive problems when cut logs were floated down the closest stream for transport to Lake Superior or other locations. Riparian vegetation was removed, stream banks were trampled, and stream bottoms were scoured or disrupted. The loss of vegetation created erosion of soils and sheet runoff into streams. Water quality was degraded, and fish habitat was often lost (TNC 1994).

In the Canadian boreal forest, logging began later than in the U.S. portion of the Lake Superior basin, mostly because the forest contained fewer timber-quality trees. The trees were harvested mostly for pulpwood (National Wildlife Federation [NWF] 1993). The pre-settlement forests of the Canadian part of the basin have not been mapped. However trembling aspen, white birch, balsam fir, and balsam poplar have increased due to poor regeneration of shade-intolerant conifers following logging and fire suppression (Carleton 2000). In particular, black spruce has declined following logging.

Red and white pine have been much reduced in abundance on both sides of the border due to selective timber harvest near the turn of the century, blister rust, and fire suppression (see White Pine).

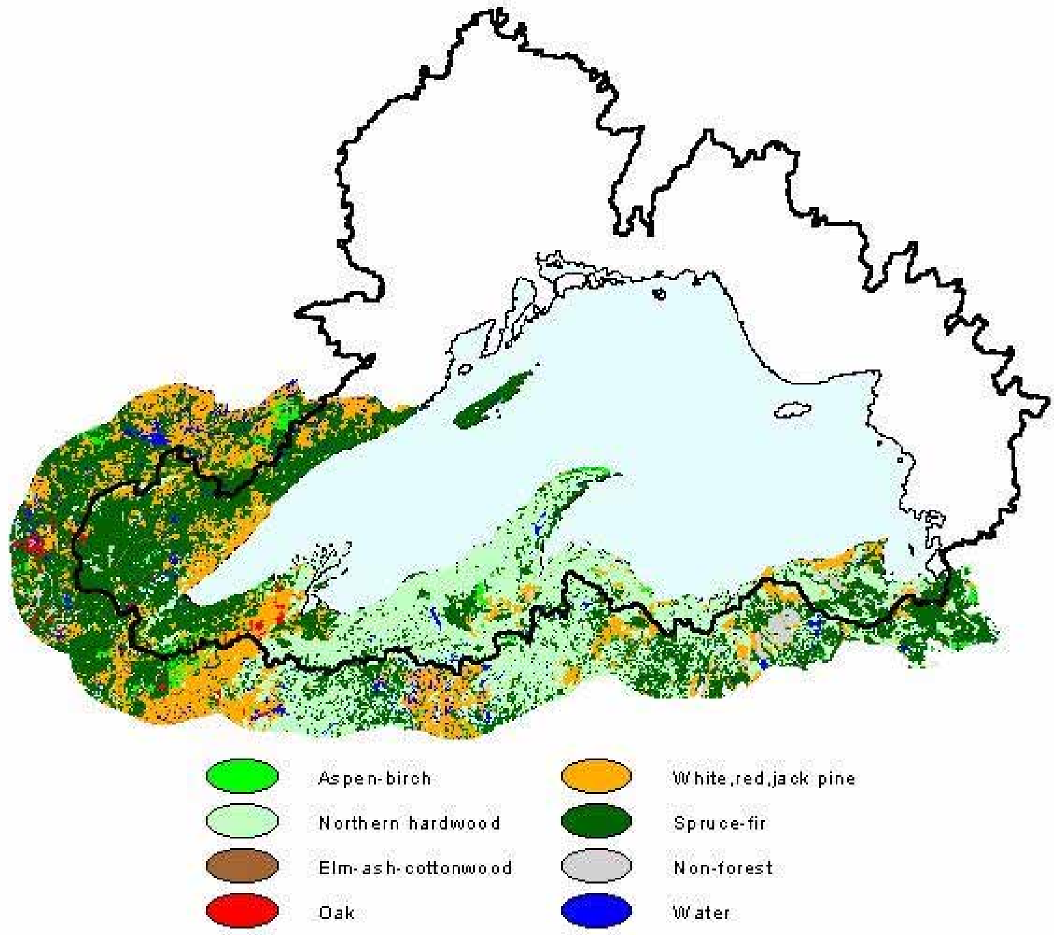


**Figure 51. Historic forest cover in the U.S. portion of the Lake Superior basin.**

The age structure of forests in the Lake Superior basin has also changed since pre-settlement times. In the predominantly boreal forests of the Canadian portion of the Lake Superior basin, there are fewer very young forests than expected under natural conditions. Fire suppression since the 1930s lengthened the fire interval from approximately 65 years to over 500 years and shifted the age class distribution (Ward and Tithecott 1993). Under natural fire regimes, a more or less negative exponential age class distribution is expected on a landscape scale, with most of the area in very young age classes i.e., <20 years (Van Wagner 1978). In contrast, 40- to 80-year age classes now dominate commercial forests in Ontario (Figure 52) (OMNR 1986). In comparison, there is less old forest, and more young and mature northern hardwood, hemlock and oak forests within the Lake Superior basin than in pre-settlement times due to clearing of forests for timber, agriculture and development.

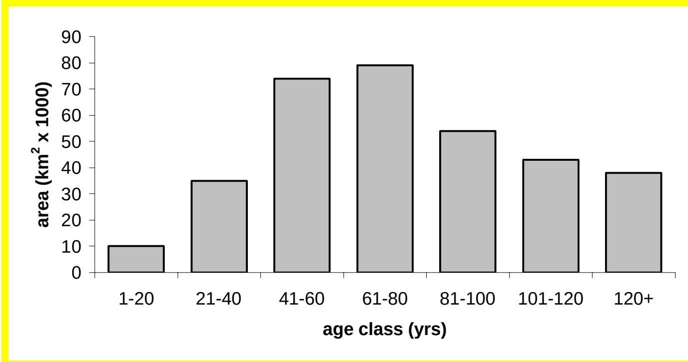


**Figure 52. Age class structure of the Ontario commercial forest (OMNR 1986).**

## 4.2 Forest Fragmentation

Forest fragmentation is a landscape-level process in which forested areas are subdivided into smaller, geometrically more complex, and increasingly isolated patches (Harris 1984). Forest fragmentation results from natural processes such as wildfire, wind, insects and climate effects. Urbanization, clearing for agriculture, and logging also contribute to forest fragmentation and affect patterns of natural disturbances.

Forest fragmentation is one of the most prevalent landscape changes occurring within the Lake Superior basin. It is recognized as a major cause in declining biodiversity (Whitcome and others 1981). For example, habitat loss as a result of forest fragmentation was a factor in extirpating species such bison, elk, cougar, wolverine and black bear from all or much of their range in the Lake Superior basin (Matthiae and Stearns 1981). The target for forest fragmentation identified in *Ecosystem Principles and Objectives* is:

> *No further increase in forest fragmentation in the Lake Superior basin as measured by several complementary indices of landscape composition and pattern. A decrease from the current level of fragmentation is desirable.*

Forests in the basin are often fragmented by roads. Forest that is at least 1 km from all roads accounts for 3,444,635 ha or approximately 44 percent of the Canadian portion of the basin (excluding Lake Nipigon). Most patches of roadless areas are less than 1000 ha, but the vast majority (80 percent) of the total area is comprised in several large patches >10,000 ha each. These tracts are located around Pukaskwa National Park, east of Lake Superior Provincial Park, in the Schreiber Highlands, and west of Lake Nipigon (Figure 54). Mean and median patch size is 1750 ha and 20 ha respectively, indicating a disproportionate amount of area in large patches. Much of the forest has been fragmented by recent clear cuts and logging roads which encompass at least 1,229,416 ha (Figure 53). Much of the forest around the city of Thunder Bay that has historically been logged is not reflected in Figure 53.

No estimates are currently available for roadless wilderness on the U.S. side, but the area and proportion of roadless wilderness are probably considerably less. Large blocks of unbroken mature mesic forest are rare in Wisconsin (WI DNR 1995).

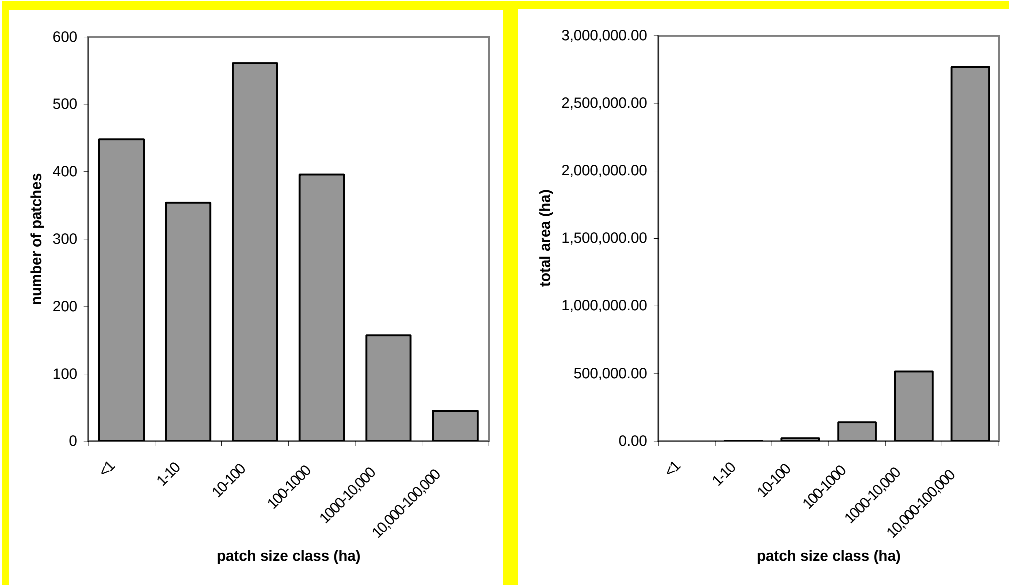


**Figure 53. Number and area of roadless wilderness patches (>1 km from nearest road) in the Canadian portion of the Lake Superior basin.**

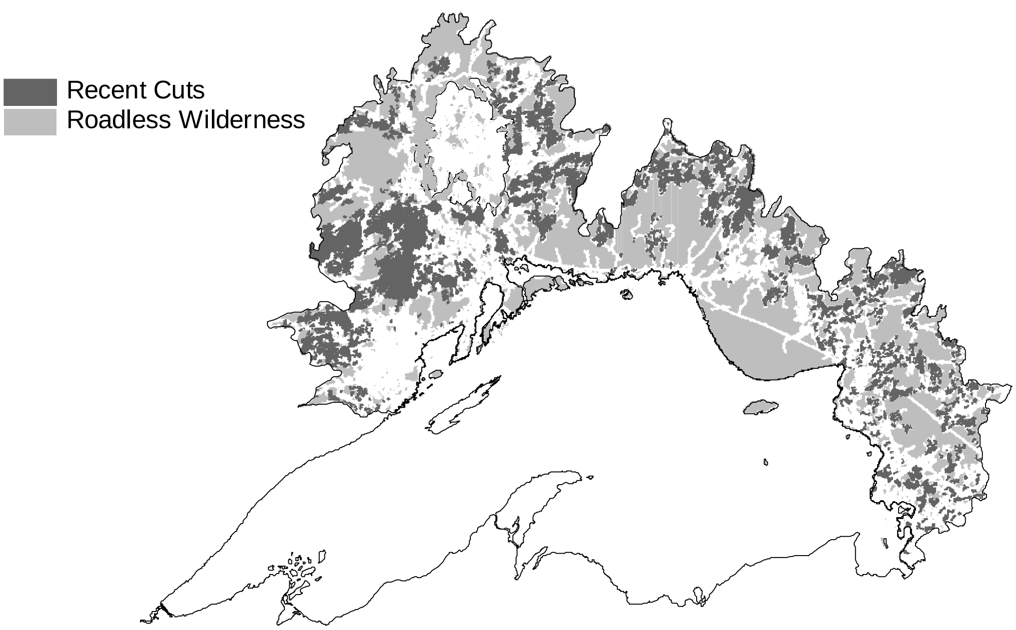


**Figure 54. Roadless wilderness (>1 km from nearest road) and recent cuts in the Canadian portion of the Lake Superior basin.**

## 4.3 Old Growth White Pine

White pine is of special significance in the Lake Superior basin due to concerns about logging in "old growth" stands, its commercial importance, biodiversity, and cultural significance. The present white pine range in the Lake Superior basin includes all of the lake states and the southern part of the Ontario basin. Approximately 3,500,000 ha or 1.9 percent of the forest in northwestern Ontario has at least 10 percent white pine in the overstory (Simpson 1996).

In much of the basin, white pine is an uncommon component of the forest and found in small, widely distributed stands that are isolated from each other and vulnerable to loss (Simpson 1996). In Ontario, white pine typically occurs in mixed wood stands in association with black spruce, balsam fir, jack pine, trembling aspen, white birch and red pine (Perera and Baldwin 1993).

Red and white pine forests are generally restricted to four physiographic site groups (Carleton and Arnup 1993):

1) Conifer-dominated stands on dry, infertile, very shallow soils over bedrock.
2) Conifer-dominated stands on dry to fresh, deep, sandy soils of glaciofluvial origin.
3) Mixed conifer-hardwood stands on dry to moist shallow, coarse loamy soils of morainal origin, often on slopes.
4) Mixed conifer-hardwood stands on deep, coarse loamy, fine loamy or silty soils of morainal or lacustrine origin, usually with level topography.

Mature white pine forests have been replaced by spruce-fir forests due to selective harvesting of white pine in the early 20th century and fire suppression. White pine harvest reached a peak between 1890 and 1910. In the Boundary Waters Canoe Area, white pine decreased from 37.5 percent of the presettlement forests to 10 percent currently, and from 29.5 percent to 5.9 percent in adjacent commercial forests (Heinselman 1973; Frelich 1995). The age class distribution of white pine in northwestern Ontario is skewed to the older age classes. For example, all white pine stands on the Thunder Bay Crown Unit are greater than 80 years, with 3 percent greater than 121 years of age (Bowling and Niznowski 1996). The scarcity of younger age classes is a result of poor regeneration due to fire suppression (Heinselman 1973). In the absence of fire, balsam fir, spruce, and shade-tolerant hardwoods replace old white pines. The lack of forest fires discourages successful white pine regeneration and is a major factor in its slow recovery in Ontario mixedwoods (Bowling and Niznowski 1996). In the absence of fire, the pine component will continue to decline and be replaced by shade-tolerant species.

## 4.4 Future Trends In Forest Cover

The Wisconsin Department of Natural Resources (WI DNR1995) projected the following trends for northern forest management in Wisconsin:

- The total forested area will probably remain the same or increase slightly.
- Aspen-birch type forest will gradually decrease as forest succession progresses. The area in aspen has declined 728,450 ha since 1936.
- Portions of current aspen-birch forests will be replaced by various mixtures of white pine, red maple, and locally, red oak. A significant proportion will succeed to mixed stands of mesic hardwoods, with sugar maple playing the largest role.
- All forests currently dominated by mesic hardwoods will remain so, but species composition will vary greatly depending on geographic location, site type, and management practices. Sugar maple will become more dominant on many mesic sites.
- Red pine plantations are likely to dominate local areas, particularly on forest industry lands. Jack pine acreage is decreasing, while acreage of red pine plantations is increasing.

- Because of great disparity between economic and biological maturity of most tree species, an increase in old-growth forests, in a biological sense, is unlikely. Increased utilization prevents development of old-growth characteristics in managed mature forests.
- Clearcuts and plantations will continue to fragment large, uniform blocks of mature mesic hardwoods. Temporary edges caused by forest cutting will continue to dominate the northern landscape.
- Small, permanent grassy openings will continue to decline to less than one percent of public and forest industry lands. Wildlife that are dependent on grassy, open areas will decline.
- Balsam fir and tag alder will continue to dominate the former white cedar forests. White cedar and Canada yew reproduction will be restricted to scattered, local areas.
- The scattered relict stands containing hemlock and yellow birch will continue to decline. Reproduction of these species will be restricted to scattered, local areas.
- Fire will not play a significant role as an ecological agent in the northern forest.
- Road networks will continue to be improved and expanded.

The demand will continue to increase for forest products such as pulpwood and sawlogs, game species such as white-tailed deer and ruffed grouse, and aesthetic characteristics such as wild country and solitude.

The WI DNR also made the following observations. Under current management practices, only selected economic tree species, a few forest game species, and selected endangered or threatened species receive funding and management attention. The result is a mosaic of many small stands of different forest age classes. Temporary edges are abundant. Fire as a natural process is rare and is not currently used as a management tool in most areas. National, state, county, and local public land units currently plan management strategies independently, but development of ecologically sound, cost-effective techniques that encourage natural processes on the forest landscape will require partnerships with the forest landowners, including the forest industry. Public pressure to pay more attention to maintaining complete and functional forest ecosystems will surely continue.

In Ontario, forest management guidelines have recently changed to better simulate the way fire disturbs the forest in terms of the size and distribution of cutovers. New guidelines are also in place for protecting old growth forests (OMNR 2003).

## 4.5 Exotic Species

Numerous non-native insects and plant species have been introduced to the Lake Superior basin. Most of these are largely restricted to urban and agricultural areas. The following species are some of the most likely to have significant impacts in terrestrial habitats.

*Gypsy Moth*
Gypsy moth is one of North America's most devastating forest pests (USDA 1998). It was deliberately introduced to the U.S. in the late 1800s and had spread to the eastern part of the Lake Superior basin by the early 1990s (USDA 1998).

Widespread defoliation of forest stands occurs in peak years. Oaks are the preferred larval food, but other hardwood trees are also eaten. The impacts of defoliation on the forest ecosystem are not well understood, but probably cause reduced growth and survival of oaks, perhaps eventually leading to a shift in forest composition to less vulnerable species (USDA 1998).

Gypsy moths have been recorded in all of the Lake States and have infested the Upper Peninsula of Michigan. In Minnesota and Wisconsin, infestation is restricted to mainly urban areas but is now spreading to rural forests (Joe Meating, personal communication). There was a major outbreak in the Sault Ste. Marie, Ontario area in the late 1990s. Oaks are absent in most of the Ontario basin, and extensive infestation is unlikely north and west of Sault Ste. Marie. Suppression means preventing buildup of populations to protect recreation areas, forested communities, and high-value timber stands in the established infestation in the northeast. This work is carried out by state agencies with help from USDA's Forest Service. All the states have monitoring programs. Control efforts have focused on slowing the spread by eradicating isolated colonies with pesticides and biological control methods (USDA 1998).

*Asian Longhorned Beetle*

The Asian Longhorned Beetle is native to China, and is a hardwood tree pest. It is believed to have been imported to the U.S. in untreated wood used for pallets and packing materials. It was first discovered in the U.S. in 1996 and in a Chicago neighborhood in 1998. These beetles spread rapidly from tree to tree, killing trees by boring deep holes in them. There is no known method of eradicating the beetles short of destroying the infested trees. Due to its recent introduction into the Great Lakes basin, the extent of potential damage due to this non-native nuisance beetle has not yet been assessed, although hundreds of trees have already been destroyed in the Chicago area. At present this species does not occur in the Lake Superior basin, but may pose a threat in the future.

*Hemlock Woolly Aphid*

Introduced into the Pacific Northwest in the 1920s, the hemlock woolly aphid was first reported in eastern Virginia in the early 1950s. Since then it has spread primarily northeastward and now occurs as far north as Connecticut and Rhode Island. The primary host is hemlock, with spruce being a possible secondary (alternative) host.

Immature nymphs and adults damage trees by sucking sap from the twigs. The tree loses vigor and prematurely drops needles, to the point of defoliation, which may lead to death. If left uncontrolled, the aphid can kill a tree in a single year. When not at serious risk to the tree, presence of the dirty white globular masses of woolly puffs attached to the twigs or base of needles reduces the value of ornamentals.

Application of insecticides is currently recommended for controlling the hemlock woolly aphid. Tree fertilization can result in more damage, as aphid populations are known to flourish on such trees. It is believed that this species originally came from Japan. Currently, researchers are investigating the prospects of identifying and importing natural enemies for use against this pest. At present this species does not occur in the Lake Superior basin, but may pose a threat in the future.

*Pine Shoot Beetle*

The pine shoot beetle, a serious foreign pest of pines, was discovered at a Christmas tree farm near Cleveland, Ohio in July 1992. A native of Europe, the beetle attacks new shoots of pine trees, stunting the growth of the tree. The USDA's Animal and Plant Health Inspection Service (APHIS) has taken steps to prevent this insect from moving to major pine-tree production areas. APHIS, in cooperation with state officials, has quarantined 43 infested counties in Michigan, Indiana, Ohio, New York, Illinois, and Pennsylvania. Most of the beetle finds have been at Christmas tree farms and pine tree nurseries. The beetle prefers Scotch pine but will feed on most, if not all, species of pine. Although the beetle is slow moving, it could spread to other areas through the movement of Christmas trees, nursery stock, and pine logs.

In cooperation with state officials, APHIS is requiring the inspection of cut Christmas trees, pine nursery stock, and pine logs, stumps, and lumber with bark attached before these regulated articles can move out of quarantined areas. Lumber and logs without bark attached are not regulated. Additionally, APHIS and cooperating officials are conducting wide-ranging detection surveys for the pest. State and federal scientists are working with the affected industries to develop appropriate control strategies. This beetle species presently occurs in many counties in the Michigan portion of the Lake Superior basin.

*Exotic Buckthorns*

Exotic buckthorn *(Rhamnus cathartica* and *R. frangula)* has invaded plant communities from state parks to back yards. European or common buckthorn invades woodlands. Glossy or columnar alder-buckthorn is generally found on moist soils. In the Lake Superior basin, both species are established in the Duluth area, Michigan, and Wisconsin. These species are not yet known to be invasive in the Ontario part of the Lake Superior basin.

*Exotic Honeysuckles*

Exotic honeysuckles *(Lonicera tatarica, L. morrowii, L. maackii,* and the hybrid *L.* x *bella)* have been used as ornamentals for decades. Birds carry their seeds from formal landscapes to natural habitats, including grasslands, marshes, and woodlands. Once established, often with European buckthorn, honeysuckle can dominate the understory of woodlands. In the Lake Superior basin, *Lonicera tatarica* is established in Duluth and Michigan. In Ontario, *Lonicera tatarica* is restricted to scattered occurrences near human habitation. The other species have not yet been documented in the basin, but are spreading and are expected to occur here.

*Garlic mustard*

Garlic mustard spreads and dominates the ground flora in forests, replacing native woodland plants. Seedlings of this biennial herb germinate in early spring and by midsummer form a cluster or rosette of three or four leaves. In the spring of its second year, it flowers, sets seed, and then dies. Floodwaters, wildlife, human footwear, and off-road vehicles carry seeds to new sites. Management methods include hand removal, herbicide treatments, and repeated burning, though none can control large infestations. A long-term control using biological agents is being sought. In the Lake Superior basin, garlic mustard is apparently restricted to Marquette County, Michigan.

*Leafy spurge*

Leafy spurge is a plant that has roots that can extend nearly 11 m, grows through asphalt, and flings its seeds almost 5 m. It invades prairies, roadsides, and pastures. Its deep root system enables it to survive dry conditions and resprout even after the foliage is destroyed. Control usually combines use of herbicides, prescribed fire, and mowing. Insects for biological control have been released at several hundred sites in the state of Minnesota by the U.S. and Minnesota Departments of Agriculture. In the

Lake Superior basin, leafy spurge is fairly widespread, but largely restricted to roadsides and other highly disturbed sites.

*Spotted Knapweed*
Spotted knapweed probably arrived in the Lake Superior basin in alfalfa or hay seed from Europe and Asia. It reproduces solely by seed. Dry prairies, oak and pine barrens, and sandy ridges are likely natural habitats. Chemical control can be fairly effective, but cost is prohibitive. The USDA is conducting a biological control program, involving a root-mining beetle, two root-mining moths, and a flower moth, which has produced varying levels of success. Two species of seed-head-attacking flies have reduced seed production by 95 percent in experiments. In the Lake Superior basin, spotted knapweed is known from Isle Royale and Grand Sable Dunes in Michigan and northern Wisconsin. In Ontario, its status is uncertain, but it has been reported from the east side of the basin.

## 4.6 Status and Trends of Terrestrial Organisms

Wildlife populations in the Lake Superior basin have undergone continuous changes since before Europeans settled the area. Native Americans influenced terrestrial wildlife communities through habitat manipulation and harvests. Harvest of beaver and large ungulates could have indirectly affected the forest community through reduction in browsing and lowland flooding (Stearns 1995). The effects, however, were likely localized and minor and have never been quantified (Stearns 1995).

The first European explorers and settlers were attracted to the Lake Superior basin by the abundance of furbearing animals. A series of forts and settlements were established along the Great Lakes to protect the fur trade (The Nature Conservancy [TNC] 1994). Many populations of furbearing mammals were depleted as a result of unregulated fur harvest. Once the stocks were depleted, the fur trade moved west to more productive areas.

Pursuit of wildlife-related recreation is important for residents of the basin. In 1996, Michigan had the highest number of hunters of all states in the United States, with 934,000 (U.S. Dept. of Interior and U.S. Dept. of Commerce 1998). This was an increase from 1991, when 826,000 people hunted in Michigan (U.S. Dept. of Interior and U.S. Dept. of Commerce 1993). In 1996, Wisconsin was fourth in the United States with 665,000 hunters, which was a decrease from 747,000 in 1991 (U.S. Dept. of Interior and U.S. Dept. of Commerce 1998, U.S. Dept. of Interior and U.S. Dept. of Commerce 1993). The total number of days that Ontario residents spent on non-consumptive wildlife-related recreation increased from 1981 to 1991, but the total number of days spent hunting decreased (Filion and others 1993).

Wildlife watching is important to both residents and nonresidents of the basin. In 1991, more than 7 million Ontario residents aged 15 years and over (91.9 percent of the population) participated in one or more wildlife-related activities (Filion and others 1993). In 1996, residents of Ontario spent $4.3 billion on nature-related activities, of which $410.9 million was spent on wildlife viewing (Environment Canada 2000). In 1996, almost $1.6 billion was spent in Wisconsin for wildlife watching, the fifth-highest of the 50 states. Michigan supported slightly more than 16 million days of nonresident wildlife watching, which was second in the nation (U.S. Dept. of Interior and U.S. Dept. of Commerce 1998).

Habitat changes on the landscape, as well as harvest and management of select species, have created some dramatic changes in wildlife communities over the past 150 years. Table 16 shows how some species and bird communities have changed since European settlement. Populations have fluctuated from common to rare or from rare to common, and community structures have shifted as a result of large-scale logging in the late 1800s and early 1900s. Species such as the gray squirrel, porcupine, and beaver were rare in the early 1900s, but populations increased as the forest began to mature. Other species, such as raccoon, eastern cottontail, and striped skunk, became more abundant as young forests, forest edges, resorts, small towns, and agriculture provided favorable habitat. Birds such as ruffed grouse and woodcock increased as young forests became available. However, forest bird species, such as the pine warbler, barred owl, and scarlet tanager, decreased in numbers as forests were converted to brushlands; current trends from young to mature forests are again providing habitat for these species (Wisconsin Department of Natural Resources 1995).

**Table 16. Changes in the Relative Abundance and Distribution of Selected Wildlife in Wisconsin's Northern Forests: 1850-1994.**

| | **Relative Abundance and Distribution** | | | |
|---|---|---|---|---|
| **Species** | **Mid-1800s** | **Early 1900s** | **Mid-1900s** | **1994** |
| White-tailed deer | Low<br>Clumpy | Low<br>Clumpy | Abundant<br>Continuous | Common<br>Continuous |
| Coyote | Low<br>Clumpy | Common<br>Clumpy | Abundant<br>Continuous | Common<br>Continuous |
| Bobcat | Low<br>Clumpy | Low<br>Clumpy | Common<br>Continuous | Rare<br>Continuous |
| Moose | Low<br>Clumpy | Rare<br>Isolated | Gone<br>Gone | Rare<br>Isolated |
| Snowshoe hare | Low<br>Clumpy | Common<br>Continuous | Abundant<br>Continuous | Low<br>Clumpy |
| Gray wolf | Common<br>Continuous | Common<br>Continuous | Gone<br>Gone | Rare<br>Clumpy |
| Fisher | Common<br>Continuous | Rare<br>Isolated | Gone<br>Gone | Common<br>Continuous |
| American marten | Abundant<br>Continuous | Rare<br>Isolated | Gone<br>Gone | Rare<br>Isolated |
| Elk, wolverine | Low<br>Clumpy | Gone<br>Gone | Gone<br>Gone | Gone<br>Gone |
| Bald eagle, osprey | Common<br>Common | Common<br>Continuous | Low<br>Clumpy | Common<br>Continuous |
| Ruffed grouse | Low<br>Clumpy | Common<br>Continuous | Abundant<br>Continuous | Common<br>Continuous |
| Woodcock | Low<br>Clumpy | Common<br>Clumpy | Abundant<br>Continuous | Common<br>Clumpy |
| Sharp-tailed grouse | Low<br>Clumpy | Abundant<br>Continuous | Common<br>Clumpy | Rare<br>Isolated |
| Beaver | Common<br>Continuous | Rare<br>Isolated | Low<br>Clumpy | Abundant<br>Continuous |

**Table 16. Changes in the Relative Abundance and Distribution of Selected Wildlife in Wisconsin's Northern Forests: 1850-1994.**

| | Relative Abundance and Distribution | | | |
|---|---|---|---|---|
| **Species** | **Mid-1800s** | **Early 1900s** | **Mid-1900s** | **1994** |
| Grassland birds | Rare<br>Isolated | Common<br>Continuous | Common<br>Clumpy | Rare<br>Isolated |
| Young-forest birds | Rare<br>Isolated | Common<br>Clumpy | Common<br>Continuous | Common<br>Continuous |

*Source: Wisconsin Department of Natural Resources 1995*
*In order of abundance, from least to most abundant: gone, rare, low, common, abundant. In order of distribution, from extirpated to widely distributed: gone, isolated, clumpy, common, continuous.*

Direct human interference and harvest also dramatically affects species abundance. Species that rely on large blocks of wild land with little human presence, such as timber wolf, Canada lynx, wolverine, and spruce grouse, were extirpated from a portion of their range (WI DNR 1995). Some of these species can be recovered with careful management and reintroduction. Many species were harvested or exploited until they nearly disappeared from the basin. For example, herring gull populations in the early 1900s were almost extirpated from the entire Great Lakes basin as a result of persecution at nesting sites and demand for bird feathers for the millinery trade during the late 1800s. The Migratory Bird Convention of 1916 provided protection, and herring gull populations began to increase in the 1940s (Ryckman and others 1997).

Environmental quality also plays a significant role in wildlife communities. Environmental contaminants from toxic chemicals that humans introduced into the environment in the mid-1900s nearly eliminated top carnivores such as bald eagles and double-crested cormorants. The effect of chemical pollutants on amphibian populations has also been noted. Species such as bald eagle, herring gull, and river otter are indicators of the quality of the environment, and some monitoring is taking place in the basin to determine contaminant levels and their effects.

The landscape, its environmental quality, and human-imposed regulations and actions are reflected in the current status and health of terrestrial wildlife communities. Tough decisions are being made and will need to be made in the future regarding restoration and management of terrestrial wildlife. As a society, we have begun to understand what needs to happen in the Lake Superior basin to provide a native, healthy, and sustainable wildlife community. But there is also much we do not know. Adaptive management and strategic decision-making may aid in moving toward our goals.

The following summaries are provided for groups of species: mammals, birds, amphibians and reptiles, invertebrates, and plants. We generally provide a broad overview of changes that have taken place in these communities and their current status. Some larger groups are broken down into smaller groups of species, depending on our knowledge.

The status and trend information helps to define the overall problems and opportunities for terrestrial wildlife communities in the Lake Superior basin and to define broad strategies for the Binational Program and its partners.

**This work is not a detailed account of status and trends of all wildlife in the Lake Superior basin.** There are two reasons for this. First, the time frame given to the working committees was very tight and did not allow for complete compilation of existing data or knowledge. Second, the Binational Program is not a wildlife management entity; rather it is a partnership of agencies from two countries trying to improve the integrity and health of the Lake Superior basin. The work is focused at the strategic level to identify broad goals and strategies. Individuals and organizations may investigate the details at the specific level as they develop and implement programs to meet the Binational Program's broad strategies.

### 4.6.1 Mammals

Mammalian populations have seen greater fluctuations and changes than any other group of terrestrial vertebrates. Furbearers were exploited during the fur trading years, which caused dramatic decreases of most species and nearly wiped out some. Ungulates were hunted for food and hides; carnivores, such as wolves, were feared and harvested to near oblivion in the southern portion of the basin. As regulations were enacted to control the harvesting of such animals, however, many populations rebounded. Wildlife management agencies have successfully reintroduced certain species, such as American marten, to their historic range. Other species, such as white-tailed deer, have become so abundant in certain areas that they may be damaging their environment.

Some species, however, remain in peril. The woodland caribou has been nearly pushed out of the basin. Canada lynx is nearly gone from the southern part of the basin. There is very little we know about the trends of many small mammals, such as voles, mice, and bats.

There are differences in abundance and diversity of species from south to north. Many of the species that were lost in the U.S. portion of the basin in the early 1900s persisted in the Canadian portion. Species such as white-tailed deer moved into the Canadian portion of the basin in the late 1800s. Because of these differences, habitat and population management and recovery efforts are different between Canada and the United States. For example, Ontario is managing habitat to protect woodland caribou and needs to understand and monitor the effect that deer, moose, and wolf have on caribou. The states have and continue to actively reintroduce some mammalian species, such as moose, which was not necessary in Ontario. It is unlikely that any work to protect and manage mammalian species has focused on the Lake Superior basin specifically. Most work has been limited by political boundaries. Therefore, no information has been specifically compiled for the basin. This report can provide a starting point.

#### *Ungulates*

Within the Lake Superior basin and surrounding area, the ranges occupied by large ungulates (woodland caribou, moose, white-tailed deer, and elk) have been substantially altered from presettlement patterns. Harvesting, human disturbance, and habitat changes have nearly eliminated species such as woodland caribou and elk. Elk have been reintroduced into northern Wisconsin and northeast of Sault Ste. Marie Ontario, but they are found nowhere else in the basin. Conversely, white-tailed deer populations in the southern part of the basin are high, largely due to favorable habitat conditions, mild winters, hunting regulations, and decline of natural predators, such as wolf. The white-tailed deer brought with it the parasitic brain worm, which is fatal to both caribou and moose. Minnesota's moose population has remained relatively stable since the early 1990s (Mark Lenarz, MN DNR, personal communication). Ontario has seen stable to increasing populations of moose since 1992 (Timmermann and Buss 1997).

Michigan successfully reintroduced moose into the Upper Peninsula in 1985 and continues to manage the population to increase its range.

*Woodland Caribou*

Woodland caribou historically ranged throughout most of the Lake Superior basin, but they currently can be found only in the northern edge of the basin in Ontario and in remnant populations on islands and in parks. A discussion of their status appears in the section on *Species and Ecosystems of Concern*.

*White-Tailed Deer*

Current deer numbers in the Upper Peninsula of Michigan are estimated to be approximately double the presettlement numbers, based on a habitat suitability model (Doepker and others 1996). Deer moved northward into northwestern Ontario in the late 1890s (Snyder 1938). McCaffery (1995) estimated presettlement populations of deer in northwestern Wisconsin to be approximately 7.5 deer/km$^2$ and peak populations in the 1940s to be 15 to 19 deer/km$^2$. The 1995 population in northern Wisconsin was about 10.3 deer/km$^2$, largely due to mild winters and opposition to liberal harvests (McCaffery 1995). Minnesota's deer population increased steadily from 1980 to 1995, but severe winters in 1995-96 and 1996-97 caused the population to decline more than 40 percent. Their numbers have increased in the last few years, however, due to mild winters since 1997 (Mark Lenarz, MN DNR, personal communication). Three primary factors that affect deer numbers in northern Minnesota, in order, are: 1) winter weather, 2) human harvest, and 3) wolf predation (Mark Lenarz, MN DNR, personal communication). A discussion on the ecosystem effects of and approach to deer management is provided as Addendum 7-B.

Increasing numbers of deer have resulted in several impacts to the ecosystem within the basin and elsewhere. Waller and Alverson (1997) suggest that chronically high deer numbers are having substantial, deleterious ecological impacts across many regions. We do not know the overall extent of the problem in the basin, but several studies have shown negative impacts on certain plant species and plant communities in this region (Stoeckeler and others 1957; Frelich and Lorimer 1985; Mladenoff and Stearns 1993; Balgooyen and Waller 1995). Stoeckeler and others (1957) identified a direct negative impact on hemlock seedlings from deer browse in northeast Wisconsin, and Frelich and Lorimer (1985) identified negative effects in the western Upper Peninsula of Michigan. Mladenoff and Stearns (1993) point out that hemlock used to be a regional dominant, but now only occupies 0.5 percent of the landscape. Hemlock requires very specific microhabitat conditions for germination and seedling establishment, and the right conditions occur only in specialized locations. Mladenoff and Stearns agree that deer browsing has a negative effect, but it is only one of many current conditions that suppress regeneration. Climate, dominant forest type (which is now hardwood), and herbivory are all factors that affect hemlock. The ecosystem approach to conservation would require a look at more than deer numbers to re-establish healthy hemlock communities.

Herbaceous plants constitute the bulk of deer summer diets (McCaffery and others 1974), so certain sensitive plants can be negatively affected by deer browsing, especially the species that might be selected by deer as most palatable. In the Apostle Islands and northern Wisconsin, Balgooyen and Waller (1995) showed declines in several woody species, overall herbaceous species diversity, and specific declines in wild sarsaparilla, Canada mayflower, and blue bead lily. The impacts to herbaceous diversity had persisted for over 30 years, with blue bead lily apparently extirpated from Madeline Island.

Other studies have suggested that an overabundance of deer affects other animal species in the ecosystem. In Pennsylvania, for example, a study showed that intermediate canopy-nesting birds declined 37 percent in abundance and 27 percent in species diversity at higher deer densities. Five species completely dropped out at very high densities (14.7 deer/km$^2$), and two dropped out at highest deer densities (24.6 deer/km$^2$) (DeCalesta 1994). In New Hampshire, deer were browsing on lupine plants, which are host plants for the endangered Karner blue butterfly (Miller and others 1992). This, in turn, decreased populations of the butterfly.

Increased white-tailed deer populations are thought to have contributed to the decline of some moose and caribou populations through the spread of brainworm.

Human interaction with overabundant deer is also seen in increased vehicle collisions, loss of crops and landscape plants, and increased nuisance occurrences.

***Furbearers, Including Mid-Sized Carnivores***

Beaver, river otter, American marten, bobcat, fisher, mink, and other furbearers were intensively trapped in the mid- to late-1800s, some to the level that they were extirpated from significant portions of the basin. Fishers, for example, were extirpated from Wisconsin and Michigan due to overharvest and habitat destruction (Racey and Hessey 1989a).

Furbearer populations were also severely reduced in Ontario, and species such as beaver, marten, and fisher were extirpated from portions of their historic range. Season closures and other regulations, along with the establishment of a number of Crown Game Preserves in the 1920s, helped reverse the declines and allowed populations to recover. Individual traplines were first established in the 1930s, and in 1950 it became a requirement for traplines to be registered. The registered trapline system, which licensed a trapper to a specific trapping area, stabilized a chaotic industry and allowed distribution of the harvest, eliminated competition among trappers, and encouraged trappers to manage their trapline areas on a long-term basis (Novak 1987). During the period of the 1940s through the 1950s, beaver, marten, and, to a limited extent, fisher, were transplanted from remaining populations to areas of their former occurrence. In 1950 both marten and fisher were generally absent or uncommon in most of the basin. They were common only in the eastern portion of the basin between Wawa and Chapleau (de Vos 1952). Since that time both fisher and marten numbers have increased, and they now reinhabit their former range. In the case of marten, current harvest levels are higher than at any time in over 100 years. Marten from Ontario were also used as source stock for an introduction into the Lower Peninsula of Michigan in 1985 and 1986 (Ludwig 1986).

In Minnesota, raccoon, fisher, American marten, red fox, and black bear populations have all recovered substantially over the past 20 or more years (Bill Berg, MN DNR, Grand Rapids, personal communication). Fisher and marten were closed to harvest in the late 1920s and reopened in 1977 and 1984. Both species have increased their ranges west and south in Minnesota (Bill Berg, MN DNR, Grand Rapids, personal communication). A long series of mild winters and general climate change have allowed many of these species to increase in abundance and range.

Populations of bobcats, fishers, martens and otters can be estimated using a population model developed by Bill Berg of the MN DNR. The model is used widely throughout the Midwest, including Minnesota, Wisconsin, and Michigan. The Wisconsin and Minnesota DNR used the model to estimate populations for their states, and this information is presented below. Unfortunately, little published information is available for population levels of Michigan furbearer species.

Harvest seasons have been established in all three states for otter, bobcat, and fisher. Marten harvest is permitted only in Minnesota. Martens, fishers, and otters have been expanding their ranges in all three states. Martens are designated as a sensitive species by the U.S. Forest Service in the Chequamegon and Nicolet National Forest Land Management Plans.

*Beaver*

Beaver have increased in abundance and regained a continuous distribution since the trapping-induced population plunge of the early 1900s. The favorable habitat conditions resulting in the overabundance of white-tailed deer have also resulted in record high beaver populations. Beaver impact both the terrestrial and aquatic ecosystems of the basin. When they harvest trees and build dams, they change the aquatic community structure and open riparian canopies, which creates a positive impact to some species and a negative impact to others.

Beaver can be harmful to the cold-water migratory fish communities. Beaver dams may create a barrier to anadromous migratory fish that use tributary streams for spawning. In addition, cold-water streams in Minnesota's portion of the basin exist and support trout by virtue of climate alone. Summer water temperatures of the surface water driven stream systems are often the limiting factor for healthy fish populations. Riparian forest cover is essential for moderating stream temperature conditions. The removal of riparian forest cover by abundant beaver populations and loss of stream shade results in thermally degraded aquatic trout habitat. Increased water temperatures are also found in ponds above beaver dams. However, beaver ponds offer many benefits to a variety of wildlife species such as waterfowl, reptiles and amphibians.

*Bobcat*

Bobcat populations in Minnesota are estimated at around 1,500 animals. This population level has been maintained for 20 years. The Wisconsin bobcat population is also estimated at 1,500 animals, which represents a 20 percent increase in population during the past five years. Bobcat harvests in all three states range from 100 to 300 animals. These harvests are regulated to provide for a size-stable population. Bobcats are very rare in the Ontario portion of the basin, with less than 50 animals harvested in the entire province each year.

*Fisher*

The fisher population in Minnesota has been increasing for about 20 years since the lows of the mid- to late-1970s and is currently estimated to be 10,000 animals. The fisher population in Wisconsin peaked in 1992 at 9,500, declined to 7,500 in 1997, and is now estimated to be nearly 8,000 animals. Both Wisconsin and Minnesota are trying to stabilize the population growth of this species through harvests at about current levels. Ontario fisher populations have experienced an increase over the last decade.

*Otter*

Otter populations in Minnesota, currently estimated at 13,000 animals, have also been increasing for nearly 20 years. The Wisconsin otter population is estimated at 14,000 animals, which represents a decline from the peak population in 1992 of 15,500. Wisconsin harvest regulations were liberalized in

1992 to take advantage of high population levels. While no population estimates are available, Ontario populations are believed to be stable based on annual trapper questionnaire responses.

*American Marten*
American marten populations in the U.S. portion of the basin declined in the late 1800s, and the species was thought to be extirpated from Minnesota and Wisconsin by the 1920s. Marten became reestablished in northern Minnesota by the 1950s and are relatively common there now. American marten are listed as a game species in Minnesota, and a trapping season has been in effect in that state for many years. The population is estimated at 12,000 animals. The marten population has been increasing steadily since 1980 with only small dips when trapping conditions are good and harvests unexpected large. Martens are classified as an endangered species by the State of Wisconsin. They were extirpated from the state in the early 1900s and were reintroduced in the 1970s and 1980s (Wisconsin Dept. of Natural Resources 1999). The marten population continues to be small and isolated, centering on the two release sites. Reasons for the lack of expansion of this species are unknown.

In Ontario, marten are relatively common and widespread

***Small Mammals***

Small mammals include mice, voles, bats, cottontail rabbits, and snowshoe hares. Little population information is available for any of these species, except perhaps on a site-by-site basis. This group of mammals plays a very important role in providing a prey base for other mammals and birds and for preying on invertebrates.

***Stressors of Mammals***

*Overabundant Populations*
The recovery of some species from near extirpation to overabundance has resulted in stresses to other species (see Addenda 7-A and 7-B). The management of overabundant deer, however, also provides opportunities to focus on ecosystem management principles and to manage wildlife communities as a whole.

*Habitat*
Habitat changes on the landscape have been a factor in the composition of mammalian communities (see Table 16). Habitat changes created by certain species, especially white-tailed deer, alter the composition of all mammalian communities.

Beaver also have a significant impact on the surrounding environment, especially riparian vegetation and adjacent aquatic communities. The long-term management of beaver populations can be addressed through management of their riparian food source. The dominant aspen/alder riparian community we see today can be steered toward less palatable coniferous stands. The restoration of coniferous old-growth riparian forest will benefit both terrestrial and aquatic ecosystems.

Some species of particular concern have specific habitat requirements that must be met for their survival. For example, American marten and fisher require blocks of mature forest, and marten seem to prefer forests with a coniferous component. These requirements are an important consideration in timber management (Racey and Hessey 1989b). Standing hollow trees must be present for den sites for both species, and coarse woody debris is critical for winter rest sites for marten (Gilbert and others 1997). Loss of mature, coniferous forest habitat related to logging and human settlement, as well as over-trapping, probably contributed to their decline (Coffin and Pfannmuller 1988). Recently introduced marten habitat guidelines call for maintaining large contiguous blocks of "core habitat" consisting of mature coniferous forest.

*Contaminants*

Mammals that are top predators accumulate toxic chemicals in their bodies, which may affect their individual health and reproductive capability. Most contaminant monitoring in the Lake Superior basin, however, has focused on birds and fish.

Concern has been expressed about cadmium levels in liver and kidney tissue of deer and moose that exceed recommended daily intake levels for humans. While negligible amounts of cadmium have been found in Ontario deer and moose muscle (Glooschenko and Burgess 1987), the OMNR recommends that people do not eat the liver and kidneys of moose and deer because of the concerns about cadmium levels in these internal organs. Kronberg and Glooschenko (1994) suggested that cadmium could serve as a proxy for other heavy metals of concern, such as lead and mercury, and that analyzing moose tissues on a regular basis could be useful for monitoring changes in environmental levels of these elements.

Studies begun on fisher (Gerstenberger and others 1996) found elevated levels of chlordane, but much work remains to be done. Mink and otter are good indicators of contaminant effects on mammals in the Great Lakes; they are carnivores, consume significant amounts of fish, and have been found to be very sensitive to PCBs and mercury (Ensor and others 1993). PCBs negatively affect mink reproduction (Heaton and others 1992; Kubiak and Best 1991). A study to develop baseline contaminant data in wildlife in Minnesota (Ensor and others 1993) found elevated levels of PCBs in mink collected along Lake Superior, with the three highest levels of mercury observed in mink. The study's authors suspect that high mercury levels in combination with PCBs may be impacting mink populations.

*Public Demands*

Many mammalian species were historically stressed by overharvest, but many populations have recovered with the implementation of hunting laws and regulations. Recent demands from the public have resulted in agencies also managing wildlife populations for non-consumptive uses. Conflicts can arise with how an agency manages certain wildlife species or communities.

### *Management Efforts for Mammals*

Management and recovery of mammalian populations is done by the state, provincial, tribal, or federal agency that has authority.

### *Current Monitoring Efforts for Mammals*

Management agencies usually monitor mammal populations, either through population indices or harvest surveys.

Ontario initiated a Wildlife Assessment Program to monitor representative wildlife species that may be affected by forestry activities. Eighty-two species were selected as a measure of sustainable forest management; 23 of these species are mammals. Small mammals (mice and voles) are monitored as part of a pilot study at a number of sites within the basin. Annual trapper questionnaires also allow the calculation of a Population Level Index and Population Change Index for furbearers and a number of other wildlife species.

National forests in the United States are monitoring some mammalian species, especially those that are indicators of the impacts of forest management activities. A few programs are monitoring contaminant levels in top predators.

***Gaps in Mammal Information***

None of the monitoring information on any mammal species has been compiled for the Lake Superior basin.

Very little research is being conducted on contaminants in mammalian predators in the Lake Superior basin.

A significant amount of research needs to be conducted on the long-term effects of herbivory on plants and animals. We need to better understand whether population management programs can reverse some of the negative trends that are seen. This type of monitoring and research should be done in conjunction with adaptive management strategies.

***Challenges for Mammals***

One of the biggest challenges concerning management of mammals is understanding what mammalian community structure represents a "healthy, sustainable terrestrial wildlife community." As noted above, the current community profile of ungulates has changed drastically from what it was pre-European settlement. Do current conditions represent a healthy terrestrial wildlife community, or is the current community simply the one that will be most accepted by human society? Mammalian communities can have a substantial effect on habitat structure, which in turn affects other terrestrial wildlife and ecosystem functions.

The Binational Program is not, and should not be, in the position of defining a healthy, sustainable mammalian community at the population level. It can, however, help define healthy ecosystems in terms of habitat structure, landscape patterns, and disturbance regimes. The appropriate agencies, however, need to become more actively engaged on a landscape scale to address overlapping goals and objectives. If this is done, the Binational Program can advance those programs where goals overlap.

### 4.6.2 Birds

***Songbirds***

Trends in songbird populations can be measured on the basis of individual species, communities, habitat guilds, or migratory status. Populations can be reviewed nationally, regionally, or locally, depending on the data set that is available. The North American Breeding Bird Survey allows us to look at continent-wide trends, as well as regional trends. Local trends are available only if individual studies or monitoring programs have been established. The Lake Superior basin has abundant information at all levels, but it has not been compiled on a basinwide basis. Therefore, we can only provide some relative trend information that is currently compiled at the national and regional level.

Portions of the Lake Superior basin have some of the highest species richness for breeding birds in North America, especially the southern and northwestern shores (Sauer and others 1997; Green 1995). Certain forest species appear to be more abundant, widespread, or productive in northern Wisconsin than in other regions. For these species, the Lake Superior basin could provide source populations. Some species include American woodcock, broad-winged hawk, black-billed cuckoo, winter wren, veery, blackburnian warbler, black-throated green warbler, and scarlet tanager (Howe and others 1992). The Minnesota portion of the basin also has some of the highest woodland species richness in North America (Sauer and others 1997).

Recent concerns have been raised about the decline of neotropical migrant bird populations (those birds that breed in North America and winter in Central or South America). Neotropical migrant birds include 143 species (Thomson and others 1992), approximately 70 percent of which breed in the Lake Superior basin. About 43 percent of the forest birds in Minnesota are neotropical migrants (Green 1995). Some neotropical migrants that are characteristic of Lake Superior forests have shown significant declines on a continent-wide basis, including eastern wood-pewee, wood thrush, veery, and indigo bunting (Peterjohn and Sauer 1994). The decline can be attributed to several factors, including habitat loss on their wintering range, changes in forest habitat in their breeding range, and migration obstacles, deforestation on neotropical wintering grounds, and increased levels of brood parasitism by cowbirds (linked with habitat fragmentation) (Terborgh 1989). Many area-sensitive neotropical migrants that are found in the basin e.g., veery, black-and-white warbler, ovenbird, and northern waterthrush, are particularly vulnerable to forest fragmentation (Robbins and others 1989). Concurrently, several species of neotropical migrants have shown an increase since 1966 on a continent-wide basis, including red-eyed vireo, solitary vireo, ovenbird, and pine warbler (Peterjohn and Sauer 1994). Thomson and others (1992) evaluated the status of neotropical migrants from the midwest (3 provinces and 14 states) based on breeding ground threats, population trends and the importance of the region to the species. The species of most management concern whose ranges encompass most or all of the basin included the chestnut-sided, bay-breasted, Connecticut, Nashville and Canada warblers. The Lake Superior basin represents a significant portion of the breeding habitat, and although they are still relatively common in the basin (Cadman and others 1987), their populations show a long-term decline. Current and past timber extraction may be differentially affecting the breeding success of these and other neotropical migrants. Connecticut and Nashville warblers are most abundant in mature conifer forests, whereas chestnut-sided, and Canada warblers commonly use younger successional hardwood and mixedwood forests, which have increased in extent within the basin. In a northern hardwood forest in New York, numbers of both chestnut-sided and Canada warblers increased in response to logging (Webb and others1977).

Local surveys, especially those that are done in forest interior, show finer trends in woodland birds. For example, the Ontario Forest Bird Monitoring Program indicates that based on analysis of 69 species, 35 showed an increasing trend (11 significant) and 34 showed a decreasing trend (9 significant). In the Boreal Ecozone, significant declines were seen for brown creeper, golden-crowned kinglet, eastern wood-pewee, winter wren, and ovenbird. Significant increases were seen for yellow-bellied sapsucker, great-crested flycatcher, white-breasted nuthatch, northern waterthrush, red-eyed vireo, pine warbler, and chipping sparrow (Cadman and others 1998).

A regional analysis of Breeding Bird Survey (BBS) data was conducted for northeastern Minnesota, specifically the Great Lakes transition forest and the spruce hardwood forest regions (Niemi and others 1995). The analysis compared data in these regions of Minnesota with statewide trends. Table 17 summarizes the findings.

**Table 17. Summary of Breeding Bird Survey Analysis in Northeastern Minnesota, 1966-1993.**

| **Species that showed a decline statewide, as well as in both regions:** | **Species that showed a decline statewide, but not in the two regions:** | **Species that showed a decline in the two regions, but not statewide:** |
|---|---|---|
| American Bittern | American Redstart | Blue-winged Teal |
| Ruffed Grouse | Red-headed Woodpecker | Brown Thrasher |
| Belted Kingfisher | | Field Sparrow |
| Northern Flicker | | Vesper Sparrow |
| Eastern Wood-pewee | | Eastern Meadowlark |
| Least Flycatcher | | |
| Ruby-crowned Kinglet | | |
| Grasshopper Sparrow | | |
| Western Meadowlark | | |
| Brown-headed Cowbird | | |
| **Species that showed an increase in the state and in both regions:** | | **Species that showed an increase in the two regions, but not statewide:** |
| Common Loon | Red-breasted Nuthatch | Black-billed Cuckoo |
| Pied-billed Grebe | White-breasted Nuthatch | House Wren |
| Canada Goose | Sedge Wren | Marsh Wren |
| Wood Duck | Eastern Bluebird | Warbling Vireo |
| Mallard | Swainson's Thrush | |
| Red-tailed Hawk | Yellow-throated Vireo | |
| Wilson's Snipe | Yellow-rumped Warbler | |
| Downy Woodpecker | Black-throated Green Warbler | |
| Hairy Woodpecker | Scarlet Tanager | |
| Pileated Woodpecker | Swamp Sparrow | |
| Eastern Phoebe | Baltimore Oriole | |
| Blue Jay | Evening Grosbeak | |
| Common Raven | | |
| Black-capped Chickadee | | |

*Source: Niemi and others 1995*

Trends from this analysis indicate:

- Some bird species of mature forests are increasing (e.g., downy woodpecker, Swainson's thrush, pine warbler) and some are decreasing (e.g., least flycatcher, eastern wood-pewee).
- Species associated with fragmented forest landscapes are increasing (e.g., American kestrel, yellow-throated vireo, warbling vireo).
- Species associated with human habitation and human-dominated landscapes are increasing (Canada goose, wood duck, blue jay, black-capped chickadee, house wren, eastern bluebird). Some of these increases are a direct result of recovery programs for specific species, such as wood ducks.
- Four of the species that are increasing are highly associated with lakes and ponds (common loon, pied-billed grebe, double-crested cormorant, and great egret). These are fish- and aquatic-feeding

species that were likely affected by chlorinated organic compounds in the 1950s and 1960s. Their increases parallel those of bald eagle and osprey.
- Several species of agricultural, rural landscapes have decreased (e.g., upland sandpiper, red-headed woodpecker, northern flicker, field sparrow, vesper sparrow, and meadowlark). Possible reasons for the decline include reduction and fragmentation of native grasslands, reductions in hayfields and pastures, and changes in agricultural practices.
- Several species associated with shrub/sedge wetlands are increasing (e.g., common snipe, sedge wren, LeConte's sparrow, and swamp sparrow). Wetlands in northern Minnesota remain in a relatively natural state when compared to other parts of Minnesota.[1]

Although the Lake Superior basin is not on a major migratory flyway, significant numbers of birds migrate through the basin. Lake Superior represents a considerable obstacle, so many birds follow either the eastern or western shore, or use the Slate Islands, Isle Royale, Michipicoten and Caribou islands as they hop cross from the north to south shore (particularly the Keweenaw Peninsula). Bird observatories at Thunder Cape (on the Sibley Peninsula) and Whitefish Point (50 km NW of Sault Ste. Marie) are well located for monitoring migrating songbirds, raptors, owls and waterbirds. At Thunder Cape, the most commonly banded species include black-capped chickadee, dark-eyed junco, yellow-rumped warbler, Swainson's thrush and palm warbler. Black-capped chickadee, Swainson's thrush, golden-crowned kinglet, yellow-rumped warbler, Nashville warbler, and Tennessee warbler are commonly sampled at Whitefish Point. Nine sites along the north shore of Lake Superior have been identified as potential Important Bird Areas (IBAs) by Birdlife International. Many of these sites are important migration staging or stopover areas.

### *Bald Eagles*

Populations of bald eagles declined sharply in the 1950s and 1960s as a result of contamination by toxic chemicals that accumulated in the food chain and affected reproductive success of eagles and other carnivores. A discussion of their status appears in the section on *Species and Ecosystems of Concern*.

### *Migratory Raptors*

Migrating raptors seek thermals to make their flights more efficient. Because thermals rarely form over water, raptors prefer to migrate around Lake Superior. Several locations around the lake provide other physiographic features (such as ridges) that concentrate raptors during migration. These locations provide excellent sites for monitoring raptors and other birds during migration (Ryan Brady, Northern Great Lakes Visitor Center, Ashland, WI, personal communication). Hawk Ridge in Duluth, Minnesota, and Whitefish Point, Michigan, are two well-known hawk migration viewing areas on Lake Superior.

### *Colonial Waterbirds*

Colonial waterbirds are good bioindicators of contaminant levels. Herring gulls and other long-lived fish-eating birds show the effects of prolonged exposure to toxic chemicals and help us understand wildlife health. Herring gull monitoring has occurred for more than 25 years in the Great Lakes. Two annual monitoring sites are located in Lake Superior (Mineau and others 1984; Pekarik and Weseloh 1988; Hebert and others1999).

---

1) It is important to note, however, that coastal wetlands are threatened and of concern in the entire Great Lakes region.

Most colonial waterbirds had nearly disappeared in the early 1900s before the Migratory Bird Convention of 1916 provided some protection. Birds like herring gulls were valued for their feathers and were persecuted at nest sites. After they were protected through federal laws, their numbers began to increase in the 1940s. But by the early 1970s, herring gull populations had once again decreased. Contaminants were blamed, especially persistent chemicals such as DDE, PCBs, and dioxin, which affected eggshell thickness and embryonic growth and caused other problems (Gilbertson 1974; Mineau and others 1984). The mid-1970s saw the greatest concentrations of these toxic chemicals in herring gull eggs, but the levels have decreased since then (Bishop and others 1992a, 1992b; Pettit and others 1994a, 1994b; Pekarik and others 1988a, 1988b). Herring gull populations are recovering in the Great Lakes, but numbers in Lake Superior have shown declines (Table 18). Declines could be due to a smaller food base in Lake Superior (Weseloh and others 1999). Also, contaminants remain in the Lake Superior ecosystem and can continue to cause problems in certain areas (Ryckman and others 1997). The Apostle Islands N. L. has two large colonial bird colonies that include approximately 80 percent of all nesting herring gulls along Wisconsin’s Lake Superior shoreline (1,010 nests in 1999).

**Table 18. Number of Herring Gull Pairs (colonies) on Lake Superior in 1976, 1989, and 1998.**

| | 1976 | | 1989 | | 1998 | |
|---|---|---|---|---|---|---|
| | Pairs | Colonies | Pairs | Colonies | Pairs | Colonies |
| Canada | 6,410 | 149 | 12,181 | 299 | 11,115* | 301* |
| Percent change from last survey | | | 90.0% | 100.7% | <-8.7% | <1.0 % |
| U.S. | 7,106 | 90 | 13,263 | 187 | 7,715 | 134 |
| Percent change from last survey | | | 86.6% | 107.8% | -41.8% | -28.3% |

**Preliminary data, some sites missing; Compiled from: McKearnan, personal communication; C. Pekarik and C. Weseloh, personal communication; Cuthbert and McKearnan 1999.*

Double-crested cormorants have also seen unnatural fluctuations in their populations. It is believed that cormorants did not historically breed in Lake Superior and the Great Lakes. The first suspected nesting occurred on the western end of Lake Superior in 1913 (Weseloh and Collier 1995). This was likely an eastward expansion of the Lake of the Woods population.

There was a continual expansion of cormorants into the Great Lakes, and by the late 1940s and 1950s, the cormorant had become so common that control measures began, especially on the lower Great Lakes. People suspected that cormorants competed with commercial and sport fisheries. There were both sanctioned and unsanctioned control measures, including annual destruction of colonies by shooting adults and destroying eggs and young. Control measures largely ended by 1960.

Cormorant populations declined drastically throughout the 1960s and early 1970s. By 1973, breeding cormorants had completely disappeared from Lake Superior (Weseloh and Collier 1995). One of the leading reasons for the decline – if not the leading reason – was contamination by toxic chemicals. Cormorants, like many fish-eating birds, were producing thin eggshells because they had accumulated DDE in their system. They were breaking their eggs by lying on them. Deformities were also noted, probably caused by agents such as PCBs (Weseloh and others 1995).

In the mid-1970s, with decreased use of toxic chemicals, cormorants began a dramatic recovery. They increased by 300-fold between 1971 and 1995 in the entire Great Lakes region. Lake Superior saw a slower growth (Figure 55), mostly because it is less productive than the lower lakes, so it has a reduced food base. The rate of bill deformities also decreased (Weseloh and Collier 1995; Ryckman and others 1998).

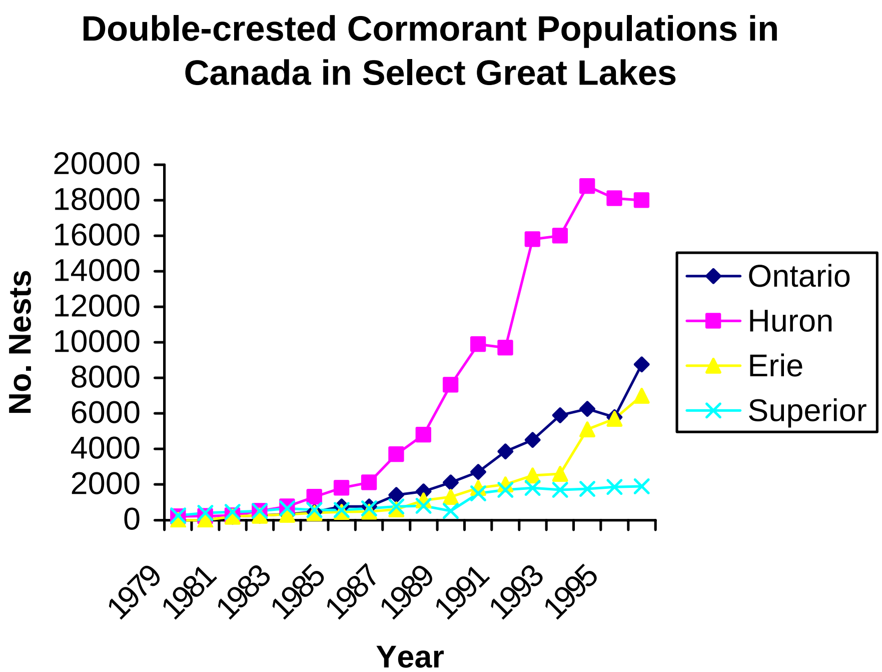


**Figure 55. Double-Crested Cormorant Populations (Weseloh and others 1999).**

The American white pelican, generally considered a bird of the great plains/prairie regions of North America, has become established in the Lake Superior basin. Breeding colonies were discovered in the early 1990s on Lake Nipigon. These birds are believed to have come from breeding colonies on Lake of the Woods, which is located along the Manitoba/Ontario/Minnesota border (Bryan 1994 and Escott 1991).

***Shorebirds***

Some information is available on the status of shorebirds east of the Rocky Mountains (Harrington 1995). Most information was gathered from migratory bird surveys and some from breeding bird surveys. Population trends were evaluated for 27 of 41 shorebird species. Of these, 12 showed no change, 1 increased, and 14 decreased. Some species that are of interest to the basin are: spotted sandpiper – no change; common snipe – significant decline; piping plover – endangered; American woodcock – significant decline.

Migration habitat is critical for many shorebirds. A high proportion of them migrate by visiting one or a small number of "staging sites," areas where the birds can accumulate fat. These staging sites are often productive areas with highly predictable but seasonally ephemeral "blooms" of invertebrates. The St. Louis River estuary at the Duluth-Superior Harbor and the north end of Black Bay in Ontario are used by many species of shorebirds and could be a significant staging site for Lake Superior (Pat Collins, MN DNR, Two Harbors, personal communication). We are not aware of other heavily used sites on Lake Superior.

***Common Loons***

Most common loon pairs use inland lakes in the basin for breeding sites. Lake Superior is used by loons as a staging area, including Whitefish Point in Michigan. Isle Royale has a large loon population for its size, and some of these loons nest on Lake Superior (Michigan Loon Recovery Program 1992).

Loon reproductive success in Ontario decreased between 1981 and 1997. Loons breeding on acid lakes declined more rapidly than those on more alkaline lakes (Weeber 1999). In the upper Great Lakes, loons nesting on acid lakes were more susceptible to mercury contamination (Evers and others 1998).

Minnesota has the largest summer population of loons in the lower 48 states, with northeastern Minnesota serving as an important area for loons (Strong and Baker 1991). Michigan had only about 300 pairs in 1988, and about 165 of these were in the Upper Peninsula (Michigan Loon Recovery Program 1992). Wisconsin saw an increase in its loon population from 1985 to 1995, probably due to good reproduction from 1986 to 1990, which was mostly weather-related (Daulton and others 1997).

***Waterfowl***

Lake Superior and the basin is not a hot spot for waterfowl production. The lake provides important habitat for migratory waterfowl, especially diving ducks. Coastal wetlands also provide important habitat for both breeding and migrating birds.

Waterfowl information has not been compiled for the Lake Superior basin. Most waterfowl indices for North America are created from surveys done outside the basin. However, trend data for Minnesota, Wisconsin, and Michigan (Figure 56) shows that waterfowl numbers are increasing, except for a few select species, such as the American black duck, lesser scaup and greater scaup. The increase in numbers in North America is mostly due to ideal conditions in the prairie region and Alaska. Increase in abundance is also reflected in the data from Minnesota (U.S. Fish and Wildlife Service 1998). The degree to which Lake Superior contributes to waterfowl production is unknown.

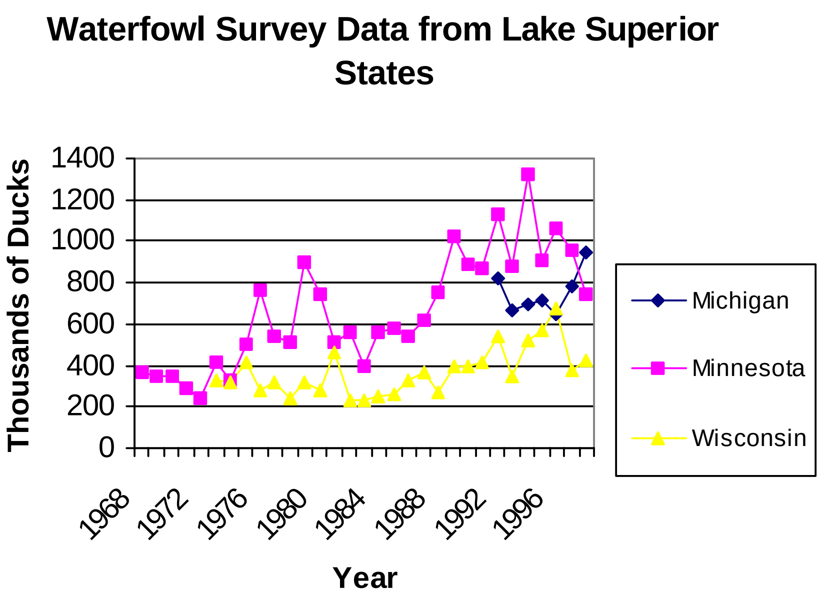


**Figure 56. Waterfowl survey data (U.S. Fish and Wildlife Service 1998).**

***Stressors of Birds***

*Chemical Contaminants*

The presence of elevated levels of toxic chemicals coincides with poor health, reproductive impairments, and other physiological problems in herring gulls, as well as ring-billed gulls, double-crested cormorants, black-crowned night-herons, bald eagles, common terns, Caspian terns, and Forster's terns. This is related to reduced hatching success, eggshell thinning, abnormal adult behavior, deformed embryos, biochemical changes, endocrine disruption, and suppressed immune function (Fox and others 1998).

Currently, contaminants are being released or recycled by atmospheric deposition, agricultural land runoff, slow leaching of discarded stocks of pesticides and other chemicals from landfill sites and agricultural soils into the Great Lakes via groundwater and resuspension of contaminated lake and river sediments. On Lake Superior, up to 90 percent of toxic contaminants entering the lake comes from the atmosphere in the form of precipitation (Eisenreich and others 1981). Table 19 summarizes contaminant-related effects in fish-eating waterbirds.

**Table 19. Summary of Some Contaminant-related Effects Observed in Herring Gulls and Other Fish-eating Waterbirds Inhabiting the Great Lakes (Ryckman and others 1997).**

| Contaminant Effect | Evidence in the Great Lakes | Current Status |
|---|---|---|
| Eggshell Thinning<br>- caused by high DDE levels in the 1950s, 1960s, and 1970s. | Resulted in widespread eggshell breakage, causing population declines of fish-eating waterbird species including double-crested cormorants, ospreys, bald eagles, black-crowned night-herons, and herring gulls. | Due to regulatory controls and banning of DDT, eggshell thinning is no longer a problem, resulting in improved reproductive success of affected species. |
| Reproductive Failure<br>-causes include early embryonic death, embryo toxicity, and abnormal parental behavior during incubation. | Herring gulls, double-crested cormorants, and bald eagles were not reproducing during the late 1960s and 1970s when highest levels of organochlorines were present. | Due to significant declines in organochlorine levels, reproductive success has improved in most fish-eating waterbird species. |
| Biochemical Changes | Abnormal liver functions and low levels of Vitamin A may increase susceptibility to infectious diseases, possibly affecting the survival and development of young chicks. | Biochemical measures indicate that herring gulls are still chemically stressed. Full effect of biochemical changes on the reproduction or life span of waterbirds is not known at this time. |
| Suppressed Immune Function<br>-several contaminants (e.g., PCBs and TCDDs) suppress important immune functions and can increase susceptibility to infectious diseases. | At highly contaminated sites, herring gulls and Caspian terns have suppressed T-lymphocyte function, atrophy of the thymus gland, and altered white blood cell counts. | Research is underway to determine the extent and significance of suppressed immune function in fish-eating waterbirds. |
| Congenital Deformities | Crossed bills, jaw defects, extra limbs, and malformed feet, joints, and eyes were found in herring gulls and at least eight other species of fish-eating waterbirds. | Waterbirds continue to display higher rates of deformities compared to clean sites outside of the basin. Studies continue on the links between contaminants and developmental problems in certain waterbird species. |

*Habitat*

Habitat changes and landscape patterns have very strong effects on birds, especially migratory songbirds. Because the Lake Superior basin is primarily forested, the composition, size, and structure of forests strongly affects songbird species diversity, abundance, and productivity. For example, some songbirds prefer to nest in forest interiors (ovenbird), and others prefer disturbed, open habitats (indigo bunting). Some require dead, standing trees (pileated woodpecker), and some prefer dense shrubs under a canopy (black-throated blue warbler). Others prefer a mix of hardwood and conifer forests (black-throated green warbler). Therefore, habitat changes and forest management policies affect each species differently. However, the following habitat changes are known to be negative for forest birds in general and have caused stresses to populations:

- Even-aged stands of hardwoods with little understory decrease bird species diversity (Howe and Mossman 1995, Green 1995).
- Some bird species are dependent on conifers (Green 1995) or prefer conifers (Howe and Mossman 1995), and loss of conifers affects abundance of those species.
- Neotropical migrant birds often increase in diversity and abundance as woodland size in fragmented landscapes increases (Friesen and others 1995).
- Shape of woodlands also plays an important role. A woodland with minimal edge is likely to have greater bird production than one with maximum edge. Edge creates many problems, including

increased predation, intrusion of invasive species, and human disturbance. Edges have the effect of increasing temperature and wind, and lowering humidity in the forest interior.

- Neotropical migrant birds consistently decrease in diversity and abundance as adjacent home development increases, regardless of forest size. This study was conducted in a heavy agriculture landscape in southwest Ontario with about 14 percent of the landscape wooded (Friesen and others 1995).
- Hard edges have a detrimental effect on most species of concern, even disturbance-dependent species such as indigo bunting (Suarez and others 1997). Soft edges and residual habitat in clearcuts are preferred (Merrill and others 1998, Suarez and others 1997).
- Large gaps without cover between woodlands are detrimental to some forest birds. The creation or preservation of woodland corridors for these species is important (Desrochers and Hannon 1997).

Even non-native plant species can decrease bird productivity. For example, buckthorn, which replaces native hawthorn, lacks sharp thorns that might deter predators. A study showed that productivity of robins and wood thrushes decreased for birds nesting in non-native shrubs (Schmidt and Whelan 1999).

Habitat changes created by shoreline development affect many species of birds and create dramatic changes in avian community guilds. A study by Gillum and others (1998) showed that ground-nesting birds decrease in numbers as development increases, probably due to vegetation alteration, increased predation, and nest disturbance. Insectivorous species are less common along developed shoreline. The proportion of omnivores, nectivores, frugivores, or seed eaters is two times greater at developed lakes than at undeveloped lakes. Concerns are mostly related to forest interior species of northern Wisconsin, such as ovenbird, hermit thrush, black-and-white warbler, black-throated green warbler, and brown creeper, because they are displaced by development. Intensive shoreline development also eliminates habitat for certain water-dependent species such as herons and kingfishers (Gillum and others 1998).

*Human Disturbance*

Species such as loons can be negatively affected by direct human disturbance. Unsuspecting recreational users sometimes chase birds off their nest, leaving eggs or chicks susceptible to heat or cold. Loons also become entangled in commercial trap nets, fishing lines and hooks, and ingest lead fishing sinkers (Michigan Loon Recovery Program 1992). Songbirds that nest on or near the ground are susceptible to predation by domestic cats and dogs.

*Invasive and Nuisance Species*

Brown-headed cowbirds parasitize the nests of songbirds, laying their eggs in the nests of other species. The adult songbirds raise and feed the cowbirds to maturity, reducing their own nesting productivity. Cowbirds thrive in edge habitat, especially if the edge habitat is near to mowed grass or pasture, which is where they feed. In the Lake Superior basin, cowbirds are a problem where human habitation is the greatest and in agricultural landscapes, but they are not a major concern in the basin overall.

Non-native plants can degrade habitat structure, resulting in decreased biodiversity. Schmidt and Whelan (1999) showed the effect of non-native shrubs on robin and wood thrush productivity. Predation of both species was higher in non-native shrubs than in native shrubs and trees, likely due to structural differences in non-native plants that provided easier access for predators.

### *Management Efforts for Birds*

In general, states, tribes, and the Province of Ontario have regulatory authority and management responsibility for resident wildlife, which includes resident birds. Federal governments have regulatory authority and management responsibility for migratory birds. Federal agencies that manage federal lands have management responsibility for both resident and migratory birds. However, many responsibilities for migratory birds are shared between states and the federal government. Some example programs include the following:

*North American Waterfowl Management Plan* – Recognizing the importance of waterfowl and wetlands to North Americans and the need for international cooperation to help in the recovery of a shared resource, the Canadian and United States governments developed a strategy to restore waterfowl populations to 1970s levels through habitat protection, restoration, and enhancement. The strategy was documented in the North American Waterfowl Management Plan signed in 1986 by the Canadian Minister of the Environment and the United States Secretary of the Interior, the foundation partnership upon which hundreds of others are built. The Plan is implemented through cooperative partnerships called "Joint Ventures." In 1994, the Mexico Secretario de Desarrollo Social signed the Plan, expanding the efforts to protect wetlands and improve waterfowl populations. The Lake Superior basin is included in Canadian Eastern Habitat Joint Venture (EHJV) and the U.S. Upper Mississippi River / Great Lakes Joint Venture (UMR/GLJV).

*U.S. Shorebird Conservation Plan* – The U.S. Shorebird Conservation Plan is a collaborative effort among researchers, land managers, and education specialists from the United States who cooperate with colleagues from Canada and Mexico to advance effective conservation of North American shorebird species. The plan was initiated in 1997. Canada and Ontario Shorebird Conservation Plans have been published and no significant shorebird sites have been identified on the Ontario side of the basin.

*North American Colonial Waterbird Conservation Plan* – This effort was initiated in 1998. The mission is to create a cohesive, multinational partnership for conserving and managing colonially-nesting waterbirds (seabirds, wading birds, terns, gulls) and their habitats throughout North America. A plan will be implemented to maintain healthy populations, distributions, and habitats of colonial-nesting waterbirds in North America, throughout their breeding, migratory, and wintering ranges.

*Partners In Flight (PIF)* – PIF is a coalition of countries, government agencies, conservation groups, academic institutions, industry, and concerned citizens who share a common vision: to maintain the health of landbird populations and their habitats. While international in its scope, Partners In Flight advocates a grassroots approach where regions develop their own goals and strategies to keep common birds common. Partners In Flight landbird planning within Ontario is currently underway for all four of Ontario's Bird Conservation Regions (BCRs) and fit into the broader PIF Continental Plan. Priorities for the Lake Superior basin on the Ontario side have yet to be determined. Priorities on the U.S. side have been described in PIF Physiographic Region 20 Plan: http://www.blm.gov/wildlife/pl_20sum.htm

*North American Bird Conservation Initiative* – NABCI was initiated in 1999 by representatives of federal, state, and provincial agencies, as well as nongovernmental organizations, to create a framework that would foster coordination among the four bird initiatives (Partners in Flight, the North American

Waterfowl Management Plan, the North American Waterbirds Conservation Plan, and both the U.S. and Canada Shorebird Conservation Plans) with the aim of conserving all birds and their habitats.

*Circle of Flight* – This program provides funding and technical assistance to lake state tribes for wetlands protection, restoration, enhancement, and management projects. Many tribes have reseeded and now manage wild rice beds under this program. Thousands of hectares of wetlands have been restored or enhanced since the program's inception in 1991. The program is administered by the U.S. Bureau of Indian Affairs and U.S. tribes. It involves many partners.

***Current Monitoring Efforts for Birds***

*Songbirds*

*North American Breeding Bird Survey* – Established in 1966, this program is a joint effort of Canada and the United States. Volunteers and natural resource agency employees complete selected roadside counts once a year. This program provides long-term trend data over a broad geographic area. The information is not currently compiled or analyzed for the basin.

*Ontario Forest Bird Monitoring Program* – This program began in 1987. Its goals are to: 1) compile a habitat-specific baseline inventory of forest songbirds, 2) describe changes over time in the numbers of forest songbirds in relation to habitat and landscape characteristics, and 3) contribute to an understanding of population trends for forest birds in Ontario. This information supplements breeding bird survey data (Cadman and others 1998). OMNR's Wildlife Assessment Program began a similar forest bird monitoring program in 2000, greatly expanding coverage in northern Ontario. A number of these forest bird monitoring sites are located within the basin.

*Ontario Landbird Monitoring Strategy* – This program encompasses all landbird monitoring, including breeding and migration monitoring. It is part of the Canadian Landbird Monitoring Strategy.

*Marsh Monitoring Program* – The Marsh Monitoring Program began in 1994 in order to monitor the condition of marshes in the Great Lakes basin, using marsh birds and amphibians as indicator species. Volunteers survey marsh birds, amphibians, or both. The Marsh Monitoring Program is a cooperative venture of Environment Canada and Bird Studies Canada. Migration monitoring is done at Thunder Cape, Ontario; Whitefish Point, Michigan; and Hawk Ridge, Duluth, Minnesota.

Songbird monitoring is conducted on many public lands to measure the effect of management on avian populations. Lands that are monitored in the basin include: U.S. national forests (Chequamegon Nicolet, Superior, Ottawa), U.S. National Parks (Apostle Islands and Isle Royale), tribal lands (Red Cliff and Bad River), and national wildlife refuges (Whittlesey Creek).

*Colonial Waterbirds*
Herring gulls are monitored for contaminants, populations, and productivity. The herring gull is considered one of the major indicator species for environmental contamination in the Great Lakes. This program has been in place for more than 25 years and is one of the longest running wildlife monitoring programs for contaminants in the world. Two of the 15 monitoring sites are on Lake Superior: at Granite Island, east of Thunder Bay, and at Agawa Rocks, south of Wawa. Populations of cormorants, gulls,

terns, and herons are monitored in the entire Great Lakes on both the Canadian and United States sides at varying intervals.

*Waterfowl*
Breeding pair and brood surveys are conducted in Minnesota, Michigan, Wisconsin, and Ontario, but a large area of the basin is not included in these surveys.

*Loons*
State and provincial agencies along with various loon watch programs monitor breeding pairs and productivity. Work was recently initiated by the BioDiversity Research Institute to monitor contaminants in loons.

*Bald Eagles*
Nesting pairs are monitored along the Great Lakes and inland lakes in the basin by the states and Ontario. Productivity is monitored in select areas.

*Habitat*
Habitat changes at the landscape level are being monitored using computerized geographic information system (GIS) software. Satellite photographs, starting from the late 1980s, have been interpreted (at 200 x 200 m resolution) and entered into GIS data layers.

### *Gaps in Bird Information*

Little information has been compiled specifically for the Lake Superior basin, but a significant amount of general information is available, particularly for breeding birds, loons, bald eagles, and colonial waterbirds. Once the information is compiled for the basin, an analysis should be conducted to determine where the information gaps are.

Monitoring was initiated on contaminants in tree swallows, but work has slowed due to lack of funds.

The ongoing GIS data could be developed at a finer resolution (50 x 50 m) and interpreted every ten years to allow comparison over time. Linkages need to be made with landscape-scale habitat changes to songbird communities.

### *Challenges for Birds*

Lake Superior forests provide very important habitat for migratory songbird populations, some of which probably serve as source populations for other areas. With concerns expressed nationwide over the decline of neotropical migrants, the Lake Superior basin should be considered a critical region for migratory songbird conservation. Significant work continues on population monitoring; some of this is being linked to habitat changes at the landscape scale. The Binational Program would be a logical organization to work toward compiling this information for the Lake Superior basin and providing it to project partners. The Binational Program should also provide recommendations for habitat conservation strategies to its project partners and to local units of government in the throes of land use planning.

Conservation of migratory songbirds remains uncertain because of the complex interactions between birds and their landscapes. However, Howe and others (1995) provide some recommendations that can be used to help guide conservation and management efforts. They include: 1) establish realistic conservation goals at several administrative levels, 2) select species that can be used as guidelines, 3) identify specific populations where priority species occur and implement appropriate management in these locations, 4) coordinate planning strategies among forest management units, and 5) design monitoring strategies to track populations and management actions.

Contaminant levels are being monitored in colonial waterbirds. This work needs to continue and should be coordinated closely with other contaminant studies being conducted in the basin. This is especially critical considering the goal of zero discharge for the Lake Superior basin.

### 4.6.3 Amphibians and Reptiles

***Status and Trends of Amphibians and Reptiles***

Little work has been done on amphibians and reptiles in comparison to other vertebrates. Until 10 to 15 years ago, few agencies and organizations even considered them in conservation efforts. Therefore, historical population data are mostly incidental. Species ranges are often derived from museum collections and records. Current efforts to monitor populations and to study the effects of anthropogenic influences have given us an increased awareness and concern for amphibian and reptile communities.

Populations of amphibians and reptiles are affected by many factors, and the overall trend for any species is not known. As with many vertebrates, the widespread changes in habitat cover across the landscape have had a dramatic effect on the community composition of amphibians and reptiles. For example, areas in the southern part of the basin that were historically mixed forest probably included species such as redback and blue-spotted salamander and species that are dependent on logs and downed branches, such as American toads, wood frogs, and redbelly snakes (Oldfield and Moriarty 1994). If those areas are logged and converted to agricultural lands, the amphibian species composition changes to those tolerant of human disturbance. Even then, the habitat must contain cover, a prey base, and water. Where these are present, American toads, garter snakes, and painted turtles might be present (Oldfield and Moriarty 1994).

It is important to understand how amphibians respond to changes in the ecosystem. Most amphibians are secretive, so it isn’t readily obvious that they constitute a large percentage of the biomass of terrestrial ecosystems. Because amphibians and reptiles are often in the middle of the food chain, their presence or absence causes a shift in patterns of predation. (Stebbins and Cohen 1995).

It is also important to consider metapopulations (a metapopulation is a network of semi-isolated populations with some level of regular or intermittent migration and gene flow among them, in which individual populations may become extinct but may be recolonized by other populations). This is especially important in areas that are being quickly developed because amphibian populations are becoming isolated (Casper 1998). Even where they are not isolated, conservation efforts need to keep in mind that individuals of many reptiles and amphibian species travel between sites, which increases genetic viability. This is also important where certain conditions (such as drought) might temporarily create population sinks.

Estimates of population trends for amphibian species in Wisconsin and Minnesota are available (Table 20). Local population declines of many amphibians are becoming a concern worldwide. Many possible reasons exist for these declines (see stressors section). Monitoring programs have been initiated to document trends.

**Table 20. Status of Amphibian Species Found in the Lake Superior Basin in Minnesota and Wisconsin.**

| Species | Minnesota | Wisconsin |
|---|---|---|
| Wood frog | Relatively stable | Increasing |
| Northern leopard frog | Relatively stable or decreasing | Decreasing |
| Pickerel frog | N/A | Decreasing |
| Mink frog | Unknown | Unknown |
| Green frog | Relatively stable | Relatively stable |
| Chorus frog | Unknown | Relatively stable |
| Northern spring peeper | Relatively stable | Decreasing quickly |
| Eastern gray treefrog | Relatively stable | Relatively stable |
| Cope's gray treefrog | Unknown | Decreasing |
| Blanchard's cricket frog | Special concern | State endangered |
| American toad | Relatively stable | Relatively stable |
| Blue-spotted salamander | Relatively stable | Relatively stable |
| Eastern tiger salamander | Decreasing? | N/A |
| Spotted salamander | N/A | Relatively stable |
| Four-toed salamander | Unknown | Special concern |
| Redback salamander | Relatively stable | N/A |
| Mudpuppy | Unknown | Unknown |

*Compiled from Casper 1998; Moriarty 1998; Mossman and others 1998.*

Some specific examples of species found in the basin and their estimated status are listed below.

*Blue-Spotted Salamander*

This is a relatively widespread species, which is tolerant of both cold temperatures and human habitat disturbance. They may be common in woodlands with the required breeding ponds. They are tolerant of selective logging and low-density residential development, as long as the critical parts of the habitat remain intact. Local populations are threatened by clear-cuts and roads that separate breeding ponds and terrestrial habitats (Harding 1997).

*Northern Spring Peeper*

Spring peepers are common in the Lake Superior basin. They require temporary and permanent ponds, marshes, or ditches for breeding. After breeding, they disperse to old fields, woodlands, and shrubby areas. They remain abundant, but their wetland habitats must be conserved to ensure they do not become a species of concern (Harding 1997).

*Northern Leopard Frog*

The leopard frog is probably one of the best-known frogs, largely because it was often dissected in school biology labs. It is a widespread, ubiquitous species, but there have been significant declines in parts of its range, including Minnesota, Wisconsin, and Ontario (Mossman and others 1998; Casper 1998; Moriarty 1998; Seburn and Seburn 1997). Leopard frogs were completely absent from a large area of northern Ontario in 1997, indicating a major population decline there (Seburn and Seburn 1997). Collections by biological supply houses have been suggested as a potential problem, but there could be other reasons for the decline, such as disease, weather, and exposure to ultraviolet radiation (Seburn and Seburn 1997).

*Snapping Turtle*
The common snapping turtle is a large freshwater turtle that can live 100+ years. They are fairly common in the southern part of the basin, but they are at the edge of their range in Ontario. They are omnivorous, and because they eat mainly animal matter, they may be exposed to higher concentrations of contaminants than most other turtle species, which are mainly vegetarian. Their eggs, which are laid in sand next to water, are often eaten by skunks, foxes, and raccoons, and hatchlings are often eaten by avian predators. The adults are harvested for their meat. Snapping turtles are often thought of as common, but all the factors listed here make them vulnerable to population declines (Shirose and others 1996).

### *Unique Characteristics of Amphibians and Reptiles*

Blaustein and Wake (1995) did a good job of describing the special characteristics of amphibians:

> "*Amphibians are valuable as gauges of the planet's health for a few reasons. First, they are in intimate contact with many components of their natural surroundings. For example, as larvae, frogs live in water, but as adults most find themselves at least partially on land. Their moist, delicate skins are thin enough to allow respiration, and their unshelled eggs are directly exposed to soil, water and sunlight. As larvae, they are herbivores and as adults, carnivores. Because amphibians sample many parts of the environment, their health reflects the combined effects of many separate influences in their ecosystems. Second, these animals are good monitors of local conditions because they are homebodies, remaining in fairly confined regions for their entire lives. What happens to frogs and their brethren is happening where humans live and might affect our species as well*."

A unique characteristic of turtles is their longevity. Certain turtle species, such as wood turtles, can live as long as 40 years. This is very important given the fact that their annual productivity is often low and they do not reach maturity until they are 12 to 20 years old (Harding 1997). They lay eggs in sandy beaches, and these are often completely destroyed by predators. When adult turtles are harvested, the remaining adults cannot replace the population with enough young to keep it viable. Collection of turtles for contaminant analysis has been discontinued for this reason (Brooks and others 1988 and Galbraith and others 1987). Tissue from their eggs provides sufficient information to analyze contaminant levels.

Concerns about amphibian abnormalities have been in the news for the past five years, since the highly publicized 1995 discovery of deformed leopard frogs by middle school students in Minnesota. Since then, reports of abnormalities have surged, and a North American database and reporting system was established through the U.S. Geological Survey. The North American Reporting Center for Amphibian Malformations is now a repository of data about amphibian deformities. A web site has also been established to make this information easily accessible.

Experts have been conducting studies to try to determine the causes of these deformities, looking mainly at parasites, chemical contaminants, ultraviolet light, temperature, and other environmental factors. According to a recent report by Jamie K. Reaser (U.S. Dept. of State) in FROGLOG (a newsletter published by the International Union for the Conservation of Nature [IUCN] Declining Amphibian Population Task Force), it is unlikely that any one particular factor can be singled out as the cause. Different factors, such as chemical contamination, UV light, and parasites, operate by similar mechanisms, impacting similar ecological and developmental pathways to cause abnormalities.

### *Stressors of Amphibians and Reptiles*

Stressors to amphibian and reptile populations are not clearly defined for the Lake Superior basin, but the problems noted for the Upper Midwest and Canada are probably reflected in the Lake Superior basin. Stressors can be related to global problems and to local problems. Global problems include the increase of ultraviolet radiation from depletion of the ozone layer, acid precipitation, and bioaccumulation and transport of toxic chemicals such as DDT. Local problems are related to habitat loss and fragmentation, direct impact from chemical applications such as pesticides and herbicides, infectious diseases, and invasive species.

*Habitat*

Degradation and loss of habitat is a concern for many species, especially those dependent on wetland habitats. Degradation of wetlands is caused by eutrophication, pollution, addition of non-native fish, and loss of surrounding upland habitat. Loss of plant diversity due to invasion of exotic, invasive species can affect invertebrate populations, which can in turn affect the health of amphibians and reptiles (Casper 1998). Changes in land use surrounding wetlands and aquatic habitats may increase sedimentation rates (Casper 1998; Lannoo 1998). Clear-cutting may affect amphibians by changing soil moisture and acidity (Blymyer and McGinnes 1977). Woodlands that are managed by removing mature trees before they fall would not be suitable habitat for species that require litter and downed logs. Habitat fragmentation also causes loss of migration corridors and loss of the mosaic of wetland types that are often critical for amphibian life cycles, especially during drought years. Some species move from a seasonal pond to a permanent pond during dry years (Lannoo 1998). Migration corridors for reptiles are often disrupted by roads and trails, which can directly cause mortality of turtles (Oldfield and Moriarty 1994).

*Ultraviolet Radiation (UV-B)*

Ambient UV-B radiation can directly or indirectly kill some amphibian eggs under both field and laboratory conditions (Blaustein and others 1994, 1995, 1997). The depletion of the ozone layer has increased the amount of UV-B radiation striking the earth, which might be one of the reasons why amphibian populations in relatively pristine habitats are declining. The increase in UV-B radiation might have a synergistic effect, by making amphibians more susceptible to diseases.

*Invasive Species*

Zebra mussels and rusty crayfish alter the native prey base of areas they invade. Zebra mussels are voracious consumers and can drastically reduce the zooplankton population, leaving other native invertebrates little to eat. This can result in a drop in native invertebrate populations and less food for amphibian larvae. Rusty crayfish can wipe out native plants, which are used by invertebrates for food and shelter. The result is similar to zebra mussels, with a lower invertebrate population and less food for amphibians and reptiles.

The non-native plant, purple loosestrife, invades and dominates wetlands. These wetlands lose many microhabitats that are needed by invertebrates, causing a decrease in invertebrate diversity, which can negatively affect amphibians and reptiles in their aquatic stage.

*Contaminants*

Many studies have been done on contaminants and their effects on amphibians and reptiles, but most were laboratory studies, so little information is available about direct and indirect effects. More research needs to be done to better understand the direct, indirect, and cumulative effects of contaminants on reptiles and amphibians. Agricultural chemicals could be a significant cause of toxic effects, but this needs to be better investigated. Habitat fragmentation and destruction, compounded by pollution of some of the remaining, otherwise suitable habitat, as well as loss of the corridors between suitable areas, may have a devastating impact on the viability of amphibian metapopulations (Diana and Beasley 1998).

Some turtle species are long-lived and consume animal matter, making them especially susceptible to contamination by toxic pollutants (Shirose and others 1996).

*Infectious Diseases and Parasites*

Outbreaks of infectious diseases may be an important indicator of stress and environmental mismanagement. The effects of a disease might not be as dramatic if the population were not already stressed. The protection of suitable habitat and maintenance of a diverse gene pool are of critical importance in limiting the ultimate impact of a range of infectious agents (Faeh and others 1998).

*Other*

Introduction of fish, crawfish, and bullfrogs into naturally fishless ponds and wetlands can cause several problems. Introduced species may provide direct competition for food, and they may prey on the larval or fledgling stages of native amphibians and reptiles.

### *Management Efforts for Amphibians and Reptiles*

All states within the Great Lakes basin and Ontario have protective laws and regulations that affect amphibians and reptiles (Harding 1997).

In Ontario, the Fish and Wildlife Conservation Act (FWCA) of 1997 lists all reptile species, with the exception of the common snapping turtle, as specially protected reptiles. The snapping turtle may be harvested within specified seasons and bag limits under the authority of an angling license. Of the 15 amphibian species found within the Ontario portion of the basin, only the salamander species and the gray treefrog are listed as specially protected under the FWCA. The frog species are not offered special protection, and, with the exception of the bullfrog, there are no harvest seasons in place. Bullfrogs may be harvested only within specified areas, seasons, and bag limits in Ontario.

The MN DNR keeps track of turtle harvest (those harvested for food). Turtles and frogs are collected by biological supply houses, under license by the MN DNR, without restriction. Minnesota law protects wood turtles and Blanding's turtles. A bounty system for rattlesnakes was removed in 1989. Minnesota

Herpetological Society and the Nongame Wildlife Program are attempting to raise the awareness of conservation needs, to conduct inventories, and to protect important habitats.

The WI DNR regulates the taking of amphibians and reptiles. They specify seasons for some species of frogs and turtles and regulate the method of capture. They also limit the size of some species, such as snapping turtles. State threatened or endangered species may not be collected except by special permit.

The MI DNR protects species that are listed as threatened or endangered. Reptiles and amphibians that are listed as special concern by the MI DNR require a permit for collection (Lori Sargent, personal communication).

The IUCN established a Declining Amphibian Population Task Force (DAPTF) in 1991. The DAPTF includes a network of over 3,000 scientists and conservationists belonging to national and regional working groups, which cover more than 90 countries around the world. Ultimately, the DAPTF hopes to understand why populations are declining and develop conservation programs to stabilize them. A Great Lakes working group was established, which covers Minnesota, Michigan, and Wisconsin. Canada has established a Canadian Amphibian and Reptile Conservation Network as part of DAPTF.

Partners in Amphibian and Reptile Conservation is a public-private network that was established in 1999 to facilitate greater conservation efforts for amphibians and reptiles in North America, encouraging the use of partnerships to facilitate successful work. Modeled after the successful Partners In Flight program, its focus is to protect amphibian and reptile populations and habitats to "keep common species common." A Midwest Working Group formed in September 1999 includes the Lake Superior basin.

***Current Monitoring Efforts***

*North American Amphibian Monitoring Program*
This program was established by the Declining Amphibian Populations Task Force. It encompasses Canada, the United States, and Mexico. The purpose of the program is to collect information to monitor populations on a global basis. It includes frog calling surveys and terrestrial salamander monitoring. Monitoring protocols along random routes are established and conducted mostly by volunteers. Surveys in the Great Lakes region are coordinated by state and provincial agencies. Routes are included in the Lake Superior basin, but the data has not been compiled for the basin.

Ontario has several surveys that monitor amphibian populations, mostly frogs and toads. These programs are: *Backyard Survey*, *Road Call Count Survey*, Marsh Monitoring, and *Adopt-A-Pond/Frogwatch*. Backyard Surveys are conducted by volunteers who record species and calling intensity from their backyard or cottage on a daily basis. This program and the Road Call Count Survey are coordinated by the Canadian Wildlife Service. The Road Call Count Survey establishes routes that have stations from which observations are made. These surveys are also conducted by volunteers who run the route three times during the spring and summer. The Marsh Monitoring Program's purpose is to monitor the health of wetland ecosystems in the Great Lakes basin, including 43 Areas of Concern around the Great Lakes. Marsh Monitoring includes an amphibian roadside survey, following the same protocols as the Road Call Count Survey mentioned above. Routes are also conducted outside of the Areas of Concern. This is coordinated by Bird Studies Canada.

*Frogwatch USA* is a new program established in February 1999. It is modeled after Frogwatch Ontario. Volunteers across the United States submit observations on their local amphibian populations by choosing and periodically monitoring a wetland site for calling frogs and toads. Adopt-A-Pond/Frogwatch in Ontario is coordinated by the Toronto Zoo and is similar to the Frogwatch USA program. This data is submitted to the Natural Heritage Information Centre of the OMNR. Both U.S. and Canadian programs allow citizens an opportunity to learn about the amphibian community in their area, as well as an opportunity to become involved in monitoring.

Various agencies, including the U.S. Fish and Widlife Service and National Park Service, have implemented calling frog and toad surveys within the Lake Superior basin. Some tribes and First Nation groups have also initiated frog and toad surveys on native lands and project areas, including Bad River and Keweenaw Bay.

***Gaps in Information about Amphibians and Reptiles***

More routes and surveys are needed for all amphibian and reptile monitoring programs in the Lake Superior basin.

Monitoring protocols should be agreed to for amphibian and reptile surveys. Existing information for the Lake Superior basin has recently been compiled (Casper 2002) and work toward development of standardized basin-wide monitoring protocols began at a workshop held in Duluth in June, 2003.

Few surveys are being conducted for reptiles, and those are usually very local or incidental. OMNR's Wildlife Assessment Program has been undertaking a pilot study on the use of artificial cover objects to monitor redbacked salamander populations. Monitoring programs should be established and followed.

Causes of population changes for both amphibians and reptiles need to be identified.

***Challenges for Amphibians and Reptiles***

Most conservation and management actions have focused on vertebrate species that are either visible or harvested. Amphibians and reptiles can be highly observable at certain times of the year and are also harvested, yet they have been ignored in management plans in the past. An ecosystem approach to conservation should encompass habitat for all species, as well as all ecosystem functions. If the Binational Program is concerned with overall ecosystem health, then we need to pay closer attention to amphibians and reptiles in our inventories, planning work, actions, and monitoring efforts.

### 4.6.4 Invertebrates

About 90 percent of the nearly one million species of animals in the world are terrestrial or aquatic invertebrates (animals without backbones). In the Great Lakes region the larger, more easily seen invertebrates include insects and mollusks, such as snails and clams. Insects are the most diverse group and globally may have the largest collective biomass of all terrestrial animals. Yet, within the Lake Superior basin, we have little information on the status and trends of the insect or terrestrial invertebrate populations. The groups are too large to encompass, and taxonomic problems have impeded the development of status and trend information.

Along with an appreciation of the interaction between plants and animals, the role of soil invertebrates, fungi, and microorganisms in ecosystem functioning must be understood. Interdependencies of every part of the biotic community, including the decomposers, must be taken into account. The complex spatial and temporal heterogeneity of habitats and species response to disturbance has to be understood. We have very little information on this, and new research must be initiated in this area.

### 4.6.5 Plants

Green plants form the base for all animal life, and yet protection of plants in the ecosystem has not been associated with the protection of wild animals. The term wildlife has been traditionally used to refer to wild animals only. This gross misconception must be corrected. It is evident from the long list of rare and endangered plants in the Lake Superior basin (see habitat committee section) that the number of endangered plants far exceeds that of wild animals. For every threatened animal there are two or more endangered plants. This connection between wild plants and animals must be clarified and highlighted to the professionals and to the public. The importance of plants to the survival and well being of wild animals must be recognized and factored into the equation of wildlife conservation.

A discussion of the status of some rare plants species appears in the section on *Species and Ecosystems of Concern*.

## 4.7 Species and Ecosystems of Concern

The species discussed in this section are considered to be rare or declining in at least one of the states/provinces in the basin. Species can be listed at the federal, provincial, or state levels.

The U.S. federal categories are as follows:

> **Endangered:** The classification provided to an animal or plant in danger of extinction within the foreseeable future throughout all or a significant portion of its range.
>
> **Threatened:** The classification provided to an animal or plant likely to become endangered within the foreseeable future throughout all or a significant portion of its range.
>
> **Species of Concern:** “Species of concern” is an informal term that refers to those species which might be in need of concentrated conservation actions. Such conservation actions vary depending on the health of the populations and degree and types of threats. At one extreme, there may only need to be periodic monitoring of populations and threats to the species and its habitat. At the other extreme, a species may need to be listed as a Federal threatened or endangered species. Species of concern receive no legal protection and the use of the term does not necessarily mean that the species will eventually be proposed for listing as a threatened or endangered species.

THE CANADIAN FEDERAL CATEGORIES ARE:

**Endangered:** A species facing imminent extirpation or extinction.

**Threatened:** A species likely to become endangered if limiting factors are not reversed.

**Vulnerable:** A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.

Ontario, Minnesota, Wisconsin, and Michigan have slightly differing definitions for the state / provincial level listings, but are similar in intent to the federal listings.

### 4.7.1 Key Mammals of Concern

***Gray Wolf***

The gray wolf was formerly distributed throughout the Lake Superior basin but declined after the early 1800s due to extermination efforts in both Canada and the U.S. Wolf populations never declined to low levels in Ontario, but were extirpated in most of the U.S. portion of the basin by the early 1970s. Remnant populations persisted in northern Minnesota and on Isle Royale. Wolves were listed federally as Endangered in the U.S. in 1967, offering them full protection. Wolf numbers and range increased in Minnesota and they repopulated Wisconsin and the Upper Peninsula of Michigan through immigration from Ontario and Minnesota. All three states now have breeding populations (Figure 57).

Recovery programs have been initiated in all three states, and recovery goals are nearly met. The U.S. Fish and Wildlife Service is drafting a proposal to change the status to threatened in Wisconsin and Michigan. A new issue with regard to wolves in the basin is their species status. White et. al. (2001) suggest that, based on DNA evidence, the wolves inhabiting the basin are not a sub-species of gray wolf (*C. l. lycaon*) as previously thought but are actually a separate species of wolf, the eastern wolf (*Canis lycaon*).

Wolf habitat consists of a relatively large land area with an adequate prey base. Major prey species are white-tailed deer in the southern part of the basin and moose in the north. Beaver and small mammals are important summer food. Habitat management to maintain or improve habitat for moose and deer is undertaken in all of the states and Ontario, mainly through timber management. Timber management can improve habitat for deer and moose by creating interspersion of mature forest with younger successional forest and, therefore, have a positive effect on wolves (Michigan Gray Wolf Recovery Team 1997, Wisconsin Wolf Advisory Committee 1999).

Wolves are most successful where there is limited human access (Michigan Gray Wolf Recovery Team 1997, Wisconsin Wolf Advisory Committee 1999). Road densities greater than 0.6 $km/km^2$ have been implicated in wolf declines due to collisions with vehicles and access by hunters and trappers. On the other hand, in areas of deep snow in Ontario, ploughed roads and packed snowmobile trails may make it easier for wolves to find and kill prey. Wolves can tolerate greater road density where humans do not kill or harass wolves (Michigan Gray Wolf Recovery Team 1997).

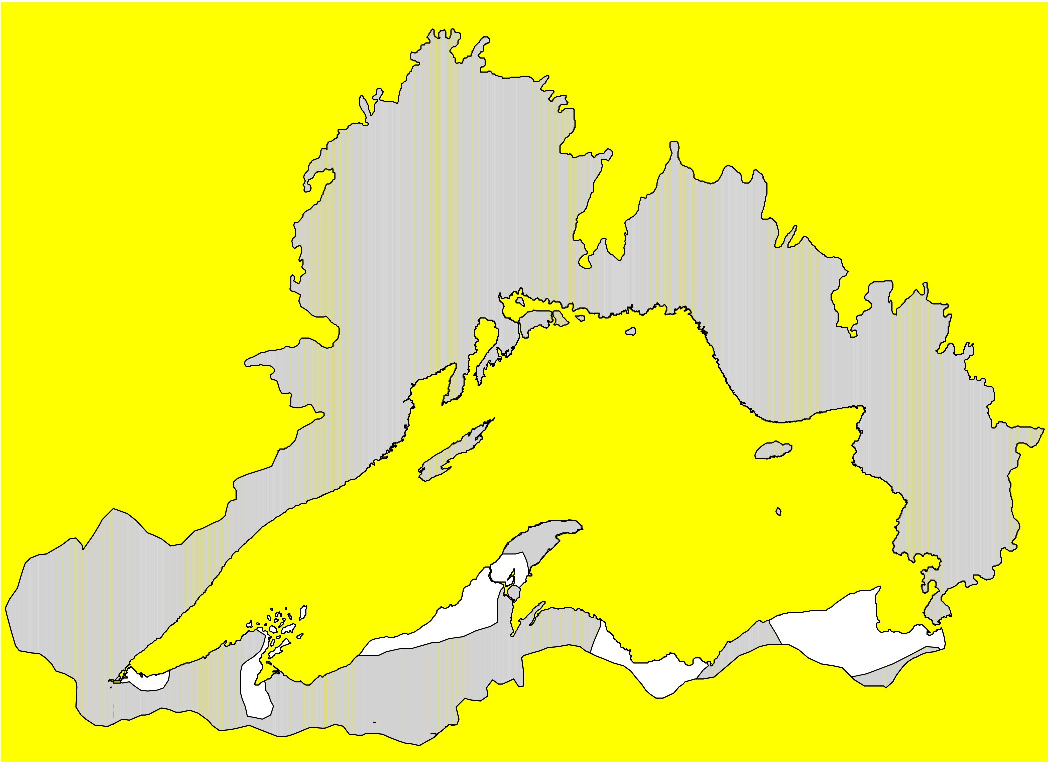

**Figure 57. Wolf range in the Lake Superior basin in 1997 (shaded) (Michigan Gray Wolf Recovery Team 1997, Wydeven 1999, Coffin and Pfannumller 1988, Dobbyn 1994).**

Human disturbance at den and rendezvous sites can cause abandonment of these areas. The area required for protection from disturbance has been estimated at approximately 0.05 percent of the pack's territory (13 ha for an average home range of 259 $km^2$) (Michigan Gray Wolf Recovery Team 1997).

Habitat corridors linking wolf populations may be important to allow wolves to move through landscapes fragmented by human activities (Michigan Gray Wolf Recovery Team 1997).

*Wisconsin*

Wolves returned to Wisconsin in the mid-1970s, and in 1975 was listed as Endangered. Management and recovery plans introduced in 1989 set goals of a population of 80 or more animals for more than three consecutive years (Wisconsin Wolf Advisory Committee 1999). In 1999, the wolf population reached 197 animals and has been at 80 or more animals since 1995. The Wisconsin Department of Natural Resources has now reclassified wolves as Threatened and is working on a management plan that will eventually delist the species. This plan would delist the wolf to a non-game species when the population reaches 250 or more animals across the state outside of Tribal Lands. A management goal of 350 is recommended.

Since 1979, the State has been monitoring the wolf population by radiocollaring one or two members of each pack. This method has been the most precise method of monitoring the population. Other survey methods include snow tracking and summer howling surveys.

Wolf habitat in Wisconsin has been assessed as primary or secondary (Mladenoff and others 1995). Based on computer models, primary habitat represents areas with a 50 percent or greater chance of supporting a wolf pack and secondary habitat represents areas with a 10 to 50 percent chance of supporting a wolf pack. Most of the primary and secondary habitat is in the northern third of the State, including much of the Lake Superior basin (Wisconsin Wolf Advisory Committee 1999).

*Michigan*

The gray wolf is considered Endangered in Michigan. Wolf populations have recovered from near extinction in the mid 1970s to at least 174 animals in 30 or more packs in 1999. This compares to 140 wolves located in 1997-98. In 1991, wolves reproduced in Michigan (other than on Isle Royale) for the first time in 40 years. All of the wolf packs are located in the Upper Peninsula (including much of the Lake Superior basin) and Isle Royale.

Monitoring for wolves is conducted by the Department of Natural Resources by using radio telemetry and snow track counts. There has also been a continuous monitoring program of wolves on Isle Royale since 1958. Two wolves first arrived on the island in the late 1940s, and the population of wolves is dependent on the local moose population. As moose numbers fluctuate (500 to 2,500), so have the wolf numbers fluctuated between 12 and 50 animals. Habitat supply analysis suggests that the Upper Peninsula could support over 800 wolves (Mladenoff and others 1995).

The Michigan Recovery Plan for the gray wolf will consider the animal recovered when there is a winter population of 200 animals for five consecutive years. At that time, the wolf will be recommended for removal from the Michigan Endangered Species List.

*Minnesota*

In 1978, Minnesota reclassified the gray wolf from Endangered to Threatened and plans to delist the animal in 2000. The 1978 Grey Wolf Recovery Plan set a population goal of 1,251 to 1,400 wolves by the year 2000. This goal was achieved when a statewide survey in 1989 estimated the population at 1,550 to 1,750 animals. Surveys estimate the population to be about 2,450 animals in the winter of 1998-1999 (Mike Don Carlos, personal communication).

A wolf management group consisting of 35 groups and individuals has been working on a revised plan for wolf management in Minnesota. This management plan has been produced, but the state has not implemented the plan.

In 1999, there were four projects using radio collars to monitor wolves in the state. The Department of Natural Resources also conducts winter snow tracking surveys.

Suitable habitat is located throughout most of the Lake Superior basin in Minnesota (Hazard 1982), but a population estimate for the basin is not available.

*Ontario*

In Ontario there is no evidence to suggest that wolves are threatened or endangered on either a regional or provincial basis. Observations by field staff and trappers suggest that wolf numbers are stable or increasing over nearly all of their historic range in the Province. The gray wolf population in Ontario is estimated at 8,000 to 9,000 animals (Buss and de Almeida 1997). Within the Ontario portion of the basin, wolf hunting and trapping is permitted year-round; however, wolves are essentially protected during the months of June through August, because the provincial small game-hunting license is not valid during that period. Hunting is prohibited in provincial and national parks, and trapping is prohibited, or minimal, in most provincial parks (Buss and de Almeida 1997). During the 1990s, the annual harvest of wolves has varied from 500 to 800 animals.

There have been two recent studies on wolf habitat use and population dynamics within the Lake Superior basin. In 1994, Pukaskwa National Park initiated a six-year predator-prey research initiative called “The P5 Project.” This project investigated the predator-prey dynamics and landscape change in the Greater Pukaskwa Ecosystem. Twenty-seven wolves were radio-collared and data were collected on prey base, home ranges and territories. Habitat analysis was also investigated but most of the data collected were related to moose and woodland caribou requirements (Keith Wade, personal communication). A second project based out of Marathon radio-collared wolves from Neys Provincial Park to White Lake. This research examined habitat use and home ranges related to roads and landscape parameters and also the influence of garbage dumps (Krizan 1997).

### ***Canada Lynx***

Canada lynx was formerly found throughout the Lake Superior basin, but its range has receded northward and it is now largely restricted to Ontario within the basin. The U.S. Fish and Wildlife Service officially listed the Canada lynx population in the contiguous United States as threatened under the Endangered Species Act on March 24, 2000. The Service plans to establish a Lynx Recovery Team and prepare a recovery plan, however a court order to reconsider its final rule has delayed these activities. On July 3, 2003, the status of lynx populations in the contiguous United States was confirmed as Threatened under the Endangered Species Act.

Habitat is associated with cool coniferous forest in southern extensions of boreal forest into the U.S. (McKelvey and others 1999). Young, dense forest stands, where snowshoe hares are abundant, are critical, but lynx home range typically also includes mature forest with large woody debris for denning (Aubry and others 1999).

Lynx populations fluctuate widely in response to snowshoe hare numbers. Following declines in prey, lynx wander from their core Canadian range into Minnesota, Michigan and Wisconsin. Particularly large incursions from Ontario into the states happened in the early 1960s and again in the early 1970s (McKelvey and others 1999).

The recession of lynx range in the U.S. is related to changes in forest conditions, loss of coniferous forest cover, trapping, and roads. Timber management practices and fire suppression that lead to poor snowshoe hare habitat is detrimental to lynx. Increased roads threaten lynx due to increased access for trappers (Koehler and Aubrey 1994).

*Michigan*
Lynx were formerly widely distributed in the Upper Peninsula and Isle Royale but virtually extirpated by 1938 (McKelvey and others 1999). The last record in the state was a trapping record from the early 1980s in Mackinac County. Lynx are now listed as Endangered in Michigan.

There is good habitat consisting of a large continuous mixture of boreal and hardwood forest in the Upper Peninsula (Kevin Dorn, personal communication), but habitat availability has not been quantified (Ray Rustem, personal communication). The Department of Natural Resources monitors trapping records, but does not conduct annual surveys.

The National Forest Service initiated a three-year monitoring program for cat species in 1999. The survey covered the West Block of the Hiawatha National Forest and was expanded into the East Block of the Hiawatha Forest and the Ottawa National Forest in the winter of 1999-2000. Monitoring involved placing scratch pads marked with catnip oil and collecting hair samples for DNA sampling (Kevin Dorn personal communication).

*Wisconsin*

Lynx were listed as Endangered in Wisconsin in 1973 but removed from the list in 1997 due to lack of evidence of a breeding population (Wydeven and others 1999). Two lynx were killed in 1992, the first specimens collected since 1974 (Adrian Wydeven, personal communication). Between 1991-1997, there were 10 reports of lynx with three observations in both 1992 and 1993. The Wisconsin DNR monitors lynx by conducting furbearer snow track surveys, wolf track surveys, reports of rare carnivores by the public, and surveys of bobcat hunters and trappers. Lynx are considered to be very rare and probably not breeding in the state.

There has been no quantitative habitat survey, but habitat may be marginal with limited areas of boreal forest. Competition for prey with coyotes and bobcats may limit lynx distribution (Adrian Wydeven, personal communication).

*Minnesota*

The status of lynx in Minnesota in the late 1800s and early 1900s is unclear due to possible confusion of early records with bobcats (McKelvey and others 1999). Lynx are a protected furbearer in Minnesota and the trapping season has been closed since 1984. Predator scent station and snow track surveys are conducted annually.

Lynx numbers in Minnesota reflect irruptions from Ontario and many records are assumed to be transient animals from Ontario, rather than a resident population. There were peaks in fur harvest returns in 1930, 1940, 1952, 1962, and 1973 (McKelvey and others 1999). In 1973, four hundred lynx were harvested in the state; in 1982, 42 lynx were harvested; and in the 1990s there has only been one record in Minnesota. These irruptions followed the snowshoe hare peak in each decade (Mike DonCarlos, personal communication).

Canada lynx are being studied in Minnesota. USFS, USFWS, USGS, and NRRI initiated the lynx ecology project over a year ago. There have been 14 lynx captured thus far. Several of these lynx have been fitted with GPS collars (the first study of lynx using GPS collars). Lynx appear to be most highly concentrated on the Laurentian Divide (between Lake Superior Watershed and Rainy Lake Watershed) where the snow accumulation is higher. The USFS has currently identified about 40 individual lynx from DNA collected from scats, hair, or tissue collected from the Superior National Forest. This study also was the first to document lynx-bobcat hybrids in the wild from three different hybrids.

Potential habitat for a resident, breeding population within the Lake Superior basin is restricted to portions of Cook, Lake, and St. Louis counties (published and unpublished data collected by L. David Mech; cited in DonCarlos 1994). Habitat consists of areas with snowshoe hare and no bobcats.

*Ontario*

Lynx are distributed throughout the Ontario portion of the Lake Superior basin. Populations fluctuate with snowshoe hare numbers, but range has apparently been stable (Dobbyn 1994). Lynx have no official protection status, except their classification as a fur-bearer.

Trapping records are the only quantitative population data available in Ontario (Neil Dawson, personal communication). In 2002, a survey was sent out to trappers in Ontario asking them to assess the population of furbearers, including lynx, during the 2001-02 trapping season. In the five districts that border Lake Superior, 228 trappers responded to the questionnaire. Thirty-nine indicated that lynx were not present, 67 said lynx were scarce, 79 stated lynx were common, and 43 reported lynx as abundant. Overall, lynx were considered common in all areas except the Sault Ste. Marie area where they were considered scarce.

Lynx habitat supply has not been quantified, but is probably not limiting (Neil Dawson, personal communication).

### ***Woodland Caribou***

Woodland caribou formerly inhabited most of the Lake Superior basin. By the late 1800s, their numbers were declining and their range was receding northward. Caribou disappeared from the U.S. part of the basin by the early 1940s (Hazard 1982) and they are now extirpated from Michigan, Wisconsin and Minnesota. In Ontario, the southern limit of caribou range receded from the north shore of Lake Superior in 1900 to northern Lake Nipigon at present (Figure 58). North of this line, caribou are more or less continuously distributed. Remnant populations are on the Slate Islands (several hundred animals), Pic Island, Neys Provincial Park, Pukaskwa National Park, and Michipicoten Island (introduced) (Harris 1999). Forest-dwelling woodland caribou are ranked as Threatened in Ontario (Harris 1999). The boreal population of woodland caribou was designated as Threatened at the federal level in Canada (COSEWIC May 2002). A recovery team was established in Ontario in 2001 and a recovery strategy is currently being prepared and scheduled for completion in spring 2004. Subsequently, recovery action plans will have to be developed in order to implement the recovery strategy.

Reasons for the decline include hunting, fire, land clearing, logging, increased predation, disease, and human disturbance (Darby and others 1989). Logging and human settlement caused forest fragmentation and loss of mature coniferous forest cover. Populations of moose and white-tailed deer increased with the changes in forest landscape. In Ontario, at least, wolves increased in response to the increased prey availability. Increased wolf predation, combined with increased hunting pressure, caused greater mortality for caribou. Their relatively low reproductive rate meant that caribou could not compensate for the increased mortality. Today, caribou within the Lake Superior basin are restricted to islands and other areas where they can avoid wolves, and where logging has not fragmented the landscape.

Forest management guidelines have recently been implemented in Ontario to protect caribou habitat by reducing forest fragmentation, protecting calving areas and minimizing human disturbance (Racey and others 1999).

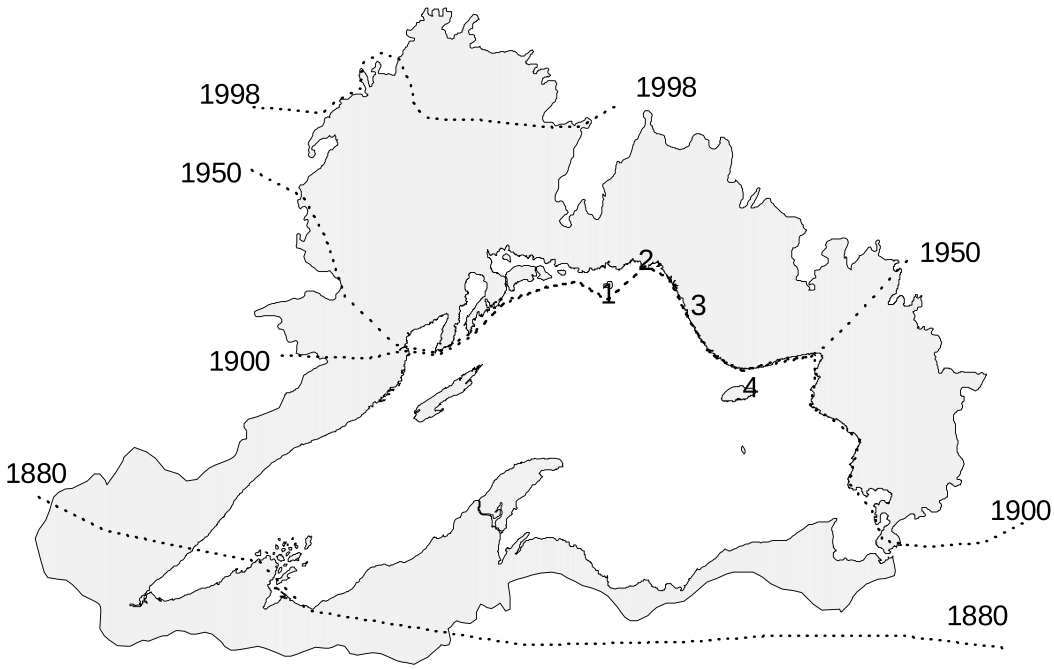


**Figure 58. Historical and present distribution of woodland caribou in the Lake Superior basin. Dotted lines indicate southern limits of caribou distribution at various periods. Numbers indicate remnant herds: 1 – Slate Islands, 2 – Neys, Pic Island, 3 – Pukaskwa, 4 – Michipicoten Island (adapted from Darby and others 1989 and Armstrong 1998).**

### 4.7.2 Key Birds of Concern

#### *Bald Eagle*

Populations of bald eagles declined sharply in the 1950s and 1960s as a result of contamination by toxic chemicals that accumulated in the food chain and affected reproductive success of eagles and other carnivores. Along the Lake Superior shoreline, bald eagles were nearly absent through the 1970s, but the population began to increase as the use of DDT was halted and DDE concentrations began to decrease. (DDE is a byproduct of DDT. It inhibits the action of the enzyme that is needed to transfer calcium carbonate to the eggshell.) Since the ban of DDT in the late 1960s, bald eagle numbers have increased throughout their range. In 1999, they were downlisted to Threatened in the U.S.

Within the Lake Superior basin, eagle numbers appear to have followed the same pattern of decline and recovery, but little specific data are available. Reproductive rates of eagles nesting along the Lake Superior shoreline are significantly lower than those nesting on inland lakes (1.0 vs. 1.3 young per active territory) (Dykstra and others 1998). Depressed reproduction rate was likely caused by low food availability and inclement weather. In Wisconsin, populations are increasing inland, but remain stable on the lake (Dykstra and others1998). Michael Hoff (U.S. Geological Survey, personal communication) suggests that burbot population dynamics play an important role in food availability, as well as the role of commercial fishermen in casting off unused catch.

Nesting habitat for Bald Eagles includes trees that are large enough to hold their massive nests. Red and white pine supercanopy trees are preferred in Minnesota (Coffin and Phannmuller 1988). Many of these nests are close to lakes or rivers, areas where the eagles scavenge for fish.

Figure 59 shows an assessment of bald eagle nesting habitat based on percentage of forested area and proximity to the shoreline, potential human disturbance, shoreline irregularity, available foraging habitat, and availablity of perching and nesting trees (Bowerman 1993).

*Wisconsin*
About 1,500 bald eagle pairs nest in Minnesota and Wisconsin, but less than five percent of these are along the Lake Superior coast (Bill Bowerman, personal communication). The number of occupied territories along the Wisconsin Lake Superior coastline tripled between 1983 and 1991 (Meyer 1992).


**Figure 59. Potential bald eagle nesting habitat within 1.6 km of Lake Superior. Unshaded areas are considered unsuitable (Bowerman 1993).**

Nesting habitat is considered good to excellent within the Lake Superior basin. However, housing construction is occurring at a record pace along lakeshores and riparian lands in northern Wisconsin, and it is not known what this threat poses for eagle nesting. Contaminant levels have declined dramatically in recent years and are no longer considered a threat to reproduction. Productivity of nesting eagles along the Lake Superior coast fluctuates from year to year depending on ice conditions and prey availability (Mike Meyer, Wisconsin DNR, personal communication).

On the Apostle Islands, there has been a fairly stable population of about five pairs for the last few years (Julie Van Stappen, Apostle Islands National Lakeshore, personal communication). Food shortage appears to limit population growth since there are many adequate nesting trees available and blood analysis indicates that contaminants are probably not impairing survivorship or reproduction. Spring ice packs restrict access to fish and the absence of deer on the islands limits late winter food availability.

Bald Eagles were delisted in Wisconsin in 1998. There have been annual surveys since 1985 but the future of these surveys is in doubt due to declining funds from the Adopt an Eagle Nest Fund.

*Minnesota*

The Minnesota population of bald eagles has increased dramatically since the 1970s and is now estimated at about 700 pairs. The last statewide survey was conducted in 1995, the same year that the birds were delisted. Based on current information (1999) in the Minnesota Heritage data, there are 41 eagle nests located in the Lake Superior basin. Most of these nests are in the interior away from Lake Superior (Maya Hamady, personal communication).

Habitat availability is probably the main factor limiting the number of eagles. Lake Superior probably offers poor foraging opportunities compared to inland lakes.

*Michigan*

The bald eagle is Threatened in Michigan. A state-wide survey is conducted each year to monitor breeding success. The state goal is to have 300 nesting pairs. The 1997 survey located 298 nests, of which 166 nests were in the Upper Peninsula. An estimate for the Lake Superior basin was not available and will be included in the final habitat report. The Michigan Department of Natural Resources also conducts mid-winter bald eagle surveys. In 1999, there were 235 eagles reported in the Upper Peninsula. The status of eagle habitat in the basin appears to be stable (Ray Rustem, Supervisor of the Natural Heritage Unit, Wildlife Division, MI DNR, personal communication).

*Ontario*

In Ontario, bald eagles are Endangered. The number of eagle nests along the north shore has been fairly stable for the last few years, although new nests are established as old ones are abandoned (Foster and others 1999).

In the Thunder Bay District, most of the larger inland lakes have established nesting pairs and there are a few nests along the Lake Superior coastline. There have been no recent surveys, but the population probably has not changed in the past few years (Steve Scholton, Thunder Bay District OMNR, personal communication).

The Lake Superior shore between Black Bay and Pukaskwa Park appears to consist of good habitat. The population has been fairly stable with 15 to 16 nests. Spring runs of rainbow trout and suckers are common and food supply should not be a limiting factor. Lake Nipigon has not been surveyed in a few years, but numbers have probably not changed dramatically in recent decades (Rosemary Hartley, Nipigon District OMNR, personal communication).

Seven active nests are in the White River to Montreal River portion of the watershed. Numbers appear to be growing and habitat does not appear to be a limiting factor (Joel Cooper Wawa District OMNR, personal communication).

The shoreline south of the Montreal River to Sault Ste. Marie has fewer than ten active nests. Habitat is adequate and there is room for more pairs (Jim Saunders, Sault Ste. Marie District ONMR, personal communication).

Eagle nest sites are recognized in timber management, and guidelines for their protection are applied in Ontario.

### *Peregrine Falcon*

Peregrine falcon populations declined across North America due to nesting failure resulting from bioaccumulation of DDT and its metabolites. They disappeared as a nesting species from most of the Lake Superior basin by the mid 1960s.

Following the ban of DDT, efforts were initiated to re-establish peregrine falcons as a breeding species within the Lake Superior basin. Between 1988 and 1996, Minnesota released 40 young peregrines on the North Shore, and Michigan released 50 young birds on Isle Royale and 46 birds in the Upper Peninsula. Ontario released 87 birds in the Thunder Bay area and 38 near Sault Ste. Marie (Bud Tordoff, Ted Armstrong, personal communication). These efforts have succeeded in establishing nesting pairs (Table 21). In the Lake Superior basin, 90 young peregrines were banded in Ontario and 59 young were banded in Minnesota between 1996 and 1999.

The peregrine falcon was removed from the United States Endangered Species List in 1999. Michigan and Wisconsin list peregrines as Endangered, while Minnesota lists peregrines as Threatened. In Canada, peregrines are classified as Threatened at the federal level, but are considered Endangered in Ontario.

Peregrines nest on cliff ledges, often adjacent to water, but inland sites are also used. Artificial structures such as buildings, bridges, smokestacks, and quarries, are sometimes used. The best peregrine habitat in the Lake Superior basin is associated with the numerous large cliffs between the Pigeon River and the Nipigon River in Ontario (Ratcliff 1997, 1998, 1999). Almost half of the nests in the basin are in this area.

Current and potential peregrine territories are shown in Figure 60. “Potential” territories include historical nest sites that are not currently used and other cliffs that have been surveyed and assessed as being suitable (Ratcliff 1997, 1998, 1999; Bud Tordoff, personal communication). Due to the large amount of potential habitat available, and inaccessibility of most of this area, the estimate is a minimum number.

Overall, the status of peregrine falcon habitat is stable or increasing. Artificial structures increase the number of potential nest sites in the Lake Superior basin over historical levels.

*Ontario*
In 1998, there were 17 known territories occupied by peregrine falcon pairs and 3 territories held by single birds. In 1999, 12 territorial pairs and six single bird territories were located in the Lake Superior basin. In addition, there are at least six confirmed and suspected historical sites that probably could support peregrine falcon pairs (Ratcliff, 1997, 1998, 1999) (Table 21). In 2003, there were 38 territories comprised of 34 territorial pairs and 4 single birds on territory. Thirty-one nests were confirmed and 70 chicks were estimated to have fledged (Ratcliff 2003).

*Minnesota*
Historically, peregrines nested on five cliff sites along the northshore. As of 1998, there were eight pairs of peregrines along the North Shore, of which two used bridges within the city of Duluth and two nests were on mining structures (Bud Tordoff, personal communication). In 2003, surveys found 10 successful pairs within the basin as well as at least one non-breeding pair. Nineteen young were fledged by the 10 adult pairs (Tordoff et al 2003). There is potential for four more cliff nesting sites (Bud Tordoff, personal communication). Annual surveys are conducted throughout Minnesota checking both cliff sites and artificial structures.

*Wisconsin*
The small cliffs within the Wisconsin portion of the Lake Superior basin are not suitable for breeding peregrines. Except for artificial structures, habitat is very limited (Bud Tordoff and Sumner Matteson, personal communication). There are no historical records for this area and any future nesting sites will probably be on artificial structures. Wisconsin conducts annual surveys for peregrines, and, to date, all nesting sites have been on artificial structures, none of which are in the Lake Superior basin.

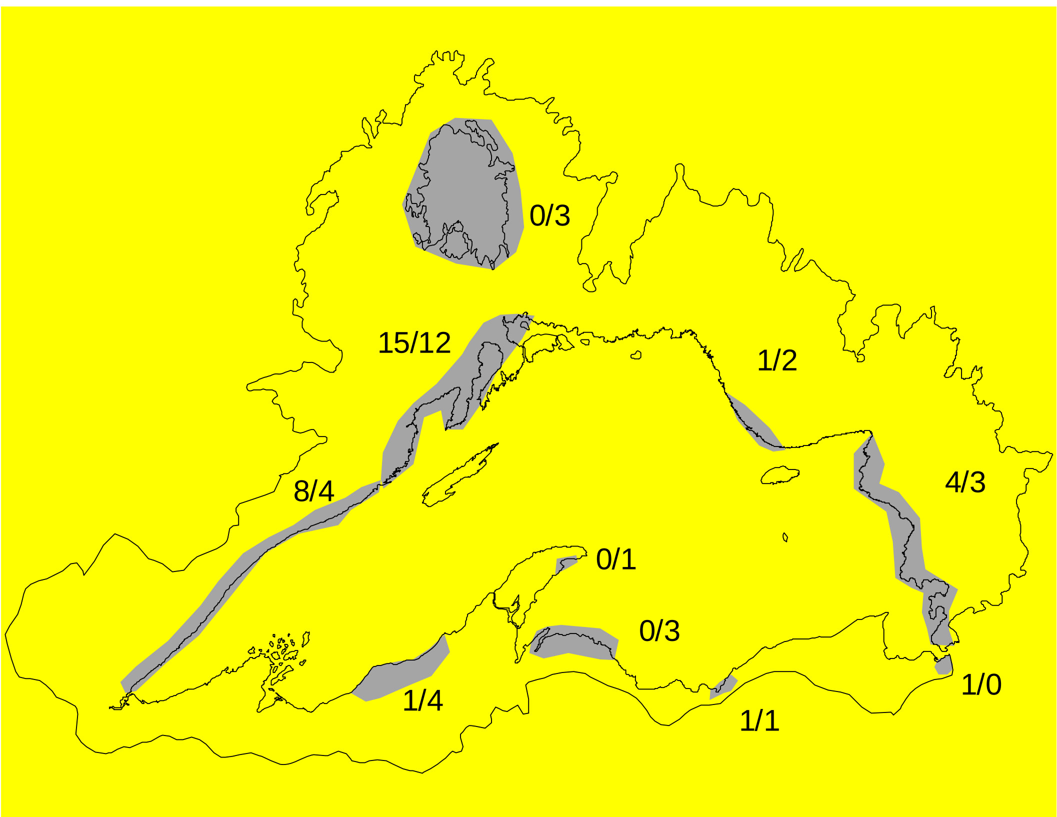


**Figure 60. Peregrine Falcon Habitat in the Lake Superior basin. Numbers of current and additional potential territories are given (current number / potential number).**

*Michigan*
Historically, peregrines nested at 13 cliff sites in the Upper Peninsula. There are four known cliff sites where peregrines nested during the 1990s (Bud Tordoff, personal communication), and in 1999 birds nested at two of these sites (Joe Rodgers, personal communication). In 2003, only one pair successfully fledged at least one young in the basin. A pair at the International Bridge at Sault Ste. Marie laid eggs

but were unsuccessful at raising young for the second year in a row. Two non-breeding pairs were also found within the basin (Tordoff et al 2003). Annual surveys for peregrines are conducted. There is good potential habitat in the Upper Peninsula (Joe Rodgers, personal communication) (Table 21).

**Table 21. Current and potential peregrine falcon territories in the Lake Superior basin.**

| **Location** | **Current Territories** | **Other Potential Territories** |
|---|---|---|
| **Ontario** | | |
| Pigeon River to Nipigon | 15 | 12 |
| Lake Nipigon | 0 | 3 |
| Pukaskwa to Michipicoten | 1 | 2 |
| Lake Superior P.P. to Sault Ste. Marie | 4 | 3 |
| **Minnesota** | | |
| Northshore | 6 | 4 |
| Duluth | 2 | - |
| **Wisconsin** | - | - |
| **Michigan** | | |
| Sault Ste. Marie | 1 | 0 |
| Porcupine Hills/Bergland | 1 | 4 |
| Pictured Rocks/ Grand Island | 1 | 1 |
| Bete Grise Bay | 0 | 1 |
| Huron Mountains/Champion | 0 | 3 |
| **Total** | **31** | **33** |

### 4.7.3 Key Plants of Concern

#### *Ginseng*

Ginseng is at the northern edge of its range in the Lake Superior basin. Although relatively widespread in the southern parts of Ontario, Minnesota, Wisconsin and Michigan, its range within the basin is confined to Gogebic County in Michigan and adjacent Vilas County in Wisconsin (Argus and White 1984, Coffin and Pfannmuller 1988, Michigan Natural Features Inventory 1996). Ginseng is Threatened in Michigan, Special Concern in Wisconsin and Minnesota, and Rare (S3) in Ontario. At the federal level, ginseng is Threatened in Canada and Special Concern in the U.S.

Ginseng has declined throughout its range due to overharvest as an herbal medicine. This has resulted in loss of local populations and contraction of range.

Preferred habitat is rich hardwood forest with loamy soil, especially on slopes and ravines (Coffin and Pfannmuller 1988, Michigan Natural Features Inventory 1996).

Habitat related concerns include forest fragmentation (which inhibits natural reestablishment after harvesting), logging, heavy grazing by deer, and cattle grazing in woodlots (Michigan Natural Features Inventory 1996, Coffin and Pfannmuller 1988).

Ginseng export is regulated by the Committee on International Trade in Endangered Species (CITES). It is also protected by legislation in Michigan and Ontario.

### *Pitcher's Thistle*

Pitcher's thistle is a Great Lakes endemic plant. Most of its range is on Lake Huron and Lake Michigan shores in Ontario, Michigan and Wisconsin. Habitat is open sandy beaches and dunes (White and others 1983).

On Lake Superior, Pitcher's thistle is known from two locations: Oiseau Bay in Pukaskwa National Park (White and others 1983) and Grand Sable Dunes in Michigan (Voss 1996). A thorough search of other suitable habitat on the Michigan shore failed to find any additional populations (Voss 1996).

Threats to Pitcher's thistle habitat include shoreline development, succession, shoreline modifications that change sand accumulation, and overgrazing from deer. A long term monitoring program in Pukaskwa National Park, Ontario, found that the population dropped from a maximum of over 700 plants to less than 200 plants following the failure of an upstream beaver dam, causing a creek to re-route its channel. The population remained low for five years, but then rebounded in 1996 (Promaine 1999). Periodic disturbances of this sort may in fact improve habitat conditions for the species by reducing competition from other species. This population is relatively secure from human trampling and overgrazing from deer.

A U.S. recovery plan for Pitcher's thistle was released in 2002 (USFWS 2002). A Recovery Team has also been established in Ontario.

### *Lake Huron Tansy*

Lake Huron tansy range extends from Maine and the Maritime Provinces, to Hudson Bay and northern Alberta. In the Great Lakes Region, it is found in northern Michigan, the Door Peninsula in Wisconsin, and eastern Lake Superior shore in Ontario (Soper and others 1989, Voss 1996).

Its preferred habitat is active sand dunes and upper sand or cobble beaches within the wave zone during high water. It occasionally grows in limestone crevices. Depauperate plants sometimes persist on older stabilized dunes (Voss 1996).

Lake Huron tansy is known from the Michigan portion of the Lake Superior basin from Alger, Luce and Chippewa counties in the Upper Peninsula (Voss 1996). In Ontario, it is found at the Sand River mouth on the eastern side of the lake (Bakowsky 1998). Ontario authorities (Argus and others 1982-1987) consider Lake Huron Tansy to be a subspecies of *T. bipinnatum*, which is common and widespread on the James Bay-Hudson Bay coast and therefore not considered to be rare in the province.

### *Houghton's Goldenrod*

Houghton's goldenrod is another Great Lakes shoreline endemic. It typically grows in interdunal shoreline wetlands and low dunes and moist sandy beaches (Voss 1996). Fluctuating water levels of the Great Lakes play a role in maintaining its habitat. During high water, plants are submerged, but some plants survive the inundation and new seedlings establish on the moist sand (USFWS 1999).

Its primarily range is the northern shores of Lakes Michigan and Huron. In Michigan, it is found in the Lake Superior basin in Chippewa County (Voss 1996). Houghton's goldenrod is rare in Ontario, but is not known from the Ontario part of the basin (Oldham 1998, Semple and Ringius 1983).

Threats to Houghton's goldenrod include trampling from foot and vehicular traffic associated with increased human activity on shorelines (USFWS 1999). Conservation efforts in Michigan include landowner contacts, monitoring, habitat protection in parks and reserves (USFWS 1999).

### 4.7.4 Other Rare Animals and Plants

Numerous other plants and animals in the Lake Superior basin are rare at the state or provincial level. These include species with fewer than 100 occurrences in the state/province (i.e., "S1," "S2," or "S3" following The Nature Conservancy rankings). Species that are rare in at least one state or province are listed in Addendum 6-A. It is important to note that some species listed here as rare are on the list because of habitat loss or population declines elsewhere in one or more of the states or the province. In some cases, such as with the kiyi, habitat in the Lake Superior area and populations of the species here are neither declining nor particularly degraded at the scale of the watershed. In these cases, habitat protection in the Lake Superior watershed is critically important.

***Mammals***

Three rare bat species: eastern small-footed bat, northern myotis and eastern pipistrelle are known from the basin, but are at the northern and western limits of their ranges. Suitable caves for hibernating may be a limiting factor (Coffin and Pfannmuller 1988).

Cougar and wolverine may have once inhabited the Lake Superior basin, but are apparently extirpated now. Occasional sighting of both species are reported, but these probably represent wandering individuals rather than a resident population. A 34 lb male wolverine was killed just outside of the basin boundary west of Thunder Bay in November 1996 and there have been a few credible, but unconfirmed, reports from within the northwestern portion basin in recent years. While reports of cougars within the basin are numerous, confirmations are lacking. A small number of cougars have been killed in Minnesota over the last decade and a few have been caught on film/video but these have been from outside the basin. Some cougar sightings may be escaped pets. Cougar and wolverine require large tracts of habitat with low human disturbance. Persecution by humans and large-scale changes in forest habitat probably contributed to their decline.

***Birds***

Over 50 bird species are considered rare in at least one state/province. This includes species that are rare in the southern portion of the basin, but abundant in Ontario (yellow-bellied flycatcher, Tennessee warbler, Swainson's thrush).

American white pelican, although listed as endangered in Ontario, is increasing in numbers and expanding its range eastward. Pelicans now nest on Lake Nipigon in the Lake Superior basin, and may further expand their range since non-breeding birds are frequently seen on Lake Superior throughout the summer (Escott 1991, Bryan 1994).

Forest fragmentation and loss of mature forest cover threaten forest-dwelling birds, such as cerulean warbler and red-shouldered hawk (WI DNR 1999). Protection of extensive mature forested tracts, especially mature floodplain habitats in Wisconsin and Minnesota, will benefit these species.

Other threats to bird species include loss of wetlands (yellow rail, black tern), chemical contamination (merlin, osprey), and destruction of shoreline habitat (common tern).

### *Reptiles and Amphibians*

Two rare species of reptiles are known form the Lake Superior basin. Wood turtle and Blanding's turtle are Threatened in Wisconsin and Minnesota. Wood turtle is Special Concern in Michigan and Vulnerable in Ontario. A Recovery Team has been established in Ontario. They are at the northwestern limit of their range in the Lake Superior basin.

Wood turtles inhabit small, clear fast streams with sandbars and meadows. In Michigan, they are distributed throughout much of the Upper Peninsula, but are restricted to small pockets of suitable habitat (Lee 1999). Wood turtles may be found in Ontario near Sault Ste. Marie. Overall, wood turtles are rare and declining in the basin. They are long-lived but do not reach maturity in northern latitudes until 14 to 18 years of age. A female lays one clutch of eggs, many of which are quickly taken by mammalian predators. A significant threat to wood turtles is the disturbance of nesting areas by recreational use of sandbars and sandy banks by off-road vehicles, canoeists, and anglers. Other threats include stream degradation, loss of forest cover along streams, and overcollecting for the pet trade and for food (Coffin and Pfannmuller 1988). The wood turtle's home range can be very small (0.25 ha) to relatively large (100 ha) (K. Smith, personal communication), making it vulnerable to habitat loss and direct exploitation. (Harding 1997; Oldfield and Moriarty 1994).

Blandings turtles live in rich wetlands near sandy uplands for nesting. Loss of wetland habitat, river channelization and dams are among the factors threatening populations (Coffin and Pfannmuller 1988).

### *Invertebrates*

Rare invertebrates of the basin include 34 insect species and three molluscs. The distribution and abundance for some of these species is poorly understood and may be more common than their rankings suggest. Conversely, other rare species may be present, but not yet documented.

Several rare insects are associated with sand dunes and beaches. Beach dune tiger beetle inhabits sand beaches in the Ontario and Wisconsin parts of the basin. It is extirpated from some historical Ontario sites, possibly due to loss of habitat to shoreline development (Marshall 1999). Lake Huron locust is endemic to the Great Lakes region. It occurs on sand dunes along the Lake Superior coast in from Chippewa to Alger counties in Michigan and in northeastern Wisconsin (Rabe 1999). Preferred habitat is extensive, sparsely vegetated dunes with unstable sand and blowouts (Rabe 1999). Habitat loss from shoreline development and habitat degradation due to invasive weeds or disruption of sand movement cause populations to decline (Rabe 1999). Dune cutworm is a moth known from Whitefish Point in Michigan. It inhabits similar habitats and is threatened by similar factors as the Lake Huron locust (Cuthrell 1999a).

### *Plants*

About 300 species of plants are considered rare at the state or provincial level in the Lake Superior basin. This represents approximately 10 percent of the total number of plant species growing in the basin (Thunder Bay Field Naturalists 1998, Coffin and Pfannmuller 1988). Many of these species are at the periphery of their range and have always been rare here. Some species are rare in one of the states/province, but common in others.

A breakdown of Minnesota's rare plants by habitat consists of 40 percent wetland species, 17 percent cliff/bedrock species, 15 percent prairie species, and 13 percent upland forest species. The rest are found in successional or transitional habitats. Most (78 percent) rare plant populations in Minnesota occur outside of protected areas (Coffin and Pfannmuller 1988).

Threats to rare plant populations include, logging, plowing native prairies, and water quality changes.

Some areas have higher concentration of rare plant habitats because of unusual features of climate, geology, and glacial history (Coffin and Pfannmuller 1988). Areas with concentrations of rare plant habitats are shown in Figure 61 and described in Table 22.

The moonworts (*Botrychium spp.*), consisting of several species of small ferns, deserve special mention. The majority of the global range of three of these species falls within the Lake Superior basin. They are false northwestern moonwort (*B. pseudopinnatum*), pale moonwort (*B. pallidum*), and pointed moonwort (*B. acuminatum*) (Wagner and Wagner 1993). Habitat for these species is primarily open sandy areas, dunes, and old fields.

**Table 22. Rare plant habitats. Refer to Figure 61 for locations (Argus and others, Coffin and Pfannmuller 1988, Epstein and others 1997, Soule 1993).**

| | Area | Description | Example species |
|---|---|---|---|
| 1 | Northshore Islands and shorelines | Arctic-alpine disjunct species | *Oplopanax horridus, Carex atratiformis* |
| 2 | Sibley Peninsula | Cliff communities, calcium-rich bedrock | *Malaxis paludosa, Arnica cordifolia* |
| 3 | Stanley Prairie | Relict prairie community | *Erigeron glabellus, Stipa comata* |
| 4 | Nor'Wester Mountains and Minnesota Border Lakes | Open cliff base and rim communities | *Calamagrostis purpurescens, Senecio eremophilus* |
| 5 | Minnesota Northshore | Arctic-alpine disjunct species | *Sagina nodosa, Draba norvegica* |
| 6 | St. Louis River Estuary | Wetland communities | *Sparganium glomeratum, Petasites sagittatus* |
| 7 | Bayfield Peninsula | Boreal species, wetlands | *Armoracia lacustris, Huperzia selago* |
| 8 | Apostle Islands | Boreal and sub-arctic species | *Senecio indecorus, Pinguicula vulgaris* |
| 9 | Isle Royale | Arctic-alpine disjunct species | *Calamagrostis lacustris, Phacelia franklinii* |
| 10 | Keweenaw Peninsula | Coastal communities, arctic- alpine species | *Arnica cordifolia, Chamaerhodos nuttallii var. keweenawensis* |
| 11 | Eastern Michigan shoreline | Sand dune species | *Cirsium pitcheri, Tanacetum huronense* |

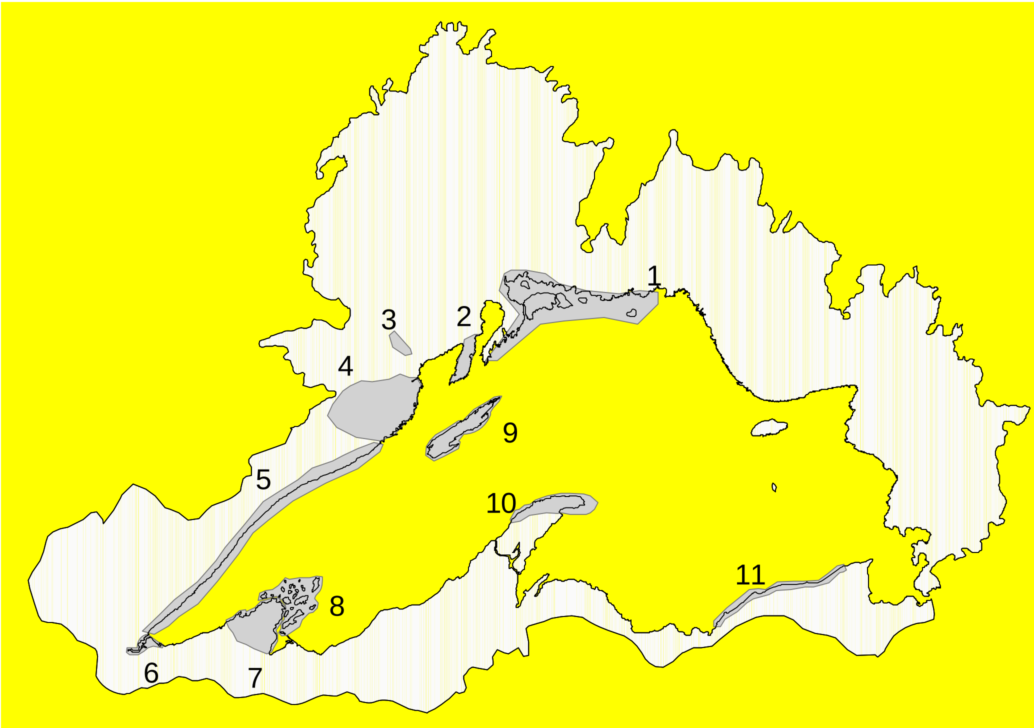

**Figure 61. Rare plant habitats. Refer to Table 22 for descriptions.**

### 4.7.5 Rare Communities

The Lake Superior basin is home to several globally rare vegetation communities. Many are directly dependent on lake processes for their existence and support many of the rare species that inhabit the basin (Reid and Holland 1997). In addition to some of the more prominent rare community types described in this section, the basin includes Oak Savannas and Alvars. A list of globally rare communities known from the Lake Superior basin is in Addendum 6-B. This list continues to be revised and updated as inventory work by the state and provincial agencies progresses.

*Sand Dunes*

Several communities associated with Great Lakes sand dunes are ranked as globally rare by the Nature Conservancy. Dunes form as sand is eroded from glacial sediments by waves and streams, moved along the coast, and deposited. Wind continues to move the sand, maintaining a continuously changing environment.

Coastal dunes have a characteristic series of zones. Foredunes develop closest to the beach, where vegetation such as marram grass and American dune grass forces the winds to drop sand. Other plants such as beach pea and wormwood are established as the foredune grows. Trees and shrubs such as white spruce, trembling aspen, sand cherry, dogwood, and willows eventually gain a foothold (Reid and Holland 1997).

Interdunal areas lie protected from wind and waves behind the foredunes. These areas include globally imperiled communities called interdunal wetlands (pannes) which are calcareous, depressions kept moist by the water table. Vegetation in interdunal wetlands includes shrubby cinquefoil, twig-rush and baltic rush (Michigan Natural Features Inventory 1999a).

Wooded dune and swale community complexes develop as postglacial uplift causes the lake level to recede, leaving dunes outside the direct influence of the lake and allowing new foredunes to form. Over several thousand years, this eventually results in a series of ridges and swales. Streams and groundwater keep the swales moist. Forest eventually develops on the older dunes. Jack pine, red pine and white pine are the dominant tree species, with white cedar and wet meadow in the swales (Michigan Natural Features Inventory 1999b).

The largest and most extensive dunes on Lake Superior are at Grand Sable Dunes National Lakeshore. Some dunes here are in the range of 100 m high (Reid and Holland 1997). Ontario's dunes are small, scattered cove dunes that develop in rocky coves of irregular coastlines. The largest examples are in Neys Provincial Park (0.9 $km^2$), at the mouths of the Pic and Sand rivers (0.4 $km^2$ each) (Bakowsky 1987).

Rare species found in dune habitats include Lake Huron Tansy, Houghton's goldenrod, Pitcher's thistle, Lake Huron locust, piping plover and dune cutworm.

Dunes are threatened by shoreline development that displaces native species and disrupts natural sand migration. A breakwall near Grand Sable Dunes was expanded in the 1950s and may be interfering with long shore drift and altering dune-forming processes (Loope 2003). Elsewhere, off-road vehicles and other recreational use increase erosion. Sand mining, logging of forested dunes, and exotic plants are other threats (Michigan Natural Features Inventory, 1999a, 1999b).

*Sand Beaches*

Great Lakes sand beaches are considered globally rare by the Nature Conservancy (Addendum 6-B).

Lake Superior has a total of 665 km of sand beach (Canada 256 km; U.S. 409 km), predominantly on the southern shore (Figure 62). The longest sand beach is a sand spit at the mouth of Chequomegon Bay in Wisconsin at 21 km in length. There are 161 sand beaches greater than 1 km long (Canada 60; U.S. 101), but most are short, narrow stretches. The Apostle Islands National Lakeshore has a very diverse collection of sandscapes, including sandspits, cuspate forelands, tombolos and a barrier spit. On Madeline Island there is a significant barrier beach in Big Bay State Park.

Sand beaches typically consist of a series of zones. The *lower beach* is scoured by waves and devoid of vegetation. The sparsely vegetated *middle beach* collects debris deposited by storms. The *upper beach* is vegetated with biennials and perennials such as wormwood and beach pea (Reid and Holland 1997). On Lake Superior, sand beaches are often associated with sand dunes, river mouths, and sheltered bays.

A number of rare flora and fauna are associated with sand beaches, many of which are shared by sand dune communities. These include Pitcher's thistle, Lake Huron Tansy, and piping plover. Many smaller beaches may be too small and isolated to support many of the plants and animals characteristic of the larger beaches.

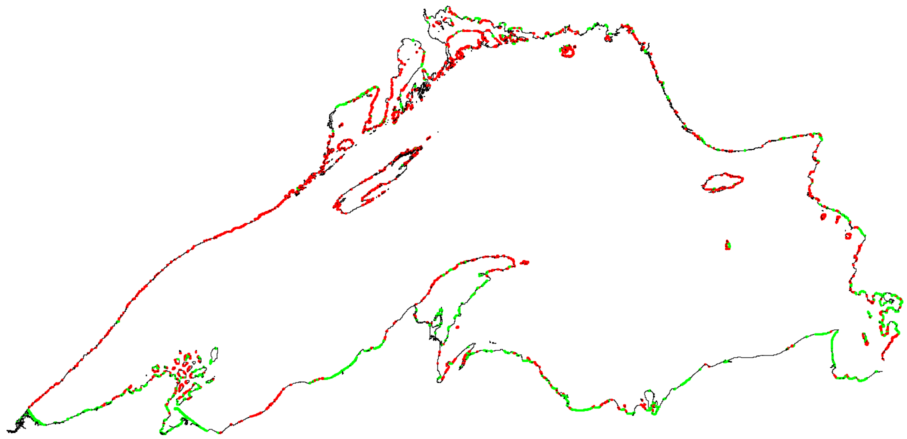

**Figure 62. Sand (green) and cobble / gravel (red) beaches (compiled from U.S. EPA 1994 and Environment Canada 1993).**

Most sand beaches depend on the natural processes of erosion, longshore sediment transport and sand deposition. When groins and other artificial shoreline structures interrupt these processes, the beach habitat is altered. Specialized beach plants can be out-competed by other species as the environment becomes more stable (Reid and Holland 1997). Increased recreational use threatens piping plover and other sensitive species on some beaches.

*Cobble and Gravel Beaches*
Cobble and gravel beaches are common along rocky shorelines. Cobbles are rock fragments 7.5 to 25 cm in diameter; gravel is 2 mm to 7.5 cm in diameter. Little vegetation is present due to exposure to severe wave and ice action and lack of soil. Great Lakes cobble and gravel beaches are considered to be globally rare by the Nature Conservancy (Addendum 6-B).

Cobble and gravel beaches are most common along the Minnesota north shore, Isle Royale, the Keweenaw Peninsula, the Sibley Peninsula, and islands along the Ontario coast (Figure 62). These beaches make up 958 km of the Lake Superior shore (Canada = 541 km – includes “cobble,” “pebble,” and “pebble and cobble” classes; U.S. = 417 km – includes “gravel” class).

*Arctic-Alpine Communities*
Arctic-alpine disjunct communities consist of plants that are isolated from their primary range in the far north or in alpine tundra. These communities are associated with the cold rocky shores of Lake Superior, where they have persisted since the retreat of the Wisconsin glacier.

Typical species include yarrow, bearberry, bluejoint grass, rocky mountain fescue and spreading juniper. Other arctic-alpine disjunct species include mountain avens, alpine chickweed, rock cranberry, butterwort, wild chives, Norwegian whitlow grass, northern eyebright, and alpine bistort (Bakowsky 1998, Reid and Holland 1997). Over 400 species of lichen are associated with this environment. Two lichen species, *Coccocarpia cronia* and *Umbilicaria torrefacta*, are found only on the Susie Islands in western Lake Superior (Reid and Holland 1997).

Arctic alpine communities are usually associated with base-rich rocks such as basalt or diabase (Bakowsky 1998). Some of the best examples can be found at Sleeping Giant Provincial Park Ontario, the Slate Islands Ontario, the Susie Islands Minnesota, and Passage Island Michigan (Bakowsky 1998, Givens and Soper 1981, Judziewicz 1997).

Glaciere talus is another environment supporting arctic-alpine flora (Bakowsky 1996). This community is known from several canyons near Thunder Bay, Ontario. The steep walls block sun from reaching the canyon floor and allow ice to persist beneath talus boulders for most of the summer. The cold microclimate allows a number of arctic-alpine species to persist.

Arctic-alpine disjunct communities are generally protected from disturbance because they are inaccessible, but second-home development, recreational use, and trampling of vegetation have the potential for significant vegetative impact (Reid and Holland 1997).

*Pine Barrens*

Pine barrens are defined as areas of deep sands with scattered, pine trees, and a ground layer of sedges and forbs. ,They have poor, sandy soils and frequent fires (Reid and Holland 1997). The flora often includes prairie species. Pine barrens are closely associated with oak barrens, sand barrens, savannahs, dunes, and prairies.

In the Lake Superior basin, pine barrens are found in the Western Superior Section (212K) (see Figure 22). Pine barren vegetation consists of jack pine, red pine, junipers, shrubs such as sand cherry, little bluestem and other grasses, sedges and forbs. Soils are sandy glacial outwash (Albert 1995).

Less than one percent of northern Wisconsin's jack pine barrens remain today (Reid and Holland 1997). Large areas are managed as jack pine plantations for pulpwood. Fire suppression has allowed non-native species to invade and permitted the forest to succeed to more closed conditions. Recreational development is another threat (Albert 1995).

## 4.8 Areas of Quality

The Binational Program's Habitat Committee has developed ecological criteria for identifying components of the Lake Superior system that warrant special attention. Areas of quality include significant ecosystems, communities, and species habitat. Addendum 6-D is an inventory of important habitat sites in the Lake Superior basin.

# 5. THE TRANSITIONAL ENVIRONMENT

## 5.1 Shorelines

### *Shoreline Development*

Compared with the other Great Lakes, the Lake Superior shoreline is still relatively undeveloped. On the U.S. side, substantial portions of the eastern shoreline and some sizable tracts in the western basin are under federal or state ownership. About 90 percent of the Ontario shoreline is owned by the provincial government. A significant portion of the Lake Superior shoreline is protected in parks and protected areas. However, shoreline development is an increasing concern on Lake Superior.

Shoreline habitats represent the fragile interface between the land and the lake and are particularly sensitive to human stresses. Stresses associated with shoreline development include disruption of natural erosion and sedimentation processes by groynes and other structures, water level regulation in the basin, filling wetlands, increased human disturbance of wildlife, and increased pollution from wastewater, stormwater runoff, and septic fields (Thorp and others 1997).

Lake Superior is increasingly viewed as a desirable location for residential use in both rural and urban settings. Large parcels of privately owned land are now regularly subdivided for potential residential development as the market demand increases for waterfront homes. Shoreline development is increasing most quickly along the North Shore in Minnesota, the Bayfield Peninsula in Wisconsin, and the Keweenaw Peninsula in Michigan, largely because they are within a half-day drive from large metropolitan areas. For example, Bayfield County in Wisconsin, which has more than half its land base in the Lake Superior basin, has seen significant land price increases in the last few years. Property values increased 21.64 percent from 1998 to 1999, which was the second highest increase in Wisconsin (Wisconsin Department of Revenue 1999). The Keweenaw Peninsula on Michigan's Upper Peninsula has seen unprecedented growth in the past 20 years, mainly as the result of recreational home building. Over 50 percent of the homes in Keweenaw County are now classified as second homes. Some of the most scenic lakeshores, home to unique ecological communities and rare plants, are frequently the same areas being subdivided or subject to other development proposals. The placement of raised sand septic fields in shallow soiled rocky headlands and the filling of sensitive wetland habitats are specific concerns. In Ontario, this trend is greatest along the shorelines east and west of Thunder Bay and north of Sault Ste. Marie. Development is not yet as extensive as in Minnesota and Wisconsin.

Most of Superior's shores are rocky and exposed to heavy wave action. Most cities, marinas, and cottage developments are located in protected estuaries and embayments, which are also important habitats. Prime building spots are rare. Rocky bluffs sport rows of huge steel and wood stair complexes giving recreational homeowners the ability to reach the water. They construct piers of stone, rock and concrete to protect their boats from the lake. Homeowners tend to remove trees, shrubs, and vegetation to gain a better view of the lake.

Highways also hug many kilometers of Superior's shore, and new homes often are squeezed into the ribbon of land between the road and shore. Homes allowed too close to the shore areas of Lake Superior are exposed to flooding during high water or storm events, causing erosion, property damage, and shore edge destruction.

The increase in residential and cottage development, and the associated infrastructure, can dramatically impact sensitive shoreline habitats. These impacts include the construction of access roads that fragment wildlife travel corridors, removal of native shoreline vegetation, construction of harbours and marinas in sensitive estuaries, lake filling, and construction of erosion control structures or breakwalls that impair natural sediment transport processes. In some cases, residential developments permitted in areas of shallow soil or rocky headlands can also lead to temporary or long-term contamination of land and water resources through faulty septic systems.

Approximately five percent of the Lake Superior shoreline consists of artificial, made-made structures (Figure 63). Much of the artificial shorelines is concentrated near cities at the mouths of the larger rivers (Nipigon, Kaministiquia, St. Louis) and in many cases is probably replacing wetland habitat. Other areas with significant artificial shoreline are the Bayfield Peninsula (presumably associated with erodable red clays) and the Keweenaw Peninsula.

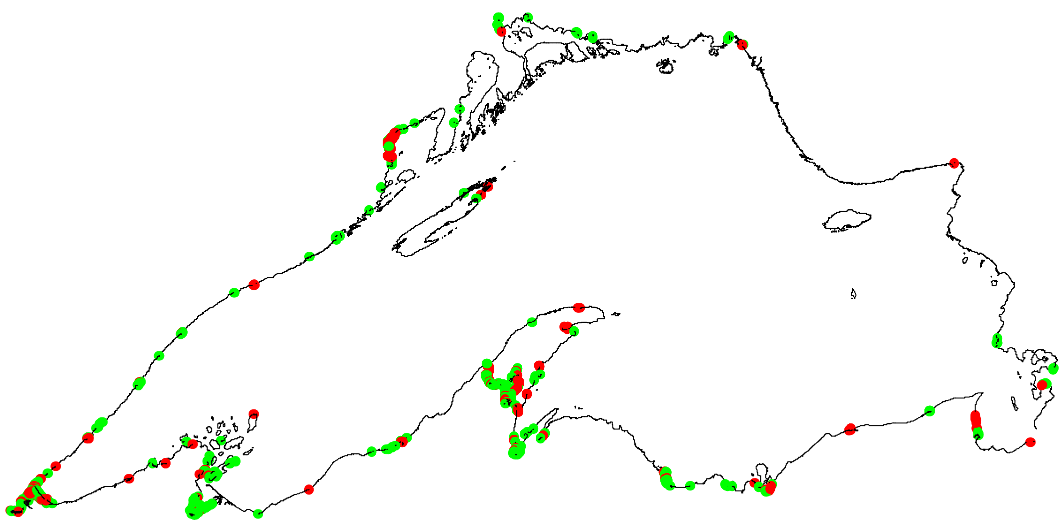

**Figure 63. Artificial shorelines: red is retaining walls, harbour structure, and breakwater; green is rip-rap (Compiled from U.S. EPA 1994 and Environment Canada 1993).**

The impact of shoreline development on Lake Superior habitat is a primary focus of many management forums. The binational State Of the Lakes Ecosystem Conferences (SOLEC) present papers that describe shoreline processes and explore stresses on these habitats. The intent is to report on the state of the Great Lakes ecosystem and the major factors impacting it and to provide a forum for exchange of this information among Great Lakes decision-makers.

### *Shoreline Regulation*

Uncontrolled development takes many forms, including industrial, agricultural, commercial, and residential, and can lead to significant cumulative impacts for natural shoreline habitats. There is no comprehensive data on the extent, distribution, or trends in shoreline development on Lake Superior. Information of this type would need to be obtained from individual municipal offices, permit review agencies (i.e., OMNR and DFO) and other land use control sources.

From a regulatory perspective, the issue of land-use planning along Lake Superior's shoreline is complex. The responsibility for land-use decisions is fragmented among many government regulatory agencies. Often the decision-making authority rests with small local municipalities or county governments that are ill-equipped to handle thorough environmental assessments. In many cases, these local governments encourage shoreline development as a mechanism for increasing their tax base.

Overall, there does not appear to be a comprehensive mechanism in place to determine the impact of shoreline development approvals. Nor does there appear to be a process for the implementation of uniform development standards across the basin (i.e., set-back requirements) for new shoreline developments in the Lake Superior basin (Thorp and others 1997). Although some regions may be making individual efforts to compile statistics on the subdivision of shoreline properties, significant data gaps exist. There needs to be a better understanding of the cumulative consequences of local land-use decisions in relation to shoreline habitat impacts.

One positive trend has been the reclamation of former industrial lands in some urban communities. Recent shifts in markets, has in some waterfront cities, reduced the industrial demand for shoreline sites. As a result many urban centres have recently focused their attention on developing strategic waterfront plans that encourage the acquisition of former industrial lands in an effort to improve public waterfront access or to encourage the restoration of green space along the shore. This trend may continue in many centers within the Lake Superior basin.

Communities struggle with the issues of economy vs. environment but new solutions are being found. Responding to requests from the local officials concerned with the explosive growth, Wisconsin has spent $2 million in the past three years to help local governments develop a lake classification system. The idea is to guide development in sensitive lakeshore areas on inland lakes. Twenty-seven northern counties are developing stronger land use strategies and rules on their shorelines.

Specific basin-wide needs include:

- Inventorying current educational programs and materials regarding shoreland development.
- Reviewing current zoning and land use ordinances and their enforcement.
- Continuing research on the impacts of shoreline development.
- Working with and bringing together local communities, government units and concerned individuals to develop long-term solutions and visions for the Lake Superior shorelands.
- Discussing the possibility of developing a Lake Superior-wide set of building standards.

### *Lake Level Management*

For over 150 years, the outflow of Lake Superior at Sault Ste. Marie has been modified to improve navigation and hydroelectric generation (Environment Canada 1993). Power canals and navigation channels increased the amount of water that could be discharged. The increased capacity required the construction of control works to compensate for the increased outflow capacity from Lake Superior.

The Lake Superior Board of Control was established to supervise the operation of all control works, canals, headgates, and bypasses and to formulate rules for them. The Board’s goal is to regulate the level of Lake Superior in such a matter as not to interfere with navigation, protect the sport fishery in the rapids of the St. Mary's River, and ensure adequate flow for hydroelectric generation. Flow regulations also help prevent ice jams in the St. Mary's River.

Regulation of Lake Superior also depends on water levels in the lower Great Lakes. Regulating outflow from Lake Superior can compensate for extreme high or low water levels in Lakes Michigan and Huron.

One of the main objectives of the IJC's 1914 order was to maintain Lake Superior levels within a more narrow range than was recorded through past monitoring history. However, this objective soon proved impossible when record high and low water levels occurred in later years. In the 1950s, the maximum water level as prescribed in the 1914 Order was exceeded. During the mid-1950s to the 1960s, water levels were also frequently below the minimum level.

In the mid-1960s, when water levels were extremely low on lakes Michigan and Huron, Lake Superior was used to help alleviate the situation on these lakes. Permission was granted to discharge outflows greater than the regulation plan. In the early 1970s, Lake Superior flows were reduced as part of an emergency action since water levels were critically high in the lower Great Lakes.

In the spring of 1985, Lake Superior's outflows were again reduced because of high water levels in the lower Great Lakes. However after four months of flow reductions it became necessary to reverse procedure and increase outflows since large amounts of precipitation on the Superior basin had caused the Lake to climb to a record high level. Continued rains saw Lake Superior levels exceed the level of 186.86 m for a period of two months despite allowing the largest outflow on record.

The presence of Lake Superior compensating facilities does not mean that full control of Lake Superior's water level is attainable or desirable. Lake Superior levels are greatly affected by natural conditions that cannot be controlled, such as evaporation, runoff, and over-lake precipitation. Since these factors cannot be accurately predicted, levels on Lake Superior remain largely a product of natural occurrences (IJC 1993, Tushingham 1992).

The effects of water level regulation on the lake ecosystem are not well understood. The reduced range of high and low water levels influences wetland and shoreline plant communities, but site-specific studies are needed to evaluate the effects of fluctuating water levels on the Great Lakes fishery. Wilcox and Whillans (1999) call for the restoration of natural lake level fluctuations on Lake Superior to restore wetland hydrological processes.

### *Water Diversion Projects*

Waters from the Albany River basin, which formerly flowed into Hudson Bay, have been diverted from the Ogoki and Kenogami rivers and now flow into Lake Superior. The purpose of the diversions was to increase flows at hydroelectric dams and improve log drives.

The Long Lac diversion was established in 1939. It consists of a concrete overflow dam on the Kenogami River at Long Lac. The diverted water passes through a channel built across the watershed divide and into the Aguasabon River, which drains into Lake Superior. A concrete dam at the end of the channel regulates flows. Since 1940, an average of about 40 cubic meters per second (cms) has been diverted to Lake Superior (IJC 1976). Electricity is generated at a power plant near the mouth of the

Aguasabon River in Terrace Bay. This diversion was also used for the transport of pulpwood logs southward.

The Ogoki diversion was established in 1943. It redirects water from the Ogoki River into Lake Nipigon, which flows into Lake Superior via the Nipigon river system. The Waboose Dam on the Ogoki raises water levels so that most of the flow is redirected across the watershed divide, and then through a number of small lakes into the Jackfish River and into Lake Nipigon. The Summit Dam controls the amount of diverted water. The diversion discharges an average of 113 cubic meters per second (cms) (IJC 1976). Since 1943, the diversion has had closures and reduced flows on at least 25 occasions for a variety of reasons. A generating station at Pine Portage at the top of the Nipigon River controls the outflow. Pine Portage generating station is the first of three hydroelectric plants on the Nipigon River. A minimum flow of 227 cms is required to ensure appropriate water levels for the town of Nipigon's water supply system. Flows in excess of 566 cms would endanger the railway and highway bridges at Nipigon.

In 1951-53, the volume diverted from the Ogoki River was reduced during a period of high water. Diversion of water was stopped for a numbers of months in each of these high water years. Ontario Hydro reduced water diversions again during 1972-74. During this period the outflow through the Nipigon River was reduced to natural levels and diversion waters were stored in Lake Nipigon. Once Lake Nipigon reached peak levels, water diversion was completely halted and Ogoki flows were temporarily diverted north again.

The Long Lac and Ogoki diversions have had significant local environmental effects resulting from the initial construction and operation of the diversion structures, channels, and reservoirs. Greatly altered flow regimes and the accumulation of bark and other woody debris from log drives represent a continuing stress on the local environment and negatively impact upon fish spawning habitat. Lower reaches of the Little Jackfish River on the Ogoki Diversion experience severe erosion of unconsolidated glaciolacustrine sediments which has resulted in increased siltation and turbidity stresses of the Obamika Bay on Lake Nipigon. This has contributed to the decline of the walleye fishery and may also be responsible for the increase in sauger compared to walleye (Bridger and Day 1978).

The Long Lac and Ogoki diversions have also had significant hydrological effects on the Great Lakes. The mean water level of Lake Superior has increased by 6.4 cm, Lakes Migichan-Huron by 11.3 cm, Lake Erie by 7.6 cm, and Lake Ontario by 6.7 cm. The changes in water level attributed to the diversions result in an estimated annual loss of $4.8 million due to erosion and flooding. However, direct benefits to the pulp and paper industry (located on the Aguasabon River), navigation (higher water levels permit greater loads), and power generation are estimated to exceed the calculated losses by $57 million annually. The effects of water level increase on recreational boating and beach use have not been quantified for Lake Superior, but generally raising water levels benefits boating and harms beaches. No basin-wide negative environmental effects have been documented for these two diversions (IJC 1985). No introductions of aquatic species from the Arctic watershed have been reported.

### *Recreational Use*

The waters and shoreline of Lake Superior have witnessed a significant growth in the volume and range of water and land based recreational activities. The impacts of leisure and recreational pursuits on water quality and shoreline habitat are largely unknown. This assessment of habitat stress related to recreational activities is drawn from anecdotal evidence from park and resource managers and members of the academic communities within the Lake Superior basin.

Commercial and private shoreline development has significantly changed the complexion and composition of natural habitats along extended sections of the Lake Superior shoreline. Developments, together with access roads and associated leisure facilities are the most visible consequences of leisure and recreational use of the lake.

The development of marinas (for example at Red Rock, Nipigon, and Michipocoten Harbour in Ontario and Silver Bay and others on the Minnesota shore in various stages of advanced planning) reflects increases or anticipated increases in motor and sailboat traffic.  Marina facilities inevitably concentrate boating activity and may amplify the impacts of fuel spillage, jetsam, and unsanitary discharge of solid wastes.  Conversely, if used as intended, marina facilities could help mitigate some of the impacts of increased boat traffic on the lake.  Commercial cruise ships are a recent phenomenon on Lake Superior. Small boats onboard the ships allow guests to disembark and explore remote and secluded shorelines. This eventuality could see repetitive, large group use of offshore islands or otherwise secluded bays and coves.

Sea kayaking is one of the fastest growing recreational activities in Apostle Islands National Lakeshore, Pukaskwa National Park, and along the Rossport/ Nipigon island archipelago.  Kayakers have the ability and a preference to visit and camp in secluded bays and inlets.  Pictured Rocks National Lakeshore and other high-use kayak areas have expressed a concern regarding the concentration of debris and the unsanitary disposal of human waste in backcountry campgrounds.  Monitoring plots have been located within the Pictured Rocks area; however, no long-term data are yet available.

Research regarding the effects of air emissions and gas and oil leaching from two cycle engines as found in snowmobiles and personal water craft has been conduced in some U.S. national parks; however, no data were located for the Lake Superior basin.  Both sledding and personal watercraft are popular recreational activities on or near Lake Superior.  The noise of these activities and the pattern of repetitive use of trails or nearshore waters may disrupt wildlife use of otherwise suitable habitats.

Off-road trucks and all-terrain vehicles have significantly impacted some shoreline habitats.  Blowouts and denuded sandscapes in the Pic River dune complex and in the Michipicoten Bay area of Ontario are the scars of repetitive use by vehicular traffic. Similar impacts have been reported in areas within and adjacent to the Picture Rocks National Shoreline, Michigan.

Evaluated individually, recreational activities have small or localized impacts on the shoreline habitats of Lake Superior.  However, the cumulative effects of recreational activities may degrade the integrity of natural patterns and processes.  The subtleties and extended time frame of these changes make it impossible to link a recreational activity that is perceived to be beneficial or benign to a change or stress in the natural habitat.

## 5.2 Coastal Wetlands

The greatest threats to Lake Superior's wetlands (Figure 64) are water level regulation and site-specific stresses such as shoreline development (Chow-Fraser and Albert 1998). Other threats include invasive species and diminished water quality (Epstein and others 1997).

Loss of wetland habitat has been small in Cook (zero percent loss) and Lake (two percent loss) counties, Minnesota (MPCA 1997), but most of the St. Louis River estuary wetlands at Duluth / Superior have been lost since the early 1900s (Epstein and others 1997). The wetlands of the Apostle Islands, Bad River and Kakagon Slough are largely intact (Chow-Fraser and Albert 1998).

Wetland loss in Ontario has not been quantified, but is probably low (0 to 25 percent) for most of the basin, given the low intensity of land use (Detenbeck and others 1999). In local areas, however, wetland losses are substantial. Wetland area around the city of Thunder Bay has declined by over 30 percent since European settlement (NWWG 1988). Lake Superior shoreline wetlands are a particular concern in Ontario, given their scarcity and proximity to developed areas. Continued cottage development at Cloud Bay, Sturgeon Bay and Pine Bay threatens wetlands (Maynard and Wilcox 1997).

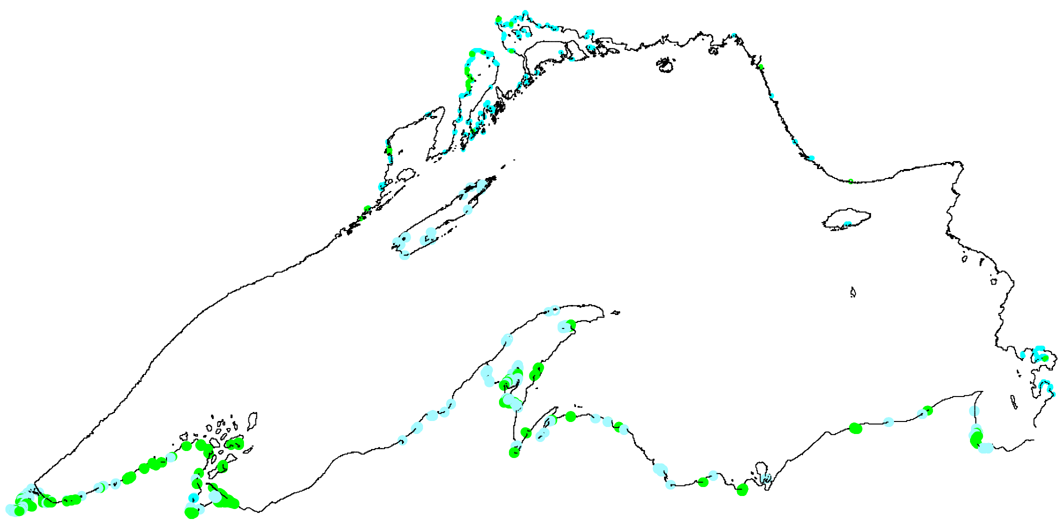

**Figure 64. Lake Superior shoreline wetlands: extensive (green) and fringing (blue) (compiled from U.S. EPA 1994 and Environmental Canada 1993).**

No estimate is available for the amount of coastal wetlands lost on Lake Superior. No large-scale losses have occurred along the north shore because the shoreline is remote and sparsely populated. However, considerable wetland area has been lost within the Areas of Concern at Thunder Bay, Nipigon Bay, Jackfish Bay, and Peninsula Harbour due to shoreline modification and urban encroachment (Wilcox and Maynard 1996). On the other Great Lakes, 11 to 100 percent of historical wetland area has been lost (LSBP 1995a). Nutrient enrichment and toxic contamination of waters and sediments and modified water level fluctuations are other potential threats to Lake Superior wetlands (Wilcox and Maynard 1996).

Water level regulation on Lake Superior has affected all coastal wetlands by restricting the natural flooding and drawdown cycle. In an unregulated wetland, periodic flooding kills back woody species along the fringe, allowing less competitive wetland plants to occupy the zone. Drawdown below the average water level allows the seed bank to germinate and promotes oxidation of substrates. Maintaining relatively constant water levels result in a smaller and less diverse wetland zone. On Lake Superior, although the flooding – drawdown cycle hasn't been altered substantially, the extreme low water levels are probably not frequent enough to maintain natural wetland conditions (Maynard and Wilcox 1997). No data on changes in wetland vegetation due to water level regulation are available. Similar effects occur on wetland on inland lakes and streams with altered water level regulation (Wilcox and Whillans 1999).

Shoreline alteration influences wetlands, both through direct loss of wetland area and disruption of hydrological and sedimentation processes. Wetlands enclosed by groynes, dykes, and breakwalls have reduced supplies of sediments that naturally nourish the shoreline and replace eroded sediments (Maynard and Wilcox 1997). By obstructing natural disturbances, such as storms and ice-scour, artificial structures cause shifts in plant species composition of enclosed wetlands.

***Dredging***

In Lake Superior, dredging has been taking place since the early 1900s. Dredging involves removal of lake bottom sediments to maintain shipping and recreational boating channels. In the period 1937 to 1972, 68.7 million $m^3$ were dredged from Lake Superior (Edsall and Charlton 1997).

Dredging can have harmful impacts on wetlands. In addition to loss of wetland area, dredging in shallow waters near wetlands can create new channels, altering water movements and changing nutrient regimes and plant communities (Maynard and Wilcox 1997). Dredging can also cause lower water tables and increased sediment loading in the rest of the marsh. Deepening the water adjacent to the marsh can prevent the natural migration of the marsh boundary during low water years.

Disposal of dredged material can also alter habitats. Dredge spoils are sometimes deposited in shorelines, filling wetlands or burying other shoreline communities (Thorp and others 1997). Depositing dredge spoils in nearshore habitats can bury spawning areas, but carefully planned open water disposal can have only temporary or minor impacts if spawning areas and other significant benthic habitats are avoided (Edsall and Charlton 1997). Most dredge spoils are now deposited in confined disposal facilities due to concerns about contaminants.

Dredging operations on Lake Superior regularly take place at the Thunder Bay harbour and the St. Louis River estuary at Duluth / Superior, with smaller operations at recreational marinas. The upper St. Marys River is also routinely dredged for channel maintenance and recent low water periods have resulted in calls for channel deepening and associated studies.

***Sedimentation***

Natural sedimentation processes of erosion, transport and deposition are essential for maintaining healthy coastal wetlands and sand dunes (Wilcox and Whillans 1999). Sediments can form barrier beaches and sand spits that protect wetlands. Some wetlands depend on sediment inputs to maintain vegetation. Active sand dunes are in a continuous state of flux as sand is deposited and eroded.

Artificial structures disrupt these processes. Breakwalls and revetments are structures placed parallel with the shoreline to enclose a harbour. Unintended side effects include scouring of sediments on the lakeside and increased erosion down wind as wave energy is transferred parallel with the wall. During high water levels, marshes inside the breakwall can be flooded out (Maynard and Wilcox 1997).

Groins are low walls constructed perpendicular to the shore. They are installed to protect beaches by intercepting longshore and beach drift. However, marshes and dunes that are eroded by storms may not be replenished if the supply of sediments is trapped by artificial structures (Maynard and Wilcox 1997). A breakwall near Grand Marais, Michigan may be interfering with longshore drift and altering habitat for Pitcher's Thistle (Loope 2003). Similarly, dams on tributary rivers trap sediment that previously nourished estuarine wetlands. Wilcox and Whillans (1999) recommend improved designs for breakwalls and other erosion protection structures that incorporate the principles of sedimentation processes.

Excessive sedimentation from upland sources can also impair aquatic habitats. Increased erosion from agriculture, lake-level changes, logging, and urban land use can increase sediment deposition in streams, smothering fish spawning substrate and causing excessive turbidity.

The extent and magnitude of these impacts on Lake Superior habitats are unknown, but they are probably greater on the south shore than the north.

***Exotic Species***

*Purple Loosestrife*

Purple loosestrife is a well-known invasive plant of wetlands. Native to Europe, it was first brought to North America in the early 1800s and is now found throughout much of the United States and Canada. Impacts of purple loosestrife can be severe. It has displaced up to 50 percent of the native plant biomass in some wetlands. Impacts on wildlife are not well understood, but some studies suggest serious declines in waterfowl and furbearer productivity in loosestrife-infested wetlands (Thompson and others 1987). Competition with rare plant species is also a concern.

In the Lake Superior basin, purple loosestrife is found around Thunder Bay, Duluth / Superior, Sault Ste. Marie and scattered other locations (Figure 65). It grows extensively along the Kaministiquia River and at number of other areas around Thunder Bay and north to Hurkett (David Ellingwood, LRCA, personal communication). Purple loosestrife is prevalent in the Sault Ste. Marie area and the St. Mary's River (S. Greenwood, OMNR, personal communication). In Wisconsin, purple loosestrife is widespread, but still at low density in most areas, occurring in only about five percent of the total wetland area statewide (WI DNR 1999).

At Thunder Bay, the Lakehead Region Conservation Authority has implemented control by digging plants and the introduction of beetles (*Galerucella* spp) that feed on loosestrife. The use of beetles has had mixed results (David Ellingwood, personal communication). Minnesota has a statewide control program using herbicides and biological control (Skinner and others 1994). In Wisconsin, there are limited control programs in place; Bad River Band of Lake Superior Indians use chemical control in the Kakagon Sloughs. The Apostle Islands Nationals Lakeshore (Gary Czypinski, personal communication) has used biological control since 1997.

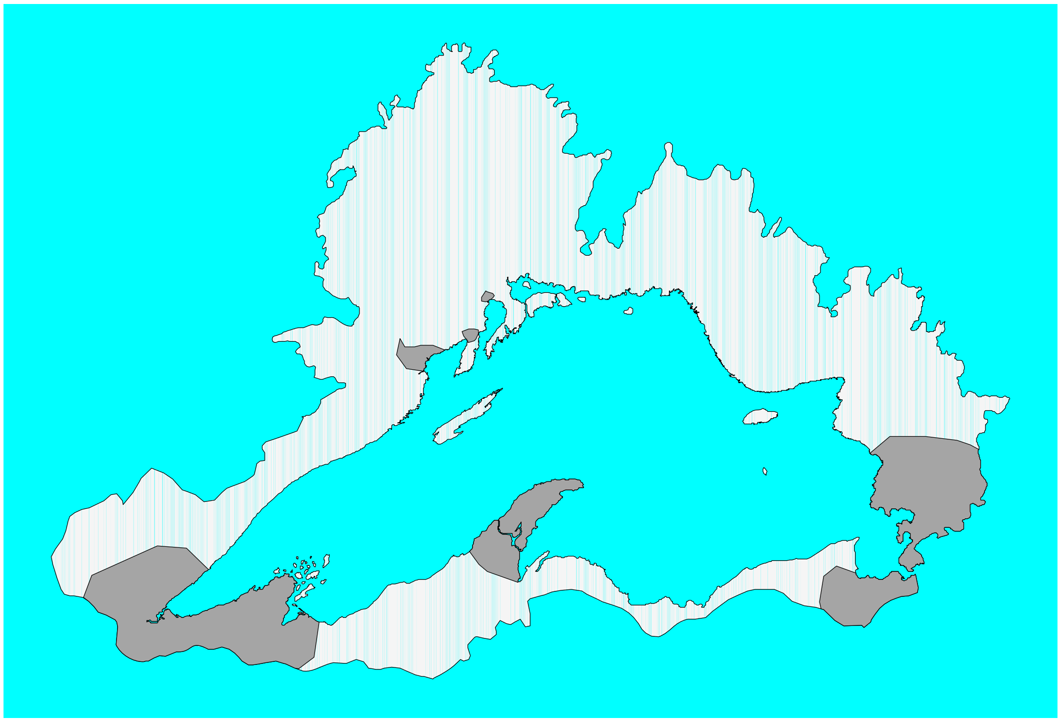

**Figure 65. Approximate distribution of purple loosestrife in the Lake Superior basin. Local occurences exist outside the shaded zones (Skinner and others 1994, Voss 1985, White and others 1993, WI DNR 1999).**

## 5.3 Species and Ecosystems of Concern

### *Wild Rice*

To Chippewa tribes around the Lake Superior basin, wild rice (*manoomin*) is "the food that grows on water." It fulfilled a prophesy in the story of the Chippewa tribe's migration from the east – they would know that they had found their new home when they found the food growing on water. Wild rice has been a vital part of Chippewa culture and religion ever since. It was also significant in the lives of the Dakota and Menominee tribes, and provided food for early European explorers.

The "wild rice bowl" extends from Manitoba, through northwestern Ontario, Minnesota, and Wisconsin (Figure 66). Some populations in Ontario were probably introduced by native peoples many years ago (Aitken and others 1988). There have been more recent introductions to several locations in the eastern part of the basin.

Wild rice habitat is shallow water in slowly-moving streams and inlets and outlets of lakes. It does poorly in stagnant water and fast moving streams. Soft organic material is the preferred substrate.

Wild rice is important to the ecology of lakes, streams, and shallow water wetlands. It helps maintain water quality by binding loose soils, tying up nutrients, and slowing winds across shallow wetlands. Wild rice is an important habitat component for many species. It provides wildlife, particularly waterfowl, with food and cover.

Many of the historic wild rice stands have been lost. Although a number of factors can harm rice, it is particularly sensitive to water level changes (Vennum 1988). Many lakes and rivers have been dammed, and even small water level changes can destroy wild rice habitat. A number of interagency efforts are underway to try and reverse this decline in wild rice populations. These include abundance and harvest monitoring, restoration and enhancement, and research.

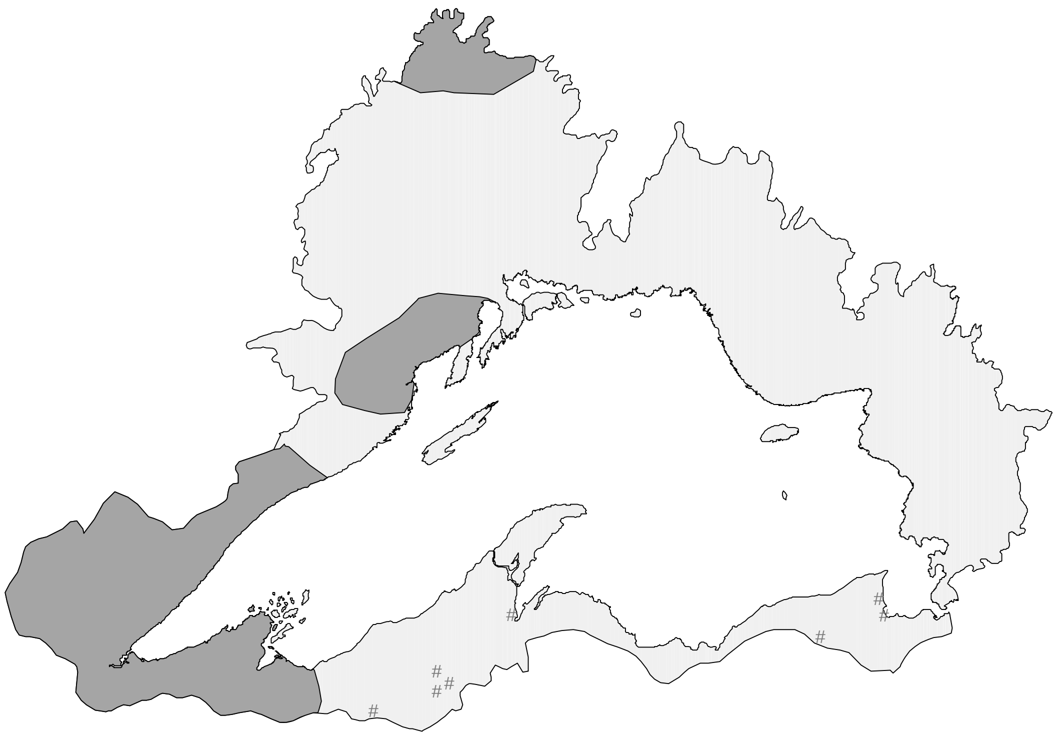

**Figure 66. Distribution of wild rice in the Lake Superior basin (Based on Aitken and others 1988, Voss 1972).**

### *Piping Plover*

Piping plover is classified as Endangered in Michigan, Wisconsin, Minnesota and Ontario and federally in both Canada and the U.S. (Great Lakes Population).

In the Great Lakes area, these birds historically nested on sandy and gravel beaches and sparsely-vegetated shorelines with gravel or pebbly mud substrate. At Duluth, they nested on dredge-spoil islands (Coffin and Pfannmuller 1988). Beaches separated from the tree line by a wide dune system or slough offer the best habitat and wide beaches provide better habitat than narrow beaches (Lambert and Ratcliff 1979).

Since the 1960s, piping plover populations have declined precipitously. Threats to habitat include high water levels (mid-summer storms), recreational uses, and all-terrain vehicles on beaches. Additional threats to plovers include increased gull populations and free running dogs on beaches. The quantity and quality of beach habitat is dynamic and influenced by fall and winter storms that erode and deposit sand and set back vegetation succession.

*Ontario*
There have been no documented reports of piping plovers nesting along the Lake Superior shoreline, although there is potential habitat at Caribou Island (good), Agawa Bay (marginal) and Beaver Rock (marginal) (Heyens 1998). Also, the mouth of the Pic River should be considered as good habitat. There are no annual surveys for piping plovers on Lake Superior.

*Minnesota*
The Minnesota north shore has very limited Piping Plover habitat. Historically they nested at the Duluth Harbour on industrial lands; with six to eight pairs during the early 1970s and three pairs in 1985. However, development pressures, recreational use, increased ring-billed gull populations, and lack of management has limited this area for breeding (Coffin and Pfannmuller 1988). No plovers have nested here in the 1990s (Katie Haws, personal communication).

*Wisconsin*
Historically piping plovers nested in the 1950s at Barkers Island and Wisconsin Point in the Duluth - Superior Harbour. Piping Plovers did not nest along Lake Superior coastline for many years, but in 1998, one pair was successful in raising four young at Long Island/Chequamegon Point (Sumner Matteson, personal communication). In 1999, one nesting pair and four other adults were observed here. The pair laid four eggs, hatched two young, but a mammalian predator killed both young. Surveys have been conducted each year since 1974. The habitat at Long Island has expanded due to lower water levels and the area could support 15 to 20 pairs (Sumner Matteson, personal communication). Long Island and the Michigan Island sandspit of the Apostle Islands N. L. were designated as critical habitat for piping plovers in 2001.

*Michigan*
Michigan has most of the piping plover habitat on Lake Superior. There is excellent habitat in Luce, Alger and Chippewa Counties. Another site at Pictured Rocks National Seashore has marginal habitat.

The 1998 survey located seven nests at four sites: four nests at two sites near Grand Marais (Alger County), one nest at Vermillion (Luce County) and two nests at Weatherhogs Beach, (Chippewa County) (Hinshaw 1998). Two historical nesting areas were surveyed with no nests found : Twelve Mile Beach, Pictured Rocks National Lakeshore, Alger Co. and Lake Superior State Forest Campground beach, Luce Co. The number of pairs is similar to those found in a 1979 survey (Lambert and Ratcliff 1979) (Figure 67, Table 23).

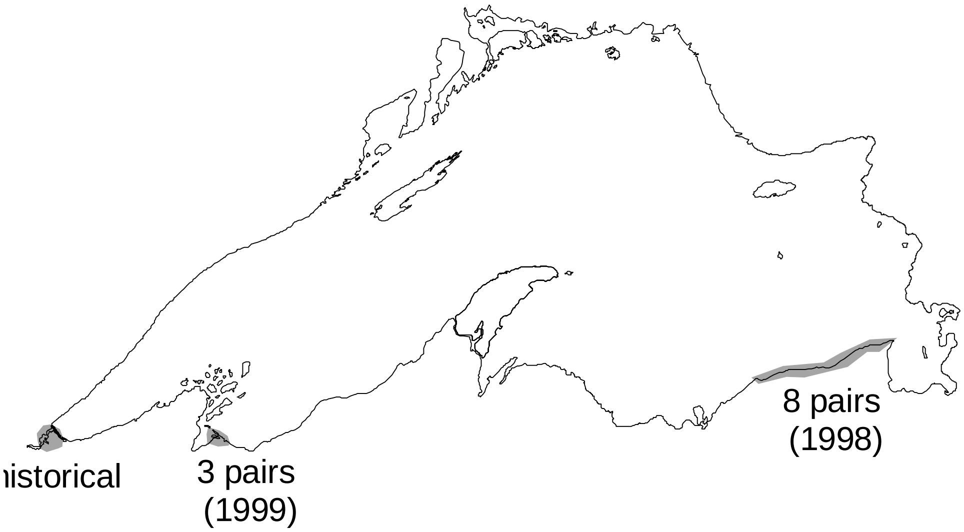


**Figure 67. Piping plover habitat in the Lake Superior basin.**

**Table 23. Piping plover survey results, Michigan (Lambert and Ratcliff 1979, Hinshaw 1998).**

| Location | Number of sites | | Nests | |
|---|---|---|---|---|
| | 1979 | 1998 | 1979 | 1998 |
| Luce County | 5 | 1 | 4 | 1 |
| Alger County | 1 | 2 | 3 | 4 |
| Chippewa Co. | 5 | 1 | 3 | 2 |

Habitat for plovers in Michigan at Vermillion is shifting eastward as vegetation encroaches on more westerly areas. The eastern portions of the beach are becoming narrower and more vegetated as well, resulting in a shift toward less suitable nesting habitat at this site. East of the Vermillion site, Weatherhogs Beach is widening and use of this area by plovers is increasing. Human disturbance of plover nests at Weatherhogs is more difficult to restrict than at Vermillion where the Whitefish Point Bird Observatory staff can restrict access and more closely monitor use of the beach. Enhancing habitat at Vermillion may be needed to retain it as a nesting area.

### *Common Tern and Caspian Tern*

Common terns are Endangered in Wisconsin, Threatened in Michigan, Special Concern in Minnesota, and unlisted in Ontario (Matteson 1988). Common terns nest at the St. Louis River estuary at the Duluth-Superior Harbor in Minnesota / Wisconsin. This colony declined 63 percent between 1977 to 1987 (Matteson 1988). In Wisconsin, there are 29 colony records on Lake Superior from the period between 1946 and 1987, most of these since the 1950s (Matteson 1988). In Michigan, common terns formerly nested along the Lake Superior coast in Chippewa County, but there are no recent nestings here (Hyde 1997). Common terns nest at several locations in the Ontario portion of the basin, but the north shore of Lake Superior constitutes a conspicuous distribution gap in the province (Blokpoel 1987). Low productivity of the lakes in the boreal shield in Ontario may be a limiting factor.

Caspian terns are Endangered in Wisconsin, Threatened in Michigan and Vulnerable in Canada. This species was probably never common on Lake Superior (Hyde 1996). They nest at several locations in the Wisconsin part of the basin (WI DNR 1999a), but apparently don't nest in Minnesota. In Michigan, Caspian terns nest in several of the counties bordering Lake Superior, but are not known to nest within the basin itself (Hyde 1996). They nested at two small Lake Superior islands in Ontario between 1997 and 2003 (Brian Ratcliff, pers. comm.), but are otherwise not known to nest in the Ontario basin (Austen and others 1994).

Chemical contamination, harvest for the millinery trade, and gull displacement contributed to the decline of these species. Important habitat includes small, sparsely vegetated islands or peninsulas for nesting. They will nest on artificial islands. Habitat related concerns include human disturbance at nesting sites, destruction of nesting habitat, and encroaching dense vegetation on nest sites. Rising water levels can flood nests and decrease available nesting habitat (Matteson 1988).

The objectives of the Wisconsin common tern recovery program are protecting nesting sites and establishing new colonies, population monitoring, evaluating chemical and habitat conditions, and enhancing awareness (Matteson 1988).

## 6. THE AQUATIC ENVIRONMENT

The principal stresses to the aquatic environment in Lake Superior include: atmospheric deposition and point discharge of contaminants, shoreline development in embayments and inland lakes, hydroelectric facilities, barrier dams, industrial effluents, mining waste, wetland draining and filling, agricultural practices, timber harvesting practices, exotic species, and discharges from Great Lakes vessels. Atmospheric deposition and exotic species are stresses to the aquatic community that have lakewide effects, whereas most of the other stresses have more localized effects.

All offshore and most nearshore habitat remains healthy and productive. As a result, all forms of lake trout are abundant. The majority of impairments to aquatic habitat and water quality are found in embayments and tributaries. These tributaries remain significantly degraded by such stressors as agriculture, mining, hydroelectric dams, industrial effluents and waste, wetland dredging and filling, nonpoint source pollution, shoreline development, and land use practices that lead to increased runoff and erosion. In particular, discharges of mine chemicals and tailings have degraded a few local areas of the nearshore habitat zone along the Minnesota and Michigan shorelines. Atmospheric deposition of contaminants lakewide has degraded all habitat zones to some degree.

The principal stresses to habitat found in each of the habitat types are as follows:

- **Offshore –** atmospheric deposition, discharges from Great Lakes vessels, and exotic species.
- **Nearshore –** atmospheric deposition, dumping or discharges from vessels, industrial effluents, exotic species, over-exploitation, and mining.
- **Embayment –** atmospheric deposition, industrial effluents, dumping or discharges from vessels, exotic species, over-exploitation, loss of wetlands, land-use practices, urban development, sedimentation, shoreline development, and petroleum emissions and spills.
- **Tributary –** hydroelectric facilities, barrier dams, water crossings, loss of wetlands, land-use practices, exotic species, timber harvesting, mining, agricultural practices, urban development, industrial effluents, and sedimentation.
- **Inland Lakes –** Shoreline development, timber harvest, agriculture, contamination through septic systems or runoff, mining, atmospheric deposition, urban development, sedimentation, industrial effluents, loss of wetlands, and hydroelectric dams.

Stresses to the physical habitat affect the structure, function, and composition of the biological community. In addition to the above stresses, over-exploitation has had a significant impact on Lake Superior fish communities. The effects of some stresses on the aquatic community are easy to recognize. Overfishing is partly responsible for the decline of deepwater ciscoes (Lawrie and Rahrer 1973), brook trout (Newman and Dubois 1997), lake sturgeon (Slade and Auer 1997), walleye (Hoff 1996), lake trout (Hansen and others 1995a), and lake herring populations (Selgeby 1982) in Lake Superior from the late-1800s to the mid-1900s. Also during the same time period hydroelectric development and artificial barriers on tributaries, sedimentation of tributaries due to poor logging and land use practices, and physical destruction of stream channels contributed to the decrease in brook trout, walleye, lake sturgeon, and lake trout numbers (Lawrie and Rahrer 1973, Slade and Auer 1997, Hoff 1996, Newman and Dubois 1997). Predation by exotic sea lampreys contributed to the collapse of lake trout and whitefish populations in Lake Superior from the 1940s through the 1960s (Jensen 1976, Pycha 1980, Smith and Tibbles 1980, Coble and others 1990, Hansen and others 1995a). Logging, road crossings, and beaver and artificial dams are currently causing loss of spawning and nursery habitat in tributaries due to sedimentation and unfavorable changes in the thermal habitat. Walleye populations in Lake Superior are affected by high mercury levels, paper mill effluent, and habitat loss (Schram and others 1991).

All of the stresses described above can and are being managed in some manner or another. The effectiveness and appropriateness of these management actions may be debateable. Inventory, monitoring, and pre- and post-assessment are required to adequately evaluate whether management actions are reducing these stresses (N. Ward 2004). Examples of how several stresses are being managed are described below.

Overfishing is currently being addressed through fishery management regulations developed separately or jointly by state, provincial, and tribal agencies (Legault and others 1978, Ebener 1997, Brown and others 1999). Overfishing is currently not a pervasive problem on Lake Superior and occurs only in isolated areas on a few fish species, such as lake trout in Whitefish Bay and eastern Ontario waters where effective regulatory mechanisms have yet to be negotiated for the native fishery.

During re-licensing of several hydroelectric facilities on U.S. tributaries through the Federal Energy Regulatory Commission (FERC) agencies have had some success changing water power management from peak operations to run-of-the-river flows which more closely mimic natural conditions and improve conditions for aquatic life and fish reproduction. Options and capabilities for such biota-friendly flow management are often not available or more difficult at older or outdated facilities. More stable flow regimes implemented on the Nipigon River in the 1990s have helped increase reproduction of brook trout. However, until recently, hydropower facilities in Canada were not bound by the same criteria as FERC and flow management occasionally did not take fishery or aquatic community considerations into account. A recent initiative, Water Management Planning, is intended to plan sustainable solutions for water resources. Feasibility studies for construction additional hydropower facilities on Ontario tributaries is currently underway.

Present day logging practices are regulated to protect aquatic life. Best management logging and forestry practices, if properly implemented and enforced, are much less stressful to aquatic life than historic methods. However, roads that cross streams often associated with logging operations may increase erosion and sedimentation if improperly constructed and maintained. Likewise, improperly placed or constructed culverts may impede fish passage permanently or seasonally. In the U.S., there are many poorly designed roads or improperly placed culverts that increase erosion and limit fish movement. In Canada, Crown land, which is the majority of the watershed, is strictly monitored for erosion and culvert placement.

Sea lamprey populations have been successfully suppressed throughout most of Lake Superior because of integrated control using chemicals, low head barrier dams, and traps. While the use of lampricides has contributed substantially to the restoration of lake trout and whitefish in Lake Superior, a few fish and aquatic organisms can be negatively affected by their use. Barriers, established to limit sea lamprey access to upstream spawning habitat limit movement of non-jumping fish that would otherwise have access to upstream reaches.

Other stresses to the aquatic community of Lake Superior are more difficult to recognize and manage. Chemical contaminants in fish flesh have apparently not limited the ability of Lake Superior fish to reproduce, although absence or lower concentrations of chemical contaminants could improve reproductive success. Some chemicals deposited in Lake Superior through atmospheric deposition originate outside of the basin (even outside North America), making it very difficult to address management of these chemicals. Chlordane originates entirely outside of the Lake Superior basin, yet the chemical is in sufficient quantity in siscowet trout from Lake Superior that consumption advisories have been issued by the state of Michigan. Michigan closed its state-licensed commercial fishery for siscowets in the early 1990s due to chlordane contamination.

## 6.1 Offshore Habitats

Offshore areas are less heavily impacted by habitat destruction than embayment, tributary stream, and inland lake habitat. The offshore habitat types of Lake Superior are probably in sufficient quantity and quality to allow achievement of fish community and environmental objectives.

## 6.2 Nearshore Habitats

Like offshore areas, nearshore areas are largely intact in terms of physical habitat. Introduced species have perhaps their greatest impacts on nearshore habitats. Over-fishing has been a problem in this area, and its effects are discussed in a subsequent section.

## 6.3 Embayments

While less extensive than in other Great Lakes, pollution and nutrient loading have severely degraded some embayments on Lake Superior.

Pollutants in Lake Superior originate from a variety of sources, including point sources, nonpoint sources, and tributary discharge. Point sources are those originating at an identifiable point, such as industrial effluent, waste dumping, and spills (Table 24). Nonpoint sources are more diffuse and may originate from outside the Lake Superior basin. Atmospheric deposition in the form of contaminated rain, snow or dust is a major source of some pollutants. Others include agricultural and urban surface runoff and release of pollutants from contaminated sediments. Tributary discharge refers to pollutants entering the lake through tributary streams transported from elsewhere in the watershed, although ultimately these pollutants originated from point or nonpoint sources.

Embayments historically used as log storage areas altered or destroyed fish habitat and have in recent years received a degree of interest for submerged log salvage. These operations cause concern for resuspension of contaminated sediments and further alteration of fish habitat structure. The latter may have positive or negative outcomes (N. Ward 2004).

**Table 24. Point sources of pollutants in the Lake Superior watershed (LSBP 1995).**

| | Water Sources | Air Sources | Dumps |
|---|---|---|---|
| **Ontario** | 20 | 27 | 190 |
| **Michigan** | 36 | 14 | na |
| **Minnesota** | 72 | 216 | 40 |
| **Wisconsin** | 40 | 5 | 105 |
| **Total** | 168 | 262 | 145 |

Nutrient loading is increased input of plant nutrients, such as phosphorus. While these nutrients are not harmful at normal levels, excessive levels can have negative effects. Agricultural and urban runoff, sewage treatment plants, and faulty septic systems are sources of nutrients.

Pollutants and nutrient loading can result in loss of habitat. In addition to toxic effects, water pollution can act as a barrier to migratory fish. Point sources also have local effects on aquatic life through thermal pollution, biochemical oxygen demand, turbidity, and bacterial contamination.

Nutrient loading can cause shifts in wetland vegetation. By encouraging species tolerant of high fertility (such as cattails), nutrient enrichment can cause reduced diversity of plant communities and loss of rare species (Maynard and Wilcox 1997). Enhanced growth of algae and submergent plants, can cause oxygen depletion as the plants die and decompose.

Loss of fish and wildlife habitat due to pollution and nutrient enrichment is a local problem on Lake Superior. Habitat loss due to contamination has been identified at six of the seven Areas of Concern (AOCs) in the lake basin. These sites are typically at bays and estuaries, among the richest and most diverse habitats on the lake, and the consequences extend throughout the lake. A substantial amount of habitat destruction has taken place in embayment habitat. Lake Superior AOCs in the embayment habitat are located in Nipigon Bay, Jackfish Bay, Thunder Bay, Peninsula Harbour, Torch Lake, and the St. Louis River.

Nipigon Bay is the most northerly area of Lake Superior and receives most of its drainage from a watershed underlain by the Canadian Shield. Environmental concerns in Nipigon Bay center around water quality issues, degraded fish populations, and impaired natural watercourses. In 1995, the Nipigon AOC completed remedial strategies for ecosystem restoration, most of which have been implemented. Actions taken include reducing water level fluctuations, completion of secondary treatment at a paper mill, and cleanup and rehabilitation of nearshore and tributary habitat.

The Jackfish Bay AOC is located on the north shore of Lake Superior, approximately 250 km northeast of Thunder Bay, ON. The AOC consists of a 14 km stretch of Blackbird Creek between the Kimberly-Clark pulp mill and Jackfish Bay including Lake ‘A’, Moberly Lake, and Jackfish Bay. The town of Terrace Bay is the closest community west of the AOC. Jackfish Bay and Blackbird Creek have been impacted by effluent from the pulp and paper industry, resulting in contaminated sediments and degradation of fish and wildlife habitat. Process changes and the installation of secondary treatment at the Kimberly-Clark mill have substantially improved effluent quality, resulting in environmental improvements. It is expected that previously deposited organic sediments will degrade over time and the Remedial Action Plan (RAP) recommends natural recovery as the preferred option in the 1998 Stage 2 report on remedial strategies for ecosystem restoration. Natural rehabilitation of aquatic communities will continue to be monitored in the Jackfish AOC. A reference on this AOC is the Jackfish Bay Remedial Action Plan, Stage 2: Remedial Strategies for Ecosystem Restoration (1998).

The Thunder Bay AOC fans out from the city of Thunder Bay, extending for about 28 km along the shoreline and up to 9 km offshore. The AOC occupies the southwest corner of Thunder Bay proper. The greatest impacts on the area have resulted from industrial and urban development along the Thunder Bay waterfront and adjoining tributaries. Dredging, waste disposal, channelization, and the release of a number of pollutants have eliminated a significant portion of quality habitat along the waterfront. The consequences have included a loss of species abundance and diversity, reduced recreational opportunities, and a decline in the aesthetic value of the area. Impacts resulting from the release of process effluent into the Kaministiquia River and Lake Superior have been significantly reduced in recent years because of improved effluent treatment and changes in industrial processes; however, the ecosystem remains impaired in a number of ways. Some areas support benthic communities reflective of organic enrichment, contaminated sediments, and habitat loss from dredging activities. Dredging restrictions are still in effect because of sediment contamination in the harbour, particularly health hazards for water based recreational activities.

Peninsula Harbour, located on the northeastern shore of Lake Superior approximately 290 km east of the city of Thunder Bay is the site of a pulp and paper mill. The AOC is roughly bounded by the watershed of the harbour and Pebble Beach, and extends outward approximately four kilometers from the Peninsula into Lake Superior. The area has problems associated with degraded fish and benthic communities and high levels of toxic contaminants in fish and bottom sediments from mill effluent. The preferred remediation option currently under consideration is to remove mercury contaminated sediments and isolate them in a confined disposal facility. Mercury levels in lake trout have stabilized at a mean value of 0.35 mg/kg from 1984 to 1996 and are not significantly different from lake trout sampled at other locations along the north shore of Lake Superior.

The St. Louis River, the largest U.S. tributary to Lake Superior, drains 9,412 $km^2$, entering the southwestern corner of the lake between Duluth, Minnesota and Superior, Wisconsin. As it approaches Duluth and Superior, the river takes on the characteristics of a nearly 4,900 ha freshwater estuary. The upper estuary has some wilderness-like areas, while the lower estuary is characterized by urban development, an industrial harbour, and a major port. The lower estuary includes St. Louis Bay, Superior Bay, Allouez Bay, Kimball's Bay, Pokegama Bay, Howards Bay, and the lower Nemadji River.

The AOC is located in the lower 63 km of river. The RAP process determined that nine of 14 identified beneficial uses were impaired. Some impairments were associated with the physical loss and degradation of habitat, with the estuary having lost an estimated 3,100 (of nearly 4,900) ha of wetland and open water habitat since settlement. Other problems were related more to pollution and toxicity. For years, the river smelled bad from industrial discharges. That changed in 1978, when the Western Lake Superior Sanitary District (WLSSD) wastewater treatment plant began operation. Nevertheless, pollution continues to come from sources such as contaminated sediments, abandoned hazardous waste sites, poorly designed or leaky landfills, airborne deposition, industrial discharges, chemical spills, improperly sewered wastes, and surface runoff. Both Minnesota and Wisconsin issue fish consumption advisories for the St. Louis River. These are based on mercury and polychlorinated biphenyls (PCBs).

The Torch Lake AOC is located on the Keweenaw Peninsula, which roughly divides Lake Superior's southern shore into its eastern and western halves. The AOC spans the lower portion of the peninsula, encompasing the Keweenaw Waterway (North Entry Harbor of Refuge, Portage Lake, and Torch Lake), its watershed, portions of two other adjacent watersheds (Trout River and the Eagle River Complex), and several kilometers of its western Lake Superior shoreline – a total of approximately 953 $km^2$ all contained within the northern half of Houghton County, Michigan. The AOC boundaries include all of the Superfund sites and associated watersheds.

The unifying problem shared by these areas is widely scattered deposits of copper mining waste materials accumulated over more than 100 years of mining, milling, smelting, and recovery activities. These wastes occur both on the uplands and in the lake and occur in four forms: poor rock piles, slag and slag enriched sediments, stamp sands, and abandoned mine slurry settling ponds. The associated contaminants include copper, mercury, arsenic, lead, chromium, and other heavy metals. The beneficial use impairments inferred from the 1987 RAP included restrictions on fish and wildlife consumption, fish tumors or other deformities, contaminated sediments, loss of fish and wildlife habitat, restrictions on drinking water consumption, restrictions on dredging and shipping activities, and degradation of benthos.

### 6.4 Tributary Streams

Tributary streams are the most vulnerable component of Lake Superior's aquatic ecosystem. Due to the connections between terrestrial and aquatic systems, impacts on streams may extend to the entire lake. Streams are critical habitat for migratory fish and other species and stream habitat quantity and quality are sensitive to changes at local and watershed scales.

*Minnesota*

The Minnesota Pollution Control Agency (MPCA) assesses selected streams for Aquatic Life Use Support, "to determine if waters are of a quality to support the aquatic life that would be found in the stream under the most natural conditions" (MPCA 1997). The assessment is based on water chemistry data, biological and habitat information and a survey of local resource managers.

Water quality in Lake Superior tributary streams is typically quite good (Table 25) (MPCA 1997). "Threatened" streams do not currently show signs of degradation, but are likely to show signs of degradation due to future changes in the watershed. Turbidity, metals, and habitat alteration are the most common indicators of impairment. Forest removal, construction, urban and rural development, and landfill leachate are suspected source of pollution (Figure 68).

Thirty-nine kilometers of the Nemadji River has been assessed as "not supporting" due to turbidity and habitat alteration from a hydroelectric dam. Twelve kilometers of the Cloquet River has been assessed as not supporting due to metals from nonpoint sources.

The lower St Louis River is polluted from industrial effluent, stormwater runoff, and other sources. This area, covered by a Remedial Action Plan, has shown improvements in water quality. Contaminated sediments, stormwater runoff and leaky landfills continue to pollute the river. In addition to water quality impairments, human activity has altered habitat in more than 58 percent of the St. Louis River Estuary through dredging, shoreline modification, and filling of wetlands.

**Table 25. Minnesota stream assessments for aquatic life (MPCA 1996).**

| Watershed | Length Assessed (km) | Fully Supporting (%) | Threatened (%) | Partially Supporting (%) | Not Supporting (%) | Not Attainable (%) |
|---|---|---|---|---|---|---|
| Lake Superior – North | 251 | 23% | 77% | - | - | - |
| Lake Superior – South | 182 | 3% | 41% | 23% | 34% | - |
| St. Louis River | 432 | - | 23% | 3% | 72% | 3% |
| Cloquet River | 12 | - | - | - | 100% | - |
| Nemadji River | 39 | - | - | - | 100% | - |

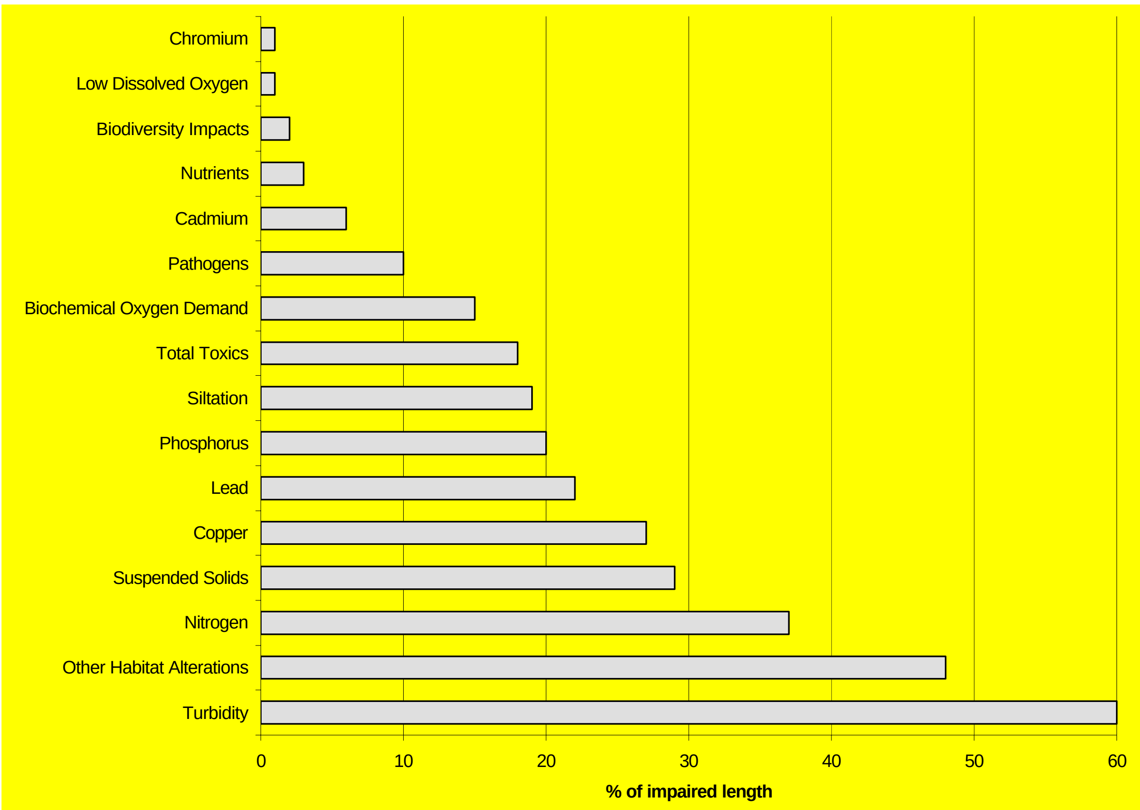


**Figure 68. Causes of habitat impairment in Minnesota tributary streams.**

The St. Louis River watershed has five hydroelectric dams, but the 1930 Shipstead-Nolan Act of Congress prohibits further construction of dams or other water-fluctuation structures in St. Louis, Lake, and Cook counties Minnesota (MPCA 1997). The small watersheds limit the feasibilty of hydroelectric dams on most streams.

*Wisconsin*

Most tributaries were impacted by a complete forest cut-over in the middle 1800s, extensive fires, and the cumulative watershed damage caused by human activities (e.g., agriculture). Resulting higher peak flood flows increased channel water velocities, which displaced the remaining woody cover, eroded stream banks, straightened channels, and ultimately sorted bottom substrates. Although watershed health has generally improved, altered runoff patterns, damage to channel structure, and redistribution of substrate components caused during this time period remain. Management actions include land acquisition, beaver control, stream habitat improvement in critical areas, watershed evaluations, wetland and riparian restoration projects, and fishery regulations.

Table 26 summarizes the habitat conditions of many of Wisconsin's Lake Superior tributaries by watershed. The relatively large amount of Threatened habitat is mostly due to potential impacts of exotic species or land use activities within the watershed, even where there are no observed effects.

**Table 26. Wisconsin Lake Superior tributaries (from Turville-Heitz 1999). "Thr" = Threatened, "Unk" = Unknown.**

| | **Watershed** | **No. Streams** | **Total Stream Length (mi)** | Watershed Area **($mi^2$)** | **Supporting Potential Use (%)** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Full** | **Part** | **Not** | **Thr** | **Unk *** |
| LS01 | St. Louis and Nemadji rivers | 78 | 284 | 159 | 7 | 12 | 3 | 22 | 78 |
| LS02 | Black and Upper Nemadji rivers | 52 | 180 | 126 | 12 | - | - | 45 | 88 |
| LS03 | Amnicon and Middle rivers | 107 | 384 | 289 | 23 | - | - | - | 77 |
| LS04 | Bois Brule | 72 | 165 | 195 | 27 | 2 | - | 49 | 71 |
| LS05 | Iron River | 36 | 147 | 218 | 9 | - | - | 79 | 91 |
| LS06 | Bayfield Peninsula Northwest | 56 | 172 | 236 | 1 | - | - | 52 | 99 |
| LS07 | Bayfield Peninsula Southeast | 56 | 142 | 302 | 3 | 2 | 4 | 56 | 91 |
| LS08 | Fish Creek | 35 | 115 | 157 | 9 | 23 | 3 | 36 | 66 |
| LS09 | Lower Bad River | 18 | 129 | 124 | - | - | - | 95 | 100 |
| LS10 | White River | 67 | 271 | 360 | tr | tr | - | 75 | 99 |
| LS11 | Potato River | 46 | 160 | 140 | 2 | - | - | 47 | 98 |
| LS12 | Marengo River | 85 | 261 | 218 | - | - | - | 47 | 100 |
| LS13 | Tyler Forks | 46 | 124 | 79 | - | - | - | 35 | 100 |
| LS14 | Upper Bad River | 62 | 194 | 135 | - | - | - | 28 | 100 |
| LS15 | Montreal River | 80 | 264 | 226 | 19 | - | - | 62 | 81 |
| LS16 | Presque Isle River | 53 | 91 | 108 | | | | | |
| | **Total** | **949** | **3083** | **3072** | | | | | |

** stream can be both "Threatened" and "Unknown" if potential impacts have been identified*

The St. Louis and Nemadji watersheds are discussed in the Minnesota section above. Tributaries within the Wisconsin part of the watershed with impaired water quality include Crawford Creek, an unnamed Drainage to Crawford Creek, and Newton Creek. Impairments are due to sediment contamination, point sources of pollution, aquatic toxicity, and other contaminants.

Habitat in the Fish Creek Watershed has been impacted by pathogens from sewage treatment plant and stormwater runoff from the City of Ashland. Other concerns are habitat loss, sedimentation and turbidity from unfenced pastureland, barnyard runoff, and logging (Turville-Heitz 1999).

Stream habitat in the Montreal River watershed has been altered by hydrologic modification. There are only six hydroelectric dams in the Wisconsin basin, three of which are in the Montreal River watershed (the others are in the White, Iron, and St. Louis watersheds). In general, Wisconsin's watersheds are small and provide inconsistent flows. Five dams have been removed or damaged and not replaced. They are the Upson Dam and Iron Lake Dam on Iron River, the Marengo Dam on the Marengo River, the Mellen Waterworks on Carrie Creek, and a dam at Red Granite Falls on the Bad River (Turville-Heitz 1999).

One of the major sources of turbidity and sedimentation in Wisconsin tributaries is related to the unstable red clay soils of the Lake Superior Clay Plain. (See text box below for a description of the Red Clay Plain.) For in-depth information on Wisconsin's Lake Superior Clay Plain, see the 1998 publication "Erosion and Sedimentation in the Nemadji River basin" (NRCS, 1998). Although there are some differences in the landscape character of the Nemadji River basin and part of the clay plain to the east, this publication's conclusions and strategies for management are very applicable. The Nemadji River basin study serves as an excellent template for remedial management of the hydrologic conditions in the clay plain in general. Any future work to improve hydrologic conditions in the clay plain should begin with a review of this document.

**Changes in Pre-European Forest Cover Type on the Red Clay Plain and Stream Erosion**

Between the late-1800s and early-1900s, the Lake Superior Clay Plain underwent substantial disturbance in association with European settlement. Effects of this disturbance still impact hydrologic processes in the clay plain today. Analyzing what disturbance forces took place, how they changed the forest landscape, and the impacts these had on forest hydrology can be helpful to planners who are applying management practices to improve stream habitat.

Although the disturbance period was initiated by timber harvest, primarily of white pine, fire and artificial drainage of upland surface water associated with agriculture and road development produced some of the greatest changes to the landscape.

Geologically speaking this landscape is relatively young. The last glacial deposit occurred between 9,500 to 11,000 years before present (BP), when receding glacial ice retreated into the Superior basin and then later advanced. The advance deposited a thin layer of clay till, Miller Creek Formation, over a deeper previously deposited coarser textured till, Copper Falls Formation (Clayton, 1984).

Young glacial landscapes generally have rapid erosion rates with geologic aging. Compounding this fact is the manner that the deposits occur. The clay till has fine clay texture and is strongly bonded. Beneath the clay lies coarse textured till, loosely bonded, and unconsolidated. Major streams have long ago cut through the clay till into the unconsolidated till. Water flowing in these streams, particularly during flooding, has been cutting away the loosely bonded till well before pre-European settlement. Streams eroding loosely aggregated channel sides are not uncommon, however the existence of the surface red clay cap has a two-punch effect in producing high erosion rates along these clay plain streams.

- Strongly bonded clay caps above a bend in a stream channel, where the loose material is being eroded, slow the stabilization process of the slope above the channel. This results in long, steep, mass-wasting slopes immediate to the stream channel.
- Water infiltration rates in uplands covered by red clay till are very slow. Runoff is very rapid during rainfall and snowmelt events, creating frequent flooding in streams. These floods produce high-energy water flows that frequently erode stream channels, compounding the problem of mass waste erosion on adjacent slopes.

Undoubtedly some of this rapid erosion occurred prior to European settlement, but there were factors in the forested landscape that buffered runoff and erosion in streams. After European settlement and the disturbance that came with it, much of this buffering was dismantled, resulting in increased erosion rates.

*Forest Cover*

Keeping in mind this characterization of the surficial geology and the effects it has on stream erosion processes, the following is a simplified description of what pre-European forest conditions were like in the clay plain. This description also includes changes that occurred in forest cover, what forest cover conditions are today, and the impacts these changes have had on forest hydrology in the clay plain.

Based on survey information (Finley 1976) the pre-European forest cover on the clay plain was predominantly coniferous. To the east of the Douglas/Bayfield county line and continuing to the eastern extent of the clay plain there was an increase of northern hardwood species associated with this coniferous forest. White pine was the predominant overstory species in number and stature. White spruce and balsam fir created a dense sub-overstory canopy beneath the white pine in the western clay plain. To the east sugar maple, yellow birch, and hemlock were mixed with the fir and spruce. White birch and aspen were common associates throughout the clay plain. Their presence was associated with natural disturbance in the forest.

At a smaller scale of forest cover, in ravines vs. uplands, there were some interesting differences in forest composition. More mature forest conditions, including a predominance of larger diameter white pine associated with dense spruce-fir and cedar trees, occurred in ravines. Uplands had a more even size class distribution of white pine. Also white birch and aspen were more common in the upland forest (Koch 1979). One conclusion to be drawn from this difference in cover type is that natural disturbance was more common in the uplands, and ravines provided protection from disturbance. Later succession forest conditions in ravines likely had well-developed vertical structure of live standing and dead downed woody debris.

Forest floors associated with these conifer forest cover types accumulated organic matter and a fairly thick duff surface soil layer existed. This duff layer along with large volumes of downed woody debris was capable of retaining large volumes of water that would otherwise runoff the clay textured surface soil.

Although natural disturbance information is not well documented for the pre-European clay plain forest, the primary disturbance forces were likely wind and fire. Wind storms could easily blow down areas of shallow rooted fir and spruce in the uplands. Ravines were somewhat protected from the wind. The downed conifer trees provided fuel for occasional fires, most likely started by lightning. These fires were seldom severe, and with fairly high moisture conditions in the standing forest, burned through the blow down and then were extinguished by the moist conditions in the adjacent standing forest. Again, ravines were very moist and resistant to fire disturbance.

When Europeans arrived they found a dense forest cover, particularly along waterways. Conditions within this dense forest cover inhibited human passage. To them, the forest was a hindrance to be overcome.

Initially harvesting the white pine was the focus. Because roads were few and poor at best, waterways were the thoroughfare to move logs to sawmills. Waterways were dammed and large volumes of logs were floated down stream to Lake Superior. The energy and force resulting from this activity drastically effected erosion along waterways. Also, log drives removed most of the large natural woody debris that had been deposited over hundreds of years. Removal of the woody debris deteriorated the structural features of the streams, reducing habitat for organisms and negatively impacting their hydrological character. Evidence of damage caused by log drives is still visible today.

Harvesting was soon followed by the desire to clear land for farming. The relatively stone-free clay soil offered great opportunity for farming. Remaining forest cover in areas to be farmed was removed. This land clearing usually involved burning of the unwanted forest debris.

While it is often thought that the harvesting of white pine is what left the clay plain landscape so barren, it was actually fire that so completely opened up the landscape. Most of these fires were man caused, likely associated with land clearing operations for agriculture. With already large volumes of conifer slash left on the forest from harvesting and land clearing, fires were much larger and more intense than natural fires that occurred during pre-European settlement times.

Where land was not farmed, burned over areas offered great opportunity for pioneer species like aspen and paper birch to become established. Conifers did remain on the landscape but due to their flammability much of the cover type was consumed by fire. Most of the remaining conifer cover was likely confined to the ravines.

Harvesting, land clearing for agriculture, and fire were the main three man-caused disturbances that removed almost all forest cover indicative of pre-European settlement. Of these disturbances, fire produced the greatest change. Log drives down streams scarred channels, initiating large erosion areas still evident today. Upland retention of rainfall and snowmelt water runoff was substantially reduced. Energy produced by increased runoff flowing through the badly scarred waterways produced high stream erosion rates.

*Artificial Drainage*
One additional man-caused disturbance that went beyond changing forest cover was changing the shape of the landscape surface itself. Artificial drainage associated with agricultural fields and road infrastructure moves rain and snow-melt water, already rapidly running off the exposed clay soil, at an even faster rate off the uplands. This expedited delivery to streams creates even greater energy available to erode stream banks and adjacent slopes. While impacts from disturbance to the pre-European forest and stabilization of stream riparian areas is slowly occurring with time through natural forest succession, artificial drainage is maintained, and likely has a great impact on modern day flooding of south shore streams.

*Michigan*
Table 27 lists the 12 streams in the Michigan portion of the Lake Superior basin that are not meeting designated uses.

Elevated copper concentrations from copper ore tailings are problems for a number of streams (i.e., Hammell Creek, Kearsarge Creek, Scales Creek, and Traprock River) in Houghton County. Habitat loss to sedimentation has also been a problem in this watershed. The west and east branches of the Eagle River also have high levels of copper.

**Table 27. Michigan non-attainment streams in the Lake Superior basin (Michigan Dept. of Environmental Quality 1998).**

| Stream | Length (km) | Problem | Source |
|---|---|---|---|
| Adventure Creek | 1 | Macroinvertebrate community rated poor | Obstruction of stream channel resulted in severe erosion and sedimentation |
| Mineral River | 1 | Macroinvertebrate community rated poor; total dissolved solids | |
| Bluff Creek | 21 | Fish community rated poor | Sedimentation and bank erosion related to extreme flow fluctuations |
| Kearsarge Creek | 6 | Copper; macroinvertebrate community rated poor | Copper ore tailings |
| Scales Creek | 418 | Copper; macroinvertebrate community rated poor | Copper ore tailings |
| St. Louis Creek | 1 | CSO, bacterial slimes, pathogens | |
| Hammell Creek-Osceola Mine Discharge | 1 | Mercury and copper | Copper ore tailings |
| Trap Rock River | 10 | Copper | Copper ore tailings |
| Eagle River, E. Br. | 10 | Copper | |
| Eagle River, W. Br. | 4 | Copper; macroinvertebrate | |

**Table 27. Michigan non-attainment streams in the Lake Superior basin (Michigan Dept. of Environmental Quality 1998).**

| Stream | Length (km) | Problem | Source |
|---|---|---|---|
| | | community rated poor | |
| Carp River | 47 | Mercury | |
| Whetstone Creek | 3 | Periodic fish kills | Urban stormwater runoff, severe sedimentation and discharges of suspected toxic substances |
| Carp Creek | 18 | Mercury | |

A standardized stream assessment protocol has been developed by the Michigan Department of Natural Resources in order to evaluate and compare stream habitats and the status of fish populations in the streams. Using this method, efforts are ongoing to establish a database of baseline habitat and population information on Lake Superior tributary streams. The standardized assessment protocol will facilitate monitoring of the effects of management actions.

*Ontario*

Hydroelectric development has impacted a number of Lake Superior tributary watersheds including the Aguasabon, Kaministiquia, Michipicoten, Montreal, and Nipigon Rivers. Other major facilities are located on the Black River and Kagiano River. Many waterpower facilities in Ontario have Operational Plans in place with constraints on water levels and flows that voluntarily recognize the multiple uses of the river.

For example, a voluntary water management agreement was developed in the 1990s for the Nipigon watershed that balances the needs of all stakeholders on the Nipigon River and Lake Nipigon with the protection of fish habitat. This agreement was brought about in part after a landslide occurred on the Nipigon River, which was partly attributed to water level fluctuations caused by a hydroelectric dam. Heavy siltation caused by the slide damaged fish habitat and forced the Town of Nipigon to relocate its water intake (Atria Engineering Hydraulics Inc. 1993). Rapid draw down for hydroelectric generation contributed to the initial slide on the riverbank, which was followed by failure of the land behind the bank (Atria Engineering Hydraulics 1993). Other factors were the naturally susceptible soils, high soil moisture due to sudden thaw, natural erosion by river water, removal of tree cover by logging and disruption of drainage patterns by a pipeline right of way. Smaller slides are common on the river. Sudden draw downs by the power company on the Nipigon River have also resulted in the stranding of spawning salmon (R. Hartley, Nipigon District OMNR, personal communication).

Recent years however have seen a restructuring of Ontario's electricity market. The OMNR, in response to amendments to the Lakes and Rivers Improvement Act and its New Business Relationship with the Power Industry, has introduced Water Management Planning to Ontario. Water Management Planning is a consultative process that brings together the OMNR, waterpower producers such as Ontario Power Generation (OPG) and local stakeholders to plan sustainable solutions for water resources. The final Water Management Plan (WMP) for a river system will include an Operational Plan for each individual waterpower facility that addresses water levels and flows. These Operational Plans will be the enforceable components of the WMP in relation to the operation of each waterpower facility.

Ontario Hydro identified ten undeveloped major sites (>10 megawatt potential) within the basin, including the Pic, University and White rivers (Cheng 1987). An additional 28 sites with 2.0 to 10.0 average megawatt potential have been identified on the Agawa, Aguasabon, Black Sturgeon, Magpie, University, Pukaskwa, Pic, Steel, Namewaminikan, Kopka, Gull, Kaministiquia, Pigeon, and Ogoki rivers (Cheng 1987).

Accessible stream length has decreased due to construction of dams, lamprey barriers, and other artificial structures. Estimates of the decrease in available habitat are not available. Power dams are the lowest barrier on some significant tributaries, including the Black, Michipicoten and Montreal rivers, but the decrease in accessible stream is not easily determined because dams sometimes are constructed at natural barriers (falls or rapids) that may or may not have passed fish pre-construction.

Another potential impact of hydroelectric developments on the Lake Superior ecosystem is elevated levels of methylmercury associated with reservoirs.

Shoreline development has impacted fish habitat in tributaries in urban and rural areas such as Thunder Bay and Sault Ste. Marie, Ontario. More widespread stresses are associated with water crossings. Both the trans-Canada highway and railway are close to the north shore of Lake Superior and cross the majority of tributaries. Many of the crossings do not meet current standards and have resulted in barriers to migration of anadromous fish, habitat fragmentation, and severe erosion problems in some cases. Improvements to some of these crossings have been undertaken as opportunities have arisen. Tail-water controls have been used to improve fish passage at perched or inclined culverts. Flood conditions frequently cause washouts and replacement culverts are sized and installed to facilitate fish passage. Recently the OMNR and DFO have taken a proactive role in ensuring that natural channel design and ‘soft’ engineering approaches are used in the design of replacement water crossings. It is anticipated that this approach will reduce the frequency of washouts as well as facilitating fish passage.

The Ontario Ministry of the Environment (OME) monitors background levels of 37 streams to assess impacts of point source pollution. These sites include the mouths of some major tributaries. Seventeen Ontario streams have habitat impairments due to point source pollution, siltation, urban runoff and other causes (Table 28). Five of these streams (McVicar Creek, McIntyre River, Neebing River, Current River and Kaministiquia River) run through the City of Thunder Bay and receive urban runoff as well as industrial effluent. Four streams near the Hemlo gold fields are contaminated by mine waste (Cedar Creek, Fox Creek, Hayward Creek, Upper Black River). A 1992 report (OME 1992) noted some improvements in pulp mill effluent and urban sources, but there are continued problems, especially during low water levels. No current (post 1992) summary is available. A summary of selected stream parameters is presented in Addendum 6-E. OMNR has conducted surveys on 65 tributary streams (Addendum 6-C).

Fish habitat has also been degraded by historical logging practices, such as log drives, logging of banks and erosion from road crossings (Lawrie and Rahrer 1973). Logging, and associated road crossings, has taken place in all the major watersheds. In Ontario, application of habitat guidelines (OMNR 1988a, 1988b) has improved stream side logging practices, but landscape-level impacts of logging across the watershed are unknown. Ontario streams have a wide range of natural turbidity levels due to differences in soil types. This makes it difficult to distinguish the influence of natural erosion processes and artificial causes.

**Table 28. Ontario streams with habitat impairments (OME 1992, OMNR unpublished data).**

| Stream | Impairment | Source of Impairment | Receiving water |
|---|---|---|---|
| Agawa River | Channelization | Bridge construction | Lake Superior |
| Blackbird Creek | BOD, pH, coliform bacteria | Pulp and paper mill effluent | Lake Superior |
| Cedar Creek | Phosphorus, nitrogen, fecal coliform bacteria | Diffuse source – extractive industrial land | Black River, Pic River |
| Current River | Fecal coliform bacteria | Rural and urban runoff | Lake Superior |
| Deadhorse Creek | Siltation | | Lake Superior |
| East Davignon Creek | Siltation, pollution, low summer flow, BOD, high temperatures, | Urban runoff, industrial effluent | Lake Superior |
| Fox Creek | Sulphates, metals, pH | Diffuse source – extractive industrial land downstream from mine seepage | Black River, Pic River |
| Hayward Creek | Conductivity, chlorides, sulphates, metals, phosphorus, pH | Mine effluent | White River |
| Little Cypress R. | Erosion, low summer flows, High temps, barrier | Highway washout | Lake Superior |
| Little Pic River | Siltation | | Lake Superior |
| Lower Kaministiquia River | BOD, suspended solids, phosphorus, nitrogen, metals, fecal coliform bacteria | Industrial point sources, pulp and paper mill effluent, sewage treatment plant | Lake Superior |
| McIntyre River | Chlorides, conductivity, metals | Rural and urban runoff | Lake Superior |
| McVicar Creek | Alkalinity, chlorides, conductivity | Urban runoff | Lake Superior |
| Michipicoten River | Water fluctuations | Power dam | Lake Superior |
| Neebing River | Alkalinity, phosphorus, organic nitrogen, fecal coliform bacteria | Rural and urban runoff | Lake Superior |
| Rudder Creek | Alkalinity, BOD, chlorides, conductivity, nutrients, suspended solids, sulphates, fecal coliform bacteria | Municipal sewage | Pic River |
| Upper Black River | Sulphates, conductivity, ammonia | Diffuse source – extractive industrial land and point source, mining | Pic River |

A standardized stream assessment protocol for wadeable streams has been developed by the OMNR in order to evaluate and compare stream habitats and the status of fish populations in the streams. This methodology was developed for southern Ontario streams but is being used for Superior tributaries in the absence of a methodology specific for northern streams. Using this method, efforts are ongoing to establish a database of baseline habitat and population information on Lake Superior tributary streams to identify streams in need of harvest controls or habitat rehabilitation. Currently data are stored in the OMNR's Habprogs database (S. Greenwood, personal communication). In addition, the standardized assessment protocol will facilitate monitoring of the effects of such management actions.

## 6.5 Inland Lakes

The status of habitat in inland lakes in the Lake Superior basin is generally very good. Gross habitat impairment from point sources has occurred in only a few lakes. More subtle changes in lake habitat, such as eutrophication, sedimentation, and warming due to land use changes, are more difficult to detect and measure, as are the impacts of nonpoint source pollutants.

Shoreline development on inland lakes typically results in the loss of aquatic vegetation, which is important to the survival and reproduction of some fish species, such as yellow perch and northern pike. However, the direct, measurable effects of shoreline development are not as recognizable. Land use practices and urban development alter drainage patterns and increase surface water runoff, but the effects on the aquatic community are difficult to assess and understand.

*Minnesota*

Most of Minnesota's inland lakes are in very good condition. High quality pristine areas in the watershed include portions of the Boundary Waters Canoe Area, natural heritage lake trout lakes that are supported only by wild populations, state parks, and state and federal forests.

The Minnesota watershed, however, is in general experiencing increased stress from a variety of sources. The major stresses include logging, iron ore mining, increased construction of roadways, increased development of both riparian stream and lake shoreline areas, and increased exploitation on the fisheries resource. There are ongoing discussions with the timber industry on implementation of best management practices, specifically requiring increased protection of the riparian zone along streams, lakes, and wetlands. The Minnesota Division of Forestry is presently working on a new policy for timber harvest in the Lake Superior watershed. Iron ore mining is an important industry in northeast Minnesota and in general the industry has made efforts to improve water quality near mining sites, but there are still areas that need attention. With the renewed interest in experiencing "wilderness" and the changing demographics of our society there is a major development boom in Minnesota's portion of the Lake Superior watershed that includes expansion of roads, businesses, cabins/homes, and general shoreline development.

Lake trout, in the natural heritage lakes, and other native species are especially affected by the above stresses because of their need for undisturbed shoreline and native aquatic vegetation for natural reproduction.

There are five major hydroelectric dams on the St. Louis River system creating two of the largest impoundments in the basin: Island Reservoir and Whiteface Reservoir (MPCA 1996). These are headwater reservoirs that store water during the spring run off and release it to augment low flows at other times of the year. Other impoundments (Two Rivers Reservoir and Whitewater Reservoir) are used for mine processing water and recreation.

Water quality monitoring in Minnesota lakes is done by the Minnesota Pollution Control Agency. Emphasis has recently shifted away from point-source influenced lakes to volunteer monitoring (approximately 30 lakes in the basin – secchi depth, recreational suitability) and reference lake monitoring (water quality, land use in the watershed) (MPCA 1997).

Water quality is generally quite good (MPCA 1996). Thompson and Fond du Lac reservoirs have significantly contaminated sediments (MPCA 1996). Ninety-four percent of inland lakes tested (137/146) have fish consumption advisories due to mercury from atmospheric deposition (n = 133), PCB levels (n = 1) or both (n = 3) (MPCA 1996).

Minnesota, Michigan, and Wisconsin have volunteer lake monitoring programs (Lake Superior Binational Program 1998).

Lake trout, in the natural heritage lakes, and other native species are especially affected by the stressors cited above because of their need for undisturbed shoreline and native aquatic vegetation for natural reproduction. Many of the other stressorss in the watershed are being addressed through a variety of policy and regulatory changes. The Binational Program will provide an important tool to assist in implementing the required changes.

*Wisconsin*

Most lakes in the Wisconsin basin have basic, descriptive data. A document summarizing the status of inland lakes in the Lake Superior basin is in preparation (Turville-Heitz 1999). The soft water seepage lakes are most commonly found in the Wisconsin Lake Superior basin. These lakes are typically clear, slightly acid, and relatively infertile. The principal fishery resources pursued by anglers in the Wisconsin basin include muskellunge, northern pike, walleye, largemouth and smallmouth bass, and panfish.

Lakes within the Wisconsin Lake Superior basin are continually being stressed as an increasing number of people purchase shoreline properties. Shoreline development has resulted in a reduction of aquatic habitat and in some cases a reduction in water quality. Management actions to improve water quality include acquisition of remaining undeveloped shoreline near fish spawning areas and wildlife marshes, and improvement in sewage treatment facilities.

Twenty six lakes in Wisconsin are listed as having “Impaired Waters” (Turville-Heitz 1999), all related to mercury levels in fish (Table 29). Five Wisconsin lakes in the basin were identified as priority sites from a biodiversity perspective (Epstein and others 1997). These are Anodanta Lake, Bad River Slough, Hoodoo Lake, Rush Lake, and Smith Lake. Most of these lakes have rich invertebrate communities or support rare invertebrate species.

**Table 29. Wisconsin lakes in the Lake Superior basin with impaired waters (Turville-Heitz 1999).**

| **Lake** | **Impairment** |
|---|---|
| Amnicon Lake | Mercury/fish advisory/atmospheric deposition |
| Annabelle Lake | Mercury/fish advisory/atmospheric deposition |
| Bear Lake | Mercury/fish advisory/atmospheric deposition |
| Bladder Lake | Mercury/fish advisory/atmospheric deposition |
| Cisco Lake | Mercury/fish advisory/atmospheric deposition |
| Diamond Lake | Mercury/fish advisory/atmospheric deposition |
| English Lake | Mercury/fish advisory/atmospheric deposition |
| Forest Lake | Mercury/fish advisory/atmospheric deposition |
| Galilee Lake | Mercury/fish advisory/atmospheric deposition |

**Table 29. Wisconsin lakes in the Lake Superior basin with impaired waters (Turville-Heitz 1999).**

| Lake | Impairment |
|---|---|
| Gile Flowage | Mercury/fish advisory/atmospheric deposition |
| Island Lake | Mercury/fish advisory/atmospheric deposition |
| Long Lake | Mercury/fish advisory/atmospheric deposition |
| Long Lake | Mercury/fish advisory/atmospheric deposition |
| Lynx Lake | Mercury/fish advisory/atmospheric deposition |
| Mineral Lake | Mercury/fish advisory/atmospheric deposition |
| Oxbow Lake | Mercury/fish advisory/atmospheric deposition |
| Palmer Lake | Mercury/fish advisory/atmospheric deposition |
| Perch Lake | Mercury/fish advisory/atmospheric deposition |
| Pike Chain of Lakes | Mercury/fish advisory/atmospheric deposition |
| Potter Lake | Mercury/fish advisory/atmospheric deposition |
| Siskiwit Lake | Mercury/fish advisory/atmospheric deposition |
| Spider Lake | Mercury/fish advisory/atmospheric deposition |
| Spillerberg Lake | Mercury/fish advisory/atmospheric deposition |
| Tahkodah Lake | Mercury/fish advisory/atmospheric deposition |
| Three Lake | Mercury/fish advisory/atmospheric deposition |
| West Twin Lake | Mercury/fish advisory/atmospheric deposition |

*Michigan*

In general, Michigan inland lakes within the Lake Superior basin receive minimal fishing pressure because of the sparse human population in their region and their remote locations. A few lakes are storage reservoirs used for hydroelectric power; associated lake level fluctuations negatively impact those fisheries. These lakes include: Gogebic, Prickett, Bond Falls, Victoria, Silver, McClure, and Autrain.

The Michigan Department of Environmental Quality and the Great Lakes Indian Fish and Wildlife Commission have instituted a general mercury advisory for fish existing within all lakes, stipulating that smaller and leaner fish should be eaten. Specific advisories exist for the following lakes: Siskiwit, Gogebic, Bond Falls Flowage, Perch, Langford, Clearwater, Lindsley, Marion, Torch, Portage, Parent, Lake Independence, Cisco Chain, Deer, and Autrain. All of the above lakes have fish advisories for mercury, while Portage, Siskiwit, and Torch lakes also have advisories related to PCB contamination.

Ten lakes in the basin are listed as "non-attainment," mostly due to fish consumption advisories for mercury (Table 30). Currently, there are two AOCs identified by the International Joint Commission within Michigan's Lake Superior basin: Torch Lake in Houghton County and Deer Lake in Marquette County. Torch Lake was the receiving water for copper ore tailings and other contaminants. Sediments have high levels of arsenic, copper, and other metals and benthic invertebrate communities are impaired (MDEQ 1998). In the Torch Lake AOC, the impaired beneficial uses identified include restrictions on fish and wildlife consumption, fish tumors or other deformities, and degradation of benthos. The 2003 fish consumption advisory includes the larger sizes of northern pike, smallmouth bass, and walleye for mercury and PCBs. However, sauger, the fish species most heavily afflicted with tumors and anomalous growths, is no longer present within the AOC and consequently is not listed in the Advisory. Deer Lake environmental concerns include elevated mercury levels in fish. The Michigan Department of

Environmental Quality has been working to address and remediate these concerns for several years. Their efforts have been supported by the Deer Lake PAC since 1997. The AOC includes the Carp River watershed, Deer Lake, and the Carp River downstream about 32 km to Lake Superior in Marquette.

**Table 30. Michigan non-attainment lakes in the Lake Superior basin (Michigan Dept. of Environmental Quality 1998).**

| Lake | Impairment |
|---|---|
| Chaney Lake | FCA – mercury |
| Marion Lake | Mercury Lake |
| Langford Lake | FCA – mercury |
| Six Mile Lake | Mercury Lake |
| Torch Lake | Macroinvertebrate community rated poor; water quality standard exceedances for copper |
| Perch Lake | Mercury Lake |
| Lake Independence | Mercury Lake |
| Deer Lake | FCA-mercury |
| Nawakwa Lake | Mercury Lake |
| Pike Lake | Mercury Lake |

*Ontario*

Some of Ontario's inland lakes, particularly in the Thunder Bay and Sault Ste. Marie areas, are experiencing stress due to the effects of shoreline development. However, the majority of the lakes are undeveloped and the shorelines are managed as public lands. Current Ontario government policy prohibits development on lake trout lakes where all of the shoreline is public land, and limits development on patent lands with lake trout lakes based on the late summer hypolimnetic dissolved oxygen level.

More widespread stresses to Ontario inland lakes are associated with logging activity and exploitation. Most inland lakes in Ontario are within forest management units where logging takes place. Potential impacts of logging and associated road construction include increased sedimentation, increased water temperatures, changes in water yield and availability of woody debris (OMNR 1988). Ontario's Timber Management Guidelines for the Protection of Fish Habitat have been used since 1988 to minimize the effects of crown land logging operations on inland lakes and streams. A large, ongoing research project was initiated in 1990 to experimentally evaluate the effects of logging on boreal forest lakes and streams. In 2001, a second long term research study, funded by Ontario's Living Legacy Trust, was undertaken to determine the effects of two partial harvesting methods in riparian reserves. The results of these projects will help in the development of more scientifically-based guidelines to ensure the protection of fish habitat. With regard to exploitation on Ontario's inland lakes, standardized rapid assessment protocols have been developed in order to identify stressed populations which may require management intervention and to facilitate the development of management support models. These protocols include the spring littoral index netting, fall walleye index netting, and nearshore community index netting. A modified version of the trap net, based nearshore community index netting, has recently been used to assess walleye populations in the Georgian Bay area of Lake Huron and may prove to be a valuable assessment tool for the assessment of sensitive populations in embayments on Lake Superior.

Lake Nipigon is the largest inland lake in Ontario's portion of the Lake Superior watershed; with a surface area of 448,060 ha, it is approximately one quarter the size of Lake Ontario. Lake Nipigon supports trophy sports fisheries for brook trout and lake trout, as well as commercial fisheries for whitefish, lake trout, walleye, and more recently rainbow smelt. Stresses acting on the fish community of Lake Nipigon include exploitation, water level fluctuations, and the introduction of the non-indigenous rainbow smelt. Declines in Lake Nipigon walleye stocks in the early 1980s, attributed primarily to over-fishing, have led to angling closures and reduced commercial walleye quotas. Recovery of the walleye stocks in Ombabika Bay is being monitored on an ongoing basis. Rainbow smelt were first discovered in Lake Nipigon in the early 1980s and smelt numbers have increased dramatically since. It is unknown, however, what the long-term impacts of smelt will be on the Lake Nipigon fish community.

The level of Lake Nipigon is controlled by hydroelectric dams on the Nipigon River and by the diversion of water from the Ogoki River into Ombabika Bay. Winter draw-downs have impacted brook trout reproduction by de-watering brook trout spawning shoals. The draw-down impact on other fall spawning species is unknown. A water level agreement signed in 1994 for the Nipigon system has reduced water level impacts on Lake Nipigon as well as on the Nipigon River. This agreement is presently under review for renewal by the parties involved including OMNR (M. Chase, personal communication).

The Lake Nipigon Fisheries Assessment Unit (LNFAU) was established by the OMNR around 1980 to collect long-term data sets on the Lake Nipigon fish community. Current LNFAU projects include fish community index netting, fall walleye index netting, commercial catch sampling, smelt index netting, and lake trout index netting. The Anishinabek/Ontario Fisheries resource Centre has partnered with Lake Nipigon First Nations and the OMNR to conduct a number of projects since 1995. Studies included walleye, whitefish, and pike tagging and index netting programs for lake trout and whitefish.

Ontario lake survey data are available from 1,251 lakes within the basin, but there are thousands of unsurveyed lakes. Surveyed lakes tend to be large, accessible and support sport fishes. Many of the lake survey data are over 20 years old.

Two lakes in the basin, Lim and Mose lakes, are severely degraded by mine effluent (OME 1992). Numerous other lakes have fish consumption advisories, primarily due to mercury levels. Ontario does not have an on-going lake water quality program.

Dams have altered water level regimes on many of the larger inland lakes. Dams were built to improve navigation or for historical log drives and many of these dams persist today. Increased water levels resulted in flooding the original shoreline and disruption of the natural flooding-drawdown cycle.

## 6.6 Species and Ecosystems of Concern

### 6.6.1 Fish Populations

The fish community of Lake Superior is generally good and remains relatively intact compared to the other Great Lakes (Figure 69). Through rehabilitation, lake trout and lake whitefish stocks have increased substantially and may be approaching ancestral states. Some stocking still occurs in selected regions, but indigenous species are naturally reproducing throughout the lake and in numbers sufficient to sustain themselves. Diporeia populations appear stable. Lake herring have recovered but under sporadic recruitment. Natural reproduction supports most salmonid populations. Some nearshore fish populations, especially lake sturgeon, walleye, and brook trout, remain below historical levels.

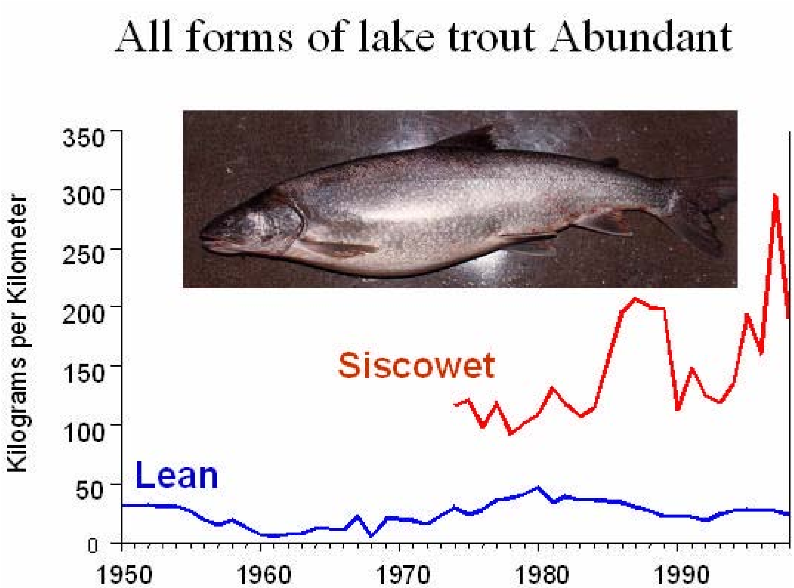


**Figure 69: All Forms of Lake Trout are Abundant**

Non-native species continue to be introduced to Lake Superior, although the fish community appears to contain enough buffering capacity to withstand and minimize the current levels of non-native species. Sea lampreys still kill thousands of lake trout each year. Ruffe and round gobies have colonized some areas and have the ability to negatively impact the nearshore cool-water fish community.

Lake Superior fish communities can be separated into two groups based on habitat preferences. The deeper water fish community made up of fish occupying the nearshore and offshore habitats are not currently habitat limited. While the shallower water fish community comprised of fish inhabiting embayments, estuaries, and tributaries are habitat limited. Habitat limits can be thermal, spatial, and artificially imposed by man due to some form of degradation or manipulation to the habitat. Species that are not limited by habitat and for which there is a sufficient amount of habitat to sustain and achieve both fish community and environmental objectives include:

- All lake trout forms, lake herring, lake whitefish, chubs, and round whitefish that spawn in Lake Superior itself;

- Salmonines other than lake trout that live in the offshore, nearshore, and embayment habitat; and
- Prey species like sculpins, trout-perch, ninespine stickleback, and pigmy whitefish.

In comparison, the following fish species are limited due to habitat loss and degradation in the Lake Superior basin, and achievement of fish community or environmental objectives may not be possible under current habitat conditions.

- Lake trout stocks that spawn in rivers found in eastern Ontario waters of the lake. The Montreal and Michipicoten River spawning populations of lake trout may be limited by habitat due to fluctuating water levels caused by a hydroelectric facility.
- The lake whitefish stock that historically spawned in the St. Louis estuary. This stock of whitefish was extirpated over 100 years ago because of habitat destruction.
- Walleyes, lake sturgeon, Pacific salmon, brown trout, brook trout, and other fish that live in Lake Superior but spawn in the tributaries, as well as tributary resident species such as brook trout, brown trout, sculpins, and cyprinids. Logging, road crossings, beaver and artificial dams are causing (1) loss of spawning and nursery habitat (due to sedimentation) and/or preventing access for upstream migrants, and (2) unfavorable changes in the thermal habitat.
- Yellow perch, northern pike, muskellunge, and smallmouth bass. Habitat loss and degradation in embayments and large tributaries has reduced the limited distribution and abundance of these species in the basin. These species are naturally limited thermally and by depth in Lake Superior.

The following are discussions of some of the fish populations impacted by overfishing, habitat loss and other stresses. These include walleye, coaster brook trout, lake trout, lake whitefish, deepwater ciscoes, and lake sturgeon.

***Walleye***

Historically, walleye was an important member of shallow-water (<3 m) fish communities in large embayments, estuaries and tributaries of Lake Superior (Hoff 1999). Walleye have been caught in at least 73 Lake Superior tributaries since 1950, and spawning has been documented at 33 areas. During the late 1800s and the first half of this century, walleye populations declined due to habitat degradation and overharvest (Hoff 1996). Walleye habitats in Lake Superior have been impaired by:

- Reduction or elimination of fish passage in spawning tributaries,
- Reduction in water quality caused by sedimentation and discharge of contaminants into the lake, and
- Degradation of spawning and nursery habitats in six areas.

Most walleye in the Minnesota waters of Lake Superior spawn within the 35 km stretch of the St. Louis River below the hydroelectric dam near the village of Fond du Lac (Hoff 1996). Spawning and nursery habitats in the St. Louis River have been degraded since the turn of the century by water pollution from the upstream discharge of untreated domestic and industrial waste. In particular, chlorophenolics and chloro-organics from pulp and paper mills caused oxygen deficiencies and reduced the palatability of walleye (Schram and others 1999). Improvements in waste treatment initiated by the Western Lake Superior Sanitary District in 1978 have curtailed obvious widespread habitat degradation caused by inadequately treated organic compounds and biochemical oxygen demand. It also dramatically improved walleye palatability and, consequently, angling pressure. Persistent toxic contaminants in walleye remain a problem in the St. Louis River, and further water quality improvements in the St. Louis

River basin have been recommended to enhance walleye populations (Hoff 1996). Key spawning areas in the St. Louis River are strongly influenced by manipulated water levels caused by hydroelectric dam operations. Fish kills and stranding of spawning walleye have been caused by bypassing water from the natural river channels to hydroelectric plants or from shutting down flows to recharge reservoirs. Recent licenses for dam operations have stipulated more favorable flow regimes, thereby increasing available walleye habitat.

The protection and enhancement of shallow nursery habitats within the St Louis River estuary has been aided by the purchase of waterfront property adjacent to the main spawning area by the Wisconsin DNR (Schram and others 1991).

In Wisconsin, there were historically three separate spawning populations:

- Western Lake Superior stocks that spawned primarily in the St. Louis River,
- Chequamegon Bay stocks that primarily spawn in the Kakagon River, and
- Bad River spawning population (Schram and others 1999).

Poor forestry and agricultural practices (e.g., management of livestock and associated wastes) in the Bad River watershed have degraded riparian habitats, increased sedimentation at some locations, and contributed to increased flooding and reduced water quality. Contaminants may also have negatively affected spawning walleye populations in the Bad River (Schram and others 1999) and consumption advisories remain for both the Kakagon and Bad Rivers.

Habitat for four of the five major walleye populations in Michigan waters of Lake Superior has been damaged. The Victoria Dam and Bond Falls Dam have impeded upstream migration to traditional spawning areas in the Ontonagon River. Peak flows from hydroelectric facilities at those dams have also caused bank erosion. Development, poor land use practices (e.g., logging), and poorly constructed road crossings have increased bank erosion and sedimentation and likely affected spawning habitats and wetlands throughout the Ontonagon River, the Huron Bay Watershed (Silver, Ravine, and Slate rivers), and the lower Tahquamenon River. Habitat loss from past logging-related shipping has also occurred in Sherman Park, Izaak Walton Bay, Cedar Point and Waishkey Bay (Hoff and others 1998). Habitat degradation does not appear to be significantly impacting the other major Michigan populations.

Black Bay and Nipigon Bay in Ontario historically had the largest population of walleye in Lake Superior. Thunder Bay and Whitefish Bay also supported large fisheries (Ryder 1968; Schneider and Leach 1977; Kelso and others 1996). The Black Bay population declined due to commercial fishing in the 1960s. Impaired water quality from paper mill effluent downstream of spawning areas on the Nipigon River has been identified as a major cause in the decline of the Nipigon Bay population in the 1960s (Ryder 1968), although overfishing also probably contributed (MacCallum and Selgeby 1987). Electrical barriers operated by the Sea Lamprey Control Centre during the 1950s and 1960s caused direct mortality of walleye in Lake Superior tributaries (including the Jackfish River) and prevented upstream migration to spawning grounds (Schram and others 1999). The Goulais Bay and Goulais River of the Whitefish Bay area supported a commercial walleye fishery until the mid 1960s. Current use of TFB-Bayer 73 lampricide treatments and low alkalinities in spawning areas are probably reducing survival of walleye eggs and larvae (Rose and Kruppert 1984). Hydroelectric dams on the Michipocoten River have restricted access to upstream spawning grounds. Habitat loss along the shoreline within the city of Thunder Bay may be limiting walleye stocks (Schram and others 1991). Concentrations of persistent toxic chemicals in walleyes from Goulais, Batchawana, and Nipigon bays remain above consumption advisories so further rehabilitation of water and sediment quality in walleye habitats is needed.

The Walleye Subcommittee of the Lake Superior Technical Committee has reported on the status of walleye populations (Hoff 1996) and drafted a rehabilitation plan (Hoff 1999). They recommend that:

> *The Lake Superior fish community will be managed to maintain, enhance, and rehabilitate habitat for, and self-sustaining populations of, walleye in areas where the species historically maintained populations.*

Objectives for rehabilitation of walleye habitats included (Hoff 1999):

- Creating or maintaining spawning and nursery habitats (St. Mary’s River, Ontonagon River, Huron Bay Watershed, Bad River);
- Enhancing fish passage past a dam in the Ontonagon River;
- Reducing sedimentation by 50 percent in the St Mary’s River, Tahquamenon River, and the Huron Bay Watershed;
- Eliminating point source discharges of persistent toxic chemicals into the lake to reduce contaminant concentrations in walleyes; and
- Improving land and water use practices in the St Mary’s River, Ontonagon River, Huron Bay Watershed, and the Bad River.

### *Brook Trout*

Brook trout are common in Lake Superior cold water tributaries. The large form of brook trout that exhibits a migratory or lake dwelling life history was historically common and widespread in the nearshore waters of Lake Superior and was often referred to as “coasters” or “rock trout” because of their preference for rocky, shallow coastal areas. Coaster brook trout typically spawn in tributaries in the fall before returning to the lake; fry remain in-stream during early development before descending to the lake. Shoal spawning coasters may spend their entire life cycle in Lake Superior, whereas others make many movements between stream and lake habitats during the year (Newman et. al. 2003).

There is little information on Lake Superior brook trout before 1900 because early catch records did not distinguish brook trout from lake trout. In the early 1800s, lake-dwelling brook trout were found in most Lake Superior waters within about 15 m from shore, or about islets and shoals close to shore (Shiras 1935). They were less common along sandy beaches and steep, wave-washed cliffs. Coasters historically spawned in at least 106 Lake Superior tributaries, including 61 in Ontario, 25 in Michigan, 12 in Wisconsin, and nine in Minnesota. They were probably present below the first barrier in all streams along Lake Superior's north shore (Waters 1983) and most coldwater streams along the south shore.

Overfishing, particularly by anglers, is considered the primary cause for the abrupt decline of coaster brook trout populations after the 1860s. Brook trout are very vulnerable to angling, and coasters particularly so because they inhabit shallow shoreline areas and congregate at stream mouths for feeding and spawning. Incidental catch of brook trout in nearshore gill nets increased as fishing effort for lake trout and whitefish expanded in the early 1900s. In some areas, spawning fish were netted at stream mouths, which led to extirpation of local populations (Newman and Dubois 1997). During the late

1800s and early 1900s, anglers from across North America fished for large brook trout in Lake Superior's waters and tributaries, particularly the Nipigon, St. Mary's, Bois Brule and Salmon Trout rivers (Newman and Dubois 1997). By the early to mid 1900s, coaster brook trout were reduced to the small, scattered populations which have persisted in less accessible areas.

Habitat loss contributed to the decline in coaster populations and may be responsible for suppressing the recovery of stocks. Most destruction of habitat resulted from logging in the Lake Superior watershed, which accelerated in the late-1800s. Critical spawning areas were degraded by sedimentation from increased erosion and deposition of bark debris from log drives. Coarse, woody material essential for fish habitat was removed from stream banks and bottoms during log drives. Elimination of riparian cover, clear-cutting of watersheds and resulting wildfires may have increased water temperatures and changed groundwater movement. Finally, dam construction blocked migration routes and altered natural stream flow, sometimes resulting in exposure of eggs during drawdown for hydroelectric production (Newman and Dubois 1997). At about the same time, introduction of non-native salmonids such as the rainbow trout, brown trout, coho salmon, and chinook salmon may have represented an additional stress.

Assessment of the current distribution and abundance of coaster brook trout is difficult due to the presence of introduced hatchery fish and non-migratory stream fish. Interbreeding with domestic strains of brook trout may also have altered the genetic composition of native brook trout and reduced their migratory tendency (Newman and Dubois 1997). Coaster brook trout now persist as scattered remnant populations and have been eliminated from many areas, especially along the south shore of the lake. They persist where there is suitable habitat and some measure of protection from overexploitation by angling.

In Ontario, small numbers of coaster brook trout are caught at numerous locations in the lake and in many tributaries. The most important remaining spawning location is the Nipigon River (Newman and Dubois 1997), which may offer some degree of protection from over harvest due to its large water volume and flow. The Cypress, Gravel, and Little Gravel rivers also support consistent spawning runs. A shoal-spawning coaster brook trout population is present at Isle Royale, and stream spawning stocks are likely present in Washington and Grace Creeks and the Big and Little Siskiwit rivers. Coaster brook trout numbers are occasionally reported at numerous locations along the south shore of Lake Superior, but abundance is considered very low. In mainland Michigan, only the Salmon Trout River still has a spawning run of coaster brook trout, and that population may be imperiled. In Minnesota, the Little Marais River may have spawning coaster brook trout, and reintroduced coaster brook trout appear to be spawning in two tributary streams on the Grand Portage Indian Reservation. No reproducing coaster populations are known from Wisconsin.

Recovery efforts for Lake Superior coaster populations have focused on identifying, protecting, and rehabilitating historical spawning streams. Efforts involve angling regulation (seasons, bag limits, and size restrictions) and water level regulation (Newman et. al. 2003). Stocking brook trout in U.S. waters of Lake Superior has taken place since the late 1800s, but return rates have been low and little or no natural reproduction has been recorded. In Ontario, brook trout were stocked in Lake Superior tributaries from 1921 to 1987. Stocking records indicate that approximately 4.8 million brook trout were planted along the north shore between 1921 and 1940, with 1.9 million of these fish being placed in the Nipigon River. Brook trout fingerlings were stocked annually on lakeshore springs and upwelling areas in western Lake Superior from 1994-1997.

The use of strains that originated outside of the Lake Superior basin may have contributed to poor stocking success. Currently there are three brood stocks from the basin that are available for stocking. The U.S. Fish and Wildlife Service maintains two strains of brook trout from Isle Royale and the OMNR and the Red Cliff Band each rear Lake Nipigon strain fish.

A binational effort is underway between federal and provincial/state agencies, universities, and two non-governmental organizations (Trout Unlimited and Trout Unlimited Canada) in order to coordinate work toward rehabilitating coaster brook trout in Lake Superior.

***Lake Trout***

Lake trout were historically the dominant predator in Lake Superior until the 1950s, when they declined rapidly due to commercial fishing pressure and sea lamprey predation (Hansen 1994). Lake trout numbers are dependent on a complex combination of fishing pressure, prey abundance, competition with introduced salmonids and other species, stocking, and predation, especially by sea lamprey. Despite stocking efforts, lake trout populations have not recovered to historical levels. With a few exceptions, habitat loss and degradation is not considered to have been a major factor in lake trout decline, nor as a limiting factor for their recovery. While consumption of alewife and smelt, two species with high concentrations of thiaminase, may be a factor hindering recovery of lake trout in other Great Lakes, there is no evidence that this was the case in Lake Superior.

Lake trout are well adapted to cold, clear, oligotrophic conditions, and most offshore and nearshore areas of Lake Superior comprise important habitat for lake trout at some life stage. Lake trout historically spawned at 337 sites in the main basin of Lake Superior, of which 210 were along the mainland and 127 offshore or along island shorelines (Table 32).

Approximately one-half of the spawning sites were in Canadian waters, with a greater proportion of the offshore sites. Lake trout typically spawn over coarse substrates (e.g., boulder and cobble) with little or no fine material on offshore reefs and shoals or on points extending into deep water (Marsden and others 1995). In Minnesota, shallow water habitats (<20 m) had a greater proportion of good spawning habitat with coarse substrate than deeper habitats that tended to have more fine materials (Richards and others 1999).

Lake Superior lake trout consist of a number of reproductively isolated stocks distinguished from each other by differences in the shape of the snout, body shape, coloration, fat content, size of the eye, and thickness of the abdominal wall. Although up to 12 variants have been identified, three main forms are recognised: leans, siscowets, and humpers (Goodier 1981).

Lean lake trout typically inhabit nearshore waters less than 80 m deep, shallow offshore reefs, and the nearshore waters around the islands in Lake Superior. Lean lake trout spawning grounds are found in both nearshore and offshore areas in <80 m of water. Approximately 23 percent or 1.9 million ha of Lake Superior is less than about 80 m deep, but in U.S. waters only 12 percent of the area <73 m deep should be considered as lean lake trout spawning habitat (Ebener 1998). A similar proportion may be suitable in Canadian waters.  Lean lake trout spawn offshore at the Gull Islands, Superior Shoal, Stannard Rock, Caribou Island, Michipicoten Bay, and the area north of Whitefish Bay.

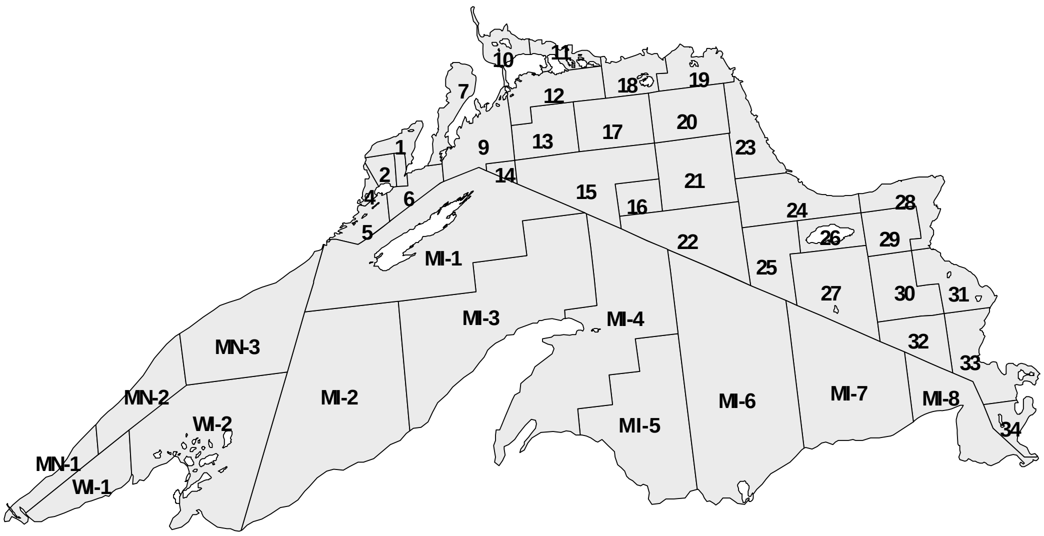


**Figure 70.  Commercial fisheries zones.**

Nearshore spawning habitats in most of the lake are associated with the mainland shoreline, with the exception of Wisconsin where almost all lean lake trout spawning habitat in the nearshore zone is located along the outer periphery of the Apostle Islands, since most of the mainland shore is sand or clay (MacCallum and Selgeby 1987).  The Gull-Michigan Island Reef, approximately 30 km offshore, is the main site of wild reproduction in Wisconsin, although limited natural reproduction occurs at numerous other locations in Wisconsin (Swanson and Swedberg 1980).

Lean lake trout spawning habitat in embayments is found in Keweenaw, Whitefish, Thunder, and Nipigon bays.  Lean lake trout historically spawned in nine tributaries in eastern Lake Superior (Goodier 1981; Ebener 1998) from the Steel to Montreal rivers.  Wild lean lake trout have been recently found in spawning condition inside the mouths of the Montreal and Dog rivers, but spawning has not been confirmed (Ebener 1998).  Lake trout also use these rivers during the non-spawning season.

Siscowets usually are found in deep (50 to 150 m), offshore waters, but they are also abundant in nearshore waters.  All water <90 m, and much that is deeper, is considered spawning habitat for siscowets.  They spawn in deep water around offshore reefs.  Siscowets appear to be more abundant in nearshore areas relative to lean lake trout than was observed in the past.

Humpers are less common and live predominantly on isolated shoals surrounded by deep waters around Isle Royale and in eastern waters of the lake around Caribou Island (Hansen 1996).  They spawn at most of the same offshore sites as leans, with the potential exception of Stannard Rock.

Table 31 summarizes critical and important habitats for leans, siscowets and humpers (Ebener 1998). Most of the identified important habitat is in offshore areas such as Superior Shoal, Caribou Island, Isle

Royale, and Stannard Rock where remnant stocks of native lake trout persisted. Offshore habitats were critical since abundance, especially of mature wild fish, never fell as low as it did in the inshore region (MacCallum and Selgeby 1987). Stocks of lean lake trout occupying many offshore reefs or shoals are probably genetically distinct (Ebener 1998). In addition, they are less vulnerable to impacts from human activities than nearshore areas. Although much of the focus has been on spawning sites, optimal habitat for other life history stages of lake trout is also essential. However, the distribution of larval lake trout in Lake Superior is too poorly known to accurately quantify nursery habitat. About 40 percent of the waters less than 90 m is suitable nursery habitat for lean lake trout.

**Table 31. Critical and important habitat in Lake Superior for lake trout.**

| STRAIN | LIFE STAGE | IMPORTANT HABITAT | CRITICAL HABITAT |
|---|---|---|---|
| **Offshore(>80 m)** | | | |
| ***Lean*** | juvenile | all water <91 m | Stannard Rk., Superior Sh., Caribou I., Gull Island Sh., Isle Royale |
| | non-spawning adult | all water <146 m | Stannard Rk., Superior Sh., Caribou I., Gull Island Sh., Isle Royale |
| ***Siscowet*** | egg | all water >110 m | unknown |
| | juvenile | all water 80 to 128 m | none |
| | non-spawning adult | all water >110 m | none |
| | spawning adult | all water >110 m | unknown |
| ***Humper*** | egg | rock substrate <60 m in offshore areas | Caribou I., Isle Royale, Superior Sh. |
| | juvenile | Unknown | none |
| | non-spawning adult | Unknown | none |
| | spawning adult | rock substrate <60 m in offshore areas | Caribou I., Isle Royale, Superior Sh. |
| **Nearshore (<80 m)** | | | |
| ***Lean*** | egg | rock substrates 0.5 to 30 m | rock substrates 0.5 to 30 m, DO>6mg/l |
| | juvenile | all water 35 to 80 m | None |
| | non-spawning adult | all water 35 to 80 m | None |
| | spawning adult | rock areas 0.5 to 30 m | rock substrates 0.5 to 30 m |
| ***Siscowet*** | egg | Unknown | Unknown |
| | juvenile | all water <80 m | None |
| | non-spawning adult | water 36 to 80 m | None |
| | spawning adult | unknown, probably very little | Unknown |
| ***Humper*** | egg | rock substrate <60 m | water <60 m Caribou I., Isle Royale, Superior Sh. |
| | juvenile | offshore banks Isle Royale, Caribou Is. | none |
| | non-spawning adult | offshore banks Isle Royale, Caribou Is. | none |
| | spawning adult | rock substrate <60 m | water <60 m Caribou I., Isle Royale, Superior Sh. |
| **Tributaries** | | | |
| Lean | egg | eastern Lake Superior tributaries | Montreal & Dog (University) rivers |
| | juvenile | eastern Lake Superior tributaries | Montreal & Dog (University) rivers |

Lake trout habitat can be adversely affected by toxic pollutants, poor water quality, watershed misuse, sedimentation, eutrophication, and residential and commercial development (Hansen 1996). Industrial pollution in the form of low-level contamination by organic pollutants and metals may have had effects on the health and reproduction of lake trout (especially fatty siscowets) (Busiahn 1990); however, the effects have not been thoroughly evaluated in Lake Superior fishes. Relatively shallow water directly adjacent to the shore is important as potential spawning areas for lake trout but such areas are frequently impacted by upland land uses (Richards and others 1999). For example, lake trout spawning habitat in Terrace Bay has been destroyed through the historic deposition of orgainc materials and chemical contamination of sediments. Mine tailing at the north and south entry to the Keweenaw Bay Waterway have degraded lake trout habitat (Donifrio 2003). In eastern Lake Superior, the Montreal River population of lake trout may currently be limited by habitat due to fluctuating water levels caused by a hydroelectric facility (Ebener 1998).

The Lake Trout Restoration Plan for Lake Superior (Hansen 1996) recommended that an atlas of lake trout spawning grounds be developed. General locations of lake trout spawning habitats were mapped by Cobery and Horrall (1980), Goodier (1981), and Goodyear and others (1981) but need to be ground-truthed. Habitat that is essential for lake trout reproduction and survival should be identified, mapped and protected (Busiahn 1990). Progress has been made in Minnesota, where lake trout spawning habitat along 65 $km^2$ of waters less than 30 m deep on Minnesota's North Shore has been surveyed using remote hydro-acoustic techniques coupled with a GPS and GIS (Richards and others 1999).

**Table 32. Estimated quantity of total, spawning, and nursery habitat, and biological parameters for lake trout in each management unit in Lake Superior. Number of spawning sites taken from Cobery and Horrall (1980), Goodyear and others (1981) and Goodier (1981) and includes present day as well as historically important areas. Spawning habitat is considered to be <9 m deep. Average CPUE, wild fish, and mortality for U. S. and Canadian waters adjusted for area <73 m and <91 m deep, respectively.**

| Mgt Unit | Total habitat (ha) | | No. spawning sites | | Spawning habitat | | Nursery habitat | | Biological parameters | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Years | Survey CPUE[3] | Wild fish[4] (%) | Annual Mortality * (%) |
| | total | <73 m[1] | onshore | offshore | (ha) | % area[2] | (ha) | % area[2] | | | | |
| MI-1 | 573,003 | 49,645 | 18 | 2 | 13,600 | 27 | 1,200 | 2 | 1993-95 | 16 | 98 | 29 |
| MI-2 | 636,599 | 87,786 | 7 | 0 | 4800 | 5 | 1,200 | 1 | 1996 | 34 | 87 | 45 |
| MI-3 | 620,654 | 64,674 | 10 | 0 | 4625 | 7 | 1,200 | 2 | 1996 | 7 | 91 | 41 |
| MI-4 | 622,657 | 132,146 | 15 | 7 | 15,213 | 12 | 2,300 | 2 | 1996 | 14 | 88 | 51 |
| MI-5 | 367,935 | 76,385 | 13 | 0 | 4,290 | 6 | 14,500 | 19 | 1996 | 32 | 83 | 42 |
| MI-6 | 761,196 | 74,934 | 7 | 3 | 36,600 | 49 | 71,500 | 95 | 1996 | 45 | 90 | 58 |
| MI-7 | 411,881 | 81,697 | 1 | 5 | 31,300 | 38 | 42,800 | 52 | 1996 | 18 | 94 | 54 |
| MI-8 | 179,626 | 176,868 | 2 | 1 | 14,300 | 8 | 40,100 | 23 | 1996 | 10 | 17 | 68 |
| WI-1 | 107,408 | 48,513 | 1 | 0 | 12 | 0 | 0 | 0 | 1995 & 97 | 20 | 42 | 36 |
| WI-2 | 400,703 | 231,797 | 12 | 23 | 7,773 | 3 | 266,131 | 115 | 1995 & 97 | 18 | 71 | 37 |
| MN-1 | 107,723 | 57,185 | 8 | 0 | 5,700 | 10 | 1,190 | 2 | 1996 | 34 | 45 | 45 |
| MN-2 | 173,567 | 7,955 | 9 | 0 | 400 | 5 | 430 | 5 | 1996 | 7 | 20 | 40 |
| MN-3 | 358,789 | 14,899 | 21 | 0 | 1,200 | 8 | 4,500 | 30 | 1996 | 26 | 70 | 45 |

**Table 32. Estimated quantity of total, spawning, and nursery habitat, and biological parameters for lake trout in each management unit in Lake Superior. Number of spawning sites taken from Cobery and Horrall (1980), Goodyear and others (1981) and Goodier (1981) and includes present day as well as historically important areas. Spawning habitat is considered to be <9 m deep. Average CPUE, wild fish, and mortality for U. S. and Canadian waters adjusted for area <73 m and <91 m deep, respectively.**

| Mgt Unit | Total habitat (ha) | | No. spawning sites | | Spawning habitat | | Nursery habitat | | Biological parameters | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Years | Survey CPUE[3] | Wild fish[4] (%) | Annual Mortality * (%) |
| | total | <73 m[1] | onshore | offshore | (ha) | % area[2] | (ha) | % area[2] | | | | |
| Subtot. | 5,321,741 | 1,104,485 | 124 | 41 | 139,813 | 13 | 447,051 | 40 | 1993-97 | 21 | 69 | 48 |
| 1 | 33,366 | 33,046 | 4 | 2 | | | | | 1992-96 | 90 | | <45 |
| 2 | 22,451 | 22,440 | 0 | 4 | | | | | 1992-96 | 47 | | <45 |
| 3 | 10,922 | 9,765 | 1 | 1 | | | | | 1992-96 | 100 | | <45 |
| 4 | 13,871 | 13,871 | 3 | 3 | | | | | 1992-96 | 44 | | |
| 5 | 41,614 | 25,361 | 5 | 1 | | | | | | 22 | | |
| 6 | 46,285 | 5,875 | 3 | 2 | | | | | 1992-96 | 46 | | |
| 7 | 60,139 | 60,139 | 2 | 0 | | | | | 1992-96 | 16 | | |
| 8 | 4,431 | 3,409 | | | | | | | | | | |
| 9 | 101,191 | 28,759 | 11 | 3 | | | | | 1992-96 | 37 | | |
| 10 | 39,818 | 39,818 | 3 | 6 | | | | | | | | |
| 11 | 35,627 | 31,229 | 1 | 6 | | | | | 1992-96 | 34 | | |
| 12 | 105,284 | 14,218 | 0 | 10 | | | | | 1992-96 | 36 | | |
| 13 | 91,264 | 0 | | | | | | | | | | |
| 14 | 27,415 | 2,784 | 0 | 3 | | | | | 1992-96 | 185 | | |
| 15 | 209,058 | 0 | | | | | | | | | | |
| 16 | 45632 | 2,192 | 0 | 4 | | | | | 1992-96 | 318 | | |
| 17 | 119784 | 919 | | | | | | | | | | |
| 18 | 67,572 | 17,485 | 9 | 8 | | | | | | 110 | | |
| 19 | 72,227 | 26,510 | 9 | 0 | | | | | 1992-96 | 27 | | |
| 20 | 119,784 | 13,209 | | | | | | | | | | |
| 21 | 159,712 | 23 | | | | | | | | | | |
| 22 | 204,436 | 0 | | | | | | | | | | |
| 23 | 99,844 | 10,240 | 8 | 0 | | | | | 1992-96 | 68 | | <45 |
| 24 | 137,912 | 26,158 | 5 | 0 | | | | | 1992-96 | 51 | | <45 |
| 25 | 109,766 | 6,347 | | | | | | | | | | |
| 26 | 49,287 | 15,657 | 0 | 15 | | | | | | 291 | | |
| 27 | 182,150 | 57,232 | 0 | 3 | | | | | 1992-96 | 270 | | |
| 28 | 88,909 | 43,661 | 10 | 0 | | | | | 1992-96 | 52 | | 23 |
| 29 | 79,856 | 10,681 | 0 | 0 | | | | | | 280 | | |
| 30 | 114,080 | 0 | 0 | 0 | | | | | 1992-96 | 229 | | <45 |
| 31 | 90,303 | 51,997 | 2 | 11 | | | | | 1987-92 | 11 | 45 | 42 |
| 32 | 77,099 | 2,552 | 0 | 0 | | | | | 1992-96 | 273 | | <45 |
| 33 | 131,729 | 90,707 | 4 | 3 | | | | | 1987-92 | 8 | 35 | 69 |
| 34 | 47,452 | 44,409 | 6 | 1 | | | | | 1987-92 | 7 | 2 | 63 |
| Subtot | 2,840,270 | 710,693 | 86 | 86 | 0 | 0 | 0 | 0 | 1992-96 | 61 | | <45 |
| **Total** | **8,162,011** | **1,815,178** | **210** | **127** | **139,813** | **0** | **447,051** | **0** | | | | |

[1] *Canadian waters is <91 m deep.*
[2] *Percent of areas <73 m deep in U. S. waters.*
[3] *CPUE is fish per 305 m of survey gill net in U. S. waters and in Canada CPUE is based on commercial catches and expressed as kg/km.*
[4] *In MN-1, MN-2, and MN-2 is percent of fish ≤635 mm total length.*
[5] *Mortality rates are for ages 5-9 in 1996-97 for MI-8, whereas ages 9-12 MI-3 through MI-7.*

### *Lake Whitefish*

Lake whitefish are not generally limited by habitat in Lake Superior. Lake whitefish spawn on sand, gravel, and rock substrates in 2 to 23 m (usually <5m) of water from late October to early December at water temperatures of 0.5 to 5.5°C (Ebener 1998). Upon hatching in the spring, the pelagic larvae float with the currents and often accumulate in embayments (Reckahn 1970). During the first summer, young lake whitefish (age-0) are believed to be associated with the 17° C isotherm in bays and estuaries until they switch from a planktivorous to a benthic diet and move to colder and deeper water in the fall. Juvenile and adult lake whitefish feed primarily on benthic invertebrates over soft bottom areas (primarily sand and silt) from the nearshore to offshore waters <73 m deep. Adults often return to shallower waters in the spring to feed on emerging mayflies (Goodier 1982). Most adult whitefish remain within 40 km of natal spawning grounds, which has led to the differentiation of semi-discrete stocks (Lawrie and Rahrer 1973).

The general locations of lake whitefish spawning grounds in Lake Superior are summarized by Cobery and Horrall (1980), Goodier (1981) and Goodyear and others (1981). These areas are considered critical spawning habitat and are generally restricted to nearshore and embayment habitats. Current whitefish spawning grounds are located in the Apostle Islands, along the Keweenaw Peninsula, and in Whitefish Bay (Table 33). Lake whitefish spawn off Isle Royale but there is very little whitefish spawning habitat in western Wisconsin waters, Minnesota waters and along the northeastern Canadian shoreline.

Approximately 123,000 ha or 11 percent of the water <73 m deep is considered lake whitefish spawning habitat. As much as 300,000 ha of suitable lake whitefish nursery habitat may be available in Lake Superior, but this estimate is very rough (Ebener 1998). Lake whitefish historically spawned at 106 sites, 60 of which were in nearshore areas and the remainder on the outside of islands. Ten sites were located in embayment habitats. Most sites (90) were in U.S. waters. Lake whitefish historically spawned in the St. Louis estuary, the Michipicoten, White, University (Dog) and Kaminstiquia rivers, and St. Mary's River above the rapids (Lawrie and Rahrere 1972, Goodier 1982). Spawning populations are still known from the Anna River near Munising (Ebener 1998).

Nearshore habitat bordered by beaches and sandy bays are critical both as spawning habitat and food sources for adults. These areas require protection from dredging, shoreline development, contaminants, and localized increase in nutrients. Past illegal dredging for aggregate on whitefish spawning grounds in Whitefish Bay reduced habitat (S. Greenwood 2004, personal communication). Mine tailing from the north and south entry, to the Keweenaw Peninsula Waterway negatively impact lake whitefish populations. Lake whitefish have been reported to contain a wide variety of organic and metallic contaminants, such as PCBs from Peninsula Harbour near Marathon (ULRG 1977). Deposition of woody debris in rivers, embayments and nearshore areas has degraded other habitat. The lake whitefish stock that historically spawned in the St. Louis River estuary was extirpated in the late 1800s because of habitat destruction. Dredging and dumping of grain screenings degraded spawning grounds in the Kaministiquia River (Goodier 1982).

Fish community objectives for Lake Superior include restoring the presence of lake whitefish to historic spawning sites in the lake and historic spawning tributaries (Ebener 1998).

**Table 33. Estimated quantity of total, spawning, and nursery habitat, and biological parameters for lake whitefish in each management of Lake Superior. Number of spawning sites taken from Cobery and Horrall (1980), Goodyear and others (1981) and includes present day as well as historically important areas. Spawning habitat is considered to be <9 m deep. Average catch per unit effort (CPUE) and mortality in U. S. and Canadian waters adjusted for area <73 m and <91 m deep, respectively.**

| Mgt unit | Total habitat (ha) | | No. spawning sites | | Spawning habitat | | Nursery habitat | | Biological parameters | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Years | CPUE[1] | Annual mortality |
| | Total | <73 m[1] | on shore | off shore | (ha) | % area[2] | (ha) | % area[2] | | | |
| MI-1 | 573,003 | 49,645 | 9 | 0 | 628 | 1 | | | 1978-81 | | 55 |
| MI-2 | 636,599 | 87,786 | 0 | 0 | 300 | 0 | 700 | 1 | 1996 | 160 | 45 |
| MI-3 | 620,654 | 64,674 | 7 | 0 | 400 | 1 | 600 | 1 | 1996 | 130 | 78 |
| MI-4 | 622,657 | 132,146 | 14 | 2 | 500 | 0 | 800 | 1 | 1996 | 72 | 73 |
| MI-5 | 367,935 | 76,385 | 2 | 1 | 18,600 | 24 | 4,700 | 6 | 1994-96 | 71 | 30 |
| MI-6 | 761,196 | 74,934 | 9 | 0 | 52,500 | 70 | 37,000 | 49 | 1996 | 57 | 50 |
| MI-7 | 411,881 | 81,697 | 1 | 0 | 13,000 | 16 | 20,000 | 24 | 1996 | 156 | 53 |
| MI-8 | 179,626 | 176,868 | 6 | 0 | 25,500 | 14 | 39,500 | 22 | 1996 | 93 | 57 |
| WI-1 | 107,408 | 48,513 | 2 | 0 | 162 | 0 | 0 | 0 | | 20 | |
| WI-2 | 400,703 | 231,797 | 4 | 35 | 8,500 | 4 | 187,023 | 81 | 1996 | 126 | 73 |
| MN-1 | 107,723 | 57,185 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| MN-2 | 173,567 | 7,955 | 5 | 0 | 0 | 0 | 7,955 | 100 | | | |
| MN-3 | 358,789 | 14,899 | 2 | 0 | 3,000 | 20 | 0 | 0 | | | |
| Subtot. | 5,321,741 | 1,104,485 | 61 | 38 | 123,090 | 11 | 298,278 | 27 | | 104 | 63 |
| | | | | | | | | | | | |
| 1 | 33,366 | 33,046 | 1 | 0 | | | | | 1992-96 | 427 | <45 |
| 2 | 22,451 | 22,440 | 1 | 0 | | | | | 1992-96 | 184 | |
| 3 | 10,922 | 9,765 | | | | | | | 1992-96 | 102 | |
| 4 | 13,871 | 13,871 | | | | | | | 1992-96 | 132 | |
| 5 | 41,614 | 25,361 | | | | | | | 1992-96 | 129 | |
| 6 | 46,285 | 5,875 | | | | | | | 1992-96 | 88 | |
| 7 | 60,139 | 60,139 | | | | | | | 1992-96 | 88 | <45 |
| 8 | 4,431 | 3,409 | | | | | | | | | |
| 9 | 101,191 | 28,759 | | | | | | | 1992-96 | 140 | |
| 10 | 39,818 | 39,818 | | | | | | | | | |
| 11 | 35,627 | 31,229 | | | | | | | 1992-96 | 74 | |
| 12 | 105,284 | 14,218 | | | | | | | 1992-96 | 200 | |
| 13 | 91,264 | 0 | | | | | | | | | |
| 14 | 27,415 | 2,784 | | | | | | | 1992-96 | 5 | |

**Table 33. Estimated quantity of total, spawning, and nursery habitat, and biological parameters for lake whitefish in each management of Lake Superior. Number of spawning sites taken from Cobery and Horrall (1980), Goodyear and others (1981) and includes present day as well as historically important areas. Spawning habitat is considered to be <9 m deep. Average catch per unit effort (CPUE) and mortality in U. S. and Canadian waters adjusted for area <73 m and <91 m deep, respectively.**

| Mgt unit | Total habitat (ha) | | No. spawning sites | | Spawning habitat | | Nursery habitat | | Biological parameters | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Years | CPUE[1] | Annual mortality |
| | Total | <73 m[1] | on shore | off shore | (ha) | % area[2] | (ha) | % area[2] | | | |
| 15 | 209,058 | 0 | | | | | | | | | |
| 16 | 45,632 | 2,192 | | | | | | | 1992-96 | 0 | |
| 17 | 119,784 | 919 | | | | | | | | | |
| 18 | 67,572 | 17,485 | | | | | | | 1992-96 | 59 | |
| 19 | 72,227 | 26,510 | | | | | | | 1992-96 | 79 | |
| 20 | 119,784 | 13,209 | | | | | | | | | |
| 21 | 159,712 | 23 | | | | | | | | | |
| 22 | 204,436 | 0 | | | | | | | | | |
| 23 | 99,844 | 10,240 | | | | | | | 1992-96 | 143 | <45 |
| 24 | 137,912 | 26,158 | | | | | | | 1992-96 | 76 | <45 |
| 25 | 109,766 | 6,347 | | | | | | | | | |
| 26 | 49,287 | 15,657 | | | | | | | 1992-96 | 109 | |
| 27 | 182,150 | 57,232 | | | | | | | | | |
| 28 | 88,909 | 43,661 | | | | | | | 1992-96 | 152 | <45 |
| 29 | 79,856 | 10,681 | | | | | | | | | |
| 30 | 114,080 | 0 | | | | | | | | | |
| 31 | 90,303 | 51,997 | | | | | | | 1992-96 | 108 | 68 |
| 32 | 77,099 | 2,552 | | | | | | | | | |
| 33 | 131,729 | 90,707 | 2 | 1 | | | | | 1992-96 | 99 | 39 |
| 34 | 47,452 | 44,409 | 1 | 1 | | | | | 1992-96 | 151 | 36 |
| Subtot. | 2,840,270 | 710,693 | 5 | 2 | | | | | 1992-96 | 131 | <45 |
| | | | | | | | | | | | |
| Total | 8,162,011 | 1,815,178 | 66 | 40 | 123,090 | 0 | 298,278 | 0 | | 114 | |

[1]*Canadian waters is <91 m deep.*
[2]*Percent of areas <73 m deep in U. S. waters*
[3]*Catch Per Unit Effort is expressed as kg/km of gill net.*

## *Lake Sturgeon*

A commercial sturgeon fishery had started by the early-1800s and the lake sturgeon population probably began to decline in the mid-1800s. By the late-1800s, the stock had declined dramatically. Low reproductive rate and slow growth made sturgeon vulnerable to over-fishing. Despite harvest restrictions implemented in the 1920s, sturgeon were commercially extinct in Lake Superior by 1940 (Waters 1987). Sturgeon populations have not recovered to historical levels (Hansen 1994).

Lake sturgeon prefer nearshore waters, 4 to 9 m deep, but are occasionally found at depths up to 43 m (Harkness and Dymond 1961). Shoals and embayments where benthic organisms are most abundant are the preferred foraging areas (Table 35). Offshore waters (>80 m) are not used. Spawning occurs in rapids in streams or in lakes over shallow rocky ledges and shoals where wave action keeps the eggs oxygenated (Scott and Crossman 1973). Larval fish drift downstream after hatching and typically remain in the stream or shallow waters for the first two years. Juvenile habitat requirements are poorly understood. Yearlings are sometimes found over flat sandy areas.

Ten Lake Superior tributaries currently have self-sustaining sturgeon populations (Table 34, Figure 70) (Auer 2003). Populations in all tributaries are reduced from historical levels. Another ten tributaries were historically used for spawning but are not presently used.

The decline of sturgeon on Lake Superior was largely due to over-fishing, but habitat loss also contributed. Dams on spawning rivers created barriers for spawning migration and altered natural stream flow regimes during the spawning period. Unnaturally low water levels can kill embryos by exposing them to air. High flows can dislodge eggs or embryos from the substrate (Kempinger 1988). Adults are sometimes trapped by falling water levels (Mike Friday, personal communication). Deposition of bark and other debris from log drives buried spawning beds (Harkness and Dymond 1961) and changes in land use along streams may have increased sedimentation and degraded water quality.

Dredging shipping channels in nearshore waters and harbor construction and shipping at river mouths contributed to decline in benthic organisms. Bioassays showed that young lake sturgeons (<100 mm) are sensitive to the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) at concentrations that were applied to streams to kill sea lamprey larvae (Johnson et al. 1999). Lampricide treatments are scheduled to avoid vulnerable life stages and lampricide is applied concentrations that minimize risk to larval and juvenile lake sturgeon.

A rehabilitation plan for lake sturgeon in Lake Superior (Auer 2003) recommends several habitat-related measures, including (1) protecting existing habitat, (2) restoring natural stream flow regimes through re-licensing criteria for hydroelectric dams, (3) providing passage past barriers and dams, and (4) minimizing the impact of sea lamprey control activities. Eight “critical management areas,” with suitable habitat and existing spawning stocks, are priorities for rehabilitation and protection (Figure 71). Other recommendations involve harvest, stocking and contaminants.

Information needs include (1) basic life history and abundance data, (2) descriptions and of nursery, juvenile, and adults habitats, and (3) quantification and mapping of habitat.


**Figure 71. Critical management areas for lake sturgeon. Numbers indicate self-sustaining spawning tributaries (Table 34) (Auer 2003).**

**Table 34. Tributaries with current or historical lake sturgeon populations (Auer 2003). Numbers refer to stream locations on Figure 71.**

| Tributary | Status | Stressors |
|---|---|---|
| Pigeon River, MN/ON | Historical | |
| St. Louis River, MN/WI | Historical | Exotic species, loss of wetlands |
| Bad River, WI (8) | Current | Sedimentation, harvest |
| *Ontonagon River, MI | Historical | Erosion, loss of wetlands, regulated flow, dredging in lower river |
| Sturgeon River, MI (9) | Current | Dam, sediment loads, regulated flow |
| Tahquamenon River, MI | Historical | Sedimentation, past logging practices, little spawning habitat |
| Batchewana River, ON | Current** | Harvest** |
| Pic River, ON (5) | Current | Dam, regulated flow, historical and current logging, |
| *Black Sturgeon River, ON (2) | Current | Dam, historical logging |
| Goulais River, ON (7) | Current | |
| Gravel River, ON (4) | Current | |
| Chippewa River, ON | Historical | |
| Kaministiquia River, ON (1) | Current | Dam, regulated flow, power plant entrainment |
| *Michipicoten River, ON (6) | Current | Dam, poaching, regulated flow |
| Montreal River, ON | Historical | Regulated flow |
| Montreal River, MI/WI | Historical | Dam, regulated flow |
| Nipigon River, ON (3) | Current | Dam, regulated flow |
| White River, ON | Historical | |

| | | |
|---|---|---|
| White River, WI | Historical | Dam, regulated flow |
| *Wolf River, ON | Historical | Dam, lamprey barrier |

* *priorities for habitat restoration*
** S. *Greenwood, personal communication 2003*

**Table 35. Embayments important to lake sturgeon in Lake Superior (Auer 2003).**

| Harbor/ Bay | Most Recent Observation | Stressors |
|---|---|---|
| Grand Portage Bay, MN | 2003 | |
| St. Louis, MN/WI | 2003 | |
| Chequamegon, MI | 2003 | |
| Bete Gris, MI | 1993 | Fishing |
| Huron, MI | 1995 | Siltation from poor stream crossings, logging practices, fishing |
| Keweenaw Bay, MI | 2003 | Treated waste management, treated paper mill effluent, fishing |
| Misery, MI | 1995 | Fishing |
| Munising Bay, MI | 1991 | Fishing |
| Whitefish Bay, MI | 2003 | Dredging for ship channel, contaminants, fishing |
| Batchewana Bay, ON | 1997 | Habitat loss, harvest |
| Black Bay, ON | 1996 | |
| Clark's Bay, ON | 1997 | |
| Goulais Bay, ON | 1997 | By-catch of juveniles and adults |
| Michipicoten , ON | 1997 | |
| Nipigon Bay, ON | 1997 | |
| Thunder Bay, ON | 1997 | Shoreline development |
| Wawanagon Bay, ON | 1997 | |

### *Deepwater Ciscoes*

Deepwater ciscoes consist of seven species, five of which inhabited Lake Superior: blackfin cisco (*Coregonus nigripinnis),* shortjaw cisco (*C. zenithicus),* bloater *(C. hoyi),* shortnose cisco *(C reighardi),* and kiyi (*C. kiyi).* Two other species, deepwater cisco *(C. johannae)* and longjaw cisco *(C. alpenae)* were found only in the lower Great Lakes, and longjaw cisco is now probably extinct. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reports as of 2003 that shortjaw cisco is in decline in Lake Superior. It is still present in Lake Nipigon and numerous smaller lakes where its status is not well known. Blackfin cisco is now probably extirpated from Lake Superior, although it is still found in Lake Nipigon and other inland lakes. All but blackfin cisco and shortjaw cisco were endemic to the Great Lakes (Scott and Crossman 1973). Five of these seven are listed by COSEWIC: the deepwater cisco is Extinct; shortnose cisco, shortjaw cisco, and blackfin cisco are Threatened; and the kiyi is considered of Special Concern.

The *Species at Risk Act* (SARA), proclaimed in June 2003, is one part of a national three part Government of Canada strategy for the protection of wildlife species at risk. Section 28 of SARA allows any person who considers that there is an imminent threat to the survival of a wildlife species to apply to COSEWIC for an assessment of that threat and to have the species listed as endangered on an emergency basis. COSEWIC has not reported on any new assessments for ciscoes or other fish species in the Lake Superior basin in their November 2003 report (COSEWIC 2003).

Deepwater ciscoes formerly supported a substantial fishery in the Great Lakes. Fish were caught in deep-water gill nets, smoked, and sold in the U.S. Fishermen targeted the larger, fatter species (blackfin, deepwater, and longjaw) until these stocks collapsed and then moved on to smaller species. The commercial cisco fishery declined through the 1940s and 1950s and collapsed by about 1960. Cisco populations increased through the early 1960s apparently in response to the decline of lake trout, an important predator (MacCallum and Selgeby 1987). Deepwater cisco populations declined again between the mid-1960s through the mid-1990s, possibly as a result of expanding lake trout population (Selgeby and others 1994, MacCallum and Selgeby 1987). Throughout this period, social factors, such as operating costs, demand, and prices caused some variability in catch. The bloater is the only species left in large numbers today (Hansen 1994).

Competition for food with introduced smelt and alewife may also have been a factor in their decline. Sea lamprey preyed on the larger cisco species (Lawrie and Rahrer 1972), but lamprey-caused mortality was offset by declines in their major predator, lake trout. Hybridization between closely related species may have hastened the decline of rarer species (Scott and Crossman 1973). Oxygen depletion resulting from eutrophication contributed to the decline in the lower Great Lakes, but was probably not a factor in Lake Superior (McAllister and others 1985, ROM 1999, Scott and Crossman 1973).

The present status of deepwater ciscoes is clouded by uncertain taxonomic status of the species and difficulty in monitoring. Hybridization between species and with the ubiquitous lake herring apparently took place as stocks began to decline, resulting in populations with characteristics intermediate between their parent species. Their deepwater habitat also makes it difficult to determine population levels (Parker 1989).

Chemical and physical habitat changes do not appear to have had an adverse impact on these species. Deepwater ciscoes are protected indirectly in the Great Lakes through Canadian and U.S. commercial harvest quotas for all deepwater ciscoes as a group. In Canada, they have the general protection given by the habitat sections of the Fisheries Act (ROM 1998). No recovery plans have been developed by U.S. or Canadian governments.

*Kiyi*

The kiyi is still relatively common in Lake Superior, but is extirpated from the other Great Lakes (McAllister and others 1985). COSEWIC lists the kiyi as a species of Special Concern in Ontario (COSEWIC, 2003). It is one of the smaller deepwater ciscoes, but otherwise very similar to the shortjaw cisco and the bloater (a common deepwater cisco). It occurs at depths of 35 to 200 m but usually at more than 100 m (ROM 1998). Changes in chemical habitat features, likely responsible for the extirpation of this species in the other Great Lakes, have apparently not resulted in significant habitat degradation for kiyi in Lake Superior.

*Shortjaw Cisco*

Shortjaw cisco lives in deep waters (50 to 150 m depth) where it can grow to a length of up to 35 cm. It is found in Lake Superior, Lake Nipigon, and in scattered inland lakes from northern Ontario west to the Northwest Territories. It is extirpated from lakes Michigan and Huron (Houston 1988, ROM 1998). The USGS Ashland Biological Station is attempting to relocate the shortjaw cisco at known historical sites (Bob Kavetsky, personal communication). COSEWIC classifies shortjaw cisco as a Threatened species in Canada.

*Shortnose Cisco*
Shortnose cisco is one of the smaller deepwater ciscoes and it inhabits shallower water than the other species (depths of 25 to 100 m). It is the only deepwater cisco that spawns in the spring rather than fall and winter, although recently spawning has occurred in the fall in Lake Michigan (McAllister and others 1985, Parker 1988c, Webb and Todd 1995). It is listed by COSEWIC as Threatened in Canada.

The historical status of shortnose cisco in Lake Superior is uncertain. Populations formerly reported from lakes Nipigon and Superior are now considered by some authorities to be shortjaw cisco. Shortnose cisco was known only from Lakes Huron, Michigan and Ontario, but may now be extinct (Bob Kavetsky, personal communication, McAllister and others 1985, ROM 1998, Scott and Crossman 1973). As with the other deepwater ciscoes, overharvest and sea lamprey predation, rather than habitat degradation, are probably responsible for its decline.

***Rare Species***

Ten rare fish species are known from the Lake Superior basin. Of these, lake sturgeon, and deepwater ciscoes have been discussed the preceding pages of this report.

*Northern Brook Lamprey*
Northern brook lamprey is a native, non-parasitic relative of the sea lamprey. Its range includes parts of the Mississippi, Hudson Bay, and Great Lakes drainages. In the Lake Superior basin, it is known from a number of small streams in Ontario, Michigan and Wisconsin (Scott and Crossman 1973).

This species apparently does not move out to Lake Superior, but completes its life cycle in streams. Larval lampreys live in streambeds and feed on diatoms and protozoans. When the larvae hatch they make burrows in soft mud and spend six years growing. Following metamorphosis into an immature adult stage, they overwinter in the mud and emerge to spawn. Adults never feed and live for about a year before dying.

Northern brook lamprey is classified as of Special Concern at the federal level in Canada (COSEWIC 2003). It is primarily a warm water species and may never have been common here. Larvae are subject to mortality by lowering water levels and increased siltation from erosion. Habitat may be limited by lampricide intended to control sea lampreys (Scott and Crossman 1973). Seventy-nine (45 United States, 34 Canada) Lake Superior tributaries have been treated with lampricide at least once during 1987-96. Of these, 53 (30 United States, 23 Canada) tributaries are treated on a regular (3 to 5 year) cycle (Klar and others 1996). Northern brook lamprey persists in untreated streams and above barriers and in backwater areas that are not affected by the treatments (Lanteigne 1991, Royal Ontario Museum 1999).

*Arctic Grayling*
Arctic grayling formerly inhabited the Otter River and Little Carp River in the Lake Superior watershed of the Michigan Upper Peninsula, as well as several streams in the Lower Peninsula (Hubbs and Lagler 1958). Relict populations of this arctic species were found in Montana and Michigan following deglaciation. Michigan populations disappeared by about 1936.

The extirpation of grayling from Michigan was caused by overfishing and habitat modification caused by logging (Eddy and Underhill 1974). Grayling spawn in the shallow water of small streams on sand and gravel substrate. This habitat is vulnerable to sedimentation, warming water, and pollution.

Suitable habitat to support this species may no longer be present in the basin. The state of Michigan stocked grayling into several lakes and streams between 1987 and 1991 (Nuhfer 1992). Most stream populations disappeared within six months as fish dispersed downstream. Dams and warm water impoundments hampered survival and dispersal upstream. Some lake populations persisted where competition and predation by other fish species was low. Hooking mortality, illegal harvest, diseases, and episodes of low pH were significant mortality factors (Nuhfer 1992). No reproduction has been detected. Introduction attempts in Minnesota (Musquash Lake and Twin Lake) and Ontario (Blue Lake) in the 1950s had similar results (Eddy and Underhill 1974, Scott and Crossman 1973).

***Other Species***

Silver lamprey and American brook lamprey live in similar habitats as northern brook lamprey and are subject to similar stresses.

Deepwater sculpin inhabits deep lakes from Quebec to the Northwest Territories. Populations in Lake Superior and Lake Huron appear healthy, but the species is extirpated in Lake Erie and was only recently rediscovered in Lake Ontario. The Great Lakes populations are therefore classified as Threatened in Canada (Parker 1988a). The decline of deepwater sculpin in the lower Great Lakes may be related to exposure to contaminants in lake sediments. Predation on larva by introduced fishes may have also played a role (Parker 1988a).

Paddlefish is known from a single record in the Lake Superior basin, a specimen from the Nipigon River in Ontario (McAllister and others 1985). Paddlefish is now extirpated in Ontario.

Three species of herring from the Lake Superior basin: Lake Ives cisco, known from Lake Ives in the Huron Mountains of Michigan; Siskiwit Lake cisco from Siskiwit Lake on Isle Royale; and Nipigon Tullibee from Lake Nipigon and Black Sturgeon Lake have been described as full species (Hubbs and Lagler 1958), but are now generally regarded as members of the lake herring “complex” (Scott and Crossman 1973).

### 6.6.2 Aquatic Nuisance Species

An increasing concern for natural resource managers and environmental policy makers in the Great Lakes region is the invasion of aquatic habitats by exotic or non-native species. These are nonindigenous species that do not naturally exist in an environment and have been introduced by human activity, either intentionally or unintentionally. Exotic species that are deemed by management agencies and society to be detrimental or harmful are considered aquatic nuisance species. Aquatic nuisance species have seriously altered and disrupted Great Lakes ecosystems due to a lack of co-evolved parasites and predators to keep their populations under control. Exotic species have the ability to out-compete native species for food and habitat and, in the most severe cases, to displace native species entirely. Although there are hundreds of exotic species in the basin, only a few are invasive enough to threaten natural habitats, native species abundance, and community structure and function.

Since the 1800s, more than 139 nonindigenous aquatic organisms have become established in the Great Lakes, including 25 species of fish (Mills and others 1993). Of the 94 fish species known to inhabit Lake Superior and its tributaries, 18 are nonindigenous (U.S. Fish and Wildlife Service [USFWS] 1995). Approximately 10 percent of the nonindigenous species introduced into the Great Lakes can be classified as nuisance species; all have had significant impacts, both economic and ecological. Unintentional introductions of these species into the Great Lakes have occurred primarily through the transport of ballast water carried in ships engaging in international trade, but other practices, such as the building of canal systems within the Great Lakes basin, fish stocking practices, angling, recreational boating, and aquarium releases have also contributed to the problem. The rate of introductions has increased; nearly a third of the nonindigenous organisms found in the Great Lakes have been introduced since the opening of the St. Lawrence Seaway in 1959. Once introduced to the Great Lakes, nonindigenous species spread inland, frequently by way of barges, recreational watercraft, bait buckets, fish stocking, and other human-assisted transport mechanisms. Natural barriers such as the open ocean, different salinity levels, and the inability of organisms to reach hospitable ecosystems on their own usually hamper the spread of species between ecosystems. However, shipping allows many organisms to bypass these natural barriers through the transportation in the ballast water of seagoing vessels involved in international trade. In summary, shipping disrupts the customary checks and balances in place to prevent introductions of nonindigenous species and the subsequent degradation of ecosystems (U.S. Coast Guard [USCG] 1999).

Some intentionally introduced species also may disrupt the Lake Superior and inland lake ecosystems. Smelt have become established in inland lakes following the original introduction into Lake Superior. Pacific salmon provide valuable sport and limited commercial fisheries on Lake Superior, but they may also negatively interact with indigenous brook trout in some tributaries (Newman et. al. 2003). Implementing changes in the stocking rates of hatchery-reared Pacific salmon typically causes substantial political problems for fishery agencies, and since most Pacific salmon now living in Lake Superior are the product of natural reproduction, there are few options available for managing their populations.

One of the impacts of an established nonindigenous species is the promotion of instability and unpredictability in stable ecosystems and the loss of diversity in biotic communities (Mills and others 1993). Aquatic nuisance species can also be responsible for extinctions of native species and ecological degradation of the Great Lakes basin.

Aquatic nuisance species have had and continue to have significant economic effects on the commercial fishing industry, agriculture, tourism, sport fishing, recreation, utilities, and other industries. The U.S. Office of Technology Assessment (OTA) delivered a 1993 Report to Congress entitled *Harmful Non-Indigenous Species in the United States*, which attempted to measure the economic impact of nonindigenous plants, animals and microbes on aquatic environments. The report assessed over 4,500 nonindigenous nuisance species, including 2,000 plants, 2,000 insects, 142 terrestrial invertebrates, 91 molluscs and 70 species of fish. Economic costs are hard to accurately estimate since no federal agency comprehensively compiles such statistics. Ecological damage and other nonmarket impacts were not assessed; the report stated, however, that even when such losses were estimated, cost assessments of losses tended to be underestimated (OTA 1993).

Another estimate of economic losses due to nonindigenous species documented over 50,000 nonindigenous species in the U.S. with an estimated annual economic cost of $138 billion (Pimental and others 1999). Included among the cost estimates were control costs, property value damage, health costs and various other expenses. If monetary values could be assigned for ecological losses, the economic cost would be much higher than the $138 billion estimated. Given the high ecological and economic costs to the Great Lakes, heightened vigilance is necessary for the prevention and control of aquatic nuisance species.

The risk of introducing exotics to Lake Superior continues to be high. Increased ship traffic represents an enormous risk for the introduction of exotics. Trans-Atlantic ships are increasingly fast, improving the likelihood that exotic organisms picked up in foreign ballast water will survive the passage. With improving water quality in Lake Superior harbors, recently arrived exotics are more likely to survive and reproduce. Currently, Canada and the United States only have voluntary guidelines in place regulating ballast water discharge. Effective legislation and compliance monitoring is required to regulate discharge of tanker ballast water. In addition, public education programs are essential to minimize further spread of introduced exotics. Most introduced species are impossible to eradicate, so prevention is the best measure.

Various federal programs have been implemented in an attempt to check the negative impact that nonindigenous species are having on the Great Lakes. Foremost is the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA), which provides federal legislative support for programs aimed at aquatic nuisance species prevention and control. Under the NANPCA, the Great Lakes became the first area where ballast water regulations were imposed. A variety of other programs to help prevent and control the spread of aquatic nuisance species have been established under the authority of the NANPCA, including the Aquatic Nuisance Species Task Force, Comprehensive State Management Plans and the Great Lakes Panel on Aquatic Nuisance Species. In 1996, the NANPCA was reauthorized through the National Invasive Species Act (NISA). President Clinton reinforced the need to stop the further introduction of nonindigenous species when he signed the Invasive Species Executive Order on Feb. 3, 1999.

Other programs implemented to help stem the invasion by nonindigenous species include Ruffe Control Program, Great Lakes Action Plan for the Prevention and Control of Aquatic Nuisance Species, model guidance, The Great Lakes Ballast Water Technology Demonstration Project (GLBTDP), U.S. Coast Guard programs, Canadian Coast Guard programs, tribal programs, and Canadian programs. In an effort to have ballast water more stringently regulated by the U.S. government, the Pacific Environmental Advocacy Center (PEAC) filed a petition with EPA requesting that EPA repeal its exemption of ballast water from National Pollutant Discharge Elimination System (NPDES) regulation under the Clean Water Act (CWA).

The management activities of aquatic nuisance species have four distinct components: educational outreach, detection and monitoring efforts, prevention activities and control activities. Within each of these components are a variety of measures that can and/or should be taken. Of particular concern is the need to design and implement effective ballast management programs and resolution of the “no ballast on board” (NOBOB) issue.

Experts disagree about the relative importance of prevention and control. Effective control in aquatic systems is often impossible, but the impacts of aquatic nuisance species merit an attempt. At least partial success has been achieved in control programs with the sea lamprey, ruffe, and purple loosestrife. Preventing an invasion is most effective, because once a species invades a new habitat, it is virtually impossible to eradicate it. Restricting and regulating ballast water discharges are key to stopping further introductions of aquatic nuisance species.

Finally, additional efforts need to be explored and implemented to stop further introduction and spread of nonindigenous species. Examples of such efforts are suggested in the policy recommendations and needed actions section and include the need for better identification of possible future invaders, the need to encourage interjurisdictional cooperation and information sharing, the necessity to devise new technology to deal with the threat of aquatic nuisance species, and the need to improve ballast water management.

The aquatic nuisance species discussed below are listed in alphabetical order and are not prioritized in terms of potential or known impacts.

***Eurasian Water Milfoil***

Eurasian water milfoil is an extremely aggressive submergent plant native to Eurasia and Africa. By the 1980s, it spread to inland lakes in the Wisconsin basin and was present in shallow bays of Lake Superior by 1993 (WI DNR 1999). In 1999 it was discovered in Lake Superior at Thunder Bay, but is suspected of being present for a number of years (P. Lee, personal communication). It is not known elsewhere in the Ontario basin.

Its preferred habitat is fertile, mineral sediments in eutrophic, nutrient-rich lakes. It is an opportunistic species that prefers highly disturbed lakebeds, lakes receiving nitrogen and phosphorous-laden runoff (WI DNR 1999).

Dense stands of Eurasian water milfoil can alter nutrient cycling from the sediments to the water column and may lead to low oxygen levels and algae blooms. It forms masses of vegetation in nutrient-rich lakes, crowding out native aquatic vegetation and interfering with water recreation (WI DNR 1999).

Eurasian milfoil is unlikely to become widespread in Lake Superior due to its oligotrophic nature and fast water of most of its tributaries, but warmer, nutrient-rich bays and inland waters are vulnerable.

It reproduces from vegetative fragments and can be inadvertently transported between water bodies by boats. Control measures have focused on increasing public awareness of the necessity to remove weed fragments at boat landings. Mechanical and biological controls are being attempted in Wisconsin (WI DNR 1999).

***Rainbow Smelt***

Rainbow smelt, native to the Atlantic coast, entered Lake Superior around 1930. Rainbow smelt populations grew rapidly during the 1950s and 1960s and became the dominant prey species for lake trout in Lake Superior (Dryer and others 1965, Conner and others 1993). Rainbow smelt became the principal forage fish for lake trout and other top predators and have been implicated as a competitor for the native lake herring, whose populations collapsed during the buildup of the smelt population. The rainbow smelt population continued to grow until the late 1970s and then declined greatly due to heavy predation by trout and salmon, reaching all-time low levels of abundance in the early 1980s. Rainbow smelt prey upon the larvae of native fish and eat a diet that broadly overlaps that of other native cisco species although there has been no direct measure of the effect of smelt on these fish species in Lake Superior (Selgeby and others 1994a). Smelt are the preferred food for predator fish, and have profoundly changed the flow of energy through the Lake Superior fish community. Rainbow smelt also contain thiaminase (about half as much as alewives) and therefore reduce the survival rate of newly-hatched salmonine larvae. Fishery management agencies in the Lake Superior basin have agreed that rainbow smelt is an undesirable species that should not be protected from fishing.

### *Round Goby*

The round goby is a small, bottom-dwelling, soft-bodied fish. It is native to the Black and Caspian Seas, was first detected in the St. Clair River in 1990, and by 1995 had spread to four of the five Great Lakes. The round goby was discovered in Lake Superior in the St. Louis River Estuary in 1995. It is believed that round gobies were introduced to the Great Lakes through ballast water transfer. The goby is currently poised to enter almost half the United States through connected waterways unless its progress can be halted. The round goby is currently found 71 km downstream in the Illinois Waterway, which connects to the Mississippi River.

Round gobies are particularly threatening because they are aggressive, territorial, competitive for food, spawning, and shelter areas, highly tolerant of a variety of environmental conditions, feed on eggs and fry of native fish, and have a large body size compared to similar bottom-dwelling fish species. On the beneficial side, gobies eat large quantities of small zebra mussels, up to 78 mussels per day in laboratory settings. Because gobies eat zebra mussels and in turn are eaten by many piscivorous fishes, they provide a conduit from mussel tissue to fish tissue that was previously less available in a goby-free environment. Contaminant transfer from zebra mussels to highly-valued fish species is an issue. Research is underway to investigate the severity of this problem.

### *Ruffe*

The ruffe, a small perch-like Eurasian fish, was first detected in the estuary of the St. Louis River in western Lake Superior in 1986 and became very abundant in the favorable habitat of the nearshore waters, raising concerns about competition with native species (Ruffe Task Force 1992, Bronte and others 1998). It was probably transported there in the ballast water of seagoing vessels, as Duluth is a major port on Lake Superior. It also occurs in the Kaministiquia River at Thunder Bay. By 1991, the ruffe was the most abundant species in the St. Louis River estuary. The ruffe is also now found in Lake Huron at Alpena Harbor, Michigan, very likely the result of transport in ballast water of interlake shipping. A negative effect of the Eurasian ruffe on the Lake Superior fish community has not currently been found, although ruffe have become the most abundant fish species in the estuaries of some tributaries to western U.S. waters of Lake Superior (Hoff and others 1998). The Great Lakes Fishery Commission estimates the European ruffe could cause losses of $105 million annually if it is not controlled. A control program for ruffe was approved in 1995 and has been successful in delaying the spread of ruffe in the Great Lakes and inland waters.

### *Rusty Crayfish*

Rusty crayfish is native to the southern Great Lakes states, but has spread to lakes and streams in the Lake Superior basin, probably by anglers using them as bait (Gunderson 1995). Control efforts have included angler education to reduce the spread of crayfish to uninfested lakes and streams. Rusty crayfish alter habitat by reducing the abundance and diversity of aquatic plants, with consequent results on the fish, invertebrates and other species that depend on submergent vegetation for food and cover. They also feed on aquatic invertebrates and can displace native crayfish species (Gunderson 1995).

Rusty crayfish were discovered in 1985 in Pounsford Lake, Ontario and have since been found in the Neebing-McIntyre, Kaministiquia, Pigeon, and Little Pine rivers. They have invaded Pigeon Bay on Lake Superior, and are probably now in Black Bay (Momot 1995, W. Momot, personal communication). They are present in the Duluth/ Superior Harbor and other inland sites in Michigan and Wisconsin (G. Czypinski, personal communication).

### *Sea Lamprey*

The sea lamprey is an eel-like, jawless fish that attaches itself to the body of a fish and sucks blood and tissue from the wound. The lamprey is native to coastal regions on both sides of the Atlantic and was first noticed in Lake Ontario in the 1830s. Originally, Niagara Falls served as a natural barrier to keep sea lampreys out of the upper Great Lakes. However, when the Welland Canal was constructed in 1829 for the shipping industry, a new route for sea lampreys was opened and the invasion of the upper Great Lakes began.

In 1921 the lamprey was discovered in Lake Erie, in 1936 in Lake Michigan, in 1937 in Lake Huron and finally in Lake Superior in 1938. The sea lamprey is considered the most devastating of all aquatic nuisance species to have infested the Great Lakes. A subsequent explosion in the sea lamprey population caused serious declines in lake trout in all the Great Lakes but Lake Superior. It is only through control and restocking activities that lake trout populations have recovered. Even today, sea lamprey continue to kill a substantial number of lake trout in Lake Superior every year (Hansen and others 1994, Weeks 1997). An international control program under the Great Lakes Fishery Commission has successfully suppressed sea lamprey populations since about 1960. The use of chemicals and barrier dams to control sea lamprey, although good at protecting lake trout and whitefish, present a difficult balancing act to managers because these control tools also have potential negative effects on lake sturgeon migration up tributaries and survival of recently hatched lake sturgeon in tributaries. This control program is the oldest control program in existence in the U.S., and yet all efforts have still been unable to eradicate the species from the Great Lakes ecosystem.

### *Spiny Waterflea*

Spiny waterflea is an exotic zooplankton (*Bythotrephes* sp.) that is very abundant in early summer in Lake Superior. It was apparently introduced in ballast water. Larger fish regularly eat *Bythotrephes* but the large size of this zooplankter may prevent its consumption by fish during the critical early life stages when zooplankton are a principal component of the diet. Its effects on the aquatic community are unknown.

Experiments with alternative prey demonstrate how (*Bythotrephes longimanus*) co-exists with lake trout (*Salvelinus namacycush*) in Lake Superior. *Bythotrpehes'* caudal spine protects the animal from small fish predation and, at intermediate densities, disrupts foraging behavior of young-of-the-year fish (Barhisel and Kerfoot, 2004). Lake trout response to *Bythotrephes* depends on spine length and fish size. Aversion to *Bythotrephes* occurs after a certain threshold of encounters and foraging efficiency on the alternate prey (*Daphnia*) improves because *Bythotrephes* becomes recognized and ignored (Barnhisel and Kerfoot, 2004).

***Zebra Mussel***

Zebra mussels were introduced into the Great Lakes in the mid 1980s through ballast water discharge from transoceanic ships (Minnesota Sea Grant 1998). This species is native to the Caspian Sea region and quickly spread throughout Europe before the Industrial Revolution. By 1989, zebra mussels were found in all of the Great Lakes, as well as many inland lakes. Under the right conditions, zebra mussels reproduce quickly, are very prolific, and are very tolerant to a wide range of environmental conditions. They can become established over a wide range of depth, light intensity, and temperatures, but are rare in wave-washed zones, except for sheltered nooks and crevices.

Zebra mussels alter habitat by filtering particulate matter, including phytoplankton and some small forms of zooplankton from the water column. This reduces the food base for many small fish, increases water clarity and alters the nutrient flow of the lake. They also densely cover any hard substrate, including the shells of native mollusks to the extent that they kill their host by encrusting their shell so heavily that the native species cannot open to feed or breathe. Zebra mussels contribute to the cycling of some contaminants. Beyond their ecological effects, zebra mussels also create serious financial costs for facilities that draw water from the Great Lakes by clogging water intake systems. Although various methods are being explored, no effective means of control in natural aquatic systems has yet been found for zebra mussels in the Great Lakes. Currently, industry treats their intake water with chlorine in order to limit zebra mussel infestations.

Zebra mussels are confirmed at only a few sites on Lake Superior, including Duluth/Superior Harbor, Chequamegon Bay and most recently Whitefish Bay (Gary Czypinski, personal communication). They are apparently not yet established on the Ontario side of Lake Superior, but have been observed attached to ships and navigational buoys at the Thunder Bay Port and at Mamainse (Jeff Black, personal communication; S. Greenwood, personal communication). They have also established small colonies in the St. Marys River in association with the navigation locks.

The spread of zebra mussels in Lake Superior might be limited by low calcium availability and low summer water temperatures (below 12 degrees Celsius) although mild weather in recent years has apparently allowed reproduction to occur in the St. Louis Estuary. As with other exotic aquatic species, increased public awareness should help controlling the spread.

***Other Species***

Several other species of concern have colonized Lake Superior and its tributaries. A summary of these species has been compiled for this chapter by Douglas A. Jensen, Exotic Species Information Center

Coordinator at the University of Minnesota Sea Grant Program, Duluth and is listed in Addendum 10-A at the end of this chapter.  For completeness, the previously mentioned species have also been included in the table.

## IV. MOST SIGNIFICANT NEEDS AND STRATEGIES

### Introduction

Five key action areas: Information Gathering, Monitoring, Communication, Planning, and Stewardship are identified in this section. For each action area, a broad statement of need is followed by a list of specific needs and some suggested strategies to address them. By implementing these strategies, we will move toward achieving a sustainable Lake Superior ecosystem which is a global model for resource management.[2]

Active and continuous *information gathering* is required to help us understand and piece together the intricacies of the complex relationship between living organisms and their physical environment. *Monitoring* may take many forms and is ultimately designed to direct management activities and policy development. Monitoring of population trends (change, stability), or research oriented monitoring to gain an understanding of the cause and effect of specific actions on species or habitats, or why a project was a success or failure, will provide sign posts to improve future management within the lake basin. Together these actions will provide insight and knowledge that can be communicated to governments, policy makers, planners, managers, and citizens of the basin. This will enable informed and effective *communication* about the links between land and resource use and ecosystem health with industry, business, landowners, and the public.

Moving toward actively *planning* at a basin-wide scale will assist in addressing the gaps in, and impediments to, sustainable resource management of land and water resources, help speak to the needs of today, and prepare us for future challenges.

Finally, addressing *stewardship* needs will help foster the development of a healthy basin ecosystem that is resilient to perturbations from human activities and provides a broad range of sustainable benefits to its citizens.

Note that these strategies represent a long term approach to identifying management needs. As opposed to representing specific committed actions, they represent work that needs to be initiated and continued over many years or decades. Projects will be accomplished not only by agencies, but by industry, non-governmental organizations (NGOs), and individuals.

### Information Gathering

*Broad Statement:* Broad-scale data collection and analysis are needed to support natural resource management and protection through informed decision-making. More specifically, resource managers need:

- **Accessible and up to date data bases containing comprehensive information related to terrestrial and aquatic ecosystems, native and exotic species, and habitat in the basin.**

[2] Lake Superior Lakewide Management Plan LaMP: 2002 Progress Report

Strategies to meet this need include:

Expand the existing, shared GIS habitat database to include information about past and present research and resource management activities and knowledge gaps for habitats, communities, and biota.

Develop comprehensive and detailed inventories of habitats for the creation of a habitat data base.

In the medium term, develop and maintain a complete, comprehensive database of important habitat information including storage in a GIS format to ensure basin wide access to data.

In the short term, begin the process of developing agreements among jurisdictions and agencies including engaged NGOs for data sharing.

Continue to provide information for an aquatic data layer in the Lake Superior Decision Support GIS database and ensure a linkage to the GLFC Aquatic GIS database under development.

Develop and support standardized quantitative protocols for the collection of physical habitat data by professionals and engaged NGOs.

- **Quantitative information about predator/prey relationships and impacts to productivity at all scales.**

Strategies to meet this need include:

Encourage academic institutions and others to conduct research into both aquatic and terrestrial predatory-prey relationships and productivity.

Encourage research into the impacts of varying prey (small mammal) abundance on wide-ranging predators (e.g., lynx, fisher, marten).

Improve the knowledge of the pelagic fish community through development of acoustic survey techniques and predictive models.

Conduct bottom trawling to waters greater than 90 m deep in Lake Superior to increase knowledge about the deep water fish community.

Improve the bioenergetics knowledge of predators and their prey in aquatic systems.

Update the knowledge of plankton communities in Lake Superior via analysis of existing collections and new collections.

Determine the distribution and abundance of benthic organisms in Lake Superior and inland lakes and their role and importance in sustaining the fish communities.

Understand the impact spring flow fluctuations on tributaries with hydroelectric facilities have on recruitment of brook trout, walleye, and lake sturgeon.

- **Analysis and insight into species interactions between native and non-native species as well as between native species in an altered or manipulated environment.**

Strategies to meet this need include:

Determine the distribution and abundance of benthic organisms in Lake Superior and inland lakes and their role and importance in sustaining the fish communities.

Describe and measure the competitive relationships between coaster brook trout and naturalized anadromous salmonines in all shared habitats.

Describe the interaction of siscowet, humper, and lean forms of lake trout related to habitat use and forage availability.

Describe and measure the interactions between non-native species (e.g., round gobie, Eurasian ruffe) with native species in all habitats where non-native species have become established in Lake Superior.

- **Knowledge of the role and influence of disease and contaminants in species demography and basin ecosystems**.

Strategies to meet this need include:

Determine present contaminant load status of "best bet" wildlife species.

Determine which species have the highest contaminant loads or are otherwise most affected by contaminants.

Establish a mechanism for reporting, tracking, and responding to diseases in wild populations.

- **An understanding of meta-population dynamics in the sustainability of species' populations, including the influence of "overabundant" species (e.g., herbivory) on ecosystem functioning.**

Strategies to meet this need include:

Identify population issues for threatened and endangered species.

Identify and conduct studies on impacts of overabundant native species.

Develop education materials which inform the public and agency managers of problems.

- **An understanding of the risk of invasion by new exotic species from outside the Lake Superior basin including an annual forecast of imminent threats.**

  Strategies to meet this need include:

  Inventory the distribution and abundance of exotic invasive species to support strategies for monitoring, determining introduction pathways, preventing range expansion, and control or eradication.

- **Descriptive information about historic and current habitat conditions and important habitat sites in the basin.**

  Strategies to meet this need include:

  Identify and quantify critical aquatic habitat for key fish species that are both indicators of ecosystem health and fish community stability and illustrate that habitat on GIS maps.

  Complete comprehensive substrate mapping for nearshore waters, harbors, bays, and estuaries of Lake Superior to identify important fish habitat.

  Complete comprehensive habitat assessment and aquatic community surveys to identify important habitat sites in tributary streams and inland lakes of the watershed.

  Create digital, basin-wide coverage of original land cover in GIS format.

  Develop an approach to quantifying land use (or habitat) change using GIS.

  Identify sites that meet the criteria for important habitat. This includes integrating co-operative, long term habitat inventory and assessment efforts.

  Inventory and assess impacts to habitat at a basin wide scale from current and historic sources of degradation.

  Complete comprehensive, systematic Natural Heritage Inventory/biological surveys in the watershed to identify remaining high-quality natural communities and locations of rare plants and animals.

  Facilitate development of decision-making tools, natural resource information, and expertise originating from an actively supported and funded Lake Superior basin research community.

**Monitoring**

*Broad Statement:* Support for and maintenance of long-term biota and habitat monitoring programs is needed to protect and restore the Lake Superior basin ecosystem. More specifically, resource managers need:

- **Biological, community-based monitoring programs on which to base species status and trends reports.**

  Strategies to meet this need include:

  Hold an annual workshop over a three year period to tackle one of the identified "Best Bet" wildlife indicators and develop a basin-wide monitoring protocol.

  Field test the proposed monitoring protocols developed above and make revisions as required.

  Solicit buy-in from basin resource agencies to conduct monitoring activities and set an implementation schedule.

  Develop a basin-wide database to track results of monitoring efforts temporally and spatially within the basin.

  Explore the development of an inventory, monitoring, assessment and reporting protocol for the Lake Superior basin and how it might be implemented.

  Inventory all levels of the biotic community, with particular attention to little known species and key species to allow assessment of species and community needs.

  Support and encourage literature reviews, which summarize the current knowledge base and provide direction on where future monitoring and research should be focused.

  Determine what monitoring programs exist and where further development of monitoring is needed.

  Continue established monitoring programs of the Great Lakes Fishery Commission's Lake Superior Technical Committee including spring lake trout assessment and siscowet surveys.

- **Information concerning control efforts and annual range extensions of existing and new exotic species in the Lake Superior basin.**

  Strategies to meet this need include:

  Prepare an annual report on control efforts and dispersal of existing and new exotic species in the Lake Superior basin.

Continue to provide on the internet the annual summary report addressing ruffe surveillance in the Great Lakes.

- **Annual tracking of development activities at the land water interface that alter ecosystem form and function at a variety of scales.**

  <u>Strategies to meet this need include:</u>

  Develop a GIS layer to track development activities at the land-water interface that may alter ecosystem form and function.

  Develop a mechanism to track existing and planned development activities and keep the GIS layer current.

- **Monitor projects in the basin annually in order to track multi agency rehabilitation effort successes and failures through time and space.**

  <u>Strategies to meet this need include:</u>

  Develop a basin database, or modify existing basin databases, to have the ability to track multi-agency rehabilitation efforts through space and time.

  Convey to project proponents and funding agencies, the concept that long term monitoring is an essential part of any restoration project and must be integral to the projects (funded and implemented).

**Communications**
*Broad Statement:* Work with local, regional and national governments and their departments to encourage policy, planning, and action that preserves and protects the Lake Superior ecosystem. Find ways to facilitate a common understanding with industry, business, landowners, and the public about the links between land use and ecosystem health.

- **Become more involved with efforts to communicate with basin citizens about the importance and value of living things and our dependence upon their well being.**

  <u>Strategies to meet this need include:</u>

  Become more engaged with Sea Grant and University Extension offices to bring a binational, basin-wide focus to outreach efforts.

  Pursue the development of informational programming related to the Lake Superior basin through existing contacts.

  Influence ongoing television and radio programming to reflect a binational, basin-wide approach to the restoration and protection of the Lake Superior basin.

Develop a position for a Binational Program educator to present material to local governments and decision makers highlighting the linkages between land use and ecosystem health.

- **Develop communication tools to present information, issues, and solutions related to the Lake Superior basin ecosystem**.

  Strategies to meet this need include:

  Develop tools to inform citizens and governments about ecosystem restoration and protection strategies, both those that are successful and those that are unsuccessful.

  Develop a guidance document for vegetation restoration projects in the basin.

  Provide information to local governments and landowners about the linkages between land use and ecosystem health.

  Develop and distribute a GIS map of known coastal wetland hectares, types, condition and areas where restoration is required.

  Support the Lake Superior Decision Support System's (LSDSS) efforts to develop methods to present user friendly information about the impact of various management/development scenarios on local and basin ecosystems.

  Ensure that a linkage between the LSDSS and GLFC Aquatic database is available to planning, development, and natural resource managers.

  Educate citizens in the Lake Superior basin about the importance and appropriate use of local native plants in restoration and landscaping projects.

  Promote the development of an IMAX film about Lake Superior.

  Develop an information focused web site for use by the Binational Program.

- **Engage governments at all levels in resource management and resource use by promoting and facilitating intergovernmental and interagency partnerships**.

  Strategies to meet this need include:

  Contact all agencies within each jurisdiction to ensure that they are aware of intergovernmental partnerships related to resources within their control.

  Establish a committee of technical/field experts to address terrestrial issues modeled after the Lake Superior Technical Committee of the Great Lakes Fishery Commission.

Advocate that existing intergovernmental partnerships become aware of issues related to full intergovernmental participation and encourage them to reach out to unrepresented or under- represented agencies.

Advance efforts to provide funding to agencies that need it in order to be able to participate in inter-jurisdictional efforts.

Develop materials and media to educate government planning personnel and development agencies (Department of Transportation, highway and road departments, etc.) and improve access to information related to threatened, endangered, and extirpated species.

**Planning**
*Broad Statement:* Discover and pursue means to achieve common understandings and consensual agreements for needed actions related to the goals of this chapter and their integration into planning at all levels within the basin.

**The following two strategies are common to each of the first five specific needs identified:**

Identify priority research needs and research gaps, and develop appropriate projects to address those needs and gaps.

Encourage funding entities to revise criteria upon which grant applications are assessed to support the needs identified in this chapter.

- **Determine the future mix of biological communities and landscape mosaics desired within the basin and integrate the principles of natural resource management to develop guidelines for long-term ecological direction to achieve that desired condition.**

Strategies to meet this need include:

See above.

Utilize existing planning documents such as Fish Community Objectives for Lake Superior and ensure that these documents are regularly revisited and updated as necessary.

Evaluate restoration projects and restoration ecology research that addresses native species in order to link successes to specific restoration features to allow planning for future needs.

- **Plan for sustainable land, shoreline and water development.**

Strategies to meet this need include:

See above.

Develop a mechanism to make the GIS layer that monitors and tracks development activities at the land-water interface available to resource/land-use/municipal managers throughout the basin for use in planning.

Identify priority research needs and research gaps, and develop appropriate projects to address those needs and gaps.

Encourage funding entities to revise criteria upon which grant applications are assessed to support the needs identified in this chapter.

Hire two staff each in the U.S. and Canada to directly assist local governments with development or amendment of community growth plans.

Promote and elevate status of protection as a mitigation tool.

Integrate into the planning process the minimization of impacts and mitigate for loss of habitat integrity and function as well as biotic community structure from existing development.

- **Determine protection levels for important habitat areas.**

Strategies to meet this need include:

See above.

Identify priority areas of important habitat throughout the basin and enter them into the LSDSS GIS database.

Develop a process by which the LSDSS GIS database is fully developed and regularly updated (twice/yr).

Develop a mechanism to integrate information contained in the LSDSS into activities of local planning agencies and organizations.

- **Address preventative measures related to aquatic species transport in ballast water in Lake Superior.**

Strategies to meet this need include:

See above.

Encourage funding entities to revise criteria upon which grant applications are assessed to support the needs identified in this section.

Ensure that all ships navigating in Lake Superior follow best management practices (BMPs) for ballast water.

Support research into ballast water treatment methods.

Develop a list of organisms that are likely to be transported through ballast water and identify their potential for ecological, economic, and social impacts.

Enact legislation that prevents the sale and transport of live non-native plants and animals into the jurisdictions of the basin.

Complete an inventory and control plan for priority existing exotic species at the scale of the Lake Superior basin and begin implementation.

- **Develop a mechanism to deal with new invasive species and diseases not transported by ballast water.**

Strategies to meet this need include:

See above.

Work with state and provincial Aquatic Nuisance Species coordinators to implement rapid response plans for new invasive species and diseases in the Lake Superior basin.

Develop a coordinated, basin-wide exotic species control and monitoring program that has the support and the participation of all municipal, state/provincial and federal jurisdictions in the Lake Superior basin.

- **Obtain greater involvement by local land, roadway, rail way and water managers in Lakewide Management Planning.**

Strategies to meet this need include:

Get representation from regional planning entities on Binational Program committees.

Educate local land and water managers and the public about the LaMP through varied outreach outlets (newsletters, presentations, web sites, newspapers, video productions, hunting/fishing expos, lawn, and garden shows, etc.).

Distribute CDs of the integrated LaMP ecosystem chapters to all Lake Superior basin governmental and NGO land and water managers and individual landowners with 40 ha or more of land.

Continue periodic contact through public meetings, workshops, local planning commission meetings, etc. to further understanding and involvement in the LaMP process.

Invite and secure participation and exchange of planning initiatives with local land and water conservation departments, soil and water conservation agencies, municipal organizations, regional planning organizations, and townships in Lake Superior Work Group meetings.

- **Over the long term, develop ecologically based integrated watershed management plans for all watersheds within the Lake Superior basin.**

  <u>Strategies to meet this need include:</u>

  Determine which watersheds have existing plans and develop a list of watersheds that need a new or revised plan.

  Prioritize the watershed list.

  Develop watershed plans for the highest priority watersheds in need of a new or revised plan.

**Active Stewardship**
*Broad Statement:* Foster a healthy basin ecosystem that is resilient to perturbations from human activities and non-native species and provides a broad range of sustainable benefits to its citizens.

- **Promote a common understanding of how the Lake Superior ecosystem functions**.

  <u>Strategies to meet this need include:</u>

  Develop educational/outreach materials and information kiosks throughout the basin to deliver common message to the public.

  Involve local and regional environmental oriented organizations in restoration projects and research studies.

- **Identify mechanisms to increase awareness of natural resource issues and enhance a stewardship conscience among the basin residents.**

  <u>Strategies to meet this need include:</u>

  Encourage the use of native species for all projects requiring vegetation restoration.

  Encourage land use planning efforts that are targeted at protecting and restoring wildlife while also maintaining economic viability of local communities.

  Educate nurseries, gardeners, florists, boaters, anglers, commercial fishers, aquaculture facilities, aquarium hobbyists, the general public, and the shipping industry to help prevent the introduction of new non-native species, and reduce the spread and control or eliminate already established non-native species.

- **Achieve no net loss of the productive capacity of habitat supporting Lake Superior basin plants and animals.**

  Strategies to meet this need include:

  Implement conservation actions to maintain and restore habitat function and structure at sites that meet the criteria for important habitat sites, including the application of special designations.

  Design and implement projects to address lost ecosystem functions at degraded sites.

  Restore degraded wetland hectares in the Lake Superior basin.

  Implement actions to reduce stressors and eliminate sources of stress to important terrestrial and aquatic habitat sites.

  Restore and protect conifer forests in appropriate upland and stream corridors.

  Restore or protect riparian conifer forests.

  Implement recommendations contained in the North American Waterfowl Management Plan.

  Encourage land use planning efforts that are targeted at protecting and restoring wildlife while also maintaining economic viability of local communities.

  Implement conservation actions recommended in watershed plans, reservation integrated resource management plans, lake management plans, and eco-regional conservation plans.

- **Reduce human induced contaminants so that traditionally consumed fish and wildlife are safe to eat by all individuals.**

  Strategies to meet this need include:

  Succeed in the zero discharge goal for nine persistent toxic chemicals for the Lake Superior basin.

- **Rehabilitate populations of indigenous species.**

  Strategies to meet this need include:

  > Restore and protect habitat for native species of economic and cultural importance, including lake sturgeon, lake trout, lake whitefish, wild rice, ginseng, and others where appropriate.
  >
  > Encourage the use of native plant species for all projects requiring vegetation restoration.
  >
  > Agencies individually and cooperatively continue to carry out aspects of Rehabilitation Plans for walleye, lake sturgeon, and brook trout.
  >
  > Implement conservation actions recommended in watershed plans, reservation integrated resource management plans, lake management plans, and eco-regional conservation plans.
  >
  > Hold workshops and conferences to establish research needs and agency coordination for brook trout and lake sturgeon rehabilitation efforts on Lake Superior.

- **Reduce the impact of existing hydroelectric facilities and prevent future impacts.**

  Strategies to meet this need include:

  > Ensure that agency personnel participate in hydropower re-licensing projects and that projects implement practices that ensure passage for all desired fish species, and maintain a natural hydrograph, thermal regime, and adequate flow rates to allow native aquatic species to thrive.
  >
  > Remove artificial impediments to fish passage or develop by-pass systems in tributaries where appropriate.
  >
  > Identify all FERC (U.S.) and Water Management Plans (Canada) projects within the basin and list those for which review or renegotiations will occur within the next five years. Ensure that agency biologists participate in the project review process.

- **Reduce or eliminate atmospheric deposition of contaminants in Lake Superior and contaminant loads in basin-dwelling fish and wildlife species in concert with efforts to de-list Areas of Concern.**

  Strategies to meet this need include:

  > Achieve and maintain water and air quality standards by enforcing existing legislation.

Develop new legislation, and/or incentive programs to meet standards that extend to those areas outside the basin that contribute to impairments within the basin.

- **Foster healthy basin communities of native species that are resistant to non-native species invasions.**

  Strategies to meet this need include:

  Implement habitat recommendations of the Great Lakes Panel on Aquatic Nuisance Species.

  Implement the recommendations contained in federal threatened and endangered species recovery plans. Restore and protect habitat for state, tribal, and provincially listed species.

  Identify recovery actions for threatened and endangered species.

  Protect, enhance, and restore species of concern such as caribou, moose, colonial water birds, boreal owl, northern goshawk, white pine, and hemlock.

  Implement conservation actions recommended in watershed plans, reservation integrated resource management plans, lake management plans and eco-regional conservation plans.

  Encourage the appropriate use of native species for all projects requiring vegetation restoration.

- **Promote management actions that maintain genetic diversity in fish and aquatic organisms.**

  Strategies to meet this need include:

  Hold workshops and conferences to establish research needs and agency coordination for brook trout and lake sturgeon rehabilitation efforts on Lake Superior.

  Ensure species reintroduction minimizes genetic distance from the original local species population rather than use a common source for reintroduction throughout the basin.

- **Control existing populations of exotic invasive species and implement actions to deal with new invasive species and diseases.**

  Strategies to meet this need include:

  As appropriate, develop legislation, regulations, or establish guidelines to prevent the sale and/or transfer of live plants and animals outside of their native range.

  Educate plant nurseries, boaters, anglers, commercial fishers, aquaculture facilities, aquarium hobbyists, general public, and the shipping industry to help prevent the introduction of new non-native species, and reduce the spread and control or eliminate already established non-native species.

Establish and implement Best Management Practices for a human transport vectors of non-native species (forest industry, recreation and tourism, intra-lake shipping, horticultural and agriculture practices, etc.) to prevent the introduction and spread of exotics.

Develop sources of native plants and seeds in an ecologically appropriate manner throughout the Lake Superior basin for use in vegetation restoration.

Establish standards of native species propagation and use as well as definitions of seed zones.

Develop a list of native species that are regionally/habitat specific and ecologically appropriate for propagation.

Complete an inventory and control plan for priority existing exotic species at the scale of the lake superior basin and begin implementation.

**Accomplishments and Next Steps**

Since its completion, the LaMP 2000 has served as a guide and provided impetus for state/provincial, tribal, and federal management and regulatory agencies to achieve their vision for Lake Superior. In addition, it has been used by local decision-makers to assist with land and water use projects and priorities. As a result, many significant accomplishments have been realized that address a mission of the Lake Superior Binational Program. That mission is, to support intact, diverse, healthy and sustainable ecosystems and the native plant and animal communities that depend on them. As we make progress toward the mission and goals of LaMP 2000, some existing issues remain or evolve, and new issues emerge that influence the future direction of natural resource use and management.

In addition to the LaMP 2000, updates on progress being made and recommendations for future direction are developed on a semi annual basis. To learn more about the LaMP 2000 visit the Environmental Protection Agency web site at http://www.epa.gov/glnpo/lakesuperior/lamp2000/. The LaMP 2002 and 2004 Progress Reports can be viewed by visiting www.epa.gov/glnpo/lakesuperior/.

## V. REFERENCES


Aitken, S.G. P.F.Lee, D.Punter, and J.M.Stewart. 1988. Wild Rice in Canada. Agriculture Canada Publication 1830. NC Press Ltd. Toronto.

Albert, D. A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: a working map and classification. Gen. Tech. Rep. NC-178.St. Paul, MN: U.S. Department of Agriculture, Forest Service, NorthCentral Forest Experiment Station. Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov /resource /1998/rlandscp/rlandscp.htm (Version 03JUN98).

Argus, G.W., K.M. Pryer, D.J. White, and C.J. Keddy. 1982-1987. Atlas of the rare vascular plants of Ontario. National Museum of Natural Sciences. Ottawa (looseleaf).

Argus, G.W. and D.J. White. 1984. Ginseng. In: Argus, G.W., K.M. Pryer, D.J. White, and C.J. Keddy. Atlas of the rare vascular plants of Ontario. National Museum of Natural Sciences. Ottawa (looseleaf).

Armantrout, N.B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Armstrong, Ted. 1999. OMNR. Personal communication.

Armstrong, E.R. 1998. Integration of woodland caribou habitat management and forest management in northern Ontario – current status and issues. Rangifer, Special Issue 10: 221–230.

Atria Engineering Hydraulic Inc. 1993. Nipigon River: Development of a water management plan: Draft Options Report. Prepared for Nipigon River Management Committee.

Aubry, K.B. G.M. Koehler, and J.R. Squires. 1999. Ecology of Canada lynx in southern boreal forests. USDA Forest Service Gen. Tech. Rep. RMRS GTR-30.

Auer, N.A. [ed.]. 2003. A lake sturgeon rehabilitation plan for Lake Superior. Great Lakes Fish. Comm. Misc. Publ. 2003-02.

Auer, M.T. and L.A. Bub. 2004. Selected features of the distribution of chlorophyll along the southern shore of Lake Superior. Journal of Great Lakes Research. In Press.

Auer, N.A. and J.E. Kahn. 2004. Abundance and distribution of benthic invertebrates, with emphasis on Diporeia, along the Keweenaw Peninsula, Lake Superior. Journal of Great Lakes Research. In Press.

Austen, M.J.W., M.D.Cadman, and R.D.James. 1994. Ontario Birds at Risk Status and Conservation Needs. Federation of Ontario Naturalists. Don Mills.

Balgooyen, C. P., and D. M. Waller. 1995. The use of *Clintonia borealis* and other indicators to gauge impacts of white-tailed deer on plant communities in northern Wisconsin, USA. Nat. Area J. 15: 308–318.

Bakowsky, W.D. 1996. Rare communities of Ontario: Glaciere talus. Natural Heritage Information Centre 3(2): 2–4.

Bakowsky, W.D. 1997. Rare communities of Ontario: Freshwater coastal dunes. Natural Heritage Information Centre 4(1): 5–8.

Bakowsky, W.D. 1998. Rare communities of Ontario: Great Lakes arctic-alpine basic shoreline. Natural Heritage Information Centre 4(2): 10–12.

Barbiero, R.P. and M.L. Tuchman. 2000. Results from the Program Office's Biological Open Water Surveillance Program of the Laurentian Great Lakes for 1998. U.S. EPA Great Lakes National Program Office. Chicago.

Barbiero, R.P, and M.L. Tuchman. 2001. Results from the U.S. EPA's biological open water surveillance program of the Laurentian Great Lakes: I. Introduction and phytoplankton results. J. Great Lakes Res. 27(2):134–154.

Barbiero, R.P., R.E. Little, and M.L. Tuchman. 2001. Results from the U.S. EPA's biological open water surveillance program of the Laurentian Great Lakes: III. Crustacean Zooplankton. J. Great Lakes Res. 27(2):167–184.

Barbiero, R.P. and M.L. Tuchman. 2004. The Deep Chlorophyll Maximum in Lake Superior. J. Great Lakes Res. 30 (sup1): 256-268.

Barnhisel, D.R. and W.C. Kerfoot. 2004. Fitting into food webs: Behavioral and functional response of young lake trout (Salvelinus namacycush) to an introduced prey, the spiny cladoceran (Bythotrephes cederstroemi). Journal of Great Lakes Research. In Press.

Barton. D. R. and H. B. N. Hynes 1976. The distribution of Amphipoda and Isopoda on the exposed shores of the Great Lakes. J. Great Lakes Res. 2(2):207–214.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Bennet, E.B. 1978. Characteristics of the thermal regime of Lake Superior, J. Great. Lakes Res., (3–4):310–319.

Bertram, P. and N. Stadler-Salt. 1998. Selection of indicators for Great Lakes basin ecosystem health. Draft for discussion at SOLEC 98. State of the Lakes Ecosystem Conference 1998.

Bishop, C. A., D. V. Weseloh, N. M. Burgess, J. Struger, R. J. Norstrom, R. Turle, and K. A. Logan. 1992a. An atlas of contaminants in eggs of fish-eating colonial birds of the Great Lakes (1970-1988). Vol. I, Accounts by species and location. Can. Wildl. Serv. Tech. Rep. 152. 313 pp.

Bishop, C. A., D. V. Weseloh, N. M. Burgess, J. Struger, R. J. Norstrom, R. Turle, and K. A. Logan. 1992b. An atlas of contaminants in eggs of fish-eating colonial birds of the Great Lakes (1970-1988). Vol. II, Accounts by Chemical. Can. Wildl. Serv. Tech. Rep. 153. 300 pp.

Best, D. 2000. USFWS. Personal communication.

Black, J. 1999. OMNR. Personal communication

Blais, J.R. 1983. Trends in the frequency, extent and severity of spruce budworm outbreaks in eastern Canada. Can. J. For. Res. 13:539–547.

Blais, J.R. 1985. The ecology of the eastern spruce budworm: a review and discussion. *In* Recent advances in spruce budworm research. [*Ed*.] CJ. Sanders, R.W. Stark, E.J. Mullins, and J. Murphy. Can. For. Serv., Ottawa, Ont. pp. 49–59.

Blaustein, A. R., D. G. Hokit, R. K. O'Hara, and R. A. Holt. 1994. Pathogenic fungus contributes to amphibian losses in the Pacific Northwest. Biol. Conserv. 67:251–254.

Blaustein, A. R., and D. B. Wake. 1995. The puzzle of declining amphibian populations. Sci. Am. 272:52–57.

Blaustein, A. R., B. Edmond, J. M. Kiesecker, J. J. Beatty, and D. G. Hokit. 1995. Ambient ultraviolet radiation causes mortality in salamander eggs. Ecol. Appl. 5:740–743.

Blaustein, A. R., J. M. Kiesecker, D. P. Chivers, and R. G. Anthony. 1997. Ambient UV-B causes deformities in amphibian embryos. Proc. Nat. Acad. Sci. 94:13735–13737.

Blokpoel, H. 1987. Common Tern. pp. 188–189. In Cadman, M.D., P.F.J. Eagles and F.M. Helleiner (eds). Atlas of the Breeding Birds of Ontario. Federation of Ontario Naturalists and the Long Point Bird Observatory, University of Waterloo Press.

Blokpoel, H., and W. C. Scharf. 1999. The importance of the islands of the Great Lakes as nesting habitat for colonial waterbirds. Pages 32–42 in K.E. Vigmostad, [ed.] Proceedings from the 1996 U.S.-Canada Great Lakes islands workshop. Mich. State Univ., East Lansing, MI.

Blymyer, J. F., and B. S. McGinnes. 1977. Observations on possible detrimental effects of clearcutting on terrestrial amphibians. Bull. of the Maryland Herpetol. Soc. 13:79–83.

Bodaly, R.A. 1986. Biology, exploitation and culture of coregonid fishes in Canada. Arch. Hydrobiol. Beih. Ergebbn. Limnol. Vol. 22:1–30.

Bowerman, B. 2000. Clemson University. Personal communication.

Bowerman,W.W. 1993. Regulation of bald eagle (*Haliaeetus leucocephalus*) productivity in the Great Lakes Basin: An ecological and toxicological approach. Ph.D. Thesis. Michigan State University.

Bowling, C. and G. Niznowski. 1996. White pine in northwestern Ontario: Distribution, silviculture history and prospects. Ont. Min. Natur. Res. NWST Tech. Rep. TR-94.

Bridger, K.C., and J.C. Day. 1978. The Ogoki River Diversion Reservoir, Downstream, Diversion Channel, and Receiving Water-Body Effects. 2001 Environment and Resources Consulting Ltd., Waterloo, Ont.

Bronte, C. R., J. H. Selgeby, J. H. Saylor, G. S. Miller, and N. R. Foster. 1998. Hatching, dispersal, and bathymetric distribution of age-0 wild lake trout at the Gull Island Shoal Complex, Lake Superior. Journal of Great Lakes Research 21 (Supplement 1): 233–245.

Brooks, R.J., D.A. Galbraith, E.G. Nancekivell, and C.A. Bishop. 1988. Developing management guidelines for snapping turtles. Pages 174 0 179 in R.C. Szaro, K.D. Severson, D.R. Patton, eds. Management of amphibians, reptiles and small mammals in North America. U.S. For. Serv. Tech. Rep. RM-166. Fort Collins, CO.

Brown, R. W., M. Ebener, and T. Gorenflo. 1999. Great Lakes commercial fisheries: historical overview and prognosis for the future, pp. 307–354. *In* Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, East Lansing, Michigan. 551 p.

Bruland, K.W., M. Koide, C. Bowser, L.J. Maher, and E.D. Goldsberg. 1975. Lead-210 and pollen geochronologies on Lake Superior sediments. Quat. Res. 5:89–98.

Bryan, S. 1994. Survey of the breeding birds of Lake Nipigon, Thunder Bay District, Ontario (Part II). Nature Northwest: Newsletter of the Thunder Bay Field Naturalists. 48 (1): 6–8.

Burt, W.H. 1975. Mammals of the Great Lakes Region. University of Michigan Press, Ann Arbor.

Busiahn, T.R. [ed.] 1990. Fish community objectives for Lake Superior. Great Lake Fishery Commission Special Publication 90–1.

Buss, M. and M. de Almeida. 1997. A review of wolf and coyote status and policy in Ontario. OMNR, Fish & Wildlife Branch, Peterborough ON.

Cadman, M. D., H. J. Dewar, and D. A. Welsh. 1998. The Ontario Forest Bird Monitoring Program (1987-1997): goals, methods and species trends observed. Can. Wildl. Serv. Tech. Rep. Ser. No. 325.

Cadman, M.D., P.F.J. Eagles and F.M. Helleiner (eds). 1987. Atlas of the Breeding Birds of Ontario. Federation of Ontario Naturalists and the Long Point Bird Observatory, University of Waterloo Press.

Candau, J. N., R.A. Fleming, and A. Hopkin. 1998. Spatiotemporal patterns of large-scale defoliation caused by the spruce budworm in Ontario since 1941. Can. J. For. Res. 28:1733–1741.

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65:803–809.

Carleton, T.J. 2000. Vegetation responses to the managed forest landscape of central and northern Ontario. pp. 178 – 197. *In*: A.H. Perera, D.L. Euler, and I.D. Thompson (eds). Ecology of a Managed Terrestrial Landscape. Patterns and Processes of Forested Landscapes in Ontario. UBC Press. Vancouver.

Carleton, T.J. and R.W. Arnup. 1993. Vegetation ecology of eastern white pine and red pine forests in Ontario. Ont. Min. Natur. Res., Forest Fragmentation and Biodiversity Project Report No. 11.

Casper, G. S. 1998. Review of the status of Wisconsin amphibians. Pages 199–205 *in* Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507 pp.

Casper, G. S. 2002. A review of the amphibians and reptiles of the Lake Superior watershed. Tech. Rept. To the Terrestrial Wildlife Community Committee, Lake Superior Binational Program. 96 pp.

Cheng, P.N. 1987. Hydroelectric power resources of the Province of Ontario. Ontario Hydro. Geotechnical and Hydraulic Engineering Department. Report No. 87360.

Chow-Fraser, P. and D.A. Albert. 1998. Biodiversity investment areas: Coastal wetland ecosystems. Draft for discussion at State of the Lakes Ecosystem Conference 1998. Environment Canada and U.S. Environmental Protection Agency.

Chase, M. 2003. OMNR. Personal communication.

Cieminski, K. 1999. Minnesota Department of Natural Resources. Personal communication.

Clayton, L., 1984. Pleistocene Geology of the Superior Region, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular Number 46.

Cobery, C.E. and R.M. Horrall. 1980. Fish spawning grounds in Wisconsin waters of the Great Lakes. Marine Studies Center, University of Wisconsin – Madison. Published by the University of Wisconsin Sea Grant Institute. 42 p.

Coble, D. W., R. E. Bruesewitz, T. W. Fratt, and J. W. Scheirer. 1990. Lake trout, sea lampreys, and overfishing in the upper Great Lakes: a review and reanalysis. Transactions of the American Fisheries Society 119: 985–995.

Coffin, B. and L. Pfannmuller. 1988. Minnesota's Endangered Flora and Fauna. Univ. of Minnesota Press. Minneapolis.

Colby, P.J. and S.J. Nepszy. 1981. Variation among stocks of walleye (*Stizostedion vitreum vitreum*): management implications. Can. J. Fish. Aquat. Sci. 38: 1814 – 1831.

Conant, R. and J.T. Collins. 1991. Reptiles and Amphibians: Eastern/Central North America. Houghton Mifflin Company, Boston.

Conner, D. J., C. R. Bronte, J. H. Selgeby, and H. L. Collins. 1993. Food of salmonine predators in Lake Superior, 1981-1987. Great Lakes Fish Commission Technical Report 59. 20 p.

Cook, D.G. 1975. A preliminary report on the benthic macroinvertebrates of Lake Superior. J. Fish. Res. Board Can. Tech. Rep. 572.

Cook, F.R. 1984. Introduction to Canadian amphibians and reptiles. National Museums of Canada, Ottawa.

Cooper, J. 1999. OMNR, Wawa District. Personal communication.

COSEWIC. 2002. Assessment and Update Status Report on the Woodland Caribou *Rangifer tarandus caribou* Boreal Population in Canada. Committee on the Status of Endangered Wildlife in Canada, 109 pp.

COSEWIC. 2003. Canadian Species at Risk. November 2003. Committee on the Status of Endangered Wildlife in Canada, 44 pp.

Crum, H. 1988. A Focus on Peatlands and Peat Mosses. University of Michigan Press. Ann Arbor.

Curtis, J.T. 1959. The Vegetation of Wisonsin. Univ. Wisc. Press, Madison.

Cuthbert, F. J., and J. McKearnan. 1999. U.S. Great Lakes gull survey: 1998 progress report. Univ. of Minn., St. Paul MN. Rep. to U.S. Fish and Wildl. Serv., Ft. Snelling, MN.

Cuthrell, D.L. 1999a. Special animal abstract for *Euxoa aurulenta* (dune cutworm). Michigan Natural Features Inventory,Lansing, MI. 2 pp.

Cuthrell, D.L. 1999b. Special animal abstract for *Somatochlora incurvata* (incurvate emerald dragonfly). Michigan Natural Features Inventory, Lansing, MI. 2 pp.

Czypinski, G. MN DNR Personal communication.

Darby, W.R., H.R. Timmermann, J.B. Snider, K.F. Abraham, R.A. Stefanski, and C.A Johnson. 1989. Woodland caribou in Ontario. Background to a policy. Ontario Ministry of Natural Resources. Toronto. 38 pp.

Daulton, T., M. W. Meyer, and P. W. Rasmussen. 1997. The 1995 status of the common loon in Wisconsin. Passenger Pigeon 59:195–205.

Dawson, Neil. 2000. OMNR. Personal communication.

Dawson, N. 2000. Report on the status of wolverine (Gulo gulo) in Ontario. OMNR. Unpublished report.

DeCalesta, D. S. 1994. Effect of white-tailed deer on songbirds within managed forests in Pennsylvania. J. Wildl. Manage. 58:711–717.

Dell, C.I., 1973. A quantitative mineralogical examinination of the clay-size fraction of Lake Superior sediments. In Proc. 16th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., pp. 413–420.

Dell, C.I. 1974. The stratigraphy of northern Lake Superior late-glacial and postglacial sediments. In proc. 17th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., pp. 179–192.

Dermott, R. 1978. Benthic diversity and substrate-fauna associations in Lake Superior. J. Great Lakes Res. 4(3–4):505–512.

Desrochers, A., and S. J. Hannon. 1997. Gap crossing decisions by forest songbirds during the post-fledging period. Conserv. Biol. 11:1204–1210.

Detenbeck, N.E., S.M. Galatowitsch, J. Atkinson, and H.Ball. 1999. Evaluating perturbations and developing restoration strategies for inland wetlands in the Great Lakes Basin. Wetlands 19: 789 – 820.

de Vos, A. 1952. Ecology and management of fisher and marten in Ontario. Ont. Dept. Lands and Forests Tech. Bull. 90 pp.

Diana, S. G., and V. R. Beasley. 1998. Amphibian toxicology. Pages 266–277 in Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507 pp.

Diehl, S., W. Maanau, T. Jordan, and M. Sydor. 1977. Transports in Lake Superior. J. Geophys. Res. 82:977–978.

Dobbyn, J. 1994. Atlas of the Mammals of Ontario. Federation of Ontario Naturalists, Don Mills.

Dobson, H.F. 1972. Nutrients in Lake Superior. Unpublished manuscript. CCIW.

Dodge, D. and R. Kavetsky 1995. Aquatic habitat and wetlands of the Great Lake. . Environment Canada and U.S. EPA. State of the Great Lakes Ecosystem Conference. Background Paper. 71 pp.

Doepker, R. V., D. E. Beyer, Jr., and M. Donovan. 1996. Deer population trends in Michigan’s Upper Peninsula. Mich. Dept. of Nat. Resour., Wildl. Div. Rep. 3254.

DonCarlos, Mike. 1999. MN DNR Personal communication.

DonCarlos, M.W. 1994. Factsheet: Management of the lynx (*Felis lynx*) in Minnesota. Unublished Report.

Donifrio,M. 2003. Keweenaw Bay Natural Resources Department. Personal communication.

Dorn, Kevin. 1999. USFS. Personal communication

Dredge, L.A. and Cowan, W.R. 1989. Quaternary geology of the southwestern Canadian Shield; in Quaternary Geology of Canada and Greenland, R.J. Fulton [ed.], Geological Survey of Canada, Geology of Canada No.1, pp.214–249. ISBN 0-660-13114-5.

Dryer, W. R., L. F. Erkkila, and C. L. Tetzloff. 1965. Food of lake trout in Lake Superior. Trans. Am. Fish. Soc. 94: 169-176.

Duffy, W.G., T.R. Baterson, and C.D. McNabb. 1987. The St. Marys River, Michigan: an ecological profile. U.S. Fish Wild. Ser., Biol. Rep. 85(7.10). 138 p.

Dyksta, C.H., M.W. Meyer, D.K. Warnke, W.H. Karasov, D.E. Andersen, W.W. Bowerman IV, and J.P. Giesy. 1998. Low reproductive rates of Lake Superior Bald Eagles: Low food delivery rates or environmental contaminants? J. Great Lakes Res. 24(1): 32–44.

Ebener, M.P. [ed.]. 1998. Discussion paper on development of fish community objectives for Lake Superior. Unpublished draft. manuscript. 52 pp.

Ebener, M. P. 1997. Recovery of lake whitefish populations in the Great Lakes: a story of successful management and just plain luck. Fisheries 22 (7): 18–20.

Eddy, S. and J.C. Underhill. 1974. Northern Fishes. 3rd Ed. University of Minnesota Press. Minneapolis. 414 pp.

Edsall, T.A. 1998. Great Lakes. In: Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran. 1998. Status and trends of the nation's biological resources. 2 vols. U.S. Department of the Interior, U.S. Geological Survey, Reston, Va. 964 pp.

Edsall, T.A., R.H. Brock, R.P. Bukata, J.J. Dawson, and F.J. Horvath. 1992. State-of-the-art techniques for inventory of Great Lakes aquatic habitats and resources, p. 179–190. *In* W

Edsall, T.A., E.F. Stoermer and J.P. Kociolek. 1991. Periphyton accumulation at remote reefs and shoals in Lake Superior. J. Great Lakes Res. 17(3): 412–418.

Edsall, T.A. and M.N. Charlton 1997. Nearshore waters of the Great Lakes. Environment Canada and U.S. EPA. State of the Great Lakes Ecosystem Conference. Background Paper. 143 pp.

Eisenreich, S. J., B. B. Looney, and J. D. Thornton. 1981. Airborne organic contaminants in the Great Lakes ecosystem. Environ. Sci. Technol. 15:30–38.

Elkie, P.C., R.S. Rempel, and A.P. Carr. 1999. Patch analyst user's manual. A tool for quantifying landscape structure. Ont. Min. Natur. Resour. Northwest Sci. and Technol. Thunder Bay, Ont. Technical Manual TM-002. 16 pp + append.

Ellingwood, D. 1999. Lakehead Region Conservation Authority, Personal communication

Ensor, K. L., W. C. Pitt, and D. D. Helwig. 1993. Contaminants in Minnesota wildlife 1989-1991. Minn. Pollut. Control Agency, St. Paul, MN. 75 pp.

Environment Canada. 2000. The Importance of Nature to Canadians: The Economic Significance of Nature-Related Activities. Prepared by the Federal-Provincial-Territorial Task Force on the Importance of Nature to Canadians. 50pp. http://www.ec.gc.ca/nature/survey.htm

Environment Canada. 1993a. Environmental Sensitivity Atlas for Lake Superior's Canadian Shoreline. Conservation and Protection Branch.

Environment Canada. 1993b. The Great Lakes-St. Lawrence River Regulation: What it Means and How it Works.

Environment Canada and U.S. EPA. 1995. The Great Lakes: An Environmental Atlas and Resource Book. 3rd ed. www.epa.gov/glnpo/atlas

Epstein, Eric. 2000. WI DNR. Personal communication.

Epstein, E.J., E.J. Judziewicz, and W.A. Smith. 1997. Wisconsin’s Lake Superior coastal wetlands evaluation. Wisconsin Natural Heritage Inventory Program. Bureau of Endangered Resouces. Dept. of Natural Resources. Madison. 330 pp.

Escott, N.G. 1991. Survey of the breeding birds of Lake Nipigon, Thunder Bay District, Ontario. Nature Northwest. Newsletter of the Thunder Bay Field Naturalists. 45 (4): 5 – 11.

Eshenroder, R. L., James W. Peck. and Charles H. Olver. 1999. Research priorities for lake trout rehabilitation in the Great Lakes: A 15 year retrospective. Great Lakes Fish Comm. Tech. Report. 64. 40 p.

Evers, D. C., J. D. Kaplan, M. W. Meyer, P. S. Reaman, W. E. Braselton, A. Major, N. Burgess, and A. M. Scheuhammer. 1998. Geographic trend in mercury measured in common loon feathers and blood. Environ. Toxicol. and Chem. 17: 173–183.

Faeh, S. A., D. K. Nichols, and V. R. Beasley. 1998. Infectious diseases of amphibians. Pages 260–265 in Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507 pp.

Fee, E.J. 1971. A numerical model for the estimation of photosynthetic production, integrated over time and depth in natural waters. Contribution 22, Centre for Great Lakes Studies, University of Wisconsin-Milwaukee.

Filion, F. L., E. DuWors, P. Boxall, P. Bouchard, R. Reid, P. A. Gray, A. Bath, A. Jacquemot, and G. Legare. 1993. The importance of wildlife to Canadians: highlights of the 1991 survey. Can. Wildl. Serv., Environ. Can., Ottawa. 60 pp.

Finley, R. W., 1976, Original Vegetation of Wisconsin: Wisconsin Geological and Natural History Survey Map, 1:500,000-scale, 1 sheet.

Foster, D.R. 1988. Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah forest, south-western New Hampshire, USA. J. Ecol. 76:105–134.

Foster, R.F., A.G. Harris, J. Holenstein and B. Ratcliff. 1999. Current trends and future impacts on the Lake Superior ecosystem. Unpublished report.

Fox, G. A., S. Trudeau, H. Won, and K. A. Grasman. 1998. Monitoring the elimination of persistent toxic substances from the Great Lakes: chemical and physiological evidence from adult herring gulls. Environ. Monit. and Assess. 53:147–168.

Freitag, R., P. Fung, J.S. Mothersill, and G.K. Prouty. 1976. Distribution of benthic macroinvertebrates in Canadian waters of northern Lake Superior. J. Great Lakes Res. 2:177–192.

Frelich, L.E. 1995. Old forest in the Lake States today and before European settlement. Natural Areas Journal 15:157–167.

Frelich, L. E., P. F. J. Eagles, and R. J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conserv. Biol. 9:1408–1414.

Frelich, L.E. and C.G. Lorimer. 1985. Current and predicted long-term effects of deer browsing in hemlock forests of Michigan, USA. Biol. Cons. 34:99–120.

Frelich, L.E. and C.G. Lorimer 1991. A simulation of landscape level stand dynamics in the northern hardwood region. J. Ecol. 79:223–233.

Friday, Mike. Personal communication. Ontario Ministry of Natural Resources, Upper Great Lakes Management Unit – Lake Superior. 435 James Street South, Suite 221e. Thunder Bay, Ontario P7E 6S8. Phone: 807-475-1231; FAX: 807-473-3024; email: mike.friday@mnr.gov.on.ca .

Friesen, L., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.

Galbraith, D.A., and R.J. Brooks. 1987. Survivorship of adult females in a northern population of snapping turtles (Chelydra serpentina). Can. J. Zool. 65: 1581–1586.

Geddes, R.S., Kristjansson, F.J. and Teller, J.T. 1987. Quaternary features and scenery along the north shore of Lake Superior; XIIth International Union for Quaternary Research (INQUA) Congress Field Excursion Guidebook, 62p. ISBN 0-660-12313-4.

Gerstenberger, S. L., J. H. Gilbert, and J. A. Dellinger. 1996. Environmental contaminants and cholinesterase activity in the brain of fisher (Martes pennanti) harvested in northern Wisconsin. Bull. Environ. Contam. Toxicol. 56:866–872

Gilbert, J. H., J. L. Wright, D. J. Lauten, and J. R. Probst. 1997. Den and rest site characteristics of American marten and fisher in northern Wisconsin. Pages 135–145 in G. Proulx, H. Bryant, and P. M. Woodard, eds. Martes: taxonomy, ecology, techniques, and management. Proc. of the Second Int. Martes Symp. Prov. Mus. of Alberta, Edmonton. 474 pp.

Gilbertson, M. 1974. Pollutants in breeding herring gulls in the lower Great Lakes. Can. Field-Nat. 88:273–280.

Gillum, S. S., A. R. Lindsay, and M. W. Meyer. 1998. Quantifying the impact of lake shore housing development on breeding bird populations in northern Wisconsin. Bur. of Integrated Sci. Serv., Wisc. Dept. of Nat. Resour. Rep. to U.S. Fish and Wildl. Serv., Ft. Snelling, MN.

Glooschenko, V., and N. Burgess. 1987. Moose and deer cadmium program 1985-86. Ont. Minist. of Nat. Resour. Internal Rep., Toronto, ON.

Givens, D.R. and J.H. Soper.  1981. The arctic-alpine element of the vascular flora at Lake Superior. National Museums of Canada. Publications in Botany No. 10.

Goodier, J.L. 1981.  Native lake trout stocks in the Canadian waters of Lake Superior, prior to 1955. Can. J. Fish. Aquat. Sci. 28:1724–1737.

Goodyear, C.D., T.A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, and P.E. Polanski.  1981.  Atlas of the spawning and nursery areas of Great Lakes Fishes, Vol. I. Lake Superiro.  Great Lakes Fishery Laboratory, Ann Arbour, Michigan 109 pp.

Green, J. C. 1995. Birds and forests: a management and conservation guide. Minn. Dept. of Nat. Resour., St. Paul, MN. 182 pp.

Greenwood, S.  1999. OMNR. Personal communication.

Greenwood, S.  2003. OMNR. Personal communication.

Gunderson, J. 1995. Rusty crayfish: a nasty invader biology, identification and impacts of the rusty crayfish. Minnesota Sea Grant Program. (http://www.d.umn.edu/ seagr/areas/aqua/rusty.html).

Hamady, M. 2000. MN DNR. Personal communication

Hansen, M.J. [ed.] 1994.  The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94–1. 110 pp.

Hansen, M.J. [ed.] 1996.  A lake trout restoration plan for Lake Superior. Great Lakes Fish. Comm. 34 pp.

Hansen, M. J., M. P. Ebener, J. D. Shively, and B. L. Swanson. 1994. Lake trout, pp. 13–34. In M. J. Hansen [ed.] The state of Lake Superior in 1992. Great Lakes Fishery Commission Special Publication 94-1. 110 p.

Hansen, M. J., J. W. Peck, R. G. Schorfhaar, J. H. Selgeby, D. R. Schreiner, S. T. Schram, B. L. Swanson, W. R. MacCallum, M. K. Burnham-Curtis, J. W. Heinrich, and R. J. Young. 1995a. Lake trout (Salvelinus namaycush) populations in Lake Superior and their restoration in 1959-1993. Journal of Great Lakes Research 21 (Supplement 1): 152–175.

Hansen, M. J., R. G. Schorfhaar, J. W. Peck, J. H. Selgeby, and W. W. Taylor. 1995b. Abundance indices for determining the status of lake trout restoration in Michigan waters of Lake Superior. North American Journal of Fisheries Management 15: 830–837.

Harding, J. H. 1997. Amphibians and reptiles of the Great Lakes region. The Univ. of Michigan Press, Ann Arbor, MI. 361 pp.

Harkness, Mary. 2000. The Nature Conservancy. Personal communication.

Harkness, W.J. and J.R. Dymont. 1961. The lake sturgeon. Ontario Department of Lands & Forests, Fisheries & Wildlife Branch Toronto. 121 pp.

Harrington, B. A. 1995. Shorebirds: East of the 105th Meridian. Pages 57–60 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, eds. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals and ecosystems. U.S. Dept. of Int., Natl. Biol. Serv., Washington, D.C. 530 pp.

Harrington, M.W. 1985. Surface currents of the Great Lakes. U.S. Department of Agriculture, Weather Bureau Bulletin.

Harris, A.G. 1999. Report on the status of woodland caribou in Ontario. Draft. OMNR. Unpublished report.

Harris, L.D. 1984. The Fragmented Forest. Island Geographic Theory and the Preservation of Biotic Diversity. Univ. of Chicago Press. Chicago.

Hartley, R. 1999. OMNR. Personal communication.

Haws, K. 1999. MN DNR. Personal communication.

Hazard, E.B. 1982. The Mammals of Minnesota. University of Minnesota Press. Minneapolis.

Heaton, S. N., S. J. Bursian, J. P. Giesy, D. E. Tillitt, J. A. Render, P. D. Jones, D. A. Verbrugge, T. J. Kubiak, and R. J. Aulerich. 1992. Effects of polychlorinated biphenyls on mink. Arch. Environ. Contam. Toxicol. 28:334–343.

Hebert, C. E., R. J. Norstrom, and D. V. Weseloh. 1999. A quarter century of environmental surveillance: The Canadian Wildlife Service's Great Lakes Herring Gull Monitoring Program. Environ. Rev.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. 3:329–82.

Heinselman, M.L. 1981. Fire and succession n the conifer forests of northern North America. Pp. 374 – 405 in D.C. West, H.H. Shugart, and D.B. Botkin, eds. Forest succession concepts and application. Springer-Verlag. New York.

Heinselman, M.L. 1996. The Boundary Waters Wilderness Ecosystem. Univ. of Minnesota Press. Minneapolis.

Heyens, L.E. 1998. The 1996 piping plover census in Ontario. Ontario Birds 16 (1): 26 – 31.

Higgins, J.V. and M.dePhilip. 1999. The Nature Conservancy. Personal communication.

Higman, P.J. and M.R. Penskar. No date. Special plant abstract for Cirsium hillii (Hill's thistle). Michigan Natural Features Inventory, Lansing, MI. 2 pp.

Hills,G.A. 1959. A ready reference to the description of the land of Ontario and its productivity. Ontario Department of Lands and Forests. Maple, Ontario.

Hinshaw, A.L. 1998. Piping Plover Breeding Success and Management in Michigan's Eastern Upper Peninsula: 1998 Final Report. Submitted to: Endangered Species Office, Michigan Department of Natural Resources, Lansing, Michigan.

Hoff, M.H. [ed.]. 1996. Status of walleye in Lake Superior and its tributaries. Lake Superior Committee Annual Meeting minutes. Great Lakes Fishery Commission. 60 p.

Hoff, M.H. 1999. [ed.] A rehabilitation plan for walleye populations and habitats in Lake Superior. Walleye Subcomm., Lake Superior Tech. Comm., Great Lakes Fish. Comm. 16 p.

Hoff, M. H., and C. R. Bronte. 1998. Population status and trends for economically and ecologically important fishes in Lake Superior, 1978-1997. Minutes of the Lake Superior Committee Meeting, March 17-18, 1998, Thunder Bay, Ontario.

Hoff, M. H., and C. R. Bronte. 1999. Structure and stability of the fish communities of Chequamegon Bay, Lake Superior during 1973-1996. Transactions of the American Fisheries Society: 128:362–373.

Hoff, M. H., J. Link, and C. Haskell. 1997. Piscivory by Lake Superior lake herring (Coregonus artedi) on rainbow smelt (Osmerus mordax) in winter, 1993-1995. Journal of Great Lakes Research 23: 210–211.

Hoff, M. H., L. M. Evrard, A. J. Edwards, and C. R. Bronte. 1998. Ruffe population investigations in Lake Superior tributaries. Final Report. U. S. Geological Survey, Biological Resources Division Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, Wisconsin, 54806. 44 p.

Hoopes, J.A., R.A.Ragotzkie, S.L. Line, and N.P. Smith. 1973. Circulation patterns in Lake Superior. Tech. Rep. WIS WRC 73-04., Water Resources Center, Univ. of Wisconsin., Madison, Wisconsin.

Houston, J. J. P. 1988. Status of the shortjaw cisco, Coregonus zenithicus, in Canada. Can. Field-Nat. 102: 97–102.

Howe, R. W., G. Niemi, and J. R. Probst. 1995. Management of western Great Lakes forests for the conservation of neotropical migratory birds. Pages 144–167 in F.R. Thompson III, [ed.] Management of midwestern landscapes for the conservation of neotropical migratory birds. U.S. For. Serv. Gen. Tech. Rep. NC-187. St. Paul, MN.

Howe, R. W., S. A. Temple and M. J. Mossman. 1992. Forest management and birds in northern Wisconsin. Passenger Pigeon 54:297–305.

Howe, R. W., and M. Mossman. 1995. The significance of hemlock for breeding birds in the western Great Lakes region. Pages 125–139 in Mroz, G., and J. Martin, eds. Proceedings of a regional conference on ecology and management of eastern hemlock. Univ. of Wisc., Madison, WI.

Hubbs,C.L. and K.F. Lagler. 1958. Fishes of the Great Lakes Region. Cranbrook Institute of Science. Bulletin No. 26. Bloomfield Hills. 213 pp.

Hyde, D.A. 1996. Special animal abstract for Sterna caspia (Caspian tern). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

Hyde, D.A. 1997. Special animal abstract for Sterna hirundo (common tern). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

International Joint Commission (IJC). 1977. Upper Lakes Reference Group. The waters of Lake Huron and Lake Superior, Vols 1–3.

International Joint Commission (IJC). 1976. Further Regulation of the Great Lakes. An IJC Report to the Governments of Canada and the United States. Unpublished Report.

International Joint Commission (IJC). 1985. Great Lakes diversions and consumptive uses.

International Joint Commission (IJC). 1993. Methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin.

Irbe, G.J. 1991. Great Lakes Surface Water Temperature Climatology. Environment Canada. Climatological Studies No. 43. 215 pp.

Jensen, A. L. 1976. Assessment of the United States lake whitefish (Coregonus clupeaformis) fisheries of Lake Superior, Lake Michigan, and Lake Huron. Transactions of the American Fisheries Society 33: 747–759.

Johnson, T.B., Hoff, M.H., Trebitz, A.S., Bronte, C.R., Corry, T.D., Kitchell, J.F., Lozano, S.T., Mason, D.M., Scharold, J.V., Schram, S.T. and D.R. Schreiner. 2004. Spatial patterns in assemblage structures of pelagic forage fish and zooplankton in western Lake Superior. Journal of Great Lakes Research. In Press.

Jones, Scott. 1999. OMNR . Personal communication.

Jonsson, B.G. and M. Dynesius. 1993. Uprooting in boreal forests: Long-term variation in disturbance rate. Can. J. For. Res. 23:2383–2388.

Judziewicz E.J. 1997. Vegetation and flora of Passage Island, Isle Royale National Park, Michigan. Michigan Botanist 36: 35–62.

Kavetsky, B. 1999. USFWS. Personal communication.

Kelso, J.R.M., W.M. Gardner, and S. Greenwood. 1996. Status in Ontario waters of Lake Superior, p. 38–44. In M.H. Hoff [ed.] Status of walleye in Lake Superior and its tributaries. Walleye Subcomm., Lake Superior Tech. Comm., Great Lakes Fish. Comm. 60 p.

Kemp, A.L.W., C.I. Dell and N.S. Harper. 1978. Sedimentation rates and a sediment budget for Lake Superior. J. Great Lakes Res. 4(3–4):276–287.

Kempinger, J.J. 1988. Spawning and early life history of lake sturgeon in the Lake Winnebago system, Wisconsin. American Fisheries Society Symposium 5:110-122.

Kenkel, N.C. and P.R. Watson, and P. Uhlig. 1998. Modelling landscape-level vegetation dynamics in the boreal forests of northwestern Ontario. Ontario Ministry of Natural Resources Forest Research Report No. 148.

Kershner, B. 1999. Survey finds last U.S. Great Lakes ancient forest. Great Lakes United. Fall 1999: 3–6.

Klar, G.T., L.P. Schleen and R.J. Young. 1996. Integrated management of sea lampreys in the Great Lakes. 1996. Annual Report to the Great Lakes Fishery Commission. Web site: http://www.glfc.org slar961.htm.

Kling,G.W., K.Hayhoe, L.B.Johnson, J.J.Magnuson, S.Polasky, S.K.Robinson, B.J.Shuter, M.M.Wander, D.J.Wuebbles, D.R.Zak, R.L.Lindroth, S.C.Moser, and M.L.Wilson. 2003. Confronting Climate Change in the Great Lakes Region:Impacts on our Communities and Ecosystems.Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington,D.C.

Koch, R.G., Stackler, S. H., Koch, L. M., and Kapustka, L., 1979, Vegetation Cover Analysis – Presettlement Vegetation of the Namadji River Basin. In: Andrews, Christensen, Wilson, eds., Impact of Nonpoint Pollution Control on Western Lake Superior; Red Clay Project Final Part II, EPA 905/9-79-002-B. pp. 276–297.

Koehler, G.M. and K.B. Aubrey. 1994. Lynx. In: L.F. Ruggiero et al.. (eds). The Scientific Basis for Conserving Forest Carnivores. American Marten, Fisher, Lynx and Wolverine. USDA Forest Service General Technical Report RM-254.

Koonce, J.F. C.K. Minns, and H.A. Morrison. 1998. Biodiversity investment areas: Aquatic ecosystems. Aquatic biodiversity investment areas in the Great Lakes Basin: Indentification and Validation. Environment Canada and U.S. EPA. State of the Great Lakes Ecosystem Conference. Background Paper. 44 pp.

Krizan, P. 1997. The Effects of Human Development, Landscape Features, and Prey Density on the Spatial Use of Wolves (*Canis lupus*) on the North Shore of Lake Superior. M. S. Thesis. Center for Wildlife and Conservation Biology, Acadia University, 109pp.

Kronberg, B. I., and V. Glooschenko. 1994. Investigating cadmium bioavailability in northwestern Ontario using boreal forest plants. Alces 30:71–80.

Kubiak, T. J., and D. A. Best. 1991. Wildlife risks associated with passage of contaminated, anadromous fish at Federal Energy Regulatory Commission licensed dams in Michigan. U.S. Fish and Wildl. Serv. Internal Rep., East Lansing, MI.

LaBerge, G.L. 1994. Geology of the Lake Superior region; Geoscience Press, Inc. 313p.

Lake Superior Binational Program. 1995. Ecosystems principles and objectives, indicators and targets for Lake Superior. Discussion Papers. Lake Superior Work Group of the Lake Superior Binational Program.

Lake Superior Binational Program. 1998. Ecosystems principles and objectives, indicators and targets for Lake Superior (revision date). Lake Superior Working Group of the Lake Superior Binational Program, Thunder Bay, Ontario. 110 pp.

Lake Superior Technical Committee. 1999. Lake Superior fish community objectives. Draft report.

Lam, D.C. 1978. Simulation of water circulations and chloride transports in Lake Superior for Summer 1973. J. Great Lakes Res. 4(3-4): 343–349

Lambert, A., and B. Ratcliff. 1979. A survey of piping plovers in Michigan, 1979. Report submitted to Michigan Department of Natural Resources, Lansing, Michigan.

Lambert, A. and B. Ratcliff. 1981. Present status of the piping plover in Michigan. The Jack Pine Warbler 59: 44–52.

Lannoo, M. J. 1998. Amphibian conservation and wetland management in the Upper Midwest: a catch-22 for the cricket frog? Pages 330–339 in Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507pp.

Lanteigne, J. 1991. Status report on the Northern Brook Lamprey, Ichthyomyzon fossor. COSEWIC. 24 pp.

Lawrie, A.H. 1978. The fish community of Lake Superior. International Association for Great Lakes Research 43: 513 – 549.

Lawrie, A.H. and J.R. Rahrer. 1972. Lake Superior: effects of exploitation and introductions on the salmonid community. J. Fish. Res. Bd. Canada. 29: 765 – 776.

Lawrie, A.H. and J.F. Rahrer. 1973. Lake Superior: a case history of the lake and its fisheries. Great Lakes Fish. Comm. Tech. Report 19. Ann Arbor, Michigan. 53 p.

Leach J.H. and R.C. Herron 1996. A review of lake habitat classification. In: W.D.N. Busch and P.G. Sly (eds). The Development of an Aquatic Habitat Classification System for Lakes. CRC Press. Ann Arbor.

Lee, H. D., and F. C. Southham. 1974. Effect and implications of differential iostatic rebound on Lake Superior's regulation limits. Journal of Great Lakes Research 20(2): 407–415.

Lee, Peter. 2000. Lakehead University. Personal communication.

Lee, Y. 1999. Special animal abstract for Clemmys insculpta (wood turtle). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

Legault, J., and T. Kuchenberg, and M. E. Sisulak. 1978. Reflections in a tarnished mirror: the use and abuse of the Great Lakes. Golden Glow Publishing, Sturgeon Bay, Wisconsin. 224 p.

Lenter, J.D. 2004 Trends in the Lake Superior water budget since 1948: A weakening seasonal cycle. Journal of Great Lakes Research. In Press.

Leskevich, G.A. 1975. Lake Superior bathythermograph data. Contribution No. 32, Great Lakes Environmental Research Laboratory. Ann Arbour, Michigan.

Loftus, D.H., C.H. Olver, E.H. Brown, P.J. Colby, W.L. Hartman, and D.H. Schupp. 1987. Partitioning potential fish yields from the Great Lakes. Can. J. Fish. Aquat. Sci. 44 (Supp. 2): 417–424.

Loope,W.L. 2003 Monitoring natural and anthropogenic change in the Grand Sable Dunes, Pictured Rocks National Lakeshore. Western Great Lakes Research Conference and Chequamegon Bay Natural Resource Conference.

Loope, W.L. and A.K. McEachern. 1998. Habitat change in a perched dune system along Lake Superior. In: Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran. 1998. Status and trends of the nation's biological resources. 2 vols. U.S. Department of the Interior, U.S. Geological Survey, Reston, Va. 964 pp.

Ludwig, J. P. 1986. A short report on the Michigan marten re-introduction program in 1985-86: comparison to trapping success with the Algonquin Park efforts of 1980-81. Unpublished report, Ecological Research Services, Inc., Boyne City, MI. 24 pp.

MacCallum, W.R. and J.H. Selgeby. 1987. Lake Superior revisited 1984. Can. J. Fish. Aquat. Sci. 44 (Suppl. 2): 23–36.

Mallik, A.U. 2002. Soil invertebrates and mycorrhizal fungi as indicators of ecosystem health in the Lake Superior basin: A literature review. Tech. Rept. to the Terrestrial Wildlife Community Committee, Lake Superior Binational Program. 28 pp.

Marsden, J.E., D.L. Perkins, and CC. Krueger. 1995. Lake trout spawning habitat in the Great Lakes – a review of current knowledge. J. Great Lake. Res. 21: 487–497.

Marshall, E.W. 1968. Lake Superior ice characteristics. In Proc. 10th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res. pp. 214–220.

Marshall, S. 1999. Tiger Beetles Of Ontario http://www.uoguelph.ca/~samarsha/photos.htm

Matheson, D.H. and M. Munawar. 1978. Lake Superior basin and its development. J. Great Lakes Res. 4(3-4):249–263.

Matteson, S. 2000. . Wisconsin DNR. Personal communication.

Matteson, S.W. 1988. Wisconsin common tern recovery plan. Wisconsin Endangered Resources Report 41. Wisconsin Dept. of Natural Resources. 74 pp.

Matthiae, P.E. and F. Stearns. 1981. Mammals in forest islands in southeastern Wisconsin. In: Forest island dynamics in man-dominated landscapes. R.L. Burgess and D.M. Sharpe (eds). Springer-Verlag. New York. Pp. 59–66.

Maynard, L. and D. Wilcox.1997. Coastal wetlands of the Great Lakes. State of the Lakes Ecosystem Conference 1996. Environment Canada and U.S. Environmental Protection Agency.

McAllister, D.E., B.J. Parker, and P.M. McKee. 1985. Rare, endangered and extinct fishes in Canada. National Museums of Natural Science. Syllogeus 54. Ottawa. 192 pp.

McCaffery, K. R., J. Tranetzki, and J. Piechura. 1974. Summer foods of deer in northern Wisconsin. J. Wildl. Manage. 38:215–219.

McCaffery, K. R. 1995. History of deer populations in northern Wisconsin. Pages 109–113 in Mroz, G., and J. Martin, eds. Proceedings of a regional conference on ecology and management of eastern hemlock. Univ. of Wisc., Madison, WI.

McCammon Soltis, A. 1999. Personal communication.

McGarigal, K. and B. Marks 1993. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure: USDA Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-351. Portland, OR. 122 pp.

McKelvey, K.S., K.B. Aubry, G.M. Koehler, and Y.K. Ortega. 1999. History and distribution of lynx in the contiguous United States. USDA Forest Service Gen. Tech. Rep. RMRS GTR-30.

McNab, W.H. and P.E. Avers (compilers). 1994. Ecological Subregions of the United States. WO-WSA-5. U.S. Forest Service. (http://www.fs.fed.us/land/pubs /ecoregions/index.html)

Meating, J. 1999. BioForest Technologies. Personal communication.

Mech, L.D. 1980. Age, sex, reproduction and spatial organization of lynxes colonizing northeast Minnesota. J.of Mammology. 61: 261 – 267.

Merrill, S. B., F. J. Cuthbert, and G. Oehlert. 1998. Residual patches and their contribution to forest-bird diversity on northern Minnesota aspen clearcuts. Conserv. Biol. 12:190–199.

Meyer, M.W. 1992. Factors controlling Great Lakes bald eagle productivity: 1992 annual progress report. Unpubl. Rep. to Great Lakes Protection Fund, Wisconsin DNR, Madison, Wisconsin.

Meyer, M. 1999. Wisconsin DNR. Personal communication.

Michigan Dept. of Environmental Quality 1998. Clean Water Act Section 303 9d. List Michigan Submittal for 1998. Unpublished Report.

Michigan Gray Wolf Recovery Team. 1997. Michigan Gray Wolf Recovery and Management Plan. Website: http://www.dnr.state.mi.us/Wildlife/Publications/Mammals/Wolf/ mgmtplan /default.htm

Michigan Loon Recovery Program. 1992. A plan for recovery of the common loon in Michigan. Rep. submitted to Mich. Dept. of Nat. Resour. 66 pp.

Michigan Natural Features Inventory. 1996. Special plant abstract for Panax quinquefolius (ginseng). Lansing, MI. 3 pp.

Michigan Natural Features Inventory. 1999a. Natural community abstract for open dunes. Lansing, MI. 5 pp. Compiler: D.A. Albert.

Michigan Natural Features Inventory. 1999b. Natural community abstract for wooded dune and swale complex. Lansing, MI. 6 pp. Compilers: D.A. Albert and P.J. Comer.

Miller, S. G., S. P. Bratton, and J. Hadidian. 1992. Impacts of white-tailed deer on endangered plants. Nat. Areas J. 12:67–74.

Mills, E.L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. Journal of Great Lakes Research 19(1): 1-54.

Mineau, P., G. A. Fox, R. J. Norstrom, D. V. Weseloh, D. J. Hallett, and J. A. Ellenton. 1984. Using the herring gull to monitor levels and effects of organochlorine contamination in the Canadian Great Lakes. Pages 426–437 in Nriagu, J. O., and M. S. Simmons, eds. Toxic contaminants in the Great Lakes. John Wiley and Sons, Inc.

Minnesota Pollution Control Agency. 1997. Lake Superior Basin Information Document. Minnesota Pollution Control Agency. 125 pp. + appendices.

Minnesota Sea Grant. 1998. Zebra mussels threaten inland waters. (http://www.d.umn.edu/seagr/areas/exotic/)

Mladenoff, D.J., T.A. Sickley, R.G. Haight, and A.P. Wydeven. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the Northern Great Lakes region. Conserv. Biology 9:279–294.

Mladenoff, D. J., and F. Stearns. 1993. Eastern hemlock regeneration and deer browsing in the northern Great Lakes region: a re-examination and model simulation. Conserv. Biol., 7:889–900.

Momot, W.T. 1995. History of the range expansion of Orconectes rusticus into northwestern Ontario and Lake Superior. Freshwater Crayfish 16: 61–72

Momot, W., 1999. Lakehead University. Personal communication.

Moore, H. H., and R. A. Braem. 1965. Distribution of fishes in U.S. streams tributary to Lake Superior. United States Fish and Wildlife Service, Special Scientific Report, Fisheries No. 516. 61 p.

Moriarty, J. J. 1998. Status of Amphibians in Minnesota. Pages 166–168 in Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507 pp.

Mossman, M. J., L. M. Hartman, R. Hay, J. R. Sauer, and B. J. Dhuey. 1998. Monitoring long-term trends in Wisconsin frog and toad populations. Pages 169–198 in Lannoo, M. J., [ed.] Status and conservation of midwestern amphibians. Univ. of Iowa Press, Iowa City, IA. 507 pp.

Munawar, M. and I.F. Munawar. 1978. Phytoplankton of Lake Superior 1973. J. Great Lakes. Res., 4(3-4): 415–442.

Munawar, M., I.F. Munawar, L.R. Culp, and G. Dupuis. 1978. Relative importance of nannoplankton in Lake Superior phytoplankton biomass and community metabolism. J. Great Lakes Res., 4(3-4):462–480.

Mysz, A., R.Reid and K. Rodriguez. 1998. Biodiversity Investment Areas – Nearshore Terrestrial Ecosystems. Background Paper – State of the Lakes Ecosystem Conference.

National Wetlands Working Group 1988. Wetlands of Canada. Ecological Land Classification Series No. 24. Sustainable Development Branch. Environment Canada, Ottawa. Polyscience Publications Inc. Montreal. 452 pp.

National Wildlife Federation. 1993. Saving all the pieces: protecting biodiversity in the Lake Superior region. A report on phase one of the Lake Superior Biodiversity Project. Natl. Wildl. Fed., Ann Arbor, MI.

Natural Resources Conservation Service (NRCS) USDA Forest Service, 1998, Erosion and Sedimentation in the Nemadji River Basin.

Niemi, G., A. Lima, A. Hanowski, and L. Pfannmuller. 1995. Recent trends of breeding birds in Minnesota and Minnesota forested regions, 1966-1993. The Loon 67:191–201.

Nelson, Sharron, MN DNR, Natural Heritage and Nongame Research Program, Personal communication.

Newman, L. E., and R. B. Dubois. 1997. Status of brook trout in Lake Superior. A report prepared for the Lake Superior Technical Committee by the Brook Trout Subcommittee. 33 p.

Newman, L. E., J. T. Johnson, R. G. Johnson, R. J. Novitsky. 1999. Defining habitat use and movement patterns of a reintroduced coaster brook trout population in Lake Superior. U.S. Fish and Wildlife Service, Ashland Fishery Resource Office and Grand Portage Natural Resources Department, P. O. Box 428, Grand Portage, Minnesota, 55605. 10 pp.

Newman, L.E. , R.B. DuBois, and T.N. Halpern [eds.] 2003. A brook trout rehabilitation plan for Lake Superior. Great Lakes Fish. Commission. Misc. Publ. 2003-03.

Novak, M. 1987. Wild furbearer management in Ontario. Pages 1049 to 1061 in M. Novak, J. A. Baker, M. E. Obbard & B. Malloch, eds. Wild furbearer management and conservation in North America. Ontario Trapper's Assoc., North Bay.

Nuhfer, A.J. 1992. Evaluation of the reintroduction of the arctic grayling into Michigan lakes and streams. Michigan Dept. of Natural Resources. Fisheries Research Report No. 1985.

Oldham, M.J. 1998. Natural heritage resources of Ontario: rare vascular plants. Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario. 53 pp.

Oldfield, B., and J. J. Moriarty. 1994. Amphibians and reptiles native to Minnesota. Univ. of Minn. Press, Minneapolis, MN. 237 pp.

Ontario Ministry of the Environment. 1992. The provincial water quality monitoring network in Northwestern Ontario: Data summary 1968 to 1990. Queen's Printer for Ontario.

Ontario Geological Survey. 1991. Geology of Ontario, Ontario Geological Survey, Special Volume 4, Parts 1 and 2, 1525 pp.

Ontario Ministry of Natural Resources (OMNR). 1999. A management framework for woodland caribou conservation in northwestern Ontario. Northwest Region Caribou Task Team.

Ontario Ministry of Natural Resources (OMNR). 1986. The forest resources of Ontario, 1986. Ont. Min. Natur. Res., Forest Resources Group. 91 p.

Ontario Ministry of Natural Resources (OMNR). 1988a. Timber management guidelines for the protection of fish habitat. Queen's Printer for Ontario. Toronto.

Ontario Ministry of Natural Resources (OMNR). 1988b. Environmental guidelines for access roads and water crossings. Toronto. 64 pp.

Ontario Ministry of Natural Resources (OMNR). Old Growth Policy for Ontario's Crown Forests. Queen 's Printer for Ontario

Ontario Ministry of Natural Resources (OMNR). 2003. Natural Resources Values Information System database.

Orr, B. 1997. Land use change on Michigan's Lake Superior shoreline: integrating land tenure and land cover type data. J. Great Lakes Res. 23 (3): 328–338.

Paloheimo, J.E. and H.A. Regier 1982. Ecological approaches to stressed multispecies fisheries resources, pp. 127–132. In: M.C. Mercer [ed.]. Multispecies approaches to fisheries management advice. Can. Spec. Publ. Fish. Aquat. Sci. 59.

Parker, B. J. 1988a. Status of the deepwater sculpin, Myoxocephalus thompsoni, in Canada. Can. Field Nat. 102: 126–131.

Parker, B. J. 1988b. Status report on the blackfin cisco, Coregonus nigripinnis. COSEWIC. 19 pp.

Parker, B. J. 1988c. Status of the shortnose cisco, Coregonus reighardi, in Canada. Can. Field Nat. 102: 92–96.

Parker, B. J. 1989. Status of the kiyi, Coregonus kiyi, in Canada. Can. Field Nat. 103:171–174.

Pascoe, D.A. and R.E. Hicks. 2004. Genetic structure and community DNA similarity of picoplankton communities from the Laurentian Great Lakes. Journal of Great Lakes Research. In Press.

Patalas, K. 1972. Crusteacean zooplankton and eutrophication of the St. Lawrence Great Lakes. J. Fish Res. Board Can. 29:1451–1462.

Pekarik, C., D. V. Weseloh, G. C. Barrett, M. Simon, C. A. Bishop, and K. E. Pettit. 1998a. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1993-1997). Vol. I, Accounts by location. Can. Wildl. Serv. Tech. Rep. 321. 245 pp.

Pekarik, C., D. V. Weseloh, G. C. Barrett, M. Simon, C. A. Bishop, K. E. Pettit. 1998b. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1993-1997). Vol. II, Accounts by chemical. Can. Wildl. Serv. Tech. Rep. 322. 214 pp.

Pekarik, C., and D. V. Weseloh. 1998. Organochlorine contaminants in herring gull eggs from the Great Lakes, 1974-1995: change point regression analysis and short-term regression. Environ. Monitor. and Assess. 53:77–115.

Penskar, M.R. and P.J. Higman. 1996. Special plant abstract for Asplenium scolopendrium (Hart's-tongue fern). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

Perera, A.H. and D.J.B. Baldwin. 2000. Spatial patterns in the managed forest landscape of Ontario. pp. 74–99. In: A.H. Perera, D.L. Euler, and I.D. Thompson (eds). Ecology of a Managed Terrestrial Landscape. Patterns and Processes of Forested Landscapes in Ontario. UBC Press. Vancouver.

Perera, A.H. and D.J.B. Baldwin. 1993. Spatial characteristics of eastern white pine and red pine forests in Ontario. Ont. Min. Natur. Res., Forest Fragmentation and biodiversity Project Report No. 9.

Peterjohn B. G., and J. R. Sauer. 1994. Population trends of woodland birds from the North American Breeding Bird Survey. Wildl. Soc. Bull. 22:156–164.

Pettit, K. E., C. A. Bishop, D. V. Weseloh, and R. J. Norstrom. 1994a. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1989-1992). Vol. I, Accounts by location. Can. Wildl. Serv. Tech. Rep. 193. 319 pp.

Pettit, K. E., C. A. Bishop, D. V. Weseloh, and R. J. Norstrom. 1994b. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1989-1992). Vol. II, Accounts by chemical. Can. Wildl. Serv. Tech. Rep. 194. 300 pp.

Pimental, D., L. Lach, R. Zuniga, D. Morrison. 1999. Environmental and Economic Costs Associated with Non-Indigenous Species in the United States. College of Agricultural and Life Sciences, Cornell University, Ithaca, N.Y.

Policy Advisory Committee 1994. Interim report on conserving old growth red and white pine. Ontario Ministry of Natural Resources. 35 pp.

Potter, Brian. 2000. OMNR. Personal communication.

Promaine, A. 1999. Threatened species monitoring: Results of a 17-year survey of Pitcher's thistle, Cirsium pitcheri, in Pukaskwa National Park, Ontario. Can. Field Nat. 113 (2): 296–298.

Pycha, R. L. 1980. Changes in mortality of lake trout (Salvelinus namaycush) in Michigan waters of Lake Superior in relation to sea lamprey (Petromyzon marinus) predation, 1968-78. Canadian Journal of Fisheries and Aquatic Sciences 37: 2063–2073.

Pye, E.G. 1997. Roadside geology of Ontario: North shore of Lake Superior; Ontario GEOservices Centre, ROCK ON Series 2, 164 pp.

Rabe, M.L. 1999. Special animal abstract for Trimerotropis huroniana (Lake Huron locust). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

Racey, G.D., A.G. Harris, E.R. Armstrong, L. Gerrish, R. Schott, and J. McNicol. 1999. Landscape planning for the conservation of forest-dwelling woodland caribou. Northwestern Ontario. Ontario Ministry of Natural Resources.

Racey, G., and B. Hessey. 1989a. Fisher (Martes pennanti) and timber management in Northern Ontario, a literature review. Ont. Minist. of Nat. Resour., Northwest. Ont. For. Technol. Dev. Unit Tech. Rep. No. 15.

Racey, G., and B. Hessey. 1989b. Marten and Fisher response to cutover: a summary of the literature and recommendations for management. Ont. Minist. of Nat. Resour., Northwest Sci. and Technol. Tech. Note TN-04. Thunder Bay, ON.

Ragotzkie 1974. Vertical motions along the north shore of Lake Superior. In Proc. 17th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res. pp. 456–461.

Rao, S.S. 1978. Seasonal surface distribution of aerobic heterotrophs and their relationships to temperature and nutrients in Lake Superior during 1973. J. Great Lakes. Res. 4(3-4):408–414.

Ratcliff, B. 1997-2003. Project Peregrine annual reports. Thunder Bay Field Naturalists. Unpublished reports.

Reckahn, J.A. 1970. Ecology of young lake whitefish (Coregonus clupeaformis) in South Bay, Manitoulin Island, Lake Huron. pp. 437 – 460. In C.C. Lindsey and C.S.Woods (eds). Biology of Coregonid Fishes. University of Manitoba Press, Winnipeg.

Reid, R. and K. Holland. 1997. The Land by the Lakes – Nearshore Terrestrial Ecosystems. Environment Canada background paper – State of the Lakes Ecosystem Conference.

Regier, H.A. and K.H. Loftus 1972. Effects of fisheries exploitation on salmonid communities in oligotrophic lakes. J. Fish. Res. Board Can. 29: 959 – 968.

Richards, C. J. Bonde, D. Schreiner, J. Selgeby, G. Cholwek, and K. Win. 1999. Mapping lake trout spawning habitat along Minnesota’s North Shore. Natural Resources Research Institute, University of Minnesota, Duluth. NRRI Technical Report No. 99–01.

Robbins, C.S., D.K Dawson, and B.A. Dowell. 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildlife Monog. No. 103.

Rogers, Joe. 1999. Shepherd, MI.. Personal communication.

Rondy, D.R. 1971. Great Lakes ice atlas. National Oceanic and Atmospheric Administration Tech. Memo. Detroit, Michigan NOS LSCR 1. 33 pp.

Rose, G.A., and G. Kruppert. 1984. An assessment of the walleye fishery and migration patterns of other species, Goulais River, spring of 1984. Ont . Min. Nat. Res., Sault Ste. Marie. 18 pp.

Royal Ontario Museum (ROM). 1999. Ontario's Species at Risk. Website (http://www.rom.on.ca).

Ruffe Task Force. 1992. Ruffe in the Great Lakes: a threat to North American fisheries. Great Lakes Fishery Commission, Ann Arbor, MI.

Russell, E.B. 1983. Indian-set fires in the forests of the northeastern United States. Ecology. 64:78–88.

Rustem,Ray. 2000. MI, DNR. Personal communication.

Ryder, R.A. 1968. Dynamics and exploitation of mature walleyes, Stizostedion vitreum vitreum, in the Nipigon Bay region of Lake Superior. J. Fish. Res. Board Can. 25:1347–1376.

Ryckman, D. P., D. V. Weseloh, and C. A. Bishop. 1997. Contaminants in herring gull eggs from the Great Lakes: 25 years of monitoring levels and effects. Fact sheet. Can. Wildl. Serv., Environ. Can., Burlington, ON.

Ryckman, D. P., D. V. Weseloh, P. Hamr, G. A. Fox, B. Collins, P. J. Ewins, and R. J. Norstrom. 1998. Spatial and temporal trends in organochlorine contamination and bill deformities in double-crested cormorants (*Phalacrocorax auritus*) from the Canadian Great Lakes. Environ. Monit. and Assess. 53:169–195.

Saulesleja, A. 1986. Great Lakes Climatological Atlas. Atmospheric Environment Service, Environment Canada.

Saunders, J. 1999. OMNR Sault Ste. Marie. Personal communication.

Sauer, J. R., J. E. Hines, G. Gough, I. Thomas, and B. G. Peterjohn. 1997. The North American breeding bird survey results and analysis. Version 96.3. Patuxent Wildl. Res. Center, Laurel, MD.

Scarf, W.C., M.L. Chamberlin, T.C. Erdman and G.W. Shugart. 1979. Nesting and migration of birds of the U.S. Great Lakes. Washington, D.C., U.S. Fish and Wildlife Service Biological Report. No. 77 (2).

Scharold, J.V., Lozano, S.J., and T.D. Corry. 2004. Status of the amphipod *Diporeia* spp. in Lake Superior, 1994-2000. Journal of Great Lakes Research. In Press.

Schertzer, W.M., F.C. Elder, and J. Jerome. 1978. Water transparency of Lake Superior in 1973. J. Great Lakes Res. 4(3-4):350–358.

Schmidt, K. A., and C. J. Whelan. 1999. The relative impacts of nest predation and brood parasitism on seasonal fecundity in songbirds. Conserv. Biol. 13:46–57.

Schneider, J.C. and J.H. Leach. 1977. Walleye (Stizostedion vitreum vitreum) fluctuations in the Great Lakes and possible causes, 1800-1975. J. Fish. Res. Board Can. 34:1878–1889.

Scholten S. 1999. OMNR Thunder Bay District. Personal communication.

Schram, S.T., J.R. Atkinson, and D.L. Pereira. 1991. Lake Superior walleye stocks: status and management, p. 1–22. In P.J. Colby, C.A. Lewis, and R.L. Eshenroder [eds.] Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop. Great Lakes Fish Comm. Spec. Pub. 91-1.

Schram, S. T., J. Lindgren, and L. M. Evrard. 1999. Reintroduction of lake sturgeon in the St. Louis River, western Lake Superior. North American Journal of Fisheries Management 19: 815–823.

Scott, W.B. and E.J. Crossman 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada. Bulletin 184. Ottawa.

Seburn, D. C., and C. N. L. Seburn. 1997. Northern leopard frog survey of northern Ontario: report on a declining amphibian. Report to Ont. Minist. of Nat. Resour., Wildl. Assess. Unit. Seburn Ecological Services, Oxford Mills, ON.

Selgeby, J. H. 1982. Decline of lake herring (Coregonus artedii) in Lake Superior: an analysis of the Wisconsin herring fishery, 1936-78. Canadian Journal of Fisheries and Aquatic Sciences 39: 554–563.

Selgeby, J. H., W. R. MacCallum, and M. H. Hoff. 1994a. Rainbow smelt-larval lake herring interactions: competition of casual acquaintances? National Biological Survey, Technical Report Series, Biological Report 25. 9p.

Selgeby, J. H., C. R. Bronte, and J. W. Slade. 1994b. Forage species. pp. 53–62. In M. J. Hansen [ed.] The state of Lake Superior in 1992. Great Lakes Fishery Commission Special Publication 94-1.

Seyler, J., J.Evers, S.McKinley, R.R.Evans, G.Prevost, R.Carson and D.Phoenix. 1996. Mattagami River lake sturgeon entrainment: Little Long Generating Station Facilities. NEST Tech. Report TR-031.

Semple, J.C. and G. S.Ringius. 1983. Solidago houghtoniana. In: Argus, G.W., K.M. Pryer, D.J. White, and C.J. Keddy. Atlas of the rare vascular plants of Ontario. National Museum of Natural Sciences. Ottawa (looseleaf).

Shiras, G. 1935. Fishes of Lake Superior, the Huron Mountains District. National Geographic Society. Vol. 1 pp. 377 – 396. Washington.

Shirose, L., C. Bishop, and A. Gendron. 1996. Amphibians and reptiles in Great Lakes wetlands: threats and conservation. Great Lakes Fact Sheet, Environ. Can., Ottawa, ON.

Simpson, E. 1996. Old growth red and white pine forests: Northwest Region report on protection. Ont. Min. Natur. Res. NWST Tech. Rep. TR-98.

Skinner, L.C. W.J. Rendall and Ellen L. Fuge. 1994. Minnesota’s purple loosestrife program: history, findings and management recommendations. Minnesota Dept. of Natural Resources Special Publictrion No. 145.

Slade, J. W., and N. A. Auer [ed.]. 1997. Status of lake sturgeon in Lake Superior. A report prepared for the Lake Superior Technical Committee by the Lake Sturgeon Subcommittee.

Smith, B. R., and J. J. Tibbles. 1980. Sea lamprey (Petromyzon marinus) in Lakes Huron, Michigan, and Superior: history of invasion and control, 1936-78. Canadian Journal of Fisheries and Aquatic Sciences 37: 1780–1801.

Snider, B. 1989. The Slate Islands. In: Theberge, John B. [ed.] Legacy: The Natural Heritage of Ontario, pp. 339–340. McClelland & Stewart, Toronto.

Snyder, L. L. 1938. A faunal investigation of western Rainy River district Ontario. Trans. Roy. Can. Inst. Vol. 14, Part 1:157–181, Toronto.

Soper J.H. C.E. Garton, and D.R.Given. 1989. Flora of the North Shore of Lake Superior (Vascular plants of the Ontario portion of the Lake Superior drainage basin). National Museum of Natural Sciences. Syllogeus 63.

Soule, J.D. 1993a. Preliminary identification of critical habitat in the Lake Superior watershed in Michigan. Unpublished Report. Michigan Department of Natural Resources.

Soule, J.D. 1993b. Biodiversity of Michigan's Great Lakes Islands: Knowledge, Threats and Protection. Lansing, MI: Michigan Department of Natural Resources.

Southam, C. and G. Larsen 1990. Great Lakes levels and flows under natural and current conditions. pp. 181 – 191 in: J.E. FitzGibbon. Ed. Proceedings of the Symposium on International and Transboundary Water Resource Issues. American Water Resources Association.

Stearns, F. W. 1995. History of the lake states forests: natural and human impacts. Lakes States Regional Forest Resources Assessment, Lake States Forestry Alliance.

Stebbins R. C., and N. W. Cohen. 1995. A natural history of amphibians. Princeton Univ. Press, Princeton, NJ.

Steedman, R.J. 1992. Centres of ecosystem function in the Lake Superior coastal zone. Making a Great Lake Superior. Lakehead University. Pp. 66 – 89.

Stephenson, S.A. 1999. Status of lake sturgeon (Acipenser fulvescens) in three Canadian Lake Superior tributaries. Lake Superior Management Unit Technical Report 99-21.

Stoeckeler, J. H., R. O. Strothmann, and L W. Krefting. 1957. Effect of deer browsing on reproduction in the northern hardwood-hemlock type in northeastern Wisconsin. J. Wildl. Manag. 21:75–80.

Storz, K., R. Clapper, and M. Sydor. 1976. Turbidity sources in Lake Superior. J. Great Lakes. Res. 2(2):393–401.

Strong, P., and R. Baker. 1991. An estimate of Minnesota's summer population of adult common loons. Minn. Dept. of Nat. Resour. Biol. Rep. 37. 30 pp.

Suarez, A.V., K. S. Pfennig, and S. K. Robinson. 1997. Nesting success of a disturbance-dependent songbird on different kinds of edges. Conserv. Biol. 11:928–935.

Sutherland, D. 1999. OMNR Natural Hertitage Information Centre. Personal communication.

Swanson, B.L. and D.V. Swedberg. 1980. Decline and recovery of the Lake Superior Gull Island Reef lake trout (Salvelinus namayscush) population and the role of sea lamprey (Petromyzon marinus) predation. Can. J. Fish. Aquat. Sci. 37: 2074–2080.

Terborgh, J. 1989. Where Have all the Birds Gone? Princeton University Press, Princeton.

Tesky, L. 1999 Wisconsin DNR. Personal communication.

The Nature Conservancy. 1994. The conservation of biological diversity in the Great Lakes ecosystem: issues and opportunities. The Nature Conservancy Program, Chicago, IL. 118 pp.

The White Pine Society. 2001. http://www.whitepines.org/index.htm

Thomas, R.L. and C.I. Dell. 1978. Sediments of Lake Superior. J.Great Lakes Res. 4(3-4):264–275

Thomson, F.R., S.J Lewis, J. Green, and D. Ewert. 1992. Status of neotropical migrant landbirds in the Midwest: Identifying species of management concern. pp. 145–158 In D.M. Finch, and P.W. Stangel (eds). Status and management of neotropical migratory birds. USDA, For. Ser. Rocky Mtn. For. & Range Expt. Station Gen. Tech. Rep. RM-229

Thompson, D.Q. R.L. Stuckey, and E.B. Thompson. 1987. Spread, impact and control of purple loosestrife (Lythrum salicaria) in North American wetlands. United States Departent of the Interior. Fish and Wildlife Research #2. 56 pp.

Thompson, I.D. 2000. Forest vegetation of Ontario. pp. 30 – 53. In: A.H. Perera, D.L. Euler, and I.D. Thompson (eds). Ecology of a Managed Terrestrial Landscape. Patterns and Processes of Forested Landscapes in Ontario. UBC Press. Vancouver.

Thorp, S., R. Rivers, and V. Pebbles. 1997. Impacts of changing land use. State of the Lakes Ecosystem Conference 1996. Background Paper. Environment Canada and U.S. Environmental Protection Agency.

Thunder Bay Field Naturalists. 1998. Checklist of vascular plants of Thunder Bay District (revised). Published by the Thunder Bay Field Naturalists. 52 pp.

Timmermann, H. R., and M. E. Buss. 1997. The status and management of moose in northern American in the early 1990s. Ont. Minist. of Nat. Resour., Northwest Sci. and Technology Tech. Rep. TR-109. Thunder Bay, ON.

Tordoff, B. 1999. University of Minnesota. Personal communication.

Tordoff, H. B., J. A. Goggin and J. S. Castrale. 2003. Midwest Peregrine Falcon restoration, 2003 report. Unpublished report, Bell Museum of Natural History, St. Paul, MN. 36 pp.

Turville-Heitz, M. 1999. Lake Superior basin water quality management plan. Wisconsin Dept. of Natural Resources PUBL-WT-278-99-REV. 300 pp.

Tushingham, A.M. 1992. Postglacial uplift predictions and historical water levels of the Great Lakes. J. Great Lakes Res. 18(3):440–455.

ULRG. 1977. The waters of Lake Huron and Lake Superior Vol. 3, Parts A and B, Report to the International Joint Commission by the Upper Lakes Reference Group.

Urban, N.R., Lu, X., Chai, Y. and D. Apul. 2004. Sediment trap studies in Lake Superior: Insights into resuspension, cross-margin transport and carbon cycling. Journal of Great Lakes Research. In Press.

U.S. Coast Guard [USCG] 1999).

U.S. Congress, Office of Technology Assessment. September 1993. Harmful Non-Indigenous Species in the United States, OTA-F-565 (Washington, DC: U.S. Government Printing Office).

U.S. Department of the Interior Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census. 1993. 1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. U.S. Gov. Printing Off., Washington, DC.

U.S. Department of the Interior Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census. 1998. 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. U.S. Gov. Printing Off., Washington, DC.

USDA. 1998. Gypsy moth in North America. Forest Service Northeastern Research Station website. (http://www.fsl.wvu.edu/gmoth/)

USEPA. 1994. Inland Spill Response Mapping Project. Digital database.

USFWS. 2002. Pitcher's Thistle (Cirsium pitcheri) Recovery Plan. Fort Snelling, Minnesota. vii + 92 pp.

USFWS 2000a. Dwarf Lake Isis Factsheet. U.S. F&WS Region 3 website: http://www.fws.gov.r3pao/

USFWS 2000b. American Hart's-Tongue Fern Factsheet. U.S. F&WS Region 3 website: http://www.fws.gov.r3pao/

USFWS 2000c. American Burying Beetle Factsheet. U.S. F&WS Region 3 website: http://www.fws.gov.r3pao/

USFWS 2000d. Kirtland Warbler Factsheet. U.S. F&WS Region 3 website: http://www.fws.gov.r3pao/

USFWS. 1999a. Houghton's Goldenrod Factsheet. U.S. F&WS Region 3 website : http://www.fws.gov/r3pao/).

USFWS. 1999b. Pitcher's Thistle Factsheet. U.S. F&WS Region 3 website : http://www.fws.gov/r3pao/).

USFWS. 1998. Waterfowl Population Status, 1998. Off. Migr. Bird Manage., Washington, DC.

USFWS. 1995. Great Lakes Fishery Resources Restoration Study. Report to Congress pursuant to the Great Lakes Fish and Wildlife Restoration Act, P.L. 101-537. 198 pp.

Utych, R. 1999. Whitefish Point Bird Observatory. Personal communication.

Van Stappen, J. 1999. Apostle Islands National Lakeshore. Personal communication.

Van Wagner, C.E. 1978. Age-class distribution and the forest fire cycle. Can. J. For. Res. 8(2):220–227.

Vennum, T. 1988. Wild Rice and the Ojibway People. Minnesota Historical Society Press. St. Paul.

Vigmostad, K. E., editor. 1999. Proceedings from the 1996 U.S.-Canada Great Lakes islands workshop. Mich. State Univ., East Lansing, MI.

Vigmostad, K. 1996. U.S. – Canada Great Lakes Islands Project: Project Summary. Michigan State University.

Voss, E.G. 1985. Michigan Flora. Part 2. Cranbrook Institute of Science. Bulletin 59. Ann Arbour.

Voss, E.G. 1996. Michigan Flora. Part 3. Cranbrook Institute of Science. Bulletin 61. Ann Arbour.

Wagner, W.H. and F.S.Wagner. 1993. Ophioglossaceae. In: Flora of North America Editorial Committee. Flora of North America Vol. 3. Oxford University Press.

Waller, D. M., and W. S. Alverson. 1997. The white-tailed deer: a keystone herbivore. Wildl. Soc. Bull. 25:217–226.

Ward, N. 2003. Fisheries and Oceans Canada Personal communication.

Ward, P.C. and A.G. Tithecott. 1993. The impact of fire management on the boreal landscape of Ontario. Aviation, Flood and Fire Management Branch Publication No. 305, Ont. Min. Natur. Res. 12 p.

Waters, T.F. 1983. The Streams and Rivers of Minnesota. University of Minnesota Press. Minneapolis. 361 pp.

Waters, T.F. 1987. The Superior North Shore. University of Minnesota Press. Minneapolis. 361 pp.

Watson, H.F. 1974. Zooplankton of the St. Lawrence Great Lakes – species composition, distribution, and abundance. J. Fish. Res. Board Can. 31:783–794.

Watson, H.F. and J.B. Wilson. 1978. Crustacean zooplankton of Lake Superior. J. Great Lakes. Res. 4(3-4):481–496.

Webb, S. A., and T. N. Todd. 1995. Biology and status of the shortnose cisco (Coregonus reighardi Koelz) in the Laurentian Great Lakes. Arch. Hydrobiol. Spec. Issues Advanc. Limnol. 46: 71–77.

Webb, W.L., D.F. Behrend and B. Saisorn. 1977. Effect of logging on songbird populations in a northern hardwood forest. Wildlife Monog. No. 55.

Weeber, R. C. 1999. The Canadian lakes loon survey: temporal patterns in breeding success of Ontario common loons (1981-1997) and representation of Ontario lakes. Prog. Rep. to Wildl. Assess. Program, Ont. Minist. of Nat. Resour., North Bay, ON.

Weeks, C. T. 1997. Dynamics of lake trout (Salvelinus namaycush) size and age structure in Michigan waters of Lake Superior, 1971-1995. MS Thesis, Dept. of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan.

Weiler, R.R. 1978. Chemistry of Lake Superior. J. Great Lakes Res. 4(3-4):370–385

Wetzel, R.G. 1975. Limnology. Saunders. Philadelphia.

Weseloh, D. V., P. J. Ewins, J. Struger, P. Mineau, C. A. Bishop, S. Postupalsky, and J. R. Ludwig. 1995. Double-crested cormorants of the Great Lakes: changes in population size, breeding distribution and reproductive output between 1913 and 1991. Colonial Waterbirds 18:48–59.

Weseloh, D. V., and B. Collier. 1995. The rise of the double-crested cormorant on the Great Lakes. Fact sheet. Can. Wildl. Serv., Environ. Can.

Weseloh, D. V. C., C. Pekarik, and H. Blokpoel. 1999. Breeding populations of cormorants, gulls and terns on the Canadian Great Lakes in 1997/98. Bird Trends: a report on results of national ornithological surveys in Canada. Can. Wildl. Serv., Env. Can.

Whitcomb, R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimkiewicz and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. Pp. 125 – 205 In: R.L. Burgess and D.M. Sharpe (eds). Forest Island Dynamics in Man-Dominated Landscapes. Springer-Verlag. New York.

White, B., P. Wilson, A. Johnson, S. Grewal and K. Shami. 2001. Status of the eastern wolf (Canis lycaon). Natural Resources DNA Profiling and Forensic Centre, Trent University, Peterborough, ON. Unpublished Rept., 14 pp.

White, D.J., R.V. Mahler and C.J. Keddy. 1983. Cirsium pitcheri. In: Argus, G.W., K.M. Pryer, D.J. White, and C.J. Keddy. Atlas of the rare vascular plants of Ontario. National Museum of Natural Sciences. Ottawa (looseleaf).

White, D.J., E. Haber, and C. Keddy. 1993. Invasive plants of natural habitats in Canada. Canadian Wildlife Service and Canadian Museum of Nature.121 pp.

Wickware, G.M. and C.D.A. Rubec. 1989. Ecoregions of Ontario. Ecological Land Classification Series, No. 26. Sustainable Development Branch, Environment Canada. Ottawa, Ontario. 37 pp.

Wilcove, D.S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology 66: 1211 – 1214.

Wilcox, D. A. 1990. Water-level fluctuations and Great Lakes wetlands. Great Lakes Wetlands 1(2):1–3.

Wilcox, D. and L. Maynard. 1996. Great Lakes coastal wetlands. SOLEC Working Paper presented at State of the Great Lakes Ecosystem Conference. EPA 905-R-95-014. Chicago, Ill.: U.S. Environmental Protection Agency.

Wilcox, D.A. and T.H. Whillans. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. Wetlands 19: 835 – 841.

Wild Rice Ecology, Harvest, Management, GLIFWC, DNR, MNR, USFWS & NA Waterfowl Management Plan (no date).

Wisconsin Department of Natural Resources. 1999. State Comprehensive Outdoor Recreation Plan, 2000-2005, Draft 2.0. Madison, WI. Web page: www.dnr.wi.us/org/land/parks/scorp/2000/index.html.

Wisconsin Dept. of Natural Resources. 1999a. Endangered species factsheets. Website: Website: http://www.dnr.state.wi.us

Wisconsin Dept. of Natural Resources. 1999b. Exotic species factsheets. (http://www.dnr.state.wi.us/ org/land/er/invasive/factsheets/)

Wisconsin Department of Natural Resources. 1995. Wisconsin's biodiversity as a management issue. Wisc. Dept. of Nat. Resourc., Madison, WI. 240 pp.

Wisconsin Wolf Advisory Committee 1999. Wisconsin Wolf Management Plan (Draft). Website: http://www.dnr.state.wi.us

Woods, G.T. and R.J. Day. 1977. A summary of the fire ecology study of Quetico Provincial Park. Ont. Min. Natur. Res. Report no. 8. Fire Ecology Study, Atikokan District. 39 p.

World Wildlife Fund. 1997. Terrestrial and aquatic protected areas representation analysis: Lake Superior basin. Draft report. 26 pp.

World Wildlife Fund. 1999. Terrestrial and aquatic protected areas gap analysis: Lake Superior basin. 34 pp. + maps and appendices.

Wright, H.E. B.A. Coffin and N.E. Aaseng (eds). 1992. The Patterned Peatlands of Minnesota. Univ. of Minnesota Press. Minneapolis.

Wydeven, A. 1999. WI DNR. Personal communication

Wydeven, A.P., R.N. Schultz, and J.E. Wiedenhoeft. 1999. Lynx and wolf track surveys in Wisconsin in winter 1998 – 1999. USFWS. Region 3, Endangered Species Grant Program. Section 6.

Wydeven, A.P. 1999. Status of the timber wolf in Wisconsin – performance report. July 1997 through June 1998. Wisconsin Endangered Resources Report #117. www.dnr.state.wi.us/org/land/er/publications/reports/report117/

Yeske, L.A., T. Green, F.L. Scarpace, and R.E. Terrell. 1973. Measurements of currents in Lake Superior by photogrammetry. Presented at the 16th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., Huron, Ohio.

Zimmerman, J. W. 1968. Water quality of streams tributary to Lakes Superior and Michigan. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries No. 559. 41p.

## VI. LIST OF ADDENDA

Addendum 6-A: Rare plant and animal species in the basin

Addendum 6-B: Rare community associations in the basin

Addendum 6-C: Habitat data for 65 Lake Superior tributaries in Ontario

Addendum 6-D: Important habitat areas of the Lake Superior basin.

Addendum 6-E: Selected stream monitoring data for Ontario tributaries

Addendum 6-F: Presence of fish species observed during 1953-1996

Addendum 6-G: Fish species names

Addendum 6-H: Lake Superior habitat map

Addendum 7-A: Ecosystem conservation example – Woodland Caribou

Addendum 7-B: Ecosystem conservation example – White-Tailed Deer

Addendum 7-C: Scientific names of non-fish species included in text

Addendum 8-A: Habitat requirements for lake trout, whitefish, lake herring, and walleye

Addendum 10-A: Documented exotic species aquatic species in Lake Superior

The addenda can be found in the LaMP 2000, Chapter 6, which is available at http://www.epa.gov/glnpo/lakesuperior/lamp2000/chap6.html.