Chapter 6:
Lake Superior Basin Habitat
Lake Superior Lakewide Management Plan

EXECUTIVE SUMMARY

The Habitat chapter of the Lake Superior LaMP 2000 consists of four main elements. Section 6.1 summarizes the status of habitat conditions in Lake Superior and its watershed. Section 6.2 outlines both a strategic and operational approach to addressing known issues and opportunities for habitat protection and restoration. Section 6.3 identifies actions underway or already completed that help restore/protect habitat in the basin. The fourth element is a map of known sites of important habitat in the watershed.

Section 6.1 of the habitat chapter represents results to date of efforts to summarize the status and trends of habitat features and ecological processes in the Lake Superior basin. While the summary is not yet complete, and broad, regional consensus has yet to be developed for the results and conclusions, some preliminary findings are emerging.

Habitat in the Lake Superior watershed supports high quality, diverse plant and animal communities. The habitat in the watershed remains in good shape despite extensive historical modifications and current stresses. The Lake Superior landscape has been modified by historic and current forest use as well as development of shorelines and forested areas. Chemical changes in water and sediments have, in some cases resulted in degraded habitat conditions for some species and communities. There have been substantial changes in the species composition of some natural communities through the introduction of non native species. Land use changes and decisions have both local and regional (sometimes lakewide) effects. Changing a mixed conifer forest to an early successional hardwood forest on highly erodible clay soils for example, can result in faster runoff of stormwater, increased streambank erosion, and higher rates of sedimentation in important fish spawning areas downstream.

Section 6.2 of the habitat chapter identifies a number of essential principles and strategies that support the protection and restoration of habitat in the Lake Superior basin. These strategies are presented as a starting point in the hope of developing a broad consensus of priorities among resource managers around the watershed. The goals for habitat that the Lake Superior Binational Program has endorsed are: 1) to protect and maintain existing high-quality habitat sites in the Lake Superior basin and the ecosystem processes that sustain them, and 2) to restore degraded plant and animal habitat in the Lake Superior basin.

Four high-priority strategies are identified, representing substantial regional consensus for habitat needs. These strategies are (1) implementation of habitat components of the Great Lakes Fishery Commission's rehabilitation plans for lake trout, lake sturgeon, walleye, and coaster brook trout; (2) complete comprehensive, systematic Natural Heritage Inventory/biological surveys in the watershed to identify remaining high-quality natural communities; (3) develop site conservation plans for known sites of important habitat and implement strategies to maintain habitat features;

and (4) implement habitat restoration/protection projects at sites meeting one or more of the committee's "ecological criteria for the identification of important habitat in the Lake Superior basin."

Section 6.2 also identifies actions and projects that entities working to improve habitat in the basin have either committed to or proposed. Where an agency is identified in association with a project, a level of commitment is indicated. "Commitment" means that funding has been secured for the project and that it has either just begun or will begin in the next year. Commitments made in this section will be tracked for reporting in the LaMP 2002. "Exploratory" indicates that the agency has proposed the project and is in the process of securing funding or other key support before beginning. These projects will also be tracked in the hope that the required support will be generated.

Finally, Section 6.2 sets out priorities for Habitat Committee work during the next two years. An important role for the Habitat Committee will be to facilitate discussion about habitat status, trends, stresses and sources of stress to the Lake Superior basin in order to achieve consensus for coordinated action. Section 6.1 will serve as a starting point for these discussions. Another role for the Committee will be to communicate the broad range of the habitat protection and restoration efforts under way throughout the basin. The World Wide Web will provide an important tool to help the Committee achieve this end.

There have been, and continue to be many projects to identify, protect and restore habitat in the Lake Superior watershed. More than 120 projects have been identified that support the Lake Superior Binational Program's goals and principles of habitat protection and restoration. These projects include efforts that can be categorized as 1) Habitat Restoration and Rehabilitation, 2) Special Designations and Acquisition, 3)Watershed Management and Forest Stewardship, 4) Monitoring, Assessment and Inventory, or 5) Education and Public Involvement.

More than 70 project summaries have been developed with the assistance of the people working on the projects. This compilation of project summaries was developed to document the work being done throughout the watershed that furthers the goals and strategies identified in the previous chapter of this LaMP. Where information was available, project summaries were developed in Section 6.3. Following the project summaries is a list of projects for which summary information is still needed. This report provides an encouraging picture of the many local and basin-wide efforts that have been undertaken. It is not a complete listing of all such projects. Development of this information will continue and can serve to provide a reference to natural resource managers and the Lake Superior community.

Developing and maintaining an inventory of important habitat sites in the basin has been a key charge of the Lake Superior Binational Program since its inception. The map "Important Habitat in the Lake Superior basin" included in this chapter represents a substantial improvement in the quality and quantity of geographic data available at the scale of the watershed since the original important habitat map was published in 1996. Revisions and improvements in habitat site information databases have also been made that substantially improve our inventory and our understanding of the range of sites and areas known to be important habitat. More than 300 important habitat areas and sites are now part of the inventory database.

Actions

Figure 6-1 summarizes actions and projects to identify, protect and restore habitat in the Lake Superior watershed. Figure 6-1 also delineates which projects are funded and those that need funding commitments. Finally, the action summary indicates the agencies and groups responsible for funding and/or managing these projects. These actions are described in further detail in Section 6.2.

Figure 6-1 Action Summary

Project	Lead Agency/ Funding Source	Funded	Needs Funding
Marsh reclamation - Thunder Bay	OMNR	X	
Cypress River Rehabilitation	OMNR	X	
Habitat requirements of coaster brook trout in Lake Superior - Nipigon Bay	OMNR		X
Biological Survey of North Shore Highlands Subsection	MN DNR	X	
Lake Superior Habitat Coordination	MN DNR	X	
Classify physical habitat in nearshore waters of Lake Superior in Michigan	MI DNR		X
Aquatic community survey in Michigan tributaries	MI DNR	X	
Develop communications package to highlight results of habitat projects.	LSHC		X
Develop regional consensus amongst resource managers on status of habitat and basin wide strategies using the LaMP2000 as the basis for agreement	LSHC		X
Maintain and continue to develop and distribute basin wide GIS data and decision support projects through the existing Lake Superior Decision Support project.	LSHC		X
Continue to develop and expand the Committee web site.	LSHC		X
The Central Lake Superior Watershed Project	CLSWP	X	
City of Marquette Riparian Habitat Protection	CLSWP		X
Salmon Trout River Watershed Project	CLSWP		X
Purple loosestrife and exotic plant control	GLIFWC	X	
Piping plover critical habitat designation	USFWS	X	
Whittlesey Creek restoration	USFWS	X	
Iron River Sea Lamprey Barrier	USFWS		X
Coordination of Superfund remediation and restoration with LaMP and RAP partners	U.S. EPA	X	
Complete remediation at Torch Lake and St. Louis River Superfund sites by 2005	U.S. EPA	X	
Work with LaMP/RAP partners to provide outreach and education on Brownfields redevelopment to local land use planners and decision makers	U.S. EPA	X	
Complete GIS maps of U.S. shoreline that include important habitat data by 2001	U.S. EPA	X	

6.0 ABOUT THIS CHAPTER

The Habitat chapter of the Lake Superior LaMP 2000 consists of four main elements. Section 6.1 summarizes the status of habitat conditions in Lake Superior and its watershed. Section 6.2 outlines both a strategic and operational approach to addressing known issues and opportunities for habitat protection and restoration. Section 6.3 identifies actions underway or already completed that help restore/protect habitat in the basin. The fourth element is a map of known sites of important habitat in the watershed.

6.1 STATUS OF HABITAT IN THE LAKE SUPERIOR BASIN

Section 6.1 is a discussion of the major habitat components in the Lake Superior basin, including the terrestrial and aquatic ecosystems.

Section 6.1 has the following components:

1. A description of the physical attributes and biological communities that make up the basin
2. A discussion of rare and declining species and communities and other significant plants and animals
3. Discussion of the stresses on the habitat.

It is based on a synthesis of data and reports from a variety of sources from the agencies around Lake Superior. These include "gray literature" from government sources, scientific papers, and personal communications from resources managers. Maps and tables are incorporated wherever possible.

6.1.1 The Lake Superior Basin

6.1.1.1 Geology and Glacial History

Most of the Lake Superior Basin is underlain by the Precambrian Canadian Shield (Figure 6-2), 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. 1110 to 1090 million years ago), an estimated 2 million km^3 of volcanic rocks, dominantly 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 6-2).

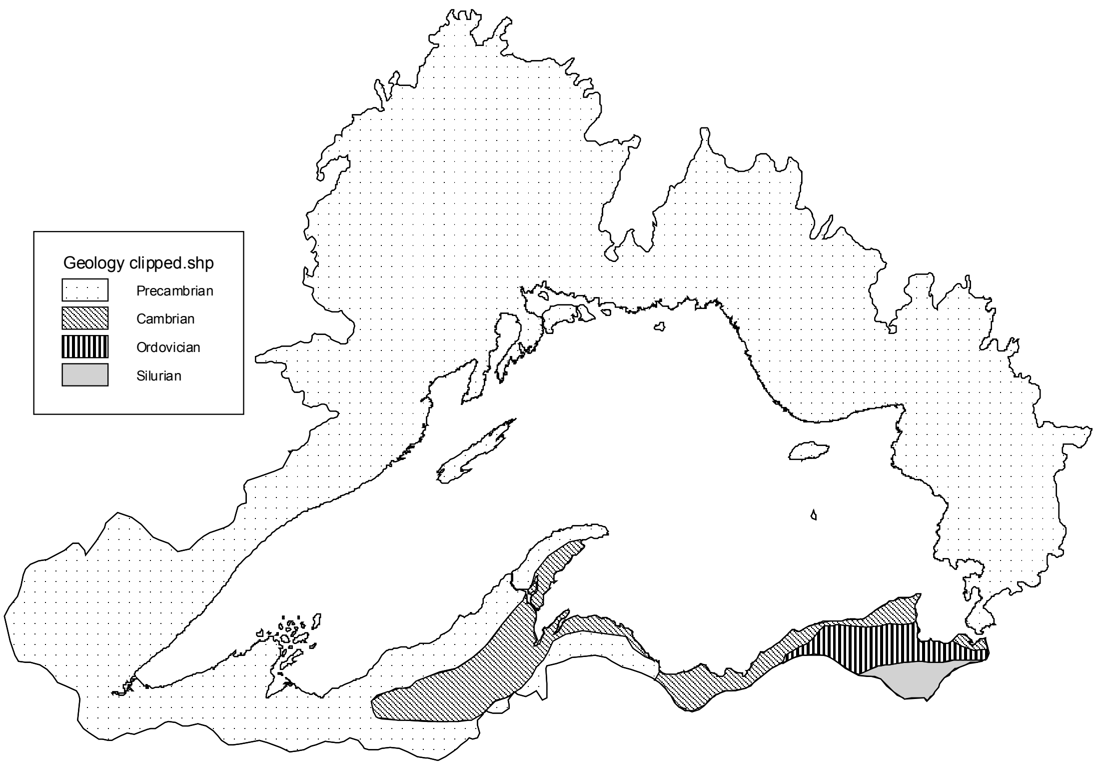


Figure 6-2. Generalized Geology of the Lake Superior Area (Government of Canada and U.S. EPA 1995)

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 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 meters and may exceed 200 meters.

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. 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 Ontanagan 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 meters 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 meters per century while emergence rates of approximately 0.27 meters per century have been estimated in the Michipicoten area of Ontario.

Table 6-1 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 Metres Above Sea Level)
0	(present Lake Superior level)	183
1000	Sub-Sault	190
2000	Sault	197
3000	Algoma	205
5000	Nipissing	220
6000		
7000	Houghton	246
8000	Post-Minong IV (Dorion) III II I	260 270 280 292
9000 9500	Minong III II I	308 315 325

6.1.1.2 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 6-3), the lake has a strong effect on climate within a few km 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 6-4). These areas also have the greatest snow accumulation. Portions of the Michigan Upper Peninsula average 875 cm of snow while Duluth, outside the greatest lake influence, receives only 138 cm (MPCA 1997).

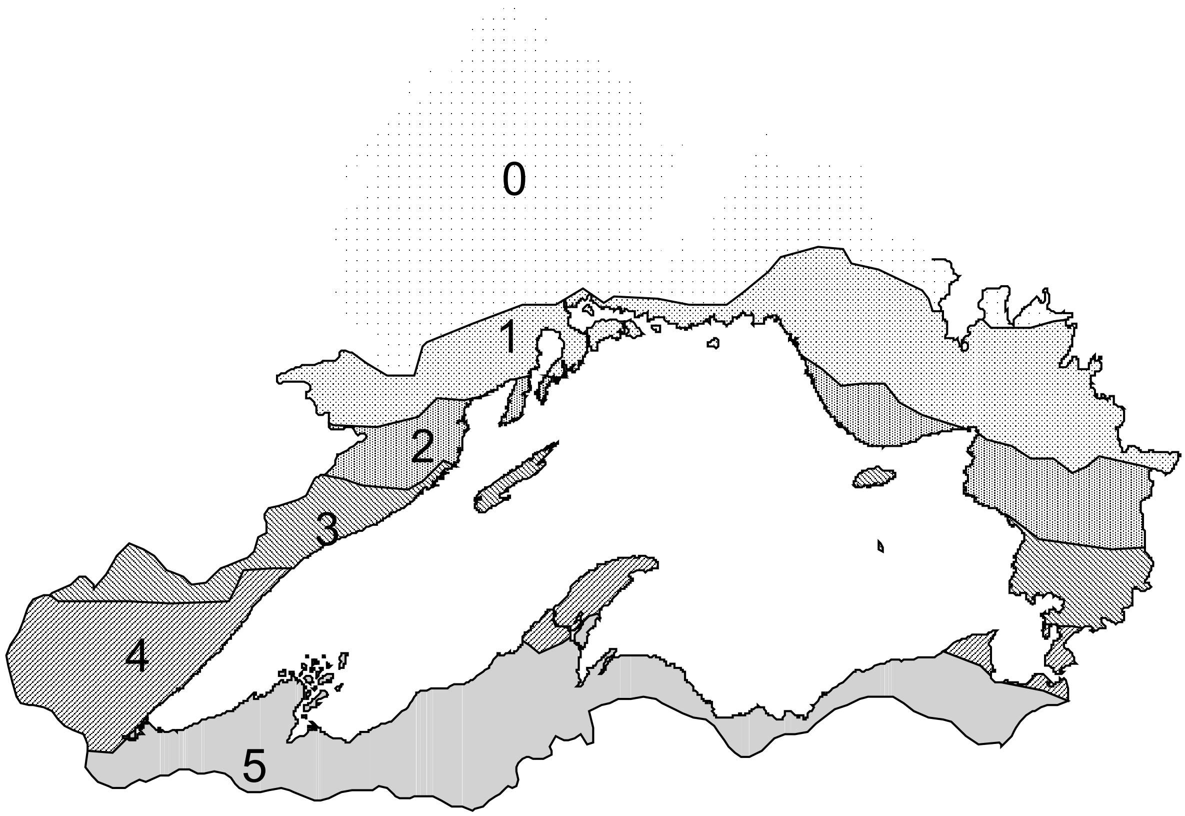


Figure 6-3. Mean annual temperatures calculated from monthly values (Lake Superior Decision Support Systems data) The numbers are mean temperatures in degrees Celsius.

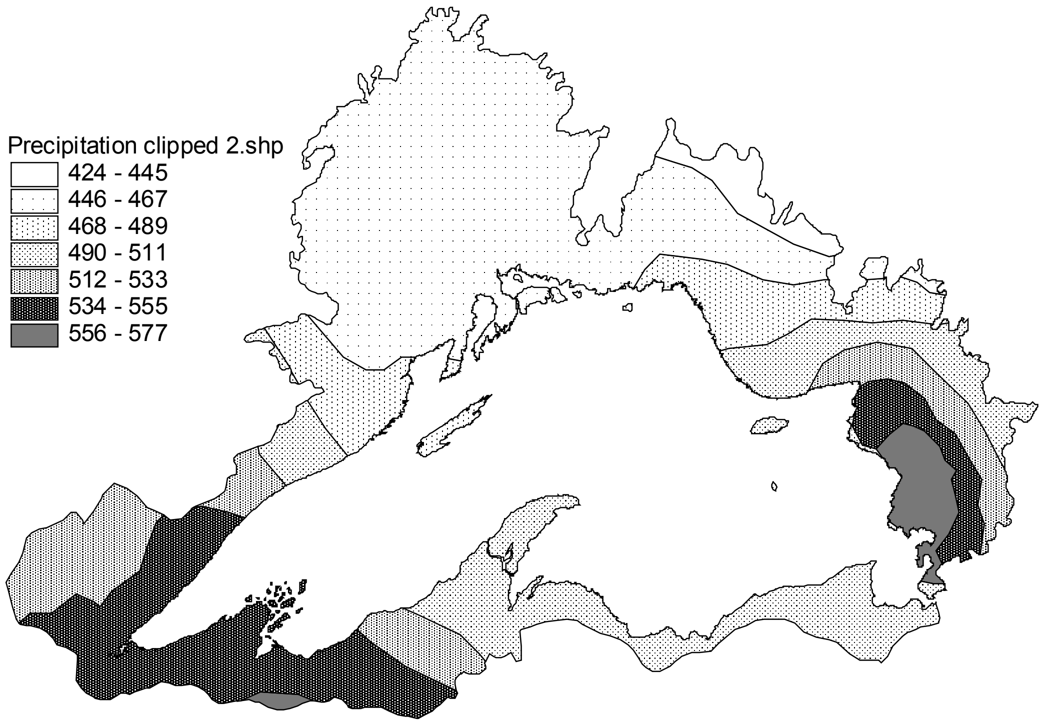


Figure 6-4. Growing season precipitation (Lake Superior Decision Support Systems data)

6.1.1.3 Human Population

The human population of the Lake Superior is estimated at 607,121 people (Environment Canada and U.S. EPA 1995). Most of the basin is sparsely populated. Most of Ontario and the Minnesota north shore has less than 2 people / km^2. Population density is greater on the on the south shore of the lake. Centers of population are at Thunder Bay, Duluth/Superior and Sault Ste. Marie (Figure 6-5). Note that census areas partly overlap the basin and reflect population statistics from outside the basin.

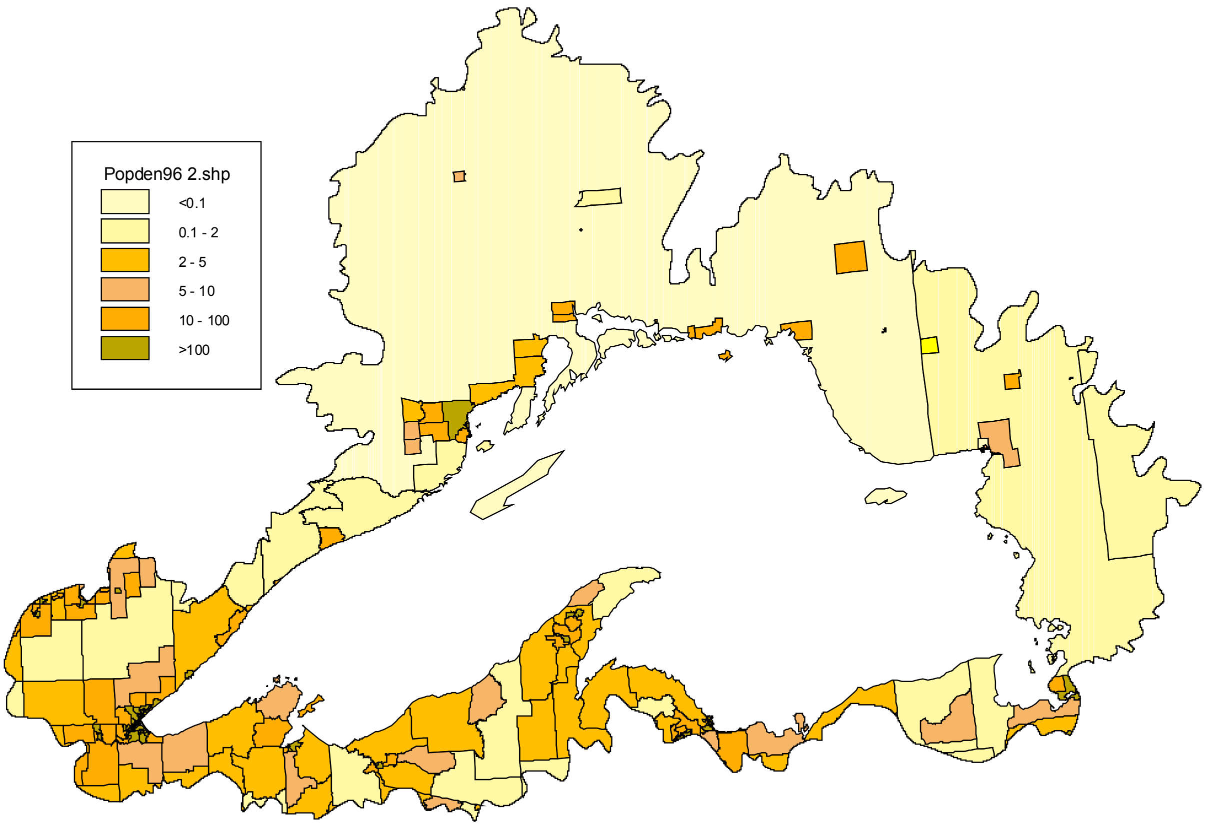


Figure 6-5. Population density of the Lake Superior Basin in 1996 (people/km^2) (Lake Superior Decision Support Systems Data, based on U.S. and Canadian census data)

Most of the basin experienced a small increase in population (0 – 5 percent) between 1991 and 1996. 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 6-6). 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.

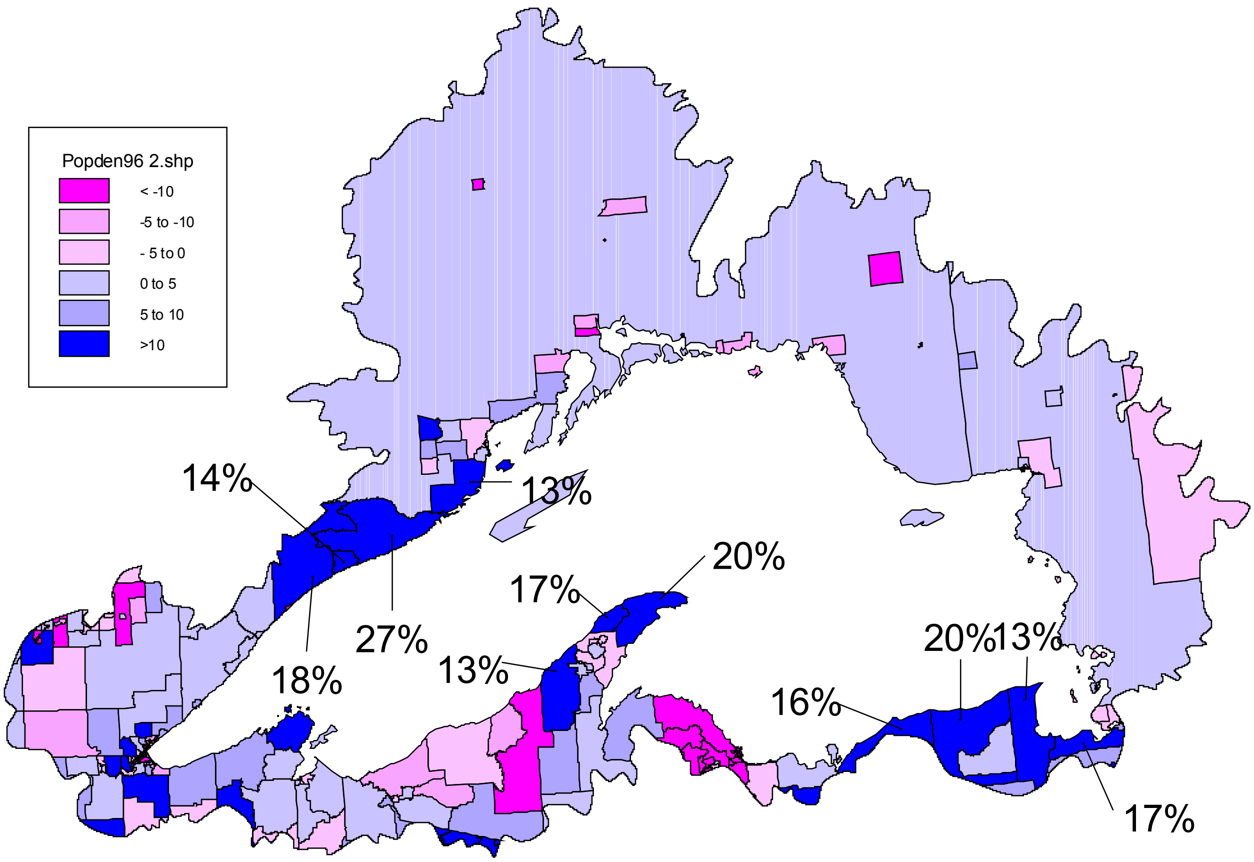


Figure 6-6. Population change (percent) between 1991 and 1996 (Lake Superior Decision Support Systems data, based on U.S. and Canadian census data)

6.1.1.4 Political Boundaries

The Lake Superior basin is divided between three states and one province (Table 6-2, Figure 6-7). Major cities are Sault Ste. Marie, Michigan/Ontario, Duluth/Superior, and Thunder Bay. 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.

Figure 6-7. Counties and districts of the Lake Superior basin

6.1.1.5 Land Use and Ownership

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, Wildlife Service), states (Department of Natural Resources), and county governments in Michigan, Minnesota and Wisconsin (Table 6-2). A number of tribal reservations are also found within the Lake Superior basin. Information summarizing the number, size, and distribution of reservations and tribal lands is currently being compiled. Note that tribal land in Michigan is not yet included in Table 6-2.

In Ontario, land ownership is primarily in the public domain, amounting to about 90 percent of the area. The Ontario Government holds this as Crown Land and Provincial Parks. The remaining 10 percent is held in private ownership (Figure 6-8). The majority of this land is held in relatively small holdings in the form of farmland, city and rural residential lots, and mining developments. There are some large consolidated blocks of land, which are privately held by railway and pulp and paper companies. Tribal Land and Indian Reservations make up less than 1 percent of the land base and are included in the 10 percent. Reservations in the basin also contain lands that are not public. These areas are not yet accurately identified in Figure 6-8.

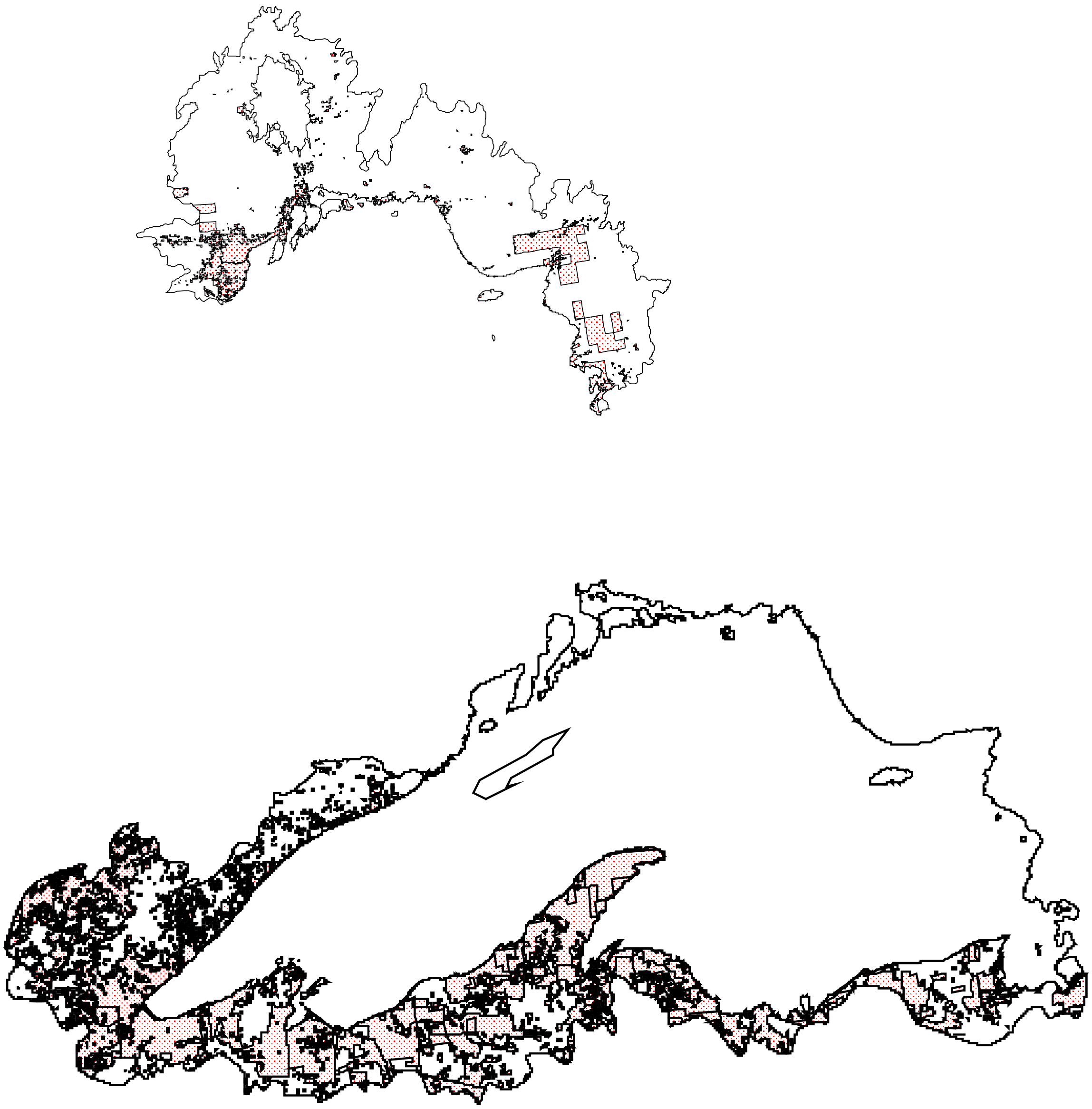


Figure 6-8. Private Land (pink) in the Lake Superior Basin (derived from OMNR and Lake Superior Decision Support Systems data)

Table 6-2 Land Ownership in the Lake Superior basin
("+" indicates < 1 percent)
(derived from OMNR and Lake Superior Decision Support Systems data)

Ownership	Ontario		Michigan		Minnesota		Wisconsin		Total	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
County Forest			152	1	3603	22	1376	19	5,131	4
National Forest			4139	20	2706	17	1061	15	7,906	7
National Park	1878	2	649	3	1	+	146	2	2,674	2
Other Federal			59	+					59	+
Other Private /Unclassified*	9067	12	8322	41	6081	38	3950	55	27,420	22
Non-industrial Private Forest					22	+			22	+
Private Industrial Forest			4435	22	482	3	341	5	5,258	4
Crown Land / State Forest	59,195	75	2338	11	2039	13	131	2	63,703	52
State / Provincial Park	3229	4	364	2	155	1	28	+	3,776	3
Conservation Reserve	5052	6							5,052	4
State Fish & Wildlife					130	1	28	+	158	+
Other State					94	1			94	+
Tribal					203	1	70	1	273	+
Army Corps of Engineers					1	+			1	+
Bureau of Indian Affairs					61	+			61	+
Bureau of Land Management					13	+			13	+
Wilderness Area					565	3			565	1
Total Area	**78421**	**100**	**20458**	**100**	**16156**	**100**	**7131**	**100**	**122,166**	**100**
Percent Area	**64 %**		**17 %**		**13 %**		**6 %**		**100 %**	

* includes Patent Land in Ontario

Note: Data presented for Michigan is incomplete. Missing data will be added in later drafts of the habitat chapter.

6.1.1.6 Parks and Protected Areas

The Lake Superior basin has approximately 10 percent of the area in parks and protected areas (see Figure 6-9). 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 ha; only part of which is within the basin) to Baraga State Park (22 ha) in Michigan.

In the last few years significant steps have been taken to improve the areas under protection around the lake. "Ontario's Living Legacy" has identified many new areas for new 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." This policy will apply to all 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" has three land use categories proposed for it, provincial Parks, Conservation Reserves & Enhanced Management Areas. In total this provides an area of 3856 km^2 of varying degrees of protection.

On the south shore of the lake there are two National Lakeshore, a National Park, many State Parks which provide protection for specific sites, and parts of five National Forests which 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 6-3).

Even with this high level of protected areas there are still areas that need to be considered. World Wildlife Fund Canada (1999), concludes that "… there remain significant gaps in the core protected areas system for the Lake Superior basin in both the terrestrial and aquatic portions, and both 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 report calls for continued effort from existing processes and agencies {(eg. Ontario's Living Legacy, Government of Ontario), the National Marine Conservation Area program (Heritage Canada), and Lake Superior Binational Program} to identify new candidate protected areas which would add to the ecological representation of the natural regions. And specifically to the enduring features and seascapes that have been identified in the WWF Canada Gap analysis.

Table 6-3 Parks and protected areas in the U.S. Lake Superior basin

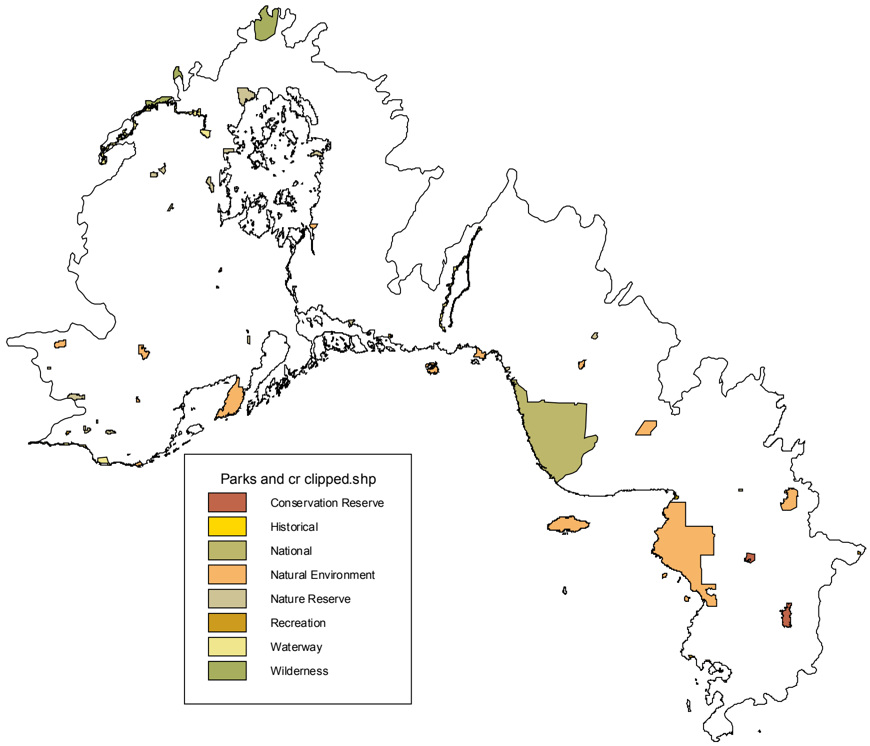
	Michigan	Wisconsin	Minnesota	Total
National Parks	1			1
National Monument			1	1
Wilderness (Forest Service)			1	1
National Lakeshore	1	1		2
National Historic Park	1			1
State Parks	13	4	13	30
State Wayside			3	3
County Parks			2	2
Wilderness Area	1			1

6.1.2 The Aquatic Environment

6.1.2.1 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 6-10). 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 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



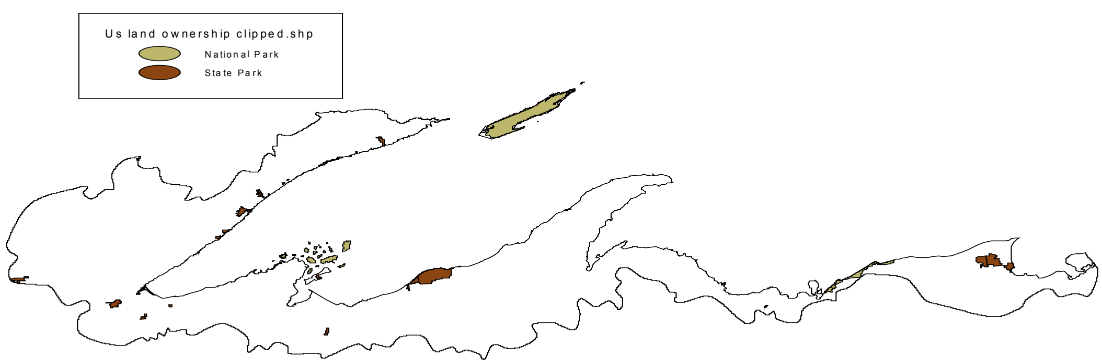


Figure 6-9. Parks and protected areas

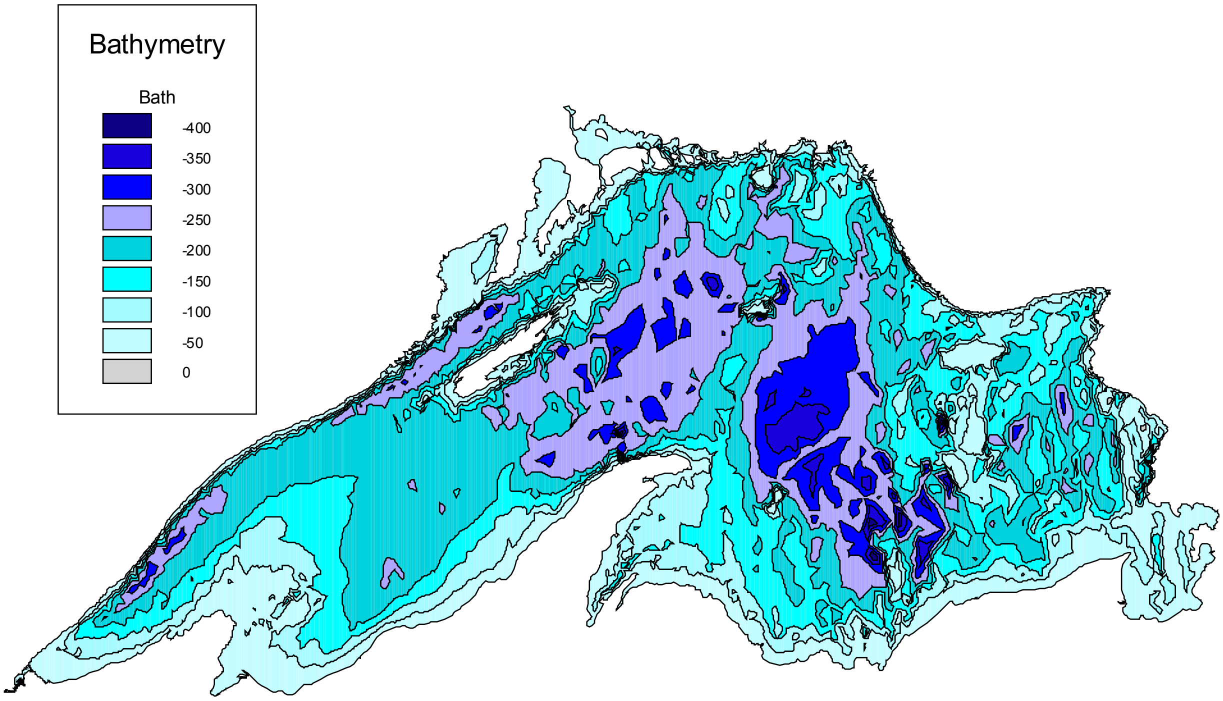


Figure 6-10. Lake Superior bathymetry

6.1.2.2 Sediments

Lacustrine sediments in Lake Superior reflect both glacial and post-glacial processes. Most of the existing sediments in Lake Superior were deposited approximately 11,000 to 9200 BP while the last Wisonsinan glacier was still within the lake's drainage basin (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 underlie 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/yr) 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 9200 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 3 m in depth, but may be as much as 9 m 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 2 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 6-11) 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 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.

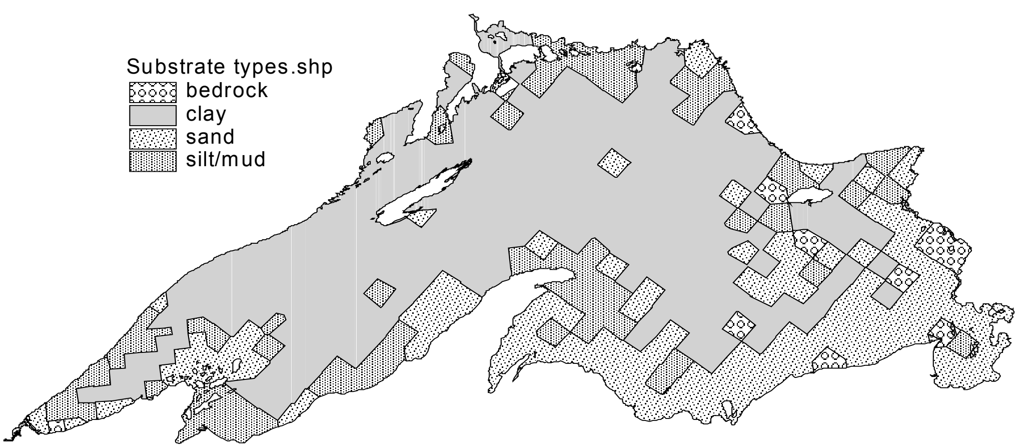


Figure 6-11. Surface sediment distribution in Lake Superior (after Thomas and Dell 1978)

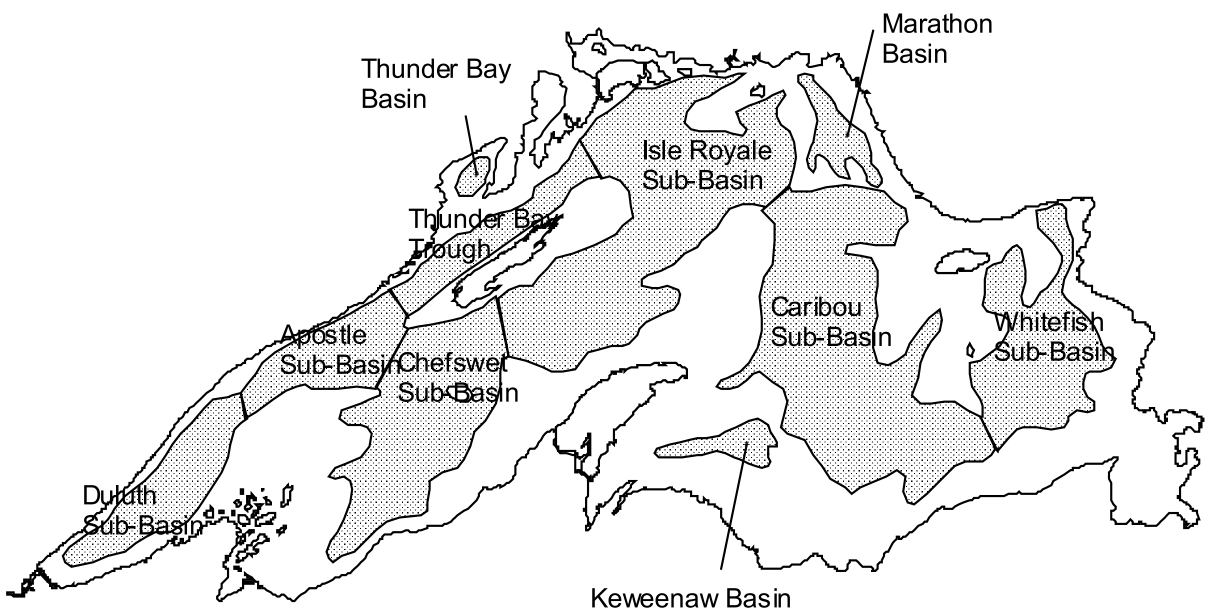


Figure 6-12. Depositional basins (shaded) (IJC 1977)

6.1.2.3 Sedimentation and Turbidity

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 at the base of step-sided troughs, and lowest midlake in areas of gentle topography. Shoreline erosion is the largest external source of sediment (Table 6-4), 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 basin and western shore of the Keweenaw Peninsula. Approximately 37 percent of the current natural sediment load is deposited in the Duluth basin, followed by the Chefswet and Keweenaw basins (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 account for 7 percent of the fine-grained sediment input. Although, annual loading of airborne particulates is low relative to other sources, these particles are of great importance because of their high concentrations of toxins and nutrients.

Table 6-4 Estimated quantity of clay and silt-sized sediment inputs to Lake Superior from various sources (adapted from Kemp and others 1978)

Source	Yield (metric tons)
Shoreline erosion	4,640,00
Taconite tailings	339,00
River inputs	2,410,00
Airborne particulates	41,00
Autochthonous organic matter	200,000
Dredged spoils	210,00
Subaqueous erosion	?

Secchi depths range from 9-15 m in midlake and 5-11 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 1.5-2.8 m under these conditions. Thunder Bay and Nipigon, and Black bay also have reduced water transparency.

6.1.2.4 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 near the north side of the Keweenaw Peninsula (Keweenaw Current). Currents are affected by wind conditions and internal pressured 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 5 cm/sec compared to less than 1 cm/sec near Duluth and the Apostle Is. 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.

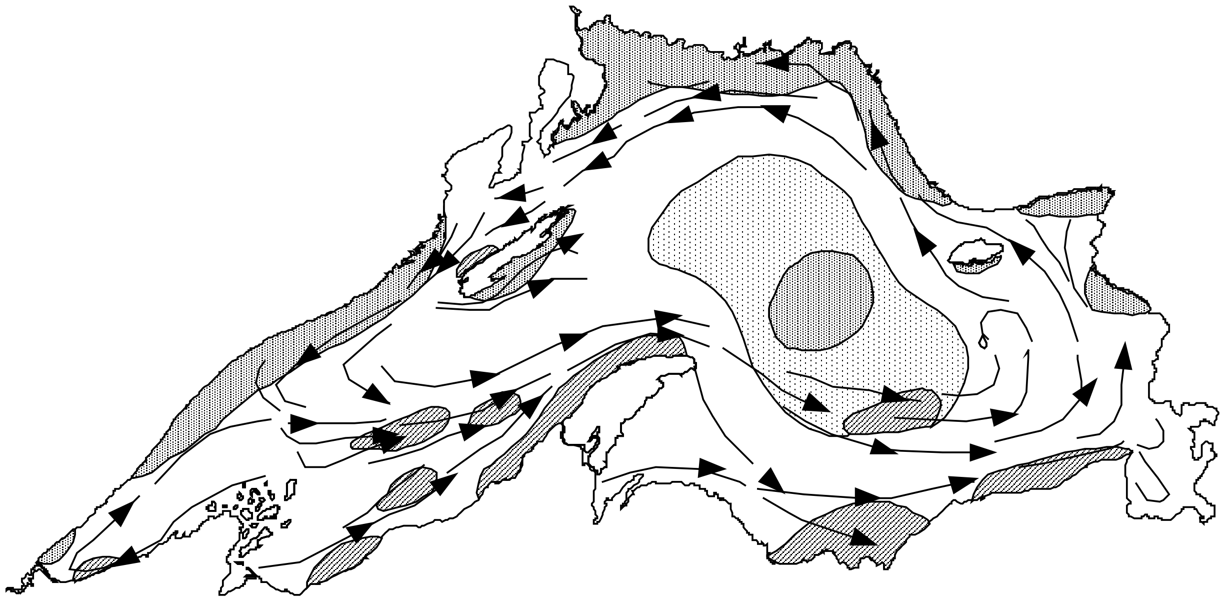


Figure 6-13. Major surface currents and upwellings
Downward water movement (cross-hatched), significant areas of upwelling (dark stipple) and extent of central upwelling (light stipple) are shown (after Harrington 1985 and WWF 1999)

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 currents speed in the hypolimnion decrease slightly because of frictional dissipation and are a seasonal minimum in August. Current speed and temperature rises 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 towards the nearshore downwelling zone along the southern shore (Bennet 1978). The general shoreward drift of surface water associated with anticlockwise 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 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 6-13 for major surface currents and upwellings in Lake Superior.

6.1.2.5 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 6-14). Although the annual heat income of Lake Superior is the second highest for any lake in the world, winter heat lost 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 longest of the Great Lakes, the summer stratification period the shortest, and the maximum surface temperature in the summer 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.

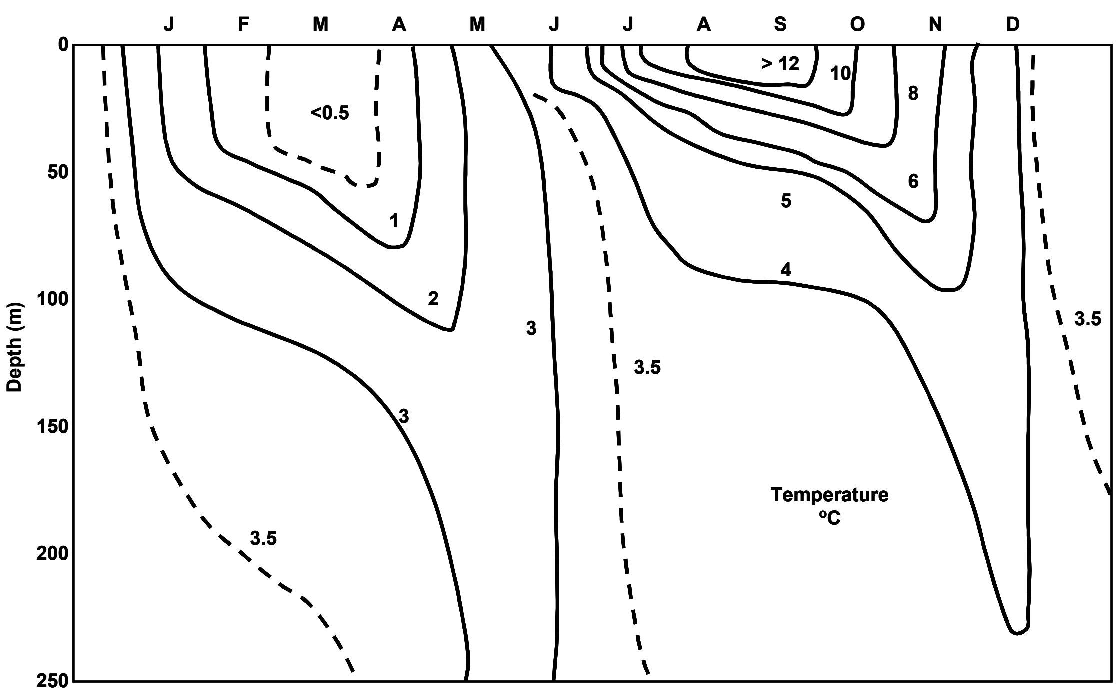


Figure 6-14. Seasonal changes in water temperature with depth for Lake Superior (Bennet 1978)

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 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 have dropped to 3°C, and decline rapidly in January as the lake stratifies.

Horizontal temperature patterns (Figure 6-15) 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 14-16°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).

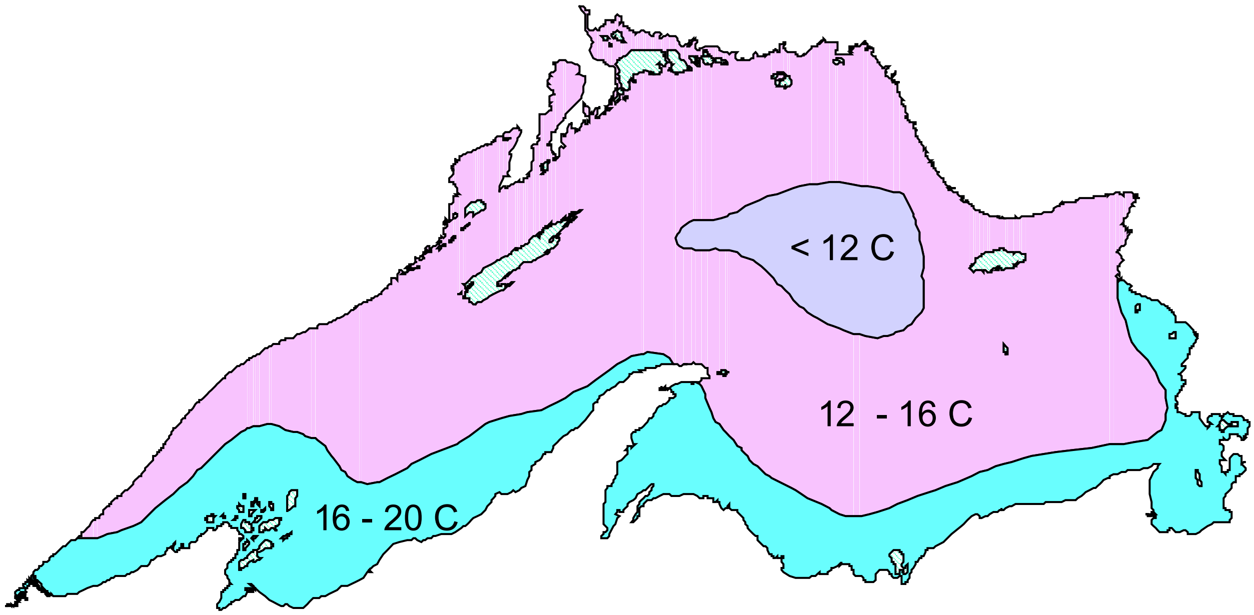


Figure 6-15. Mean August surface water temperature for Lake Superior

6.1.2.6 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 upon fish reproduction (e.g. ling) 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 6-16). At this time, consolidated pack ice occurs in most of the shallow bays and along much of the north shore. Close pack ice (70-90 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).

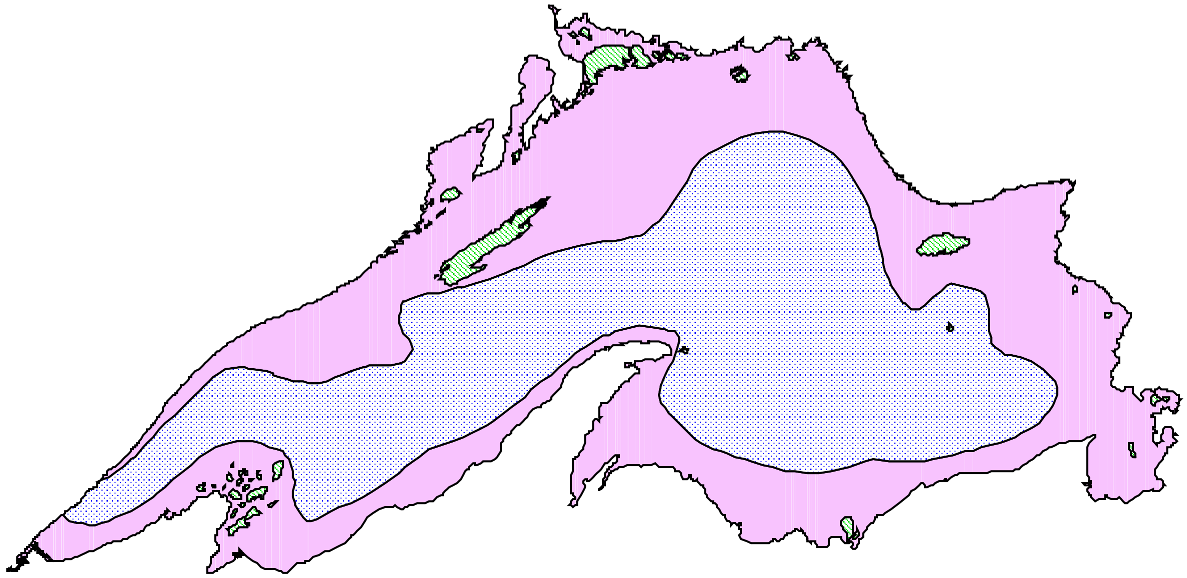


Figure 6-16. Normal winter maximum ice cover for Lake Superior (Rondy 1971)

6.1.2.7 Nutrients

Lake Superior has been classified as an ultra-oligotrophic lake on the basis of its very low nutrient availability and cold temperature. The water chemistry of Lake Superior is determined by the geology and climate of its drainage basin, anthropogenic inputs, bottom topography, circulation patterns, thermal regime, and biological processes. 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 western end near Duluth, Thunder Bay and Whitefish Bay. Nearshore areas, near Duluth in particular, exhibit generally elevated levels of total phosphorus and silica that are linked to man-made 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).

6.1.2.8 Oxygen

For most of the year, Lake Superior is saturated with dissolved oxygen. During the spring, convective mixing to nearly 300 m depth brings nearly all of the lake water in contact with the atmosphere (Bennet 1978). As a result, nearly the entire lake volume becomes saturated with dissolved oxygen. Some oxygen depletion can occur locally, but dissolved oxygen levels remain over 80 percent (Matheson and Munawar 1978). There is also a small loss of oxygen from the hypolimnion caused by the oxidation of organic matter that has settled through the thermocline. However, the great depth, low productivity, and the persistence of vertical mixing through June precludes the possibility of any deleterious effects of biological oxygen demand (BOD) in deep water. In addition, the relative shortness of the summer stratified period (approximately four months compared to five months for Lake Ontario), in principle results in a lower seasonal BOD per unit area of the hypolimnion. BOD per unit volume would also be comparatively lower due the large thickness of the hypolimnion in Lake Superior compared to the other Great Lakes.

6.1.2.9 Primary Production - Chlorophyll *a*

Chlorophyll *a* concentrations, which are a measure of phytoplankton biomass, 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, ranging on average from 0.6 to 2.5 μg/L, with Duluth-Superior Harbour showing even 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 to which photosynthetically active radiation penetrates the water surface i.e., the euphotic zone (Fee 1971). The euphotic zone averages 20-30 m depth in offshore areas, and less than 20 m 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 2 m deep. In general, Lake Superior has similar water transparency to Lake Huron, and both Upper Great Lakes have lower mean vertical extinction coefficients (MVEC) than the other Great Lakes (Schertzer and others 1978).

Lakewide chlorophyll *a* concentration decreases in mid-October due to the decline in solar radiation and decreased water temperatures associated with deep vertical mixing.
Water transparency varies spatially and temporally and is generally correlated with seasonal changes in chlorophyll *a* concentration.

6.1.2.10 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 1 m 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 result from year-to-year fluctuations in precipitation and runoff. Table 6-4a and Figure 6-17 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 are not well understood (Edsall and Charlton 1997).

Table 6-4a 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

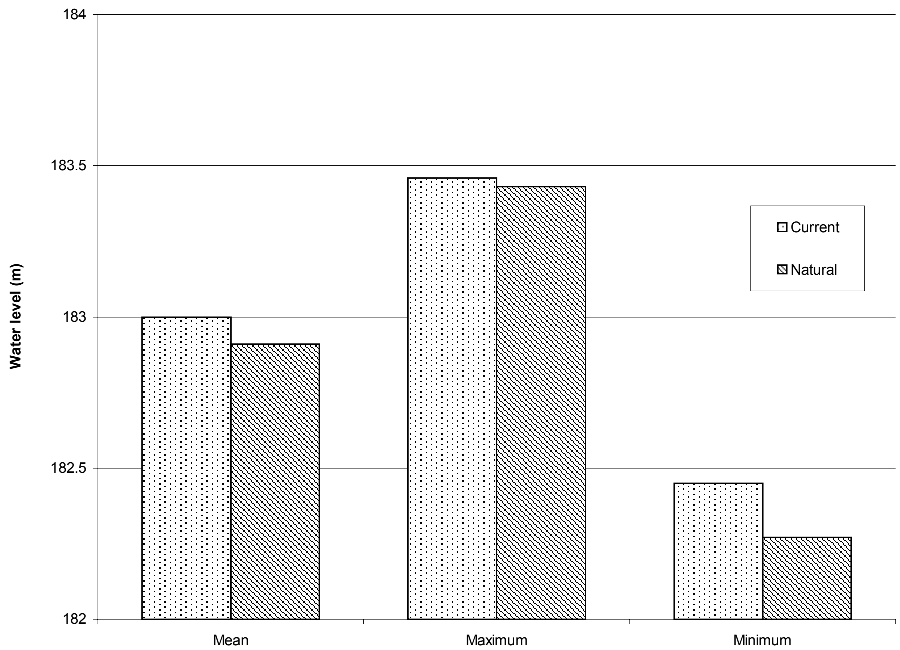


Figure 6-17. Annual water level fluctuations in Lake Superior, comparing present and natural values

6.1.2.11 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 6-18). 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 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).

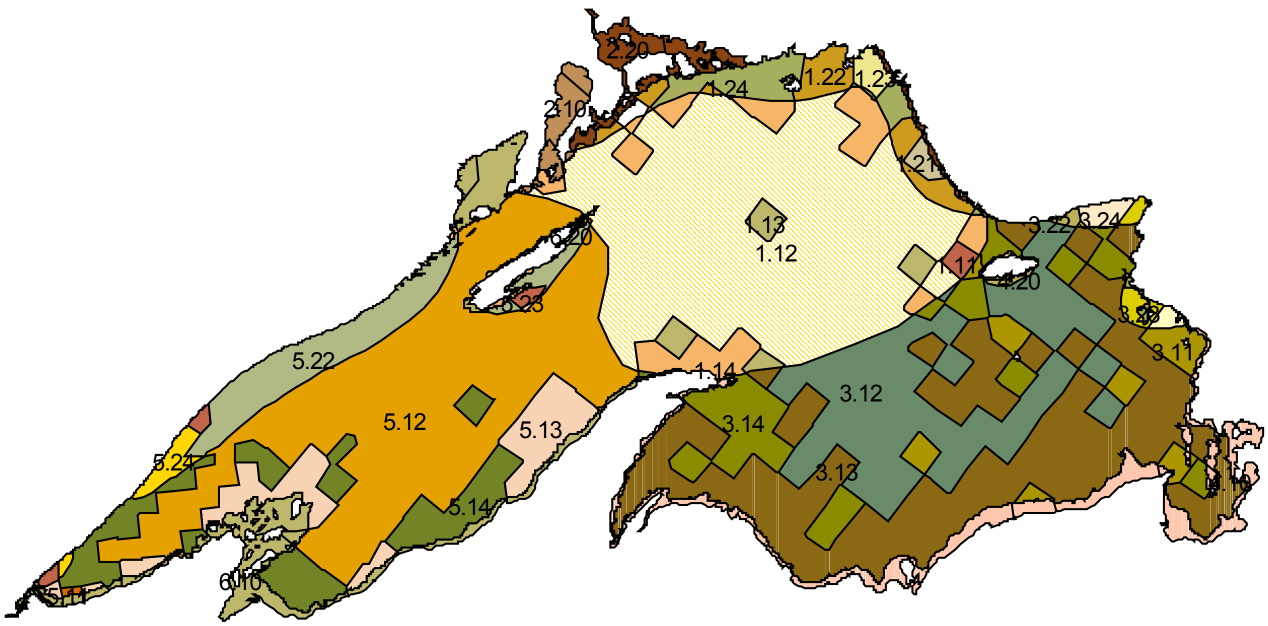


Figure 6-18. Seascapes of Lake Superior (World Wildlife Fund Canada 1999)

6.1.2.12 Nearshore Habitat and Embayments

Nearshore open water habitat consists of areas where the water depth is less than 80 m (Lake Superior Technical Committee 1999). Embayments (or bays) are partially enclosed by land and therefore less exposed to wind and wave energy. Together, these habitats make 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 6-19). The most extensive areas of nearshore habitat are at the east and west 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. Major embayments include Black Bay, Nipigon Bay, Thunder Bay, Batchawana Bay, Whitefish Bay, Keweenaw Bay, and Chequamegon Bay.

Figure 6-19. Nearshore (dark) and offshore (light) habitats.

Despite their relatively small area, nearshore areas are important because they are more diverse and productive than offshore waters. Most of Lake Superior's fish species use nearshore waters at some stage of their life cycle and many commercially important fish use nearshore waters exclusively (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 6-20). Aquatic vegetation is found only in nearshore habitats.

Table 6-5 shows nearshore areas and bays that have been identified as Aquatic Biodiversity Investment Areas (Koonce and others 1998). These are sites in the Lake Superior ecosystem that 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).

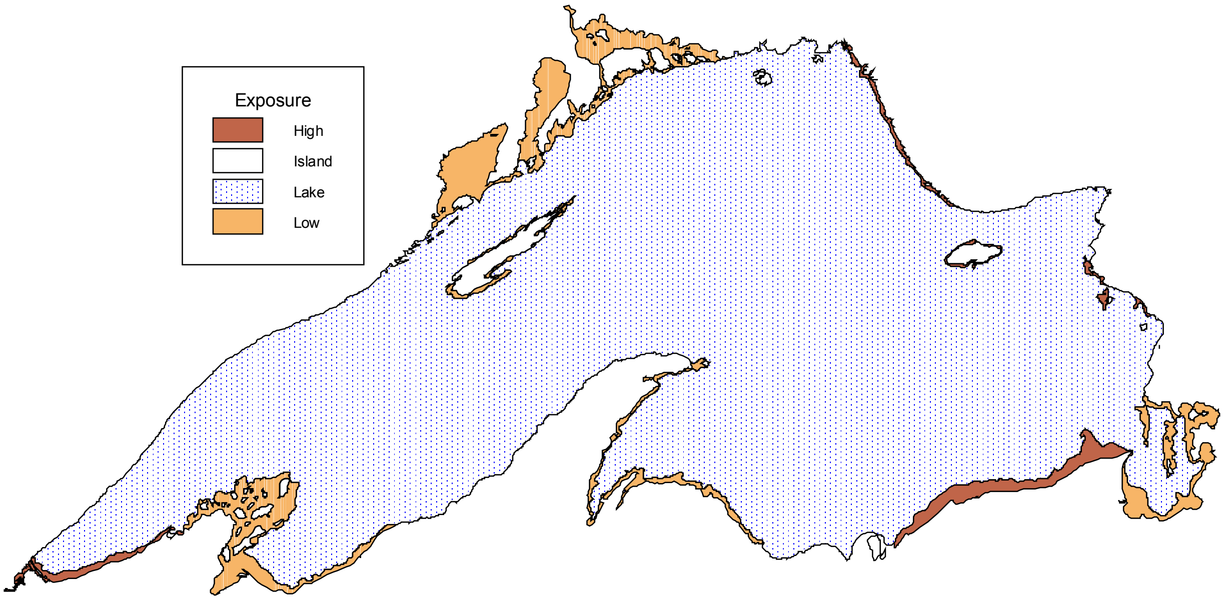


Figure 6-20. Wave exposure zones (WWF).

Nearshore habitats, especially bays, have been exposed to more impacts of human activities than offshore areas. Many of the bays are adjacent to intensive human use and are exposed to a variety of stresses. Loss of fish and wildlife habitat, primarily in the nearshore zone, has been identified at most of the Areas of Concern on Lake Superior.

Some nearshore waters have an accumulation of sawdust and woody debris associated with log drives and sawmills in the late 1800's and early 1900's, degrading spawning habitat for fish (Lawrey 1978). Embayments are also impacted by dredging, dumping of dredged material, and thermal loading. Exotic species, such as purple loose strife and ruffe affect the nearshore habitat.

Eutrophication, caused by nutrients input from sewage plants, industry and agriculture, results in algal blooms. This impairs visibility and decreases oxygen availability for aquatic life. On Lake Superior, eutrophication is a local problem on some bays, but algal mats have recently been discovered covering isolated rock shoals in Lake Superior (Edsall and others 1991).

Table 6-5 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

6.1.2.13 Offshore Habitat

Offshore habitat is deeper than 80 m. This habitat makes up about 80 percent of the surface area of Lake Superior (Figure 6-19).

Offshore habitats are less productive and diverse than nearshore habitats. Communities made up of a few species of pelagic and bottom-dwelling fish. The benthic habitat is dark and has a constant temperature of 4^oC

Offshore habitats in Lake Superior are generally regarded to be healthy (LSBP 1998). Dumping or discharges from vessels may threaten habitat, but the impacts are not well understood.

6.1.3 Aquatic Communities

6.1.3.1 Phytoplankton

The Lake Superior phytoplankton community represents a unique assemblage of approximately 300 species. Scientific names of all species presented in this chapter can be found in Addendum 6-G. Nannoplankton (<60 µm) dominate the phytoplankton biomass and primary production, but most surveys have focused on diatoms and other net plankton (>60µm) (Munawar and others 1978). Phytoflagellates (cryptomonads, chrysomonads, dinoflagellates) comprise approximately 35 percent of the species, followed by diatoms (31 percent) and Chlorophyta (22 percent).

Lake Superior has been divided into six phytoplankton regions based on taxonomic and biophysical data (Munawar and Munawar 1978) (Figure 6-21) The Duluth, Thunder Bay, and Whitefish Bay regions are unique environments and show relatively high biomass concentrations during the summer (July-September) compared to other regions of the lake. With the exception of Duluth region, species composition is broadly similar among regions.

Common phytoflagellate species typical of oligotrophic lakes (e.g. *Cyclotell*a spp. and *Fragilaria crotonensis*) characterize the open lake. There are also a large number of rare species, some of which are indicative of cold-stenothermal 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.

Most of the lake has very low (0.1-0.2 g/m^3) phytoplankton biomass and can be classified as ultra-oligotrophic on that basis. Biomass is homogeneously distributed with little inshore/offshore differentiation (Munawar and Munawar 1978) with the exception of Western Lake Superior has relatively high biomass concentrations. Nannoplankton comprise approximately 65 percent of the total phytoplankton, and smaller fractions (<10 µm) account for 32 percent of the biomass. Diatoms and phytoflagellates, especially cryptomonads and chrysomonads, dominate the lake-wide phytoplankton biomass. Dinoflagellates, green and blue-green algae contribute little to the total biomass.

No clear seasonal trends in biomass are apparent for most of the lake, although biomass is lowest when Lake Superior is unstratified (May-June, November-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.

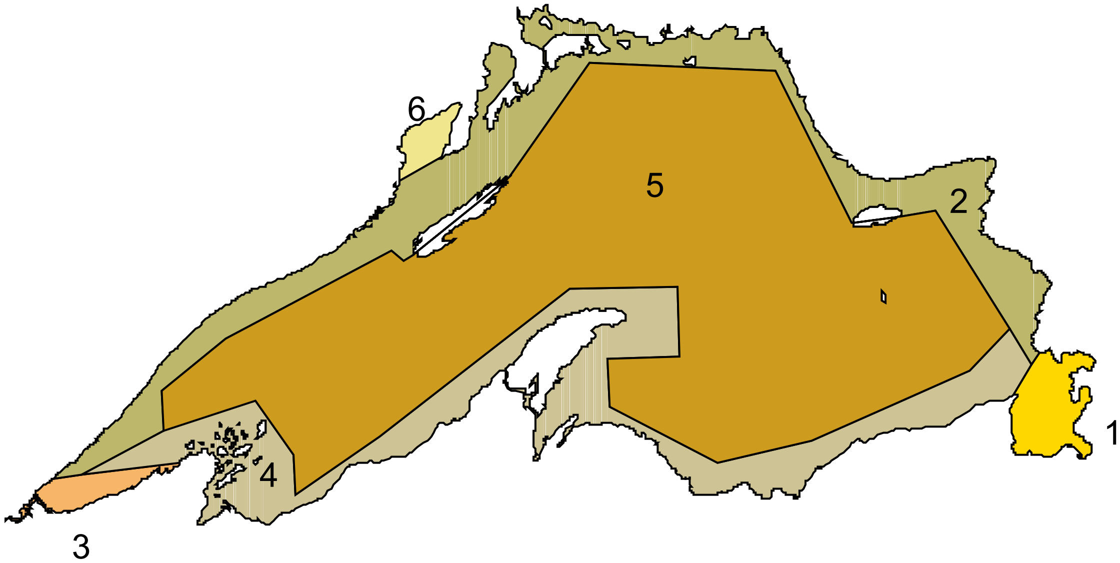


Figure 6-21. Phytoplankton zones of Lake Superior based on taxonomic data (1) Whitefish Bay, (2) Northern Nearshore, (3) Western End, (4) Southern Nearshore, (5) Main Lake, (6) Thunder Bay (Munawar and Munawar 1978)

6.1.3.2 Zooplankton

The zooplankton community of Lake Superior is spatially and temporally heterogenous. The lake-wide zooplankton is relatively homogenous in the spring, but during the early summer local clusters appear in many inshore areas, and by early fall the zooplankton community distribution is heterogenous. Zooplankton distribution and abundance is strongly associated with surface water temperature, and highest concentrations are found inshore, especially in the major embayments. Abundance is generally low in comparison with the lower Great lakes, and little variation in total numbers/m^3 is evident throughout the ice-free season. Seasonal concentrations peak at 45,000 individuals/m^3 in some inshore areas (Whitefish Bay) compared to only about 3000 individuals/ m^3 in the open lake (Watson and Wilson 1978).

The zooplankton community of Lake Superior 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 lake-wide average, is dominated by large calanoid copepods such as *Diaptomus sicilis*, *Limnocalanus macrurus*, and *Senecella calanoides.*

These species appear to be present year-round, with a single reproductive pulse during the fall or early winter. Upwelling along the northern shore pushes warmer inshore water and its entrained zooplankton offshore, resulting in a unimodal pattern similar to those of the offshore areas. 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 lake-wide conditions return quickly with the turnover in late fall (Watson and Wilson 1978).

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 movement of water masses (e.g. upwelling, thermal bars, 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 lake-wide 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 increases five-fold between May and September (Watson and Wilson 1978). The authors are unaware of additional recent research on zooplankton and will include these data, if such data exists, as this report is finalized.

Table 6-6 Dominant zooplanton species in Lake Superior (Watson and Wilson 1978)

Taxa	**Percent total numbers**	**Percent total biomass**
Calanoid copepods		
Diaptomus sicilis adults	11.0	20.0
Diaptomus ashlandi adults	2.5	2.5
Diaptomus spp. copepodites	18.0	17.0
Diaptomus spp. nauplii	44.0	7.0
Limnocalanus macrurus	5.5	32.0
Senecella calanoides	0.6	5.0
Calanoid Total	**81.6**	**83.5**
Cyclopoid copepods		
Cyclops bicuspidatus thomasi adults	1.0	1.0
Cyclops spp. copepodites	6.5	2.0
Cyclops spp. nauplii	5.0	0.5
Cyclopoid Total	**12.5**	**3.5**
Cladocerans		
Bosmina longirostris	1.2	0.1
Daphnia galeata mendotae	3.0	8.0
Holopedium gibberum	0.2	0.3
Cladoceran Total	**4.4**	**8.4**
Total	**98.5**	**95.4**

6.1.3.3 Benthic Communities

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

The 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 were associated with shallow water, on sandy and finer substrates respectively. *Diporeia* is most abundant in relatively shallow water (40-80m) compared to the mean depth of Lake Superior (160 m) (Freitag and others 1976; Dermott 1978). Tubificid *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 deep water communities and much of western Lake Superior, mollusc and insect populations are extremely scarce, and in mid-lake locations with extremely low productivity, only the stenotherms *Diporeia* and *Stylodrilus* were 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 22), due to lower mean depth (63 m) and higher algal populations. In contrast to the lake-wide mean, oligochaetes were dominant and Sphaeriidae comprised 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 and pelagic heterotrophic bacteria populations (Munawar and Munawar 1978, Rao 1978).

6.1.3.4 Fish Communities

The native fish community of Lake Superior was and is still dominated by salmonines and coregonines, typical of post-glacial oligotrophic lakes in North America. Approximately 80 fish species belonging to 19 families occur in Lake Superior or its tributaries. Of these, twenty species are non-native that have been deliberately (e.g. chinook salmon, rainbow trout) or accidentally introduced (e.g. ruffe, sea lamprey, rainbow smelt) since the late 1800's. Commercial and sport fishing pressure, introductions of non-native species, and changes in the physical environment (e.g. dams, mine tailings) have resulted in a fish community somewhat different and less stable than it was in the mid 1800's (Hansen 1994, Paloheimo and Regier 1982).

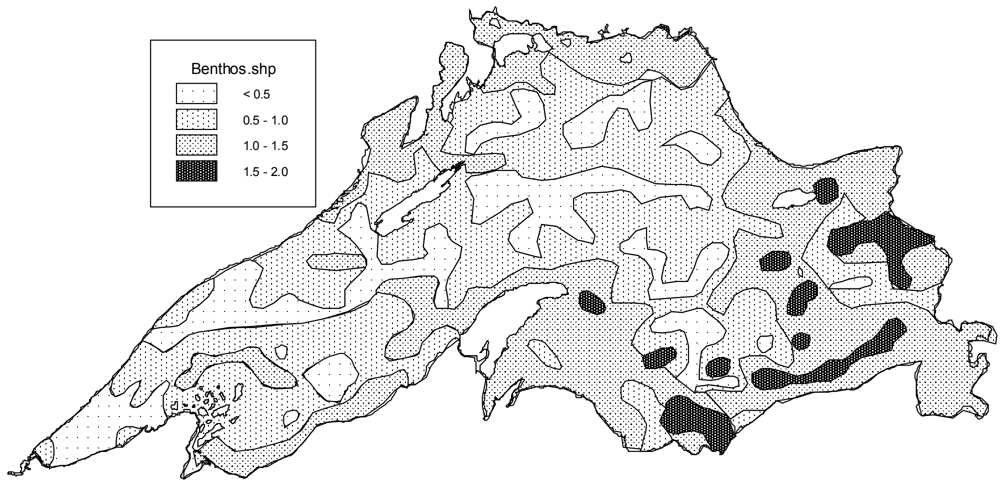


Figure 6-22. Benthic biomass diversity (Shannon's diversity index) (Dermott 1978)

Commercial fishing for lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*) began in the mid 1800's in Lake Superior to provide food for fur trading posts and other settlements (Waters 1987). By the late 1800's, 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 1870's and there was a general pattern of decline for many commercial species between the mid 1940's and early 1970's (Lawrie and Rahrer 1972). Declining populations of lake trout, burbot, whitefish and other species were further decimated during the 1940's and 1950's by sea lamprey (*Petromyzon marinus*) (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 not killed by sea lamprey 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 6-7) mainly due to the collapse of the lake herring and lake trout, species that have not yet fully recovered. Angling has had less impact on fish populations, but contributed to the decline of some populations of lake trout and brook trout, especially in shallower waters. Since 1983, lake herring have produced larger year classes and most lake trout stocks have been restored. 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.

Table 6-7 Mean annual fish yield ($kg \cdot ha^{-1} \cdot yr^{-1}$) and percent of total yield for Lake Superior contributed by different species or species groups (from Loftus and others 1987)

Species or Species Group	Early (1913-50)		Recent (1979-83)	
	Yield	**Percent**	**Yield**	**Percent**
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 1990's (M. Ebner 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 the1960's and 1970's, but re-emerged as major forage species in the 1980's following a decrease in rainbow smelt and abundance and production of several strong lake herring year classes (Selgegy and others 1994). Coregonines (mainly deepwater ciscoes), burbot, and sculpins are principal forage fish for siscowets.

Lean lake trout, steelhead, 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. Coaster brook trout were formerly more abundant in nearshore areas but have been reduced by overfishing, competition with introduced species and destruction of spawning habitat in tributaries. Lake whitefish are less pelagic than other coregonines and are most abundant at depths of 20-50 m. Rainbow smelt are also abundant in nearshore waters.

The fish community of bays, harbors and estuaries is comprised mainly of perches, suckers, sculpins, and minnow species. 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 river ruffe, white bass and round gobies may have profound impacts on these warmwater communities. Approximately twenty 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.

Table 6-8 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	macroinvert.[1]				X	X		X	X				X
pink salmon	plankton	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.				X	X		X	X				X
lake trout	fish	X	X	X	X	X	X						
lake whitefish	macroinvert.	X	X	X									
lake herring	plankton	X	X		X	X	X						
bloater	plankton	X	X	X									
kiyi	macroinvert.	X	X	X									
rainbow smelt	plankton				X			X	X	X			X
burbot	fish				X								X
ninespine stickleback	macroinvert.	X			X						X		
ruffe	macroinvert.				X			X	X	X			
Walleye	fish				X			X	X				X
slimy sculpin	macroinvert.	X									X		
Deepwater sculpin	macroinvert.	X											

[1] macroinvertebrates

Shoals and spawning areas for lake whitefish, lake herring, round whitefish and lake trout are shown in Figure 6-23.

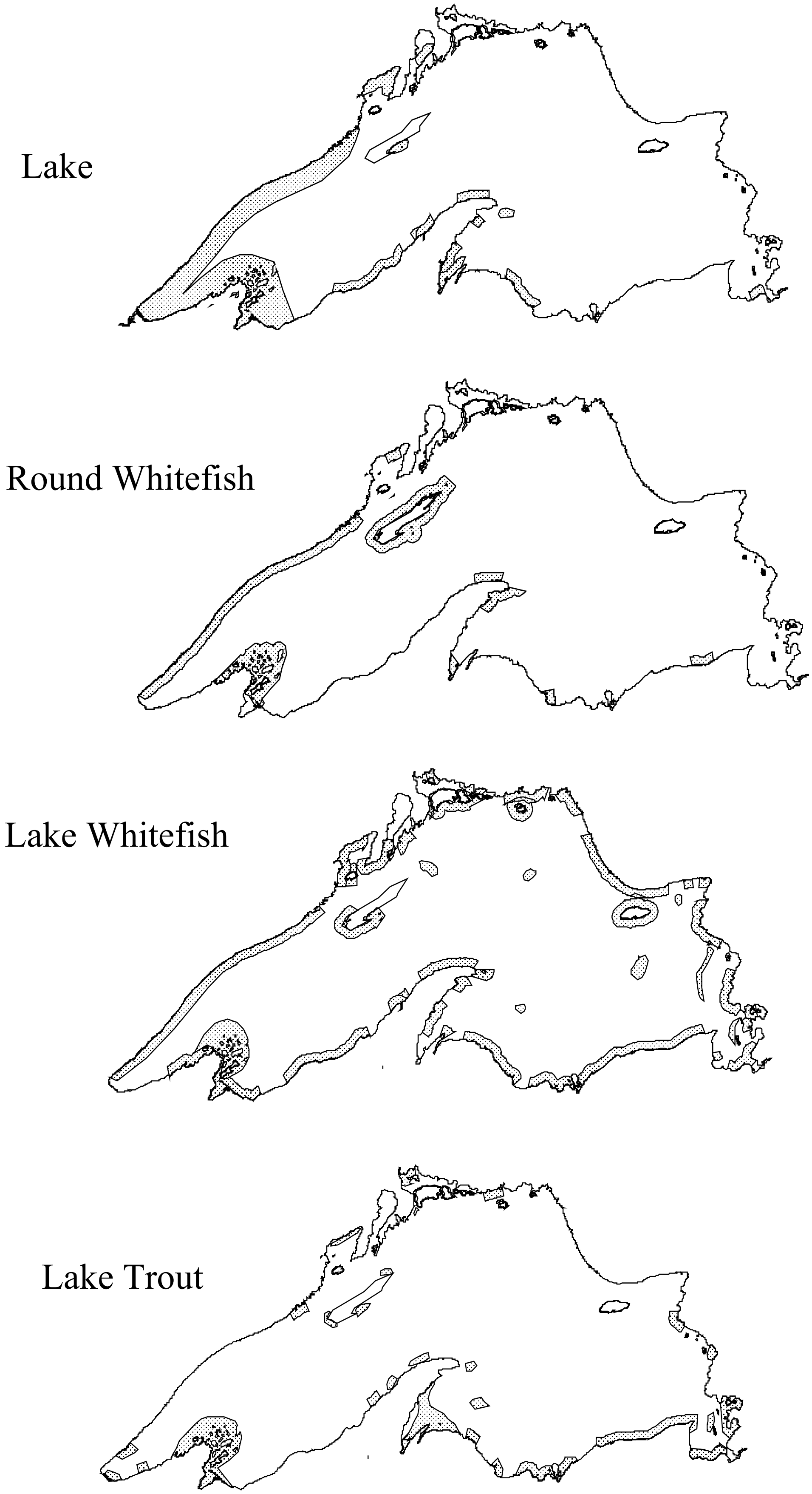


Figure 6-23. Spawning habitat for major fish species (from Goodier and others 1981)

6.1.4 The Terrestrial Environment

6.1.4.1 Ecological Land Classification

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

The Lake Superior basin is subdivided into 37 land units following the U.S. Regional Landscape Classification (Albert 1995) and Ontario's Site Region classification (Hills 1959) (Figure 6-24). The U.S. system is based on climatic and physiographic features (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' system, at least within the basin.

Section VIII makes up most of the eastern part of the U.S. basin. Sandy soils, dunes and beach ridges associated with glacial lake plain are prevalent. Large expanses of peatland and swamp are associated with poorly-drained soils and flat topography. This Section is mainly forested, except the clay lake plains, which are used for pasture and forage crops. Prevailing winds off Lake Superior result in cooler summers and milder winters than Section IX. Lake effect snow and rain is common near Lake Superior (Albert 1995).

The middle part of the south shore (Section IX) consists of bedrock ridges and glacial moraines, lake beds, outwash channels and plains (Albert 1995). Soils are relatively nutrient-poor, acidic, and rocky. The Lake Superior Lake Plain (IX.8) extends for approximately 200 miles 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. Climate is strongly continental with only moderate lake influence.

Section X constitutes most of the Minnesota basin. It consists mainly of morainal landforms with low bedrock knobs. Forest composition shifts from northern hardwoods in Section IX to more boreal pines and hardwoods in Section X. Climate is slightly drier and cooler than IX, but winter precipitation is less, contributing to spring fires.

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 are found.

Site Region 3W (Lake Nipigon) and Site Region 3E (Lake Abitibi) have typically 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.

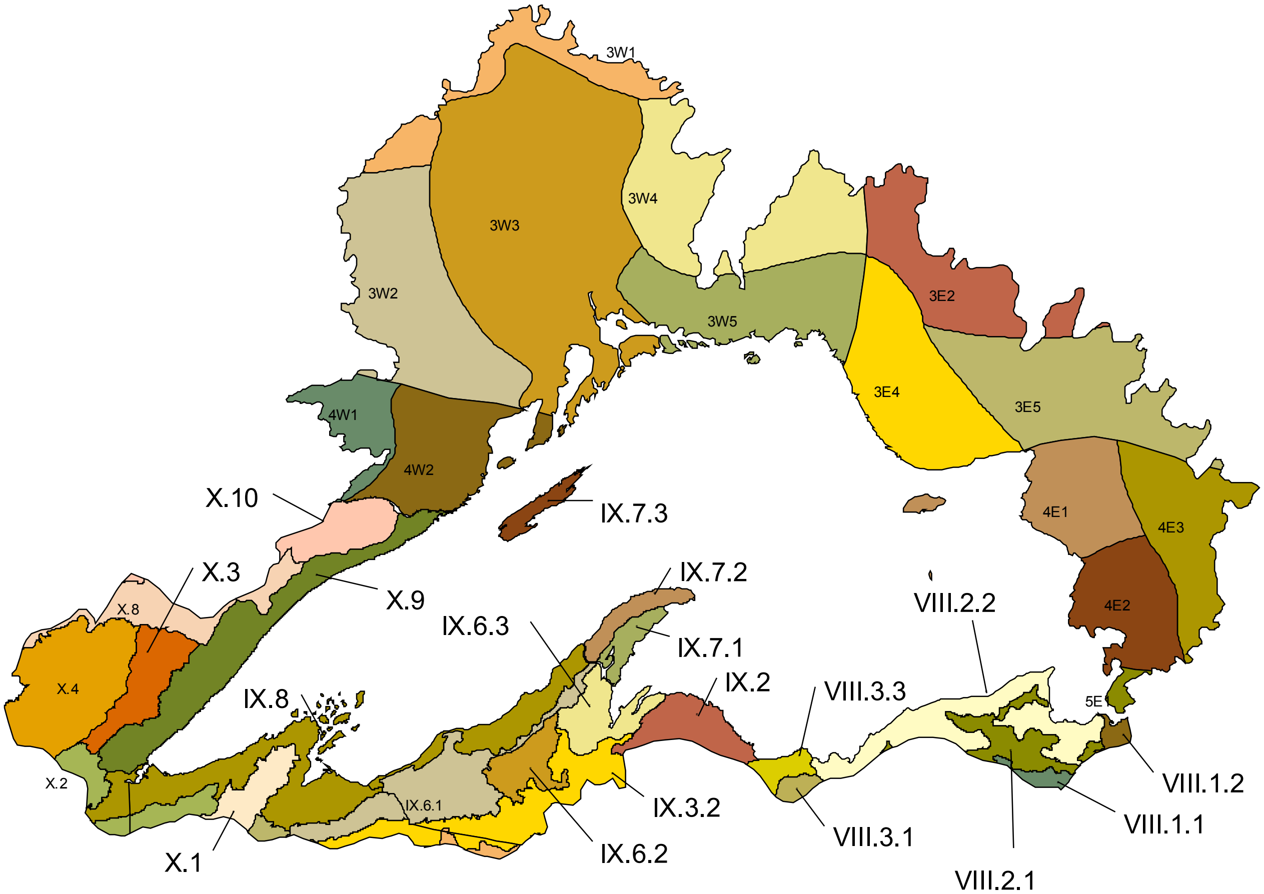


Figure 6-24. Ecological land classification of the Lake Superior basin (Hills 1969 and Albert 1995)

Table 6-9 Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin (Albert 1995)

SECTION/ SUBSECTION	SUB-SUBSECTION	
Section VIII. Northern Lacustrine-Influenced Upper MI and WI		late Wisconsinan-age glaciated landscape; northern hardwoods forest, jack pine barrens, white pine-red pine forest, conifer swamp, bog.
VIII.1. Niagaran Escarpment and Lake Plain	VIII.1.1. St. Ignace	Limestone bedrock and sand lake plain; conifer-dominated upland and wetland forests, northern hardwoods, fens, coastal emergent marshes, alvar
	VIII.1.2. Rudyard	Clay lake plain; conifer and hardwood-conifer-dominated uplands and wetlands; coastal marshes.
VIII.2. Luce	VIII.2.1. Seney Sand Lake Plain	Very poorly or excessively drained sand lake plain, transverse dune, outwash; shallow, paludified peatlands (many patterned), jack pine barrens, hardwood-conifer and conifer swamp.
	VIII.2.2. Grand Marais Sandy End Moraine and Outwash	Sandy end-moraine ridges and outwash aprons, Lake Superior shoreline features, transverse dunes, sand spits; white pine-red pine forest, jack pine barrens, red pine forest, northern hardwood forest, and patterned peatlands.
VIII.3. Dickinson	VIII.3.1. Northern Lake Michigan (Hermanville) Till Plain	Sandy and loamy ground moraine, drumlin fields; northern hardwood forest (with large amounts of hemlock and northern white-cedar), northern white-cedar swamp, hardwood-conifer swamp.
	VIII.3.3. Deerton	Sandstone bedrock and high sandy ridges; northern hardwood forest, conifer swamp.

Table 6-9 Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin (Albert 1995)

Section IX. Northern Continental MI, WI, and MN		Precambrian Shield bedrock, late Wisconsinan-age glaciated landscape; northern hardwoods forest, white pine / red pine forest, jack pine barrens, hardwood-conifer and conifer swamp, bog.
IX.2. Michigamme Highland	Precambrian granitic and sandstone bedrock knobs, rocky ground moraine, bedrock lakes, localized outwash plains; northern hardwood forest, white pine-red pine-red oak on bedrock, balds, localized jack pine barrens.	
IX.3. Upper WI/MI Moraines	IX.3.2. Winegar Moraine	Coarse-textured ice-stagnation moraines (with numerous kettle lakes); northern hardwood forest, bog.
	IX.3.4. Chippewa-Green Bay Lobes	Stagnation moraine with sandy soils, kettle lakes; northern hardwood forest and bogs
IX.5. Lac Veaux Desert Outwash Plain	(Northern Highland Lakes Barrens); pitted outwash plain, kettle lakes; jack pine barrens, white pine-red pine forest, conifer swamp, bog.	
IX.6. Bergland	IX.6.1. Gogebic-Penokee Iron Range	Bedrock and large moraine ridges; northern hardwoods, white pine-red pine forest on thin soils.
	IX.6.2. Ewen	Highly dissected lake plain; northern hardwood forest, white pine forest, spruce-fir forest
	IX.6.3. Baraga	Broad ridges of coarse-textured rocky till; northern hardwood forest, few wetlands.
IX.7. Keweenaw	IX.7.1. Gay	Coarse-textured broad ridges and swamps; sandy till plain; rocky, sandy ground moraine; northern hardwood forest, hardwood-conifer and conifer swamp, bog.
	IX.7.2. Calumet	Basalt and conglomerate "trap rock"; bedrock knobs and shoreline; northern hardwood forest, balds, white pine forest, white pine-red pine-red oak on bedrock, spruce-fir forest, bog.
	IX.7.3. Isle Royale	Island of volcanic bedrock ridges and wetlands; hardwood-conifer-dominated upland and wetland vegetation.
IX.8. Lake Superior Lake Plain	Level clay lake plain and water-reworked moraine of clayey till; spruce-fir forest, white pine-hemlock forest.	
Section X. Northern MN		Precambrian Shield bedrock, late Wisconsinan-age glaciated landscape; upland conifer forests, extensive paludified peatlands and conifer swamps.
X.1. Bayfield Barrens	Ice-stagnation topography with kettle lakes and outwash; jack pine barrens.	

Table 6-9 Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin (Albert 1995)

X.2. Mille Lacs Uplands	Rocky, loamy ground moraine and end moraines; white pine-sugar maple, white pine-red pine, and aspen-birch forests, oak forests at south and west edge of subsection, conifer swamps.
X.4. Tamarack Lowlands	(Upham lake plain and Aurora till plain); loamy glacial lake plain and ground moraine; conifer swamp, bog, aspen-birch forest.
X.8. Nashwauk Uplands	Steep to gently sloping ground moraine with calcareous, loamy soils and sandy outwash plains; aspen-birch forest, mixed hardwood-pine forest, jack pine barrens; conifer bog, conifer swamp, and muskeg.
X.9. North Shore (Lake Superior) Highlands	End moraine, ground moraine, and clay lake plain; white pine-red pine and aspen-birch forests on uplands, localized sugar maple on uplands near the Lake Superior shoreline.
X.10. Border Lakes	Glacially scoured granitic and basaltic bedrock knobs and lakes; spruce-fir forest, jack pine forest, white pine-red pine forest.

6.1.4.2 Vegetation

Approximately 10,688,000 ha or 88 percent of the Lake Superior basin (excluding Lake Nipigon and Lake Superior itself) has been classed as forest, either conifer, hardwood or a mixture using Landsat TM spectroanalysis (Figure 6-25 and 6-26). An additional 1.3 percent of the basin is comprised by early seral hardwoods and only 4.5 percent is classed as grass or brush. Most of the smaller non-forested communities, including the majority that are rare, are not identified at this level of resolution however.

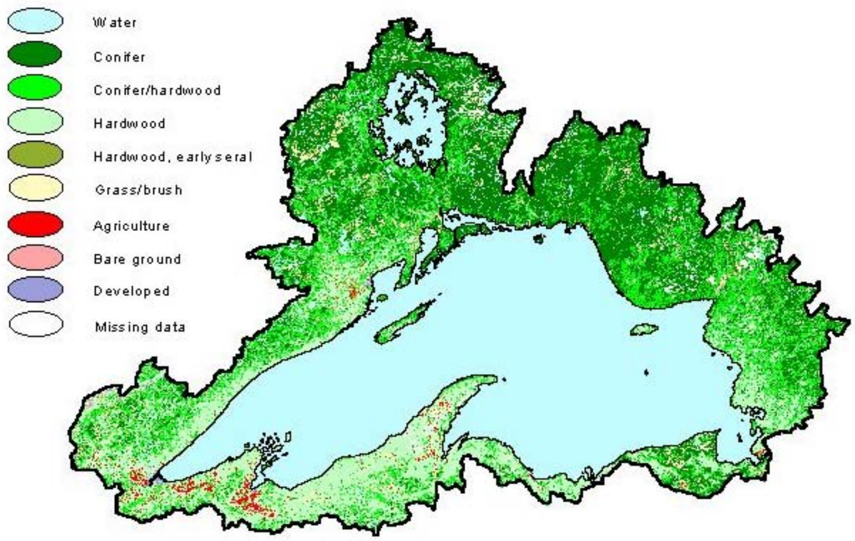


Figure 6-25. Current land cover classes of the Lake Superior basin (derived from Landsat Thematic Mapper (TM) remote sensing)

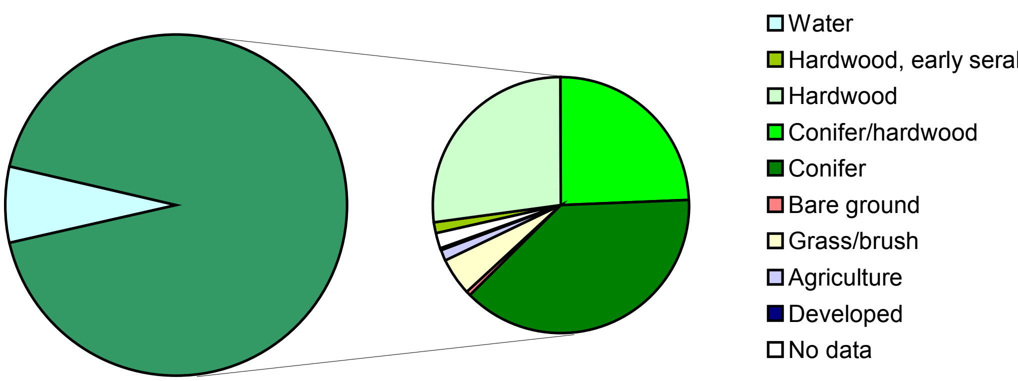


Figure 6-26. Proportion of Lake Superior basin (excluding the lake itself) in various land cover classes (1999)

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 is approximately at 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 trembling aspen, paper birch, balsam fir and jack pine are relatively old at age 80 and are have been referred to as “old-seral” forest (Frelich 1995). Old growth usually refers to primary forests i.e., those that were established naturally and show little or no evidence of human disturbance, but may also be secondary forest (those that have experienced human-caused fires or logging).

The age structure of presettlement 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 5 to 8 percent of the Lake States forest is presently old-growth (including old seral forest). Only about 1 percent of the presettlement 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 American side of the basin is retained in large wilderness areas 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 presettlement forests in the Lake States were old growth. The proportion of old growth varied among presettlement forest types, with 20 percent of jack pine forests, 45-55 percent of red-white pine, spruce-fir-birch, swamp conifer, oak-hickory, river bottom forests, 89 percent of northern hardwood forests (Frelich 1995).

The only large, primary upland forests in the American side of the Lakes 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 (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, but has been logged. Over 90 percent of the forest in the Porcupine Mountains WSP are older than 120 years, compared to approximately only 10 percent in adjacent commercial forests (Frelich 1995). The Porcupine Mountains is 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 totaling 1600 to 2000 (Kershner 1999). The private Huron Mountain Reserve has 2600 ha of old growth (Kersner 1999).

Most of the Canadian side of the basin is boreal and predominately seral forest. A summary report, which defines the onset and duration of old growth conditions is being prepared by the OMNR and will be available later in the year. A Conservation Strategy for Old Growth Forest Ecosystems in Ontario was developed in 1994 by the MNR (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 a total of 3819 ha. Most of these stands are in the southeast or northwest portion of the basin (Figure 6-27). Distribution and abundance of old growth for other species are not yet available.

6.1.4.3. Disturbance

Two major disturbance regimes naturally occurred in the forests of the Lake Superior basin. 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 is the most important landscape-level disturbance 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 for example is less frequent than xeric 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 1997) 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 Canadian portion of the basin (on average 0.2 percent per year), most of which is predominately boreal (Figures 6-28 and 6-29).

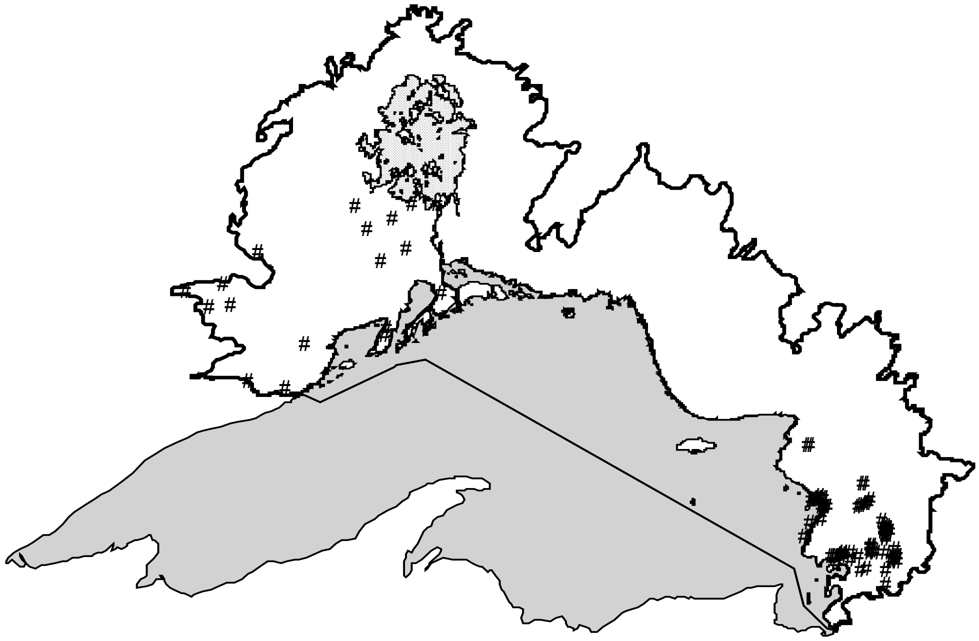


Figure 6.27. Old growth red and white pine stands in the Ontario Lake Superior Basin (OMNR data)

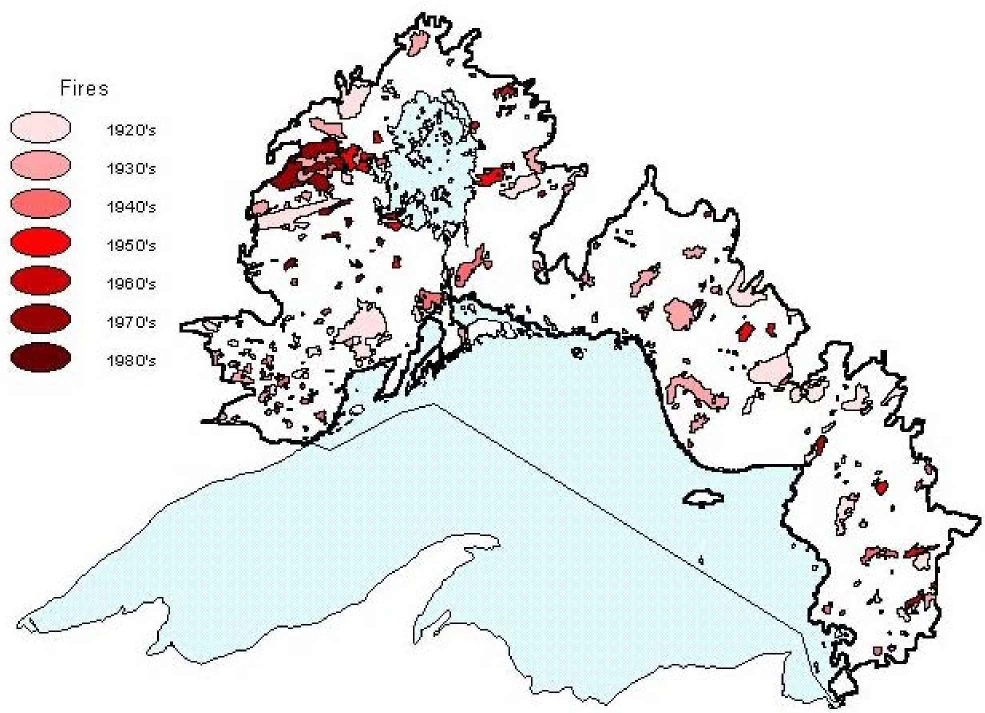


Figure 6-28. Occurrence of fire in the Canadian portion of the Lake Superior basin 1920-1990

The areal extent of fires in each decade has decreased steadily within the basin as a result of a more aggressive policy of 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, there are fewer large fires currently than historically would have occurred.

The main source of ignition historically was probably lightning. Lightning is more or less random, but ground strikes tend to be more frequent on high ridges (Heinselman 1996) and lightning-induced fire is often associated with bedrock. First Nations would have been another possible source of fire, but native peoples may not have been a major cause of forest fires in northeastern North America (Russell 1983). Habitat manipulation for large game would have been unlikely, since caribou was historically the dominant ungulate and prefer mature forests. Habitat manipulation for food plants may have occurred since it has been reported that the Ojibway regularly burned ridges in the BWCA to encourage blueberry production (Heinselman 1996).

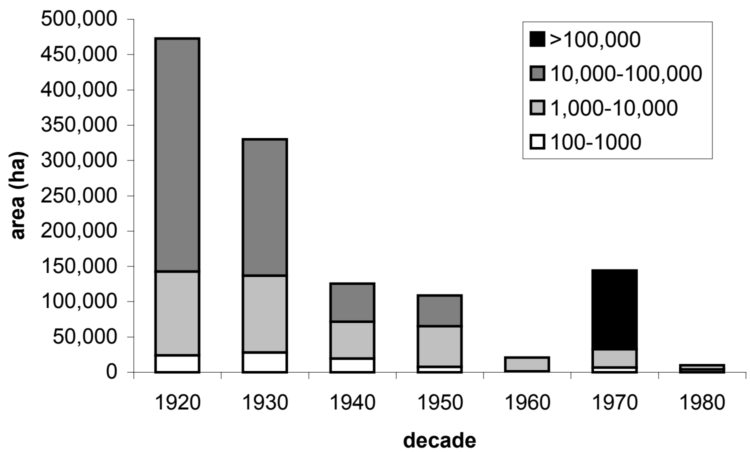


Figure 6-29. Areal extent of fires in the Canadian portion of the Lake Superior basin by fire size class (ha) and decade

Spruce budworm (*Choristoneura fumiferana*) 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 3-5 years of consecutive years of defoliation, and almost all the trees in dense, mature balsam fir stands can be killed during uncontrolled outbreaks. Spruce budworm outbreaks are very 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 5 to 15 years (Blais 1983). During the 18th and 19th 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 that has been 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, with 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, with associated public safety risks and degraded aesthetics.

Windthrow relatively common in boreal forests, and is the other 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. For example, a violent windstorm resulted in approximately 2300 ha of moderate to severe blowdown in 1997. Mineral soil exposed following windthrow may be important in boreal forest regeneration dynamics (Jonsson and Dynesius 1993).

6.1.4.4 Succession

Succession in the boreal forest and oak or pine forests farther south in the basin are dependent on disturbance by fire. These forests are typically dominated by pioneer species such as jack pine, white birch and trembling that have low to moderate shade tolerance. The successional species 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 hardwood component, 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 mesotrophic sites. On more oligotrophic sites in the boreal forest, black spruce is often the dominant species.

Succession in the hemlock and hardwood forests of the southern portion of the basin was historically characterized by gap dynamics. In between infrequent disturbance events, 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 and green ash and basswood could reproduce in gaps caused by the death of canopy trees (Frelich 1995).

6.1.4.5 Wildlife

The Lake Superior basin represents a north-south and, to a lesser extent, an east-west transition zone for wildlife. Although many of the 59 species of mammals native to the Lake Superior basin have wide-ranging distributions, approximately 1/4 are predominately boreal and 1/5 are species primarily from more southerly deciduous forests (Burt 1975; Dobbyn 1994). Most of the remaining species have predominately eastern (e.g. rock vole) or western (e.g. thirteen-lined ground squirrel) affinities. Lake Superior itself represents a barrier to dispersal, as does the change in forest composition and climate. With the potential exception of the kiyi (*Coregonus kiyi*) and the blackfin cisco (*C. nigripinnis*), no vertebrate species are endemic to the Lake Superior basin. Introduced species include the European hare, Norway rat, and house mouse.

The fauna of the Lake Superior basin has changed since the last Wisconsin glaciation, particularly so in the past several hundred years as a result of over-hunting and habitat change, notably the loss of unfragmented and older successional forests. Large predators and ungulates have been most affected. Bison and wapiti have been extirpated from the basin; woodland caribou, wolverine, cougar, and grey wolf have been greatly reduced in abundance and distribution, particularly in the southern portion of the basin. A few species such as white-tailed deer and the coyote, have benefited from habitat change and expanded their ranges and numbers (Hazard 1982; Frelich and Lorimer 1985). Many game species, predators and furbearers such as the moose, black bear, river otter, bobcat and beaver were nearly extirpated near the turn of the century but have recovered to some degree, although not to presettlement levels (Burt 1975).

The avifauna of the Lake Superior basin also reflects this north-south transition. In the northern portion of the basin, boreal species such as the great gray owl, spruce grouse and three-toed woodpeckers are most common. Farther south, species typical of the Great Lakes/St. Lawrence and/or deciduous forests are found, e.g. rose-breasted grosbeak, scarlet tanager, and red-headed woodpecker. 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 also found locally. Approximately 130 to 150 species, including most waterfowl, shorebirds and passerines, breed within the Lake Superior basin during the summer, but overwinter elsewhere (Cadman and others 1987). A smaller number of species (<30) are permanent residents, for example most owls, woodpeckers and grouse. A few (<10) species, such as the snowy owl, northern shrike and redpolls, breed further 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. Introduced species include the rock dove, house sparrow, starling, and Hungarian partridge among others.

The herpetofauna of the basin is limited to approximately 31 species, primarily due to the northern climate. Reptiles include at least eight species of snake, most of them south of Lake Superior, and five species of turtles, including Blanding's and wood turtles which are declining throughout much of their North American range. The spring peeper, American toad, northern leopard and wood frogs are the most abundant of 11 anuran species, and the eastern newt, eastern redback and blue-spotted salamanders are the most widespread of the seven species of caudates (Cook 1984; Conant and Collins 1991).