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Assessment of Natural Resource Conditions

Isle Royale National Park

Natural Resource Report NPS/NRPC/WRD/NRR—2010/237

ON THE COVER
Left: Lichens on Rock at Davidson Island (Photograph by Dave Mechenich)
Top Right: Foggy Morning at Scoville Point (Photograph by Dave Mechenich)
Bottom Right: Sunrise on Davidson Island (Photograph by Steve Seiler)

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This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Commonly Used Abbreviations

AIS	aquatic invasive species
BP	before present
BTEX	benzene, toluene, ethylbenzene, and xylene
C	Celsius
CAA and CAAA	Clean Air Act and Clean Air Act Amendments
CASTNet	Clean Air Status and Trends Network
cm	centimeter
DO	dissolved oxygen
DOC	dissolved organic carbon
FIA	Forest Inventory and Analysis National Program (USDA–Forest Service)
FPOM	fine particulate organic matter
FRI	fire return interval
GCM	general circulation model
GLKN	Great Lakes Inventory and Monitoring Network
ha	hectare
HACCP	Hazard Analysis and Critical Control Point
HCB	hexachlorobenzene
HFO	heavy fuel oil
HUC	Hydrologic Unit Code
IADN	United States-Canada Integrated Atmospheric Deposition Network
IJC	International Joint Commission
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPCC	International Panel on Climate Change
kg	kilogram
km	kilometer
L	liter
LaMP	lakewide management plan
LUST	leaking underground storage tank
m	meter
m^3day^{-1}	cubic meters per day
m^3sec^{-1}	cubic meters per second
m^3year^{-1}	cubic meters per year
MDCH	Michigan Department of Community Health
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
$mg\ L^{-1}$	milligram per liter (part per million in water)
MI	Michigan
MN DNR	Minnesota Department of Natural Resources
MNFI	Michigan Natural Features Inventory
MT	metric ton
MMT	million metric tons
MTBE	methyl tertiary butyl ether
MN	Minnesota
N	nitrogen

NADP	National Atmospheric Deposition Program
NADP NTN	National Atmospheric Deposition Program National Trends Network
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrous oxides
NPS	National Park Service
NWI	National Wetlands Inventory
OSRW	outstanding state resource water
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PM	particulate matter
ppm	parts per million
PWC	personal watercraft
SLSMC	St. Lawrence Seaway Management Corporation
SOLEC	State of the Lakes Ecosystem Conference
TMDL	total maximum daily loading
TN	total nitrogen
TP	total phosphorus
TSI	Trophic State Index
$\mu g\ L^{-1}$	microgram per liter (part per billion in water)
$\mu S\ cm^{-1}$	microSiemens per centimeter (units of specific conductance)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGAO	United States General Accounting Office
USGS	United States Geological Survey
VHS	viral hemorrhagic septicemia
VOC	volatile organic compound
WDNR	Wisconsin Department of Natural Resources
WI	Wisconsin
WRD	NPS Water Resources Division

Executive Summary

This report is an assessment of the condition of the natural resources of Isle Royale National Park (ISRO) and an evaluation of the threats and stressors that act on these resources. This assessment focuses on three broad resource groups: Lake Superior, inland waters, and terrestrial resources. It is based entirely on an in-depth review of scientific literature and agency reports, and on compilations, syntheses, and new analyses of existing data; no new field studies were conducted. It broadly describes ISRO and its natural resources, identifies stressors and threats to those resources, examines existing data about natural resource conditions, and makes recommendations for further study and management priorities where appropriate.

ISRO consists of a group of islands in northwestern Lake Superior, the surrounding Lake Superior waters up to 4.5 miles (7.2 kilometers [km]) offshore, and a small portion of the mainland. The main island, 45 miles (72 km) long and 9 miles (14 km) wide, is surrounded by approximately 400 much smaller islands. The park protects 572,000 acres (231,400 hectares [ha]) of land and water (NPS ca. 2003). Although ISRO is generally perceived as isolated, it is only about 15 miles (24 km) from points on the Canadian and Minnesota shoreline.

Lake Superior has the greatest surface area of any freshwater lake in the world and includes 10% of the world's fresh surface water. ISRO encompasses over 400,000 acres (165,000 ha) of Great Lakes waters (Lafrancois and Glase 2005). With its many inlets and islands, ISRO includes 337 miles (543 km) of Lake Superior shoreline (Crane et al. 2006). Rock pools on the Lake Superior shoreline provide a unique habitat for frogs and other amphibians as well as arctic and alpine plant and insect species.

ISRO's topography is generally rugged and determined by ridges and valleys in the volcanic and sedimentary bedrock. The resulting "washboard-like" pattern affects animal and plant distributions, migration patterns, microclimates, wetland distribution, and human uses (Thornberry-Ehrlich 2008). Soils are derived from bedrock and range from thin and sandy or loamy in northern uplands (Woodruff et al. 2003) to deeper, better-developed, and more calcareous in the south (NPS 2005, Schlesinger et al. 2009). Holocene soils are mainly alluvium in the form of lake and stream deposits on beaches and in swamps, bogs, and ponds made by beaver (*Castor canadensis*) (Thornberry-Ehrlich 2008).

ISRO has 278 lakes and ponds (USGS 2008), ranging in size from Siskiwit Lake at 1,635 ha and over 45 m deep to numerous shallow ponds. It has 43 named inland lakes, more than any other Great Lakes area national park, six named perennial streams, and many kilometers of unnamed perennial and intermittent streams. Most streams, lakes, and wetlands are oriented southwest to northeast as determined by the bedrock topography. Beaver activity has also enhanced wetland formation (Lafrancois and Glase 2005, Crane et al. 2006).

ISRO is densely forested, with northern boreal spruce-fir forest in the northeast part of the island and near the cool, moist shoreline of Lake Superior and northern hardwood forests in the warmer, drier interior, especially in the southwest (NPS ca. 2003). The ridges and interior portion of the main island support many open, non-arboreal plant communities. ISRO has 52 plant community types, two of which (the white cedar–yellow birch forest and the boreal calcareous seepage fen) are globally rare.

The plant composition of ISRO is highly diverse. In 2008, ISRO had 55 plant species that are currently state-endangered, threatened, or of special concern (NPS 2008b, MNFI 2009b). The greatest botanic value of the park lies in its disjunct species, those that are most commonly found in arctic or alpine habitats or in the western U.S. Most of these occur along the Lake Superior shoreline (Judziewicz 1995, 1997, 2004) and on Passage Island. The range of community types, large number of species of concern, and minimal incidence of exotics, coupled with minimal human impact during the settlement era, make ISRO a suitable reference condition for other protected areas in the region (Schlesinger et al. 2009). Fire exclusion has not occurred long enough on ISRO to cause major changes in plant species composition.

Critical animal resources in ISRO include moose (*Alces alces*, a species of special concern in Michigan) and the federal-endangered and state-threatened gray wolf (*Canus lupus*), whose interrelationships have been intensively studied. ISRO has the only naturally reproducing coaster brook trout (*Salvelinus fontinalis*) populations in the United States; the most genetically diverse lake trout (*S. namaycush*) population in Lake Superior; the largest remaining population of state-threatened common loon (*Gavia immer*) in Michigan (MI), and increasing nesting populations of bald eagles (*Haliaeetus leucocephalus*) and osprey (*Pandion haliaetus*) (NPS ca. 2003). Two state-endangered birds, the short-eared owl (*Asio flammeus*), and peregrine falcon (*Falco peregrinus*) are occasional visitors to ISRO, and the park is home to other animals that are threatened or of special concern in MI.

Bird and mammal assemblages present contrasting situations at ISRO. Mammalian composition (both additions and losses) has fluctuated significantly over the past approximately 115 years. There are currently 15 mammals confirmed present on ISRO (NPS 2003b), and some conspicuous species that are common on the mainland are absent (Hansen et al. 1973). The bird community, though not static, has been more stable and is more comparable to that of mainland areas. The important difference is primarily dispersal capacity, and this fundamental difference suggests the mammalian community will be more susceptible to future stressors.

ISRO is also rich in human history. Native Americans likely inhabited ISRO throughout the Holocene (the past 11,000 years) and may have mined pure native copper on Isle Royale as long as 4,500 years ago (Schlesinger et al. 2009). The North Shore Ojibwe people had a long history with ISRO and regularly used it for subsistence activities such as making maple sugar, harvesting plants, snaring rabbits, netting passenger pigeons, and gathering gull eggs. ISRO was also "the good place," which still has spiritual significance to them (Cochrane 2009).

ISRO experienced three distinct periods of copper mining activity in the 1800s, and 22 mine sites from this era are known (Karamanski et al. 1988). ISRO was not extensively commercially logged, although a great deal of lumber was needed to operate the mines and establish the associated settlements. An extensive forest fire in 1936 followed a large pulpwood logging operation in the spruce and balsam swamp near Siskiwit Bay, just before ISRO was dedicated as a national park (Karamanski et al. 1988, Schlesinger et al. 2009).

The first commercial fishing operation in Michigan was run on ISRO by the American Fur Company from the 1830s–1842. The largest human population related to fishing on ISRO occurred in the 1920s, but commercial fishing was virtually eliminated by 1960 (Karamanski et al. 1988). Four hotels existed on ISRO by 1910, and a golf course was built at Belle Island. Resorts were located in Washington Harbor, Chippewa Harbor, and Rock Harbor, and on Belle Island, Barnum Island, and Davidson Island (Karamanski et al. 1988). Ten shipwrecks are documented around ISRO. The *Emperor*, which sank off Canoe Rocks on the northeast end of ISRO in 1947, was the last major wreck at ISRO (Karamanski et al. 1988).

ISRO was authorized as the 21st national park by Congress in 1931 "to conserve a prime example of North Woods Wilderness," and the private holdings on the island were bought up from the late 1930s to 1940. ISRO was further designated part of the National Wilderness Preservation System in 1976. Over 99% of ISRO's land area is designated as wilderness (Crane et al. 2006). In 1980, the United Nations Man and the Biosphere Programme named ISRO an International Biosphere Reserve, giving it global scientific and educational significance.

ISRO has no roads and is accessible by boat or plane. The National Park Service maintains a ferry service from Houghton, MI, to ISRO; commercial ferries travel from Copper Harbor, MI, and Grand Portage, MN. The National Park Service also operates a seasonal headquarters on Mott Island, visitor centers at Rock Harbor and Windigo, and a dormitory for visiting researchers on Davidson Island. A concessionaire operates lodging at Rock Harbor, with 60 lodge rooms and 20 cottages. The National Park Service makes available 113 tent sites, 88 shelters, and 43 group tent sites for camping (Isle Royale and Keweenaw Parks Association 2009). Visitation to ISRO increased from 2,962 in 1940 to a high of 31,760 in 1987; the mean was 16,350 yr^{-1} from 2004–2008 (NPS 2009).

Although ISRO is isolated from the mainland, it is by no means isolated from stressors and pollution sources. Lake Superior waters contain measurable levels of mercury and other toxic metals; pesticides such as chlordane, aldrin, dieldrin, and DDT; and other organic compounds such as polychlorinated biphenyls (PCBs), dioxin, and polycyclic aromatic hydrocarbons, to name just a few (LSBP 2008). Atmospheric deposition is the major source of mercury and persistent organic pollutants to Lake Superior (Swackhamer and Hornbuckle 2004). Some contaminants originate in the southern U.S., such as chlordane (Hafner and Hites 2003) and toxaphene (Ma et al. 2005). DDT originates both from Midwestern soils and from Mexico and Central America (Bidleman et al. 2006, LSBP 2006a). The Chicago area is the major source of PCBs to the region (Hafner and Hites 2003). Regulated facilities in the U.S. and Canada within 155 miles (250 km) of ISRO produce 167,000 tons (151,138 metric tons) yr^{-1} of criteria air pollutants (carbon monoxide, nitrous oxides, sulfur dioxide, particulate matter, volatile organic compounds, and ammonia) that are linked to smog and acid rain. ISRO waters are not particularly sensitive to the acidifying effects of acid rain. Acid deposition has not yet caused notable alteration of terrestrial ecosystem function, but ISRO is experiencing additions of some nutrients and losses of others that could affect its ecosystems, especially the boreal forest, over time.

Great Lakes shipping also presents risks including accidental releases of fuel and the introduction of aquatic invasive species. Approximately 1,000 vessels use the channel between

Blake Point and Passage Island each year en route from the locks at Sault St. Marie to the port of Thunder Bay, Ontario. Rayburn et al. (2004) simulated a spill of 26,000 gallons (100 m^3) of Intermediate Fuel Oil in this channel and concluded that "a spill of this magnitude to Isle Royale will be a major event with regional, national and international importance." In addition to using the channel, vessels may use ISRO for shelter during harsh weather while traveling between the locks and ports at the head of the lake such as Taconite Harbor, Silver Bay, Two Harbors, Duluth, Superior, and Ashland.

Ballast water is the source of 29 invasive aquatic animal and protist species introduced and established in the Great Lakes since 1959 (Grigorovich et al. 2003a). In addition to deliberately introduced fish species such as rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salmo trutta*), and Pacific salmon (*Oncorhynchus* spp.), known aquatic invasive species at ISRO are the sea lamprey (*Petromyzon marinus*), threespine stickleback (*Gasterosteus aculeatus*), spiny waterflea (*Bythotrephes longimanus*), and the plants *Typha* spp. (cattails) and *Phragmites australis* (common reed). In addition, either zebra mussels (*Dreissena polymorpha*) or quagga mussels (*D. bugensis*) were found in Washington Harbor in September 2009 (Flesher 2009b, Myers 2009).

Climate change is also a threat to ISRO resources. Statistically significant increases in monthly mean and monthly mean maximum temperatures occurred at Mott Island from 1940 to 2004. This observation agrees with the published report of Austin and Coleman (2007) for the Lake Superior region. Tree species now at ISRO that would lose >90% of their range in the U.S. under current climate change scenarios include quaking aspen (*Populus tremuloides*), sugar maple (*Acer saccharum*), northern white cedar (*Thuja occidentalis*), balsam fir (*Abies balsamea*), and paper birch (*Betula papyrifera*) (Hansen et al. 2001). Although Lake Superior may buffer ISRO from temperature changes compared to mainland sites (Davis et al. 2000), current climate change scenarios will likely result in changes in plant species ranges, species abundance, community composition, and many ecosystem properties.

ISRO's wilderness status does protect it from local anthropogenic contamination sources, however. For example, ISRO inland lakes are free from many human impacts present in mainland lakes, and the water quality of ISRO lakes is good, although in some cases outside the boundaries of the ecoregion reference criteria. There has been minimal introduction of terrestrial exotic plant species. No truly problematic terrestrial exotic species are present at levels of concern, although the larch sawfly (*Pristiphora erichsonil*) greatly reduced the population of tamaracks on the island in the past. However, recreation is a possible dispersal mechanism, and thus careful regular monitoring is important.

Major recommendations for future study on ISRO include bathymetric assessments, habitat mapping, water quality monitoring, and biological inventories of Lake Superior nearshore waters and shoreline splash pools. Water quality sampling of inland lakes should continue. We endorse continued or expanded monitoring for both aquatic and terrestrial invasive species, including earthworms. Inland and nearshore fish surveys should be regularly conducted, and the status of coaster brook trout should be carefully monitored. Wetland biota and chemistry need further study. Atmospheric deposition impacts on aquatic and terrestrial ecosystems need continued study. More information is needed about the status of the boreal forest relative to its historic range and variability. Finally, given ISRO's status as a refuge for arctic and disjunct species, and the limited dispersal potential of its mammalian population, monitoring should be done to identify and assess potential effects of climate change.

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Introduction and Park Description

Congress, in its FY 2003 Appropriations Act, instructed and funded the National Park Service (NPS) through the Natural Resource Challenge to assess environmental conditions in coastal watersheds where national park units are located, including Great Lakes coastal parks and lakeshores. This report for Isle Royale National Park (ISRO) is one such assessment. Its purpose is to use the many existing published reports, unpublished research findings, and agency reports to briefly describe the natural resources of ISRO, assess the degree to which they are affected by natural and anthropogenic stressors, identify information gaps, and make recommendations for future study and management where appropriate.

ISRO consists of a group of islands in northwestern Lake Superior, the surrounding Lake Superior waters up to 7.2 kilometers (km) offshore, and a small portion of the mainland. The main island, 72 km long and 14 km wide, is surrounded by approximately 400 much smaller islands. The park protects 231,400 hectares (ha) of land and water (Figure 1) (NPS ca. 2003). Although ISRO is generally perceived as isolated, it is located only about 24 km from points on the Canadian and Minnesota (MN) shoreline. Ninety-nine percent of the land area of ISRO is managed as wilderness.

ISRO is densely forested, with northern boreal spruce-fir forest near the cool, moist shore of Lake Superior, and northern hardwoods in the warmer, drier interior (NPS ca. 2003). ISRO has 278 lakes and ponds, more named inland lakes than any other Great Lakes area managed by the National Park Service, six named perennial streams (Washington, Grace, and Tobin creeks and Big Siskiwit, Little Siskiwit, and Siskiwit rivers), and many kilometers of unnamed perennial and intermittent streams. Numerous inland wetlands are associated with lake littoral zones and the pronounced ridge-valley topography; beaver activity has also enhanced wetland formation (Lafrancois and Glase 2005, Crane et al. 2006).

A scoping report by the NPS Great Lakes Inventory and Monitoring Network (GLKN) lists “critical resources” for ISRO, including the moose, a species of special concern in Michigan (MI), and the federal-endangered and state-threatened gray wolf, whose interrelationships have been intensively studied. ISRO also has the only naturally reproducing coaster brook trout population in the United States, the most genetically diverse lake trout population in Lake Superior, the largest MI population of the state-threatened common loon, and increasing nesting populations of bald eagles and osprey (NPS ca. 2003). Two state-endangered birds, the short-eared owl and peregrine falcon, are occasional visitors to ISRO (NPS 2003b), and the park is home to other animals that are threatened or of special concern in MI (MNFI 2009a, b).

ISRO also includes a park headquarters, visitor center, parking area, and dock on the Portage Lake waterfront on the east side of Houghton, MI (SENW and SWNE, S 36, T55N, R34W). This small area is not managed for its natural resource value and will not be discussed further in this report.

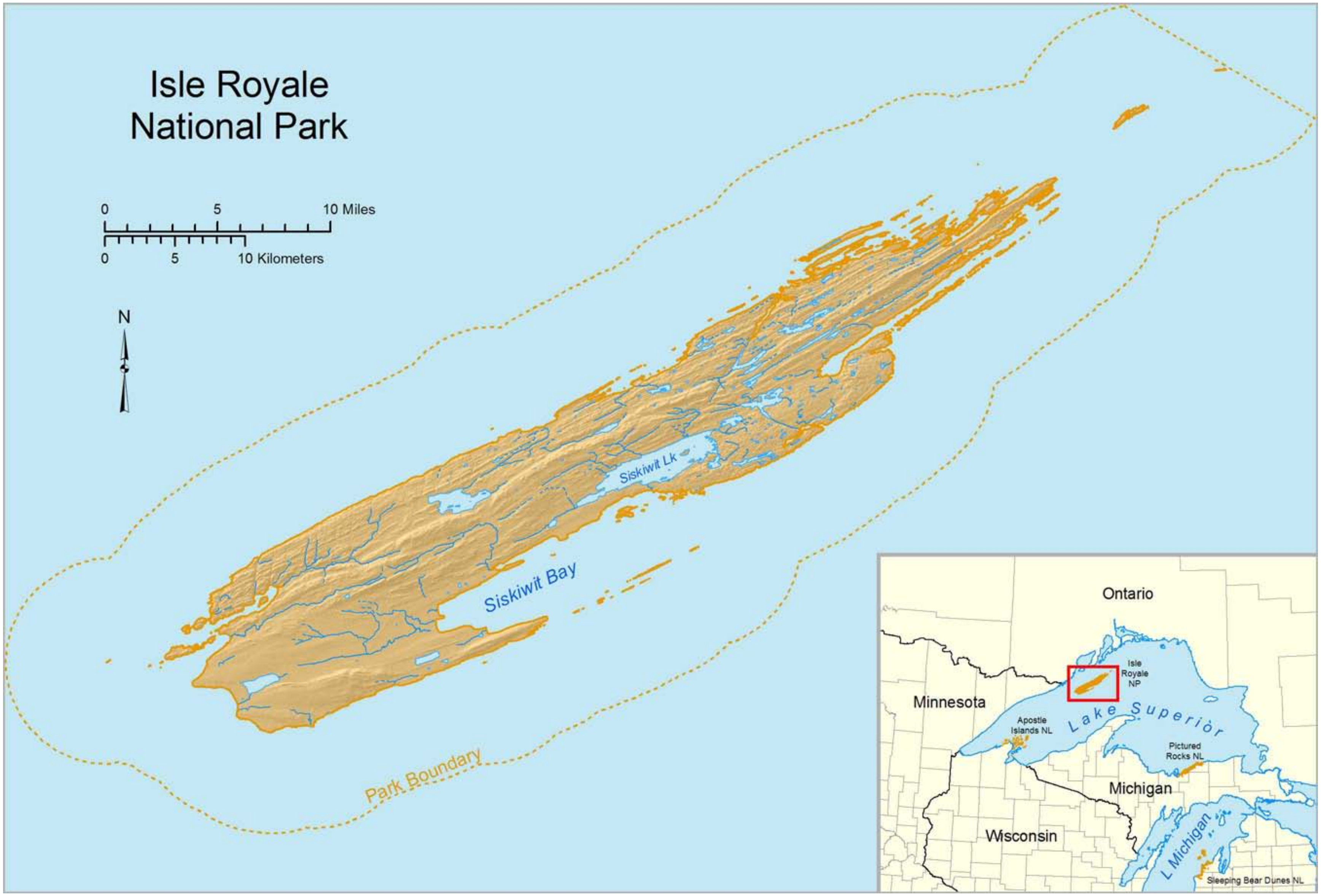


Figure 1. Location of Isle Royale National Park in the upper Great Lakes region of the United States (see Appendix A for sources).

Island Communities and Regions

Although ISRO is legally part of Keweenaw County in MI's Upper Peninsula, it is physically closer to, and shares greater biogeographic affinity with, its northern neighbors of MN and Ontario. It is located in an ecotone (zone of transition) between two major North American ecosystems or biomes—the boreal forest and the northern hardwood forest. On ISRO, boreal forest vegetation dominates the NE part of the island and nearshore terrain, while northern hardwoods are more prevalent to the SW (Schlesinger et al. 2009).

ISRO is entirely contained within the USGS Lake Superior Hydrologic Unit (HUC 04020300) (Seaber et al. 1987). The United States Environmental Protection Agency (USEPA) includes ISRO in its ecoregion VII, level III ecoregion 50, Northern Lakes and Forests (USEPA 2000) for purposes of assessing nutrient levels in streams and lakes (USEPA 2000, 2001).

The ISRO terrestrial ecosystem has been categorized as coastal rock barrens (S4b) (USEPA and Environment Canada 2008c). On the Canadian Shield, this ecosystem includes both the basalt bedrock systems found on ISRO and gneissic or granitic barrens. The basalt bedrock systems are characterized by thin soils and exposed areas of bedrock and a plant community composed of scattered trees, shrub thickets, and a partial layer of graminoids, mosses, and lichens. Throughout the Great Lakes basin, the coastal rock barrens ecosystem is considered to be in good or improving condition, with the main threats being shoreline development and recreational uses such as campsites and boat launches (USEPA and Environment Canada 2008a). In the Regional Landscapes Ecosystem classification, Isle Royale is given its own sub-subsection (IX.7.3) of Section IX, Northern Continental Michigan, Wisconsin, and Minnesota. The Isle Royale sub-subsection is described in brief as "island of volcanic bedrock ridges and wetlands; hardwood-conifer-dominated upland and wetland vegetation" (Albert 1995). It is distinguished from other sub-subsections of the Keweenaw subsection (IX.7) by the even-stronger influence of Lake Superior on its climate. Its bedrock balds and bedrock beaches support a diverse flora of boreal and disjunct northwestern montane species (Albert 1995).

The Michigan Natural Features Inventory (MNFI) lists 18 distinct natural communities for ISRO (Table 1) (Kost et al. 2007). Two (northern balds and volcanic lakeshore cliffs) are ranked S1 (critically imperiled in MI) and two others (volcanic cliffs and volcanic bedrock glades) are ranked S2 (imperiled). Most occurrences of threatened, endangered, and special concern species and high-quality natural communities are in the NE one-third of the island (Figure 2).

Ecologic Groups Based on Vegetation Mapping

A vegetation mapping project conducted for ISRO in cooperation with the United States Geological Survey (USGS) and the Nature Conservancy (TNC) identified 52 plant associations, which they combined into 14 "ecological groups" (hereafter, ecologic groups) as follows: 1) northern shrub/graminoid fens and bogs, 2) rooted/floating aquatic marshes, 3) wet meadows/marshes, 4) northern conifer and hardwood forest and shrub swamps, 5) Great Lakes rocky shores, 6) rock barrens, 7) cliffs and talus, 8) northern dry conifer (hardwood) forests and woodlands, 9) northern mesic conifer (hardwood) forests, 10) northern spruce-fir (hardwood) forests, 11) boreal hardwood forests and woodlands, 12) northern hardwood forests and woodlands, 13) northern shrublands, and 14) semi-natural meadows (TNC 1999, USGS 2000a). This classification system will be used through the remainder of the report. Ecologic group 5 is discussed in the Lake Superior section (page 19), groups 1–4 in the inland aquatic resources section (page 56), and groups 8–14 in the terrestrial resources section (page 80).

Table 1. Natural communities of Isle Royale National Park (Kost et al. 2007).

Natural Community	State Rank	Global Rank
Northern bald	S1	GU
Volcanic lakeshore cliff	S1	GU
Volcanic cliff	S2	G4G5
Volcanic bedrock glade	S2	GU
Intermittent wetland	S3	G2
Northern fen	S3	G3
Poor fen	S3	G3
Dry northern forest	S3	G3?
Sand and gravel beach	S3	G3?
Dry-mesic northern forest	S3	G4
Hardwood-conifer swamp	S3	G4
Mesic northern forest	S3	G4
Volcanic bedrock lakeshore	S3	G4G5
Boreal forest	S3	GU
Bog	S4	G3G5
Poor conifer swamp	S4	G4
Northern wet meadow	S4	G4G5
Northern shrub thicket	S5	G4

State Ranks (S1-S5)
S1 = critically imperiled; S2 = imperiled; S3 = vulnerable; S4 = uncommon but not rare; S5 = common and widespread in the state.

Global Ranks (G1-G5)
G2 = imperiled; G3 = vulnerable; G4 = apparently secure: uncommon but not rare; G5 = secure: common; widespread; GU = currently unrankable due to lack of information or substantially conflicting information about status or trends.

Lake Superior Communities and Regions

Great Lakes Natural Regions and Seascapes, equivalent to terrestrial ecoprovinces and ecodistricts, were developed for Lake Superior in the late 1990s (World Wildlife Fund 1997, World Wildlife Fund Canada 1999). Natural regions are delineated on the basis of light penetration and macrotopography. Lake Superior consists of 11 natural regions. Four benthic natural regions (Figure 3) are overlain by seven pelagic natural regions (not pictured). Three of the benthic regions (#2 – #4) each have two different pelagic zones; a euphotic zone of <20 m depth, and a deeper dysphotic-aphotic zone where light does not penetrate. In the zone where light penetrates to the bottom (#1), there is no dysphotic-aphotic pelagic zone.

The Photic Zone (Natural Region #1) is the entire benthic euphotic zone of Lake Superior, including significant offshore shoals. The West Slope (Natural Region #2) lies on the windward side of the lake and is characterized by low relief at depth of about 150 m. The Central Basin (Natural Region #3) is a deep basin (up to 400 m) with upwelling zones. The Southeastern Rise (Natural Region #4) is characterized by very irregular bottom topography and depths from 100 to

300 m. The north side and part of the south side of ISRO lie in Natural Region #2, while the eastern and western ends of the island lie in Natural Region #1.

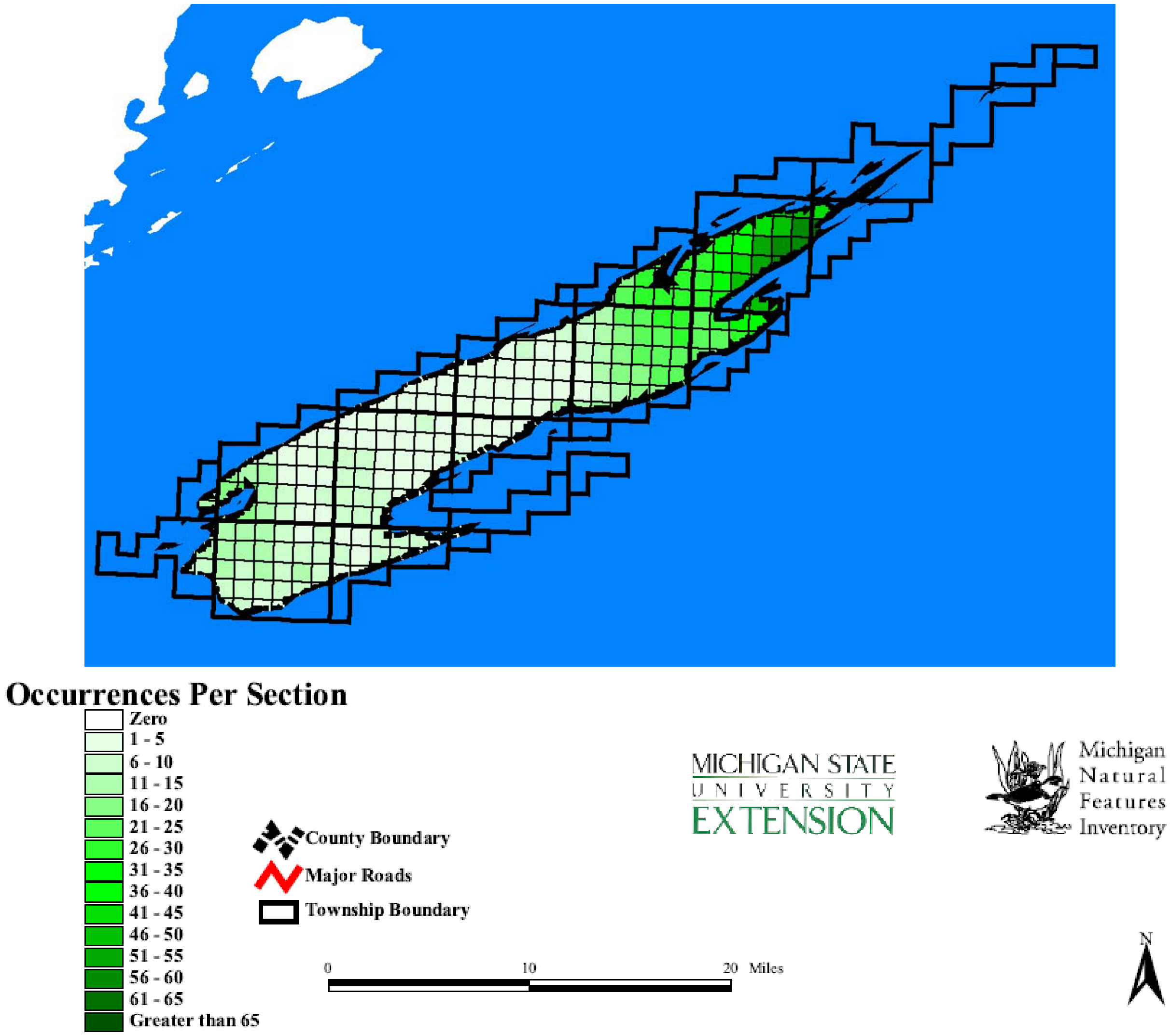


Figure 2. Occurrences of endangered, threatened, and special concern species and high-quality natural communities by section, Isle Royale National Park (from MNFI 2004).

Lake Superior can be further divided into 20 seascapes, 13 benthic and seven pelagic (LSBP 2006a). The pelagic seascapes are identical to the pelagic natural regions. The benthic seascapes within the nearshore euphotic zone (#1) are defined by exposure to wave energy. Benthic seascapes in the offshore natural regions (#2 – #4) are delineated by water mixing (upwelling and stratification) and bottom substrate type (particle size).

The benthic seascapes are labeled on Figure 3 as 1a–1b, 2a–2d, 3a–3b, and 4a–4e. Unfortunately, we were unable to discover the meaning of the letter labels, since the LSBP (2006a) used the map without including a complete key. We can surmise, however, that the eastern and western ends of ISRO share similarities with the near south shore areas of Lake Superior. The north side of ISRO is similar to the open lake area to the west of it, while the south side of ISRO is a unique seascape (ecodistrict).

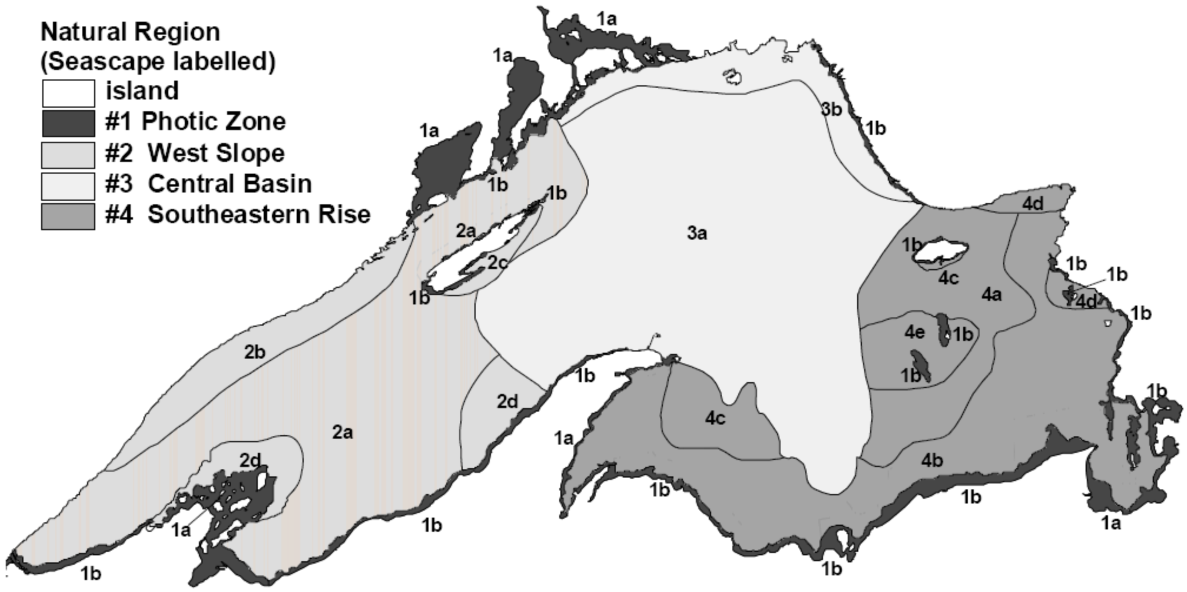


Figure 3. Benthic natural regions and seascapes for Lake Superior (from LSBP 2006a).

Climate

The climate of ISRO is dominated by the influence of Lake Superior. Short, cool summers and long, cold winters are normal. Winters are somewhat warmer and summers cooler than on nearby inland sections of the mainland. The mean annual frost-free period is 120 to 140 days yr^{-1} (USEPA and Government of Canada 1995). Fog is frequent near the lakeshore, especially in the spring (NPS 2004a) and from mid-July to late summer (Crane et al. 2006). The strongest winds come in October and November, when waves can reach 8 m in height (Shelton 1997).

Precipitation falls year-round, mostly as rainfall, averaging approximately 75 centimeters (cm) yr^{-1}. Snow typically accumulates from mid-November through April (NPS 2005). On average, from 1973 to 2002, Lake Superior on the north side of ISRO had 90% ice cover 60–75 days yr^{-1} and the south side had 90% ice cover only 30–60 days yr^{-1} during the period January –March (Assel 2003). However, Lake Superior ice cover is declining; at the current rate of decline, the lake will be ice-free in a typical winter in about three decades (Austin and Colman 2007).

Thirteen weather stations are located in ISRO, with varying periods of record; five were still active in 2007 (Davey et al. 2007). One of these stations on Mott Island, part of the National Climatic Data Center (NCDC) network, has precipitation and temperature data, mainly for summer months, going back to 1940 and available at www.ncdc.noaa.gov/oa/climate/stationlocator.html. Local climate data for ISRO is also available through the National Data Buoy Center (NDBC), part of the National Oceanic and Atmospheric Administration (NOAA), which maintains automated stations at Passage Island Lighthouse, NE of the main island, and Rock of Ages Lighthouse off the SW end of the main island (NDBC 2009a, b). Standard meteorologic data and continuous wind data are available for a 12-month period. Historic meteorologic data are available from 1984 to present and wind data from 1996 to present. Climate summary tables are also available for wind speed, air temperature, sea level pressure, and wind gusts at www.ndbc.noaa.gov.

We plotted monthly mean (mean of the mean of each day's high and low temperature) and mean maximum temperatures (mean of each day's maximum temperature) for the Mott Island station from 1940 to 2004 (Figure 4). Observations were available for a minimum of 42 years (mean September temperature) and a maximum of 55 years (mean maximum July temperature). A statistically significant upward trend was observed for each of the months ($p < 0.02$). We increased the size of the data set by including all months with 27 or more observations, increasing the minimum number of years to 55 (mean September temperature). The upward trend for all months was then significant at $p < 0.01$. Similarly, Austin and Colman (2007) reported that stations within a 500-km radius of the center of Lake Superior had an increasing summer (July–September) temperature trend of $0.059 \pm 0.018^{o}C\ yr^{-1}$ from 1979 to 2005.

Historic and Current Uses

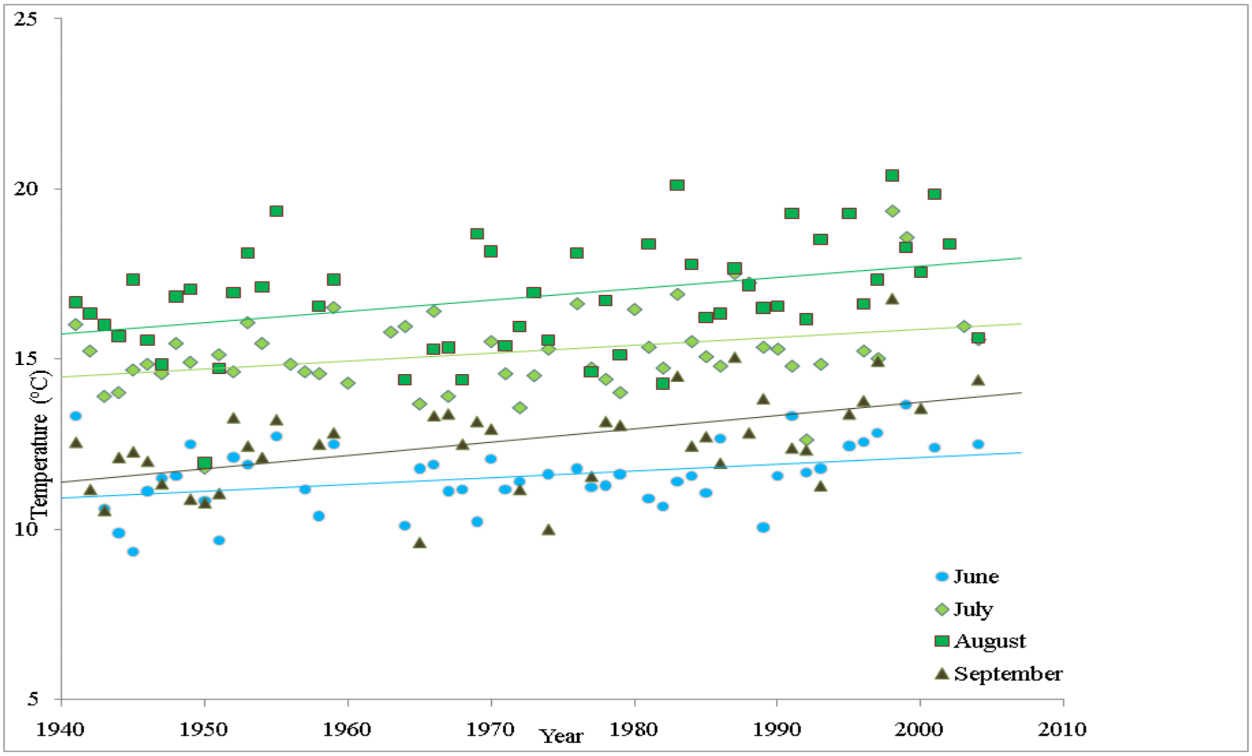
Native Americans likely inhabited ISRO throughout the Holocene. The island was first visited and claimed by the French in 1671 and became a possession of the United States in 1783 (Schlesinger et al. 2009).

Native Americans likely mined pure native copper on Isle Royale 4,500 years ago (Schlesinger et al. 2009). Prehistoric mining sites are found at Scoville Point, Mott Island, Hill Island, McCargoe Cove, the Siskiwit Mine, and the Island Mine (Karamanski et al. 1988). Archeologists estimate that 280–375 tons of copper were removed from ISRO (Rennicke 1989) using oblong beach stones as tools (Karamanski et al. 1988).

The North Shore Ojibwe people had a long history with ISRO and regularly used it for subsistence activities such as making maple sugar, harvesting plants, snaring rabbits, netting passenger pigeons, and gathering gull eggs. It was also "the good place," which had spiritual significance to them (Cochrane 2009). Their relationship to the island was greatly changed in the latter third of the 19th century after the island was ceded to the United States in the 1842 Treaty of La Pointe (Karamanski et al. 1988, Cochrane 2009). The Grand Portage Ojibwe, who claimed ISRO, were not party to the treaty, which was made with other Ojibwe (Cochrane 2009). Today, the Grand Portage Ojibwe are working with NPS to reclaim their ancestral connections to ISRO.

Ten shipwrecks are documented around ISRO. The oldest known shipwreck in ISRO is the *Cumberland*, which lies near the Rock of Ages Lighthouse. The two largest wrecks in ISRO waters are the *Congdon* and the *Emperor*. The *Congdon* sank in 1918 in Congdon Shoals on the NE end of ISRO; it involved the largest loss of life and cargo in Lake Superior up to that time. The *Emperor*, which sank off Canoe Rocks on the NE end of ISRO in 1947, was the last major wreck at ISRO (Karamanski et al. 1988).

ISRO experienced three distinct periods of copper mining activity in the 1800s; a "speculative" wave from 1843–1855; a period of exploitation of archaeologic copper mining sites from 1873 to 1881, which also saw the development of year-round settlements on ISRO; and a "scientifically-a.



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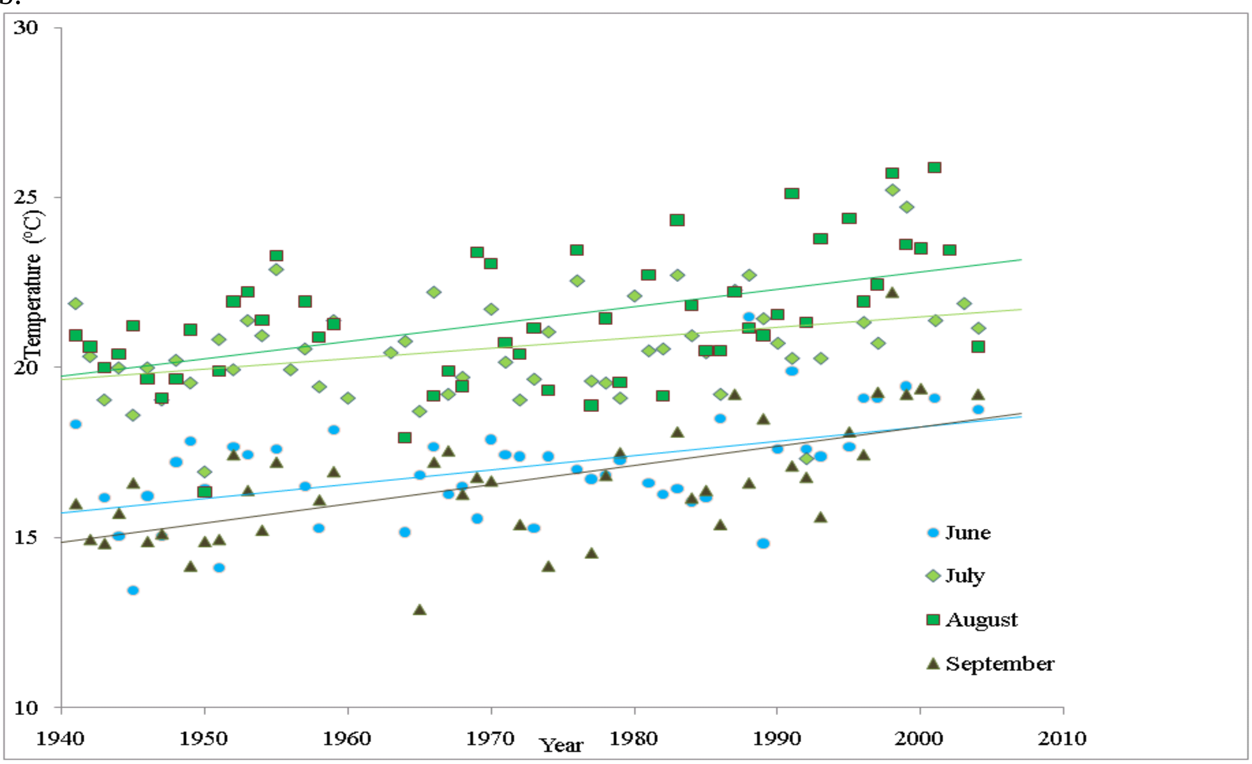

Figure 4. (a) Monthly mean and (b) monthly mean maximum temperatures for summer months, Mott Island, Isle Royale National Park, 1940–2004.

based, well-capitalized" effort from 1889 to1893 (Karamanski et al. 1988). Twenty-two sites from this era are known on ISRO.

The first commercial fishing operation in MI was run on ISRO by the American Fur Company from the 1830s to 1842. Because of whitefish population declines, stocking began in the Great Lakes by the 1870s and near ISRO in 1893. The largest human population related to fishing on ISRO occurred in the 1920s (Karamanski et al. 1988). Scandinavian immigrants "surged" into the ISRO region, especially from 1880 to 1900; they had great success in fishing for lake trout and herring (Cochrane 2009), but commercial fishing was virtually eliminated by 1960 (Karamanski et al. 1988).

ISRO was not extensively logged; Karamanski et al. (1988) reported that "By 1920 there had been no significant logging on the Isle." A logging effort in the 1890s near Washington Harbor may have included a dam across Washington Creek; a storm pushed most of the logs into Lake Superior, and most of those were lost. An extensive forest fire in 1936 followed a large pulpwood logging operation in the spruce and balsam swamp near Siskiwit Bay (Karamanski et al. 1988, Schlesinger et al. 2009). More details on the effects of human uses on ISRO's terrestrial resources are included in the Stressor section below.

Four hotels existed on ISRO by 1910, and a golf course was built at Belle Island. Resorts were located in Washington Harbor, Chippewa Harbor, and Rock Harbor, and on Belle Island, Barnum Island, and Davidson Island (Karamanski et al. 1988). ISRO was authorized as a national park by Congress in 1931 "to conserve a prime example of North Woods Wilderness"; the private holdings on the island were bought up from the late 1930s to 1940. ISRO was further designated part of the National Wilderness Preservation System in 1976; over 99% of ISRO's land area is designated as wilderness (Crane et al. 2006). In 1980, the United Nations Man and the Biosphere Programme named ISRO an International Biosphere Reserve, giving it global scientific and educational significance.

ISRO has no roads and is accessible by boat or plane. The National Park Service maintains a ferry service from Houghton, MI, to ISRO; commercial ferries travel from Copper Harbor, MI, and Grand Portage, MN. The National Park Service also operates a seasonal headquarters on Mott Island, visitor centers at Rock Harbor and Windigo, and a dormitory for visiting researchers on Davidson Island. A concessionaire operates lodging at Rock Harbor, with 60 lodge rooms and 20 cottages. The National Park Service makes available 113 tent sites, 88 shelters, and 43 group tent sites for camping (Isle Royale and Keweenaw Parks Association 2009). Visitation to ISRO has generally increased since 2,962 people visited in 1940 (Figure 5); the high was 31,760 in 1987, and the mean was 16,350 yr^{-1} from 2004 to 2008 (NPS 2009).

Soils and Geology

The bedrock units exposed at ISRO are of the Proterozoic Eon of Precambrian time (approximately 2.5 billion to 542 million years ago). They consist of thick lava flows interlayered with sedimentary rocks (together, the Portage Lake Volcanics) overlain in some places by the Copper Harbor Conglomerate (Figure 6) (NPS 2004c). The lava flows document a period in Earth history when a mid-continental rift extended across what is now the center of Lake Superior, possibly as far south as the Gulf of Mexico (Huber 1975). Lava flows also contain rare minerals, including the Michigan state mineral chlorastrolite. This stone is commonly called Isle Royale greenstone, although it is not technically a greenstone (Thornberry-Ehrlich 2008). The Copper Harbor conglomerate reflects the presence of a sedimentary basin and the cessation of rifting. It is an alluvial fan deposit that spread over the Portage Lake Volcanics from a highland area to the west (Huber 1975).

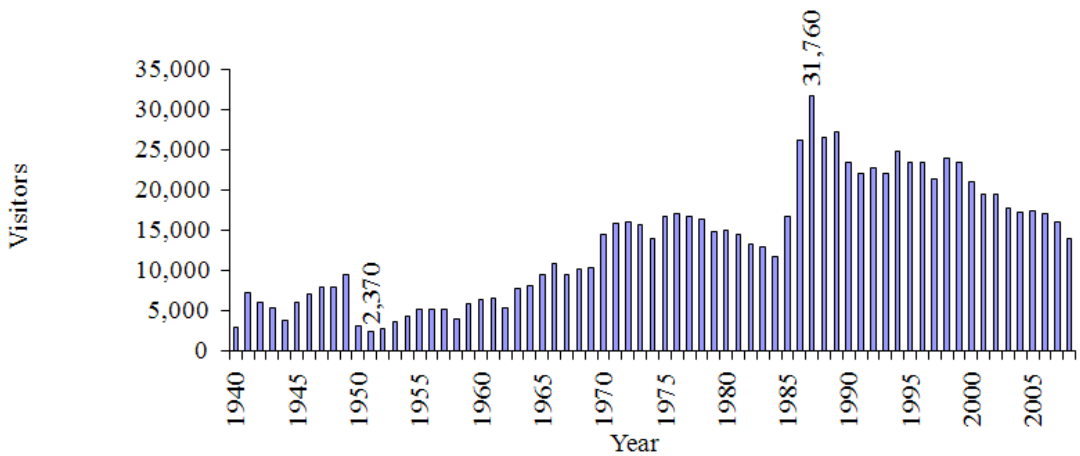

Figure 5. Number of visitors per year to Isle Royale National Park, 1940–2008 (NPS 2009).

The Portage Lake volcanics are generally tilted SE toward the long axis of the Lake Superior basin; erosion has exposed the upturned edges of the individual layers. The island's topography is dominated by a series of long parallel ridges and valleys, with the SE-facing slopes being gentler than the NW-facing ones. Ridges are frequently interrupted by crosscutting ravines or depressions (Huber 1975). The sedimentary rocks interbedded in the lava flows are not generally exposed; they are more easily eroded than the volcanic rocks and usually lie buried beneath surficial materials in depressions between the ridges of more resistant volcanic rock (Huber 1975). Thus, the bands of alluvium in Figure 6 are likely underlain by sedimentary rock, although a bedrock geology map was not available for verification.

The age gap between the bedrock and the overlying unconsolidated surficial deposits is more than 570 million years. Approximately 10,000 years ago, thick ice sheets covered the Great Lakes area; glacial features on ISRO are the result of the most recent Marquette readvance. Glacial plucking and scouring helped form the parallel ridges on ISRO; their alignment and the islands' shape and orientation indicate that the most recent glaciers covering the area flowed from NE to SW over the northern part of the island and E to W in the southern part (Thornberry-Ehrlich 2008). The resulting "washboard-like" pattern affects animal and plant distributions, migration patterns, microclimates, wetland distribution, and human uses (Thornberry-Ehrlich 2008). Glacial features, including layers of till, ice margin deposits, drumlins, and moraines, are concentrated on the SW part of the island (Huber 1973). ISRO also exhibits several paleoshorelines that correlate with Lake Agassiz levels that were low for their times but were still much higher than Lake Superior levels today. These include features such as beaches, terraces, and wave-cut benches (Thornberry-Ehrlich 2008).

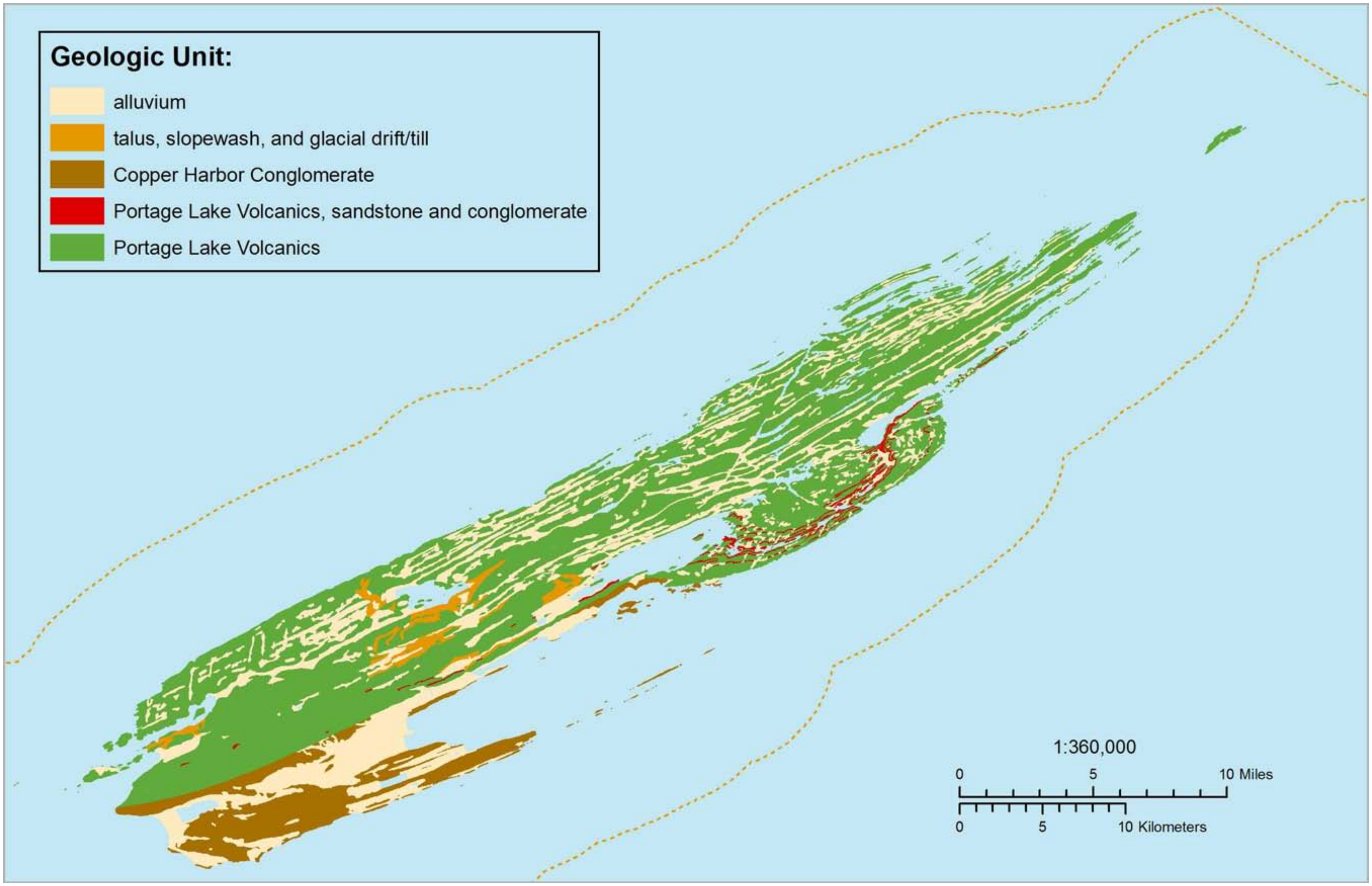

Figure 6. Surficial bedrock geology of Isle Royale National Park (NPS 2004c).

Most soils on ISRO are derived from materials left by retreating glaciers and meltwater (NPS 2005). Shetron and Stottlemeyer (1991) mapped 15 soil series and 14 distinct soil associations at ISRO. Soils on uplands in the northern part of ISRO developed directly on bedrock or on thin glacial cover; they are typically thin and sandy or loamy, and boulders are common (Woodruff et al. 2003). In the northeast, the thin soils are highly organic and are a major influence in the dominance of boreal forest vegetation (NPS 2005). In the southern part of ISRO, soils are deeper, better-developed, and less organic (NPS 2005) and more calcareous (Schlesinger et al. 2009), favoring northern hardwoods. Holocene soils are mainly alluvium in the form of lake and stream deposits on beaches and in swamps, bogs, and beaver ponds (Thornberry-Ehrlich 2008). A detailed soil survey is currently being prepared for ISRO but was not available in time for this report.

Lake Superior

Physical Characteristics

ISRO is located in Lake Superior, which has the greatest surface area of any freshwater lake in the world. The lake is 563 km long and 257 km wide at its longest and widest points, respectively, and its shoreline length is 4,800 km, including islands. With its many inlets and islands, ISRO includes 543 km of Lake Superior shoreline (Crane et al. 2006). Since ISRO includes the waters of Lake Superior out to 7.2 km from the shoreline, it encompasses over 165,000 ha of Great Lakes area (Lafrancois and Glase 2005).

The volume of Lake Superior is 12,100 km^3, 10% of the world's fresh surface water (USEPA and Government of Canada 1995). Lake Superior's mean depth is 147 m, and its maximum depth (near Pictured Rocks National Lakeshore, PIRO) is 406 m (LSBP 2006a). Within the ISRO boundaries, depths are over 230 m N of Five Finger Bay and over 250 m S of Siskiwit Bay (Figure 7).

The modern-day water level of Lake Superior (approximately 183 m above mean sea level) was naturally established approximately 2,000 years ago when uplift of the St. Marys River sill isolated the Superior basin (LSBP 2006a). The level of Lake Superior has been regulated since 1914 by structures on the St. Marys River (Wilcox et al. 2007); the average difference between summer (August–September) high and late winter (March–April) low levels was about 30 cm from 1918–1999 (Trebitz et al. 2002). In the last 90 years, the lake level has varied from 182.72 m in April 1926 to 183.91 m in October 1985 (USACE 2008). Since 1998, the lake has generally been below its long-term (since 1918) historic average (USACE 2009), with a record low for the month of September (183.02 m) set in 2007 (NOAA 2009a).

Bennett (1978a) proposed a water budget for Lake Superior with inputs of direct precipitation (69.6 cm, 51%) and land drainage (65.7 cm, 49%) and outputs of evaporation (47.0 cm, 35%) and outflow through the St. Marys River (88.3 cm, 65%). Similarly, Holtschlag and Nicholas (1998) estimated that approximately 56% of the lake's water arrives as direct precipitation on the lake surface, 11% enters as runoff from adjacent land surfaces, and 33% arrives as indirect groundwater discharge, defined as the groundwater component of streamflow. Direct groundwater discharge to Lake Superior has not been measured, but it is estimated to be "insignificant" in the vicinity of ISRO, on the north shore of Lake Superior, because of the low permeability of the aquifers (Olcott et al. 1978). Similarly, Young and Skinner (1974) estimated that "underflow to Lake Superior averages 0.5 inches (1.3 cm) yr^{-1} from the Wisconsin Lake Superior shoreline." Lake Superior has a residence time (volume related to inputs) of 113 years, and a flushing time (volume related to outflow) of 177 years, but mixing time within the lake is only a few years. Thus, persistent substances can remain in the lake for a long time, but become uniformly distributed in relatively short order (Matheson and Munawar 1978).

Lake Superior is strongly dimictic, with summer stratification beginning from late June to mid-July and ending in November, and weaker winter stratification from January to mid-April (Bennett 1978b). A strong relationship exists between vertical temperature structure and horizontal water currents. Both Lake Superior's currents and circulation influence water temperatures, sediment transport, ice cover, distribution of nutrients and oxygen, and dispersal of planktonic organisms, and so are important to the aquatic community (LSBP 2006a). The lake

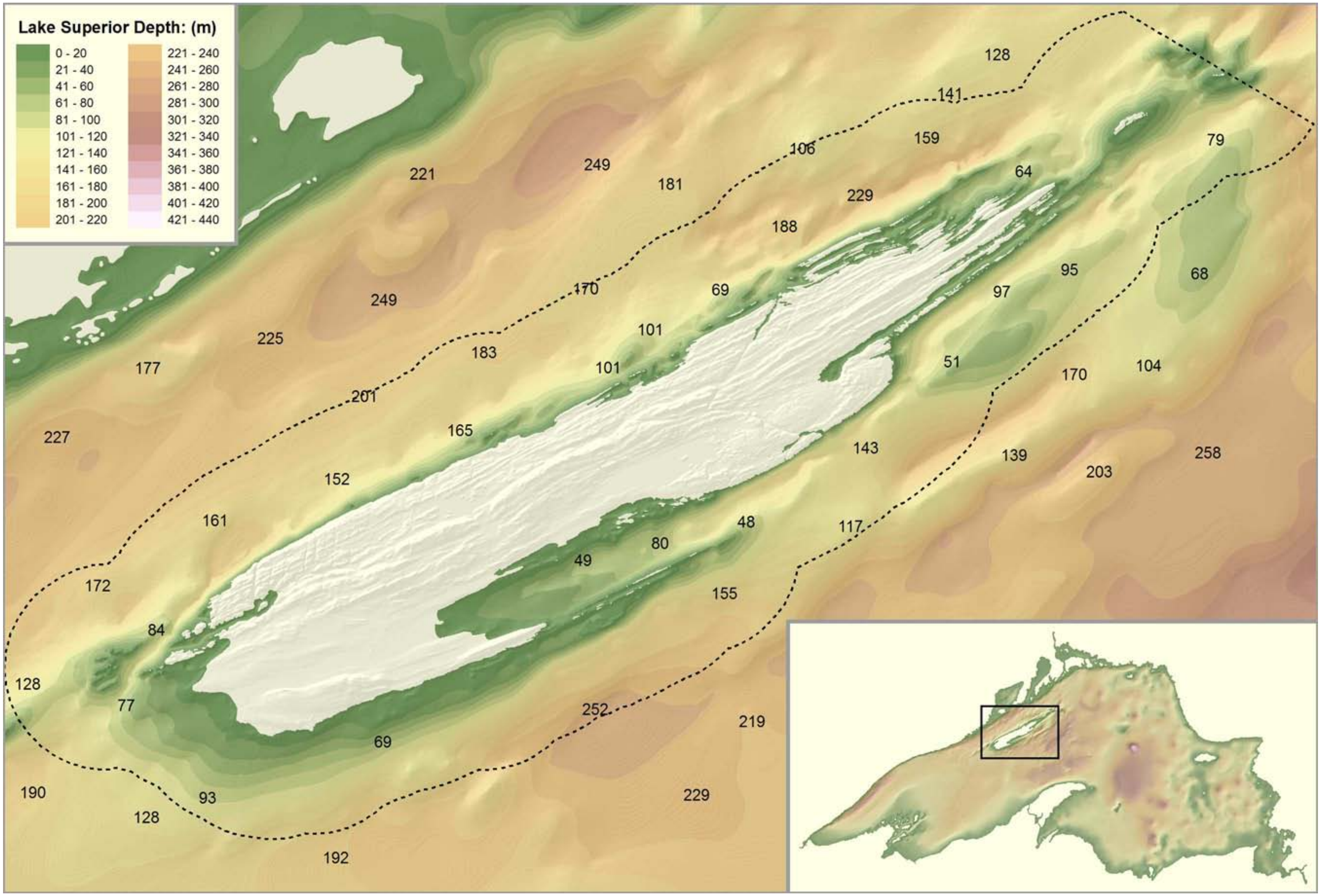

Figure 7. Lake Superior bathymetry and soundings (NOAA 2007a, b, c, d).

has both epilimnetic and hypolimnetic currents, mainly longshore (LSBP 2006a). The summer circulation is generally counterclockwise (Beletsky et al. 1999), although in the relatively shallow western Lake Superior basin, the circulation is clockwise (Harrington 1895) (Figure 8). A small gyre also forms south of ISRO (LSBP 2006a). Overall, currents on the south side of the lake are strongest (Matheson and Munawar 1978). Current speeds are low and uniform with depth in the spring. As temperatures warm, currents accelerate in the epilimnion, reaching a maximum in early September, while currents in the hypolimnion decelerate, reaching a minimum in August (Bennett 1978b). Fall mixing again makes the current speeds homogeneous (Lam 1978), and they decelerate from summer epilimnion levels and continue to flow through the winter (LSBP 2006a).

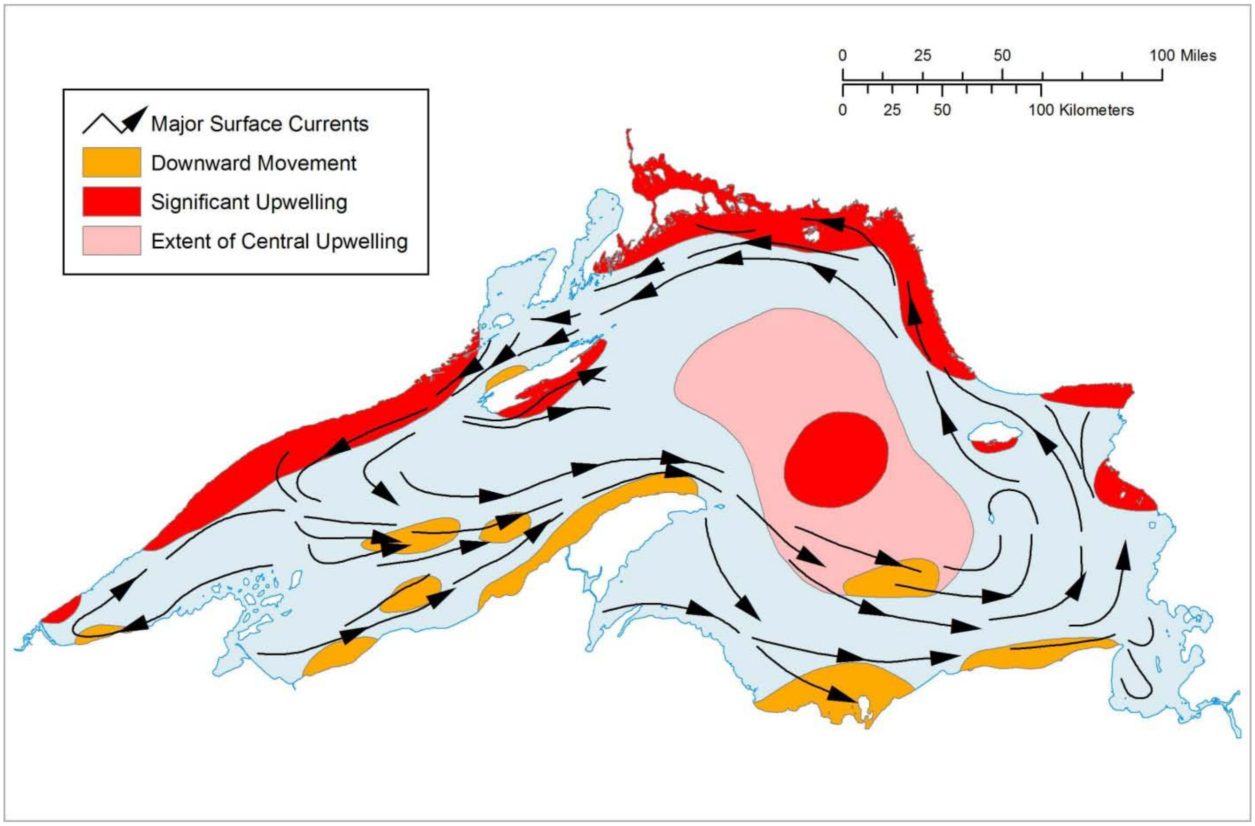

Figure 8. Major surface currents, downward water movements, and upwellings for Lake Superior (after LSBP 2006a).

Upwelling likely contributes to strong summer hypolimnetic currents on the south side of ISRO. Such upwelling may bring nutrients and organic matter from the lake bottom and hypolimnion into more biologically active surface waters and thus increase productivity (LSBP 2006a). In summer, upwelling tends to force surface water from the north side of the lake toward the south side. In August 1999, a band of warm water was observed stretching from the south side of ISRO toward the Keweenaw Peninsula, and chlorophyll levels were elevated in this band (Budd 2004). Other water movements on Lake Superior are related to weather systems, including storm surges (rising water levels), storm set-downs (water level drops), and seiches (tide-like periodic oscillations caused by rapid changes in wind direction or air pressure) (Keillor and White 2003).

Coastal Geomorphic Zones and Processes

The Lake Superior shoreline of ISRO can be divided into three general zones, each with its own geomorphic characteristics (Mackey 2005). The coastal margin, from the ordinary high water mark to the 3 m isobath, has a low-energy area of embayments, tributary mouths, and coastal wetlands and a high-energy area around open coasts and island fringes. The nearshore open water area from the 3 m–15 m isobaths can be further divided into two areas based on water depth: <10 m water depth (including shallow reef complexes) and >10 m water depth. The former is a low-energy area characterized by limited exposure, short fetch distances, and fine-grained, soft substrates, while the latter has an open exposure, long fetch distances, and coarse-grained, hard substrates and bedrock.

Mackey (2005) has further described the natural physical processes that affect these zones and organized them according to their place of origin, the direction in which they operate, their variability, and their interconnectivity (Table 2). Evaluating the relative significance of these processes at ISRO is difficult because the groundwater flow system is not well understood (Thornberry-Ehrlich 2008) and the only long-term streamflow monitoring site is the gaging station on Washington Creek near Windigo (currently not in operation) (Crane et al. 2006).

Coastal Wetlands and Nearshore Habitats

Great Lakes coastal wetlands are important ecosystems that are generally biologically productive, store and cycle nutrients and organic materials carried in by rivers and streams, and provide habitats for a wide variety of Great Lakes species. Many fish species, for example, depend upon coastal wetlands for some portion of their life cycles (USEPA and Environment Canada 2008c). Coastal wetlands are a subset of Lake Superior nearshore habitat, and the term "nearshore" has been variously defined to begin at depth contours of 10 m (Bennett 1978b), 15 m (Gorman and Moore 2006), and 80 m (LSBP 2000).

Although ISRO reportedly has 10.2 km of coastal wetland shoreline (USEPA Region 5 2000), details about these are generally lacking. The USGS–NPS Vegetation Mapping Program lists one vegetation community, the Great Lakes shoreline bulrush–cattail marsh, dominated by hardstem bulrush (*Scirpus acutus*) and also including arrowhead (*Sagittaria latifolia*), woolly-fruit sedge (*Carex lasiocarpa*), and flat-leaf bladderwort (*Utricularia intermedia*) (TNC 1999). A photointerpretation signature was not established for this community, so it could not be mapped. Albert et al. (2005) have listed 10 geomorphic types of Great Lakes coastal wetlands in three hydrologic systems (Table 3), but the location and proportion of each type in ISRO are unknown. In a fourth category, Herdendorf et al. (1981) listed 29 palustrine coastal wetlands for ISRO totaling 971 ha (Table 4), but this list also includes some relatively isolated inland lakes (e.g., Patterson Lake). Rayburn (2003) also describes some ISRO bays and coastal wetlands.

Gorman and Moore (2006) conducted a nearshore fish population and community structures survey and reported four major nearshore habitat types in ISRO: low slope with fine substrates, low slope with coarse substrates, high slope with coarse substrates, and high slope with bedrock substrate. The predominant nearshore habitat of ISRO is characterized by moderate to steep slopes and coarse substrates, composed of cobble to boulder-sized sediments and the underlying basalt bedrock. Most shorelines were relatively unprotected and were exposed to wind and wave action from the open lake. Embayments of varying lengths and widths provided protection from the open lake; at the heads of these embayments, nearshore habitats were characterized by fine to mixed substrates and low slopes (Gorman and Moore 2006, Gorman et al. 2008).

Table 2. Physical processes that affect nearshore and coastal margin zones (after Mackey 2005).

Natural Process	Attributes	Pathways/Area	Connectivity
Fluvial Processes	Channelized flow Highly dynamic Spatially and temporally variable and episodic	Generally unidirectional (down slope) flow Acts within or along linear stream corridors and/or drainage networks within watersheds	Lateral hydraulic connectivity with adjacent floodplain and watershed surface Longitudinal hydraulic down-slope continuity and connectivity within stream channels
Groundwater Processes	Infiltration and groundwater flow Highly dynamic Spatially and temporally variable and episodic	Unidirectional and/or bidirectional flows Act across broad landscape surfaces and/or within stream channels or lakes	Hydraulic continuity (groundwater-surface water connections) and recharge area Potentiometric surface (water table elevation) – surficial geology and soils (aquifers)
Coastal Margin and Nearshore Processes	Wave and storm-generated currents and flows Intermittent fluvial influence near river mouths Highly dynamic Spatially and temporally variable and episodic	Oscillatory bidirectional and/or unidirectional flows Act within or along both shore-parallel and shore-normal linear corridors, with seasonal onshore-offshore components Water-depth dependent	Shore-parallel hydraulic connectivity (littoral processes) Shore-normal hydraulic connectivity (deltaic, estuarine, wetland, barrier connectivity)
Open Lake Processes	Wave and storm-generated currents and flows Superimposed over broad-scale hydraulic (riverine) or thermally-driven (seasonal) flows Spatially and temporally variable and episodic	Oscillatory bidirectional and/or unidirectional flows Broad-scale regional unidirectional flows Act within and between lake sub-basins, major connecting and tributary channel inflows and outflows	Lateral hydraulic connectivity with adjacent water masses Hydraulic connectivity with major connecting and tributary channel inflows and outflows

Table 3. Categories of Great Lakes coastal wetlands (Albert et al. 2005).

Hydrologic system	Geomorphic types
Lacustrine	Open shore, open embayment, protected embayment, sand-spit embayment
Riverine	Connecting channel, delta, drowned river-mouth (barred), drowned river-mouth (open)
Barrier-enclosed	Barrier beach lagoon, swale complex (ridge and swale complex, sand-spit swale, tombolo)

Table 4. Palustrine coastal wetlands of Isle Royale National Park (Herdendorf et al. 1981, Meeker et al. 2007).

		Streams Entering		
Wetland Location	Size (ha)	Named	Unnamed	Intermittent
Grace Harbor	18	Grace Creek	0	0
Thomsonite Beach	12			
Little Todd Harbor	79			
Florence Bay-Pickett Bay	111		1	
Pickett Bay Area	4		1	
Beaver Lake-McDonald Lake Area	136		1	
McCargoe Cove	71		2	1
Lake Eva	4		1	
Lane Cove	2			
Horner Area	2			
Five Finger Bay Area	4			
Patterson Lake	20			
Duncan Bay Tributary	38		1	
Duncan Bay	45			
Hidden Lake	16			
Tobin Harbor	10			
Moose Lake	8		1	
Tobin Creek	61	Tobin Creek		
Raspberry Island	6			
Siskiwit Mine Area	6			1
Moskey Bay Campground	28			
Chippewa Harbor Area	2			
Lake Richie Outlet	8		1	
Malone Bay Area	30			
Hay Bay Area	65	Little Siskiwit		
Caribou Creek	65	Caribou Creek		
Francis Point Area	4		1	
Attwood Beach Area	72			1
Long Point Area	45			1
Brady Cove*				
Pickerel Cove*				
Robinson Bay*				
Stockly Bay*				

Unstarred wetlands listed in Herdendorf et al. (1981); starred wetlands added by Meeker et al. (2007).

Lake Superior Shorelands

USEPA Shoreline Types

ISRO includes 530–540 km of Lake Superior shoreline (USEPA Region 5 2000, Lafrancois and Glase 2005). In 1993, NOAA identified and mapped 14 shoreline types in ISRO as part of a USEPA assessment of shoreline vulnerability to oil spills (Table 5, Figure 9) (USEPA Region 5 2000). The shoreline types in ISRO can be roughly described as sheltered scarps or vegetated low banks (40%); rocky cliffs or bedrock shores (36%); sand, sand and gravel, or gravel beaches, sometimes with shelving bedrock (22%); wetlands (2%); and human-made structures (<1%) (USEPA Region 5 2000).

Table 5. Lake Superior shoreline types, lengths, and USEPA shoreline sensitivity classification for Isle Royale National Park (USEPA Region 5 2000).

Shoreline Type	Length (km)	% of ISRO	NOAA ESI Shoreline Classification	USEPA Shoreline Sensitivity Classification
Exposed Rocky Cliffs	69.6	13.0	1A	Low
Shelving Bedrock Shores	123.2	23.1	2	Low
Riprap Revetments, Groins, and Jetties	0.3	0.1	6B	Low
Subtotal	193.2	36.2		
Sand Beaches	1.4	0.3	4	Low-Medium
Exposed Flats/Shelving Bedrock Shores	0.3	0.1	7/2	Low-Medium
Mixed Sand and Gravel Beaches	27.0	5.1	5	Low-Medium
Mixed Sand and Gravel Beaches/Shelving Bedrock Shores	0.4	0.1	5/2	Low-Medium
Gravel Beaches	84.2	15.8	6A	Low-Medium
Gravel Beaches/Shelving Bedrock Shores	1.5	0.3	6A/2	Low-Medium
Subtotal	114.8	21.5		
Sheltered Scarps in Bedrock	184.7	34.6	8A	Medium-High
Sheltered, Solid Man-made Structures	0.6	0.1	8B	Medium-High
Sheltered, Vegetated Low Banks	30.3	5.7	9A	Medium-High
Subtotal	215.6	40.4		
Fringing Wetlands	8.7	1.6	10A	High
Extensive Wetlands	1.5	0.3	10B	High
Subtotal	10.2	1.9		
Total	533.7	100.0		

Great Lakes Rocky Shores (Ecologic Group 5)

The Great Lakes basalt/diabase cobble-gravel lakeshore as described by the USGS–NPS Vegetation Mapping Program is 2.6% of the ISRO shore, mainly occurring at the SW end in Lake Superior bays underlain by sandstone and conglomerate bedrock (Figure 10) (TNC 1999, USGS 2000a). Most of the shore has little or no vegetation because it is regularly disturbed by waves and winter ice movement. The most abundant herbs are grasses. A shrub zone usually occurs on the highest beach ridge with shrub cover of 20–60% (TNC 1999).

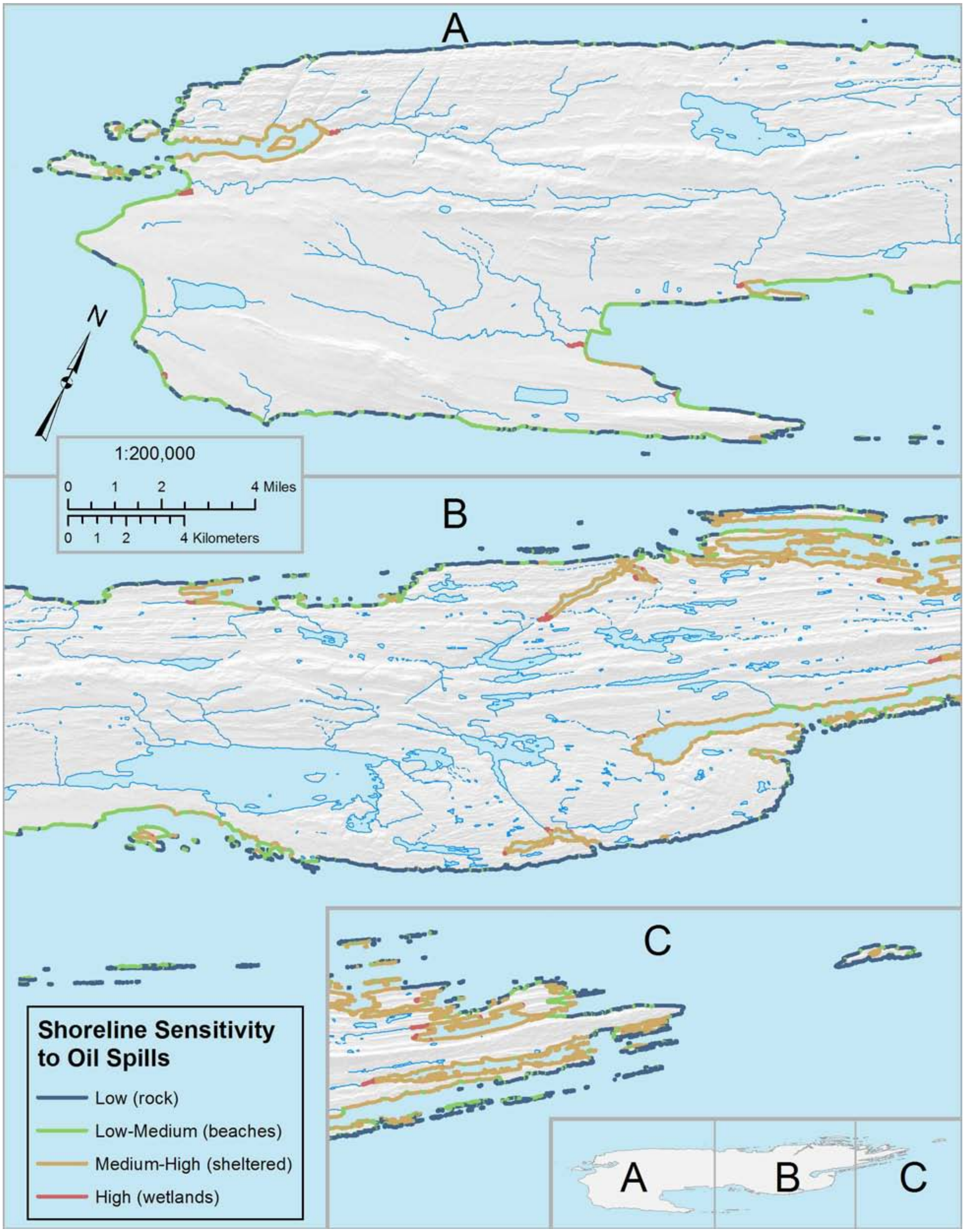

Figure 9. Shoreline sensitivity classifications for Isle Royale National Park (USEPA Region 5 2000).

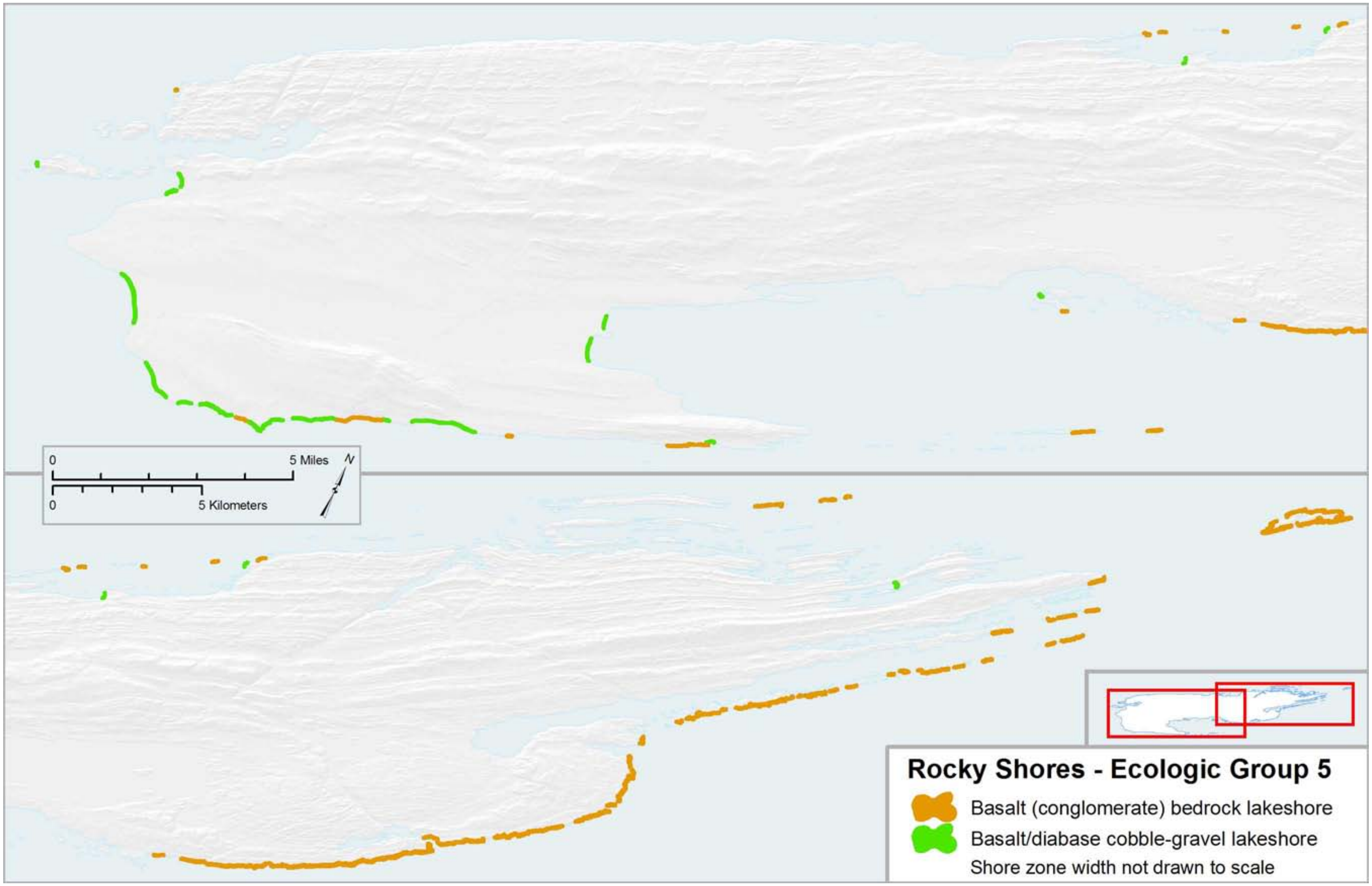

Figure 10. Rocky shores (Ecologic Group 5) in Isle Royale National Park (USGS 2000a).

The Great Lakes basalt (conglomerate) bedrock lakeshore, another community of sparse vegetation, occupies 9.7% of the ISRO shore and occurs primarily along SE-facing shores (Figure 10) (TNC 1999, USGS 2000a). In general, this association is dominated by crustose and foliose lichens (average 25%–50% cover) and mosses; the most common herb is shrubby fivefingers (*Sibbaldiopsis tridentata*, average 2% cover). Rock pools are generally part of this community; around rock pools, perched meadows, dominated by tufted graminoids, can be found (TNC 1999). This community is the most common location in ISRO for arctic/alpine disjunct species, probably because of cold water upwelling offshore, protection from wind, and proximity of open water to the east in winter (Judziewicz 1995).

Shoreline Rock Pools

Rock pools are a feature of the Lake Superior shoreline found on gently sloping, exposed, and rocky shores at the NE end of ISRO (Crane et al. 2006), on Passage Island, on "unexplored portions of the main island shoreline," and on many of ISRO's south-facing barrier islands (Glase and Lafrancois 2007). They are created by wind and wave action and ice scour and are filled with rainwater and wave wash.

The pools are biologically active and usually support a simple community of aquatic invertebrates, algae, and amphibians (Van Buskirk 1992a). They are one of the most southern locations for *Aeshna juncea*, a dragonfly typically found in arctic ponds and peat bogs (Van Buskirk 1992a, 1993), and the terrestrial habitats surrounding them include rare floral elements characteristic of arctic and alpine environments (Judziewicz 1995, 1999). Black crowberry (*Empetrum nigrum*), dwarf false asphodel (*Tofieldia pusilla*), and small cranberry (*Vaccinium oxycoccos*), all listed as threatened in MI, occur in rock pool habitat at ISRO, as do butterwort (*Pinguicula vulgaris*) and English sundew (*Drosera anglica*), which are MI species of special concern (Judziewicz 2004). Boreal chorus frogs (*Pseudacris maculata*) on ISRO are thought to breed almost exclusively in these pools (Smith 1983). Adult green frogs (*Lithobates clamitans melanota*), larval blue-spotted salamanders (*Ambystoma laterale)*, eastern red-spotted newts (*Notophthalmus viridescens viridescens*), and dace (*Rhinichthys* and/or *Phoxinus* sp.) have also been observed (Glase and Lafrancois 2007).

Crane et al. (2006) summarized past studies on rock pool ecology that focused on ecologic interactions between larval frogs, salamanders, and dragonflies, including Smith (1987), Van Buskirk and Smith (1991), Van Buskirk (1992a, b, 1993), and Smith and Van Buskirk (1995). Boreal chorus frogs are constrained mainly to pools of intermediate size and shoreline position; small pools and those near the shoreline do not persist long enough for metamorphosis, and large permanent pools near the forest edge contain predators such as dragonfly and salamander larvae (Smith 1983). A study of these pools is currently underway with Great Lakes Restoration Initiative funding.

Biologic Resources

Aquatic and Shoreline Vegetation

Lake Superior has been classified as an ultra-oligotrophic lake because of its low nutrient levels and cold temperatures (LSBP 2006a). When aquatic vegetation is present, it is generally confined to nearshore areas (Edsall and Charlton 1997).

Meeker et al. (2007) collected aquatic plants and searched for exotic species in ten Lake Superior bays (Chippewa Harbor, Duncan Bay, Five Finger Bay, Lane Cove, McCargoe/Brady Coves, Moskey Basin, Pickerel Cove, Robinson Bay, Stockly Bay, and Tobin Harbor) from 2003 to 2006. In ISRO, 402 wetland plant taxa were identified. The seven aquatic taxa that occurred in >50% of 40 Lake Superior cove and bay transects were quillwort (*Isoetes* spp., 85.0%), needle spikerush (*Eleocharis acicularis*, 82.5%), long-beak water-crowfoot (*Ranunculus longirostris*, 75.0%), whorl-leaf water-milfoil (*Myriophyllum verticillatum*, 65.0%), Richardson pondweed (*Potamogeton richardsonii*, 65.0%), water sedge (*Carex aquatilis*, 60%), and grass-leaved pondweed (*Potamogeton gramineus*, 52.5%). Thirteen shoreline taxa occurred in >50% of 31 shoreline segments: reed canary grass (*Phalaris arundinacea*, 87.1%), spotted joe-pye-weed (*Eupatorium maculatum*, 83.9%), winter bentgrass (*Agrostis hyemalis*, 80.6%), jewelweed (*Impatiens capensis*, 64.5%), narrow-panicle rush (*Juncus brevicaudatus*, 64.5%), purplestem aster (*Aster puniceus*, 61.3%), fireweed/willowherb (*Epilobium* spp., 61.3%), water sedge (54.8%), bluejoint (*Calamagrostis canadensis*, 51.6%), bottlebrush sedge (*Carex hystericina*, 51.6%), American bugleweed (*Lycopus americanus*, 51.6%), wild mint (*Mentha arvensis*, 51.6%), and purple meadow-rue (*Thalictrum dasycarpum*, 51.6%).

Meeker et al. (2007) also searched for seven aggressive plant taxa: broadleaf cattail (*Typha latifolia*), narrow-leaf cattail (*Typha angustifolia*), common reed, reed canary grass, curly-leaf pondweed (*Potamogeton crispus*), Eurasian water-milfoil (*Myriophyllum spicatum*), and purple loosestrife (*Lythrum salicaria*). Curly-leaf pondweed, Eurasian water-milfoil, and purple loosestrife were not found at any sampling sites in ISRO. Reed canary grass was widely distributed along bay shorelines, as indicated above. Broadleaf cattails were found in all bays except for Robinson Bay and Tobin Harbor, and were also found in Washington Harbor. Narrow-leaf cattails were found in Brady Cove and McCargoe Cove. Common reed occurred in Brady Cove and Duncan Bay.

Phytoplankton, Zooplankton, Aquatic Invertebrates, and Benthos

Both the zooplankton and phytoplankton communities at ISRO are indicative of Lake Superior's oligotrophic conditions. Approximately 300 phytoplankton species are present (LSBP 2006a). Lake Superior has been divided into six phytoplankton regions based on taxonomic and biophysical data. Lake Superior areas north and west of ISRO's NE/SW axis are in the northern nearshore region, while those south and east are in the open lake region. The open lake region has the lowest phytoplankton biomass, and the northern nearshore region has a moderate biomass; however, species composition is broadly similar among regions. Phytoflagellates (including cryptomonads, chrysomonads, and dinoflagellates) comprise approximately 35 percent of the species, while diatoms comprise 31 percent and green algae (Chlorophyta) comprise 22 percent (Munawar and Munawar 1978).

In 1973, diatoms and phytoflagellates, especially cryptomonads and chrysomonads, contributed most of the lake-wide phytoplankton biomass, which is in general very low (0.1–0.2 g m^{-3}). No clear seasonal trends were observed, and there was little difference in biomass between inshore and offshore waters (Munawar and Munawar 1978). A 1998 study similarly found the spring lake biovolume dominated by cryptophytes (27%), diatoms (33%), and chrysophytes, and concluded that the results "suggest the lake has changed little in the past 20 years" (Barbiero and Tuchman 2001). However, unlike Munawar and Munawar (1978), Barbiero and Tuchman (2001) did find a difference in species composition between spring and summer, with the cryptophyte

Rhodomonas minuta and the filamentous centric diatom *Aulacoseira islandica* most common in spring and the diatom *Cyclotella comta* and the chrysophyte *Dinobryon bavaricum* most common in summer.

In a published study of Lake Superior phytoplankton at ISRO, Taylor (1935) examined phytoplankton samples collected in July and August from McCargoe Cove, Rock Harbor, Tobin Harbor, and an open water site approximately 2.2 km off McCargoe Cove toward Hawk Island. Except for Rock Harbor, the sampled sites were dominated by *Dinobryon* and diatoms, with *Botryococcus* third in rank. In relatively shallow waters at Rock Harbor (0.6 and 3 m), the blue-green alga *Anabaena* and the dinoflagellate *Ceratium* were also important (Taylor 1935).

Lake Superior has the lowest zooplankton density of all the Great Lakes, as well as the lowest number of taxa (Barbiero et al. 2001). In the open waters of Lake Superior, large calanoid copepods dominate the zooplankton community; four species of calanoids (*Leptodiaptomus sicilis*, *L. ashlandi*, *Limnocalanus macrurus*, and *Senecella calanoides*) and one species of cyclopoid copepod (*Diacyclops thomasi*) are known to exist in the lake year-round and comprise 99.9% of the spring zooplankton community. Cladoceran zooplankton, indicative of more eutrophic conditions, are uncommon. Little change was detected in this community from the early 1960s to 1998 (Barbiero et al. 2001). Nearshore trawls in four Lake Superior ecoregions (MN North Shore between Two Harbors and the Canadian border, Wisconsin (WI) Apostle Islands, MI eastern Keweenaw Bay between Sand Bay and Bete Grise, and MI Whitefish Bay) were also dominated by *Leptodiaptomus sicilis* and *Limnocalanus macrurus*, as well as the smaller cyclopoid *Diacyclops thomasi* (Barbiero et al. 2007).

Watson and Wilson (1978) divided Lake Superior into fifteen zones based on temperature variations for purposes of zooplankton analysis; the three surrounding ISRO were 11^{th}, 12^{th}, and 13^{th} in zooplankton concentration (numbers m^{-3}) and 10^{th}, 12^{th}, and 14^{th} in zooplankton biomass (mg m^{-3}), and are characterized by an early summer peak population. Two of the zones that touch on ISRO are open-water zones that encompass a large part of Lake Superior, and the third is a zone between the north side of ISRO and the north shore of the lake. In a lakewide sampling during summer 1998, Barbiero et al. (2001) found one of the highest zooplankton densities NW of ISRO; over half these zooplankton were immature calanoids, and cladocerans were not present in significant numbers. In general, however, zooplankton distribution and abundance are strongly associated with surface water temperature, and so highest concentrations are found inshore, especially in the major embayments of the southern and eastern shores (LSBP 2006a).

Two large-bodied zooplankters, *Mysis relicta* and *Diporeia affinis*, were major components of Lake Superior food web at the time of European settlement (GLFC 2001). *Diporeia* is an indicator of lake health because it was once the most abundant benthic organism in cold, offshore regions of all the Great Lakes and is food for many forage fish species (USEPA and Environment Canada 2008b). *Diporeia* are “in a state of dramatic decline” in parts of all the Great Lakes except Lake Superior, likely due to the rapid spread of zebra and quagga mussels (USEPA and Environment Canada 2008b). *Diporeia* numbers did not significantly decline from 1994 to 2000 in western Lake Superior (Scharold et al. 2004) and are currently thought to be in “good” condition in Lake Superior, with an “unchanging” trend (USEPA and Environment Canada 2008b).

In addition to *Diporeia*, the offshore benthic community at depths 56–228 m also included oligochaetes, especially the Enchytraeidae and the lumbriculid worm *Styoldrilus heringianus* in 1999 (Barbiero et al. 2007). Molluscs (primarily the sphaeriid pea clam *Pisidium conventus*) and insects (primarily the chironomid *Heterotrissocladius oliveri*) accounted for less than 10% of the total biomass (LSBP 2006a). A total of 10 taxa were found at the 11 sites sampled in 1999 (Barbiero et al. 2007). The relatively simple benthic community of Lake Superior reflects the low diversity of habitat rather than impaired water quality (LSBP 2006a).

Barton and Hynes (1978) described the macrobenthos in wave-swept nearshore zones of the north shore of Lake Superior as typically lotic. They also determined that the diversity and abundance of macrobenthos were directly related to the stability of substrate, with more stable substrates supporting higher diversity and abundance. Granitic boulders commonly hosted Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Orthocladiinae (midges), and Oligochaeta (worms). Granitic bedrock was home to chironomids, including Orthocladiinae and Tanytarsini, hydropsychids (caddisflies, including *Lepidostoma*), *Antocha* (craneflies), Naididae (worms), *Baetis* (mayflies), and Acari (mites) (Barton and Hynes 1978). Nichols et al. (2001a) surveyed 30 m^2 of McCargoe Cove and found five species of mussels; additional sampling was performed in inland lakes and is addressed in more detail in the Inland Waters section. The mussels found, although common, are at great risk in the Great Lakes basin because of invasive mussels, sprawl, and herbicide and pesticide use (Nichols et al. 2001a). The authors suggested that ISRO's mussels may be among only a few remaining populations in MI in 10–15 years (Nichols et al. 2001a). The authors also looked for sponges but did not find any in McCargoe Cove. Detailed information for other ISRO nearshore and offshore benthos was not found; the Water Resources Management Plan (Crane et al. 2006) identified this as a need.

Lake Superior Fish Communities

At the time of European settlement, over 70 fish species occurred in Lake Superior and its tributaries. Today, 96 fish species are listed for Lake Superior, 16 of those nonindigenous (Horns et al. 2003). The deliberate introduction of Pacific salmon and the invasion of exotic fish species have perhaps irreversibly altered the food web of the lake. However, Lake Superior's native fish community has remained relatively intact, and unlike the other Great Lakes, "the past 30 years is highlighted by recovery rather than continued ecological disruption" (Bronte et al. 2003).

The highest trophic level in Lake Superior is occupied by siscowet lake trout (*Salvelinus namaycush siscowet*) (Horns et al. 2003). They feed on coregonines and cottids (sculpins), which in turn feed on zooplankton and larger invertebrates (Table 6) (Harvey et al. 2007). Siscowet are closely followed by burbot (*Lota lota*) and lean lake trout (*Salvelinus namaycush*) on the trophic level pyramid (Harvey and Kitchell 2000). Burbot occupy both offshore and nearshore habitats, where they prey on a variety of benthivores, including sculpins, sticklebacks (primarily ninespine sticklebacks [*Pungitus pungitus*]), suckers (*Catostomus* spp. and *Moxostoma* spp.), and pygmy whitefish (*Prosopium coulteri*). Humper lake trout, a variety of *S. namaycush* found mainly on deep offshore underwater reefs around Isle Royale and in the eastern waters of the lake around Caribou Island (Horns et al. 2003), probably occupy a slightly lower trophic level since they eat the zooplankter *Mysis relicta* as well as sculpins (Sitar et al. 2007). Many piscivores, including brook trout (*Salvelinus fontinalis*), walleye (*Sander vitreus*), lake sturgeon (*Acipenser fulvescens*), yellow perch (*Perca flavescens*), and northern pike (*Esox lucius*), also occupy rivers, bays, and coastal waters (Horns et al. 2003).

Table 6. Ecologic roles of important Lake Superior fish species, including nonindigenous species (Horns et al. 2003).

Common Name	Scientific Name	Adult Habitat
Planktivores (diet predominantly zooplankton or phytoplankton)		
Lake herring	*Coregonus artedi*	Offshore, nearshore
Bloater	*Coregonus hoyi*	Offshore
Rainbow smelt*	*Osmerus mordax*	Nearshore
Benthivores (diet predominantly macroinvertebrates)		
Kiyi	*Coregonus kiyi*	Offshore
Lake whitefish	*Coregonus clupeaformis*	Nearshore
Brook trout	*Salvelinus fontinalis*	Tributaries, bays, coastal waters
Ninespine stickleback	*Pungitus pungitus*	Nearshore
Pygmy whitefish	*Prosopium coulteri*	Nearshore
Slimy sculpin	*Cottus cognatus*	Nearshore
Lake sturgeon	*Acipenser fulvescens*	Nearshore, tributaries
Deepwater sculpin	*Myoxocephalus thompsoni*	Offshore, nearshore
Longnose sucker	*Catostomus catostomus*	Nearshore, tributaries
White sucker	*Catostomus commersoni*	Nearshore, tributaries
Piscivores (diet predominantly fish)		
Coho salmon*	*Oncorhynchus kisutch*	Offshore, nearshore, tributaries
Chinook salmon*	*Oncorhynchus tshawytscha*	Offshore, nearshore, tributaries
Sea lamprey*	*Petromyzon marinus*	Offshore, tributaries
Pelagic lean lake trout	*Salvelinus namaycush*	Offshore, nearshore
Humper lake trout	*Salvelinus namaycush*	Offshore, nearshore
Siscowet lake trout	*Salvelinus namaycush siscowet*	Offshore, nearshore
Rainbow trout*	*Oncorhynchus mykiss*	Nearshore, tributaries
Brown trout*	*Salmo trutta*	Nearshore
Burbot	*Lota lota*	Offshore, nearshore, tributaries
Walleye	*Sander vitreus*	Tributaries, bays, coastal waters
Northern pike	*Esox lucius*	Tributaries, bays, coastal waters
Smallmouth bass	*Micropterus dolomieu*	Tributaries
Yellow perch	*Perca flavescens*	Tributaries, bays, coastal waters

*nonindigenous species

Approximately 77% of the surface area of Lake Superior is offshore habitat (>80 m deep) and 23% is nearshore habitat (Horns et al. 2003). The offshore zone contains nearly all the spawning and feeding habitat for siscowet lake trout, humper lake trout, deepwater ciscoes (*Coregonus* spp.), and deepwater sculpin (*Myoxocephalus thompsoni*). Burbot, Pacific salmon, sea lamprey, and lake herring (*Coregonus artedi*) are also members of the offshore community. The nearshore zone contains most of the important and critical habitat for lean lake trout, lake herring, and lake whitefish (*Coregonus clupeaformis*). Other members of the nearshore fish community are siscowet lake trout, humper lake trout, burbot, Pacific salmon, brown trout, round whitefish (*Prosopium cylindraceum*), rainbow smelt (*Osmerus mordax*), lake sturgeon, ninespine sticklebacks, pygmy whitefish, deepwater ciscoes (including the two commercially harvested "chubs" bloater [*Coregonus hoyi*] and kiyi [*C. kiyi*]), slimy sculpin (*Cottus cognatus*), deepwater sculpin, trout perch (*Percopsis omiscomaycus*), and longnose and white suckers (*Catostomus catostomus* and *C. commersoni*) (Table 6). The major sport and commercial fisheries in Lake Superior utilize the nearshore zone (Horns et al. 2003).

Gorman and Moore (2006) characterized the ISRO fish community for the subset of the nearshore zone <15 m deep. Sampling with Windermere traps and fyke nets, they found a community dominated by common native species, including lake chub (*Couesius plumbeus*), ninespine stickleback, slimy sculpin, burbot, and trout-perch, in a habitat characterized by coarse and bedrock substrates with moderate to steep slopes. At the heads of bays, protected areas provided habitat for spottail shiner (*Notropis hudsonius*), blacknose dace (*Rhinichthys atratulus*), and white sucker. Mouths of bays were characterized by high slope, rocky substrates, and high structure and were home to simple assemblages dominated by lake chub. A similar nearshore fish community was found at Apostle Islands National Lakeshore (APIS), suggesting that nearshore fish communities in the two parks are drawn from a common source pool (Gorman et al. 2008).

One of the most studied fish species at ISRO is the coaster brook trout. Many brook trout are stream-resident forms that live their entire life in tributary streams feeding Lake Superior. However, some utilize nearshore habitat along broad sections of the coastline; these are collectively referred to as 'coaster' brook trout. Coaster brook trout can be broadly defined as brook trout that "have the potential to utilize lake habitats for an ecologically significant portion of their development and resource acquisition" (Huckins et al. 2008). There are two forms; the adfluvial form moves out of streams and into Lake Superior to forage for a time and returns to stream habitats to spawn, while the lacustrine form spends its entire life in Lake Superior and spawns on shoals. One noticeable result of using lake habitat is that coaster brook trout often attain large size, probably by exploiting more or higher quality food resources.

Brook trout were once the most common salmonid in tributary streams throughout Lake Superior, with portions of each population also utilizing nearshore habitat for foraging and spawning (Newman and Dubois 1997, Wilson et al. 2008). Presently, coaster brook trout populations are known only from the Lake Nipigon region in Canada, the Salmon Trout River in MI, and at Isle Royale, with adfluvial populations in Siskiwit River, Siskiwit Bay, and Washington Creek and a lacustrine population in Tobin Harbor (Huckins et al. 2008, Ridgway 2008). They may also persist in other areas of Lake Superior, including streams in PIRO and APIS; however, confirming migratory behavior in small populations of trout from remote streams is difficult. A creel survey from recreational fishing boats at Isle Royale conducted in 1998 did not document coaster brook trout (Lockwood et al. 2001). The small coaster brook trout population (an estimated 150 fish) in Tobin Harbor (Gorman et al. 2008) and uncertain size of other ISRO populations highlight the need for protection and restoration efforts.

Habitat alteration by the mining and timber industries and ecologic factors such as competition and predation by nonnative fish species are considered primary reasons for the decline and collapse of brook trout populations that utilize lake habitats (Newman and Dubois 1997). Overharvest of coaster brook trout, due to their large size and nearshore distribution, is thought to be a key reason for their decline throughout Lake Superior (Newman and Dubois 1997). Coaster brook trout populations remain low despite control of sea lamprey populations, reduction in stocking of nonnative fishes, and other conservation efforts. As a result, multi-agency efforts that include state, federal, tribal, and provincial cooperation are being conducted, with the aim of preserving the remaining diversity within brook trout populations and planning recovery efforts throughout Lake Superior and tributary streams. Changes to fishing regulations to reduce bag limits and, more recently, toward catch and release fishing only, have been enacted by state and provincial managers to help coaster brook trout populations. Unfortunately, the stocking of nonnative salmonid species such as rainbow trout, brown trout, and coho salmon for recreational fishing may impact coaster populations, because these species probably require similar stream and nearshore habitats (Newman et al. 2003).

Protecting the genetic diversity of the remaining populations of coaster brook trout is a concern shared by researchers across Lake Superior (Schreiner 2008, Hewitt et al. 2008, Huckins et al. 2008). Studies by Burnham-Curtis (2001), D'Amelio (2002), and Wilson et al. (2008) indicate that coaster brook trout are genetically more closely related to the resident brook trout in streams they utilize for spawning than to coaster brook trout populations elsewhere, suggesting that migration to lake habitats is a life-history strategy that was present in Lake Superior brook trout and may return if stream resident populations recover sufficiently. Alternatively, stocking stream resident populations with fish created using gametes from coaster brook trout populations may introduce migratory behavior back into stream populations. Coaster brook trout populations on ISRO play an important role in the range-wide recovery efforts for two key reasons. First, ISRO has important remnant populations of coaster brook trout that exhibit both life histories. Collection of gametes from adfluvial fish at Siskiwit River and lacustrine fish at Tobin Harbor has created captive hatchery stocks that are used in restoration efforts at mainland streams. Second, stream and nearshore habitat at ISRO remains relatively pristine, and the threat of future development to this habitat is very low compared to coaster populations in mainland sites. In fact, the survey by Gorman et al. (2008) identified several embayments at ISRO that have similar habitat to Tobin Harbor and thus may provide good opportunities for creating new, self-supporting populations.

Fish Abundance and the Commercial and Sport Fishery

Commercial fishing began in Lake Superior in the 1830s (Horns et al. 2003). For larger species, such as lake trout, lake whitefish, and lake sturgeon, maximum commercial harvest occurred before 1904 (Table 7) (Baldwin et al. 2002). Numerous authors have documented the near-collapse of the commercial fishing industry between 1940 and 1960 and its causes (LSBP 2000), which included overfishing, logging, dam building, discharge of paper mill wastes, toxic contaminants in water and air, mining, agriculture, urban development, and road and railroad construction (Horns et al. 2003). The introduction of non-indigenous species, some accidental (such as the sea lamprey and rainbow smelt) and others deliberate (including rainbow trout and Pacific salmon) also affected the natural food web and fish distribution within the lake. The 1960s marked the period of maximum degradation of the lake and its fisheries (Horns et al. 2003). However, with some notable exceptions in embayments and tributaries where there are Areas of Concern (AOCs), the status of fish habitat in the lake is generally good at this time (Horns et al. 2003).

Lean lake trout stocks declined in Lake Superior in the 1950s, but appeared to be "close to restoration" in the early 2000s (Bronte et al. 2003). As of 2001, lean lake trout stocking was no longer required in most areas of the lake to meet Great Lakes Fishery Commission (GLFC) fish community objectives, but sea lamprey predation continued to be a problem (Horns et al. 2003).

Table 7. Commercial harvest of Lake Superior fish from 1867 to 2000 and in 2006 (Baldwin et al. 2002, NOAA 2009b).

Species	Maximum Harvest (kg)	Year	2006 Harvest (kg)
Lake Herring	8,740,000	1941	327,000
Lake Trout	3,335,000	1903	72,000
Lake Whitefish	2,350,000	1885	638,000
Smelt	1,835,000	1976	9,800
Chubs	1,000,000	1965	20,000
Suckers	259,000	1988	3,800
Walleye	171,000	1966	1,000
Lake Sturgeon	102,000	1885	0
Round Whitefish	83,000	1995	600
Yellow Perch	63,000	1981	200
Sauger	56,000	1952	0
Northern Pike	52,000	1921	0
Burbot	36,000	1978	14
Pacific Salmon	13,000	1989	1,700
Rainbow Trout	500	1999	0
Carp	900	1998	0

Most lake trout harvested in Lake Superior in the 1990s came from the U.S., specifically from MI and WI (Figure 11), at a value of $151,258 in 2000 (Kinnunen 2003) and $46,284 in 2006 (NOAA 2009b). Commercial lean lake trout harvest is prohibited in MN because the fishery is not yet considered fully recovered (Bronte et al. 2003). Commercial lean lake trout harvest was closed in 1962 in MI and is allowed only by tribal fishers and in limited assessment fisheries in management zones MI-1 (in which ISRO is located), MI-5, and MI-6 (Peck and Sitar 2000). Assessment fisheries are located in both Washington and Rock Harbors (Crane et al. 2006). In Washington Harbor, private commercial fishers are allowed up to 600 lean lake trout, 4,500 kg each of lake whitefish and lake herring, and 7,300 kg of chubs annually. In Rock Harbor, the Edison fishery is a demonstration fishery, and ISRO is the permittee. Allowable annual harvests are 400 lean lake trout, 450 kg of lake whitefish, and 450 kg of other coregonines.

Siscowet (a type of lake trout) increased in abundance from 1970 to 1999 and may be approaching an ancestral state of abundance (Bronte et al. 2003). Siscowet was a commercially important species in 2000 (Kinnunen 2003), The market for siscowet as an edible fish has declined (Figure 11) because of its high fat content, but there is currently interest in exploring its use for producing high-grade fish oil as a nutritional supplement.

Lake whitefish are abundant and considered “resistant to exploitation” (Horns et al. 2003). They have been the primary target of the commercial fishery in Lake Superior since the late 1980s (Bronte et al. 2003) and were the most important fish species commercially harvested in Lake Superior in the year 2006, with an estimated value of $1,000,000 (Figure 11) (NOAA 2009b). Throughout the 1990s, most lake whitefish were harvested from MI and WI waters (Kinnunen 2003). However, from 1997 to 2004, gill-net fishing for lake whitefish was “minimal” (<1,000 kg yr^{-1}) in the Lake Superior management unit around ISRO (Schneeberger 2006).

Commercially harvested “chubs” in Lake Superior are two deep-water ciscoes: bloaters and kiyi. Peck (1977) determined that bloaters were the most abundant chub (51–87%) in commercial catches around the Keweenaw Peninsula from 1974 to 1976. Kiyi were 7–40% of the catch over

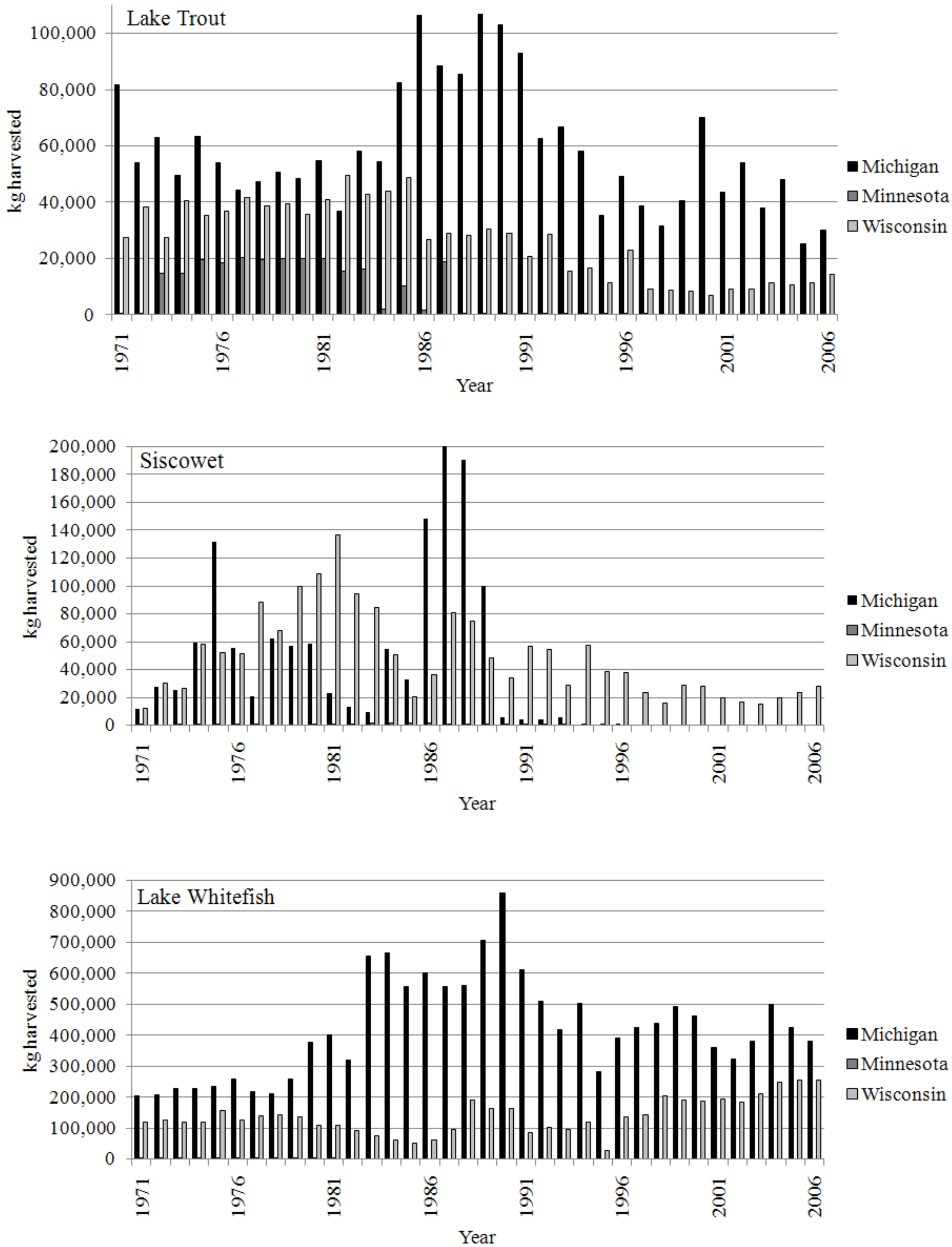

Figure 11. Lean lake trout, siscowet, and lake whitefish harvests from Michigan, Minnesota, and Wisconsin waters of Lake Superior, 1971–2006 (NOAA 2009b).

the same time period. The commercial chub fishery has declined greatly since the 1970s (Figure 12).

Lake herring were historically the dominant prey fish in Lake Superior but declined drastically in the mid-1960s, likely because of overfishing and competition with and predation by introduced rainbow smelt (Horns et al. 2003 and citations therein). Biomass of lake herring was relatively high from the mid-1980s to the mid-1990s but has since declined and, in 2008, was <3% of peak biomass (Gorman and Bunnell 2008). Rainbow smelt were abundant during the 1930s, 1940s, and 1950s (Horns et al. 2003), but their numbers have been greatly reduced by lake trout predation (Bronte et al. 2003). Their biomass fluctuated but declined during 1978–2008 and in 2008 was only 3% of peak levels (Gorman and Bunnell 2008). Commercial harvest of rainbow smelt has declined as well (Figure 12).

Populations of some nearshore fish, especially lake sturgeon, walleye, and brook trout, are still below historic levels, but state and tribal management agencies are attempting rehabilitation. Harvest controls are being developed by state and tribal management agencies (Horns et al. 2003). Fishing for coaster brook trout in the Lake Superior waters of ISRO is catch and release only (Schreiner 2008).

In 2007, 359 charter boat excursions were conducted in the MI waters of Lake Superior, carrying 1,630 anglers. This number of excursions is the lowest for the period of record 1990–2007; 791 excursions occurred in 1990, and the number has been variable but generally declining since then (Wesander and Clapp 2008). The MI Department of Natural Resources (MDNR) also collects data periodically on charter fishing excursions in the ISRO vicinity (MDNR 2009); the number of excursions ranged from 100 in 1999 to 5 in 2006 (Table 8). Lake trout are the great majority of the fish harvested.

Table 8. Charter boat excursions and catch for 1999, 2001, and 2005–2007 in the vicinity of Isle Royale National Park (MDNR 2009).

Year	Number of excursions	Angler hours	Lake trout harvested	Pacific salmon harvested	Other fish harvested
1999	100	3,263	850	17	3
2001	59	1,758	502	1	2
2005	33	482	97	3	2
2006	5	52	8	0	0
2007	28	306	58	1	0

Ecosystem Condition

The USEPA and Environment Canada (2007) reported that the overall status of the Great Lakes ecosystem in 2006 was mixed, with some conditions good and others poor, and that ecosystem trends varied from improving to worsening. Assessment is made more difficult by the fact that "for many indicators, ecosystem objectives, endpoints, or benchmarks have not been established" (USEPA and Environment Canada 2007). Numerous authors are currently engaged in developing indices of biologic integrity that will allow resource managers to assess the condition of specific parts of the Great Lakes, especially in coastal waters. Indicators used in these indices include invertebrates (Uzarski et al. 2004); diatoms (Reavie et al. 2006); fish (Uzarski et al. 2005); and a community approach using rock bass (*Ambloplites rupestris*), woolly-fruit sedge, stephano-

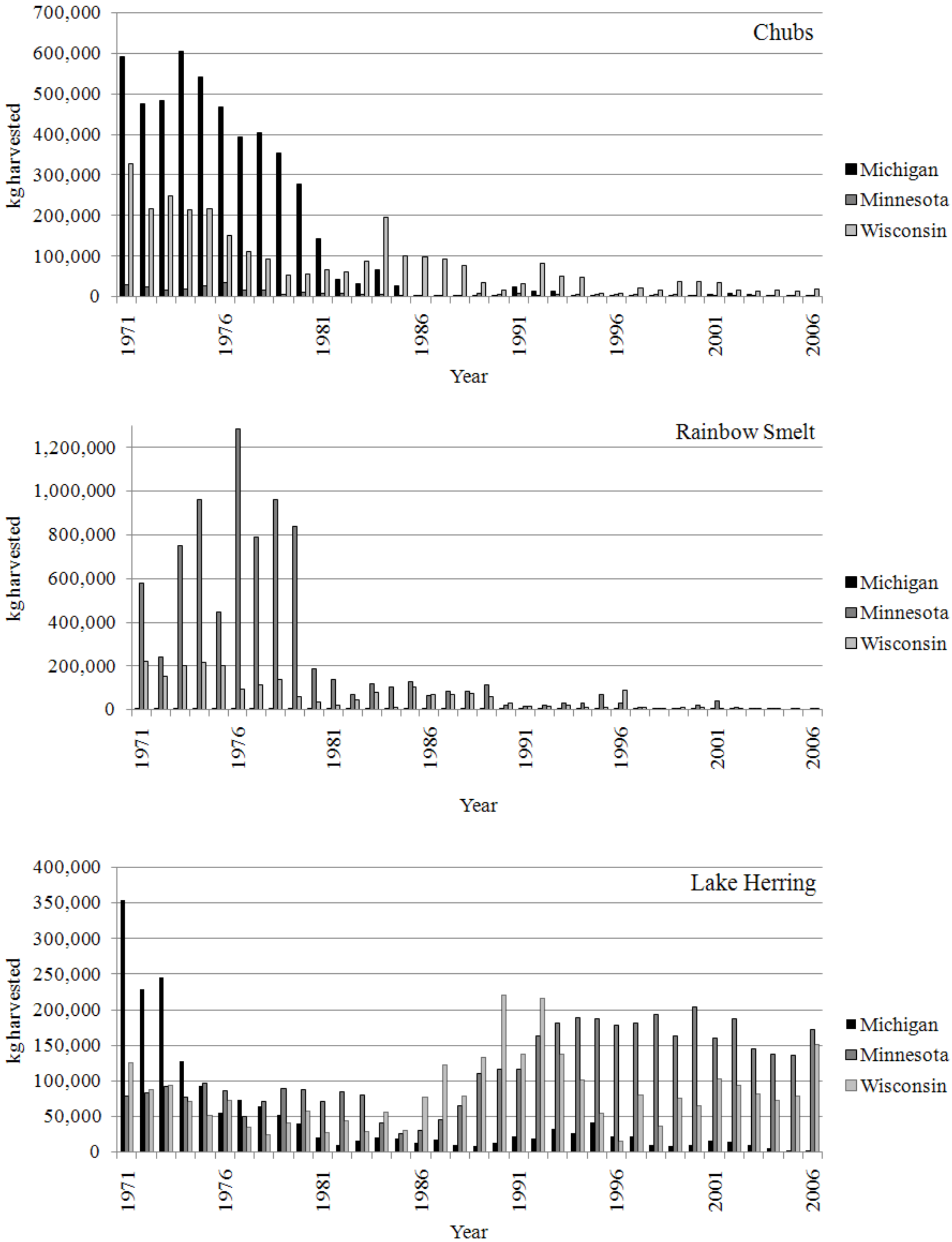

Figure 12. Chub, rainbow smelt, and lake herring harvest from Michigan, Minnesota, and Wisconsin waters of Lake Superior, 1971–2006 (NOAA 2009b).

discoid diatoms, spring peepers (*Pseudacris crucifer*), and insectivorous birds (Brazner et al. 2007).

Offshore Water Quality

The USEPA conducts offshore sampling on the Great Lakes during spring and summer each year. Lake Superior has 23 sampling sites. Sites SU-11 to SU-16 roughly surround ISRO, and SU-13 is within ISRO's boundaries (Figure 13). Parameters measured at least once for sites SU-11 to SU-16 include polychlorinated biphenyls (PCBs), alkalinity, ammonia nitrogen, beam attenuation, calcium (Ca^{2+}), organic carbon, chloride (Cl^{-}), chlorophyll-*a*, specific conductance (field and laboratory), fluorescence, chlordane, chlorthal-dimethyl, cis-nonachlor, lindane, total hardness, heptachlor epoxide, hexachlorobenzene (HCB), irradiance, magnesium (Mg^{2+}), total kjeldahl nitrogen, nitrate+nitrite nitrogen (NO_3+NO_2-N), dissolved oxygen (DO), oxychlordane, pH, total phosphorus (TP) (filtrate and bulk), dissolved silica (Si), sodium (Na^{+}), total solids, temperature, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), horizontal transmittance, trans-nonachlor, turbidity, and volume (USEPA 2008a). Plankton and benthos samples are also collected.

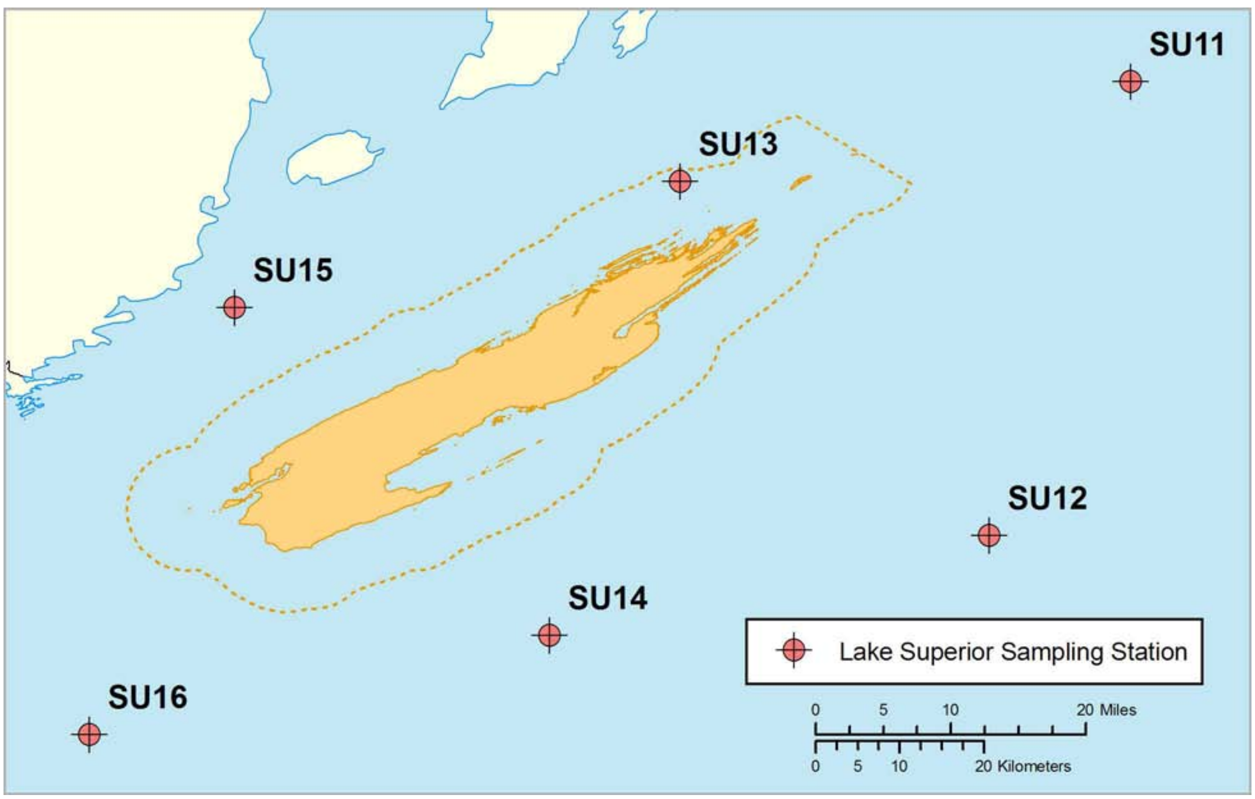

Figure 13. Locations of USEPA water sampling sites in Lake Superior in the vicinity of Isle Royale National Park (USEPA 2006, 2008a).

Nutrients

In an examination of nutrients in Great Lakes waters, Kelly (2008) focused on TP, NO_3+NO_2-N, dissolved silica (Si), and chlorophyll-*a* (Table 9). Lakewide, TP levels are below the upper limit of 5 µg L^{-1} set by the 1980 Phosphorus Management Strategies Task Force to maintain the lake's oligotrophic state (USEPA and Environment Canada 2007). The lakewide TP average is similar to the average for the offshore sites around ISRO, with SU-11, SU-14, and SU-16 slightly lower and SU-12, SU-13, and SU-15 slightly higher (Table 9, Figure 14). In 2007, the status of Lake Superior offshore waters for TP was "good," with an "undetermined" trend (USEPA and Environment Canada 2007).

NO_3+NO_2-N levels lakewide occur within a narrow range of 0.29–0.36 mg L^{-1}, and values in the ISRO vicinity are similar (Table 9, Figure 15). This concentration of inorganic nitrogen, when it occurs in spring, is sufficient to support summer algal blooms in lakes (Shaw et al. 1996). However, nitrogen is not the limiting nutrient in Lake Superior. Nitrate concentrations in Lake Superior doubled every 34 years between 1906 and 1976, from 0.075 mg L^{-1} to 0.311 mg L^{-1} (Bennett 1986). Bennett thought this increase was caused almost entirely by atmospheric deposition, but more recent research indicates that atmospheric deposition represents only about 27% of annual N loading to the lake (Sterner et al. 2007). In-lake nitrification is currently thought to be responsible for the increase in nitrate over time; Lake Superior is a net generator of nitrate because it is so strongly limited by phosphorus, organic carbon, and iron (Finlay et al. 2007, Sterner et al. 2007, Kumar et al. 2008).

Table 9. Water quality data (averages and ranges) for Lake Superior and for offshore sites around Isle Royale National Park, 2001–2007 (Kelly 2008, USEPA 2008a).

Location	TP (µg L^{-1})	NO_2+NO_3-N (mg L^{-1})	SiO_3+SiO_4 as Si (mg L^{-1})	Chlorophyll *a* (µg L^{-1})
Epilimnion composites, offshore waters, summer, 2001–2007				
Lakewide	2.13 (0.89–3.77)	0.34 (0.29–0.36)	2.17 (1.62–2.79)	0.96 (0.11–2.07)
SU-11	2.04 (1.24–3.15)	0.32 (0.32–0.33)	1.01 (0.87–1.12)	1.08 (0.73–1.35)
SU-12	2.16 (1.25–3.26)	0.32 (0.29–0.35)	0.98 (0.84–1.08)	1.21 (0.42–1.64)
SU-13	2.19 (1.80–2.76)	0.30 (0.29–0.33)	0.95 (0.83–1.10)	1.56 (1.02–2.04)
SU-14	1.92 (0.99–2.86)	0.32 (0.31–0.33)	0.99 (0.77–1.10)	1.13 (0.62–1.65)
SU-15	2.32 (1.47–2.84)	0.32 (0.31–0.32)	1.00 (0.87–1.07)	1.19 (0.65–2.03)
SU-16	2.06 (1.42–2.57)	0.32 (0.31–0.34)	1.02 (0.95–1.06)	1.08 (0.47–1.73)
Nearshore waters, summer, 2002–2007				
Lakewide	6.43 (1.90–19.21)	0.33 (0.14–0.50)	2.23 (1.75–4.40)	1.10 (0.27–15.3)

Dissolved reactive silica is high in Lake Superior relative to the other Great Lakes (LSBP 2000) and is considered to be available in sufficient quantities for diatom production. Si levels around ISRO generally ranged from 0.8 to 1.3 mg L^{-1} (Figure 16) and were uniformly lower than the lakewide average (Table 9). Conversely, mean chlorophyll-*a* levels around ISRO were higher than the lakewide average (Table 9, Figure 17), perhaps indicating that diatoms were producing chlorophyll and lowering silica levels.

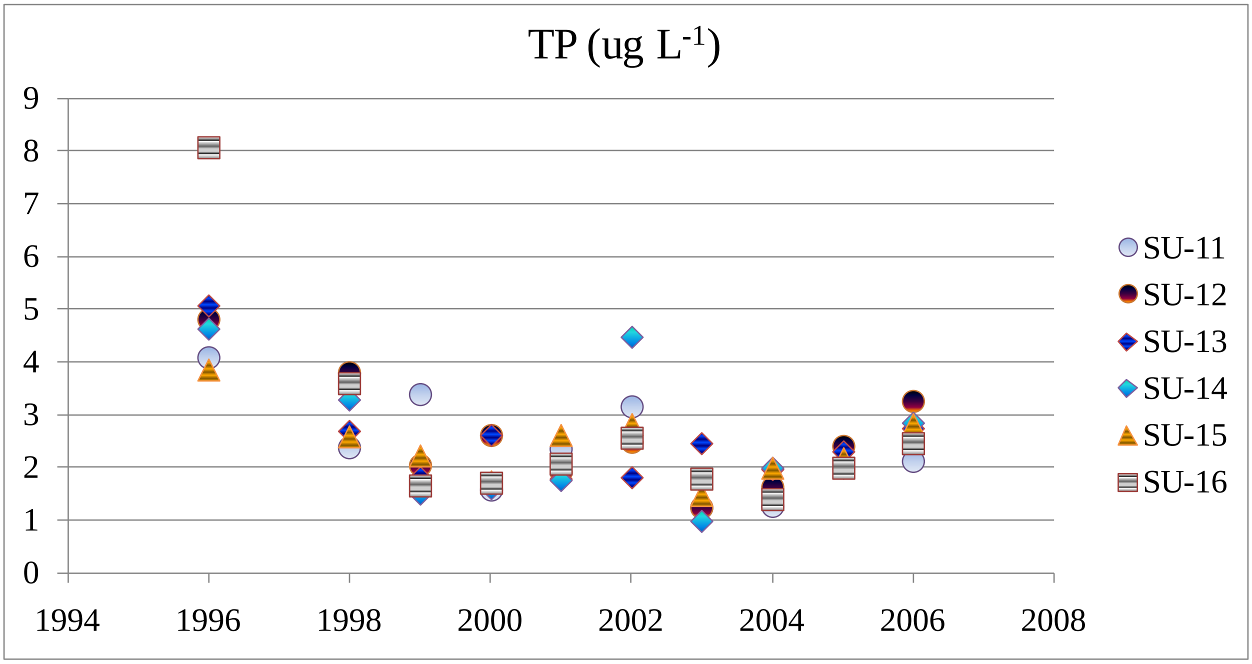

Figure 14. Total phosphorus (unfiltered) for summer epilimnion composites, Lake Superior offshore sites around Isle Royale National Park, 1996–2006 (USEPA 2008a).

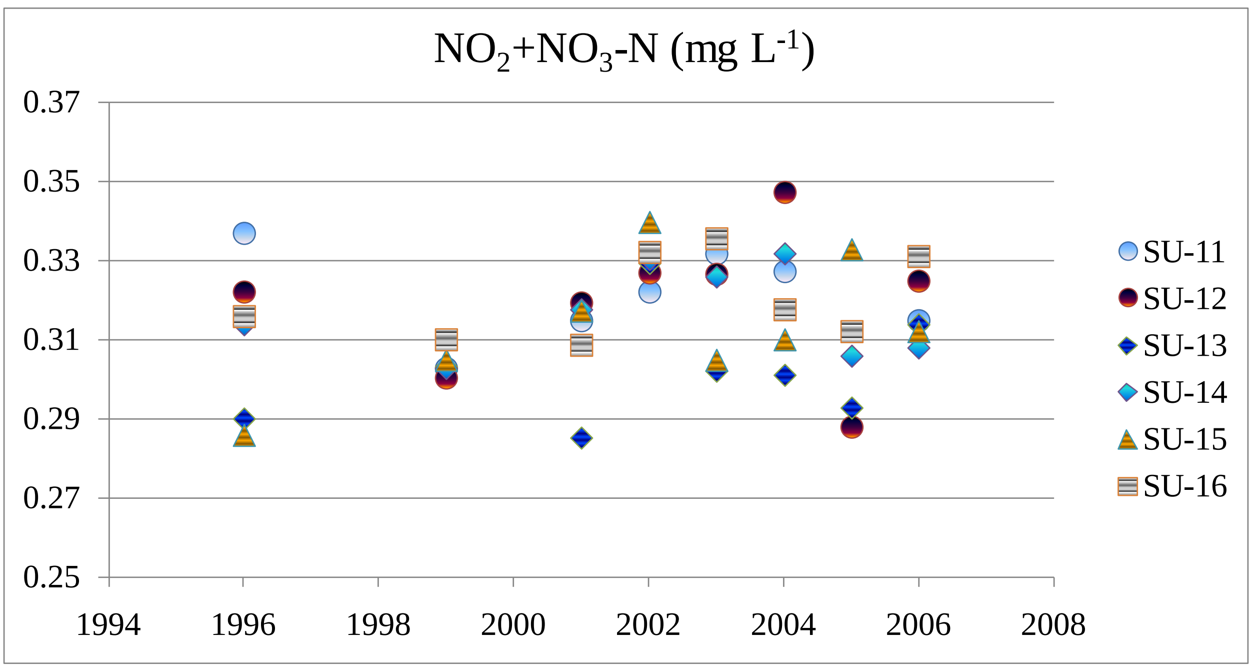

Figure 15. Nitrate and nitrite-nitrogen (filtered) for summer epilimnion composites, Lake Superior offshore sites around Isle Royale National Park, 1996–2006 (USEPA 2008a).

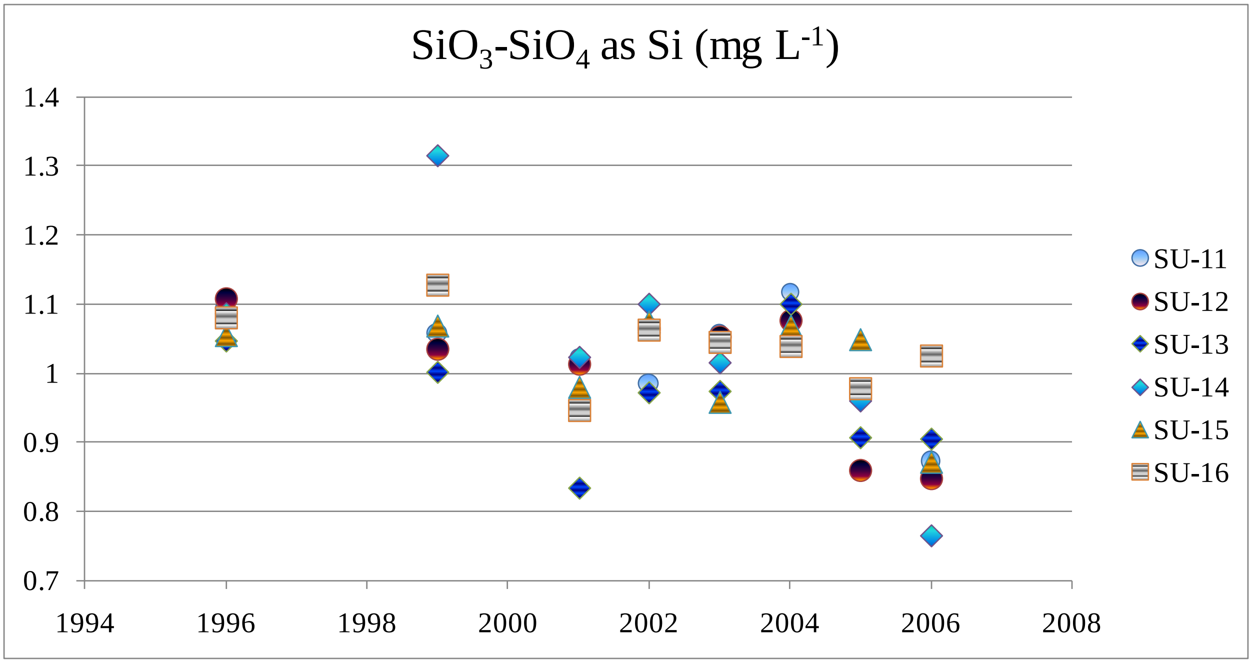

Figure 16. Dissolved silica (filtered) for summer epilimnion composites, Lake Superior offshore sites around Isle Royale National Park, 1996–2006 (USEPA 2008a).

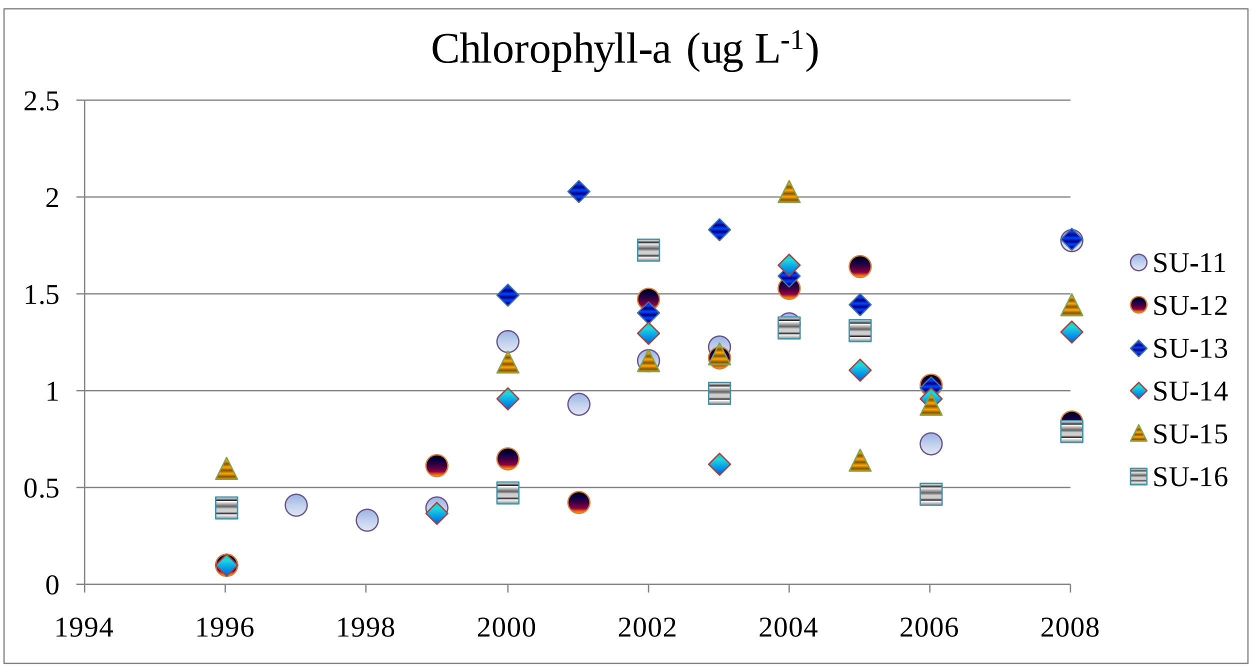

Figure 17. Chlorophyll-*a* levels for summer epilimnion composites, Lake Superior offshore sites around Isle Royale National Park, 1996–2008 (USEPA 2008a).

Dissolved Oxygen

All but one of 1,108 DO samples collected contained more than the 7 mg L^{-1} necessary for trout survival and optimal growth; no trends are apparent (Figure 18) (Shaw et al. 1996, USEPA 2008a).

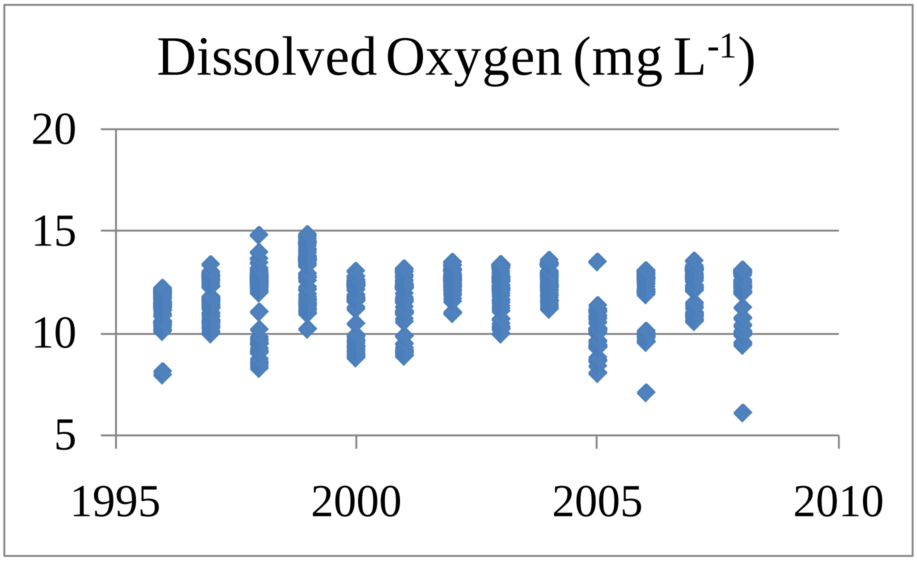

Figure 18. Dissolved oxygen (n=1,108) values for all depths, Lake Superior offshore sampling sites SU-11–SU-16 near Isle Royale National Park, 1996–2008 (USEPA 2008a).

Alkalinity, Specific Conductance, and pH

Alkalinity is a measure of water's buffering capacity and ability to resist a change in pH (USEPA 1986). Alkalinity values for sites around ISRO ranged from 39 to 47 mg L^{-1} as $CaCO_3$ and showed a significant upward trend from 1996 to 2008 (Figure 19). All values were well above 25 mg L^{-1}, the threshold below which lakes are considered susceptible to acid rain (Taylor 1984). Laboratory conductivity (specific conductance) values ranged from 96 to 104 µS cm^{-1}, agreeing well with calculated field values labeled "specific conductance" (21–104 µS cm^{-1}). As expected (Shaw et al. 1996), the numeric values for specific conductance (in µS cm^{-1}) were approximately double the values for total hardness or alkalinity (in mg L^{-1} as $CaCO_3$) (Figure 19). All pH values were within the acceptable range of 6.5 – 9.0 pH units (Figure 19).

Major Cations and Anions

Average concentrations for major cations were Ca^{2+}, 13.8 mg L^{-1}; Mg^{2+}, 2.8 mg L^{-1}; and Na^{+}, 1.4 mg L^{-1} (all n=35) (USEPA 2008a). No recent data were found for potassium (K^{+}). For anions, Cl^{-} levels were low from 1996 to 2008 (<1–2 mg L^{-1}) (Figure 19) but are projected to increase over the next 500 years from anthropogenic sources (road salts and brines) (USEPA 2008a, b). No recent data were found for sulfate (SO_4^{2-}).

Temperature

Water temperatures ranged from 0 to 18.6°C at depths of 1–5 m from 1996 to 2008, with April and May samples being much colder than those taken from August to October (Figure 20). A clear trend did not appear in this data set. However, three buoys installed in Lake Superior from 1979 to 1981 and since operated continuously from April to November indicate that July–September surface water temperatures increased 2.5°C from 1979 to 2006, and that this increase was significantly in excess of regional atmospheric warming (Austin and Colman 2007). This trend was attributed to declining winter ice cover, which is causing the stratified season to start earlier at the rate of a half-day per year.

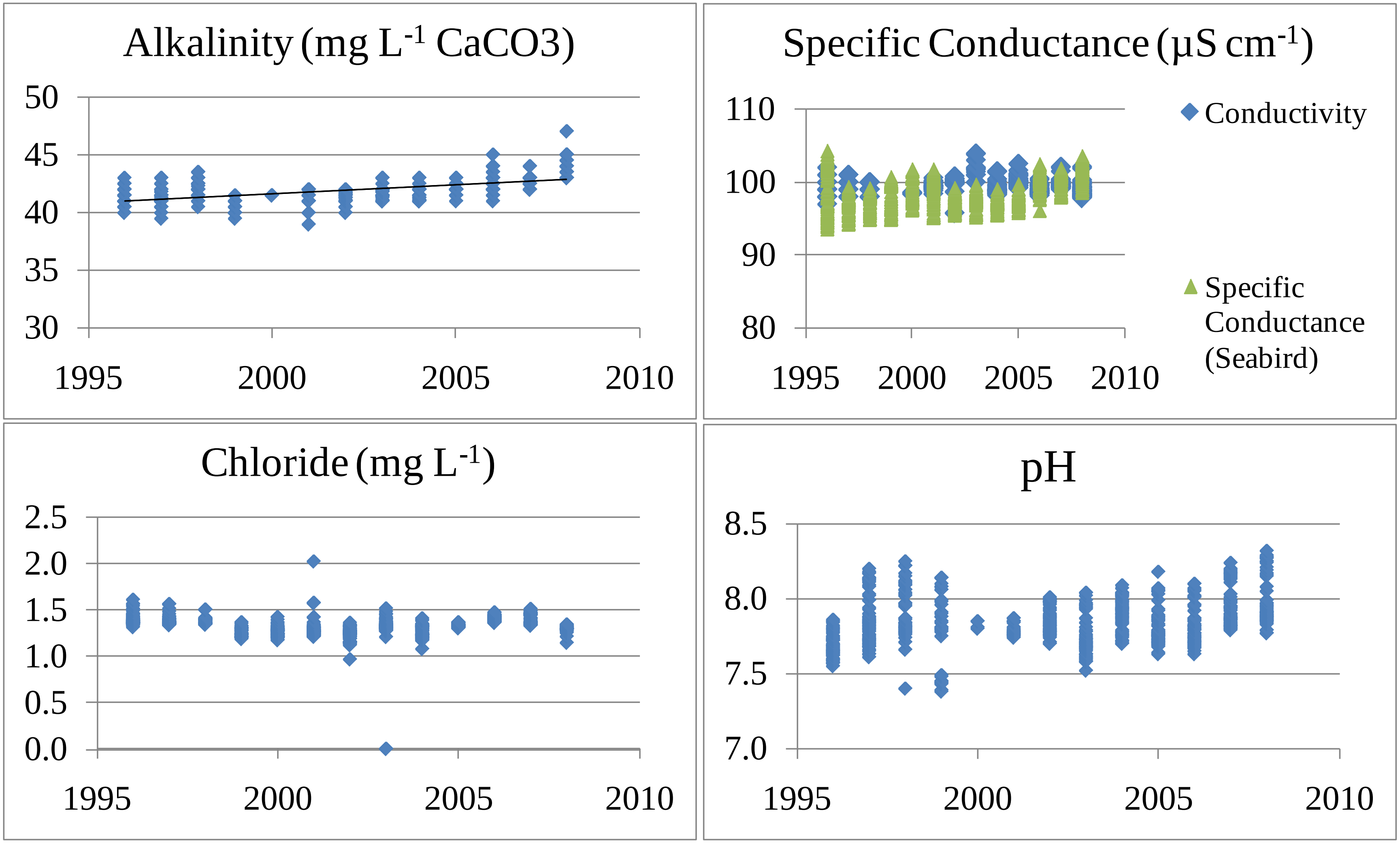

Figure 19. Alkalinity (n=671), specific conductance (n=1,566), chloride (n=934), and pH (n=653) values for all depths, Lake Superior offshore sampling sites SU-11–SU-16 near Isle Royale National Park, 1996–2008 (USEPA 2008a).

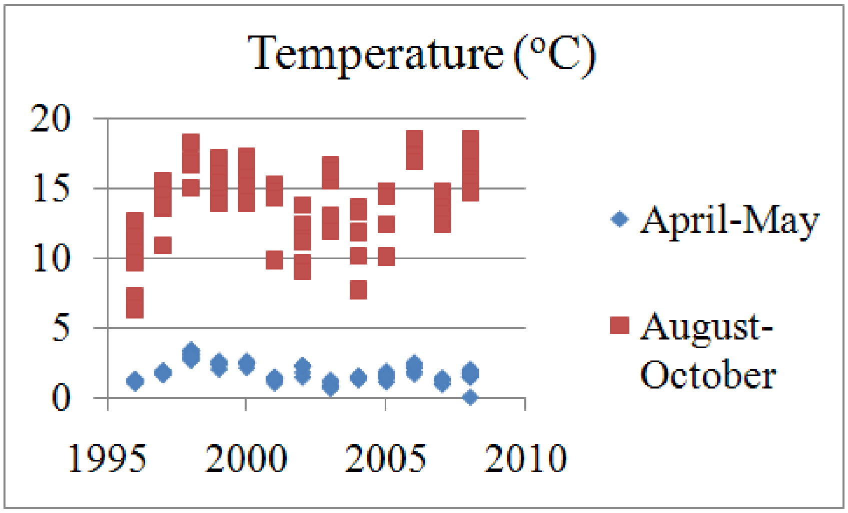

Figure 20. Water temperature (°C) for 1–5 m depths, Lake Superior offshore sampling sites SU-11–SU-16 near Isle Royale National Park, 1996–2008 (USEPA 2008a).

Critical Pollutants and Substances of Emerging Concern

The Lake Superior Binational Program (LSBP) has initiated a Zero Discharge Demonstration Program to end the use of nine critical pollutants in industrial processes and products and prevent their release in the Lake Superior basin by 2020. These pollutants are chlordane, DDT and its metabolites, aldrin/dieldrin, dioxin, HCB, mercury, octachlorostyrene, PCBs, and toxaphene (LSBP 2008). Although progress has been made, concentrations of PCBs, HCB, dieldrin, and toxaphene in Lake Superior water still remained above one or more "yardstick values" established by states or the province of Ontario as of 2005 (LSBP 2008). Another set of chemicals (polycyclic aromatic hydrocarbons [PAHs], alpha-hexachlorocyclohexane [α-HCH], cadmium, heptachlor and its breakdown product heptachlor epoxide, and another set of dioxins and furans) are on a "critical pollutant lakewide remediation" list, while a third set of chemicals (mostly heavy metals) is on a "local remediation" list (LSBP 2008).

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

In 2007, the status of Lake Superior for toxic chemical contaminants in offshore waters was fair, with an undetermined trend (USEPA and Environment Canada 2007). Thirteen of 21 organochlorine pesticide compounds for which tests were conducted were detected in Lake Superior at very low concentrations. Mercury concentrations were very low offshore, but the highest concentrations occurred near Thunder Bay and Duluth. PAHs were found throughout Lake Superior, although at extremely low concentrations.

Nearshore Water Quality

There has been little systematic water quality sampling of the nearshore waters of Lake Superior, either lakewide (Kelly 2008) or in the ISRO vicinity. Crane et al. (2006) stated that three sites sampled near Amygdaloid Island between June and August 1974 (NPS 1995) exceeded the 10 m depth contour that defines the nearshore environment but are thought to give a general indication of Lake Superior conditions near ISRO. No USEPA data were found for nearshore sites near ISRO (USEPA, Mid-Continent Ecology Division, Anne Cotter, email, May 26, 2009). However, the 2008 draft State of the Lakes Ecosystem Conference (SOLEC) document titled “Nearshore Areas of the Great Lakes 2008” presented summary data for 207 samples collected in other Lake Superior nearshore areas from 2002 to 2007 (Table 9). For TP, the lakewide average was higher for nearshore samples than offshore samples (6.43 µg L^{-1} vs. 2.13 µg L^{-1}), and the coefficient of variation was lower (48% vs. 69%). The 2007 status and trend for Lake Superior nearshore waters for TP were “undetermined” (USEPA and Environment Canada 2007). Lakewide averages for nearshore and offshore environments were similar for NO_3-N (0.33 vs. 0.34 mg L^{-1}), Si (2.23 vs. 2.17 mg L^{-1}), and chlorophyll-*a* (1.10 vs. 0.96 mg L^{-1}). Coefficients of variation were higher nearshore for Si (13% vs. 7%), much higher for chlorophyll-*a* (103% vs. 38%), and lower for NO_3-N (14% vs. 31%) (Kelly 2008).

Total and Fecal Coliform Bacteria

Total and fecal coliform are groups of organisms used to assess the suitability of water for drinking or for body-contact recreation. Some bacteria in the total coliform group are naturally found in soil and thought to present negligible health risk, while fecal coliform are generally accepted to represent the presence of human or animal fecal material in water (Health Canada 2006). Debate currently exists about the human health significance of animal fecal material in recreational waters; USEPA currently does not differentiate between human and animal fecal sources in its recreational waters criteria, citing “a lack of detailed and unequivocal information concerning the relative risks of human illness from various…(human or animal) sources of fecal contamination in recreational waters” (USEPA 2009e).

Little sampling for fecal or total coliform has been documented for ISRO. A 1995 report (NPS 1995) covering the period 1965–1993 included sampling sites at Amygdaloid Island and at Washington Creek at Windigo and revealed some violations of the WRD screening limits for primary body-contact recreation for both total and fecal coliform. However, it is unclear how these results were interpreted, since current standards require examination of five or more samples taken over a 30-day period and the calculation of a geometric mean (Ledder 2005). A 1984–1985 study (Meldrum 1987 in Crane et al. 2006) explored bacterial contamination in Isle Royale waters, especially in Lake Superior bays near heavy human-use areas. The ratio of fecal coliform to fecal streptococcus bacteria (FC:FS) was used as an indicator of whether the bacteria were of human or animal origin, and ISRO samples normally were indicative of non-human sources. Higher bacteria levels were generally found at Rock Harbor, and FC:FS ratios indicative of human fecal sources were occasionally found at Chickenbone West, Moskey Basin, and McCargoe Cove. Follow-up sampling occurred in 1987 at Benson Creek and Daisy Farm, and the conclusion was that “there was no evidence of human waste from pit toilets” in Benson Creek or Lake Superior in the Daisy Farm vicinity (Crane et al. 2006).

Contaminants in Fish and Other Organisms

In 2007, the MI Department of Environmental Quality (MDEQ) analyzed USEPA contaminant data on whole lake trout from Lake Superior from 1977 to 2000 and reported that overall, contaminant concentrations were less in Lake Superior fish than in fish from the other Great Lakes (MDEQ 2008a). Carlson and Swackhamer (2006) reported that in 1999 and 2000, contaminants in lake trout and salmon were generally lowest in Lake Superior and highest in Lake Michigan by a factor of three. However, they reported that concentrations of toxaphene and α-HCH in water and fish flesh are greatest in Lake Superior. Lake Superior is losing toxaphene (and probably α-HCH) at a slower rate than the other Great Lakes because of the lake's larger volume, lower productivity, and colder temperatures (Carlson and Swackhamer 2006).

In 2007, the status of Lake Superior for contaminants in whole fish was fair, with an improving trend (USEPA and Environment Canada 2007). Total PCB concentrations in fish tissue showed little change from the late 1970s to 2003 and were above the Great Lakes Water Quality Agreement (GLWQA) criteria of 0.1 parts per million (ppm) and the USEPA wildlife protection value of 0.16 ppm. Total DDT had fluctuating concentrations but was below the GLWQA criterion of 0.1 ppm. Mercury was below the GLWQA criterion of 0.5 ppm. Toxaphene concentrations were declining. Other contaminants, including PBDEs and perfluoroctanesulfonate (PFOS), have more recently been detected in Lake Superior fish (USEPA and Environment Canada 2007).

The MI waters of Lake Superior have fish consumption advisories for chlordane, dioxin, mercury, and PCBs. The PCB advisory includes the greatest number of species (brown trout, Chinook and coho salmon, lake herring, lake trout, rainbow trout, siscowet, suckers, and whitefish). The mercury advisory includes lake trout and walleye. For the general population, these advisories pertain mainly to the largest fish; for women and children, most fish should be eaten only once a week or once a month (Table 10). Siscowet have an advisory for chlordane and dioxin as well as PCBs; the MI Department of Community Health (MDCH) advises no consumption of siscowet greater than 46 cm in length (MDCH 2009).

Table 10. Fish consumption advisories for species of Lake Superior fish (MDCH 2009).

Contaminant	Species	Consumption Advisory - Women and Children	Consumption Advisory- General Population
Mercury	Burbot	>56 cm, one meal/month	>56 cm, one meal/week
	Walleye	>56 cm, one meal/month	>56 cm, one meal/week
PCBs	Brown trout	>25 cm, one meal/week	No restrictions
	Chinook salmon	>25 cm, one meal/month	No restrictions
	Coho salmon	>25 cm, one meal/week	No restrictions
	Lake herring	all, one meal/week	>76 cm, one meal/week
	Rainbow trout	>66 cm, one meal/week	No restrictions
	Suckers	all, one meal/week	No restrictions
	Whitefish	all, one meal/week	No restrictions
Chlordane, PCBs, Dioxins	Siscowet	36–46 cm, one meal/month; >46 cm, do not eat	>46 cm, do not eat
Mercury, PCBs, Chlordane	Lake trout	36–66 cm, one meal/week; 66–76 cm, one meal/month; >76 cm, do not eat	>76 cm, one meal/week

Toxic contaminants have also been found in the flesh of fish taken from ISRO interior lakes. Swain (1978) documented PCBs, DDT, α-HCH, and dieldrin in lake trout from Lake Superior near ISRO and from Siskiwit Lake; concentrations were higher in Siskiwit Lake. A later study (Swackhamer and Hites 1988) showed that organochlorine concentrations in lake trout from Siskiwit Lake and Lake Superior were similar, and that they generally decreased between 1975 and 1983. More recently, Kannan et al. (2000) documented polychlorinated naphthalene (PCNs) and PCBs in fish from Siskiwit Lake. All inland lakes, reservoirs, and impoundments in Michigan have an advisory against eating most types of fish more than once a week because of mercury contamination, with additional restrictions for women of childbearing age and children under age 15 (MDCH 2009).

Monitoring of six organic contaminants (PCBs, DDE, HCB, heptachlor epoxide, mirex, and dieldrin) in herring gull (*Larus argentatus*) eggs has been conducted at 15 Great Lakes sites, including two sites in Lake Superior, since 1974 (Weseloh et al. 2006, USEPA and Environment Canada 2007). The current status of contaminants in colonial nesting waterbirds is considered good in Lake Superior, with an improving trend. Levels of these six contaminants have declined 93.9–99.8% between 1974 and 2005 (USEPA and Environment Canada 2007). The closest of the 15 sites to ISRO is at Granite Island, 60 km N. Granite Island was the 10th most contaminated overall, with a range of 3rd most contaminated by dieldrin to 10th most contaminated for PCBs. Statistically, Granite Island was not different from a site in the Niagara River that was within gull feeding distance of an Area of Concern. Eggs from Granite Island had significantly greater dieldrin concentrations than those from Chantry Island in Lake Huron and significantly greater heptachlor epoxide concentrations than all other sites except Gull and Big Sister islands in Lake Michigan and Agawa Rocks in Lake Superior (Weseloh et al. 2006).

One exception to the declining contaminant concentrations in herring gull eggs is brominated diphenyl ethers (BDEs), used as fire retardants; these increased dramatically in gull eggs during 1981–2000 at the same 15 Great Lakes sampling sites (Norstrom et al. 2002). Granite Island was the 6th most contaminated site for total BDEs. The most contaminated sites were in northern Lake Michigan and in Toronto Harbor on Lake Ontario; the authors suggested that some Lake Superior herring gulls travel to northern Lake Michigan during severe winters and may pick up contaminants there. In 2002, BDEs had the third highest concentrations among groups of organohalogen compounds, behind PCBs and DDE but ahead of chlordanes, chlorobenzenes, HCHs, and dieldrin (Norstrom et al. 2002).

The GLKN monitoring protocol for monitoring and assessing methylmercury and organic contaminants in aquatic food webs calls for testing yellow perch, northern pike, and dragonfly larvae at three-year intervals (Wiener et al. 2008); candidate sites include Angleworm (or Eva), Harvey, Richie, and Sargent lakes. William Bowerman of the Institute of Environmental Toxicology at Clemson University is reportedly tracking contaminants in herring gull eggs and in blood and feather samples from bald eagles in the Great Lakes region, including ISRO (Crane et al. 2006).

Inland Aquatic Resources

ISRO has perennial and intermittent streams, numerous inland lakes, and wetlands widely distributed across the island. Generally, streams are oriented along a SW to NE axis as controlled by the underlying ridge and valley bedrock topography. The numerous inland lakes on ISRO are the result of glacial quarrying that accentuated the existing stream channels; thus, many lakes exhibit a long axis oriented to the ridge and valley topography. Lake Halloran and Feldtmann Lake are unique in that they are basins originally connected to Lake Superior that were enclosed by beach bars (Crane et al. 2006). The many wetlands on ISRO are broadly associated with stream margins in the ridge and valley topography, the littoral zone in lakes, and beaver activity (Lafrancois and Glase 2005).

Physical Description

Lakes

Wallace (1966) estimated that ISRO contains 202 lakes and ponds ranging in size from Siskiwit Lake at 1,635 ha and over 45 m deep to numerous shallow ponds. Based on the National Hydrography Dataset (NHD), ISRO has 278 lakes (USGS 2008); total surface area of these lakes is 3,618 ha. Only 43 ISRO lakes have been named, and these include larger lakes that receive recreational use or have been subject to investigation for biologic or chemical characteristics (Figure 21–Figure 23, Table 11).

Koelz (1929) provided one of the first physical descriptions of lakes on ISRO while surveying fish populations from 38 inland lakes. Lagler and Goldman (1959, 1982) gave brief descriptions of 32 lakes in a guide to recreational fishing. They roughly divided ISRO lakes into two types: large and deep lakes that contain whitefish (*Coregonus* sp.) and shallow and boggy lakes. Toczydlowski et al. (1978) conducted a broad survey of 13 lakes/ponds and eight stream sites to provide baseline data relevant to basic water chemistry and biologic characteristics that included plankton and macroinvertebrate diversity and aquatic vegetation mapping.

The most complete physical description of ISRO lakes was provided by Kallemeyn (2000), who surveyed 32 of the lakes originally studied by Koelz (1929) and collected morphometric, water chemistry, and fish community data. Aside from being the first comprehensive study of ISRO lakes in 70 years, a particular strength of this study was in establishing baseline data for fish communities and chemical parameters through standardized sampling methods.

Siskiwit Lake has the largest watershed area of any ISRO lake, and its surface area is almost four times greater than the next largest lake, Lake Desor (430.0 ha) (Kallemeyn 2000). Excluding Siskiwit Lake, the mean surface area of the lakes surveyed by Koelz (1929) and Kallemeyn (2000) is 55.4 ha, and average maximum depth is 5.8 m. Only Lake Desor, Lake Richie, Feldtmann Lake, and Sargent Lake have watershed areas >100 ha. Of the 43 named lakes, 20 have surface areas that are <50 ha and 11 have a maximum depth ≤ 5 m (Table 11). The mean perimeter and surface area of the 235 unnamed lakes on ISRO is 383.5 m and 0.78 ha respectively (USGS 2008).

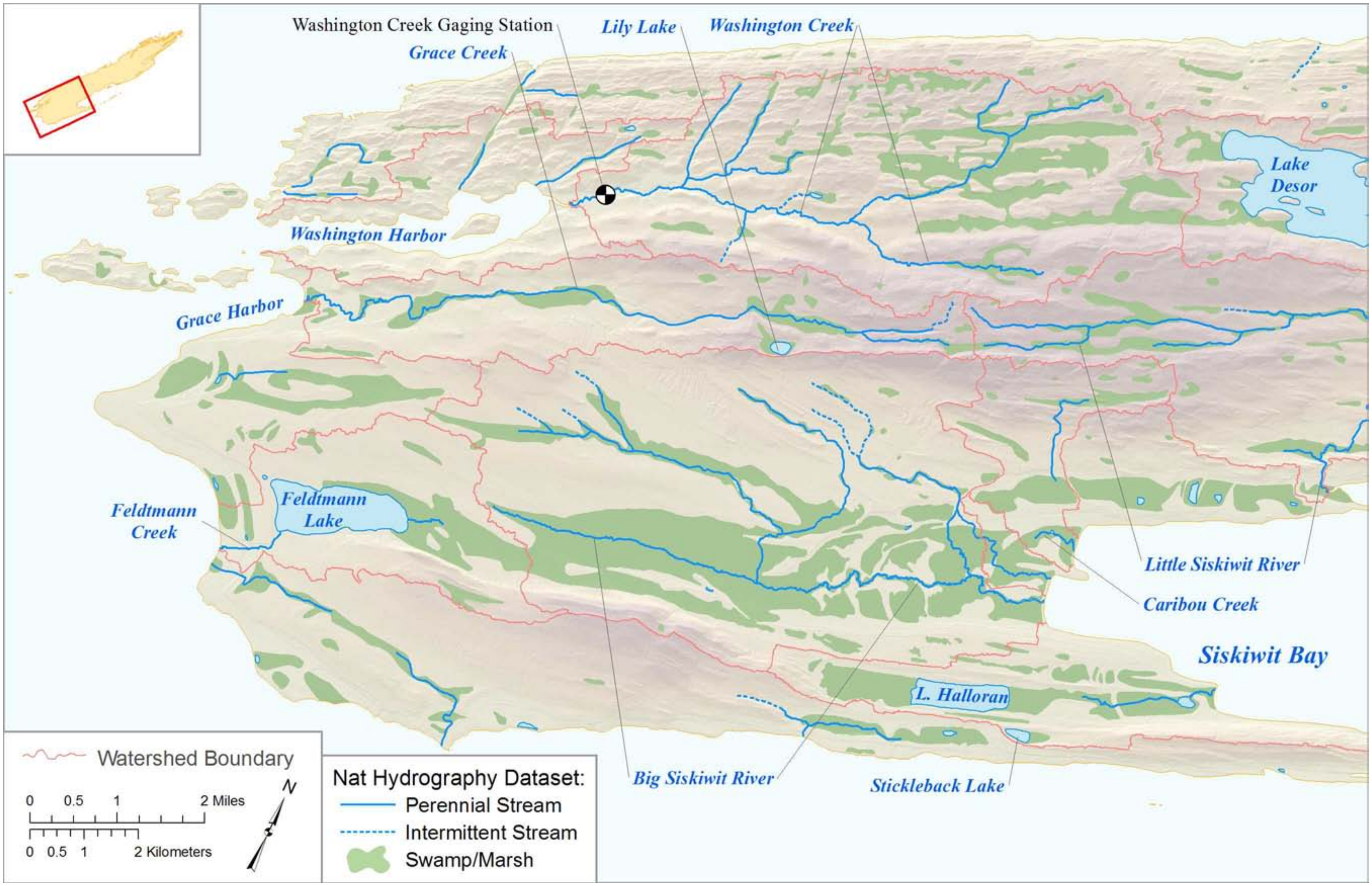

Figure 21. Water features and watersheds of the western section of Isle Royale National Park, including the Washington Creek gaging station (USGS 2008).

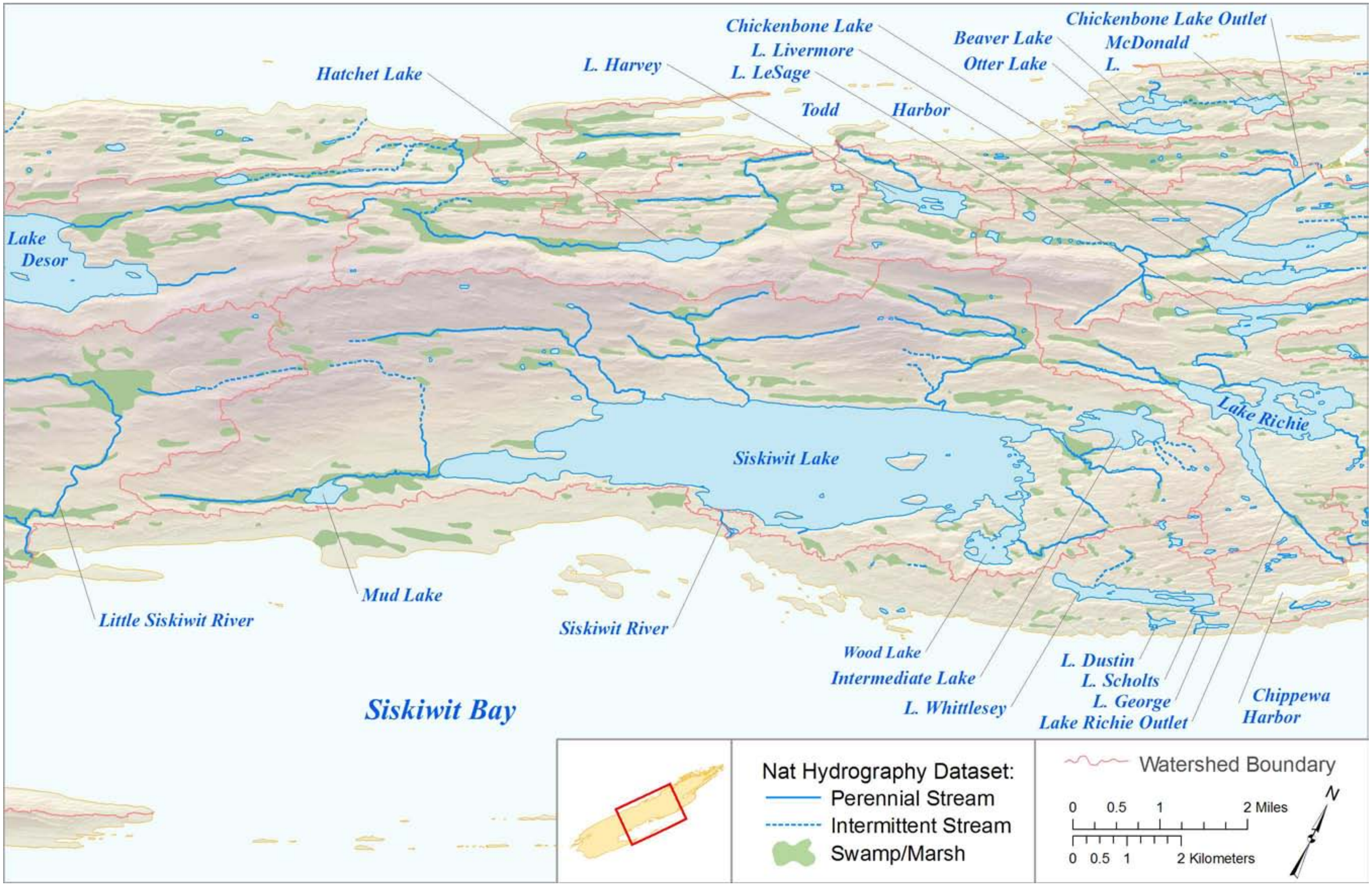

Figure 22. Water features and watersheds of the central section of Isle Royale National Park (USGS 2008).

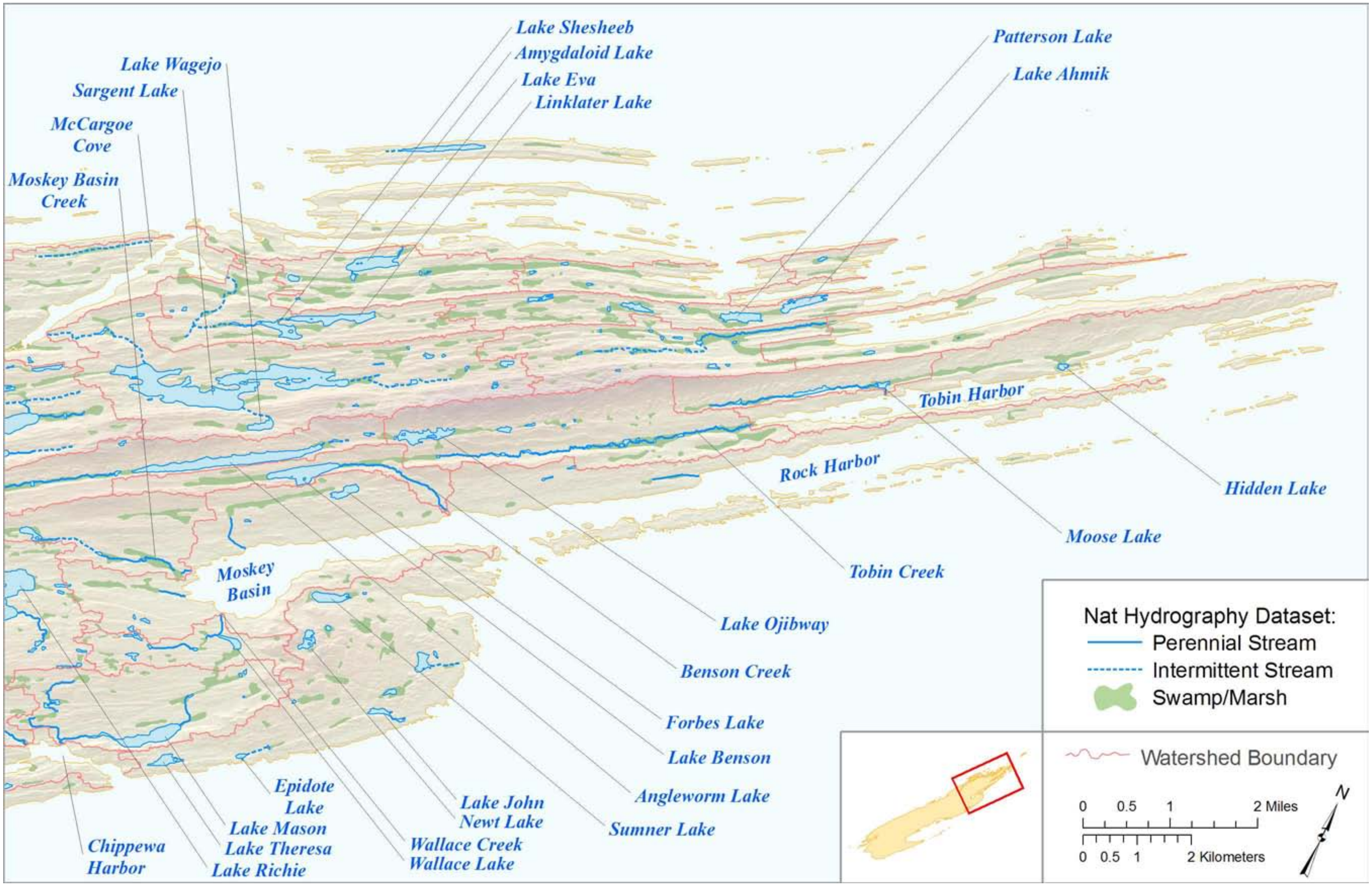

Figure 23. Water features and watersheds of the eastern section of Isle Royale National Park (USGS 2008).

Table 11. Morphometric characteristics of 43 named lakes in Isle Royale National Park. Lake area and perimeter from the USGS (2008)**.** Watershed area, maximum length, breadth, and depth data from Kallemeyn (2000).

Lake	Map page	Area (ha)	Perimeter (m)	Watershed area (ha)	Maximum length (km)	Maximum breadth (km)	Maximum depth (m)
Ahmik	46	10.32	2,600.7	35.4	0.89	0.16	3.35
Amygdaloid	46	11.12	3,133.5	26.1	1.53	0.10	8.84
Angleworm	46	49.80	7,331.4	495.6	3.51	0.20	8.40
Beaver	45	20.35	3,110.1	258.3	1.09	0.31	5.18
Benson	46	23.75	3,209.1	83.0	1.38	0.33	3.80
Chickenbone	45	91.01	8,903.8	1,556.4	2.84	0.36	6.40
Desor	44-45	429.96	15,404.9	1,436.7	4.45	1.91	14.02
Dustin	45	4.31	1,257.0	497.8	0.49	0.14	6.10
Epidote	46	1.18	449.2	55.8	0.19	0.09	3.96
Eva	46	17.15	2,572.7	231.1	0.97	0.23	6.40
Feldtmann	44	186.04	6,524.0	886.6	2.66	1.02	2.74
Forbes	46	6.56	1,326.6	40.8	0.54	0.17	2.70
George	45	3.71	1,388.8	18.1	0.61	0.10	2.70
Halloran	44	78.93	4,395.7	230.7	1.82	0.42	2.70
Harvey	45	51.40	6,009.5	292.8	1.75	0.46	4.00
Hatchet	45	49.54	4,094.3	502.2	1.90	0.41	5.20
Hidden	46	1.54	573.7	-	-	-	-
Intermediate	45	70.32	6,522.5	481.7	1.77	1.01	6.70
John	46	3.25	1,115.1	126.4	0.47	0.16	5.49
LeSage	45	44.83	5,845.9	933.0	1.66	0.48	6.40
Lily	44	6.72	981.0	-	-	-	-
Linklater	46	17.42	3,506.0	99.4	1.56	0.17	6.00
Livermore	45	29.82	3,729.4	168.8	1.57	0.30	5.50
Mason	46	23.78	3,852.6	492.8	1.73	0.24	8.50
McDonald	45	15.06	2,346.4	104.9	0.93	0.31	4.00
Moose	46	1.99	914.2	-	-	-	-
Mud	45	21.00	2,107.1	-	-	-	-
Newt	46	5.58	1,776.6	-	-	-	-
Ojibway	46	15.02	3,659.5	-	-	-	-
Otter	45	20.34	2,858.6	96.3	1.19	0.28	4.27
Patterson	46	10.25	2,018.3	43.3	0.76	0.19	3.60
Richie	45	200.04	15,671.7	2,080.2	3.20	1.99	10.67
Sargent	46	142.41	16,661.6	1,089.3	4.37	0.86	13.72
Scholts	45	2.45	1,104.2	469.3	0.52	0.08	1.52
Shesheeb	46	10.69	2,547.2	155.1	0.88	0.35	5.49
Siskiwit	45	1,619.12	38,389.2	7,287.1	11.06	2.30	46.00
Stickleback	44	6.93	1,137.8	-	-	-	-
Sumner	46	9.32	1,744.7	-	-	-	-
Theresa	46	6.56	1,746.3	-	-	-	-
Wagejo	46	6.04	1,264.7	58.2	0.49	0.22	2.19
Wallace	46	3.91	1,115.6	-	-	-	-
Whittlesey	45	60.83	8,597.1	450.5	2.97	0.27	7.65
Wood	45	44.67	5,090.5	-	-	-	-

Kallemeyn (2000) recognized three main ISRO lake types based on thermal regime: those that have stable stratification during summer (dimictic), those that are not stratified during the summer (continuous polymictic), and those that become stratified during short and irregular intervals during warm weather (discontinuous polymictic). Although continuous monitoring would be required to definitively describe thermal regime in ISRO lakes, Kallemeyn (2000) found 21 stratified and 11 unstratified lakes during single sampling events in summers of 1995–1997. Generally, deeper lakes were stratified, and shallower lakes (maximum depths <5 m) were not.

An extension of the analysis of the lake habitat data from Kallemeyn (2000) indicates that ISRO lakes can be classified into four categories: 1) small shallow lakes with high dissolved organic carbon (DOC), 2) large deep lakes with low DOC, 3) lakes with hard water and high algal biomass, and 4) soft water lakes with high phosphorus (Carlisle 2000). Although there does not seem to be a distinct spatial pattern of these lake types, there is a higher concentration of hard water lakes on the north-central to NW end of ISRO (Figure 24). These categories correlate with fish assemblages (Carlisle 2000) and are probably associated with other biologic characteristics. Because ISRO is remote, and park personnel have limited ability to perform regular monitoring of lakes, this classification framework with four lake types was recommended as a starting position in choosing index lakes for long-term water quality monitoring programs through agencies such as the GLKN (Crane et al. 2006, Elias et al. 2008).

Streams

The NHD recognizes eight named streams on ISRO: Benson Creek, Big Siskiwit River, Caribou Creek, Grace Creek, Little Siskiwit River, Siskiwit River (outlet from Siskiwit Lake), Tobin Creek, and Washington Creek (USGS 2008). Other streams have been referenced by name in various publications; these shorter stream segments are outlets from lakes and often take the name of the water body or basin they drain. Five prominent streams that fit this category are Wallace Creek (outlet from Wallace Lake), Moskey Basin Creek (draining an unnamed lake to the east of Moskey Basin), Lake Richie outlet, Chickenbone Lake outlet, and Feldtmann Lake outlet (Figure 21–Figure 23, Table 12). The combined length of these 13 streams is 71.57 km. Given the remoteness of ISRO and its topography, it is not surprising that many smaller streams remain unnamed. In total, 172.3 km of perennial streams exist on ISRO, with an additional 44.9 km identified as intermittent (USGS 2008).

Washington Creek is 10.4 km long with a total watershed area of 3,616 ha. As part of the USGS National Hydrologic Network, a gage was operated on Washington Creek from 1964 to 2003. During that time, Washington Creek mean monthly discharge ranged from 0.016 m^3sec^{-1} in September 1976 to 4.66 m^3sec^{-1} in April 2001 (USGS 2010). Peak flow occurs during spring runoff, and a secondary increase in flow occurs in late fall due to lowered evapotranspiration and increased precipitation (Crane et al. 2006).

Wallace Creek has also been the subject of long-term biologic and chemical study; however, much of the island contains smaller perennial and intermittent streams that remain unstudied.

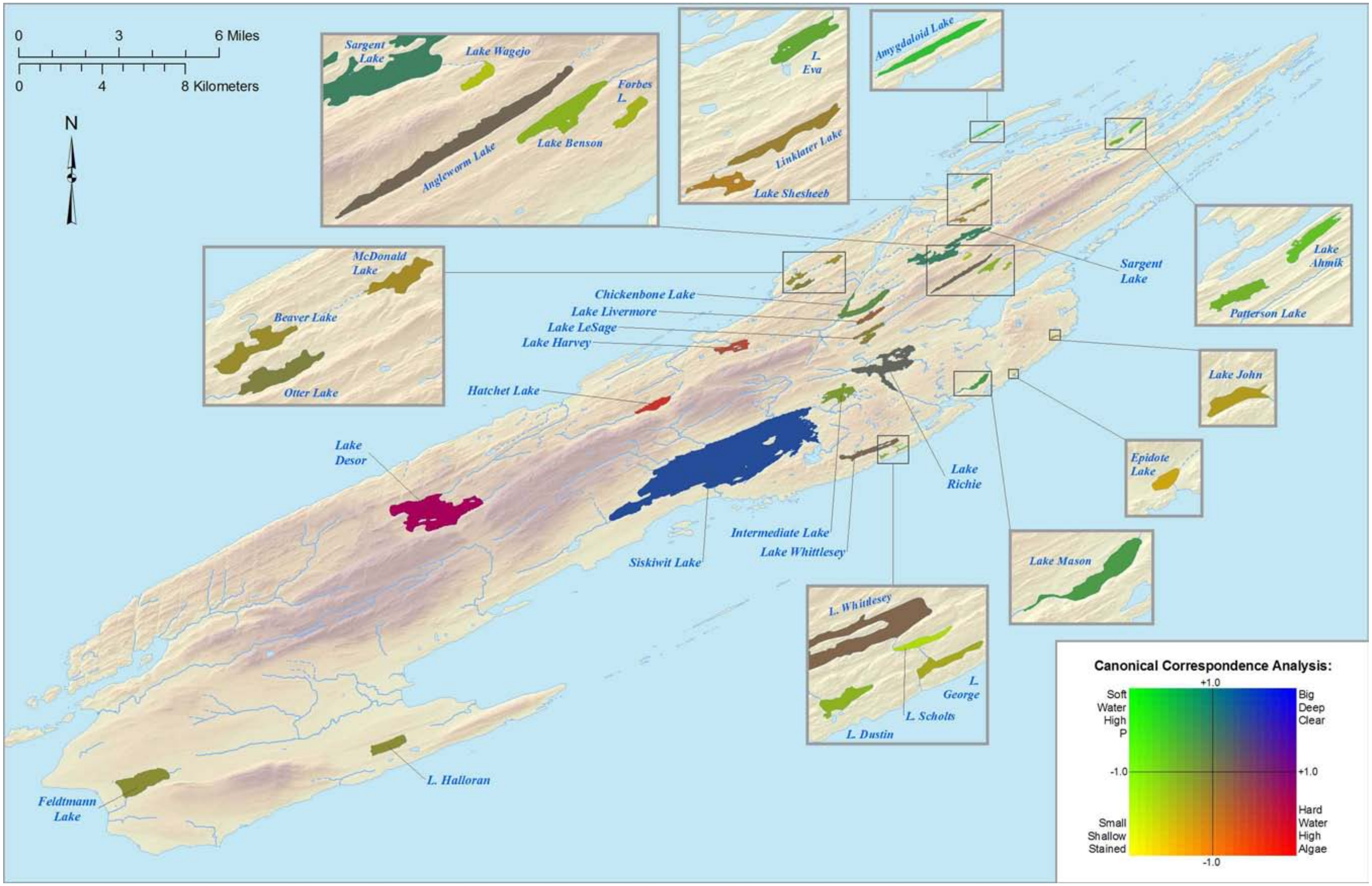

Figure 24. Lake types of Isle Royale National Park by canonical correspondence analysis (Carlisle 2000).

Table 12. Lengths and watershed areas of named streams, Isle Royale National Park (USGS 2008). Watershed areas from Crane et al. (2006).

Stream	Map page	Total length (km)	Notes	Watershed Area (ha)
Named in NHD				
Benson Creek	46	2.52	1	216
Big Siskiwit River	44	12.95	2	5,075
Caribou Creek	44	1.09	3	-
Grace Creek	44	14.55		1,684
Little Siskiwit River	44-45	13.49	4	3,054
Siskiwit River	45	0.67		6,894
Tobin Creek	46	6.76	5	869
Washington Creek	44	10.43		3,616
Referenced in publications				
Lake Richie outlet	45	2.16		2,768
Chickenbone Lake outlet	45	0.79		1,885
Feldtmann Creek	44	1.38		1,265
Wallace Creek	46	0.43		213
Moskey Basin Creek	46	4.35		193
Total Named		71.57		

1. Includes 80 m connecting creek to Moskey Basin not indicated as perennial in the dataset.
2. Includes 518.4 m that appear as ponds or wetlands along stream path.
3. Includes 45 m that appear as ponds or wetlands along stream path.
4. Includes 113.9 m that appear as ponds or wetlands along stream path.
5. Includes 934.5 m that appear as ponds or wetlands along stream path.

Wetlands

Wetland habitats on ISRO have been inventoried in the NHD, the National Wetland Inventory (NWI) (USFWS 2008) and the USGS–NPS Vegetation Mapping Program (TNC 1999, USGS 2000a). Crane et al. (2006) have described some of the advantages and disadvantages of the NWI for ISRO, which lists 14,890 ha of wetlands (10,155 ha palustrine, 4,564 ha lacustrine, and 172 ha other wetlands). Based on the NHD, ISRO has 7,030.3 ha classified as wetlands but not differentiated by type (USGS 2008). The USGS–NPS Vegetation Mapping Program (TNC 1999, USGS 2000a) lists 10,445.0 ha in Ecologic Groups 1–4 and is considered to be the best currently available description of ISRO wetlands; this is the classification we will discuss here.

Ecologic Groups 1–4 include communities that vary from sedge (*Carex* spp.)-dominated (sedge meadow complex) to shrub-dominated communities (especially alder and leatherleaf [*Chamaedaphne calyculata*]), to a variety of tree-dominated associations. Group 1 and 2 wetlands are too small or do not have a photointerpretation signature and so could not be mapped. We have grouped mapped wetlands in Ecologic Groups 3 and 4 into seven categories. White cedar–dominated communities are the most abundant of all ISRO wetlands (approximately 6,178 ha for both the closed and open phases, or 61.3%) (Table 13) (USGS 2000a). Various forms of the (wet) sedge meadow association occupy nearly 1,500 ha (14.5%), making it the second most common wetland type. Speckled alder (*Alnus incana*), bluejoint eastern meadow, and black spruce (*Picea mariana*)–dwarf shrub swamp complex are the third

Table 13. Wetland types and sizes in Isle Royale National Park (USGS 2000a).

% of total	Hectares	% of group	Name (Photointerpretation- NPS)	Map Name (Figure 25–Figure 27) and Ecologic Group	Not mapped but related
	258.0	76.9	Black ash-mixed hardwood swamp complex		
	61.8	18.4	Black ash (cedar)-mixed hardwood swamp complex		
	15.7	4.7	Red maple-ash-birch swamp forest		
	--	<1	White cedar-black ash swamp		
	--	<1	Black ash-mixed hardwood swamp		
3.2	335.5	100.0		Mixed Hardwood Swamp–Ecologic Group 4	
	230.0	3.6	Northern tamarack rich swamp		White cedar-sweet gale scrub fen–Ecologic Group 1
	4,652.7	72.6	White cedar-(mixed conifer)/alder swamp (closed phase)		
	1,525.1	23.8	White cedar-(mixed conifer)/alder swamp (open phase)		
61.3	6,407.8	100.0		White Cedar/Alder Swamp–Ecologic Group 4	
	--	<1	Black spruce/Labrador tea poor swamp		
4.6	479.6	100.0	Black spruce/dwarf-shrub swamp complex	Black Spruce/Dwarf Shrub Swamp–Ecologic Group 4	
1.0	108.2	100.0	Dwarf shrub fen complex	Dwarf Shrub Fen–Ecologic Group 4	Leatherleaf-sweet gale shore fen, Leatherleaf bog, white cedar-sweet gale scrub fen–Ecologic Group 1
9.3	974.4	100.0	Speckled alder swamp	Speckled Alder Swamp–Ecologic Group 4	
	42.9	2.8	Sedge/sphagnum meadow complex		Northern poor fen–Ecologic Group 1
	1,476.2	97.2	Sedge meadow complex		Boreal calcareous seepage fen–Ecologic Group 1 Northern sedge wet meadow, twig rush wet meadow–Ecologic Group 3
14.5	1,519.1	100.0		Sedge Meadow–Ecologic Group 3	
5.9	620.4	100.0	Bluejoint eastern meadow	Bluejoint Eastern Meadow–Ecologic Group 3	
100.0	10,445.0		All wetlands		

Table 13. Wetland types and sizes in Isle Royale National Park (USGS 2000a) (continued).

Other unmapped wetlands
Ecologic Group 2: Midwest pondweed submerged aquatic vegetation (not discernable on early spring photography). Related to Water mapping unit.
Northern water lily aquatic wetland (not discernable on early spring photography, noted as uncommon). Related to Water mapping unit.
Ecologic Group 3: Midwest mixed emergent deep marsh (generally below minimum mapping unit size, noted as uncommon)
Water horsetail-spikerush marsh (generally below minimum mapping unit size, noted as an uncommon and extremely narrow type)
Ecologic Group 4: Black spruce/alder rich swamp (noted as rare on the island)
Ecologic Group 11: Aspen-balsam poplar lowland forest (below minimum mapping unit, several individual balsam poplar trees observed near Caribou Creek west of Siskiwit Bay)

through fifth most common associations or groups, followed by mixed hardwood swamp and dwarf shrub fen.

Physiography, soil characteristics, groundwater and surface water movement, and the chemical makeup of parent material collectively determine where wetlands occur and which species or group of species dominate the association. The first four factors interact to determine how much moisture there is on a site, for how long the soils stay saturated, the magnitude of annual water fluctuation, and the amount and type of nutrient input (Richardson 2000, Weber et al. 2007). These hydrologic characteristics determine, at a community level, which species are suited for a site. At a smaller scale, the hydrologic conditions are modified by microtopography and windthrow.

In ISRO, inland wetlands are associated with lakes, stream valleys, and upland areas and generally occur along a SW to NE axis following the underlying geology (Figure 25–Figure 27). The largest concentration of wetlands is found in the SW, associated with the Big Siskiwit River and its tributaries where alluvial soils are more developed (Figure 6).

Northern Shrub/Graminoid Fens and Bogs (Ecologic Group 1)

Fen-type associations stand out from the other wetland types. These communities occur on uncommon soil and/or parent materials (e.g., calcareous) that result in higher soil pHs, and often have high levels of dissolved salts in soil solution. These chemical differences may have important impacts on nutrient and mercury input to lakes or creeks.

Bogs are another physiographic feature that support a conifer-dominated community. They typically have no drainage outlets and thus have standing water for much of the year. The soil is

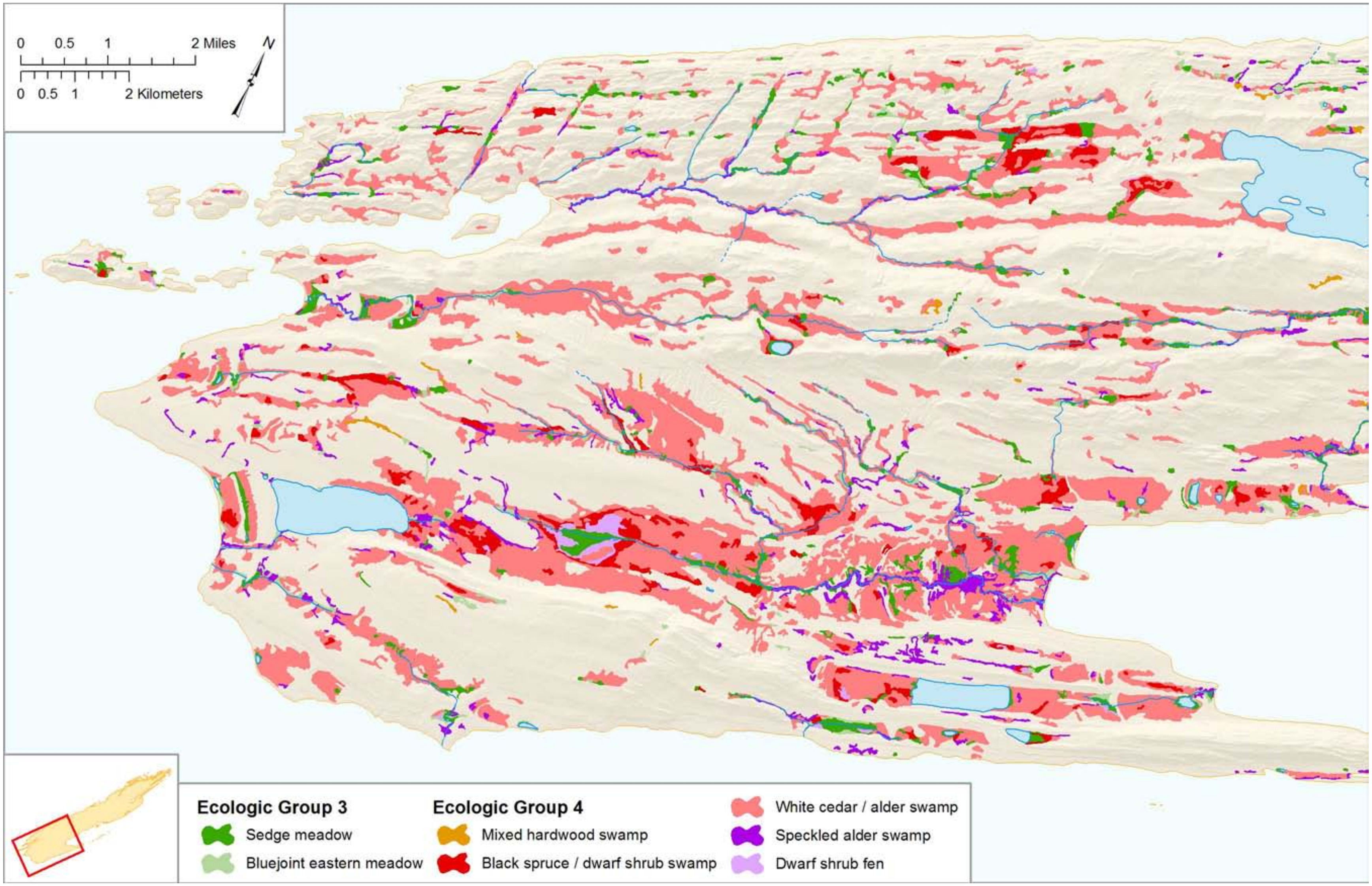

Figure 25. Mappable wetland types for the western section of Isle Royale National Park (TNC 1999, USGS 2000a).

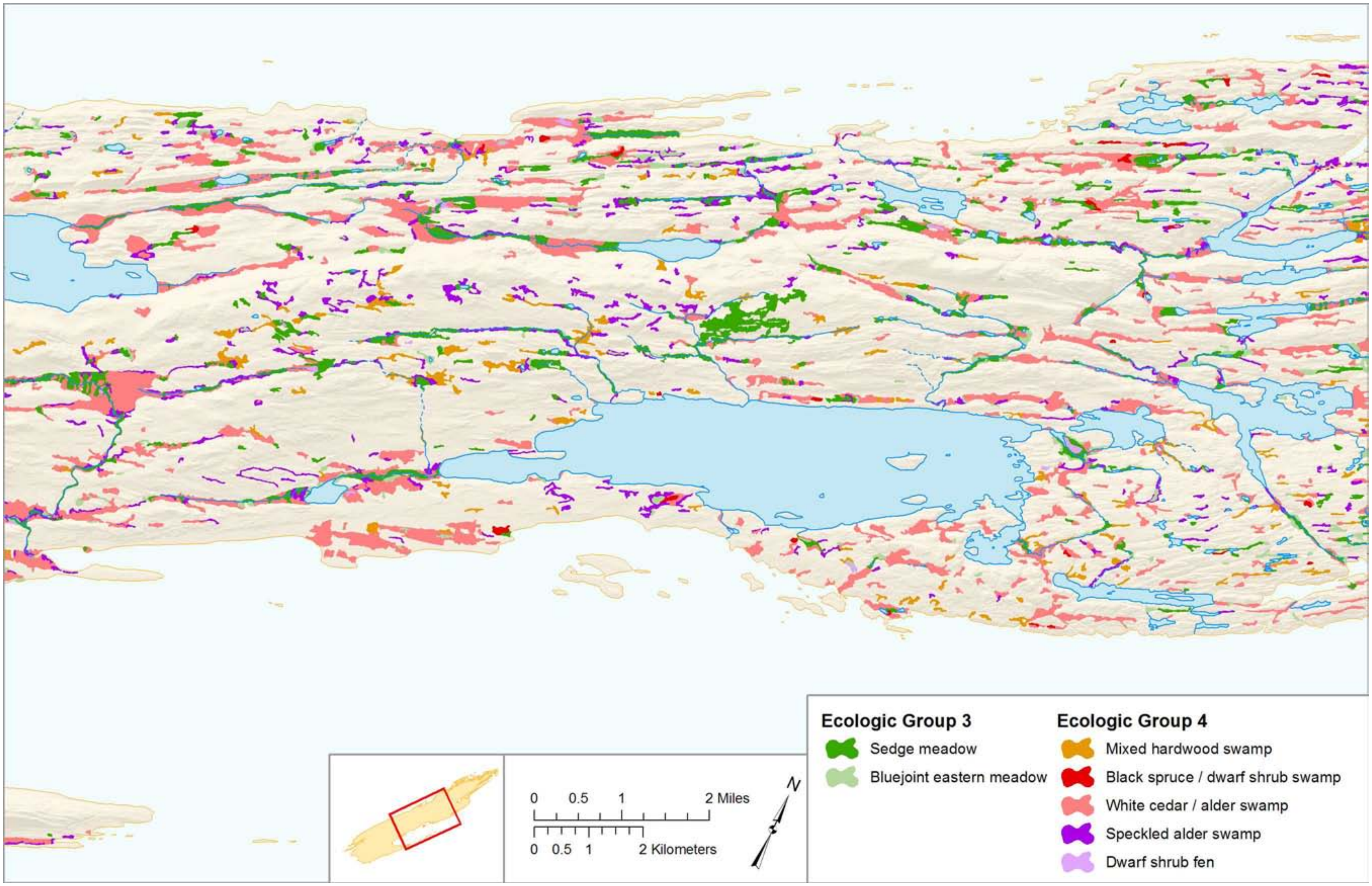

Figure 26. Mappable wetland types for the central section of Isle Royale National Park (TNC 1999, USGS 2000a).

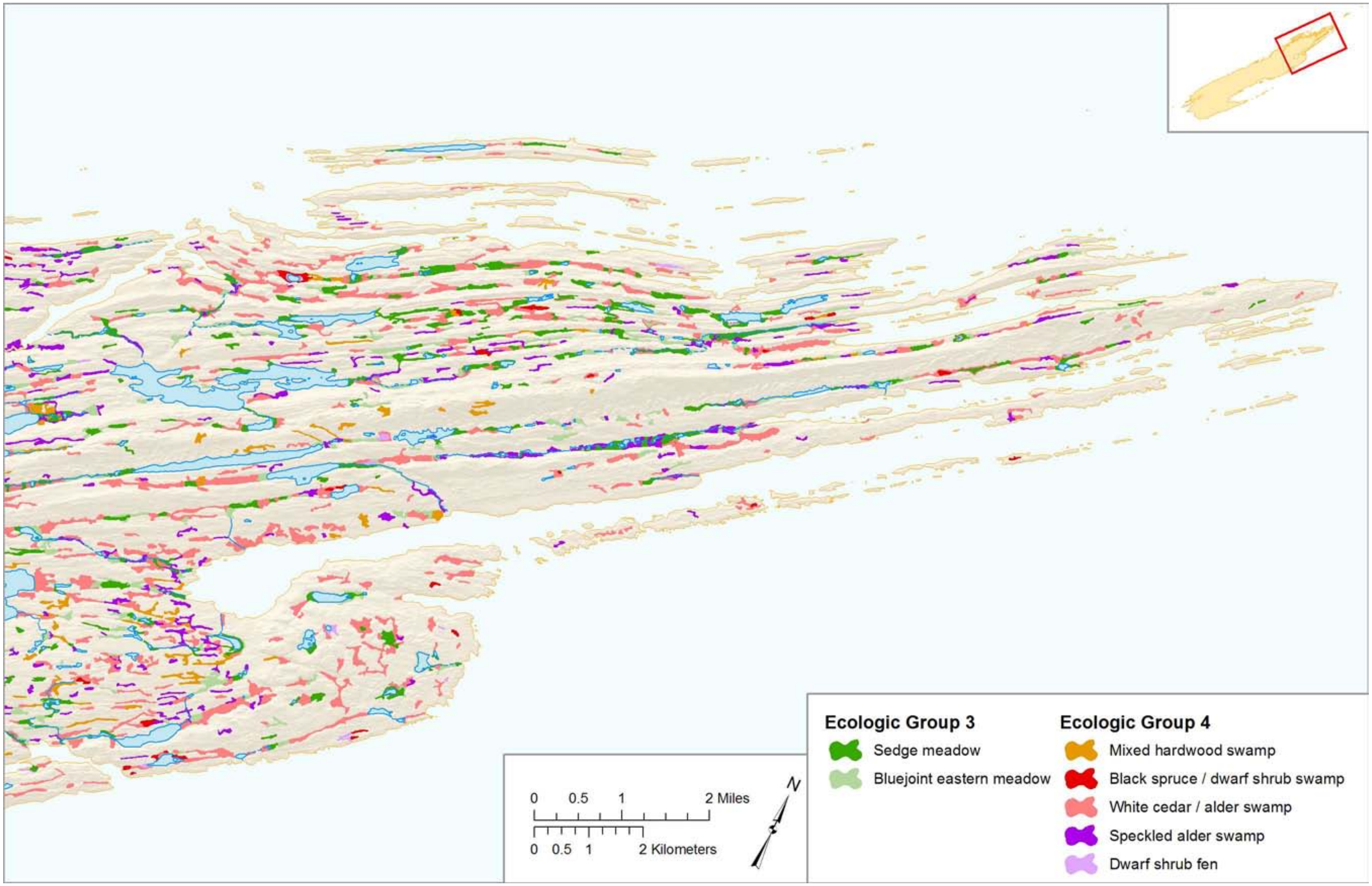

Figure 27. Mappable wetland types for the eastern section of Isle Royale National Park (TNC 1999, 2000a).

acid to very acid. They occur on peat soils in a narrow elevational band (183–213 m). Black spruce–speckled alder–sphagnum moss (*Sphagnum* spp.) is the community type found in bogs at ISRO. This is an uncommon type and is scattered. These communities have a sparse tree layer (< 20% cover) which occasionally includes white spruce. The tall shrub layer is denser than in the rich swamps (TNC 1999).

The leatherleaf–Labrador tea (*Ledum groenlandicum*)–laurel (*Kalmia polifolia*) dwarf shrub community is a type that shares many characteristics and species with the spruce–alder–sphagnum moss type. It is uncommon and found at elevations from 183 to 232 m on saturated, fibric peat soil. It is very acidic (pH < 4.3) and isolated from groundwater. The community often has a few scattered trees and stunted trees in the tall shrub layer (approximately 5% cover). The short shrub layer for which the community is named is extensive (40–70% cover) and includes some combination of the three dwarf shrubs. A sedge (*Carex oligosperma*) is the most common herbaceous plant (TNC 1999).

Wet Meadows and Marshes (Ecologic Group 3)

The ISRO wetlands in Ecologic Group 3 are sedge meadow and bluejoint eastern meadow. Sedge meadow is concentrated along stream channels on the western side of ISRO (Table 13, Figure 25) and along stream channels and bays/coves of several lakes in central and eastern ISRO (Figure 26–Figure 27). Two distinct areas of sedge meadow that are not directly associated with stream valleys include a strip to the west of Feldtmann Lake along a beach bar (Figure 25) and a section to the north of Siskiwit Lake. The sedge meadow category includes four groups from the Vegetation Mapping Program (TNC 1999): northern sedge wet meadow, northern poor fen, boreal calcareous seepage fen, and twig rush wet meadow. All of these categories are characterized by a high percent coverage of sedge and smooth sawgrass (*Cladium mariscoides*) and a lower percent coverage of sweetgale (*Myrica gale*) or leatherleaf. Sphagnum moss may be common in the groundlayer in drier soils (i.e., all groups except northern sedge wet meadow).

Bluejoint eastern meadow (Table 13, Figure 25–Figure 27) is commonly found in close association with sedge meadow. Bluejoint eastern meadow is primarily composed of bluejoint (43%), bulrush (*Scirpus cyperinus*, 25%), and beaked sedge (*Carex rostrata*, 15%). Other species commonly found but at less than 10% coverage include woolly-fruit sedge, speckled alder, and sphagnum moss (TNC 1999).

Northern Conifer and Hardwood Forest and Shrub Swamps (Ecologic Group 4)

As noted above, the common forest type in this group is the cedar-speckled alder swamp. Cedar swamps are most commonly found at elevations between 183 and 305 m in wet depressions on level to gently sloping terrain. The soil is peat or muck and is saturated most of the year. The shrub layer of this type typically includes speckled alder and alder-leaf buckthorn (*Rhamnus alnifolius*). There may be scattered black spruce or balsam fir (TNC 1999).

The tamarack–alder community type is rare, covering only 230 ha in ISRO. It is a 'rich swamp' (i.e., minerotrophic due to consistent groundwater input) and has soils similar to the cedar–alder type, but is found in the SW part of the island only on conglomerate or sandstone parent material. The tall shrub layer may include stunted forms of cedar and birch, whereas leatherleaf and bog Labrador tea are the most common short shrubs (TNC 1999).

Mixed hardwood swamps are dominated by the black ash (*Fraxinus nigra*)–mixed hardwood swamp complex (258 ha, Table 13). Soils are muck, and black ash averages 37% cover, with speckled alder averaging 62% cover. Red maple (*Acer rubrum*) and birch are found in other minor variants of the mixed hardwood swamp type.

Other life forms and water quality of wetlands remain relatively unstudied on ISRO; a recent assessment of vegetation in wetland habitat of lakes by Meeker et al. (2007) had a goal to serve as a baseline for future studies and is described in the Macrophytes section below.

River-Associated Wetlands

As noted by Crane et al. (2006), riverine wetland habitats in ISRO have not been quantified by previous studies. The NWI classification scheme (Cowardin et al. 1979) defines riverine wetlands as those “contained within a channel” and excludes “wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens.” By this definition, few, if any, riverine wetlands exist on ISRO because of the lack of large river channels. However, since information about wetlands along ISRO rivers has been described as a need, we performed the following analysis to provide estimates of wetland coverage in river corridors. We will refer to these wetlands as ‘river-associated’ rather than ‘riverine’ wetlands.

We overlaid stream vectors from the NHD (USGS 2008) onto vegetation types from the Vegetation Mapping Program (TNC 1999, USGS 2000a) to estimate river-associated wetlands on ISRO. Because this estimate is based solely on proximity to streams, the specific amounts and types of river-associated wetlands on ISRO vary with the definition of the stream corridor. We compared four corridors: 1) a simple quantification of stream lengths adjacent to wetlands, in essence a ‘zero-width’ corridor; 2) a variable-width corridor defined by the size of the wetland polygons touching the stream; 3) a 100 m buffer zone along each side of a stream or a 200 m wide corridor; and 4) a 10 m buffer zone along each side of a stream or a 20 m wide corridor (Table 14–Table 15).

Most ISRO streams (73.5%) are associated with wetland areas (Table 14). Wetlands within 10 m of a stream tend to be of the sedge meadow (34.2%) or white cedar/alder swamp (32.7%) types but account for only 3.9% of all ISRO wetlands. The larger the corridor or buffer width selected, the more closely the distribution of wetland types mirrors the overall distribution of those types within ISRO. The adjacent wetland polygon method (2) estimates nearly twice the total river-associated wetland area as the 100 m buffer method (3) (4,381 ha and 2,223 ha, respectively). This reflects the large wetland areas touching streams but also extending considerable distances from the stream vectors, such as in the Big Siskiwit River valley dominated by white cedar/alder swamp areas (Table 15, Figure 28).

Groundwater

The groundwater of ISRO is generally poorly understood; there are no hydrologic models or maps of recharge zones or fracture zones for the park (Thornberry-Ehrlich 2008). However, its ecologic significance has been noted by some authors. Schlesinger et al. (2009) noted that newly identified areas of deeper soils in ISRO have influence on groundwater storage and discharge, and that ISRO’s groundwater-fed seepage lakes will likely respond differently to climate change than its drainage lakes. Some groundwater-fed mineral springs are important sources of minerals for ISRO's moose (Thornberry-Ehrlich 2008).

Most of the limited study of groundwater in ISRO has related to the potential for development of drinking water supplies. Groundwater at ISRO is most likely to be found in fractured and jointed zones associated with faulting in bedrock, or in glacial sand and gravel deposits. In 1981, three test wells installed near Windigo revealed that the basaltic lava at that location did not yield sufficient water at depths less than 50 m (Grannemann and Twenter 1982). Water at that depth or below might be salty, based on yields from similar rocks in the Keweenaw Peninsula. The authors recommended that further water supply exploration at Windigo occur in glacial deposits. Static water levels were reported for two of the three wells; they were 15 m and 37 m above the level of Lake Superior. However, given the complexity of the geology, the significance of this finding is undetermined.

Shallow soils and a high water table at ISRO may make its groundwater vulnerable to contamination from human wastes, oil spills, and other spills or past disposal of toxic substances (Thornberry-Ehrlich 2008).

Table 14. Stream lengths in Isle Royale National Park and their proximity to wetlands by type (TNC 1999, USGS 2000a, 2008).

Wetland Type	(1) Stream Lengths Adjacent to Wetland Type	
	Meters	Percent
White Cedar/Alder Swamp	66,076	32.3%
Sedge Meadow	70,398	34.4%
Speckled Alder Swamp	37,086	18.1%
Bluejoint Eastern Meadow	21,471	10.5%
Black Spruce-Dwarf Shrub Swamp	4,149	2.0%
Mixed Hardwood Swamp	4,666	2.3%
Dwarf Shrub Fen	521	0.3%
Total stream lengths adjacent to wetlands	204,365	
Total of all stream lengths	277,981	
Percent of all stream segments adjacent to wetlands	73.5%	

Table 15. Wetland types in Isle Royale National Park and their proximity to streams (TNC 1999, USGS 2000a, 2008).

Wetland Type	All Wetlands		(2) Variable-width Corridor		(3) 200 Meter Stream Corridor		(4) 20 Meter Stream Corridor	
	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent
White Cedar/Alder Swamp	6,408	61.3%	2,840	64.8%	1,026	46.1%	132	32.7%
Sedge Meadow	1,519	14.5%	759	17.3%	604	27.2%	138	34.2%
Speckled Alder Swamp	974	9.3%	343	7.8%	288	12.9%	73	18.0%
Bluejoint Eastern Meadow	620	5.9%	219	5.0%	188	8.5%	42	10.5%
Black Spruce-Dwarf Shrub Swamp	480	4.6%	138	3.1%	62	2.8%	8	2.1%
Mixed Hardwood Swamp	336	3.2%	49	1.1%	41	1.8%	9	2.3%
Dwarf Shrub Fen	108	1.0%	34	0.8%	14	0.6%	1	0.3%
Total wetland hectares adjacent to streams	10,445		4,381		2,223		404	
Percent of wetlands adjacent to streams			41.9%		21.3%		3.9%	

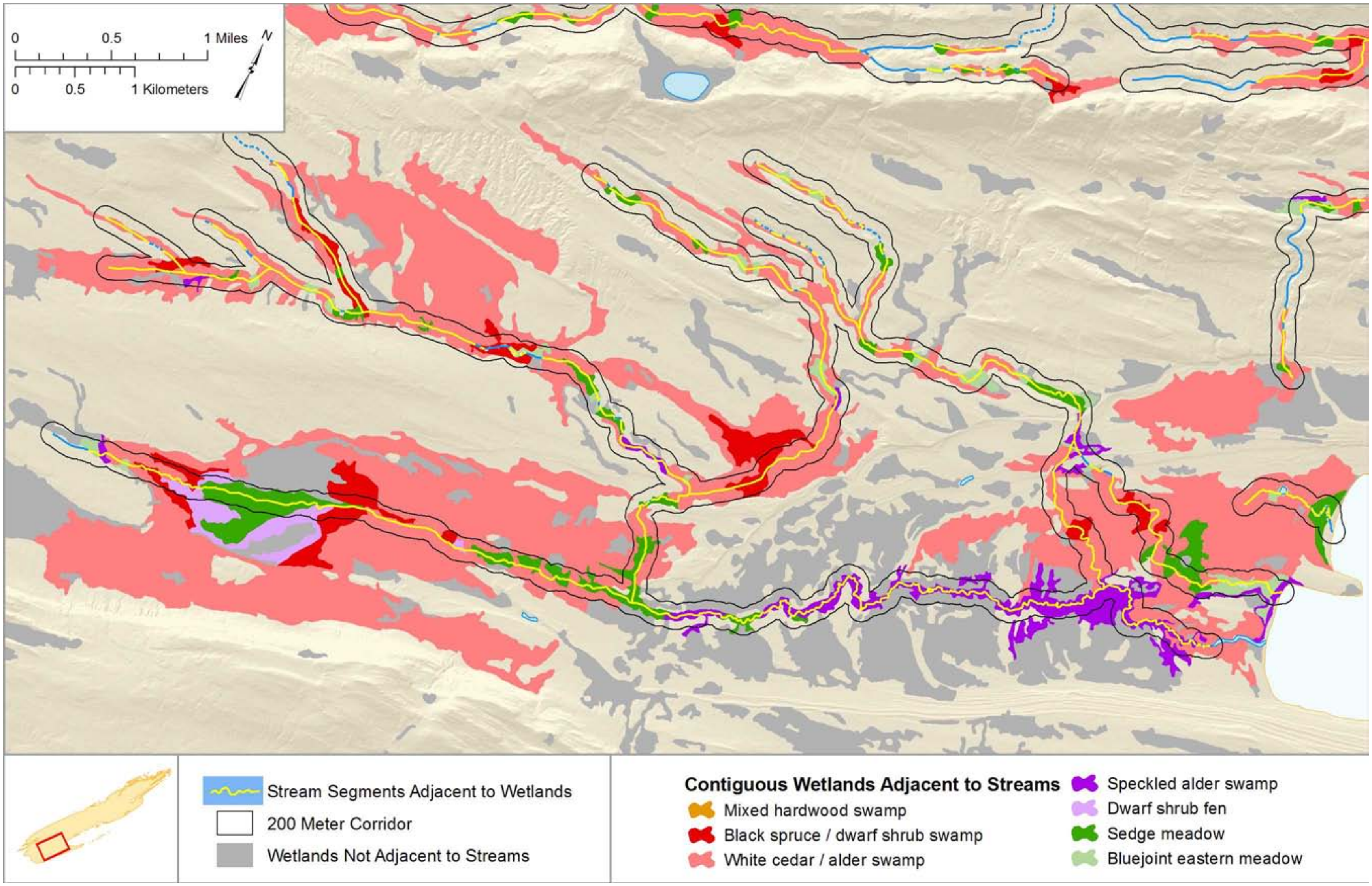

Figure 28. River-associated wetlands in the Big Siskiwit River valley, Isle Royale National Park, by various delineation methods.

Biologic Resources

Fish Communities

Although early biologic surveys on ISRO documented fish communities (Ruthven 1909), the first larger scale survey of fishes was not until Koelz (1929), who sampled 38 lakes across the island. This survey documented lake depths and gave descriptive summaries of the inlet and outlet streams to many lakes. Despite additional studies documenting fish species on ISRO (Hubbs and Lagler 1949, Lagler and Goldman 1959, Sharp and Nord 1960), a study comparable in scale to the Koelz survey did not take place until 1995–1997 (Kallemeyn 2000). Because Kallemeyn (2000) is the most comprehensive and current study of inland fishes on ISRO, we use it as the primary source to report on fish resources.

The main goals of Kallemeyn (2000) were to document changes or stasis in aquatic communities since 1929 and establish a standardized sampling protocol for future monitoring. Kallemeyn (2000) used minnow traps, seines, and gill nets to survey fish from 32 lakes and found 26 of 28 fish species that were originally reported by Koelz (1929) and Hubbs and Lagler (1949) (Table 16). Despite numerous nonnative fish species being present in Lake Superior, including invasive species such as the round goby (*Neogobius melanostomus*) and ruffe (*Gymnocephalus cernuus*), no new fish species, either native or nonnative to the Great Lakes, were found by Kallemeyn (2000).

Northern pike and yellow perch are the most prevalent species in ISRO lakes, found in all but four of the 32 surveyed lakes. Northern pike are absent from Lake Desor, Forbes Lake, Harvey Lake, and Hatchet Lake; yellow perch are absent from Lake Desor, Hatchet Lake, Mud Lake, and Lake Wagejo. Blacknose shiner was the most common prey fish, found in 20 lakes. Lake trout were present only in Siskiwit Lake, probably due to its connectivity and conditions similar to Lake Superior. In general, larger lakes on ISRO have more fish species than smaller lakes.

Two species noted by Koelz (1929) but not collected by Kallemeyn in any lake during 1995–1997 were brook trout and mottled sculpin (*Cottus bairdi*). Kallemeyn (2000) concluded that these species are still present in ISRO lakes because both have been collected during other recent studies on ISRO and from inlets and bays on Lake Superior near ISRO. Absence of these in Kallemeyn was thought to be due to sampling method.

A main component of Kallemeyn (2000) was documenting the loss or gain of fish species in lakes compared to earlier surveys. Numerous lakes gained species through apparent natural dispersal of fish upstream or downstream from other lakes or through upstream movement from Lake Superior. Failure to detect species in lakes where they were reported earlier was attributed to either sampling inefficiency for smaller species (i.e., stickleback, sculpin, and logperch are not easily captured using beach seines or gillnets) or possible species loss for larger species. Two species that exemplify the latter situation were brook trout absent from Lake Desor and Hatchet Lake and northern pike from John Lake. Kallemeyn (2000) concluded that water temperature and/or dissolved oxygen levels were marginal for brook trout in Lake Desor and Hatchet Lake but stated that “there is no apparent explanation for the disappearance of northern pike from John Lake” while noting that a former beaver dam on its outlet stream is no longer present allowing more accessibility to Lake Superior. A potential ecologic explanation is that that the small size of John Lake (at 3.3 ha, only two ISRO lakes are smaller) and corresponding smaller population size of fishes relative to larger lakes may cause these population to be more susceptible to extinction MacArthur and Wilson 1967).

Table 16. Inland fish species found in lakes, Isle Royale National Park (from Kallemeyn 2000).

Scientific name	Common name
Coregonus artedi	Cisco
Coregonus clupeaformis	Lake whitefish
Salvelinus fontinalis	Brook trout *
Salvelinus namaycush	Lake trout
Esox lucius	Northern pike
Couesius plumbeus	Lake chub
Margariscus margarita	Pearl dace
Notemigonus crysoleucas	Golden shiner
Notropis atherinoides	Emerald shiner
Notropis heterolepis	Blacknose shiner
Notropis hudsonius	Spottail shiner
Notropis volucellus	Mimic shiner
Phoxinus neogaeus	Finescale dace
Pimephales promelas	Fathead minnow
Semotilus atromaculatus	Creek chub
Catostomus commersoni	White sucker
Percopsis omiscomaycus	Trout-perch
Lota lota	Burbot
Culaea inconstans	Brook stickleback
Pungitius pungitius	Ninespine stickleback
Lepomis gibbosus	Pumpkinseed
Etheostoma exile	Iowa darter
Perca flavescens	Yellow perch
Percina caprodes	Logperch
Sander vitreus	Walleye
Cottus bairdi	Mottled sculpin*
Cottus cognatus	Slimy sculpin
Cottus ricei	Spoonhead sculpin

*Brook trout and mottled sculpin were identified by Koelz (1929), but not collected in samples from Kallemeyn (2000); these species are considered present on ISRO.

A fish that is listed as threatened in MI is the Siskiwit Lake cisco (*Coregonus bartlettii*) (MNFI 2009a). Some confusion exists with taxonomic classification of this population and Great Lakes ciscoes in general. In the 2004 edition of *Fishes of the Great Lakes*, Hubbs and Lagler (2004) describe cisco from Siskiwit Lake as a subspecies of the shortjaw cisco (*C. zenithicus*), and MDNR has referred to these fish as a subspecies of lake herring (MDNR 2005). The American Fisheries Society (AFS) recognizes ciscoes from Siskiwit Lake as *C. artedi* (Nelson et al. 2004) based on the genetic analyses from Turgeon and Bernatchez (2003). The common name ‘cisco’ is more often used than ‘lake herring;’ thus, the latter has been dropped from use by AFS (Nelson et al. 2004).

As noted earlier, riverine habitat in general on ISRO is understudied (also see Crane 2006), and fish communities in ISRO streams have received relatively little attention. Notable exceptions include investigations by Slade and Olson (1994) to report fish communities from several tributaries draining to Lake Superior and studies aimed at identifying coaster brook trout populations (Slade 1994, Quinlan et al. 1999). Gametes were collected from coaster brook trout from Big Siskiwit River and Little Siskiwit River in 1995 and 1999 to establish and maintain populations in hatcheries for reintroduction efforts (Newman et al. 2003).

Kallemeyn (2000) commented that perennial and intermittent streams and rivers serve as corridors for fish dispersal between lakes and from Lake Superior. Perennial streams and rivers probably also serve as important spawning and rearing locations for many species. As also noted by Kallemeyn (2000), fish communities on ISRO exemplify the unique opportunities to study ecologic and evolutionary questions about fish dispersal and speciation in a relatively pristine setting. Management practices to protect inland lakes and streams should continue. A Fisheries Management Plan is currently in progress for ISRO.

Zooplankton, Phytoplankton, Macroinvertebrates, and Macrophytes

Surveys of invertebrate aquatic communities in ISRO lakes, streams, and wetlands have often taken place in conjunction with studies of water quality or fish communities. Toczydlowski et al. (1978) initiated one of the first baseline studies for water quality and aquatic invertebrates and plants from lakes and streams primarily on the southern portion of ISRO, including the Wallace Lake watershed. More recently, a study by Whitman et al. (2000) used systematic and standardized sampling techniques to document phytoplankton and zooplankton from Sargent Lake and Siskiwit Lake. Larson et al. (2000) analyzed zooplankton samples from 36 lakes, 32 of which were also the focus of the fish community and water quality survey by Kallemeyn (2000). We will use these studies as the primary sources for ISRO invertebrate communities.

Zooplankton: During 1995 and 1996, Larson et al. (2000) analyzed 55 plankton samples collected by Kallemeyn using a 63 µm mesh net at the deepest point of each lake. Single samples were taken from the majority of the sites; however, four samples were taken from Lake Ahmik, Angleworm Lake, Lake Desor, Sargent Lake, and Siskiwit Lake, and three samples were taken from Feldtmann Lake and Mud Lake. These samples were taken at different times during the summer of either 1995 or 1996.

Across all samples, species richness ranged from 3.00 to 15.00 with species diversity ranging between 0.6 and 2.39. Five species were found in >75% of the samples: the cladoceran crustacean *Bosmina longirostris* (46/55) and the rotifers *Keratella cochlearis* (54/55 samples), *Conochilus unicornis* (47/55), *Ploesoma hudsoni* (44/55), and *Polyarthra dolichoptera* (42/55). Across all samples, *K. cochlearis* and *C. unicornis* had relative abundances of 39.0% and 30.8%, respectively, illustrating the prevalence of these species in ISRO lakes. *B. longirostris* comprised <10% of the individuals in 46 samples. Density of rotifers or crustaceans, species richness, and species diversity were not correlated with any water quality variables or environmental characteristics from the lakes (Larson et al. 2000).

In concluding their report, Larson et al. (2000) noted that zooplankton assemblages across ISRO lakes are similar to each other and nearby mainland lakes. Zooplankton communities from ISRO lakes were distinct from zooplankton communities in Lake Superior, which are dominated by three copepod species not found in ISRO lakes. The authors also cautioned that further sampling is needed to assess interannual variation in zooplankton composition and recommended a subset of lakes based on water quality and spatial distribution to serve as a proxy for long-term monitoring activity.

Whitman et al. 2000) provided additional detail about the zooplankton and phytoplankton communities in Sargent Lake and Siskiwit Lake using samples collected during 1997 and 1998. Zooplankton were collected from limnetic sites (deeper water) and littoral sites using an 80 µm or a 63 µm mesh net and preserved. The authors reported on the density and species composition calculated from triplicate samples taken from limnetic and littoral zones at multiple time periods between May and October between 1997 and 1999 in order to draw conclusions about temporal trends.

Sargent Lake had similar total zooplankton density within the limnetic zone between 1997 and 1998, with averages over the summer of 82 ± 10 individuals L^{-1} and 104 ± 20 individuals L^{-1} for 1997 and 1998, respectively. Pronounced peaks occurred in early summer and late summer, with lowest density in mid-summer (Whitman et al. 2000). Zooplankton density in the littoral zone was lower than in the limnetic zone and showed a consistent decline in abundance in midsummer with a rebound in late summer (Whitman et al. 2000). The community consisted of 39 species, dominated by rotifers and cladocerans, including abundant species such as *C. unicornis* and *Keratella* spp. also found by Larson et al. (2000). Whitman et al. (2000) concluded that the zooplankton community in Sargent Lake was typical of large, cold lakes from northern latitudes.

The zooplankton in Siskiwit Lake showed many contrasts to Sargent Lake during the concurrent sampling between 1997 and 1999. In particular, zooplankton density in the limnetic zone was lower in Siskiwit Lake, 22 ± 4 individuals L^{-1} and 17 ± 3 individuals L^{-1} in 1997 and 1998, respectively, probably due to lower primary productivity (Whitman et al. 2000). Additionally, zooplankton abundance in Siskiwit Lake showed just a single peak in late June to early July. Thirty zooplankton taxa were found; the composition was evenly distributed, with no dominance by particular rotifer or cladoceran species. Because total density of zooplankton was low and variable between years and sampling locations, the authors cautioned about making interpretations from these data and recommended increased sampling efforts on Siskiwit Lake to confirm the true community composition.

W. Charles Kerfoot of MTU conducted zooplankton surveys of ISRO inland lakes in 2008 and 2009; these data were not received in time for inclusion in this report.

Phytoplankton: Whitman et al. (2000) summarized phytoplankton communities sampled from limnetic and littoral zones of Sargent Lake and Siskiwit Lake during 1997, 1998, and 1999. They identified 55 and 57 taxa for Sargent Lake in 1997 and 1998, respectively, with abundant species including *Cyclotella* sp., *Sphaerocystis* sp., *Chlorochromonas* sp., and *Synedra* sp. In general, community composition was even between yellow-green algae, diatoms, and green algae, with some seasonal variation. In July 1997, diatoms reached a high of 48% of the total density in the littoral zone, while in May 1998, yellow-green algae were the dominant species (62%) in the limnetic zone (Whitman et al. 2000).

Forty and 49 phytoplankton taxa were collected from Siskiwit Lake in 1997 and 1998, respectively. This community was considerably different from that of Sargent Lake. Diatoms in limnetic samples ranged from 60–80% of the total density and increased from 54% of the littoral samples in June to 87% of the total density by August. *Cyclotella* sp. and *Dinobryon* sp. were very abundant, while green algae, yellow-green algae, and other groups were never recorded higher than 20% of the community (Whitman et al. 2000).

Macroinvertebrates: Scientific descriptions of macroinvertebrate communities on ISRO are limited to notes from a few reports, a pair of master's theses, and the aquatic inventory by Toczydlowski et al. (1978). Nichols et al. (2001a) reported that *Bulimnea megasoma*, a large snail, was collected nearshore in Siskiwit Lake and Lake Superior, and Johnson (1980) and Bowden (1981) summarized trends in invertebrates from stream habitats. We use Whitman et al. (2000) as the main description of macroinvertebrate communities because it is recent, the authors used standardized methods, and their intent was to continue sampling to build a long-term dataset.

Whitman et al. (2000) collected benthic macroinvertebrates from limnetic and littoral zones of Sargent and Siskiwit lakes using an Ekman dredge sampler. Total invertebrate density in Sargent Lake was "about 3,000 m^{-2} in both the littoral and limnetic zones" during 1997. Chironomidae were the dominant group in the littoral zone. However, two measures of community diversity (Margalef's and Shannon-Weiner) were always higher in the littoral zone because of a greater number of invertebrate species relative to the limnetic zone (Whitman et al. 2000).

In 1997, the total invertebrate density in Siskiwit Lake was "about 4–5 times lower" in the littoral zone than the limnetic zone, with the amphipod *Diporeia* predominant in the benthic community of the limnetic zone and various insects dominating the littoral zone community (Whitman et al. 2000). Higher total abundance in the littoral zone did not persist in 1998, when density between the zones was similar. Similar to Sargent Lake, both measures of species diversity were higher in the littoral zone during 1997, but the Shannon-Weiner index was higher in the limnetic zone than the littoral zone in 1998 (Whitman et al. 2000).

Mussels: Whitman et al. (2000) reported finding some sphaeriid clams (*Pisidium* sp.) in their benthic samples from Sargent and Siskiwit lakes, but the most comprehensive survey of ISRO mussels is by Nichols et al. (2001a), who visually inspected ISRO lakes and streams for unionid mussels, followed by systematic sampling from 11 lakes. No mussels were found in streams, most likely due to unsuitable substrate and heavy ice formation during winter. Across all lake sampling sites on ISRO, four species from two genera were found: *Lampsilis luteola*, *L. radiata*, *Pyganodon cataracta*, and *P. grandis*.

Three lakes had all four mussel species present, as well as individuals that were identified as hybrids between *P. cataracta* and *P. grandis* (Table 17). At least one mussel species was found in five of the eight remaining lakes. Feldtmann Lake, Hatchet Lake, and the smaller lake along the Minong Ridge Trail that the authors named "Leech" Lake did not have any mussels, despite having suitable substrate and biotic and environmental factors similar to ISRO lakes that support mussels (Nichols et al. 2001a). The authors could only speculate that the concentration of copper or other untested factors may prevent mussels from occupying these sites.

Mussel distribution within ISRO lakes appeared related to depth. Most individuals were found at depths <9.1 m; the authors attributed the lack of individuals at greater depths to lower temperature below the thermocline. Because mussels are filter feeders and can bioaccumulate contamination, analysis of tissue was undertaken in some individuals, but the few contaminants detected were "well below any concentration of concern" (Nichols et al. 2001a). Exotic mussel species such as zebra and quagga mussels were not found in this survey. The native unionid mussel populations were healthy and considered valuable because many species in streams and lakes from nearby mainland locations are imperiled or extinct.

Table 17. Presence of unionid species in inland waters of Isle Royale National Park, 2000–2001. X = present, O = absent. (Nichols et al. 2001a).

Lake			Unionid Species		
	Lampsilis luteola	*L. radiata*	*Pyganodon cataracta*	*P. grandis*	*Pyganodon* hybrids
Chickenbone	X	X	X	X	X
Desor	O	O	X	O	O
Feldtmann	O	O	O	O	O
Hatchet	O	O	O	O	O
Intermediate	X	X	X	X	X
"Leech"	O	O	O	O	O
Livermore	O	O	X	O	O
LeSage	O	O	X	O	O
Richie	O	X	X	X	X
Siskiwit	X	X	X	X	X
Whittlesey	O	O	X	X	X

Freshwater Sponges: During their survey of unionid mussels, Nichols et al. (2001a) documented unique freshwater sponge colonies in four of 11 lakes visually surveyed on ISRO. Although sponges are common in water bodies, Nichols et al. (2001a) observed "tall sponges" forming large colonies that are considered rare in freshwater systems. Further research was suggested to better understand the role sponges may have in primary production, contaminant cycling, and ecologic interactions (i.e., competition) with other species (Nichols et al. 2001a).

Further details about the distribution and identification of sponge species on ISRO comes from Meeker et al. (2007), who documented the presence of three sponges (*Spongilla lacustris*, *Corvomeyenia everetti* [classification marked as questionable], and *Ephydatia mulleri*) while surveying aquatic vegetation from lakes. At least one sponge species was found in Ahmik Lake, Amygdaloid Lake, Lake Eva, Forbes Lake, Intermediate Lake, Lake LeSage, Lake Richie, and Wood Lake. *S. lacustris* was the species most frequently encountered.

Macrophytes: Whitman et al. (2000) estimated macrophyte coverage and community composition from multiple transects on Sargent Lake and Siskiwit Lake during August 2000. They reported 20 taxa and estimated 30% macrophyte coverage in the littoral zone for Sargent Lake. Although their specific definition of littoral zone was not given, it is assumed that their surveys progressed from the shoreline to the maximum depth where light was suitable for rooted vegetation. One notable species was alternate-leaved water-milfoil (*Myriophyllum alterniflorum*), a species of special concern in Michigan. In Siskiwit Lake, only eight taxa were found and were estimated to cover <1% percent of the littoral zone, probably due to rocky substrate and steep slope prevalent in this lake (Whitman et al. 2000). Given the high clarity of

Siskiwit Lake, the authors left open the possibility that additional species may be present in unsampled locations away from the shoreline at depths difficult to survey.

Between 2003 and 2006, Meeker et al. (2007) collected aquatic plants and searched for exotic species in 36 ISRO lakes. The lakes were chosen primarily to overlap with the fish and water quality survey from Kallemeyn (2000), but additional lakes were included. An effort was made to compare plant communities from small lakes (<20 ha) to large lakes (>20 ha), which were thought to have communities similar to Lake Superior bays and coves.

In all, 402 wetland plant species were encountered. The nine species that were found in >50% of 84 transects from large lakes were muskgrass (*Chara* spp., 72.6%), spikerush (*Eleocharis palustris*, 63.1%), water horsetail (*Equisetum fluviatile*, 79.8%), quillwort (78.6%), slender naiad (*Najas flexilis*, 76.2%), bullhead pondlily (*Nuphar variegata*, 54.8%), big-leaved pondweed (*Potamogeton amplifolius*, 57.1%), grass-leaved pondweed (95.2%), and Richardson pondweed (70.2%). The 16 species that were found in 50% or more of the 44 transects from small lakes were Beck's water-marigold (*Bidens beckii*, 61.4%), woolly-fruit sedge (63.6%), muskgrass (50.0%), threeway sedge (*Dulichium arundinaceum*, 63.6%), needle spikerush (50.0%), spikerush (59.1%), water horsetail (81.8%), northern mannagrass (*Glyceria borealis*, 54.5%), quillwort (59.1%), bullhead pondlily (97.7%), big-leaved pondweed (65.9%), grass-leaved pondweed (90.9%), broad-leaved arrowhead (63.6%), hemlock water-parsnip (*Sium suave*, 56.8%), floating-leaved bur-reed (*Sparganium fluctuans*, 59.1%), and common bladderwort (*Utricularia vulgaris*, 77.3%). The project also added 13 new taxa to the flora of ISRO. These included the aquatic lake cress (*Armoracia lacustris*) and Farwell's water milfoil (*Myriophyllum farwellii*), both ranked as threatened in MI. The authors noted "a hint of separation" between large and small lakes in their ordination analysis and speculated that reasons might include differences in wave energy, water temperature, substrate, and nutrient availability (Meeker et al. 2007).

The aggressive wetland invaders cattails and common reed were detected in several inland lakes. Specifically, individual plants or larger beds of cattails were found in 30 lakes (83.3%), and common reed was found in 11 lakes (30.6%) (Meeker et al. 2007).

Herptiles

Six species of anurans, three species of salamanders, one species of turtle, and two species of snakes are currently known within ISRO (Casper 2008). The anurans include one toad (eastern American toad, *Anaxyrus americanus americanus*) and five frogs (spring peeper, boreal chorus frog, northern green frog, mink frog [*Lithobates septentrionalis*], and wood frog [*L. sylvaticus*]). Spring peepers are considered to be in high abundance, chorus frogs in low abundance, and the other three of intermediate abundance (Egan 2005). Egan (2005) reported on annual calling surveys for frogs and toads at 42 points on the main island of ISRO (seven vernal pond sites, three wet meadow sites, one bog, 12 marsh sites, 15 wooded swamp sites, and four pond sites). Wet meadows, ponds, and marshes were preferred frog habitats; vernal ponds and wooded swamps were rarely used (Egan 2005). Beaver play a role in providing the ponds preferred by frogs, but their numbers in ISRO are declining; the effect of this ecologic change on frog populations is uncertain (Egan 2005).

The three salamanders present are the blue-spotted salamander, central newt (*Notophthalmus viridescens louisianensis*), and common mudpuppy (*Necturus maculosus maculosus*), although Casper (2008) expresses some uncertainty about the latter. Eastern red-spotted newts were also reported by Glase and Lafrancois (2007). Casper (2008) indicated that differentiation between eastern red-spotted newts and central newts is problematic in the region. The reptiles present are the northern red-bellied snake (*Storeria occipitomaculata occipitomaculata*), common garter snake (*Thamnophis sirtalis*), and western painted turtle (*Chrysemys picta bellii*) (Casper 2008). With the exception of the boreal chorus frog and the common mudpuppy, which were not found in Casper's (2008) survey, resident species probably have park-wide distributions in appropriate habitats (Casper 2008).

Water Quality–Lakes

Despite the long history of ecologic research on ISRO, water quality monitoring efforts at ISRO have been few, with data collected from a limited number of lakes or streams for specific research programs. An aquatic baseline survey sampled six lakes in the late 1970s (Toczydlowski et al. 1978). Stottlemyer et al. (1998) surveyed 18 lakes in the early 1980s. The most complete characterization of ISRO inland lakes was done in Kallemeyn's (2000) survey of 32 lakes in 1995–1997. Whitman et al. (2000) studied two of those lakes (Sargent and Siskiwit) in 1997 and 1998. Crane et al. (2006) provided detailed analysis of water quality studies conducted to that date and reproduced many of the reports' summary tables; that work will not be repeated here. The most recent work is the sampling of nine lakes by Elias and VanderMeulen (2008) and Elias (2009) in 2007 and 2008, respectively; this work is intended to be representative of all ISRO lakes and is expected to be ongoing. A protocol has been developed for inland lake monitoring to standardize and guide future sampling efforts (Elias et al. 2008).

Toczydlowski et al. (1978) provided one of the earliest attempts to document biotic and abiotic conditions of water bodies on ISRO. As part of this effort, they sampled six inland lakes (Feldtmann, Intermediate, Richie, Siskiwit, Whittlesey, and Wood). They reported a mean pH of 5.70 (range 5.25–6.50) and low buffering capacity, measured as alkalinity, and concluded that aquatic habitats on ISRO may be susceptible to acidification through atmospheric transport of ions in precipitation. A detailed analysis of the Wallace Lake watershed also laid the groundwork for long-term analysis of geochemical processing of precipitation (Stottlemyer and Toczydlowski 1999b) discussed in the Air Quality section of this report.

Stottlemyer et al. (1998) reported pH and other parameters from 18 lakes sampled in 1980 and 1981. The mean pH was 7.2 ± 0.5 (mean ± standard deviation). Only one lake had a pH value below 6.5, (Chickenbone Lake, 6.3) and 13 had pH values ≥ 7.0. These values, along with moderate to low values for NH_4^+ (undetected in 15 lakes) and NO_3^- (10 lakes below detection limits), suggest that acidic precipitation is moderated by soil processes before reaching surface waters.

Whitman et al. (2000) surveyed Sargent Lake and Siskiwit Lake during 1997 and 1998 as part of an NPS program to monitor trends in lakes within national parks in the Great Lakes region. They provided a narrative description of the watershed conditions, shoreline habitat and development, presence of inlet and outlet streams, occurrence and size of islands, unique features about bay habitats, and use of the lakes by humans and wildlife, and reported lake morphometrics, water temperature from multiple sampling events, and water chemistry information. Sargent Lake is slightly alkaline. Mean littoral zone alkalinity was 38.64 ± 0.93 mg L^{-1} (mean ± standard error for all ranges in this paragraph). Mean pH was 7.97 ± 0.05. Mean specific conductance for 15 sampling events from the littoral zone was 86.5 ± 2.64 µS cm^{-1}. Nitrate, nitrite, and ammonia were mostly below detection limits, and TP was low, suggesting that Sargent Lake is oligotrophic to slightly mesotrophic. Siskiwit Lake was also slightly alkaline (mean littoral zone alkalinity 29.20 ± 0.34 mg L^{-1}). The mean pH was 8.13 ± 0.05. All measurements of specific conductance from the littoral zone were <90 µS cm^{-1}, with a mean of 66.76 ± 2.02 µS cm^{-1} for 17 sampling events. TP, nitrate, nitrite, and ammonia were mostly below detection. Siskiwit Lake is considered a hardwater lake and was classified by Whitman et al. (2000) as oligotrophic or slightly mesotrophic. In both Sargent and Siskiwit lakes, there were no significant differences between samples collected in the littoral zone and the limnetic epilimnion.

Kallemeyn (2000) conducted a comprehensive study of water quality on ISRO during 1996 and 1997 by surveying a suite of 17 chemical parameters from 32 lakes known to contain fish. This survey covered a broad range of chemical parameters from the largest number of ISRO lakes ever sampled and used modern, standardized methodology. Angleworm, Sargent, and Siskiwit lakes exhibited notably high clarity, with Secchi disk depths >4.0 m. More details of Kallemeyn's (2000) study are discussed in the individual parameter descriptions below. Qualitatively comparing the surveys from Toczydlowski et al. (1978) and Kallemeyn (2000), the water quality of ISRO lakes did not change during the nearly 20 years between sampling events.

To meet the goal of long-term monitoring of lakes in the Great Lakes region, Elias and VanderMeulen (2008) and Elias (2009) sampled water quality in nine index lakes on ISRO (Ahmik, Beaver, Desor, Feldtmann, George, Harvey, Richie, Sargent, and Siskiwit) as part of a larger monitoring effort developed by the NPS GLKN (Route and Elias 2006, Elias et al 2008). Multiple sampling events were conducted during 2007, 2008, and 2009, and will continue into the future, for lake water levels, a core water quality suite (clarity, temperature, specific conductance, DO, and pH), an estimate of primary productivity based on chlorophyll-*a*, relative concentrations of nutrients (phosphorus and nitrogen species), and an advanced water quality suite of nine additional parameters. Diatom communities were sampled as part of a separate project in 2007 but will be incorporated into the monitoring plan in the future.

Water quality can be evaluated in reference to narrative and numeric criteria intended to protect aquatic life and human health. In the case of ISRO, these criteria are determined by the State of Michigan but cannot be less stringent than USEPA standards (see Ledder 2005 for a discussion of these water quality standards for ISRO). They are included in MI Administrative Code (State of Michigan 2006b). Water quality can also be evaluated in terms of USEPA ecoregion nutrient reference criteria (USEPA 2000, 2001). The intent of these criteria is to "represent conditions of surface waters that are minimally impacted by human activities and thus protect against the adverse effects of nutrient overenrichment from cultural eutrophication" (USEPA 2000). They are based upon the 25th percentile of all sampled lakes in a USEPA region. Thus, water quality standards might be thought of as "what is harmful for some intended use," while ecoregion nutrient reference criteria include a smaller set of parameters and might be thought of as "what is natural or normal in a geographic region."

Water quality can also be evaluated in terms of changes over time. However, the limited data for ISRO inland lakes requires proceeding with caution. We have chosen to use the largest set of

ISRO inland water data (Kallemeyn 2000) and the two most recent, but smaller, sets (Elias and VanderMeulen 2008, Elias 2009). In order to aggregate the data as much as possible, we averaged the Elias data for the two years (n=6) and compared the data for each lake for each parameter to the Kallemeyn data (n=1 or 2). We have plotted the results as a ratio (Figure 29), where values >1 (above the dashed black line) indicate an increase in the value between the time periods, and values <1 indicate a decrease. These comparisons must be interpreted with the understanding that equipment, methods, and personnel have changed over time, and metadata for past results are not always available.

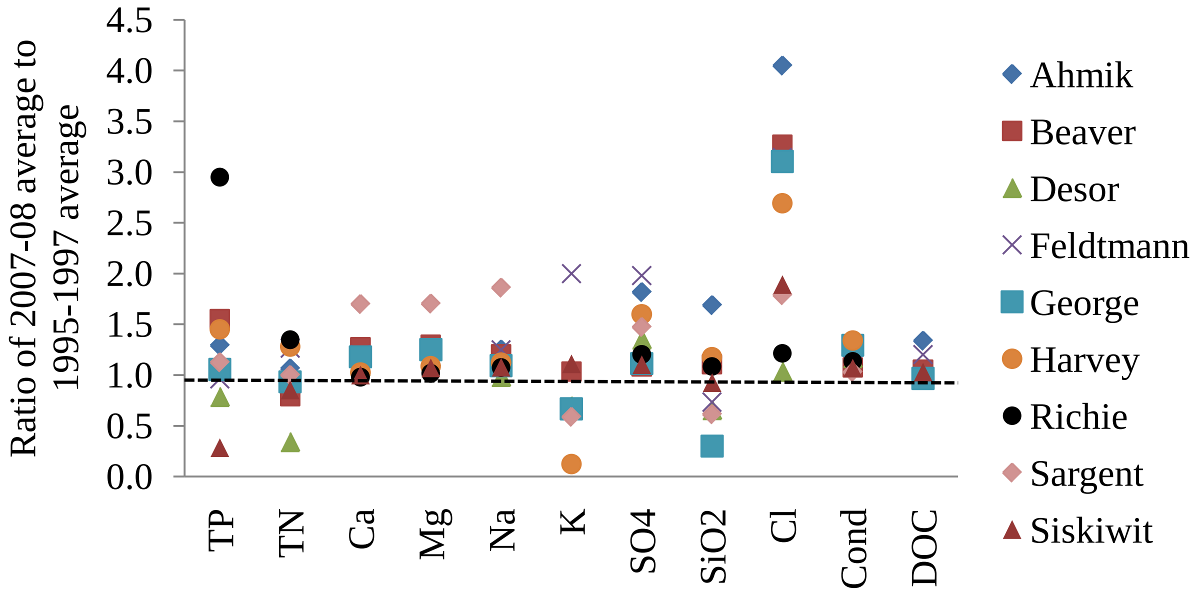

Figure 29. Comparison of values for selected water quality parameters between 1995–1997 and 2007–2008 (Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009).

Water Clarity

The photic depth of 32 ISRO lakes in 1995–1997, as determined by Secchi disk readings, was 1.3–9.0 m, with a mean of 2.9 m (Kallemeyn 2000). Similarly, photic depths for the nine index lakes were 1.4–7.8 m in 2007 and 2.2–7.2 m in 2008 (Elias and VanderMeulen 2008, Elias 2009). In 2008, the Secchi disk was visible at the bottom of three lakes. Five lakes had Secchi disk depths less than the USEPA reference criterion of 4.2 m. Elias (2009) attributed this finding to tannin-stained waters and algae.

Temperature

Mean summer epilimnetic temperatures, or water column temperatures in unstratified lakes, ranged from 16.7 to 23.9°C in 32 lakes in 1995–1997 (Kallemeyn 2000). Similarly, temperatures at 1.0 m depth ranged from 17.6 to 22.0°C in nine lakes in 2008 (Elias 2009).

Specific Conductance

Specific conductance values ranged from 50.7 to 99.5 µS cm^{-1} in 32 lakes in 1995–1997 (Kallemeyn 2000) and from 69 to 120 µS cm^{-1} in nine lakes in 2007 (Elias and VanderMeulen 2008). Specific conductance values for nine lakes were higher by ratios of 1.0–1.3 from 1995–1997 to 2007–2009 (Figure 29).

Dissolved Oxygen

Mean epilimnetic/water column DO levels were not included in Kallemeyn (2000); in the nine index lakes, they ranged from 7.7 to 9.5 in 2007 and 7.6 to 9.7 in 2008 (Elias and VanderMeulen 2008, Elias 2009). However, DO levels in the hypolimnion of all stratified lakes except Siskiwit Lake dropped below 4 mg L^{-1}, the USEPA criterion for freshwater aquatic life, in 1995–1997 and 2007 (Kallemeyn 2000, Elias and VanderMeulen 2008). In 2007, Lake Richie became anoxic at depths below 5 m; the likely reason is the dieoff of a large cyanobacteria bloom (Elias and VanderMeulen 2008).

pH

The pH values for 32 lakes ranged from 7.3 to 8.9 in 1995–1997, with only Lake Harvey exceeding 8.0 (Kallemeyn 2000). In 2007, mean near-surface pH ranged from 7.6 in Lake Ahmik to 8.5 in Lake Richie, with one value greater than the USEPA criterion of 9.0 for freshwater aquatic life. This exceedence likely related to the cyanobacteria bloom that also likely affected DO levels at depth (Elias and VanderMeulen 2008). Three lake means were 8.0, and three were >8.0. In 2008, mean near-surface pH values ranged from 7.5 in Lake Ahmik to 8.4 in both Lake Harvey and Lake George. One lake mean was 8.0, and four were >8.0. Elias (2009) suggests that pH levels may be increasing over time. A very small data set (three lakes that were sampled in 1980–1981, 1995–1997, and 2007–2008) also suggests this (Table 18); future sampling should be able to shed further light on this possible trend.

Major Ions

The ionic composition of ISRO inland lakes is characteristic of lakes in the temperate zone (Kallemeyn 2000). Among cations, proportions of Ca^{2+} and Mg^{2+} are higher in lakes associated with the Copper Harbor conglomerate and sandstone and conglomerate outcrops (Kallemeyn 2000). Ca^{2+} values in 32 ISRO lakes ranged from 5.8 mg L^{-1} in Angleworm and Sargent Lakes to 14.0 in Patterson Lake in 1995–1996 (Kallemeyn 2000). Ca^{2+} and Mg^{2+} appear to have increased between 1995–1996 and 2007–2008; ratios for nine lakes were 1.0–1.7 (Figure 29). Values for Lakes Desor, George, and Richie also generally increased from 1980–1981 to 2007–2008 (Figure 30) The Ca^{2+} increase, if verified in future sampling, is of concern because the minimum Ca^{2+} threshold for zebra mussel settlement and growth is 8–12 mg L^{-1}, with peak mussel densities at concentrations $\geq$ 20 mg L^{-1} (Jokela and Ricciardi 2008 and citations within). Ratios of Na^{+} also increased, but ratios of K^{+} decreased for nine lakes between 1995–1996 and 2007–2008 (Figure 29).

Table 18. Comparison of water quality data for selected parameters for three lakes sampled in 1980–1981, 1995–1997, and 2007–2008, Isle Royale National Park (Stottlemyer et al. 1998, Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009).

Lake	pH (pH units)			Specific conductance (µS cm^{-1})			Ca (mg L^{-1})		
	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08
Desor	7.9	7.9	8.25	88	88	103	7.4	11.7	12.65
George	7	7.9	8.55	94	92	118.5	10.1	17.5	20.65
Richie	7.5	7.5	8.2	77	68	77.5	6.3	9.8	9.6
	Mg (mg L^{-1})			Na (mg L^{-1})			K (mg L^{-1})		
	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08
Desor	5.49	3.47	4.1	1.84	1.83	1.8	0.51	0.72	0.5
George	1.48	1.56	1.95	0.46	0.96	1.05	0.04	0.15	0.1
Richie	2.6	2.9	2.95	1.45	1.49	1.6	0.23	ND	0.3
	NH_4-N (µg L^{-1})			NO_3-N (µg L^{-1})			SO_4 (mg L^{-1})		
	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08	1980-81	1995-96	2007-08
Desor	ND	19	5	ND	13	2.5	4.32	2.55	3.45
George	ND	<10	4	154	<5	1.5	3.7	2.29	2.55
Richie	ND	<10	8.5	ND	<5	2	5.62	3.24	3.9
	Cl (mg L^{-1})								
	1980-81	1995-96	2007-08						
Desor	0.32	0.87	0.9						
George	0.28	0.29	0.9						
Richie	0.64	1.03	1.25						

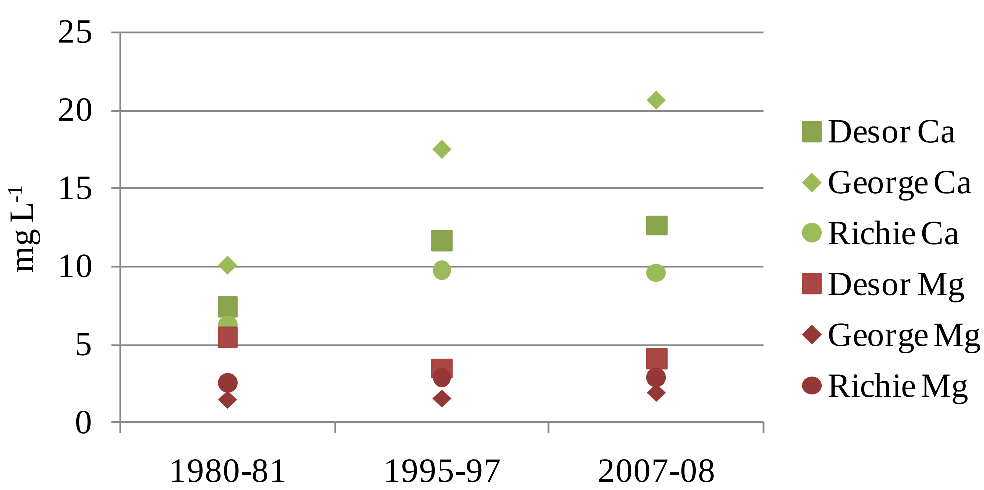

Figure 30. Comparison of calcium and magnesium values for three lakes sampled in 1980–1981, 1995–1997, and 2007–2008, Isle Royale National Park (Stottlemyer et al. 1998, Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009).

Among major anions, SO_4^{2-} appeared to have decreased between 1980–1981 and 1995–1996 (Figure 31). Crane et al. (2006) suggested that the decrease may have been caused by more stringent air quality regulations. However, SO_4^{2-} in nine index lakes increased slightly from 1995–1996 to 2007–2008 (Figure 29). Cl^- in nine index lakes apparently increased from 1995–1996 to 2007–2008, with ratios from 1.0–4.0, and had an upward trend from 1980–1981 to 2007–2008 (Figure 29, Figure 31).

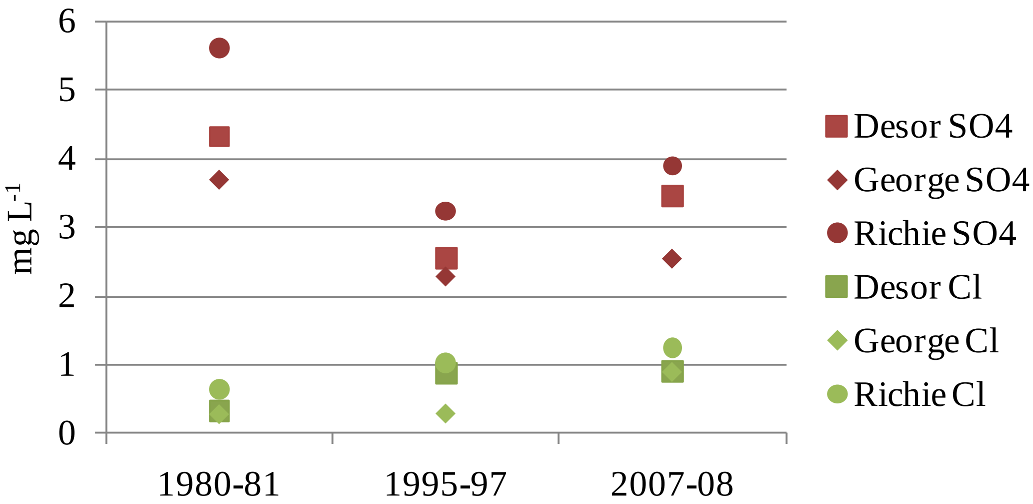

Figure 31. Comparison of sulfate and chloride values for three lakes sampled in 1980–1981, 1995–1997, and 2007–2008, Isle Royale National Park (Stottlemyer et al. 1998, Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009).

Dissolved Silica

Silica is an important nutrient for freshwater sponges and diatom algae. Some of the nine lakes sampled by Elias and VanderMeulen (2008) showed great variability throughout the summer season, reflecting uptake and release by organisms. Thus, comparisons between years become even more difficult, but ratios between 1995–1997 and 2007–2008 were generally <1, with a range of 0.3 in Lake George to 1.7 in Lake Ahmik (Figure 29). The September 2007 silica values for seven sampled lakes were 1.0–12.0 mg L^{-1} SiO_2, within the range considered sufficient for diatom production (Elias and VanderMeulen 2008).

Alkalinity

Alkalinity ranged from 20.8–53.5 mg L^{-1} in 32 ISRO lakes from 1995–1997; 19 were soft-water lakes (20–39 mg L^{-1} alkalinity) while the other 13 had medium alkalinity (Kallemeyn 2000). From 2007 to 2008, the range of alkalinity values was 22–58 mg L^{-1}, and the only lake with mean alkalinity below the acid rain susceptibility threshold of 25 mg L^{-1} (Taylor 1984) was Feldtmann Lake in 2008. Alkalinity for nine lakes appeared unchanged between 1995–1997 and 2007–2008, with ratios ranging from 1.0 to 1.1 (Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009) (Figure 29).

Dissolved Organic Carbon

Dissolved organic carbon (DOC) values in 32 ISRO lakes from 1995 to 1997 ranged from 5.0 in Siskiwit Lake to 15.3 in Epidote Lake (Kallemeyn 2000). DOC for nine lakes appeared mostly unchanged to slightly higher between 1995–1997 and 2007–2008, with ratios ranging from 1.0–1.1 (Figure 29). Elias and VanderMeulen (2008) reported that DOC sources in these nine ISRO lakes were both autochthonous and allochthonous, and high enough to attenuate light and reduce photosynthesis.

Chlorophyll-a and Trophic State Indices

Chlorophyll-*a* values in 32 ISRO lakes from 1995 to 1997 ranged from 0 mg m^{-3} in Scholts Lake to 7.68 mg m^{-3} in Lake Eva (Kallemeyn 2000). As with dissolved silica, chlorophyll-*a* values vary considerably at one site throughout a sampling season, and so comparisons between sample sets are difficult. However, for nine ISRO lakes sampled both in 1995–1997 and 2008, only four of the earlier samples fell within the range of the more recent samples (Table 19); for four lakes, recent samples had higher chlorophyll-*a* ranges, and only one (Lake Desor) had a lower range. The significance of this disparity is unknown and may be determined by future annual sampling.

Table 19. Comparison of chlorophyll-*a* values for nine lakes sampled in 1995–1997 and 2008, Isle Royale National Park (Kallemeyn 2000, Elias 2009).

Lake	1995–1997	2008 mean	2008 range
Ahmik	1.27	1.9	1.71–2.20
Beaver	0.53	2.6	2.38–2.79
Desor	3.80	2.6	2.23–2.84
Feldtmann	0.27	4.7	2.89–7.48
George	1.00	1.6	0.46–2.96
Harvey	2.32	2.4	1.97–2.84
Richie	2.86	6.0	5.03–8.42
Sargent	0.07	2.5	1.66–3.34
Siskiwit	1.07	1.0	0.75–1.45

The trophic state of a lake is based on the total weight of its living biologic material at a specific location and time (Carlson and Simpson 1996). Carlson's trophic state indices (TSIs) use algal biomass as the basis for trophic state classification. Three variables (chlorophyll pigments, Secchi depth, and TP) independently estimate algal biomass, with chlorophyll being the best predictor (Carlson 1977). Carlson TSIs were calculated for 32 ISRO lakes by Kallemeyn (2000), for Sargent and Siskiwit Lakes by Whitman et al. (2000), and for nine ISRO lakes by Elias and VanderMeulen (2008) and Elias (2009) (Table 20). Since Kallemeyn (2000) provided only summary data, comparisons for individual lakes between 1995–1996 and 2007–2008 could not be made.

Using chlorophyll–*a* values, Kallemeyn (2000) found 47% of the 32 sampled lakes to be oligotrophic, 50% to be mesotrophic, and 3% to be eutrophic in 1995–1997. In 2008, Elias (2009) found only Siskiwit Lake to be oligotrophic by this standard, with the other eight lakes being mesotrophic. However, Kallemeyn (2000) and Elias (2009) did not use the same breakpoint for dividing oligotrophic lakes from eutrophic ones (35 vs. 30, respectively). If Kallemeyn's breakpoint was applied to Elias's data, Lake George, with a chlorophyll-*a* TSI of 32, would also be categorized as oligotrophic.

Kallemeyn (2000) found that the Secchi TSI gave the greatest number of mesotrophic (88%) and eutrophic (9%) lakes. He attributed this to the negative relationship between transparency and both color and DOC. Elias (2009) found that Siskiwit Lake was mesotrophic by its Secchi TSI, although the difference in values (29 for chlorophyll-*a* TSI and 32 for Secchi TSI) was slight. On the other end of the scale, Elias and VanderMeulen (2008) found Lake Richie to be eutrophic in 2007 (TP and Secchi TSIs of 55). In 2008, Lake Richie was at the upper end of the scale for mesotrophic (TSI $\geq$ 50) lakes, with chlorophyll-*a* and TP TSIs of 50 and a Secchi TSI of 47 (Elias 2009).

Table 20. Trophic state indices (TSIs) for inland lakes, Isle Royale National Park (Kallemeyn 2000, Elias and VanderMeulen 2008, Elias 2009).

Year	Assessment Method	N	Trophic State		
			Oligotrophic	Mesotrophic	Eutrophic
1995–1997	TP TSI	32	8 (25%)	24 (75%)	0
	Secchi TSI	32	1 (3%)	28 (88%)	3 (9%)
	Chl-a TSI	32	15 (47%)	16 (50%)	1 (3%)
2007	TP TSI	9	1 (11%)	7 (78%)	1 (11%)
	Secchi TSI	8	1 (13%)	7 (88%)	0
	Chl-a TSI		-	-	-
2008	TP TSI	9	1 (11%)	8 (89%)	0
	Secchi TSI	9	0	9 (100%)	0
	Chl-a TSI	9	1 (11%)	8 (89%)	0

Total Phosphorus and Total Nitrogen

Mean summer TP for nine ISRO index lakes from 2007 to 2008 ranged from 4 µg L^{-1} in Siskiwit Lake to 25–34 µg L^{-1} in Lake Richie (Elias and VanderMeulen 2008, Elias 2009). The USEPA reference criterion for TP for lakes in the ISRO ecoregion is 9.69 µg L^{-1} (USEPA 2000). Eight and seven of the index lakes exceeded this criterion in 2007 and 2008, respectively. In Kallemeyn's (2000) study of 32 ISRO lakes from 1995 to 1997, TP ranged from 5–18 µg L^{-1}. The ratios of current to past TP between 1995–1997 and 2007–2008 for the nine current index lakes ranged from 0.3 for Siskiwit Lake to 3.0 for Lake Richie (Figure 29).

Mean summer TN values for nine ISRO index lakes ranged from 0.241 mg L^{-1} in Siskiwit Lake to 0.664 mg L^{-1} in Lake Richie in 2007 (Elias and VanderMeulen 2008) and from 0.220 in Siskiwit Lake to 0.766 mg L^{-1} in Lake Ahmik in 2008 (Elias 2009). The USEPA reference criterion for TN for lakes in the ISRO ecoregion is 0.4 mg L^{-1} (USEPA 2000). Six and seven of the index lakes exceeded this criterion in 2007 and 2008, respectively. In Kallemeyn's (2000) study of 32 ISRO lakes from 1995 to 1997, TN ranged from 0.25 to 0.65 mg L^{-1}. The ratios of current to past TN between 1995–1997 and 2007–2008 for the nine current index lakes ranged from 0.3 in Lake Desor to 1.3 in Feldtmann Lake, Lake Harvey, and Lake Richie (Figure 29). Thus, TN levels appear less variable than TP levels in the index lakes. Elias (2009) noted that these lakes do not receive direct anthropogenic inputs, so sources of TP and TN are likely resuspension within the lakes or atmospheric deposition.

Water Quality–Streams

Two stream monitoring programs provide long-term datasets allowing temporal trends to be analyzed. A USGS gaging station on Washington Creek (Figure 21) provides approximately 30 years of data ending in 2003 as part of the Hydrologic Benchmark Network, and the NPS Watershed Research Program monitored acidic deposition, climate change, and other large-scale stressors in the Wallace Creek watershed from 1982 to 1996 (summarized by Stottlemyer et al. 1998). GLKN will begin pilot monitoring work on Washington and Benson Creeks in 2010.

Washington Creek is the longest flowing water body on ISRO, draining much of the northwest part of the island. Mast and Turk (1999) summarized station data for the years 1967–1995. The number of samples was 141–145, with exceptions noted below. The median field pH was 7.5, median alkalinity was 61 mg L^{-1} as $CaCO_3$, and median specific conductance was 130 µS cm^{-1}. Median values for major cations were Ca^{2+},18.0 mg L^{-1}; Mg^{2+}, 5.1 mg L^{-1}; Na^+, 3.0 mg L^{-1}; and K^+, 0.5 mg L^{-1}. Among anions, median SO_4^{2-} was 5.8 mg L^{-1} and median Cl^- was 3.0 mg L^{-1}. Median NO_3+NO_2-N was 0.44 mg L^{-1} (n=102) and median ammonium was 0.04 mg L^{-1} (n=61) (Mast and Turk 1999). Washington Creek did have a few exceedences for metals and pH, which are discussed in the section on Indicators.

The authors concluded that Washington Creek was well buffered, and base cation, silica, and Cl^- concentrations were related mainly to geologic sources in the basin, while SO_4^{2-} was derived primarily from atmospheric sources. The report also noted that observed elevated SO_4^{2-} concentrations in the late 1980s may have been related to the analysis method used between 1986 and 1989. However, decreases in Ca^{2+}, Mg^{2+}, and Cl^- were likely caused by environmental change; a statistically significant decrease in annual mean discharge at the gaging station occurred between 1965 and 1980, and National Atmospheric Deposition Program (NADP) air monitoring stations also noted declines in these ions in precipitation between 1980 and 1992 (Mast and Turk 1999).

Water quality monitoring in the Wallace Creek watershed, draining into the western end of Moskey Basin, was initiated in 1982 as part of the NPS Watershed Research Program. The main focus of this program was to measure ecosystem structure and function in response to atmospheric deposition and climate change in study sites in four national parks (ISRO, Olympic, Rocky Mountain, and Sequoia-Kings Canyon). Stottlemyer et al. (1998) summarized data collected from 1982 to 1996 that included surveys of several streams and lakes on ISRO and concluded that surface waters are well buffered and parameters indicative of acidic deposition (i.e., SO_2) declined after passage of the Clean Air Act.

In planning for initiation of the Watershed Research Program on ISRO, numerous sites were sampled once from 1980 to 81, including 26 stream sites. As reported by Stottlemyer et al. (1998), most streams had moderate values for chemical parameters, including pH (range 6.2–7.8) and conductivity (range 55–162 µS cm^{-1}). Ranges for major cations were Ca^{2+}, 1.5–15.8 mg L^{-1}; Mg^{2+}, 1.3–17.0 mg L^{-1}; Na^+, 0.5–5.4 mg L^{-1}; and K^+, less than detection to 1.3 mg L^{-1}. Among anions, the range for SO_4^{2-} was 1.4–21.9 mg L^{-1}, and the range for Cl^- was less than detection to 1.9 mg L^{-1}. The ranges for nitrate and ammonium were less than detection to 0.99 mg L^{-1} and 1.3

mg L^{-1}, respectively. The survey revealed that ISRO surface waters were not susceptible to acid precipitation, and lower specific conductance and pH waters were dominated by high concentrations of dissolved organics (Stottlemyer et al. 1998). Because precipitation is processed by snowpack or soils before reaching surface water, more recent studies from the Wallace Creek watershed focus on possible changes in biogeochemistry, surface water quality, and nutrient cycling given potential climate change scenarios (Herrmann et al. 2000, Stottlemyer et al. 2002).

Terrestrial Resources

The terrestrial communities of ISRO have been viewed and studied at both coarse and fine scales. At the coarse scale, the vegetation is often placed into three broad community types consisting of shoreline vegetation and two types of forest vegetation: boreal forest and northern hardwoods. Many ecologic studies (e.g., Risenhoover and Maass 1987, Pastor et al. 1988) have not distinguished among the many variants of the boreal forest or the deciduous forest types.

At a fine scale, detailed botanic and classification efforts have enumerated up to 52 associations (TNC 1999), including various shoreline communities, meadows, shrublands, woodlands, and deciduous and/or evergreen forests. At least six new community types were identified in this effort (white cedar-sweet gale [*Myrica gale*] scrub fen, Canada yew [*Taxus canadensis*] mixed shrubland, yellow birch [*Betula alleghaniensis*]-spruce forest, white spruce [*Picea glauca*] rocky woodland, Great Lakes boreal talus woodland, and thimbleberry [*Rubus parviflorus*] shrubland). They also identified at least three unusual community types—the twig rush wet meadow, boreal calcareous seepage fen, and the sweet gale shrub fen. At least two from the 'new and unusual group' (the white cedar–yellow birch forest and the boreal calcareous seepage fen) are globally rare.

The plant composition of ISRO is quite valuable for its diversity, and various estimates have been made over time of the number of rare or special plants found there. Judziewicz (1995) reported 102 "species of concern" in ISRO. Judziewicz (1997) quoted a MDNR report stating that ISRO contains over 70 plant "species of concern." A GLKN report on Great Lakes national parks (NPS ca. 2003) listed "over 80 species of state-listed rare" plants. A recent NPS environmental impact statement (NPS 2008b, MNFI 2009b) listed 55 species that are currently state-endangered, threatened, or of special concern. In general, these changes are the result of differences in definitions between authors and not an indication that plant species are widely disappearing from ISRO.

The greatest botanic value of the park lies in its disjunct populations, most of which are found along the Lake Superior shoreline (Judziewicz 1995, 1997, 2004) and on Passage Island. This group contains 21 arctic and alpine species and 12 species whose ranges are centered in the western U.S. (Judziewicz 1995). The majority of these plants are found on S–SE-facing slopes at the NE end of the island (Judziewicz 1995), but two other areas ("nodes") have secondary concentrations of these species. These disjunct populations and other regionally uncommon species were part of the 102 "species of concern" Judziewicz (1995) listed for the park. Judziewicz (1997) documented 12 plant communities on Passage Island alone, five of which are dominated by woody species. Many of the species of concern at the state level (34) are on Passage Island (Judziewicz 1997).

The detailed surveys conducted by Judziewicz (1995, 1997) are invaluable in their contribution to our understanding of the flora of ISRO. His surveys updated and refined previous reports of occurrence, distribution, and abundance of many 'uncommon–to–rare' species, and he found that many of these are in fact more abundant and found in more places than previously reported. Judziewicz (1995) also reported a species—dwarf mountain cranberry (*Vaccinium vitis-idaea*)—that had not been documented anywhere in Michigan since 1868. On the other hand, at least seven species previously reported were not found by Judziewicz (1995, 1997).

A detailed and useful study by Hansen et al. (1973), which focused on forests, listed at least 16 forest types; they also described minor variants of several of these. Though these authors sampled the understory, only the overstory was used in their classification. Their criterion for naming a 'type' was the species that comprised 50% or more of the overstory. Thus, their effort is relatively fine scale, but essentially ignored the subordinate layers in defining a community type. The forest types were mapped using 1957 aerial photographs, and a cover type had to be relatively homogenous and distinguishable from adjacent forests based on composition, age (size), or "developmental differences." They tabulated the acreage by cover type and also estimated the amount of shrubs, lakes, rock outcrops, and beaver ponds. This mid-20th century assessment found that upland boreal forest types collectively covered almost 72% of the land surface of the island, lowland boreal types (black spruce, tamarack [*Larix laricina*], and northern white cedar) occupied 9.3%, and the northern hardwood type occupied 7.3%.

Due to the relative isolation of the island, the upland plant and animal communities are relatively simple; that is, they contain only a subset of the species typically associated with these plant communities in the nearby continental areas of MN, WI, MI, and Ontario. ISRO as a whole, and the communities in general, also have a much lower exotic species presence, both in terms of number of species (approximately 15% of the flora) (NPS 2005) and the abundance of those species.

Historic Vegetation

One useful perspective for assessing the current status and condition of ISRO terrestrial ecosystems is to look at the changes in plant community composition and distribution since the last glacial retreat; another is the landscape conditions just prior to extensive European settlement. Pre-European settlement condition(s) should not be viewed as 'the benchmark' because they are simply a set of conditions at one point in time, and these conditions fluctuate naturally (Swetnam et al. 1999). In the eastern U.S., the pre-settlement landscape has been frequently characterized by use of the General Land Office survey notes (Manies and Mladenoff 2000).

Flakne (2003) studied sediment cores from two lakes—Lake Ojibwa in the NE end surrounded by boreal forest and Lily Lake in the SW end surrounded by northern hardwoods—to describe changes in vegetation since approximately 10,000 years before present (BP). Flakne concluded that the overarching trends matched those noted in the region. The strongest patterns for woody species were dominance by spruce early in the Holocene due to a cooler climate and an increase in pine dominance in the mid-Holocene due to drier conditions. In the late Holocene, the two sites diverged as precipitation increased. A typical boreal mix established around Lake Ojibway, whereas birch dominated in the Lily Lake watershed. Throughout the past 9,000 years, pine and birch have strongly dominated the pollen profile. There was a shift from pine to birch domination approximately 4,000 years BP, as the dry period of the mid-Holocene waned.

Janke et al. (1978) utilized General Land Office records (survey conducted 1847–1848) to compare the "upland boreal forests" of ISRO to the forests of 1974, restricting their sampling to areas less than 244 m above mean sea level. The 1974 data were split between areas burned by 1936 fires and those not burned. They found massive shifts in some species, including large reductions in the relative density of balsam fir and northern white cedar, a large increase in paper birch, and a modest increase in quaking aspen. Tamarack was uncommon (2% relative density) in the 1840s but not found at all in 1974. The burned area had much less balsam fir, less aspen, and less spruce, but considerably more paper birch than the unburned areas. A highly significant shift in the shrub layer was also noted. Canada yew was the most common shrub noted by the surveyor in 1847–1848, and thimbleberry was not noted at all. By 1974, yew was completely absent from the main island, whereas thimbleberry was found at 51% of the locations sampled.

Current Vegetation

In 2008, the USDA–Forest Service inventoried 51 locations on ISRO as part of their annual Forest Inventory and Analysis (FIA) nationwide long-term, permanent, plot-based monitoring program. This equates to one sample per 1,012 ha, and thus the precision of estimates for uncommon forest types is low; however, the estimates are adequate for the common forests and for all forested areas combined. Due to differences in forest type classification, it was not always possible to align these estimates with those of Hansen et al. (1973). However, it was generally possible to match the forest types, and thus make valid comparisons over time. Therefore, the primary values of these data are to illustrate broad trends. Forty-seven of the ISRO sample locations were classified as forestland (USDA–Forest Service Northern Research Station, Houghton, MI, Scott Pugh, Research Scientist, pers. comm.) and are the basis for the following characterization of current forest conditions. The data summaries specific to ISRO were extracted from the FIA website with the program 'Evalidator' with the assistance of Scott Pugh.

These data suggest some very significant changes in forest community type abundance since the late 1960s (based on the extensive survey of Hansen et al. 1973). Total forest land increased approximately 2,429 ha, and the northern hardwood forest type(s) exhibited an increase from approximately 10% to almost 23%. The upland boreal forest types have exhibited a concurrent decrease from 71.5% to approximately 52.6%. Among the lowland forest types, Hansen et al. (1973) reported 'black spruce–northern white cedar' as the most abundant (4,089 ha). The FIA data reveal that 10,628 ha are dominated by northern white cedar today, and an additional 445 ha is a mixed black spruce-balsam fir-northern white cedar forest type. Though a small, but unknown, portion of this is uplands, the data clearly document that a large area has succeeded from black spruce to northern white cedar.

Overstory age data were also extracted from the FIA website. To simplify reporting, we have grouped the age data into 10-year age classes from 46 to 96 years, and into a young forest ranging from 16 to 45 years. The two most common age classes are > 100 years and 86–96 years, and both are dominated by northern white cedar and northern hardwood forest types. These data corroborate the successional changes noted in the paragraph above. The third most common age class is 46–56 years, and paper birch is the most common type in this group. However, this group, which partly originates from the 1936 fires, is not the most abundant for birch; there is about 60% more birch acreage in the 76–86 years age class, indicating that a large portion of paper birch forests originated in the 1920s. The dominant age class for other common forest types is balsam fir, 46–56 and 66–76 years (roughly tied), and aspen, 76–86 years. Approximately 4% of the landscape is occupied by forest <46 years old. Collectively, these data indicate the park is dominated by mature, but not old-growth, forest, and that there has been very little severe disturbance for approximately 50 years.

Most of the associations identified in the USGS–NPS Vegetation Mapping Program have not been studied in detail, although GLKN will begin terrestrial vegetation monitoring in 2010. For a strong majority, the only descriptions of entire communities are the ones produced as part of this mapping and classification effort (TNC 1999). The 52 associations were placed in 14 Ecologic Groups, which will serve as the structure for more detailed descriptions when available. Groups 2, 3, and 5 are primarily aquatic and are covered in other sections of the report. The ecologic and botanic investigations that have taken place at ISRO either pre-dated the Classification work, or the investigators were unaware of it; thus, the vegetation descriptions in these studies cannot always be linked to a particular association, but we can place them in an Ecologic Group.

Boreal Associations, Uplands (Ecologic Groups 8-11, 13)

These communities include all those dominated by woody vegetation and found on upland sites; i.e., the soil is not saturated for much of the growing season. It is important to note that several species (e.g., northern white cedar and paper birch) also occur in lowland forest types, and several of the woody species (paper birch, aspen, balsam fir, and white spruce) occur as minor elements in the Northern Hardwood Forest & Woodland Group (Ecologic Group 12).

Boreal associations are the dominant group of plant communities at ISRO, and one or more of these occupy the vast majority of the near-shore habitat, most slopes and ridge tops on the NE two-thirds of the island, and other places where the soil is shallow (Figure 32, Table 21) (Pastor et al. 1988, Stottlemyer and Toczydlowski 1999a). Ecologic Group 10, the Northern Spruce-Fir (Hardwood) Forests, is the most abundant group in this association, covering just over 20,000 ha (TNC 1999). The tree species that commonly define this group include balsam fir and white spruce, with lesser amounts of paper birch, quaking aspen, or balsam poplar (*Populus balsamea*). Ecologic Group 9, Northern Mesic Conifer (Hardwood) Forests, covers 1,627 ha in ISRO. In this group, white cedar is the most abundant canopy species, and balsam fir is typically a co-dominant. The white cedar–yellow birch forest type is a variant in this group that is rather unique. Occasionally, black spruce, yellow birch, jack pine (*Pinus banksiana*), and white pine (*P. strobus*) are found in the overstory. Ecologic Group 8, Northern Dry Conifer (Hardwood) Forests and Woodlands, almost always contains one species of pine as a dominant and is found predominantly along the south shore, with smaller amounts on ridges and drier slopes in the interior; it makes up 765 ha in ISRO (Figure 32, Table 21) (TNC 1999, USGS 2000a).

Aspen and/or paper birch are the species that largely define the Boreal Hardwood Forests and Woodlands group, Ecologic Group 11. They can form pure stands or occur in almost any proportional mixture. This forest type is largely restricted to elevations below 300 m (Albert 1995) and covers 13,450 ha in ISRO (TNC 1999, USGS 2000a). The aspen-birch type often functions as a classic pioneer community. Balsam fir and white spruce commonly establish in the understory of this type and gradually replace aspen and birch. In forests of this type ranging in age from 60 to 120 years, tree basal areas ranged from 6.9 to 57.4 m^2 ha^{-1} (mean = 25.7) and tree density averaged 741 stems ha^{-1}. The upper canopy exceeded 24.4 m in height, and tree diameters ranged from 2.5 to 58.4 cm (Hansen et al. 1973). Albert (1995) reported that fir and thimbleberry often dominate the “short shrub” layer in the aspen-birch (fir, spruce) forest type. Hansen et al. (1973) found at least 19 species in the shrub layer (across all stands), the most speciose by far of the cover types they reported. Seven taxa averaged more than 240 stems ha^{-1} (see Hansen’s Table 6 for composition and exact numbers). Reproduction of trees taller than 0.3 m in this type was dominated by balsam fir, mountain ash (*Sorbus decora*), and aspen (Hansen et al. 1973). Hansen and co-workers sampled about 30 stands in the ‘birch-aspen-fir-spruce’ cover type, and these stands were scattered the full length of the main island, on both the south and

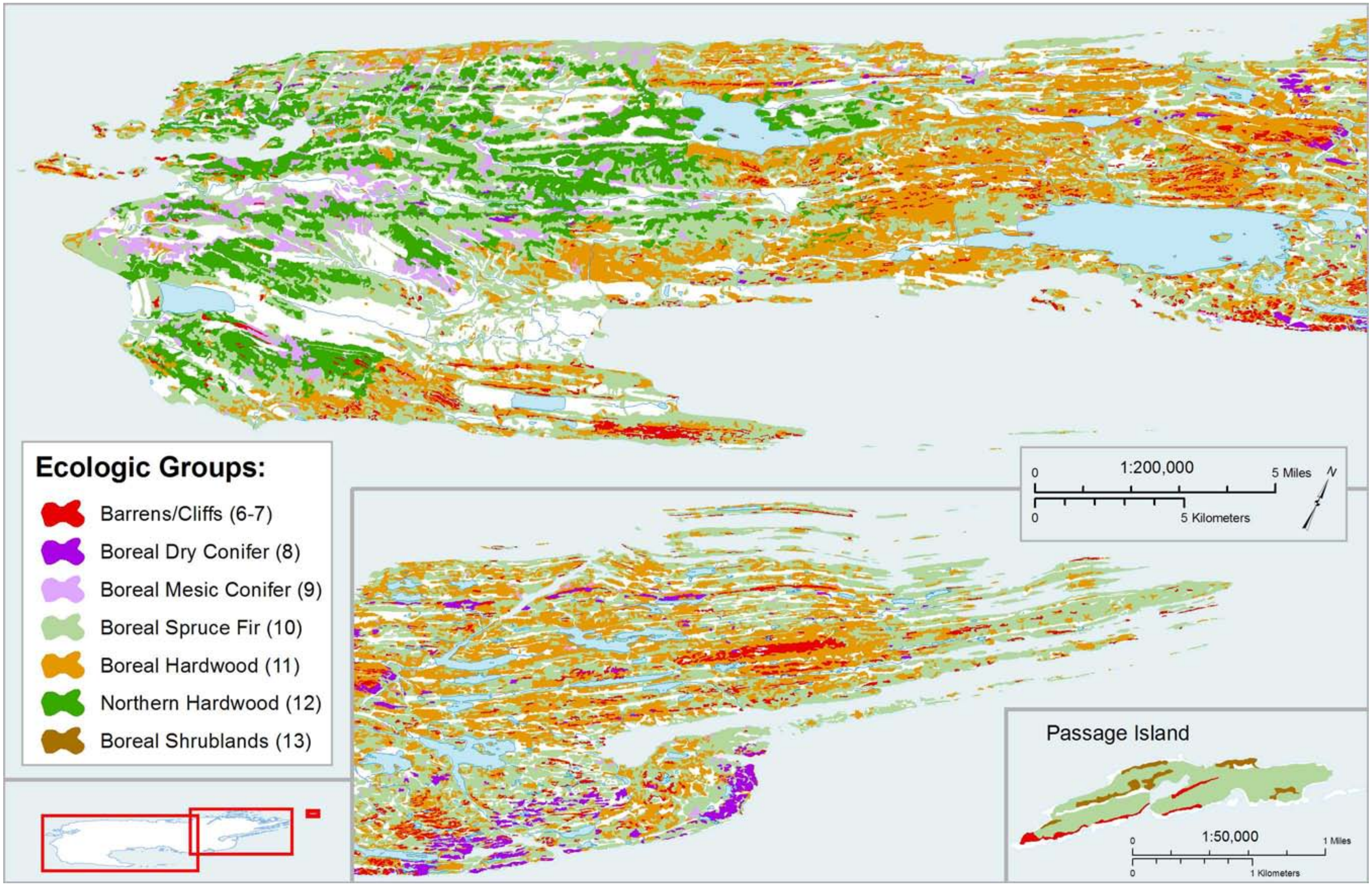

Figure 32. Upland ecologic groups for Isle Royale National Park (TNC 1999, USGS 2000a)

Table 21. Names and sizes of upland forest Ecologic Groups, Isle Royale National Park (TNC 1999, USGS 2000a).

Ecologic Group	Forest Type	Area (ha)
8-Northern Dry Conifer-(Hardwood) Forests and Woodlands	Boreal pine rocky woodland	198
	Jack pine-black spruce/feathermoss forest (forest phase)	286
	Jack pine-black spruce/feathermoss forest (woodland phase)	132
	White pine-aspen-birch forest	149
	Total Ecologic Group 8	765
9-Northern Mesic Conifer-(Hardwood) Forests	White cedar-boreal conifer mesic forest	1,004
	White cedar-yellow birch forest (cedar-birch phase)	116
	White cedar-yellow birch forest (mixed phase)	507
	Total Ecologic Group 9	1,627
10-Northern Spruce-Fir-(Hardwood) Forests	Balsam fir/Canada yew-devil's club	53
	Balsam fir woodland	5
	Balsam fir-aspen-paper birch forest	6,177
	White spruce-balsam fir-aspen forest	1,570
	Spruce-fir-aspen open forest	269
	Balsam fir/paper birch forest	576
	Spruce-fir/feathermoss forest	6,377
	Spruce-fir and sugar maple-yellow birch mosaic	1,956
	White spruce woodland alliance	3,020
	Total Ecologic Group 10	20,003
11-Boreal Hardwood Forests and Woodlands	Aspen-red maple forest	194
	Aspen-red maple rocky woodland	594
	Aspen-birch/boreal conifer forest (sparse canopy phase)	616
	Aspen-birch/boreal conifer forest (aspen phase)	790
	Aspen-birch/boreal conifer forest (mixed aspen-birch phase)	6,816
	Aspen-birch/boreal conifer forest (woodland phase)	1,722
	Aspen-birch/sugar maple-mixed hardwoods forest (aspen phase)	309
	Aspen-birch/sugar maple-mixed hardwoods forest (paper birch phase)	787
	Aspen-birch/sugar maple-mixed hardwoods forest (mixed phase)	771
	Paper birch/bush honeysuckle-fir forest	851
	Total Ecologic Group 11	13,450
12-Northern Hardwood Forests and Woodlands	Maple-yellow birch-northern hardwoods forest (yellow birch phase)	359
	Maple-yellow birch-northern hardwoods forest (mixed phase)	456
	Maple-yellow birch-northern hardwoods forest (sugar maple phase)	2,426
	Red oak-sugar maple forest	31
	Yellow birch-(spruce) forest	1,917
	Total Ecologic Group 12	5,189
	Total Ecologic Groups 8-12	41,034

north sides, and a few on the smaller islands. Thus, this type is the most completely characterized of any forest type.

The understory layer of Ecologic Groups 10 and 11 is the most diverse of all cover types. Hansen et al. (1973) list a total of 62 vascular species for this broad community type, but do not indicate how many they found, on average, per community. They list the average cover of each species, but not constancy, so only a general indication of abundance is provided.

A version of this type, without much balsam fir, occupies much of the area burned by the large 1936 wildfire. Paper birch was a strong dominant 32 years after the fire, with white spruce and aspen as minor components of the overstory (Hansen et al. 1973). The overstory averaged around 12.2 m tall and 17.8 cm in diameter by this time. Stem density was very high, 7,360 stems ha^{-1}, and basal area was moderate at 20 m^2 ha^{-1}. Paper birch also was the most common species (3,952 stems ha^{-1}) in the seedling size class (greater than 0.3 m tall). Sugar maple was present in modest amounts (874 stems ha^{-1}). The understory is almost as diverse as that of the group discussed above and has a high degree of compositional similarity. Thus, the understory had largely recovered from the fires by 1972.

Hansen et al. (1973) documented 21 shrub species in ISRO, with the boreal forest types being the most diverse.

Northern Hardwood Forest & Woodland Group, Ecologic Group 12

There are four specific community types in this group, each with distinct overstory dominants: 1) sugar maple–yellow birch, 2) mountain ash–mountain maple (*Acer spicatum*)–spinulose wood fern (*Dryopteris carthusiana*), 3) northern red oak (*Quercus rubra*)–sugar maple, and 4) yellow birch–spruce. The forest types in this group are strongly concentrated in the SW one-third of the island (Figure 32).

Unlike the others, the mountain ash–mountain maple–spinulose wood fern community (called a “scrub” in the Vegetation Mapping Program report) is rare and restricted to a few other islands at the NE tip of the park. The canopy cover varies from 40 to 90%; uncommon tree species include fir, white spruce, and paper birch. The shrub layer may be sparse or abundant (10–70% cover) and may include the disjunct species devil’s-club (*Oplopanax horridus*) (TNC 1999).

The sugar maple–yellow birch community type is the ISRO variant of the traditional ‘Northern Hardwood forest’ that is common in northern MN, northern WI, the upper peninsula of MI, and parts of Ontario (TNC 1999). Canopy cover ranges from 60 to 80%, and co-dominant canopy species include white pine, northern white cedar, and northern red oak. This type is found at elevations from 208 to 385 m on moderately to well-drained, loamy soils.

The northern red oak–sugar maple type is closely related to the sugar maple–yellow birch community type, but is more rare and restricted to somewhat steep, very well-drained sites above 367 m. Co-dominant canopy species (< 10% cover) include white pine, northern white cedar, red maple, white spruce, and mountain ash (TNC 1999). This forest type has greater shrub cover (in both the ‘tall’ and ‘short’ layers) than the sugar maple–yellow birch community type and different dominant species. Common juniper (*Juniperus communis*) and serviceberry (*Amelanchier* spp.) dominate in the northern red oak–sugar maple forest, whereas beaked hazelnut (*Corylus cornuta*) is most common in the related forest type. Hansen et al. (1973) inventoried three stands with very complex age structures that had a mixed yellow birch–maple overstory; the co-dominant species suggest these stands are examples of community type 1 in this Group. The basal area and canopy height ranges were 23–37 m^2 ha^{-1} and approximately 18.3–23.2 m, respectively. The larger birch and maple were 71 cm and 63.5 cm in diameter, respectively. The tree reproduction of these three stands was strongly dominated by sugar maple (59,500 stems ha^{-1}) with red maple a distant second (2,400 stems ha^{-1}) and yellow birch uncommon (123 stems ha^{-1}).

Unlike Janke et al. (1978), Hansen et al. (1973) found Canada yew in two variants of the boreal hardwood types on the main island.

The compositions of the understory assemblages in this group are largely unknown. Dominant species, and the ranges of understory cover, are presented in TNC (1999). This publication lists vast differences in cover among the three forest types described; cover ranges from 40 to 80% in the yellow birch–spruce type to 0–5% in the sugar maple–yellow birch type. These data suggest large differences in richness. Hansen et al. (1973) provide abundance information on the common shrubs, forbs, and ferns in the various upland forest types (see Hansen's tables 6 and 7). The ground layers of the northern hardwood types are extremely depauperate according to their data (Hansen et al. 1973), with only 18 species listed for three communities.

The understory of northern hardwood forest can be quite diverse and includes species with different phenologies; the two most speciose groups are spring ephemerals and summer deciduous (Rogers 1982). In one year of sampling vegetation less than 0.5 m tall, Kern et al. (2006) found 94 species (spring and summer combined) in a sugar maple-dominated northern hardwood forest in NE WI. Other studies of the northern hardwood type in the region generally found similar levels of richness (e.g., Cain 1935, Rogers 1982, Scheller and Mladenoff 2002). Though the richness of the understory is probably lower on ISRO, the level documented by Hansen et al. (1973) is certainly non-representative. Detailed studies are needed to assess the differences among forest types and their conservation value.

Upland Shrub and Herbaceous Associations, Ecologic Groups 6, 7, 13, 14

Twenty-eight associations have no or few arboreal species in them. Three of these twenty-eight are in Ecologic Group 5, Great Lakes Rocky Shores (with an areal extent of approximately 141 ha); these are covered in the Lake Superior section of this report. Similarly, two are clearly more aquatic than terrestrial (Ecologic Group 2), and three are considered marshes (part of Ecologic Group 3). Among the remaining non-arboreal associations, there are very striking compositional, life form, and structural differences. From a biodiversity standpoint, these associations are quite important because many species found in one or two of these are not found elsewhere in the park, and these communities contain the majority of the species of concern (Judziewicz 1995). An example is the 'bedrock glades' (*sensu* Judziewicz 1995) that resemble meadows comprised of alpine species, prairie species, and western disjunct species. The TNC classification effort greatly increased the number of distinct associations at ISRO; as of 2007, the MNFI listed only 18 distinct natural communities for ISRO (Kost et al. 2007), 12 of which are non-arboreal.

A challenge with monitoring and management of these associations and the species they contain is their extent. At least five of the 20 terrestrial groups were not mapped because they occurred at a spatial scale below the minimum mapping unit (0.5 ha). Another, Canada yew shrubland, is found only on Passage Island and is the only mappable member of Ecologic Group 13. Exceptions to this pattern are the communities that occur on rock outcroppings. Hansen et al. (1973) estimated this type of feature to cover 2,023 ha, or 3.7% of the island. In contrast, 'upland shrubs' were found on only 23.5 ha (0.04%). The mapping effort of TNC (1999) for types that fall in the Upland Shrub and Herbaceous Association category totals approximately 1,813 ha, and the Rock Barrens group contributes 98% of that acreage. Thus, this broad group has been relatively stable in extent over the past 50 or more years.

The Rock Barrens (Ecologic Group 6) in ISRO includes one forested community (the spruce–fir basalt bedrock glade), 1,202 ha in three shrubland communities (rocky boreal shrubland and common juniper rocky krummholz with its white cedar–balsam fir/leatherleaf/black crowberry krummholz phase), and 580 ha in herbaceous vegetation (poverty grass [*Danthonia spicata*] barrens) (TNC 1999, USGS 2000a). Spruce–fir basalt bedrock glades occur on well-drained, rocky ridges where usually 5–30% of the ground surface is exposed bedrock. White spruce is the most abundant tree (20–50% cover); balsam fir, paper birch, mountain ash, and white cedar are also found. Boreal rocky shrublands are also found high on ridges. Shrub cover is 25–80% and consists mainly of beaked hazelnut, hawthorn (*Crataegus douglasii*), serviceberry, or saplings and browsed scrub of pin cherry (*Prunus pensylvanica*), white spruce, or mountain ash. Also on well-drained rocky ridges are poverty grass barrens, where poverty grass averages 46% cover.

Common juniper rocky krummholz is found on low, often steep, S- or SE-facing rocky ridges near the Lake Superior shore. The most abundant shrubs are common juniper (average 33% cover) and creeping juniper (*J. horizontalis*, average 21% cover); lichens and feathermoss are also common. On Passage Island, a rare phase of this community is dominated by stunted, scrub forms of white cedar and balsam fir in the 2–5 m height range. Leatherleaf and black crowberry are the most abundant shrubs <1 m tall (TNC 1999).

The Great Lakes basalt/diabase cliff (Ecologic Group 7) is an uncommon community at ISRO, found mostly on ridges near the NW shore. It is sparsely vegetated; crustose and foliose lichens average 40% cover, and mosses average 30% (TNC 1999). Also found on steep NW–facing talus slopes or cliffs on the NE end of the island are the Great Lakes boreal cliff forest and Great Lakes boreal talus woodland. Mountain maple dominates the cliff forest and is abundant in the talus woodland. Both include white spruce, paper birch, and Canada yew, but the most common herbs vary. In the talus woodland, mosses such as *Pleurozium schreberi* are common in the groundlayer.

Avian Community

The composition of the avian community on ISRO has been documented since the early 1900s, with two reports in 1909 (Egan 2009). Periodically, reports of new species (e.g., Wood 1937) have come in, and by the mid-1960s, 197 species had been reported on the island (Krefting et al. 1966 in Hansen et al. 1973). New sightings and confirmations continued through the 1980s (e.g., Martin 1989). In 1985, Van Buskirk presented a record of breeding birds on 36 small islands within 1.5 km of the main island and assessed the relationship between island size and bird richness. He found a tight relationship between island size and number of breeding pairs, and the study indicated that pairs on these islands need less area than the same species on the mainland. Recent efforts to locate all breeding species on the island have led to two atlas surveys (Egan

2009). The NPS species list, dated April 2003 (NPS 2003b) for ISRO includes 238 bird species (confirmed reports only). This includes 88 breeding species, 69 migrants, 54 residents, and 27 vagrants. The most recent atlas, based on field work from 2002 to 2008, noted 144 species, with 79 confirmed as breeding on the island. Unlike the mammalian community, the avian community on ISRO is essentially the same as the community in adjacent Canada (Van Buskirk 1985).

The park has a number of recent or ongoing surveys of various breadth and focus. These include a bald eagle and osprey survey in the 1960s, 1980s, and 1990s. Surveys for all raptors were carried out in 1996, 1997, and 2001. Common loon surveys have been conducted since 1990. Since the 1980s, inventories for herring gull, ring-billed gull (*L. delawarensis*), great blue heron (*Ardea herodias*), and double-crested cormorant (*Phalacrocorax auritus*) have been done. In 1994, a 'formal' breeding bird survey with a focus on neo-tropical migrants was established. In 1996, each sample point was tagged so that each year the surveys were done from the exact same point utilizing standard 'point count methods' (Ralph et al. 1995). The trends from 1996 to 2008 were reported in Egan (2009) and provide an evaluation of changes in composition and abundance. Based on the 130 points surveyed, 57 species were detected annually, with an accumulated total richness of 85 species over the 13-year period. Significant increases were noted for 10 species, and declines for eight. The population trends were compared to adjacent study areas (MI, MN, and Ontario) and most were similar (Egan 2009). This analysis confirms that the avian species on ISRO are functionally a part of a larger population, and that they have not suffered more declines than has been observed regionally in northern North America.

Mammalian Community

Due to its isolation (Belant and Van Stappen 2002), the mammalian community of ISRO changes frequently when viewed from an ecologically relevant time frame. The basic principles of island biogeography theory (MacArthur and Wilson 1967, Belant and Van Stappen 2002) are quite evident in the recent history of the composition and density of the mammalian assemblage. The key processes of immigration, emigration, and local extirpation continue to shape this assemblage (and others). Accordingly, the mammalian community of ISRO is less species-rich than the nearby mainland areas in MN and Canada.

The most common mammals on the island today include red squirrel (*Tamiasciurus hudsonicus regalis*), red fox (*Vulpes vulpes*), beaver, moose, deer mouse (*Peromyscus maniculatus*), and hare (*Lepus americanus*) (Mech 1966). A number of common and conspicuous mammals found at this latitude were not reported at ISRO in 1973: black bear, fisher, gray fox, eastern chipmunk, gray squirrel, and porcupine (Hansen et al. 1973). The community is currently comprised of 27 species (15 "present in park," three "historic," five "probably present," and four "unconfirmed"), seven of which are bats (four "present in park" and three "probably present") (NPS 2003b). In 1905, there were 14 species, including three bats. The early-20th-century estimate is probably a conservative one due to limitations of access. The history of mammalian presence since approximately 1900 is fairly well established in the survey by Adams (1909). Some very conspicuous mammals apparently did not exist on the island in the late 19th century but showed up in the 20th century (e.g., moose, coyote [*Canis latrans*], and wolf), and others (caribou [*Rangifer tarandus*] and lynx [*Lynx canadensis*]) were still present in 1905 but disappeared shortly thereafter (Johnson and Shelton 1960, Mech 1966). This assemblage continues to be dynamic as populations fluctuate due to weather shifts, biotic interactions, genetic bottlenecks, and, in a few cases, disease. The species with small home ranges and high capacity for reproduction will probably always be part of the mammalian assemblage at ISRO; however, significant fluctuation in composition and density of the other non-volant mammals (those without wings) is to be expected. The extremely low amount of genetic variation within the wolf population probably makes it particularly susceptible to extirpation from agents such as disease (Peterson 1999). The lack of success of intentional introduction of white-tailed deer by the State of Michigan in 1906 is testament to the vagaries of population establishment in this habitat island. It is probable that currently unrepresented species (e.g., coyote) will appear, as they have the capacity to disperse to the island, and conditions seem suitable. Humans have probably had a small hand in this compositional dynamic since the mid-1800s, but their precise impact is unknown.

There are detailed, long-term population density estimates and predator-prey pairs that have been studied intensely. These include red fox-hare, wolf-moose, and beaver.

Moose-Wolf Interaction and Population Changes

These long-studied species form a predator-prey system in that the moose is the primary food item for wolves (Peterson and Vucetich 2001). However, the moose population exhibited very large swings prior to arrival of the wolf. The species probably arrived shortly after the turn of the century and grew in population very rapidly after that. It reached very high densities by the 1920s and early 1930s, and then the population crashed. Wolves did not come on the scene until the late 1940s (Pastor et al. 1988). Wolves have been aerially censused since the late 1950s; between 1988 and 1997, 15 were live-captured, had blood drawn, and were radio-collared. Moose were also counted by air beginning in 1983 (Peterson 1999). The density from 1982 back to 1959 was "reconstructed" by Fryxell et al. (1988), and Mech (1966) compiled various accounts to document the major trends in moose density from 1915 to 1957.

Recent analyses of these data have generated a range of conclusions, some of which are contradictory. During the 1960s and 1970s, both wolf and moose increased in density. Wolf numbers then declined from 1980 to 1996, due in part to an introduced disease. The moose population began to increase in 1984–1985 and continued to climb until 1996. It then crashed, with 80% mortality (Peterson 1999). This suggests limited density-dependent regulation within the moose population and a rather loose coupling of the two species. Post et al. (2002) reported a non-linear time series analysis of densities from 1958 to 1999. This mathematic analysis suggested a distinct phase-dependent system with significant changes in the degree of density dependence, and delayed density dependence in moose. A concurrent analysis of the same data, but focused on kill-rate, found that a) predator density outperformed prey density as a predictor, b) a ratio model outperformed a prey-based model, and c) the maximum explanatory power of any model was 37% (Vucetich et al. 2002) These results support the characterization of a 'loose' connection between species. A very recent analysis of the situation has uncovered an important weather signal in the relationship of the two species (Peckarsky et al. 2008). In particular, the North American Oscillation, which exerts a large influence on snowfall totals, impacts wolf predation rates due to the concentration of its prey during high snowfall years or its dispersion during low snow years. Thus, this more-or-less cyclic weather pattern is an important driver of predation rates (kill rates), and thus has some influence on the densities of both species.

Role of Moose in the Ecology of the Boreal System

The conclusions regarding the impacts of this large herbivore are based on exclosures set up in the 1940s or on patterns noted across gradients of moose density that occur naturally. The moose is closely associated with the boreal forests. The overall pattern of abundance has been described as "…. southwestern end where densities are greatest" (Peterson 1977 in Pastor et al. 1988). Likewise, the study by Brandner et al. (1990) had two of three intermediate density and high density study sites at the SW end. This generally confirms the pattern noted by Peterson (1977), but it is clear that moose density varies spatially over smaller areas. In addition, moose density has fluctuated dramatically over time. The general pattern has been from 4 to 10 animals km^{-2} in the 1930s, to a low point in the late 1950s of about 1 animal km^{-2}, increasing to approximately 3 animals km^{-2} in 1973–74, followed by an approximate 10-year decline, a rapid increase for 10 years, and a precipitous decrease from the mid-1990s to 1998 to only 1 animal km^{-2} once again (Peterson 1999). Thus, the magnitude (intensity, spatial extent, etc.) of moose herbivory is quite variable in space and time. The population densities on Isle Royale are much higher than populations in Canada and Alaska (Peterson 1999). This, coupled with their need to consume approximately 15 kg of food per day (Pastor et al. 1988), indicates they have the potential to significantly affect the vegetation. The diet of moose includes herbaceous upland plants, aquatic plants, deciduous trees, and, when food is scarcer, conifer seedlings and saplings (Pastor et al. 1988).

By the 1930s, Canada yew was practically eliminated from the main island, and this is consistently attributed to moose browsing (Brown 1935 in Brandner et al. 1990, Slavik and Janke 1987). Red-osier dogwood (*Cornus stolonifera*) and mountain ash have declined precipitously in some areas, as has balsam fir. However, there are a suite of other influences (or lack of in some cases) that should be noted to fully understand the impacts of moose. Total tree seedling density typically shows no increase with moose exclusion and is not lower in high moose-density areas (Janke 1979, Risenhoover and Maass 1987). Where balsam fir sapling densities are low, moose suppress the trees and limit their height growth (Brandner et al. 1990). A similar effect was noted for sugar maple in 'transitional' and boreal forests (Sell and Jordan, ca. 2006). However, where sapling densities are high, moose serve to release the residual balsam fir saplings, resulting in increased height growth and recruitment to larger size classes. For patches of low balsam fir density, the longer-term effect is to reduce its abundance in the canopy and thereby favor white spruce (Brandner et al. 1990). In two valleys on the NE end of the island with moose density of 3.7 km^{-2}, Pastor et al. (1998) noted elimination of aspen and birch stems less than 10–15 cm as annual browse consumption exceeded 4 g m^{-2}; neither balsam fir nor white spruce showed this effect. A wide range of impacts on the shrub layer has been noted. Janke (1979) noted reduced heights, an increase in biomass was reported by McInnes et al. (1992), and Snyder and Janke (1976) found no effect on tall shrubs. As moose density increases, herb-layer diversity and biomass typically increase (McInnes et al. 1992). Low levels of browsing permit greater numbers of stems (and perhaps species) to recruit to the canopy, which in turn suppresses the shrub and herb layers.

Effect of Moose on Ecosystem Processes

The documented effects of moose browsing on ecosystem processes are rather limited, and the vast majority are restricted to areas of high (above average) moose density and have taken more than four decades to manifest (e.g., Pastor et al. 1993). Within ISRO, the number of locations (not samples) where these linkages have been assessed is small, and thus most conclusions from these studies should not be viewed as established fact for the park in general. The most consistent effects have been seen in productivity, nitrogen availability and cycling, and cation concentrations (McInnes et al. 1992, Pastor et al. 1993, 1998). In particular, tree and litter production were greater in areas protected from moose browsing; herbaceous litter was lower, but shrub production was unaffected (McInnes et al. 1992). Standing biomass also differed between exclosures and control (browsed) areas for all three strata; tree biomass was greater while shrub and herb biomass was lower in the exclosures.

The first ISRO study to report on below-ground processes found 10 of 24 monitored parameters differed between exclosures and controls. At the Windigo site, which had much higher moose density than the other three sites, six parameters (soil carbon, soil N, cation exchange capacity [CEC], field N mineralization, potentially mineralizable N, and microbial respiration) were higher in the exclosure (Pastor et al. 1988, Table 1). In a follow-up study at the same exclosures, annual N mineralization, potential N mineralization, CEC, and the concentrations of Na^+, K^+, and Mg^{2+} were higher at the Windigo site (Pastor et al. 1993). The only significant difference at the Siskiwit Camp site, which had intermediate moose density, was annual N mineralization. Total N and total carbon in the soils differed at only one site for one of three months tested. These results are 40 years after the exclosures were erected; during this time period the vegetation changed markedly. After 33 years, total woody stem density was almost twice as high in the control area (excluding *Rubus*, which probably was not included in the original count), and the relative abundance of many species changed (Risenhoover and Maass 1987). The relative abundance of balsam fir, paper birch, mountain maple, and mountain ash declined while that of yew went up in the exclosures. In the browsed plots, both balsam fir and white spruce increased dramatically (3X), but fir was six times more common and was tied with mountain ash as the dominant arboreal species by 1982. Paper birch was the third most common arboreal species in the control plots, which had a small tree/shrub layer dominated by mountain maple, serviceberry, and bush honeysuckle. Between 1949 and 1982, aspen disappeared from both browsed and control plots (Risenhoover and Maass 1987).

Thus, the community in the exclosure at Windigo had less vertical structure and a tighter canopy, but its composition did not differ from the browsed plots. In areas, or time periods, of modest-to-low herbivory, forest structural changes may contribute to a ‘browsing effect’ on below-ground processes by enhanced warming of the litter layer and waste deposition that enhance nutrient cycling (Pastor et al. 1993). The study by Pastor et al. (1998) noted above extended the scope of the relationship between moose browsing, arboreal vegetation composition, and nitrogen availability. They found a relationship between high levels of browsing (approximately 5 g m^{-2}), N-availability, and conifer basal area at the patch and small-valley scale (250–500 m wide).

This body of work suggests that most areas used by moose will not have had any pronounced alteration of ecosystem processes, either because the level of browsing is below the threshold level, or the intensity of browsing varies over time such that the arboreal component of the community has time to recover during low browsing periods. Variation in intensity of browsing can arise due to weather patterns altering moose behavior, their large (500–1000 ha) home range, the variety of habitats used, or changes in moose density (see Population Changes, above; Pastor et al. 1988). Though it is clear that moose browsing can affect vegetation, which in turn affects nutrient cycling and availability, these effects are probably not the norm for ISRO but vary spatially and temporally. Pastor et al. (1988) noted that there are significant differences in the microbial communities between locations that create effects as large as those induced by browsing. Thus, moose browsing is only one of several important factors that determine ecosystem function in this landscape.

Effect of Moose on Aquatic Communities

Moose were recognized as utilizing aquatic vegetation from ISRO lakes as early as the survey by Koelz (1929). As cited in Lafrancois and Glase (2005), later studies by Jordan and Aho (1978) and Aho and Jordan (1979) found that moose probably alter the aquatic community on ISRO through direct consumption of aquatic vegetation and by disturbing sediment while foraging, increasing turbidity. Most recently, Meeker et al. (2007) compared photographs of their sample sites from the early 1900s, before moose arrived on ISRO, to conditions present during 2003–2006 to illustrate that aquatic vegetation in several ISRO lakes has been reduced or eradicated. The presence of remnant underwater stems and moose prints in lake sediments suggest that moose have a strong impact on aquatic plants (Meeker et al. 2007). Both consumption of vegetation and increases in turbidity may negatively affect fish and sponge communities. However, no studies have been conducted to specifically test these hypotheses.

Beaver Population Dynamics and Landscape Influence

Beaver appear to have occupied ISRO in the early 1800s but then disappeared toward the end of the 19th century (Mech 1966, Hansen et al. 1973). This pattern is consistent with the findings of Belant and Van Stappen (2002) in the Apostle Islands, which indicate limited colonization potential but high local extirpation rates for non-volant vertebrates. Adams (1909) did not note any sign of beaver, but by 1920 the species was "common along the south shore." The population has exhibited large fluctuations since then, peaking in the late 1940s (Hansen et al. 1973). A population decline from the late 1940s to approximately 1960 was attributed to a combination of depleted food resources, coyote predation, and a tularemia-like disease (Hansen et al. 1973). Krefting (1963) and Shelton (1966) documented dozens of active colonies, perhaps as many as 140 in 1960. Peterson and Romanski (2008) reported their beaver sightings and population estimates for 2006–2008, as well as presenting an annual estimate back to 1960. There was a sharp increase in number of beaver from approximately 1960 to 1970, up to more than 300 active colonies, followed by a rapid decline. By the early 21st century the numbers were down to less than 75 colonies. From 2006 to 2008, beaver density was relatively stable (125–135 active colonies). The species is concentrated on the eastern end of the island due to the steeper and more dissected topography (Peterson and Romanski 2008).

Food resource level and predation will continue to affect the dynamics of the species. The wolf is the primary predator now that the coyote is gone. Shelton (2004) reported that wolves heavily preyed upon the beaver population, whereas Mech (1966) (in Hansen et al. 1973) found that between 7 and 19% of wolf scat contained evidence of beaver. Fluctuating food resources are to be expected due to beavers' preference and ability to deplete the local resource. Fryxell (2001) reported an association between colony size and local food availability in Algonquin Provincial Park. The current and potential effect of disease is unknown. Fryxell (2001) concluded that local interactions were more important than broad-scale influences, such as weather, in determining the fate of local populations.

The beaver has been characterized as an ecosystem engineer and keystone species (Naiman et al. 1986) due to its impacts on key processes such as hydrology and, in some cases, channel geomorphology. At ISRO, more than 80% of the active colonies are on streams (Shelton 2004), primarily 3rd and 4th order streams (Naiman et al. 1986). The dams erected by a colony, which typically include primary and secondary dams, have a multitude of influences. They temporarily create new shallow, flooded wetland habitat in and adjacent to the stream channel. The dam(s) catch sediment (up to 6,500 m^3 per dam), moderate some floods, alter hydrology, change channel morphology, and alter biogeochemical pathways such as denitrification (Naiman et al. 1986). Due to their ability to fell relatively large, sometimes mature trees, beaver have profound effects on riparian community structure and composition (Johnston and Naiman 1990). These effects fall into two distinct classes when viewed from the standpoint of temporal persistence. All effects directly or indirectly associated with dams are typically short lived (< 10 years) because most colony sites are not used consistently for extended periods of time (Fryxell 2001, Peterson and Romanski 2008). In contrast, effects related to the utilization of trees can last for many decades and even exceed 100 years.

Utilization of woody plants by beaver is concentrated in a small area; for streams, the beaver do not commonly forage more than 50–70 m from the water's edge. Within this zone, tree basal area can be reduced up to 43% over a six-year period. Beaver show strong preference for deciduous species, especially aspen, willow, and birch, and avoid conifers and alder (Johnston and Naiman 1990). In one study, about two-thirds of all stems cut were <5 cm, but the average size of aspen used was 12 cm, and the largest was 43.5 cm (Johnston and Naiman 1990). This selective foraging shifts the woody plant composition toward conifers, non-palatable hardwoods, and shrubs. Thus, over decades, the long-term effect of beaver activity is to make the habitat decidedly sub-optimal for the species.

Indicators of Natural Resource Conditions

Vital Signs

The GLKN has developed conceptual ecosystem models for long-term ecological monitoring (Gucciardo et al. 2004); models pertinent to ISRO are those for Great Lakes nearshore and coastal wetland areas, inland lakes, wetlands, and northern forests. A detailed discussion of natural resource conditions in ISRO based on these models and their associated vital signs is found in the Conclusions section beginning on page 147. A discussion of other indicators requested as part of the task agreement for this report follows.

Designations and Protections

ISRO was designated as the 21st national park in 1931. It was further designated part of the National Wilderness Preservation System in 1976; over 99% of ISRO's land area is managed as wilderness (Crane et al. 2006). In 1980, the United Nations Man and the Biosphere Programme named ISRO an International Biosphere Reserve, giving it global scientific and educational significance.

All waters within the designated boundaries of ISRO (including Lake Superior and inland lakes and streams) are designated as "Outstanding State Resource Waters (OSRW)" by the State of Michigan. These waters are protected by applying controls on pollution sources so that existing uses are maintained and water quality is not reduced in the OSRW (State of Michigan 2006a). In addition, Desor, Ritchie, Sargent, and Siskiwit lakes are designated as "cisco lakes" where the state-threatened cisco, or lake herring, is found (MDEQ 2008b).

Presence of Endangered, Threatened, or Special Concern Species

A list of federal- and state-listed species appears as an appendix in two recent ISRO management plans (NPS 2003a, 2008b). We have updated the status of species on this list (which was current as of 1999) using data from the 2009 MNFI (MNFI 2009a, b).

ISRO has one federal-endangered species: the gray wolf, which had been delisted but was relisted in September 2009 (USFWS 2009). No ISRO species are currently listed as federal-threatened.

ISRO is occasionally visited by two state-endangered birds, the short-eared owl and peregrine falcon. ISRO has six state-endangered plants: round-leaved orchid (*Amerorchis rotundifolia*); rosy pussytoes (*Antennaria rosea*), listed as "historic" in the ISRO species list; smooth whitlow-grass (*Draba glabella*); Canbyi's bluegrass (*Poa canbyi*); awlwort (*Subularia aquatica*); and mountain cranberry. One ISRO plant species, blue lettuce (*Lactuca pulchella*) is now considered extirpated (MNFI 2009b). In addition, ISRO has the state-threatened gray wolf, seven state-threatened birds, four state-threatened fish, and 36 state-threatened plants. Among species of concern, ISRO has the moose, 10 birds, the boreal chorus frog (*Pseudacris triseriata maculata*), two fish, and 13 plants (MNFI 2009a, b). From 1999 to 2009, five ISRO species have improved in state status, while two have declined (Table 22).

Table 22. Comparison of 1999 and 2009 state status for state-listed species found at Isle Royale National Park (NPS 2008b, MNFI 2009a, b) (+ indicates improved status from 1999–2009, - indicates a decline in status).

Common name	Scientific name	1999 MI status	2009 MI status	+/-
Gray wolf	*Canis lupus*	Endangered	Threatened	+
Siskiwit Lake cisco	*Coregonus bartlettii*	Special concern	Threatened	-
Bald eagle	*Haliaeetus leucocephalus*	Threatened	Special concern	+
Osprey	*Pandion haliaetus*	Threatened	Special concern	+
Rosy pussytoes	*Antennaria rosea*	Threatened	Endangered	-
American rock brake	*Cryptogramma acrostichoides*	Endangered	Threatened	+
Blue lettuce	*Lactuca pulchella*	Threatened	Extirpated	-
Mountain cranberry	*Vaccinium vitis-idaea*	Extirpated	Endangered	+

ISRO does not have a comprehensive inventory of its insects, snails, or mussels (NPS 2008b). The MNFI (2009c) lists state-endangered, threatened, and special concern lichens, snails, insects, and other organisms for Keweenaw County, but their presence or absence in ISRO is undocumented. State-endangered and threatened natural communities are listed in discussed in the Lake Superior section (page 21), groups 1–4 in the inland aquatic resources section (page 58), and groups 8–14 in the terrestrial resources section (page 82).
Table 1.

Violations of Water Quality Standards

During 1993 an NPS contractor reviewed water quality data for ISRO Lake Superior waters and inland lakes and streams using USEPA's national water quality databases. The summary report ('Horizon' report) covered the period 1962–1993 (NPS 1995). Data included 26 monitoring stations, 15 of which were within ISRO, and 9,248 water quality observations representing 366 water quality variables. Only two stations (Washington Creek at Windigo and an offshore site 5 km S) collected long-term data; the Washington Creek station accounted for 81% of all ISRO data (NPS 1995).

The report revealed six parameters (pH, total coliform, cadmium, copper, lead, and zinc) that exceeded screening criteria at least once (NPS 1995). At the Washington Creek at Windigo station, isolated violations for pH, cadmium, copper, lead, and zinc occurred between 1965 and 1974 (Table 23). In all cases, numerous subsequent samples failed to show further violations, so these violations appeared to be of a temporary or transient nature.

The Washington Creek at Windigo site also recorded ten violations of the NPS Water Resources Division (WRD) total coliform criterion for bathing waters (1,000 colony-forming units [CFU]/most probable number [MPN]/100 mL) from 1967 to 1980, and ten violations of the fecal coliform criterion of 200 CFU/MPN/100 mL from 1971 to 1993.

Table 23. Exceedences of freshwater and drinking water criteria for pH and metals for Washington Creek at Windigo, Isle Royale National Park, 1962–1993 (NPS 1995).

Criterion Exceeded or Equaled	Value	Month/year	Later Sampling Dates that Met Criterion
pH freshwater life 6.5–9.0 pH units	6.3 pH units	5/1965	179 samples from 7/1965 to 2/1993; range of values 6.6–8.1 pH units
Cadmium freshwater life 3.9 µg L^{-1}; drinking water 5.0 µg L^{-1}	10 µg L^{-1}	10/1969	60 samples from 5/1970 to 5/1982; range of values 0–3 µg L^{-1}
Copper freshwater life 18 µg L^{-1}	20 µg L^{-1}	5/1968	22 samples from 10/1968 to 5/1982; range of values 0–11 µg L^{-1}
Lead drinking water 15 µg L^{-1}*	33 µg L^{-1} 22 µg L^{-1}	10/1970 5/1974	17 samples from 10/1974 to 5/1982; range of values 0–14 µg L^{-1}
Zinc freshwater life 120 µg L^{-1}	200 µg L^{-1}	5/1974	55 samples from 10/1974 to 8/1991; range of values 0–59 µg L^{-1}

*more violations were reported in NPS 1995 because lead criterion was mistakenly reported as 5 µg L^{-1}

Impairments, 303(d) Reports, and Fish Consumption Advisories

The federal Water Pollution Control Act (PL92-500, Clean Water Act) requires each state to prepare a biennial report on the quality of its water resources, often called a Section 305(b) report after the pertinent subsection of the act. Michigan's 2008 report includes Lake Superior and Siskiwit Lake in its list of impaired water bodies (often called a Section 303(d) list, again after the pertinent subsection of the act). These water bodies must have total maximum daily loads of pollution (TMDLs) established for them (Table 24) (MDEQ 2008b). Lake Desor and Lake Richie are included on the 303(d) list as being "not assessed" or having "insufficient information" for the development of TMDLs (MDEQ 2008b). In addition to these impairments, all inland lakes, reservoirs, and impoundments in MI have an advisory against eating most types of fish more than once a week because of mercury contamination, with additional restrictions for women of childbearing age and children under age 15 (MDCH 2009).

Table 24. Water bodies on Michigan's 303(d) list in Isle Royale National Park (MDEQ 2008b).

Water Body	Impairment	TMDL Date
Lake Superior	Chlordane	2012
	Dioxin (including 2,3,7,8-TCDD)	2012
	Mercury in fish tissue	2012
	PCB in fish tissue	2012
Siskiwit Lake	PCB in fish tissue	2010
	Mercury in fish tissue	2011

Stressors

ISRO Air Quality

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

ISRO is designated as a Class I air quality area, which provides it with the highest degree of protection against air pollution under the USEPA Clean Air Act (CAA). In 2006, ISRO met the NPS goal of having stable or improving air quality, as defined by meeting the national ambient air quality standards for ozone, particulate matter less than 2.5 microns in size ($PM_{2.5}$), and sulfur dioxide (SO_2) (NPS 2007). Nitrogen and sulfur deposition were rated as being of "significant concern" and "caution," respectively. Ammonia and sulfur concentrations in precipitation increased during 1996–2005, although the increases were not statistically significant.

No trend was found during 1996–2005 for the haze index (related to visibility) at ISRO on either the clearest or dirtiest days; its condition was rated as "caution." Ozone data were insufficient to establish a condition or trend (NPS 2007). An analysis of air pollution data and plant species type and relative abundance ranked Isle Royale as the least susceptible to vegetative damage from ozone, as well as sulfur oxides, among 22 midwestern parks (Crane et al. 2006).

Air Monitoring Stations Near ISRO

Currently, no international, federal, or state air quality monitoring stations are operated on the island. However, Eagle Harbor, MI, 64 km SE, is the site of an Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring site where fine aerosols, particulate matter less than 10 microns in size (PM_{10}), and light extinction and scattering are measured (IMPROVE Network 2004). The site also features a camera for qualitative observation. Also at Eagle Harbor, an Integrated Atmospheric Deposition Network (IADN) station operated by the USEPA and Environment Canada monitors PCBs, organochlorine pesticides, and PAHs (IADN 2002). The Midwest Regional Planning Organization operates a HazeCam at the Grand Portage Indian Reservation in MN that looks out at ISRO, 32 km SE, and provides particulate monitoring and meteorologic data (www.mwhazecam.net).

A NADP National Trends Network (NTN) site that monitored wet deposition was operated at ISRO from 1980 to 1984 and 1985 to 2006. Now, the closest NADP NTN sites are at Hovland, MN (41 km W), and Chassell, MI (83 km SSE) (http://nadp.sws.uiuc.edu/). A seasonal ozone monitoring site was operated on ISRO from 2002 to 2004 (Crane et al. 2006). A passive ozone monitoring site is reportedly part of the IMPROVE site on the mainland (Maniero and Pohlman 2003), although no ozone data were found for this site. The nearest dry deposition site operated by the Clean Air Status and Trends Network (CASTNet) is at Voyageurs National Park (VOYA), 180 km W of ISRO (Figure 33).

Figure 33. Air quality monitoring sites in the vicinity of Isle Royale National Park.

Local and Regional Air Emissions

Within ISRO, park vehicles, recreational marine engines, and campfires are potential sources of several major air pollutants: nitrous oxides (NO_x), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), and PAHs (Swackhamer and Hornbuckle 2004). Although quantification is difficult, long-range sources are generally thought to be of greater concern for these pollutants than in-park sources (Swackhamer and Hornbuckle 2004).

Waterborne commerce is also a local source of air emissions. Corbett and Fischbeck (2000) estimated that cargo movement on the Great Lakes produced NO_x emissions of 5–10 metric tons (MT) km^{-1}. The USEPA (2002b) estimated that the four U.S. Lake Superior ports nearest ISRO (Duluth-Superior, Taconite Harbor, Two Harbors, and Silver Bay) produced combined emissions of 19 MT yr^{-1} hydrocarbons, 81 MT yr^{-1} CO, 540 MT yr^{-1} NO_x, 34 MT yr^{-1} PM, and 235 MT yr^{-1} SO_2 (Table 25). The USEPA has made rule changes in recent years to reduce emissions from diesel boats and ships: allowable levels of sulfur in fuel used in marine vessels were reduced by 99% in 2007, which also resulted in a decrease in PM emissions (USEPA 2009a). In March 2008, the USEPA also finalized a three-part program to reduce emissions from category 1 and 2 marine diesel engines. PM emissions from some ships that exclusively sail the Great Lakes would have been reduced as much as 90% and NO_x emissions as much as 80%, when these rules were fully implemented (USEPA 2009a). However, a deal reached with congressional negotiators in October 2009 exempted 13 ships from these regulations and allowed others to apply for exemptions (Flesher 2009a).

Within 50 km of ISRO, the Thunder Bay area has several regulated facilities that produce one or more of the criteria air pollutants (CO, NO_x, SO_2, PM_{10}, VOC, and ammonia [NH_3])

(Environment Canada 2009). A 100-km radius includes the Keweenaw Peninsula. We mapped a 250 km range (Figure 34) to be consistent with the report of Swackhamer and Hornbuckle (2004); this includes the western half of MI's Upper Peninsula, part of northern WI, and the Iron Range of MN.

Regulated facilities in the U.S. and Canada within 250 km of ISRO produce 151,138 MT yr^{-1} of criteria air pollutants (Canadian data from 2007 and U.S. data from 2002) (Table 25) (Environment Canada 2009, USEPA 2009c). The largest sources of CO in the ISRO vicinity are at Thunder Bay and Terrace Bay, Canada (Figure 35). The largest sources of PM_{10} are on the Iron Range (Figure 36), while large VOC source areas include Thunder Bay and Terrace Bay, Canada, and the Rhinelander and Phillips areas in northern WI (Figure 37). Compared to Swackhamer and Hornbuckle's (2004) report, CO emissions in the U.S. within 250 km of ISRO decreased 23% from 1996 to 2002; PM_{10} emissions decreased 64%, and VOC emissions increased 114% (from 578 to 1,239 MT yr^{-1}) during the same time period. SO_2, NO_x, and NH_3 are discussed in the section on acid and nutrient deposition.

During 2007–2008, the prevailing wind directions at ISRO's Passage Island were N to E, 23%; E to S, 18%; S to W, 26%; and W to N, 33%. At Rock of Ages, they were 29%, 15%, 29%, and 27%, respectively (Figure 34) (NBDC 2009a, b). Thus, wind directions are relatively evenly distributed, with E–SE–S winds slightly less likely at ISRO, making it unlikely that any one source of pollutants is the predominant influence on ISRO's air quality.

Table 25. Criteria pollutant emissions for regulated facilities and some ports within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

Regulated facilities locations	Pollutant emissions (metric tons yr^{-1})					
	NO_x	NH_3	SO_2	PM_{10}	CO	VOC
Terrace Bay, Canada	<91	185	<91	<91	3,096	271
Thunder Bay, Canada area	2,563	11	3,703	333	5,057	1,098
Iron Range, MN	25,916	<91	7,326	9,227	<91	159
Duluth-Superior, MN/WI area	1,548	11	2,624	1,156	2,820	521
Rhinelander, WI area	<91	<91	<91	<91	<91	661
Phillips, WI area	<91	<91	<91	<91	<91	232
Iron Mountain, MI/WI area	<91	<91	<91	<91	1,694	<91
Hubbell, MI area	<91	161	<91	<91	<91	<91
Marquette, MI area	17,796	<91	17,812	1,266	<91	242
Other (including those <91 MT yr^{-1})	15,977	185	16,668	3,088	6,579	1,152
Total regulated facilities	63,800	553	48,133	15,070	19,246	4,336
Ports of Duluth-Superior, Taconite Harbor, Two Harbors, and Silver Bay	540	no data	235	34*	81	19**
Total regulated facilities and ports	64,340	553	48,368	15,104	19,327	4,355

*all PM, not just PM_{10}; **hydrocarbons

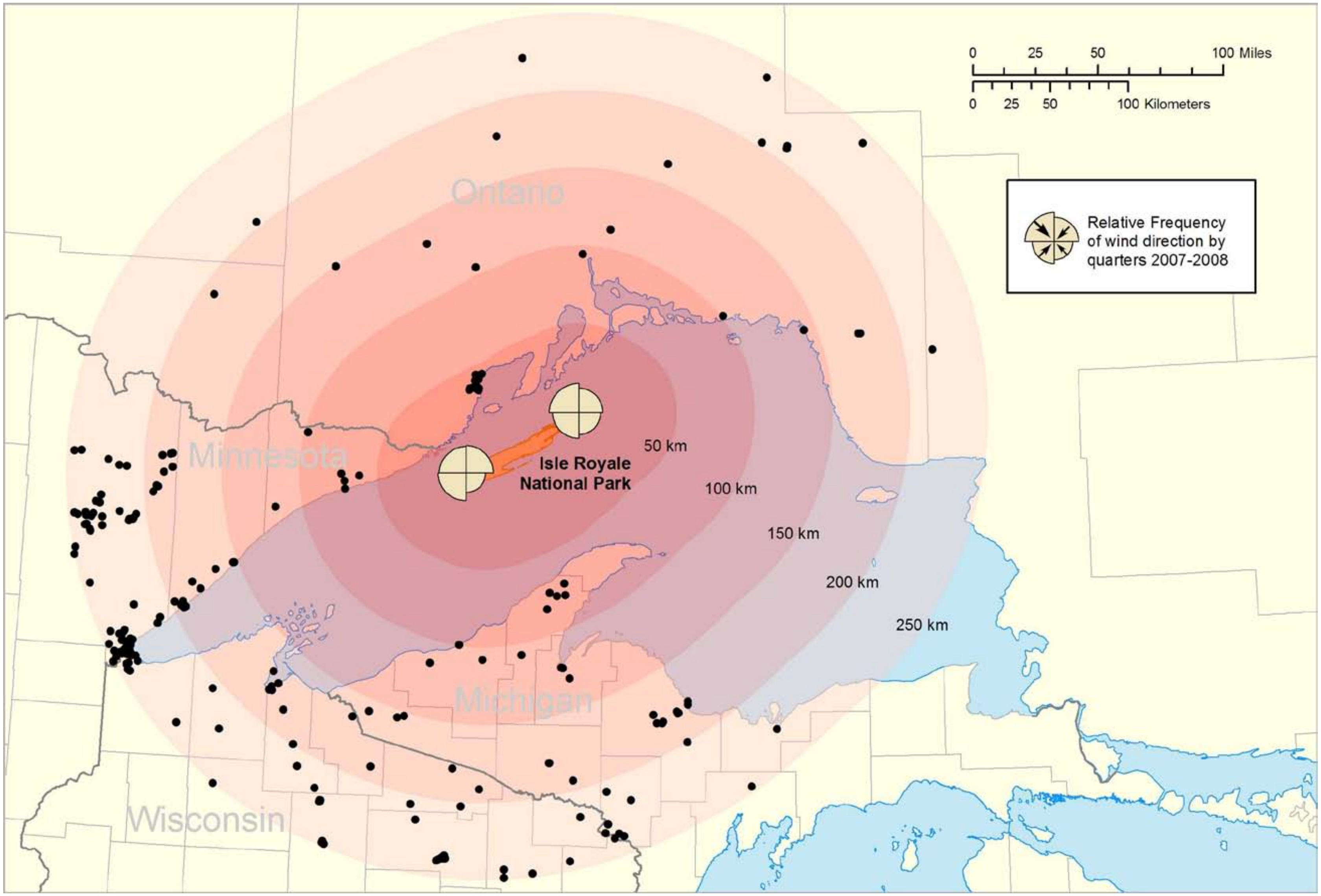

Figure 34. Regulated facilities that emit criteria air pollutants within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

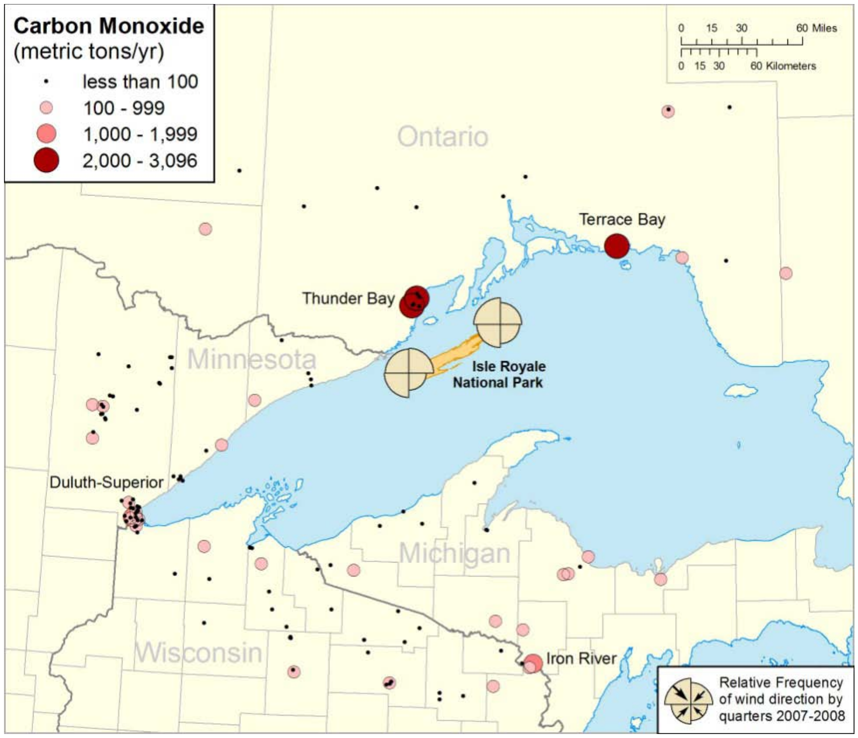

Figure 35. Emissions of carbon monoxide from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

Figure 36. Emissions of particulate matter less than 10 microns from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

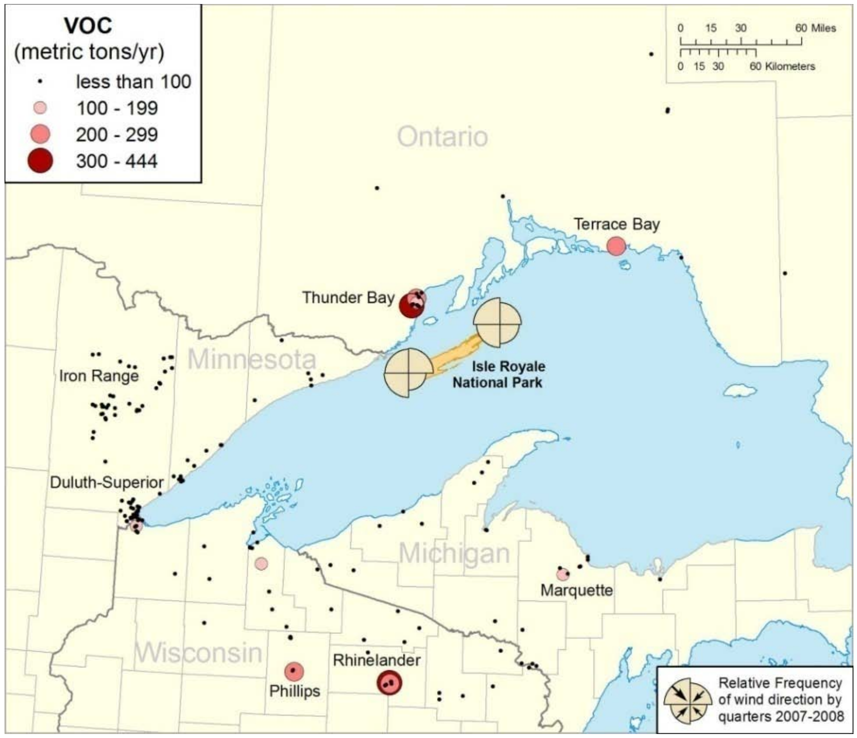

Figure 37. Emissions of volatile organic compounds from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

Long-Range Atmospheric Deposition

The effects of atmospheric deposition have been extensively studied at ISRO because of its wilderness status and lack of local air pollution sources. Swackhamer and Hornbuckle (2004) conducted an extensive review of past studies and monitoring efforts on ISRO and concluded that long-range atmospheric transport was the major source of mercury and persistent organic pollutants (POPs) including dioxins, PCBs, chlorinated compounds (DDT and metabolites, transnonachlor, cis- and trans-chlordane, hexachlorobenzene, octachlorostyrene, pentachloroanisole, decachlorodiphenyl ether, and mirex), fluorinated compounds, and brominated flame retardants.

Volatilization of the pesticide chlordane from soils in the southern U.S. is the predominant source of chlordane to the Great Lakes (Hafner and Hites 2003), even though chlordane has been banned in the U.S. since 1988. Similarly, soils in the cotton-growing region of the SE U.S. account for 59% of the toxaphene deposited in Lake Superior, even though it was banned in 1982 with residual use allowed until 1986 (Ma et al. 2005). Midwestern agricultural soils and urban areas continue to emit significant quantities of DDT (Bidleman et al. 2006), although continuing use in Mexico and Central America is another potential DDT source. An LSBP committee (LSBP 2006b) reported that Lake Superior is moving toward a steady state for some banned contaminants, such as PCBs and α-HCH. At steady state, atmospheric inputs to the lake will equal outputs from the lake.

Hafner and Hites (2003) reported that the major source of PCBs to the IADN monitoring site at Eagle Harbor is the Chicago area. Fluorene, one of the PAHs (products of incomplete combustion of fossil fuels), arrives at Eagle Harbor mainly from a SW source region reaching from MI through Iowa and North Dakota (Hafner and Hites 2003).

Thurman and Cromwell (2000) found that trace concentrations of triazine herbicides also arrive at ISRO via atmospheric transport. Atrazine, deethylatrazine, deisopropylatrazine, and cyanazine were detected in ISRO rainfall and inland lakes during their study period from 1992 to 1994. The authors suggested that residence time for these compounds is longer (up to 10 years) in deeper ISRO lakes than in shallower ones.

Within the Lake Superior basin, emissions of pollutants (to both air and water) were reduced by the following percentages between 1990 and 2005: mercury, 71%; dioxin, 76–79%; and HCB, 85% (HCB reduction on the Canadian side only). PCB reductions cannot be estimated because the inventory is incomplete (LSBP 2006b).

Acid and Nutrient Deposition

Acid deposition is a subset of air pollution that includes all reactive forms of nitrogen and sulfur that form or can form acids when in contact with water. It specifically includes gases, particles, rain, snow, clouds, and fog that are composed of sulfuric acid, nitric acid, and ammonium, derived from SO_2, NO_x, and NH_3, respectively. These compounds are emitted primarily by the burning of fossil fuels, but also by agricultural activities (Driscoll et al. 2001). The potential effects of acid precipitation include acidification of ecosystems and addition of sulfur and nutrients, especially nitrogen that can lead to eutrophication.

Regional Emissions: Emissions of SO_2 from regulated facilities in the U.S. and Canada within 250 km of ISRO are 48,133 MT yr^{-1} (Canadian data from 2007 and U.S. data from 2002) (Table 25) (Environment Canada 2009, USEPA 2009c). The largest source of SO_2 is a power plant at Marquette, MI (Figure 38). Despite these seemingly large sources, atmospheric SO_4^{2-} deposition at ISRO exhibited a downward trend from 1985–2005 (Drevnick et al. 2007). Similarly, in New England, the region with the longest deposition record in North America, a decline in SO_4^{2-} input has been documented since the 1970s (Hedin et al. 1994, Likens et al. 1996). This decline extended as far west as MN. Driscoll et al. (2001) reported a decrease in SO_4^{2-} wet deposition in northern MI as a result of the Clean Air Act Amendments (CAAA) of 1990.

However, in the 1990s, nitrate and ammonia emissions, which had not yet been fully addressed by the CAAA, continued to increase in northern MI (Driscoll et al. 2001). Emissions from regulated facilities in the U.S. and Canada within 250 km of ISRO include 63,800 MT yr^{-1} of NO_x and 553 MT yr^{-1} NH_3 (Canadian data from 2007 and U.S. data from 2002) (Table 25) (Environment Canada 2009, USEPA 2009c). The largest sources of NO_x in the ISRO vicinity are iron ore–related industries in MN's Iron Range (Figure 39), while large NH_3 sources are located at Terrace Bay, Canada, and Hubbell, MI (Figure 40). Compared to Swackhamer and Hornbuckle's (2004) report, NO_x and SO_2 emissions in the U.S. within 250 km of ISRO decreased 6% and 8%, respectively, from 1996 to 2002. Comparative data for NH_3 were not available.

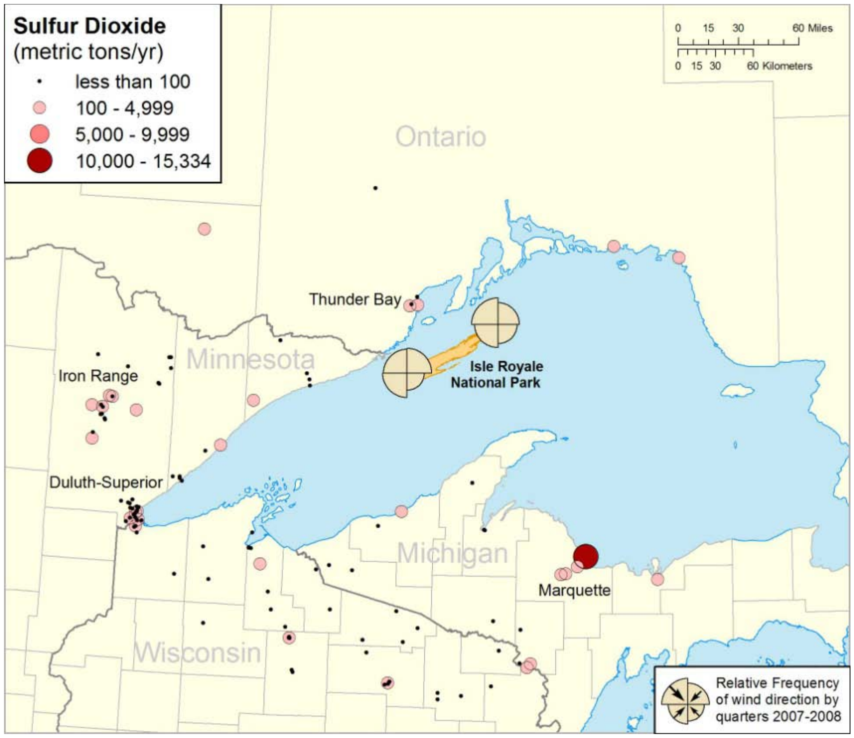

Figure 38. Emissions of sulfur dioxide from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

Figure 39. Emissions of nitrous oxides from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

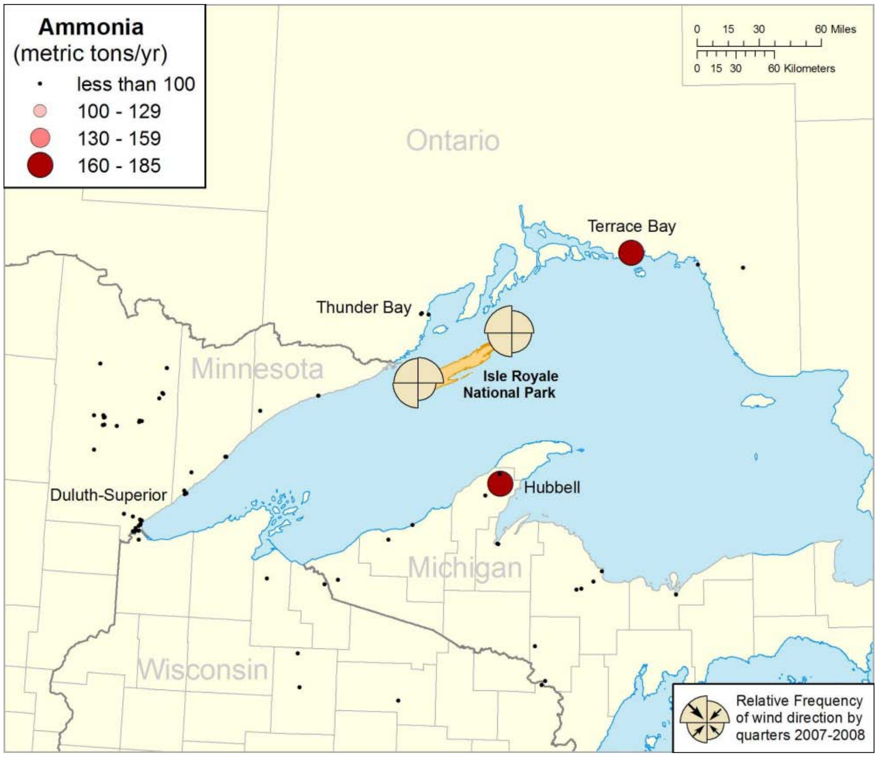

Figure 40. Emissions of ammonia from regulated facilities within 250 km of Isle Royale National Park (Environment Canada 2009, USEPA 2009c).

Local Deposition Rates: Estimating the amount of inorganic nitrogen deposition at ISRO is difficult both because the NADP station was discontinued in 2006, and because prior to that, only summer deposition levels were monitored. Deposition rates ranged from 0.52–1.42 kg ha^{-1} inorganic N^{-1} summer during 1985–2006, with a mean of 0.86 kg ha^{-1} and no apparent trend (Figure 41). The nearest NADP station monitoring inorganic N deposition year-round is at Hovland, MN, and summer deposition rates at ISRO had a statistically significant relationship ($p \leq 0.02$) to deposition rates at Hovland (Figure 42). Summer inorganic N deposition at Hovland averaged 25.0% of annual inorganic N deposition (S.D. 8.5%, range 10.2–38.5%). By extrapolation, ISRO would be estimated to have received an average of 3.5 kg ha^{-1} inorganic N yr^{-1} during 1985–2006, with a range of 2.2–8.5 kg ha^{-1}, compared to the average of 4.0 kg ha^{-1} yr^{-1} for Hovland during 1997–2008. Similarly, Stottlemyer et al. (1998) found a bulk precipitation nitrogen input of 3.5 kg ha^{-1} from 1982 to 1996 in the Wallace Creek watershed, and Stottlemyer and Toczydlowski (1999b) measured an average precipitation N input of 3 kg ha^{-1} yr^{-1} in year-round sampling from 1992 to 1997.

The form in which nitrogen is deposited may be significant and depends in part on whether the deposition is wet or dry. Wet deposition may include HNO_3, NO_3^-, and NH_4^+. Dry deposition includes HNO_3, particulate NO_3^-, particulate NH_4^+, and NH_3 (NAPAP 2005). Of total nitrogen deposition at VOYA from 2005 to 2007, 83.5% was wet deposition, while the remaining 16.5% was dry deposition (USEPA 2009b); similar estimates have not been made for ISRO.

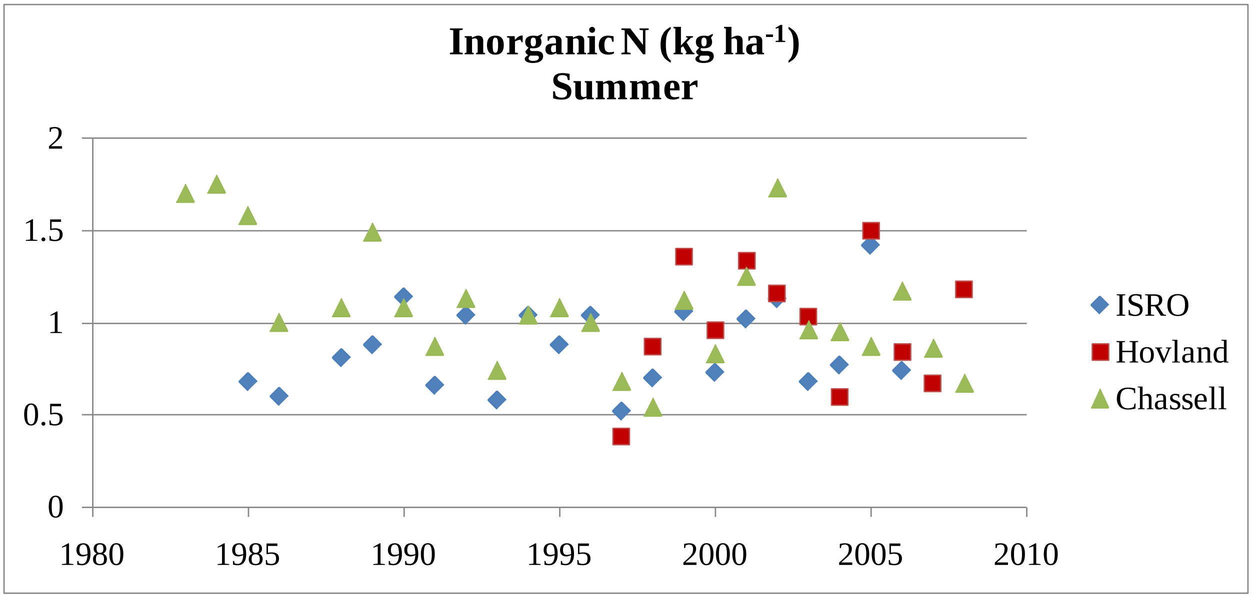

Figure 41. Summer wet deposition of inorganic N (NH_4-N plus NO_3-N) for NADP stations at Isle Royale National Park (1985–2006), Hovland, MN (1997–2008), and Chassell, MI (1983–2008) (NADP 2009a, b, c).

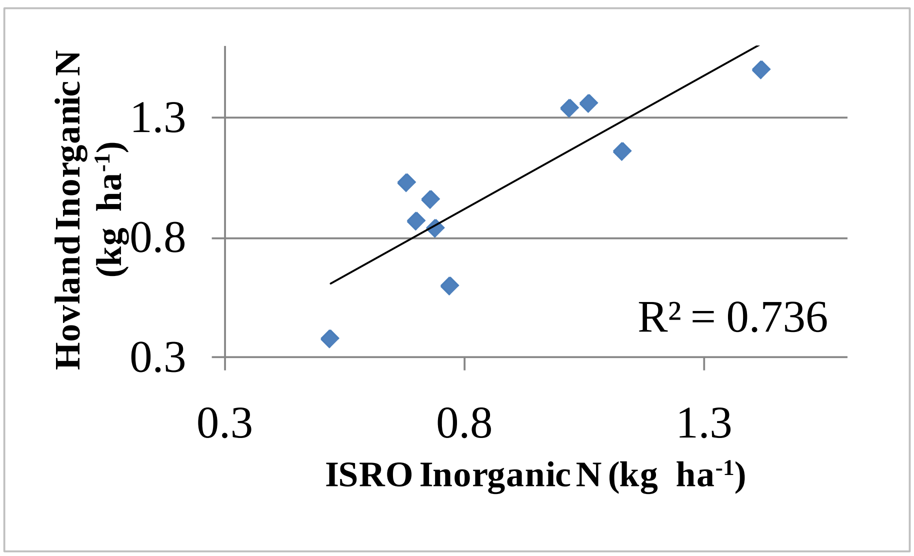

Figure 42. Relationship between summer inorganic N wet deposition (kg ha^{-1}) at Isle Royale National Park and Hovland, MN, 1997–2006 (NADP 2009 a, c).

The emission and atmospheric deposition of base cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}), which help counteract acid deposition, have declined significantly since the early 1960s with the enactment of particulate matter pollution controls (Driscoll et al. 2001). A decline in base cation input has been documented for New England since the 1970s (Hedin et al. 1994, Likens et al. 1996), and a concentration trend of -1.2 µeq/L yr^{-1} was observed for 12 stations in the Midwest (including three in MI) from 1979 to 1990 (Hedin et al. 1994). The average summer wet deposition of base cations at ISRO during 1985–2006 was 13.1 µeq/L, with a weak upward trend ($p \leq 0.1$). At Hovland, the average summer base cation deposition during 1997–2008 was 12.9 µeq/L with no trend (Figure 43). For individual cations, Ca^{2+} deposition (in kg ha^{-1}) appeared to increase at ISRO from 1985 to 2006 (Figure 45), Mg^{2+} appeared unchanged, and Na^{+} and K^{+} appeared to decrease, but the changes were not significant.

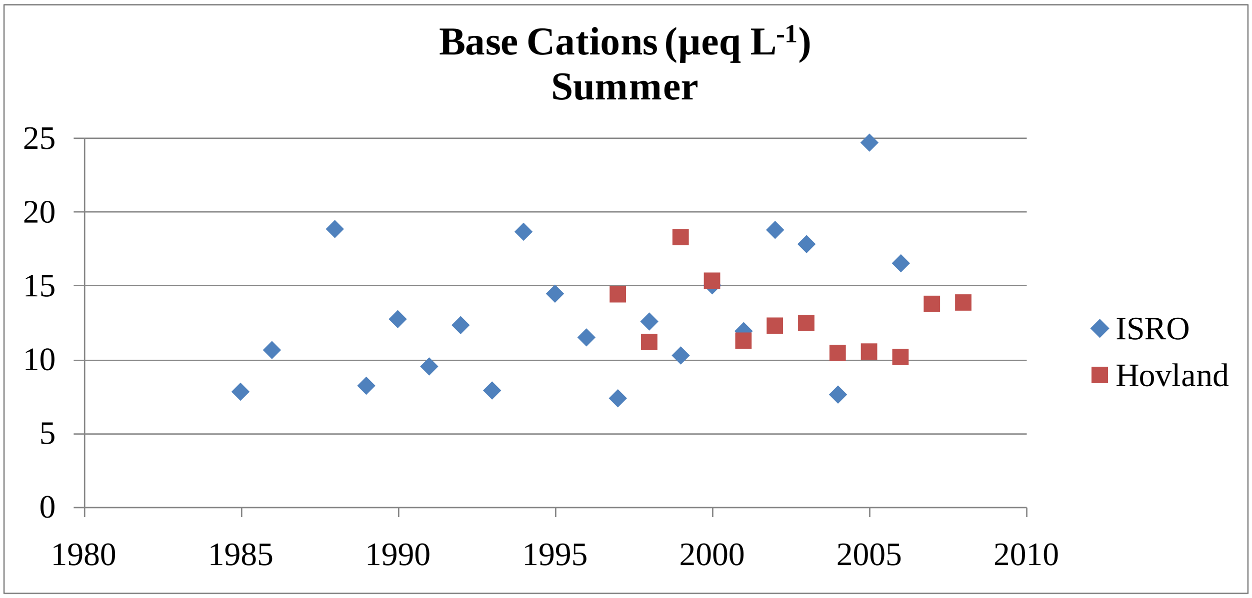

Figure 43. Base cations in summer wet deposition for Isle Royale National Park (1985–2006) and Hovland (1997–2008) (NADP 2009a, c).

A basic measurement of acid deposition is rainfall pH. The mean pH of rain at the NADP monitoring station on ISRO has varied from 4.35 in 1992 to 5.38 in 2006, with a general upward trend, but with notably lower values in 2004 and 2005 (Figure 44).

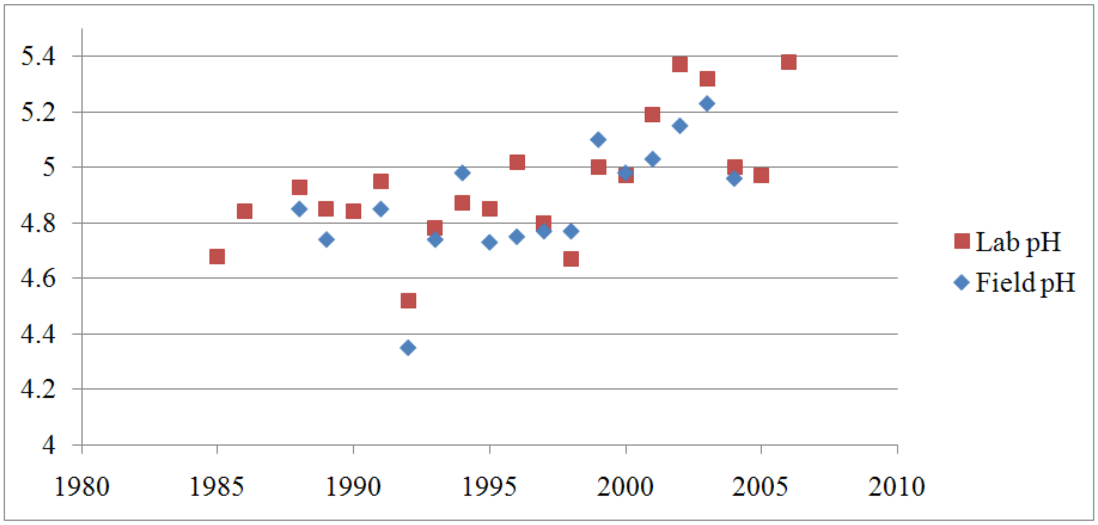

Figure 44. Summer field pH and laboratory pH for precipitation, NADP station at Isle Royale National Park, 1985–2006 (NADP 2009a).

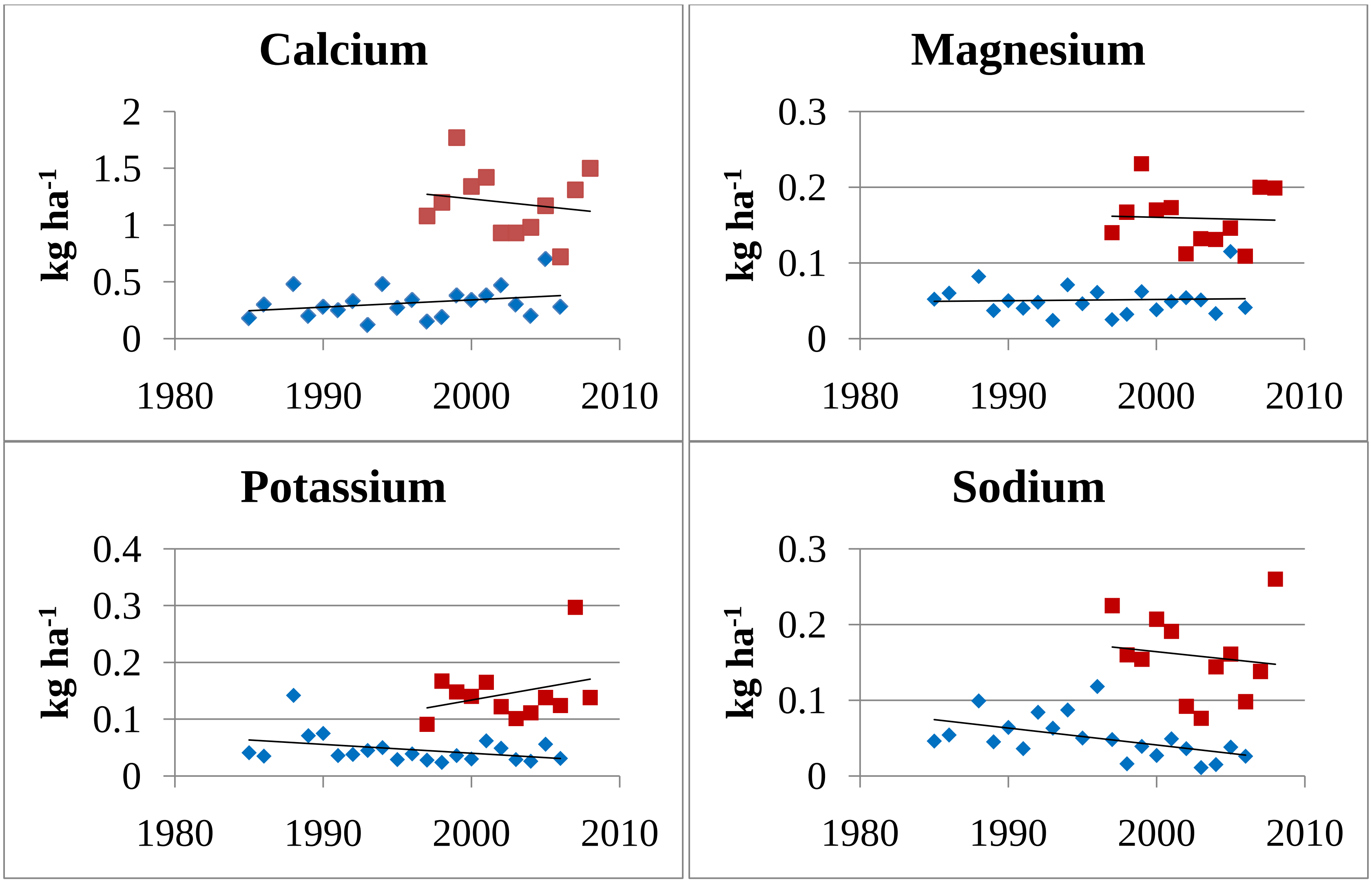

Figure 45. Calcium, magnesium, sodium, and potassium trendlines and values (kg ha^{-1}) for annual wet deposition for Hovland, MN (squares), 1997–2008, and summer wet deposition for Isle Royale National Park (diamonds), 1985–2006 (NADP 2009a).

Ecosystem Effects: The effect of acid precipitation on aquatic ecosystems is determined largely by the ability of the water and watershed soil to neutralize the acid deposition they receive. Generally, small watersheds with shallow soils and few alkaline minerals are most sensitive to acidification. Watersheds that contain alkaline minerals such as limestone, or those with well-developed riparian zones, generally have a greater capacity to neutralize acids. Low pH levels and higher aluminum levels that result from acidification hinder fish reproduction and decrease fish sizes and population densities (NAPAP 2005). Lake Superior and ISRO inland waters, with alkalinities over the threshold value of 25 mg L^{-1} as $CaCO_3$, are not considered particularly vulnerable to acid precipitation (Sheffy 1984, Shaw et al. 1996).

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

Buffering capacity in forest soils is largely a function of four factors: a) surface horizon texture and depth, b) B-horizon texture and depth, c) total CEC and base saturation, and d) abundance of fungi and bacteria in the upper soil profile (Johnson et al. 1983, Aber et al. 1998). Generally, buffering capacity is low in systems with coarse, acid soils; soils low in organic matter (OM); and soils that are shallow. Since ISRO soils are generally shallow, acidic, and moderately coarse, their buffering capacity is generally low. This is partially offset in some locations in the NE end of the island by greater OM content (NPS 2005), a combination of forest floor depth and OM in the upper soil profile. The Wallace Lake watershed in the NE has been studied for more than 20 years by Robert Stottlemyer and colleagues. In this watershed, the soil pH under spruce was 4.4–4.5 and slightly higher (4.6–5.0) in the deciduous forest (Stottlemyer and Toczydlowski 1999a).

Eutrophication can also be a consequence of nutrient deposition. A compilation and analysis by Aber et al. (2003) indicates that some effects on terrestrial and aquatic systems are likely to occur if the N-deposition rate exceeds approximately 8 kg $ha^{-1}yr^{-1}$ for an extended period of time. At this deposition rate, N saturation generally occurs (Aber et al. 1998); nitrogen cycling processes such as mineralization, immobilization, and retention efficiency are affected; leaching increases; and increased N is detected in surface waters. Since the deposition monitoring stations around ISRO indicate a deposition rate of approximately 3 kg N $ha^{-1}yr^{-1}$, nitrogen saturation is unlikely.

However, in susceptible systems, N saturation can occur at low deposition rates if the input is elevated over a long enough period of time (Aber et al. 2003). In the Engelmann spruce forest type of central Colorado, litter quality (assessed by many indicators) and potential net mineralization were affected at deposition rates of 3–5 kg N $ha^{-1}yr^{-1}$ (Rueth and Baron 2002). A large-scale, longitudinal study of 161 spruce-fir forests across the NE U.S. suggested that effects will show up at a deposition rate of 6–8 kg N $ha^{-1}yr^{-1}$, and that many nutrient cycling processes respond to increasing levels of deposition (McNulty et al. 1991). A study in Alaska with white spruce found many of the same effects from approximately 30 years of increased deposition (Lilleskov et al. 2001). One very striking result from the Alaska study was the responsiveness of the ectomycorrhizal fungal community, which was ten times richer at the upper end of the deposition gradient. Other sensitive organisms (e.g., lichens, phytoplankton) may show a negative effect at deposition rates of 3–8 kg N $ha^{-1}yr^{-1}$ (Fenn et al. 2003). Because streams and rivers integrate the deposition on land and deposition directly to the aquatic system, the N concentration in water has been suggested as a suitable sentinel of N-deposition problems (Williamson et al. 2008).

Old-growth coniferous forests in Colorado have exhibited different responses to low levels of fertilization. A site with small N pools and high carbon-to-nitrogen (C/N) ratios, which has received 1.1–1.7 kg N $ha^{-1}yr^{-1}$, had no soil processes affected, but foliar N levels and the amount of N in the organic horizon increased (Rueth et al. 2003). The site with higher N pools and a lower C/N ratio (deposition rate of 3.2–5.5 kg N $ha^{-1}yr^{-1}$) showed an increase in mineralization and an increase of N in the soil fraction. These results suggest how initial N-deposition effects will likely manifest in the boreal forests of ISRO, well before any N increase is noted in the streams or rivers.

The slow decomposition rate and demand for N demonstrated by the high level of nitrate and ammonium immobilization by soil profile decomposers in the Wallace Lake watershed (Stottlemyer and Toczydlowski 1999a) suggests that N is the prime limiting nutrient in the boreal forest types at ISRO, as it is elsewhere (Bonan and Shugart 1989). In boreal forests in Sweden, a fertilization effect on productivity has been noted with increased N deposition (Zackrisson et al. 2004). The additional N can cause plants to grow later in the season, but then the newer tissue is killed by the first frost. This effect has been noted in high elevation spruce-fir of New England and could happen at ISRO, given the climatic regime.

The boreal system may have low resilience to chemical stressors. Stottlemyer and Hanson (1989) determined that the concentrations of SO_4^{2-}, Ca^{2+}, and Mg^{2+} were higher in soil solution than in precipitation at ISRO sites, and SO_4^{2-} had a flux 2–3 times that of other nutrients under conifers. These findings demonstrate how acid deposition could affect a terrestrial system by setting the stage for accelerated loss of cations. The hydrogen ions associated with sulfate anions replace other cations on the soil exchange sites (Tomlinson 2003), and then the cations are leached if water moves down through the soil profile. The cations being lost are important macronutrients, needed by plants and decomposers in fairly large amounts, and have the potential to become limiting resources. An imbalance in Mg^{2+} was suggested as a possible cause of forest decline in spruce-fir forests in the NE U.S. (McNulty et al. 1991), though at higher sulfate deposition rates than are occurring at ISRO. Here, K^+ appears most likely to become a limiting resource due to reduced input since 1990.

Nutrient deficiency is particularly likely for any upland ecosystem that has low base saturation, which is common on acidic sites. However, cation loss occurs even on soils with high buffering capacity. The effect is cumulative and continues even after acid deposition is mitigated. In New England, large quantities of Ca^{2+} and Mg^{2+} have been lost from the soil (Likens et al. 1996, Friedland and Miller 1999) even after nitrate and sulfate inputs were reduced and the pH of precipitation increased (Likens et al. 1996).

A second undesirable effect that might manifest from N deposition is simplification of composition. That is, a subset of species is favored under the changed nutrient conditions and is able to outcompete other species. Simplification has not been documented in a boreal forest, but has been demonstrated in some forest fertilization trials (Rainey et al. 1999). Shifts in relative abundance of common understory species could also occur. Canada mayflower (*Maianthemum canadense*) and starflower (*Trientalis borealis*) moved in opposite directions in response to increasing nitrogen in a red pine forest, and one fern (*Dennstaedtia punctilobula*) appeared to be at a sharp competitive disadvantage as nitrogen was added (Rainey et al. 1999).

In 2004, Swackhamer and Hornbuckle concluded there is "… little indication of this problem (acid rain) … at ISRO." Factors supporting the Swackhamer and Hornbuckle (2004) conclusion include relatively low nitrogen deposition rates, an upward trend in precipitation pH from 1985 to 2006, an overall low sulfate deposition rate with a downward trend from 1985 to 2006, and the magnitude of conservation within the forest floor and soil of potassium and nitrate-N (Stottlemyer and Hanson 1989, NADP 2009a). However, N deposition cannot be completely dismissed as a potential stressor for the boreal system, which is N limited (Bonan and Shugart 1989, Zackrisson et al. 2004). The boreal system may have low resilience to chemical stressors and be susceptible to cation losses due to low buffering capacity and inherently low soil pH values (Stottlemyer and Hanson 1989, Stottlemyer and Toczydlowski 1999b). Further, N saturation can occur at low deposition rates if the input is elevated over a long enough period of time and the system is susceptible (Aber et al. 2003).

Mercury

Mercury is a persistent, bioaccumulative toxic pollutant with harmful health consequences for both humans and animals. Although it is naturally occurring, human activities have facilitated its spread throughout the environment. Mercury emissions to the atmosphere are the result of industrial processes and incineration, but the major source is coal-fired power plants. In 1999 and 2000, respectively, 56.7% of the mercury emissions in Michigan and 43.5% of those in Minnesota were related to the generation of electricity (MDEQ et al. 2003). Approximately 3,700 kg yr^{-1} of mercury were released to the atmosphere in MI, MN, and WI in that time frame (MDEQ et al. 2003).

The presence and concentration of mercury have been studied in a number of lakes at Isle Royale, and the concentration is quite variable across the landscape. In some lakes, it has reached levels in fish that are a concern. At present, Lake Superior and Siskiwit Lake are on Michigan's 303(d) list because of the presence of mercury in fish tissue (MDEQ 2008b), and of 32 ISRO inland lakes sampled in 1995 and 1996, six (Angleworm, Eva, Intermediate, Sargent, Shesheeb, and Wagejo) had fish with mercury levels that exceeded fish consumption advisory levels (Kallemeyn 2000, Drevnick et al. 2007). At first, bedrock was suspected of contributing mercury to soils and surface water. Further studies showed that mercury resulted mainly from atmospheric deposition, although some minerals associated with native copper minerals had trace amounts (Cannon and Woodruff 1999, 2000, Woodruff et al. 2003, Thornberry-Ehrlich 2008). Studies have also shown that precipitation at ISRO (Hall et al. 2005) and soils in a broad zone including ISRO (Nater and Grigal 1992) have mercury concentrations at or above the regional averages.

Crane et al. (2006) reviewed ISRO aquatic mercury studies to date, including Kelly et al. (1975), which compared mercury levels in fish in a 1971 sample to fish from museum collections (ca. 1929). Mercury levels were elevated, but there was no indication of a change over time. In 1987–1989 and 1992–1993, the MDNR sampled lake trout from Siskiwit Lake and nearshore waters of Lake Superior. They found no change over time, and fish from Siskiwit Lake met health guidelines for mercury, but some from Lake Superior did not (Crane et al. 2006). In mussels, the highest mercury concentrations have been found in Lake Richie; at 0.221 mg kg^{-1}, they were slightly above the threshold effects concentration of 0.200 mg kg^{-1} (Nichols et al. 2001a).

Kaplan and Tischler (2000) described ISRO adult common loons as having “moderate to low” blood mercury levels compared to loons in other parts of the Great Lakes and North America. Male loons had significantly higher blood and feather mercury levels than female loons (Evers et al. 1998, Kaplan and Tischler 2000). Ten percent of adult loons at ISRO had feather mercury concentrations at or above the suggested threshold level of 20 µg g^{-1} (Kaplan and Tischler 2000), and mercury concentrations were approximately ten times greater in adults than in juveniles (Evers et al. 1998). Kaplan and Tischler (2000) noted that their study results suggested a link between elevated mercury levels in fish and reproductive failure of loons on ISRO inland lakes.

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

Although mercury has been studied extensively in ISRO’s aquatic systems, little study has been done on terrestrial systems. Such study is warranted both because mercury can bioaccumulate in the methylmercury form and because of the intimate process connection between terrestrial and aquatic systems. Because most of the ISRO landscape is terrestrial and largely forested, the majority of the total mercury load for the island enters via forest ecosystems. Studies have shown that between 5% and 25% of deposited mercury will reach associated lakes (Grigal 2002). Thus, the land is an important contributor to the mercury status of lakes, and a strong majority of the incoming mercury stays in the terrestrial system for some period of time. This suggests that bioaccumulation needs to be examined, as well as direct effects on organisms in the soil.

The roots of plants act as a natural barrier to mercury, and an adsorption site, and thus there is limited uptake (Grigal 2003). The review of inputs and outputs by Grigal (2002) concluded that less than 10% of the mercury in plants is from the soil. The gas-phase elemental form adsorbs to leaf surfaces and enters the plant through open stomates. It binds to mesophyll tissues readily and is easily oxidized, and thus ‘captured,’ in the leaves. Consequently, litterfall is the dominant flux between the atmosphere and the terrestrial system, and is the primary pathway by which mercury gets to the soil sub-system. This fact explains why characteristics of the surface are an important part of the movement of mercury; the length of the growing season, the longevity of leaves, and the amount of leaf surface area all play a critical role in determining how much mercury is deposited on an annual basis. Though Hg(0) is the most abundant form, approximately 1.5% of the mercury in litterfall is MeHg.

The fate of mercury in the terrestrial system is not well understood. It is subject to volatilization at ambient temperatures and readily adheres to most forms of organic matter. For this reason, the concentration of mercury in the organic horizon on the forest floor is six times that of the mineral soil, though the total mass in the mineral soil is five times higher (Nater and Grigal 1992). At ISRO, soils burned in the 1936 forest fire have low carbon and mercury content compared to unburned areas (Cannon and Woodruff 2000).

Hg(0) and Hg(II) are the more common forms in the soil (MeHg is about 0.6% of the total), and both forms go into solution and adhere to soil adsorption sites (Grigal 2003). Thus, mercury decreases with depth in the soil profile. Under certain conditions, it is converted to the MeHg form.

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

Sulfate-reducing bacteria are the organisms responsible for the methylation of mercury (Grigal 2003, Drevnick et al. 2007). These microbes are most abundant under anoxic conditions and in places where carbon accumulates. This explains why the wetland area around a lake is a critical determinant of mercury concentration in lakes, and why beaver ponds have higher levels of mercury than lake sediments (Grigal 2003). Sulfate availability influences mercury methylation. Recent research indicates that for the last century, mercury accumulation in ISRO fish has been controlled by the deposition and cycling of sulfur. Thus, acid rain reduction programs have had the unexpected benefit of reducing methylmercury contamination of fish at ISRO and in other sulfur-limited environments; mercury levels in northern pike had “substantially declined” in the past decade at ISRO and dropped below the fish consumption advisory level at Sargent Lake, after a lag time caused desorption from soil of sulfate deposited in earlier years (Drevnick et al. 2007). The authors warned that a significant increase in atmospheric sulfur loading (such as that proposed by some to slow climate change) could reverse this positive effect (Drevnick et al. 2007). However, Drevnick et al. (2008) showed that even at the reduced levels of mercury contamination found in ISRO fish, fish health, as suggested by condition factor, is inversely related to total mercury levels in liver tissue; mercury toxicity is still a concern.

Great Lakes Shipping

Lake Superior is an important water highway for the transfer of goods and materials. The largest port on the lake, Duluth, handles 40 million metric tons (MMT) of cargo annually and is ranked first among Great Lakes ports and 18^{th} in the nation in total cargo volume. About 1,100 vessels visit the port of Duluth each year (Duluth Seaway Port Authority 2009a), and approximately 400 vessels visit the port of Thunder Bay (Thunder Bay Port Authority 2009).

Cargo ships may affect aquatic ecosystems in numerous ways, including the introduction and transfer of aquatic exotic species; emissions of air pollutants such as oxides of sulfur and nitrogen; accidents that spill cargo or fuel; normal losses of fuel during engine operation; transfer of substances to water from biocides and antifouling paints; noise and vibration; prop wash, surge, and wake; groundings and anchoring; wildlife encounters; and discharges of garbage, cargo sweepings, human sewage, dunnage (material placed between cargo during shipping), ballast water, and bilge water (Lewey et al. 2001, Transport Canada et al. 2007). Ballast water and bilge water are described in more detail below.

Many regulations are in place to attempt to prevent water pollution from both recreational boating and commercial shipping activities. The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and its amendments is an international treaty that addresses pollution from oil, noxious substances, harmful substances in packaged form, sewage, garbage, and air pollution (International Maritime Organization 1978). The Refuse Act of 1899 prohibits the throwing of any refuse into the waters of the United States (Code of Federal Regulations 1899). The Federal Water Pollution Control Act prohibits the discharge of oil or hazardous substances into U.S. navigable waters (Code of Federal Regulations 1987). All vessels with propulsion capability must have capacity to retain oily materials on board. Coast Guard regulations make it illegal to dump plastics, dunnage, lining and packaging materials, and garbage (except dishwater, greywater, and fresh fish parts) anywhere in the Great Lakes. The discharge of raw sewage from boats is also prohibited in the Great Lakes, and no discharge of treated sewage from marine sanitation devices is permitted in Lake Superior in MI (USEPA 2005). Ballast water rules are discussed in the Ballast Water section below.

Shipping Lanes and Shipwrecks

The risk of a shipwreck or accident on Lake Superior that results in a spill of fuel or cargo is not insignificant. Lake Superior's cliffs and reefs and unpredictable weather have contributed to 350 shipwrecks in the past (Minnesota Sea Grant 2005), including at least 13 within the present boundary of ISRO (Rayburn et al. 2004). The most recent shipwreck on Lake Superior occurred in November 1975 NW of Whitefish Point; the *Edmund Fitzgerald* was the largest ship ever to sink on the Great Lakes (NOAA 2000).

Approximately 1,000 large commercial vessels use the channel between Blake Point and Passage Island at ISRO each year en route from the Locks at Sault Ste. Marie to the port of Thunder Bay, Ontario (Figure 46) (Rayburn et al. 2004). In addition, at the discretion of ships' masters, vessels may use ISRO for protection during harsh weather while traveling between the locks and ports at the head of the lake (Taconite Harbor, Silver Bay, Two Harbors, Duluth, Superior, or Ashland). Typically, they seek refuge off the north shore of ISRO because of strong southeasterly or southwesterly winds or off the south shore when winds are northwesterly. Such

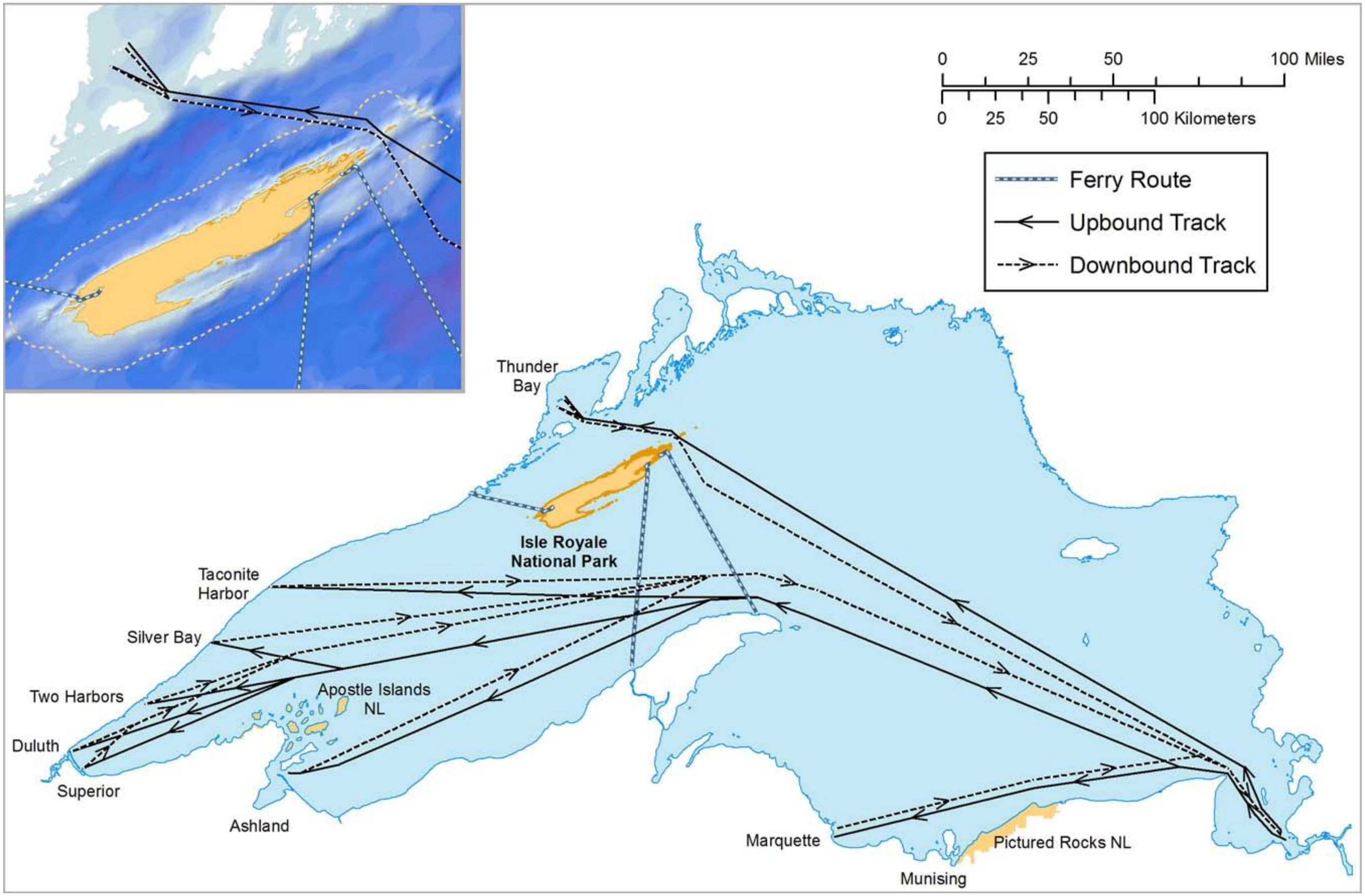

Figure 46. Lake Superior shipping lanes (NOAA 2007 a, b, c, d).

rerouting usually occurs only a few times a season, and the vessels approach no closer than a kilometer from shore (Rayburn et al. 2004). However, since accidents are more likely in bad weather conditions, the location of the designated shipping lanes around ISRO does not fully describe the degree of risk. The *Edmund Fitzgerald* had passed the south side of ISRO on her final voyage (NOAA 2000). In 1990, the M/V *Kinsman Independent* ran aground on a reef at the entrance to Siskiwit Bay because of a navigational error, but was later pulled free and proceeded to Thunder Bay (NOAA 1990).

Cargo

In 2008, the port of Thunder Bay handled 5.7 MMT grain (70% of cargo), 1.7 MMT coal (20%), 0.3 MMT potash (4%), and 0.4 MMT liquid bulk, dry bulk, and general cargo. It also announced a "breakthrough" in reaching an agreement with CN Rail to provide a "gateway" to move supplies and heavy equipment to the oil sands region of Alberta. Its first major shipment was five reactors that arrived from Japan after traveling through the Panama Canal and the St. Lawrence Seaway (Thunder Bay Port Authority 2008). Also in 2008, the port of Duluth-Superior handled 20 MMT coal and coke (48% of cargo), 17 MMT iron ore and concentrates (40%), and 3.5 MMT limestone, grain and byproducts, bulk, and general cargoes (Duluth Seaway Port Authority 2009b). Other smaller ports from which ships may pass ISRO are Two Harbors, MN, which ships iron ore; Taconite Harbor, MN, and Ashland, WI, which receive coal; and Silver Bay, MN, which ships iron ore and receives coal (Lake Carriers Association 2009).

The Great Lakes–St. Lawrence Seaway System is considered "underutilized" (Transport Canada et al. 2007), and the "Hwy H2O" program has been established to promote marine transportation and attract new shippers. As a result, the St. Lawrence Seaway Management Corporation (SLSMC) reported in 2006 that new cargoes attracted to the system had doubled since the previous year (SLSMC 2006).

Fuel and Engine Types

Both oceangoing ships ("salties") and ships confined to the Great Lakes ("lakers") carry cargo on Lake Superior. In the late 1990s, 90% of the commercial vessel trips to the port of Duluth-Superior were reportedly made by lakers, and 10% were made by salties (USEPA 1999a). In 2008, 6% of the vessels using the port of Duluth-Superior were salties (Duluth Seaway Port Authority 2009c). Also in 2008, 346 domestic (Canadian) vessels, 5 American vessels, and 64 (15%) foreign vessels used the port of Thunder Bay (Thunder Bay Port Authority 2009).

Between 2002 and 2006, between 2,075 and 2,569 trips were made into and out of Duluth-Superior by commercial vessels; 56–66% were by domestic vessels and 34–44% were by foreign-flagged vessels (Table 26) (USACE 2002, 2003, 2004, 2005, 2006). However, since Canadian vessels are foreign-flagged in this listing, these data are not useful in separating salties from lakers.

Cargo ships are very large vessels that carry large volumes of fuel. For example, a typical 300 m ship carries 689 m^3 of primarily #6 fuel oil (a heavy fuel oil [HFO] also known as residual fuel or bunker C fuel), 167 $m^3$of #2 fuel oil (a lighter diesel fuel), and 72 m^3 of lube and waste oil (U.S. Coast Guard, Greg Schultz, pers. comm. 2005). The type of fuel burned by lakers may differ from the fuel burned by salties, depending on the speed and type of the engine.

Table 26. Commercial vessel trips to and from the port of Duluth-Superior, 2002–2006 (USACE 2002, 2003, 2004, 2005, 2006).

Year	Domestic vessel trips	%	Foreign vessel trips	%	Total
2002	1,378	56	1,079	44	2,457
2003	1,227	57	924	43	2,151
2004	1,387	61	882	39	2,269
2005	1,363	66	712	34	2,075
2006	1,564	61	1,005	39	2,569

Marine diesel fuels are categorized as residual, intermediate, or distillate fuels depending on their viscosity. Residual fuels (HFO) are those that do not boil during the distillation process; they are thicker and more tar-like than distillate fuels. Intermediate fuels can be formed during the distillation process or created by blending residual and distillate fuels (USEPA 1999b).

A 2003 study of oceangoing transport ships showed that 91% of the bulk carriers and tankers, and 100% of large container vessels, were operated with two-stroke engines, and 95% of low-speed two-stroke engines burn HFO. Seventy percent of four-stroke, medium-speed engines also burn HFO, while the remaining 30% burn intermediate weight marine distillate oil or lightweight marine gas oil. Thus, the vast majority of salties burn HFO (Corbett and Koehler 2003). These heavier fuels are harder to clean up in a spill, and the two-stroke engines in which they are used operate less efficiently and generate more emissions than four-stroke engines. Lakers tend to have USEPA Category 2 engines (USEPA 2002a), which have a smaller displacement per cylinder (and are therefore less powerful) than the Category 3 engines in most oceangoing ships (USEPA 2004). Most Category 2 ships burn distillate diesel fuel similar to non-road diesel fuel (ICF Consulting 2005).

The potential harm from an oil spill resulting from a bulk cargo vessel running aground was evaluated for ISRO in Lake Superior in a simulation assuming a spill of approximately 100 m^3 of Intermediate Fuel Oil (Rayburn et al. 2004) from a ship running aground on the SW side of Passage Island in late April. The scenario’s primary impact was to the NE tip of ISRO, heavily oiling Duncan Bay, Merritt Lane, Tobin Harbor, and Rock Harbor. It was approximated that the oil would reach Blake Point in seven hours and Tobin Harbor in 18–19 hours (Rayburn et al. 2004).The researchers concluded that shoreline cleaning methods for freshwaters are not well documented and that floating platforms would be needed in the nearshore environment for cleanup operations. The greatest risks occurred under the “natural recovery” scenario and included catastrophic losses to coastal wetland macroinvertebrates; shoreline vegetation, herptiles, and birds; and nearshore fish. Critical losses were also anticipated for birds and fish in coastal wetlands, wolves, and shoreline mammals. Because of the number of populations in ISRO that are highly rare, genetically distinct, or otherwise unique, “a spill of this magnitude to Isle Royale will be a major event with regional, national and international importance” (Rayburn et al. 2004).

The Western Lake Superior Area Committee has an Area Contingency Plan that “describes the strategy for a coordinated federal, state and local response to a discharge or substantial threat of discharge of oil, and or a release of a hazardous substance within the boundaries of the coastal and inland area of Western Lake Superior." In 2006, it determined that the "worst case discharges" for a vessel in western Lake Superior are the grounding of a tanker passing on the north side of ISRO on its way to Thunder Bay, potentially spilling 9,500 m^3 cargo and 750 m^3 bunker fuel, or a freight vessel grounding and discharging 600 m^3 of fuel in the form of a light to intermediate grade oil (Western Lake Superior Area Committee 2006).

In 1993, NOAA identified and mapped 14 shoreline types in ISRO as part of a USEPA assessment of shoreline vulnerability to oil spills (USEPA Region 5 2000). Areas of low sensitivity included 193 km of exposed rocky cliffs, shelving bedrock shores, and riprap revetments, groins, and jetties. Low-medium sensitivity areas were 115 km of sand beaches, exposed flats/shelving bedrock shores, mixed sand and gravel beaches, and gravel beaches. Medium-high sensitivity areas were 216 km of sheltered scarps in bedrock, sheltered solid (hu)man-made structures, and sheltered vegetated low banks. High sensitivity areas were 10.2 km of wetlands (Table 5, Figure 9).

Bilge Water

Bilge water is the water that collects at the bottom of the hull of a ship or boat. It is often contaminated with fuel as well as oily materials used to lubricate moving parts. Bilge water may also carry solid wastes, and often has a high oxygen demand (Copeland 2005).

Although MARPOL 73/78 specifically forbids the discharge of bilge water that produces a sheen or has an oil content of more than 15 mg L^{-1} (International Maritime Organization 1978), illegal bilge discharges do occur. Specific data for the Great Lakes were not found, but data on ships' practices in the ocean may provide some insight into possible risks to Lake Superior. Currently, 50% of the oil entering the sea from shipping activities comes from bilge and fuel oil sludges, mainly due to the lack of onshore reception facilities, according to the Ocean Conservancy (2001). A study of foreign-flag cruise ships found 72 cases in which they had discharged oil or oil-based products into U.S. waters between 1993 and 1998 (USGAO 2000).

In 2002, the World Wildlife Fund of Canada reported that 300,000 birds are killed each year on Canada's ocean coast because of illegal bilge discharges (Wiese 2002). Bird mortality rates in the U.S. were significantly lower. Fines up to 1,000 times higher in the U.S. were thought to dissuade more ships from discharging in U.S. waters.

Ballast Water

Ballast water is water carried in special holding tanks on a ship to allow for trimming and more efficient and safe sailing. Ballast water is usually taken on board when cargo is unloaded and discharged when cargo is loaded. Concerns with ballast water discharges center around the possible introduction of exotic invasive species. Ballast water contains organisms ranging from bacteria and algae to worms and fish. Grigorovich et al. (2003a) identified 67% of the 43 invasive aquatic animal and protist species introduced and established in the Great Lakes since 1959 as having originated in ballast water from commercial vessels.

All oceangoing ships are required to exchange their ballast water in the open ocean before traveling into the Great Lakes. However, 90% of ships that enter the Great Lakes are reported as "no ballast on board" (NOBOB) because they are filled with cargo (Grigorovich et al. 2003a).

Because the ballast tanks of NOBOB ships are not completely empty, some organisms survive in sediments or the small remaining amount of water in the tanks. As the ships unload cargo, they take on additional ballast water from other Great Lakes ports. From 1981 to 2000, 70% of NOBOB ships made their final stop at Lake Superior, where they discharged their mixed ballast water as new cargo was loaded. Lake Superior also received about 75% of the ballast water discharged by transoceanic ships that enter the Great Lakes with ballast on board (Grigorovich et al. 2003b). Thus, Lake Superior appears to be at high risk for the introduction of exotic species. However, Lake Superior's oligotrophic nutrient state, limited primary productivity, and high ratio of profundal-limnetic to littoral zones may be mitigating factors that limit aquatic invasive species (Grigorovich et al. 2003b).

The State of Michigan has established a general permit system for ballast water reporting on the Great Lakes. Permit holders must demonstrate that they do not discharge ballast water into state waters or that they have treated the water with hypochlorite, chlorine dioxide, deoxygenation, or ultraviolet light preceded by suspended solids removal . The permit system does not apply to lakers that move only within the Great Lakes (MDEQ 2006). The MDEQ maintains a list of oceangoing ships that report compliance with the "Code of Best Management Practices for Ballast Water Management" provided by the Shipping Federation of Canada and of non-oceangoing vessels that report compliance with the "Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species within the Great Lakes by United States and Canadian Domestic Shipping" provided by the Lake Carriers Association and the Canadian Shipowners' Association to the MDEQ. The MDEQ listed 244 ships as of April 6, 2009; 62 were from the U.S., 76 from Canada, and the remainder from 14 foreign nations (MDEQ 2009a).

In April 2005, a U.S. District Judge ordered the USEPA to repeal regulations exempting ship owners from obtaining pollution discharge permits for ballast water, and in September 2006, a federal court ordered the USEPA to develop new ballast water regulations under the Clean Water Act by September 2008 (Ocean Conservancy 2006). In 2008, the U.S. House of Representatives passed a ballast water control measure, but it was never signed into law, and the USEPA issued a general permit for ballast water discharges. As of May 15, 2009, the Department of Homeland Security (which contains the U.S. Coast Guard) had submitted a Ballast Water Discharge Standard Notice of Proposed Rulemaking package to the Office of Management and Budget (USCG 2009).

Ferry Service

ISRO is served by the *Ranger III*, a 50 m ship that is the largest vessel operated by the NPS (NPS 2008a). It operates from Houghton to Mott Island, Rock Harbor, and occasionally to Windigo, and can carry 128 passengers and 590 MT of cargo, including refrigerated and frozen goods, dry goods, and 28,000 L of #2 fuel oil (LeLievre 2006, NPS 2008a). In an average year, it transports 300 recreational and NPS work boats to and from the island. It has a strengthened bow and is capable of breaking ice in the spring (NPS 2008a). The *Ranger III*'s ballast water currently undergoes treatment to destroy aquatic invasive species.

Commercial ferry service is provided by two carriers. The Isle Royale Line operates the 30 m *Isle Royale Queen IV* from Copper Harbor to Rock Harbor. The Grand Portage–Isle Royale Transportation Lines operates the 18 m *Voyageur II* from Grand Portage to Windigo, McCargoe

Cove, Belle Isle, Rock Harbor, Chippewa Harbor, and Malone Bay and the 19 m *Wenonah* from Grand Portage to Windigo. Seaplane service is also available from Houghton (Isle Royale and Keweenaw Parks Association 2009). Risks associated with these forms of transportation are similar to those for cargo ships, most notably accidental transfer of aquatic invasive species and fuel releases.

Recreational Boating

All ISRO waters are closed to water skiing and personal watercraft (PWC). No-wake zones are established in all or parts of Todd Harbor, Johns Island, Barnum and Washington Islands, Hay Bay, Wright Island, Malone Bay, Chippewa Harbor, Conglomerate Bay, Moskey Basin, Lorelei Lane, Tobin Harbor, Merritt Lane, Passage Island, Duncan Bay, Five Finger Bay, Stockly Bay, Lane Cove, the Robinson Bay/Pickerel Cove/Belle Harbor Area, Crystal Cove, and McCargoe and Brady coves. Inland lakes can be explored only by portaging in and paddling (NPS 2004b).

In general, the major impacts of motorized watercraft on aquatic ecosystems may include sediment resuspension, water pollution, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion. The mechanisms by which these impacts occur include propeller contact with plants and animals, turbulence caused by the propulsion system, wakes, noises, and movement that disturbs wildlife (Asplund 2000). Recreational boating may also help to transfer invasive species; this effect is discussed in the Introduction Pathways and Control Strategies subsection of the Exotic Species-Aquatic section.

Conventional two-stroke outboard engines contribute to both air and water pollution because they burn gasoline inefficiently and discharge as much as 30% of their fuel to the environment. Direct-injection two-stroke engines are cleaner than conventional engines, but still not as clean-burning as four-stroke engines. For example, when 90-horsepower gasoline-powered outboard motors are compared, a conventional two-stroke engine creates 164 g of smog-forming pollution per kilowatt-hour, while a direct-injection two-stroke engine creates 45 g and a four-stroke engine creates 11 g (California Environmental Protection Agency Air Resources Board 1999).

The primary water and sediment pollutants of concern from marine engines include MTBE (methyl tertiary butyl ether); PAHs; BTEX (benzene, toluene, ethylbenzene, and xylene); and heavy metals such as copper (NPS 2002). In 2003 and 2004, Clements and Cox (2006) sampled 12 locations in ISRO for 39 PAH compounds. Background sites were dominated by petrogenic PAH compounds (of natural origin); marina sites were influenced by pyrogenic PAH compounds, which are produced by the burning of fossil fuels, industrial processes, and emissions from combustion engines. Highest concentrations were found at Rock Harbor marina. The amphipod *Diporeia* spp. was consistently more abundant at reference sites than at paired marina sites, although results in 2004 were statistically significant at only one site. The survival of another amphipod, *Hyalella azteca*, was negatively correlated with PAH concentrations normalized to total organic carbon concentrations in toxicity tests. However, the only statistically significant difference ($p \leq 0.05$) was between Rock Harbor marina and its reference location. The authors considered this finding “not surprising” because Rock Harbor marina is the only ISRO location to exceed the threshold effect concentration for PAHs (Clements and Cox 2006).

Water Use and Wastewater Treatment

The ISRO Water Resources Management Plan (Crane et al. 2006) cites a 2001 ISRO Business Plan to document the presence of nine electric generators, seven water treatment facilities, one wastewater treatment plant, 115 privies (including 90 pit toilets at 36 campgrounds), eight residential septic systems, and five remote ranger and research stations with individual solar electric and water treatment systems as part of ISRO's utility infrastructure.

ISRO has three federal-regulated transient non-community public water supplies (supplies that serve at least 25 people at least 60 days of the year, but do not serve the same people over six months of the year) (USEPA 2009f). Mott Island serves 75 people day^{-1}, while Windigo serves 115 and Rock Harbor, 335 (USEPA 2009f). No violations of water quality standards have been noted for these three facilities in the past ten years.

With water shortages becoming more prevalent nationwide, concerns have been raised about the possibility that Great Lakes water will be sold or diverted to other parts of the nation or world. The Great Lakes–St. Lawrence River Basin Water Resources Compact of 2005 would prevent new or increased diversions of water from the Great Lakes except under limited circumstances, mainly for public water supplies for counties that "straddle" the Great Lakes basin (Council of Great Lakes Governors 2005). The compact was approved by the U.S. Senate and House of Representatives and was signed into law by President George W. Bush in October 2008.

ISRO now has two wastewater treatment systems with National Pollution Discharge Elimination Permits. The Mott Island facility has a very small flow (2.6 m^3 day^{-1}, or 700 gallons day^{-1}) and participates in a self-monitoring annual certification program. The larger Rock Island facility discharged 56 m^3 day^{-1} (14,700 gallons day^{-1}) in 2008 and 35 m^3 day^{-1} (9,400 gallons day^{-1}) in 2009 (USEPA 2009f). The discharge is monitored for various chemical parameters (Table 27).

Table 27. Results of monitoring for chemical and biologic parameters in 2008 and 2009 at the Rock Harbor wastewater treatment plant, Isle Royale National Park (USEPA 2009f).

Parameter	2008	2009
DO (minimum) (mg L^{-1})	4.57	6.93
pH	6.62–7.47	7.22–7.36
Total Suspended Solids (average) (mg L^{-1})	2.24 (92.8% removal)	1.98 (98.1% removal)
TP (mg L^{-1})	0.492	0.503
Chlorine	0	0
Fecal bacteria (MPN/100 mL)	1.4	0
Biological oxygen demand (average) (mg L^{-1})	1.22 (97.8% removal)	1.50 (98.6% removal)

No violations of discharge requirements were reported. The plant won a National Wastewater Management Excellence Award in 2001.

Natural and Altered Terrestrial Disturbance Regimes

All terrestrial ecosystems in the temperate and boreal regions have, throughout their evolutionary history, been subjected to a suite of disturbances (White 1979, Bonan and Shugart 1989). Thus, disturbance is the factor most integral to the short- and long-term dynamics of a plant community. The disturbance history of ISRO is poorly known due to very limited study, but the historic disturbance regime for communities at ISRO must be described to the extent possible to help understand the current vegetation patterns and how the vegetation is likely to change in the future.

A complete disturbance regime is described by these components: frequency, intensity (a measure of the force of the phenomenon), timing and season, extent, duration (in some cases), variation in frequency, and variation in intensity for each type of disturbance (White 1979, Sousa 1984).

Disturbances with severe impacts have significant and immediate effects on vegetation and abiotic conditions as well as important indirect effects (Halpern and Franklin 1990). These indirect effects often stress a significantly larger number of organisms and create an opportunity for invasion and establishment of novel species. In some cases, disturbance is necessary for the maintenance of specific communities or landscape patterns (Sousa 1984, Turner et al. 1997, Barnes et al. 1998).

A potentially important factor whose precise influence at ISRO is unknown is the heterogeneous physiography of the area. Work elsewhere has conclusively demonstrated that topography exerts a strong influence on some disturbance components. Slope, elevation, and aspect result in changes in radiational load and soil water, which in turn influence the vegetation. Thus, fire intensity and spread can change due to fuel combustibility (moisture differences) and fuel complex (community) structure (Graham et al. 2004). Wind damage often varies by slope, species, and canopy position (Foster 1988, Canham et al. 2001).

Boreal Forest

The fire regime for boreal forests in ISRO has not been fully described, although the fire regimes of boreal forests in general have been well-described in northern MN (Heinselman 1973, Frelich and Reich 1995, Frelich 2002); parts of Canada (Bergeron 1991, Arseneault and Sirois 2004); and Alaska (Viereck 1983). However, the fire return interval (FRI) is variable across this broad region, with a range of 65–200 years, and reports from other sites may not apply well to ISRO (NPS 2004a). The study by Bergeron (1991) in Quebec was the only study found to compare fire regimes on islands and an adjacent mainland in the boreal region. The islands experienced more fires than the lakeshore, and fire years were uncorrelated. Bergeron (1991) also documented a greater range of fire sizes on the islands. In both landscapes, fire frequency had declined over the past approximately 120 years (i.e., from 1870 to 1990). The FRI on the islands was 74 years prior to 1870 and 112 years thereafter. Thus, it would be incorrect to assume that fire was less common or consistently smaller on ISRO than on the mainland.

The Isle Royale Fire Management Plan (FMP) (NPS 2004a) cites a compilation (Martin 1988) of documents that describe fire occurrence since 1848, but expresses concern about the accuracy of extrapolation based on this time period. The concern is warranted; this period is too short, given the probable fire cycle, to describe the regime well. It does provide a complete picture of fire frequency and extent since approximately 1900 but understates fire occurrence during the 'Mining Era.' A careful reading of Karamanski et al. (1988) adds to the characterization of the regime pre-1900.

The FMP also draws on sediment cores taken by Cole et al. (1995) to characterize fire occurrence over the past 4,500–5,000 years. Unfortunately, the information in Cole et al. (1995) is qualitative and incomplete. The statement that the SW end of the island has "... seen little fire over the past 4,500 years" may be true but is based on very limited data. Extrapolating from a few cores with very limited spatial coverage is tenuous. The SW end of the island is not a homogenous landscape; there are notable changes in topography, and there is a significant amount of boreal forest near the lakeshore. The FMP concludes, based primarily on Cole et al. (1995), that "… fire was more frequent and/or severe prior to settlement" on the NE half of the island. This statement may be accurate, but it is a coarse characterization of the fire regime without sufficient data to warrant a solid conclusion. The information presented by Janke (1975), based on work by graduate student Randal Raymond, provides a useful extension of probable fire history. This student determined the charcoal influx curve for four lakes (Angleworm, Chickenbone, Siskiwit, and Wallace). These data (Figure 1, Janke 1975) reflect, broadly, fire occurrence and intensity in the surrounding watershed over a 1,000-year period. The four curves suggest a) that fire was constant at an interval of approximately 50 years at all four sites; b) there were more severe fires or periods of greater fire activity at one or more points in time; and c) the Wallace Lake watershed experienced more fire than the other three (Janke 1975).

Though the fires since the 1930s are well documented (NPS 2004a), information is sketchy about the role of fire across the island. More importantly, little is known about the historic range of variation in the fire regime, other than the two limited studies cited above. Extensive work in Canada has documented notable shifts in the fire cycle within the past 500 years or less (reviewed in Johnson et al. 2001) and over longer time scales in a black spruce–jack pine forest (Arseneault and Sirois 2004).

In addition to the above, there are several lines of evidence to suggest that the boreal forest fire regime is different than presented in the FMP. This evidence includes a) lightning-caused fires noted in the FMP are equally common in the SW and NE parts of the island; b) since the boreal forest type is more flammable than pure birch-aspen, or any of the northern hardwood types, then the significant amount of boreal forest in the SW half should tend to make the regimes on the two ends more similar; and c) pine is abundant in the pollen record (Flakne 2003), which suggests frequent fire occurrence (Arseneault and Sirois 2004).

We can be confident that the historic (pre-1840s) disturbance regime of ISRO included fire (unknown frequency, probably long-interval high-severity fire); frequent, small-scale canopy gaps; beaver activity; and spruce budworm outbreaks (unknown frequency, sometimes of high severity). A budworm outbreak in the 1930s killed a large number of trees, mostly balsam fir. Herbivory by the budworm during outbreaks has frequently impacted large areas across eastern North America (Peltonen et al. 2002) since at least the 1920s. However, it is not known how many other outbreaks also occurred on ISRO. Different types of disturbance can readily interact, as was noted for the 1936 fire; fire in an area impacted by the budworm was more severe than in the non-impacted area. The same is true for widespread windthrow.

Since 1840, the disturbance regime has changed in several ways: a) more human-caused ignitions occurred between 1843 and approximately 1940 or perhaps a little later; b) a major herbivore (moose) became part of the regime; 3) widely scattered, but locally important removal of overstory trees occurred during the mining era; and 4) fire suppression occurred after approximately 1940. The net effect on the regime is unclear, because humans increased fire frequency (at the scale of the island) during one period and reduced it in another. Furthermore, the scientific consensus is that 20th-century fire suppression has not yet altered the fuel load, fuel structure, or fire regime in boreal forests in any significant way (Johnson et al. 2001). Therefore, we cannot conclude that the fire regime has been altered substantially by humans since 1840. We can be confident that a portion of the island, concentrated within a band along the shore, had elevated canopy disturbance and non-fire mortality rates from approximately 1845 through 1940.

Thus, we have an incomplete picture of the historic disturbance regime for the boreal forests in ISRO. This is especially important for the two more severe types of disturbance—fire and spruce budworm outbreaks—because they determine, to a large degree, landscape structure. Of equal importance is the lack of information about the historic range of variation in the regime (Landres et al. 1999).

Northern Hardwood Forest

The diverse nature of the overstory in the northern hardwood type (Allen 1988) usually results in less impact from outbreak-type insects or pathogens. Though the northern hardwood forests on ISRO are less diverse than their mainland counterparts, the tree composition is variable enough so that this general characterization probably applies. Consequently, the long-term dynamics of the northern hardwood forest type are driven by low-to-moderate intensity disturbances, primarily abiotic, and the life history traits of the constituent species. Based on data from MI's Upper Peninsula, a typical forest would have 5.7–6.9% of its canopy die or be killed every decade (Frelich and Lorimer 1991). This translates into a canopy residence time of less than 175 years. In contrast, severe disturbances reoccur on very long intervals (>800 years) (Whitney 1986, 1987, Frelich and Lorimer 1991). The FRIs for all sites, pre-suppression period, were 566 years for surface fires and 2,797 years for canopy-killing fires (Frelich and Lorimer 1991). Thus, fires of any type were very infrequent in this forest type pre-settlement; return intervals for spreading surface fires range from 300 to 900 years depending on the site and assumptions of the calculation. Note that this is more frequent than implied by Cole et al. (1995). Though we have no direct estimates of gap-formation rates for ISRO, it is likely that the northern hardwood forest type rate is similar to that on the mainland because the agents of damage (ice, wind, pathogens, and secondary insects) are common there also. Because this forest type occurs at higher elevations on the island, we would expect higher rates of wind-caused disturbance than on the mainland, other factors being roughly equal.

The recent (post-settlement) and future (next 25–50 year) disturbance regime has not been and will not be significantly different than the pre-settlement disturbance regime. This is due to the highly infrequent and limited extent of fires (Frelich and Lorimer 1991) and the dominance of the regime by localized, small-scale abiotic (wind and ice) and biotic (endemic insects and pathogens) events; these small scale and generally low-severity events have largely been unaffected by anthropogenic activities in the 19th and 20th centuries. As in the boreal forest, the period of anthropogenic fire exclusion is too short to have made a difference from the natural regime (Johnson et al. 2001). Since this forest type is found further inland and is not readily accessible, it was largely spared from harvesting and local use during the mining and resort eras.

Other Upland Conifer Forests

Fire is one of the most important types of disturbance for all pine forests in the Great Lakes region (Heinselman 1973, Whitney 1986). ISRO includes forest types dominated by white, red (*Pinus resinosa*), and jack pines (TNC 1999). A strong majority of the jack pine at ISRO occurs in three community types: boreal pine rocky woodland, jack pine–black spruce/feathermoss forest, or jack pine–black spruce/feathermoss woodland phase. The latter two types have more moisture than typical jack pine forests across the Great Lakes. In the boreal pine rocky woodland, the white pine present is most commonly found mixed in with broadleaf species (aspen and birch), the trees are small, and the vegetation is patchy. These conditions, plus the patchy, small-scale nature of these forest types at ISRO and the climatic conditions, all suggest that fire occurrence would be less frequent in these forest types on the island than in their mainland counterparts.

Though there is a considerable body of work on fire from the region, there are no published studies from ISRO. As a starting point, Whitney (1986) estimated that FRIs for high-intensity fires in MI's Lower Peninsula were 80–167 years (generally <100) for jack pine and 120–260 years for mixed pine forests. Heinselman (1973, 1981) reported FRIs of 50 years for jack pine and 180 years for mixed pine for the Boundary Waters Canoe Area of northern MN. Frissell (1973) reported a similar value (150 years) for a mixed pine forest in central MN. Cwynar (1977) examined an 18,600 ha preserve in Ontario dominated by white pine and aspen and found a FRI (for a fire anywhere in the park) of 14 years, a FRI for 'major fires' of 45 years, and a rotation of 70 years.

Thus, there is general consistency among studies of high-intensity fires, with a shorter FRI for jack pine than the other pine types. The fuel characteristics and weather at ISRO probably mean that the FRI is at the upper end of the range noted elsewhere, and that there are fewer, high-intensity fires, making the fire regime in jack pine areas roughly equivalent to that of the boreal forest. Other components of the disturbance regime for upland conifer forests undoubtedly included small-scale canopy damage and mortality, as noted for the types above. The current disturbance regimes in upland conifer forest types at ISRO are probably quite similar to those of the boreal forest, with two exceptions: less frequent windthrow for those sites that are drier and have modest soil depth and the potential inclusion of blister rust for white pine (described in more detail in the Terrestrial Invasive Species section). The regime has changed in several ways since European settlement, mostly in line with the impacts noted on the boreal forest types: 1) more human-caused ignitions between 1843 and 1940, 2) widely scattered but locally important removal of white pine overstory trees during the Mining Era, 3) fire suppression after approximately 1934, and 4) potential white pine blister rust mortality.

Lowland Forests

Physiography, soil characteristics, water movement, and tree characteristics collectively determine the primary form of disturbance—windthrow—in these community types. Shallow roots and growth on soils that are commonly saturated and have high levels of organic matter make trees susceptible to windthrow. When a tree is windthrown, microtopographic heterogeneity in the form of pit-and-mound topography is created. The mound part provides a microsite that is considerably drier than the area in general. The bole of the downed tree also provides surface heterogeneity that is important for the regeneration of some plant species (e.g., white cedar [Rooney et al. 2002] and conifers in general [St. Hilaire and Leopold 1995]). As a result, plant diversity is greater because the microsites provide places for species that are not quite so tolerant of saturated soils to survive.

As one might expect, the return interval for high-severity fire is quite long in lowland forests of MI's Lower Peninsula (1,400 years in the hemlock–white pine–northern hardwoods type and 3,000 years in the swamp conifer type) (Whitney 1986), and probably also at ISRO. Since dominant species, especially white cedar, have natural resistance to pests, insect and disease-related disturbance had a minimal influence historically. One exception is tamarack (larch); its occurrence has been greatly reduced by the larch sawfly (described in more detail in the Terrestrial Invasive Species section).

Human Effects on Terrestrial Resources, 1840–1940

Mining

Activity associated with copper mining between approximately 1843 and 1920 added several new anthropogenic disturbances to the landscape and had pronounced effects on part of the island. Though the mine sites were strongly concentrated near the lakeshore (Figure 47), their impacts extended inland. Mining-related impacts included the cutting of trails and roads from docking points and the use of fire. Karamanski et al. (1988) state that prospectors commonly used fires in their searches for areas to mine. Two such fires are evidence of the extent to which mining has impacted the park. The Island Fire in 1875 burned for three days before it went out, and in 1892, a fire that was started near Todds Harbor spread for three weeks before rains put it out.

Though most mines and mining camps were small, and hence had a small impact area, each required some clearing and one or more small roads for access. A few of the mining camps grew to considerable size. The Island Mine north of Siskiwit Bay (1874–1875) had its own sawmill. The Minong Mine site (1875–1891) had at least 150 people and may have swelled to 300 for a short period. The Island Mine site had the largest number of occupants (approximately 600) but was active for a shorter period of time than the Minong site (Karamanski et al. 1988). These mines were farther inland than most, so sizable roads were pushed through the vegetation to bring in wagons with supplies.

Logging

Mining operations preferentially used tamarack, white pine, and white cedar trees (Karamanski et al. 1988). Relatively large quantities of wood were necessary to support even a mid-sized mine, and near the larger mines, wood utilization reached a high level. Karamanski et al. (1988)

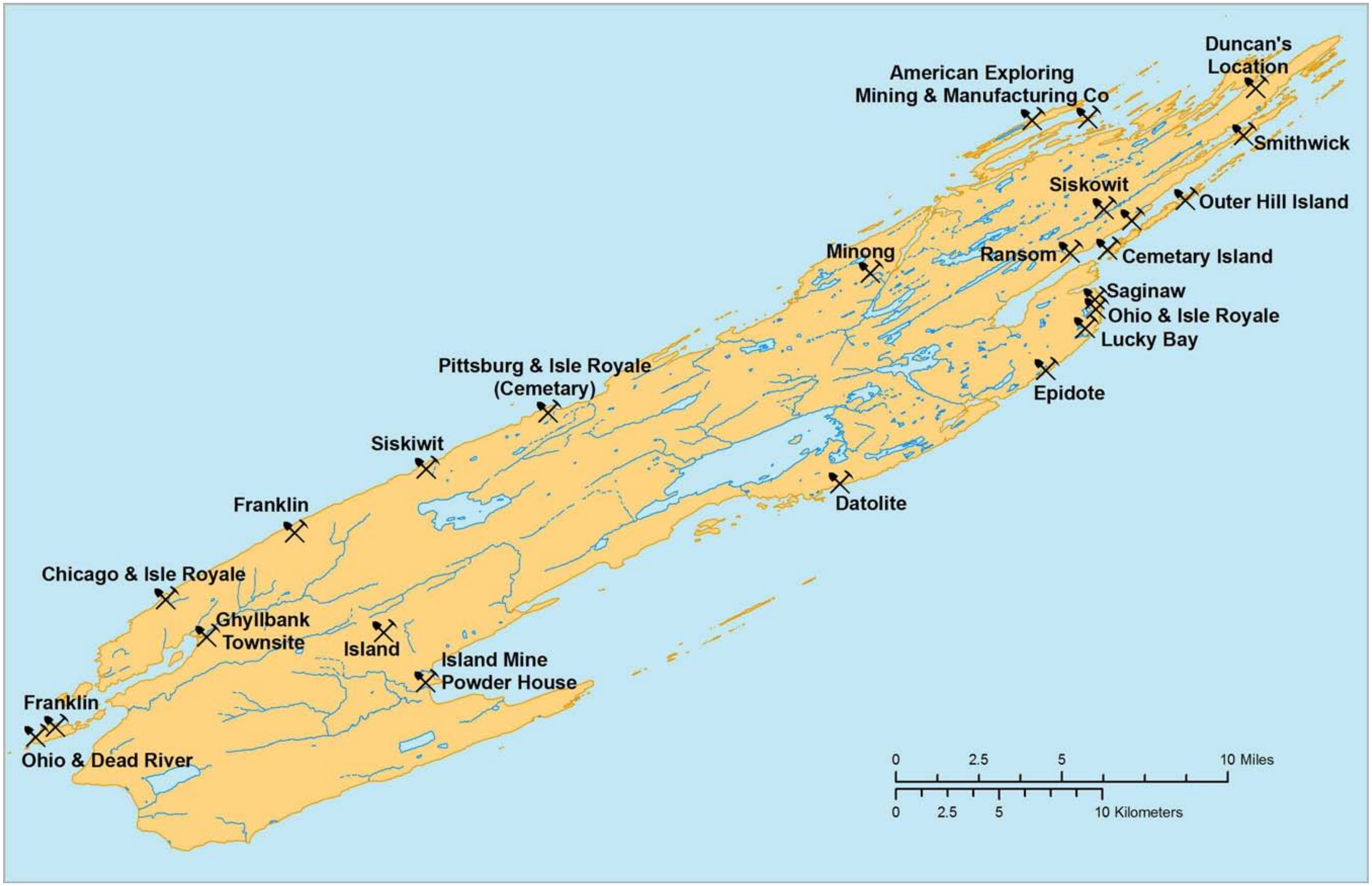

Figure 47. Location of mines operated between 1843–1920, Isle Royale National Park (after Karamanski et al. 1988, NPS 2004d).

stated “The mines consumed great quantities of wood ….. many areas were effectively cut as if there had been commercial lumbering.” Utilization by families (e.g., home construction) and personal use (heating, cooking) would have involved other species. These disturbances were concentrated near the mines and largely within 2–3 km of the shoreline. With the exception of the forest immediately adjacent to the village/mine site, harvesting would have been somewhat selective by size and/or species of tree.

The isolation of the islands and the rather mediocre value of the timber resource greatly reduced the level of commercial logging at ISRO, compared to adjacent areas in MN, WI, and MI. Meager commercial logging began at ISRO in the 1890s. In 1894–1895, extensive logging took place in forests near Washington Harbor, and the paper mills in Duluth began purchasing spruce, but only a small amount was actually cut and transported from the island. Practically speaking, there was no significant commercial logging prior to 1920. In 1922, a precursor of the Mead Corporation bought 26,900 ha near Siskiwit Bay. Though a camp with approximately 200 men was set up on the SW shore of Siskiwit Bay, much of this acreage was never cut. The Minnesota and Ontario Paper Company harvested some timber in the mid-1930s, also near Siskiwit Bay; these two efforts were the last commercial operations on the island (Karamanski et al. 1988). Timber utilization was much heavier in the vicinity of the Island Mine; however, it was short-lived and concentrated near Lake Superior.

The direct and indirect impacts of logging on the understory are an important and valid concern (Gilliam and Roberts 2003). This is true because the vast majority of plant species are found in this layer, and there is potential to substantially change the composition by harvesting (Craig and Macdonald 2009). The abundance and composition of the ground layer also can play an important role in nutrient retention, as documented in Appalachian spruce-fir (Moore et al. 2007) and boreal forests in Sweden (Nilsson and Wardle 2005). The more intensive the tree utilization, the greater is the potential for a reduction in diversity (Craig and Macdonald 2009) and/or the initiation of a novel successional pathway (Roberts 2004). However, many understory species survive a harvest, even a clearcut (Crowell and Freedman 1994), and thus the understory can be more diverse after a harvest than before (Crowell and Freedman 1994, Gilliam and Roberts 2003). This net increase involves the loss of a few late-successional species and the invasion of many pioneer species. Whether or not logging has decreased the vascular plant richness on ISRO is unknown due to the lack of pre-logging data or recent, detailed studies. Climate, growth rates, and dispersal capacity of many species affect recovery time from severe disturbance. In southern mixedwood boreal forests of Saskatchewan, understory richness was still declining 200 years after stand-replacing fires (Chipman and Johnson 2002).

Given the history and distribution of timber utilization, the boreal forest and the forests containing northern white cedar are the two broad community types likely to have been impacted, but only in scattered locations around the island, and especially in the vicinity of Siskiwit Bay. Studies in different types of boreal forest have noted that disturbance of the forest floor is as important as, or more important than, the magnitude of overstory reduction (Fleming and Baldwin 2008, Craig and Macdonald 2009). This means that season of harvest (Wolf et al. 2008) would have played a role, as well as the method of extraction (machine vs. horse, etc.). Given that all commercial logging occurred prior to 1936, the method of extraction should have minimally disturbed the forest floor and soil, unless the soil was wet at the time.

We can only hypothesize, due to lack of data from the island, but it seems unlikely that logging reduced native plant diversity. However, it is probable that some areas near the shore and in the vicinity of Siskiwit Bay are still recovering from the harvesting that occurred between the mid-1800s and the mid-1930s.

Fragmentation

All roads, the few railroad tracks installed by the miners, and even trails create a narrow break in the canopy and thus have some edge effects. In addition to breaking up extensive areas of vegetation, these human-created breaks and corridors can serve as 'conduits' for exotic plants (Gelbard and Belnap 2003, Watkins et al. 2003). In a northeastern WI landscape dominated by hardwood forests, exotic species were most prevalent within 15 m of roads; however, native richness and diversity were equal to interior conditions within 5 m of the roads (Watkins et al. 2003). Tyser and Worley (1992) studied alien species along three transportation corridors in grasslands of Glacier National Park: primary roads, secondary roads, and backcountry trails. Surprisingly, they found equal abundance of alien species 2, 25, and 100 m from the trails. Thus, the potential for exotic invasion at ISRO may be much higher than the level of human impact and utilization in the interior would suggest. Invasiveness can differ significantly among community types, and thus we do not know if 15 m is about the limit, or if exotics might show up 100 m away from a trail. See the section below on Exotic Plants for discussion of the possible impacts by exotic species.

Recreational Effects and Visitor Use

Beginning in the late 1800s, a number of resorts were established on Isle Royale. They utilized wood for construction and heating purposes, and also cut trails toward the center of the island for their guests. As with the mining effort, very few resorts lasted long, and all were located very close to the lake's shore. Thus, the impact of this activity was also quite localized. The negative impacts of the past resort industry on terrestrial systems could include soil compaction, fragmentation of the vegetation, reduction or elimination of native species, and introduction of exotics. Soil compaction would be highly concentrated, if present, and is most likely to have occurred in areas that are currently devoted to non-wilderness objectives.

As noted in the introduction, ISRO had an average of 16,350 visitors yr^{-1} from 2004–2008 (NPS 2009). A wilderness and backcountry environmental impact statement prepared in 2005 (NPS 2005) documented potential visitor impacts. The effects of campground development and use may include increased light intensity when sites are cleared, increased runoff, littering, water pollution, track formation, soil compaction and loss, and an increase in fire frequency (Sun and Walsh 1998, NPS 2005). These changes create damage to and loss of vegetation, changes in plant composition, and ideal conditions for the establishment of weeds and exotic plants. Foot trampling by campers and hikers reduces plant cover, biomass, and species richness (Cole 2004). In a study conducted in canoe-accessible campsites in low-elevation riparian forests in the eastern U.S., most vegetation had been eliminated, and a shift in the remaining vegetation from forbs to graminoids was observed (Marion and Cole 1996).

Trail use can cause erosion, especially when hikers widen trails to avoid wet and muddy patches (NPS 2005). Hiking trails may get enough use to cause soil compaction. Even backountry recreation can have negative impacts. In a study of six midwestern forest sites at three nature preserves, Adkison and Jackson (1996) found that areas along the trails had reduced litter cover at five of six study sites, and significant soil compaction at all six, compared to sites 10 m away from the trails. In hiking and camping areas, an array of damages may show up; tree damage is a common form and can be rather pervasive (Reid and Marion 2005). This, however, is highly localized and probably does not cause long-term harm. The possibility of local extirpation of an uncommon or rare species is relatively high because the vast majority of the species of concern occur near the shoreline (see Upland Resources section) where recreation, logging, and mining were concentrated. The lack of a species list from the 1800s precludes any rigorous assessment of the extent of this possible impact to date. Nonetheless, this threat merits careful consideration as it relates to recreational use of different areas of the park.

Many visitors to NPS and USDA–Forest Service campgrounds perceive campfires to be an important aspect of their camping experience, but numerous aesthetic and ecologic impacts have been attributed to campfires (Reid and Marion 2005). In an extensive literature review, Reid and Marion (2005) report that the resource damage attributable to campfires includes "fire site proliferation; overbuilt fire sites and associated seating arrangements; fuel wood depletion; sterilized soils; charred rocks and tree roots; ash and charcoal buildup; semimelted plastic, glass, and metal trash; chemical contamination of soils; unburned food, which attracts wildlife; tree damage and felling; and vegetation trampling associated with firewood collection." Studies conducted at ISRO and two other national parks (Great Smoky Mountains and Shenandoah) showed that the total number of damaged trees at campsites where fires were allowed ranged from 190 to 1,128; ISRO had 281 (Reid and Marion 2005). Firewood collecting affects the availability of woody material and density of saplings around campsites (Cole 2004). Trampling in search of firewood causes soil compaction and changes the composition of the understory. The gathering of downed wood for fires may also reduce site productivity, especially on droughty or infertile soils, and habitat for spiders, arthropods, birds, and small mammals (Cole and Dalle-Molle 1982). Burning garbage in campfires produces toxic metals that remain in the ash and may be washed into surface waters during high water or storms. Plastic cup lids, chip bags, and plastic forks and spoons contribute lead to ash; colored cardboard boxes contribute cadmium; and cigarette and candy wrappers contribute mercury (Davies 2004).

Detailed research on noise levels and their effects on the natural environment has not been done at ISRO. However, the draft wilderness and backcountry management plan for ISRO (NPS 2005) included an inventory of human-made sources of noise and light within the park. These included human voices; motorboats operated by visitors and park personnel; seaplanes; aircraft; emergency medical helicopters; generators at Windigo, Rock Harbor, and Mott Island; chainsaws and other power tools used by park personnel; and foghorns at Passage Island and Rock of Ages. Light pollution within ISRO originates from residential areas within the park and Thunder Bay to the north (NPS 2005).

ISRO participates in a Leave No Trace project, in which a booklet is available for visitors describing how to minimize human impacts by traveling and camping on durable surfaces, properly disposing of wastes, leaving natural features undisturbed, eliminating introduction of non-native species, minimizing campfire impacts, respecting wildlife, and being considerate of other visitors (Leave No Trace Center for Outdoor Ethics 2004). The 2005 wilderness and backcountry environmental impact statement (NPS 2005) also called for a monitoring plan and a report at five-year intervals, including such topics as campsite crowding, rates of trail encounters, annual visitation and its temporal and spatial distribution, density of boats in anchorage areas, biophysical conditions and recreational impacts at campgrounds and off-trail, wolf-human encounters, loon success, and conditions of archaeologic sites and cultural landscapes.

Fuel Storage and Discharges at ISRO

ISRO has five oil storage facilities that are regulated under the Oil Pollution Act of 1990 as "significant and substantial harm facilities." Tanks are located at Rock Harbor, Mott Island, Amygdaloid Island, Windigo, and Malone Bay (Table 28) (USEPA Region 5 2000). ISRO maintains trained personnel and some equipment to respond to the accidental release of oil from one of their tanks (Rayburn et al. 2004).

Table 28. Locations of fuel storage tanks at Isle Royale National Park (USEPA Region 5 2000).

Location	Products stored	Volume (L)	Number of tanks
Rock Harbor	Gasoline, diesel	189,000	3
Malone Bay	Gasoline	7,600	1
Mott Island	Gasoline, diesel	210,000	4
Windigo	Gasoline, aviation fuel, diesel	197,000	5
Amygdaloid Island	Gasoline	7,600	1

The MDEQ keeps records of discharges of hazardous materials (ERD sites) and of leaking underground storage tanks (LUST sites) under Parts 201 and 213, respectively, of MI's Natural Resources and Environmental Protection Act 451 of 1994 (State of Michigan 1996). Keweenaw County has 10 active Part 201 sites, four of which are within ISRO (Table 29). One active Part 213 site is located on Amygdaloid Island (MDEQ 2009b, c).

The risk scores in Table 29 are determined by an MDEQ Site Assessment Model and range from zero to 48, with 48 indicating the highest degree of risk (MDEQ 2009d). Up to 20 points are awarded for environmental threats associated with the contaminants, up to five points are awarded for the mobility of the contaminants, and up to three points are given for sensitive environmental resources at the site. Up to 15 points are awarded for the types and quantities of the released chemicals, and the final five points are given for the size of the individual and institutional human populations around the sites.

Table 29. Part 201 hazardous material discharge (ERD) sites in the vicinity of Isle Royale National Park (MDEQ 2009b).

Name	Substances and Source	Risk Score and Date	Status
Rock Harbor Lodge	benzo(a)pyrene, naphthalene; Petroleum and coal products	33/48; 12/12/2003	interim response in progress
Windigo Generator Shed	naphthalene; n/a	32/48; 2/13/2004	inactive; no actions taken to address contamination

Windigo Tank Farm	phenanthrene; Petroleum products	42/48; 2/18/2004	evaluation in progress
Passage Island Lighthouse	benzene, lead; National security	30/48; 1/19/2006	evaluation in progress

Aquatic Invasive Species

Invasive species are those organisms not native to an area whose introduction harms or is likely to harm the economy, environment, or human health (USEPA 2008c). They may be either terrestrial or aquatic. Aquatic invasive species (AIS) may threaten the diversity or abundance of native species or the ecologic stability of the waters into which they are introduced, or impair the water for some human use (MDEQ 2002). At least 182 invasive species are found in the Great Lakes basin, and a new invader is discovered every 28 weeks (Ricciardi 2006). The introduction of aquatic invasives may be the most serious threat to the ecologic health of the Great Lakes today (Jude et al. 2002).

Crane et al. (2006) described AIS as a particular threat to ISRO because of the high quality, uniqueness, and fragility of its aquatic ecosystems, especially its inland lakes. The prevention and control of AIS was identified as the top priority at an April 2002 water resources management plan scoping workshop (Crane et al. 2006).

Known AIS at ISRO are deliberately introduced non-native fish (i.e., rainbow and brown trout and Chinook and coho salmon) and accidental introductions such as sea lamprey, threespine stickleback, spiny waterflea, and the plants cattails and common reed. In addition, either zebra or quagga mussels were found in Washington Harbor in September 2009 (Flesher 2009b, Myers 2009). AIS believed to be encroaching on ISRO are invertebrates (fishhook waterflea [*Cercopagis pengoi*], Asian clam [*Corbicula fluminea*], rusty crayfish [*Orconectes rusticus*], and Chinese mitten crab [*Eriocheir sinensis*]); fish (ruffe, white perch [*Morone americana*], round goby, and tubenose goby [*Proterorhinus marmoratus*]); a virus (viral hemorrhagic septicemia [VHSv]); and plants (purple loosestrife and Eurasian water-milfoil) (Crane et al. 2006, Meeker et al. 2007, Quinlan et al. 2007, NPS and Grand Portage Band of Lake Superior Chippewa 2008, Benson and Fuller 2009, Schlesinger et al. 2009, USEPA 2009d). These species are further described below. The USFWS has identified five of these species (ruffe, white perch, rusty crayfish, zebra mussels, and quagga mussels) as priority species for monitoring at ISRO (Quinlan et al. 2007); however, mitten crabs and VHSv were not included in their analysis.

AIS Known in ISRO

Introduced Non-Native Fish Species: Of Lake Superior's seven top predator fish, only three are native species (lake trout, burbot, and walleye) while the other four are introduced species (coho salmon, Chinook salmon, rainbow trout, and brown trout) (GLFC 2001). These non-native fish consume prey fish, eat native fish eggs, and take over optimal habitat for native fish (Crane et al. 2006). Environmental changes, including overfishing and logging in the late 19th century, as well as the introduction of these non-native species, mean that natural, pre-European settlement fish communities may never return to Lake Superior. However, a recent review reported that the introduction of non-native fish species appears to have little effect on native aquatic species in Lake Superior with the notable exception of coaster brook trout (Schlesinger et al. 2009). Rainbow trout and salmon compete with juvenile coaster brook trout for food and rearing areas in stream and nearshore Lake Superior habitats. Non-native salmonids also compete with adult coaster brook trout and lake trout in nearshore and reef areas (Schlesinger et al. 2009).

Sea Lamprey: Probably the best-known exotic species in Lake Superior is the sea lamprey. This species, native to the Atlantic Ocean, entered Lake Superior via the St. Lawrence Seaway in the early 1940s (Smith et al. 1974) and quickly depleted lake trout populations in eastern Lake Superior (Crane et al. 2006). Adult lampreys spawn on gravel beds in tributary streams, and immature lampreys grow from three to seven years before migrating into the lake. Adults parasitize fish, extracting blood and body fluids with their suctorial mouths. Each sea lamprey may kill as much as 18 kg of fish during the 12–20 months of its adult life (GLFC 2000). Sea lamprey numbers in Lake Superior declined slowly from 1962 to 2000 as a result of chemical treatments and barriers, but the GLFC's target of $<5\%$ lake trout mortality attributable to sea lamprey has not yet been met (Fodale and Cuddy 2007).

Threespine Stickleback: The threespine stickleback has been known in Lake Superior since at least 1994. Threespine stickleback feed on a variety of fauna, including zooplankton, oligochaete worms, macroinvertebrates (insect larvae), small fish, fish eggs, crustaceans, adult aquatic insects, and drowned aerial insects (Quinlan et al. 2007). The species was introduced to the Great Lakes in ballast water and had not resulted in any documented environmental damage as of 2002 (Jude et al. 2002). However, it is a very aggressive fish (Zhuikov 1997) and may outcompete native sticklebacks for food and space (Quinlan et al. 2007). It was reported present in ISRO by Quinlan et al. (2007), but not in a nearshore survey by Gorman and Moore (2006).

Spiny Water Flea: Spiny water flea is a large cladoceran (zooplankter) with a long spine, native to freshwater, oligotrophic lakes of Eurasia. Its spine makes it unattractive as prey for small fish (Lehman and Caceres 1993). It competes for common zooplankton resources with native pelagic fish (Jude et al. 2002), but it may be a food source for larger fish (Minnesota Sea Grant 2006b). Live bait fish can disperse the spiny water flea because its resting eggs can survive passage through the digestive tract of fish (Garton and Berg 1990). It is easily introduced into new lakes through fishing and anchor lines, bilge water, and live fish bait. Therefore, lakes that are popular fishing spots are the most susceptible to new invasions of the spiny water flea (Jarnigan 1998). If introduced into ISRO inland waters, it might adversely affect native fish, mussels, and sponges. It was first found in Lake Superior in 1987 (Cullis and Johnson 1988), and it is currently found in Tobin Harbor and the Lake Superior waters of ISRO (Crane et al. 2006). It was not found in a survey of eight inland lakes in ISRO during July 2005 (Crane et al. 2006).

Reeds, Cattails, and Other Invasive Aquatic Plants: Common reed and two species of cattails were found in ISRO in a survey published in 2007 (Meeker et al. 2007). These aggressive plants form clones that crowd out nearly all other wetland plants. The authors suggested that although cattails would continue to spread in ISRO, they would not reach "extreme abundance"; currently, 1.2% of the interior lake and Lake Superior bay shoreline are occupied by these species. This same survey looked for, but did not find, the invasives curly-leaf pondweed, Eurasian water-milfoil, or purple loosestrife on ISRO (Meeker et al. 2007).

Zebra Mussels and Quagga Mussels: Invasions of zebra mussels and quagga mussels are a major concern in the Great Lakes because of the resulting catastrophic decline of native mussels. These two species have expanded their ranges at an “alarming rate” because of their wide environmental tolerances and high reproductive rate (Nichols 1993). They are very mobile and colonize most hard surfaces, including the shells of native mussels (Nichols et al. 2001b). They are omnivores as adults and will feed on algae, zooplankton, their own young, and detritus. Quagga mussels can live in colder water (Snyder et al. 1997) and live at greater depths and on softer substrates than zebra mussels (Dermott and Kerec 1997).

Zebra mussels probably entered the Great Lakes in 1985 or 1986 in ballast water in Lake St. Clair (Minnesota Sea Grant 2006a). They have difficulty establishing populations in Lake Superior because they need calcium for proper shell development (Crane et al. 2006). As previously noted, the minimum Ca^{2+} threshold for zebra mussel settlement and growth is 8–12 mg L^{-1}, with peak mussel densities at concentrations $\geq$ 20 mg L^{-1} (Jokela and Ricciardi 2008 and citations within), and concentrations in Lake Superior currently average 14 mg L^{-1} (USEPA 2008a). Zebra mussels have been detected in Duluth and Thunder Bay, and areas around ISRO are considered moderately susceptible to invasion (USEPA 2008d). In September 2009, news reports stated that either zebra or quagga mussels were found in Washington Harbor on the pier at Windigo (Flesher 2009b, Myers 2009). Quagga mussels were first found in Lake St. Clair in 1988 (Minnesota Sea Grant 2006b). They have been found in Duluth Harbor and near the tip of the Keweenaw Peninsula (USEPA 2008d).

AIS Believed to Be Encroaching on ISRO

Fishhook Water Flea: The fishhook water flea is an exotic species from the Caspian Sea. It is similar to the spiny water flea in its size, life history, and habits, although it may eat smaller prey (Jude et al. 2002); however, it does not have a straight caudal spine but rather a spine that is curved at the end. It may compete with larval fish and fish planktivores for small zooplankton (Jude et al. 2005). A single specimen of this species was found in Lake Superior in 2003, but it is not believed to be established there (Benson et al. 2009).

Asian Clam: The Asian clam is considered “one of the world’s most invasive species” because of its rapid dispersal, high fecundity and growth, and early maturity (Jude et al. 2002). It, like the zebra and quagga mussels, colonizes and fouls hard surfaces (USEPA 2008d). Asian clams were found throughout the Great Lakes as early as 1984 (White et al. 1984), and have been found in the Portage Canal at Houghton, MI, in effluent water from Upper Peninsula Power Company (Ward and Hodgson 1997). They are considered “established” in Lake Superior (USEPA 2008d), but specific locations were not reported.

Rusty Crayfish: Rusty crayfish are native to the Ohio River basin, but are considered a threat to MI’s native crayfish populations (MDNR 2007). They have been invading northern lakes and streams, including 31 lakes and streams in 11 counties in WI (Gunderson 2008) and five North Shore counties in MN (USGS 2009), but are not yet found in the Great Lakes (USEPA 2008d). They are easily transported as live fish bait, in bait bucket water, and in live wells, although it is illegal to take, possess, or sell them in MI. They inhabit lakes, ponds, and streams (including pools and riffles), and prefer areas that have rocks and/or logs as cover (Gunderson 2008). They are aggressive toward other crayfish (Capelli 1982) and destructive of aquatic macrophytes

(Lodge and Lorman 1987). They consume twice the food of the similar sized *Orconectes virilis*, a native crayfish (Momot 1992).

Chinese Mitten Crabs: A single Chinese mitten crab was found on a water intake screen in Lake Superior at Thunder Bay (Herborg et al. 2007). However, this species' swimming planktonic larvae require saline water, so it is uncertain that they pose a serious threat to the Great Lakes.

Eurasian Ruffe: Ruffe are a small but aggressive type of exotic percid native to Eurasia. They are highly fecund, feed on a wide assortment of prey, and are able to forage efficiently under reduced light conditions such as in turbid water or at night (Gunderson et al. 1998). They were introduced to the Great Lakes in ballast water at the St. Louis River near Duluth in the early to mid-1980s, and were found in Thunder Bay harbor in 1991 (Keppner et al. 1997). Based on bottom trawl samples, ruffe are approximately 80% of fish in the SW regions of Lake Superior (Leigh 1998). Ruffe may harm more desirable Lake Superior species, such as yellow perch, whitefish, or walleye, by feeding on the young of these species or by competing for food (Crane et al. 2006, Fuller and Jacobs 2009). At ISRO, its most significant threat is to the nearshore native fish communities from ecologic and sportfishing standpoints (Crane et al. 2006).

White Perch: The white perch, not a perch at all, is a species of the temperate bass genus. It was first found in Lake Superior in 1986 in Duluth Harbor and appears to continue to be restricted to that location, perhaps because the harbor is warmer than the rest of the lake. It eats the eggs of walleye and white bass, and could contribute to a decline in the populations of those two species (Wisconsin Sea Grant 2002).

Round and Tubenose Gobies: The round goby, originally from the Black and Caspian seas of Eastern Europe, is a small, aggressive, bottom-dwelling fish that exhibits prolific spawning and voracious eating behaviors. It was first introduced to Duluth Harbor in 1986 via ballast water. In some areas where it has become well-established, it appears to be the only fish species present (USGS 2000b). The tubenose goby, with similar aggressive tendencies, was discovered in Duluth Harbor in September 2003 (Crane et al. 2006).

A concern about the potential invasion of gobies at ISRO is that they compete with native benthic fish such as sculpin, trout-perch, and darters (*Etheostoma* spp.) for food and habitat. Because they can deeply penetrate interstitial spaces in cobble substrates, they might become effective predators on lake trout eggs, setting back lake trout rehabilitation (Crane et al. 2006).

VHSv: Viral hemorrhagic septicemia rhabdovirus (VHSv) kills fish by causing both internal and external hemorrhages (Whelan 2009). Twenty-eight vulnerable fish species have been identified in Lake Superior (NPS and Grand Portage Band of Lake Superior Chippewa 2008). Preliminary positive results for VHSv were found at four locations in Lake Superior (Paradise/Whitefish Point and Skanee/Huron Bay in MI and St. Louis Bay and Superior Bay near Duluth, MN) in January 2010 (Cornell University 2010, WDNR 2010). Ballast water was the most likely mechanism by which it entered the Great Lakes, while anglers and recreational boaters are the most likely mechanism for transfer into inland waters (NPS and Grand Portage Band of Lake Superior Chippewa 2008).

Other AIS Found in Lake Superior

Alewife: The alewife is a planktivorous marine member of the herring family, first found in Lake Superior in 1954. Alewives are considered beneficial as prey for salmonines, but are detrimental to zooplankton and the pelagic larvae of native fish species (Jude et al. 2002).

New Zealand Mud Snail: The New Zealand mud snail is a tiny snail first discovered in the Duluth-Superior harbor in fall 2005, probably introduced via ballast water from ocean-going ships. It reproduces asexually. The mud snail outcompetes important forage species for native trout and other fishes, but provides little nutrition to these predators (MN DNR 2007).

***Didymosphenia geminata* (Didymo)**: Didymo is a freshwater diatom that produces dense benthic algal blooms. These can block sunlight and disrupt ecologic processes, causing a decline in native plant and animal life (USDA 2009). Although it has become an AIS in some locations, it is native to Lake Superior, and has been known on the North Shore for over fifty years (USEPA Mid-Continent Ecology Division, Jo Thompson, Biologist, email September 15, 2009). Stoermer (1980) characterized it as a sensitive, boreal species that on the Lake Superior shoreline preferred oligotrophic conditions. Therefore, recent concerns about its presence (Spaulding et al. 2008, USEPA 2009d) appear to be unwarranted.

Introduction Pathways and Control Strategies for Aquatic Invasive Species

Numerous pathways, both natural and human-made, exist to transfer aquatic species from one location to another. Ludwig and Leitch (1996) list connections between basins at times of high water, animal transport, and extraordinary meteorologic events as natural mechanisms for species transfer. Bossenbroek (2006) also notes the importance of stream connections. These natural events and conditions may be difficult to predict or manage. However, human-initiated mechanisms, including escapes from aquaculture facilities, aquarium release, stocking activities, ballast release, and angler escape or release are more amenable to control through management and public education. Eberhardt (2008) provided a comprehensive list of human-initiated mechanisms (Table 30).

Table 30. Human-initiated mechanisms for transfer of aquatic invasive species in Lake Superior (Eberhardt 2008).

Category	Subcategories
Maritime Commerce	ballast water, hull/anchor fouling
Water Recreation	boating equipment, live wells, fishing equipment, bait
Organisms in Trade	pets/aquariums, aquatic plants, shoreline restoration, bait, live food fish, on-line sales
Commercial Fishing	fishing equipment/vessels, bait, fish aquaculture
Canals and Diversions	locks, power canals, compensating works, diversions
Agency Activities	stocking/hatcheries, assessment, harbor maintenance, navigation, homeland security, research
Illegal Activities	plants, fish stocking, on-line sales
Tourism	charter fishing, ecotours, float planes, diving

The three most apparent pathways for the introduction of AIS at ISRO are ballast water from commercial ships, recreational boating in Lake Superior and its harbors, and commercial touring vessels (Crane et al. 2006). ISRO's inland lakes and streams are accessible only by kayak or canoe and only at a limited number of established portages. The use of natural fishing bait is prohibited in inland waters. ISRO also has a spiny water flea awareness program that asks visitors to change their reel line before moving from Lake Superior to inland waters to fish (NPS and Grand Portage Band of Lake Superior Chippewa 2008).

Terrestrial Invasive Species

The introduction of alien species probably began with the arrival of European settlers (DiTomaso 2000). It was not unusual for immigrants to bring useful plants or seeds with them from their native lands. Collectively, exotic plants represent an important ecologic threat (Ehrenfeld 2003, Heneghan et al. 2006). In the recent past, eastern North America has experienced a rapidly increasing number of exotic plant populations. Effects have been widespread and have included, at a minimum, alteration of community structure (Heneghan et al. 2006); reduction of native richness (Rooney et al. 2004); alteration of ecosystem process such as decomposition, mineralization, and primary productivity (Ehrenfeld 2003, Heneghan et al. 2006); and altered fire regimes (Brooks et al. 2004). However, most exotics do not have any appreciable ecologic effects, and among those that do, some have minor impacts.

Many, although not all, of the problem exotic species are especially adept at invading recently disturbed areas. Spotted knapweed (*Centaurea* spp.) is such a species and is rapidly expanding its range in the Lake States. Even in largely unfragmented landscapes and mature forests, more subtle human manipulation of the landscape and accidental introduction can lead to steady increases in the number and dominance of exotics in the flora (Martin et al. 2009); this was recently documented for a 50-year period in upland forests of northern WI (Rooney et al. 2004). The increase by exotics led to an 18.5% decrease in native species density at a 20 m^2 scale. Even the establishment of a park by no means guards land against further exotic invasion. A recent study of a small (19 km^2) newly established national park in Quebec found that the proportion of exotics increased from 16 to 25% in just 21 years (1984–2005) (Lavoie and Saint-Louis 2008).

For forests in general, exotic taxa of serious concern are garlic mustard (*Alliaria petiolata*), the alien buckthorns (*Rhamnus* sp.), Oriental bittersweet (*Celastrus orbiculatus*), Japanese knotweed (*Fallopia japonica*), Norway maple (*Acer platanoides*), and the honeysuckles (*Lonicera* spp.) (Nuzzo 1991, Woods 1993, Czarapata 2005, Martin et al. 2009). These species can invade intact communities and reduce the number and/or diversity of native species. The buckthorns can thrive in richer soils and thus could invade birch, aspen, or northern hardwood forests.

Careful, regular, and extensive monitoring is the key to prevention of an exotic problem. At ISRO, the areas in which exotic plants are most likely to come into the island are around the docks and developed areas and along the popular trails. The staff at ISRO regularly monitor near developed areas and along trails and respond quickly to any new findings (NPS, Mark Romanski, pers. comm., 2009). These efforts must be continued on a frequent basis to prevent the invasion and spread of problematic exotics.

Gypsy Moth

Two gypsy moths (*Lymantria dispar*) have been found on the island, but both were males (NPS, Mark Romanski, pers. comm., 2009); a reproducing population is not thought to be present. It should be noted that the female gypsy moth cannot fly. Nonetheless, this discovery has raised questions about whether this exotic pest is likely to get established on ISRO and what its probable impact would be. The egg masses are laid on the underside of limbs and bark, but also on campers and boats (Edmonds et al. 2000). Hence, the species could readily reach the island by human transportation, and a preliminary assessment of its potential impacts is warranted.

Gypsy moth populations were well distributed in the lower peninsula of MI by the mid-1980s (Liebhold et al. 1997) and in WI by the late 1990s (Tobin 2005). Thus, possible source populations for ISRO have existed for over 25 years. The fact that a population has not become established on ISRO to date is encouraging.

The gypsy moth is considered the "worst defoliation threat to deciduous trees in northeastern North America" (Doane and McManus 1981 in Edmonds et al. 2000) and is highly polyphagous (will feed on and survive on a wide variety of species). Over 300 trees and shrubs have been utilized in North America (McManus et al. 1992, Liebhold et al. 2000), though it shows a preference for oak. According to Liebhold et al. (2000), *Populus* is one of the more common hosts, and McManus et al. (1992) listed alder, white birch, and poplar as preferred species. Climatic regime has been commonly suggested as limiting the northern spread of the species (Tobin 2005). For example, gypsy moth egg masses cannot withstand temperatures below -29^{o}C for more than 48 hours (McManus et al. 1992). Furthermore, alternating freeze-thaw cycles in late winter and early spring are believed to prevent eggs from hatching. However, the rate of spread in MI has recently been *inversely* related to temperature (Tobin 2005) suggesting that the relationship between growth/dispersal and weather is not as straightforward as previously thought. This does not, of course, negate the importance of weather to the population dynamics of the species; recent analyses have determined that weather is an important factor contributing to the large scale synchrony of outbreaks (Liebhold et al. 2000). Given the presence of several preferred tree species on ISRO, the continued spread of gypsy moth in WI, and the possibility of minimal temperature limitation, it may be easier for a population to become established on ISRO than appears on the surface.

If a population gets a foothold on ISRO, it most likely will be in an aspen, paper birch, or mixed aspen-birch forest. Gypsy moths avoid the conifers that dominate the upland boreal forest types (balsam fir, white spruce, and occasionally northern white cedar) (McManus et al. 1992). Larval development is strongly influenced by both plant host and temperature (Knapp and Casey 1986, Rossiter 1987); utilization of non-preferred hosts and temperatures $< 25\,^{o}$C substantially retard larval development. Gypsy moth larvae typically emerge in mid-May (Knapp and Casey 1986); thus, cold temperatures could realistically serve to minimize population growth. Given these factors, it is unlikely that many of the common forest types on ISRO, including those classified as northern hardwood (Liebhold et al. 1994), would support more than endemic-level populations of gypsy moth.

Most vigorous broadleaf trees can endure up to 50% defoliation by gypsy moths with minimal growth loss (McManus et al. 1992), and some can experience a second year of defoliation at the same level and still recover. However, repeated defoliation often results in a major increase in mortality, at least among oak species. Only one growth and mortality study of gypsy moth defoliation involved species common on ISRO. In Massachusetts, New York, and New Jersey, the previous year's level of defoliation had little or no effect on the growth of aspen (Muzika and Liebhold 1999). Thus, it is likely that aspen-dominated forests could sustain a low-density population of gypsy moths with no substantial changes in structure or composition. If the population were to reach epidemic levels and stay there for a few years, extensive aspen growth loss and die-back would be expected [based on its response to tent caterpillar (Hahn et al. 2000)], but mortality would be uncommon. This level of impact would encourage understory and/or midstory growth, and thus alter forest structure. It could also facilitate recruitment of new species into the forest. Safford et al. (1990) list gypsy moth as a common defoliator of paper birch, but state that defoliation alone (by any insect) seldom results in mortality of a healthy tree, though it does result in growth loss. Thus, it appears that the resiliency of birch is almost as high as that of aspen.

Our current state of knowledge suggests that the only extensive susceptible forest types on ISRO are those with paper birch and/or aspen as dominants (e.g., the 1936 burned area). Given the location of these forest types and the probable weather limitations, a population of gypsy moths would not build to epidemic proportions on the island. Should an endemic-level population become established, the resiliency of birch and aspen, plus the low utilization of later successional species (white spuce, balsam fir, or sugar maple in some areas) suggest that the outcome would be minor shifts in forest type abundance.

Emerald Ash Borer

Another exotic herbivore that is moving through the Midwestern U.S. and causing extensive tree mortality is the emerald ash borer (*Agrilus planipennis*) (Poland and McCullough 2006). Black ash is the susceptible species at ISRO, occurring on approximately 300 ha, but almost always in mixed deciduous forests or with northern white cedar. If human introduction (e.g., firewood) is prevented, it is very unlikely that this insect will reach ISRO. Should it find its way to the island, the impact on community structure would be minimal and short-lived as other species would fill in the gaps. The possible concern is any species, such as invertebrates, fungi, or others, that are specialists on black ash; if these exist, there could be a loss of biodiversity due to the lethality of the ash borer.

White Pine Blister Rust

White pine has an important biotic disturbance agent, white pine blister rust (*Cronartium ribicola*), an exotic fungal pathogen that was brought into the country in the late 1800s (Edmonds et al. 2000). This pathogen killed many white pine in the 20th century and was prevalent throughout the white pine–growing area of Minnesota by the mid-1950s (Stewart 1957). We found no documentation of the disease on ISRO, though it could be or could have been present but overlooked. The impact of this fungus was likely never great, and the potential is lower today due to the restricted distribution of white pine. White pine was not even mentioned by Hansen et al. (1973), indicating how rare the species was on ISRO in the mid-20th century. The USGS-NPS Vegetation Mapping Program (TNC 1999) identified only one community type that contained white pine (white pine–quaking aspen/beaked hazelnut forest) and described it as "uncommon."

Larch Sawfly

The larch sawfly is a foliage-feeding insect introduced from Europe in 1880 (USDA–Forest Service 2001). It apparently arrived in the Great Lakes region by approximately 1900, and the population reached epidemic levels in MN in the early 1900s (Brown 1935 in Janke et al. 1978). It is thought that this herbivore reached ISRO later in the 20^{th} century and greatly reduced the abundance of larch (tamarack) (Janke et al. 1978). The witness trees noted in the original land survey were 2% larch, but in their 1974 inventory of the same area, Janke et al. (1978) found none.

Earthworms

The scientific consensus is that there are no native earthworms in the forests of the western Great Lakes Region because they have not migrated back since the retreat of the Wisconsin glacier (Hendrix and Bohlen 2002). However, due to human migration and commerce (e.g., use of worms as fish bait and for composting) at least 45 exotic species have been introduced to North America. Most exotic earthworms are from Europe. They have spread substantially over the past few decades (Bohlen et al. 2004) and are found on ISRO. Regionally, the most numerous are members of the family Lumbricidae (Hendrix and Bohlen 2002). As early as the 1960s, it was noted that these species had significant impact on soil properties in areas devoid of native earthworm species (Hendrix and Bohlen 2002). More recently, some far-reaching implications for the composition and function of northern hardwood forests, aspen forests, and pine-dominated forests in the northern parts of the Great Lakes region and Canada have been identified (Hale et al. 2005, Frelich et al. 2006).

When earthworms invade a site, there is typically a succession of species, similar to the changes of plant species during succession (Hale et al. 2005, Suárez et al. 2006). The first group to invade typically are smaller, stay in the litter (O_i) layer, have minimal impact on the lower layers of the forest floor, and have almost no impact on soil properties or nutrient cycling (Frelich et al. 2006). The second and third waves include larger species and ones that move between the litter/duff layer and mineral soil. The species *Lumbricus rubellus* (Hale et al. 2005) and *L. terrestris* (Suárez et al. 2006) seem to be of particular influence. These later-successional species reduce the depth of the litter layer and move substantial amounts of carbon into the soil to depths of 25–30 cm (Bohlen et al. 2004, Frelich et al. 2006). In a northern hardwood forest, the presence of earthworms increased the rate of litter breakdown by 1.5–3.0 times under field conditions (Suárez et al. 2006). Subsequent alterations occur in the dynamics of carbon and nitrogen in the soil, soil structure (e.g., bulk density) and the composition of the understory (Bohlen et al. 2004, Hale et al. 2005, 2006). Exotic earthworms have consistently increased the total N in the system (Groffman et al. 2004, Wironen and Moore 2006), but the effects on its availability and movement have been variable—ranging from no change (Groffman et al. 2004) to increased availability and increased leaching (Bohlen et al. 2004). After invasion, the understory in the northern hardwood forest will typically have reduced species richness, reduced recruitment of sugar maple saplings, and increasing amounts of Pennsylvania sedge (*Carex pensylvanica*) (Hale et al. 2006). It has also been noted that at least one plant species, little goblin moonwort (*Botrychium mormo*), is negatively correlated with the abundance of *L. rubellus* (Gundale 2002). Although this plant is not reported from ISRO, other species of *Botrychium* are, and this finding adds to the threat exotic earthworms may represent.

Most of the earthworm work in North America has been in northern hardwood forests. However, studies from Europe indicate significant differences in invasion potential among the various forests at ISRO. A strong majority of earthworm species are sensitive to litter quality, dry conditions, and soil pH. Thus, forest ecosystems such as the spruce-fir or pine-spruce boreal types are not likely to be invaded because of their acidic conditions and low-quality (high lignin and low nitrogen) litter (Frelich et al. 2006). These forest types have not been invaded in northern Scandinavia despite the presence of earthworms for thousands of years. However, a mixed deciduous–conifer forest (e.g., aspen-spruce) has a substantially higher risk of invasion due to the moderating effects of the deciduous species.

Climate Change

Global air temperatures increased $0.74 \pm 0.18^{o}C$ from 1906 to 2005, mostly attributable to human activities (IPCC 2007). In addition to creating this general warming, climate change also likely contributes to rises in sea level; changes in wind patterns and extra-tropical storm tracks; increased temperatures on extreme hot nights, cold nights, and cold days; increased risk of heat waves; increased area affected by drought; and greater frequency of heavy precipitation events (IPCC 2007). Signs that climate change is already occurring in the Great Lakes region include increases in average annual temperatures, more frequent severe rainstorms, shorter winters, and decreases in the duration of lake ice cover. By the end of the 21st century, winter temperatures in MI and MN may increase $3^{o}C$ –$6^{o}C$, and summer temperatures may increase $4^{o}C$ –$7^{o}C$ and $4^{o}C$ –9 ^{o}C, respectively. The growing season might increase by 8–10 weeks in MI and 3–6 weeks in MN. Annual average precipitation may not change much, but may increase in winter and decrease in summer to the point where soil moisture declines and more droughts occur. The frequency of heavy rainstorms could increase 50–100% in both states (Kling et al. 2003a, b).

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

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

Lake Superior Water Level Changes

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

Changes in Lake Superior water levels have been limited since 1914 by a control structure at the lake's mouth. In the 55 years of preregulation data, water levels had a range of 1.10 m, from 182.76 m in February 1866 to 183.86 m in August 1876. As regulated, the mean annual variability is 0.30 m, with a 1.19 m range from 182.72 m in April 1926 to 183.91 m in October 1985 (Wilcox et al. 2007, USACE 2009). However, Lake Superior set a new record low for September of 183.02 m in 2007, and as of January 2009 was 0.22 m below the average for the last 90 years (NOAA 2009a). In Lake Michigan, which is unregulated, water levels are currently 0.38 m below average (NOAA 2009a) and have been described as "worrisome" because they appear consistent with several climate change projections (Sellinger et al. 2008).

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

Other Surface Water Impacts

In the future, surface waters will likely be warmer. DO may decline, and extended periods of thermal stratification may increase the decline's effects. Lower oxygen levels and warmer temperatures in inland waters may promote phosphorus release and increase mercury release and uptake by biota (Kling et al. 2003c). Warming of the Great Lakes would cause greater volatilization of semi-volatile compounds from the water column, which will cause contaminants currently sequestered in sediment reservoirs to desorb and re-enter water and air (Boyer et al. 2006). Nonpoint pollution may also increase with higher intensity precipitation events.

Biologic productivity of aquatic ecosystems will likely increase with temperature, because of longer growing seasons and increased metabolic rates, but existing natural communities may be greatly changed (IJC 2003). However, Lake Superior's already-low productivity may further decrease because of a longer summer stratification period that prevents the recycling of nutrients and redistribution of oxygen (Kling et al. 2003c). Populations of coldwater fish may decline. Whitefish reproduction may be harmed by loss of winter ice cover (Kling et al. 2003a). Some habitats may be reduced, especially wetlands and their vegetation communities. Invasive species may be more successful (Kling et al. 2003c).

Coastal Wetland Impacts

Models for Great Lakes coastal wetlands in the Canadian Great Lakes (Erie, Ontario, and St. Clair) were examined for their responses to climate change and lake-level changes as projected by climate models. Results indicated that "the lower water levels projected under most climate change scenarios will have an impact on the distribution and abundance of wetland vegetation, bird, and fish communities; major shifts in all taxonomic groups are likely with long-term water level declines, beginning with vegetation responses" (Mortsch et al. 2006). Wetland communities within lacustrine embayments were the most capable of naturally adapting to lower water levels, while drowned river-mouth wetlands showed the greatest potential for change. Invasive plant species such as purple loosestrife and common reed were less vulnerable to change than native species, and the spread of invasives may be facilitated by cumulative stresses on natural ecosystems. Birds that need prolonged, relatively stable water levels during the breeding season, such as terns, grebes, rails, and bitterns, were considered vulnerable, as were fish that spawn in shallow water in spring and have a preference for vegetated habitat in all life stages (Mortsch et al. 2006). Loons are also vulnerable to fluctuating water levels.

Water level fluctuations are essential to the diversity of wetland plant communities and the habitats they provide for fish and wildlife. Lake level regulation has already created problems for Lake Superior wetlands (Wilcox et al. 2007). Periodic high lake levels are needed to kill trees, shrubs, and canopy-dominating emergent plants in Great Lakes wetlands. Subsequent low water levels are needed to promote seed germination and growth of numerous species (Wilcox et al. 2007).

Projected Impacts on Plants

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

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

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

Predicted responses for common tree species (below) highlight the probable magnitude of the impact, as well as what is likely to happen for some other life forms and species. However, it would be dangerous to extrapolate from one or a few species in an assemblage to all of the species; the dendro-chronologic and pollen records clearly show that co-occurring species can respond in very different ways to decade- and century-long climatic change (Villalba et al. 1994, Villalba and Veblen 1998, Black and Abrams 2005). Two key components to the response by a species (or population) are how quickly it can adapt, if at all, and how rapidly it can disperse (Davis et al. 2005, McKenney et al. 2007). The capacity to adapt increases with greater population-level genetic variation and effective population size, a mating system that is partially or entirely out-crossing but does not rely on a specialized pollinator, and a larger range size. It is anticipated that adaptation will vary tremendously among life forms and significantly among species within a life form (Dale et al. 2001, Davis et al. 2005). Herbaceous species should adapt more quickly than trees and insects more quickly than most plants; this is primarily a function of life cycle length. However, annual plants and short-lived species are more sensitive than longer-lived species to temperature fluctuation (Morris et al. 2008). The second component is migration. Based on the pollen record, we know that species, even within a life form, migrate at very different rates (e.g., Graumlich and Davis 1993) at the scale of millennia. The primary question is whether a species will be able to disperse rapidly enough to match the rates of change in temperature and precipitation regimes (Williams et al. 2007).

Hansen et al. (2001) predicted the impacts of climate change on forest types and major tree species in the conterminous U.S. The future distribution of trees and forest types was based on changes in hydrology, light, nutrients, and plant response to increased CO_2. Relevant predictions for ISRO include that suitable habitat for both spruce-fir and aspen-birch will decrease by >90%; species now at ISRO that would lose 90% of their range within the U.S. include quaking aspen, sugar maple, northern white cedar, balsam fir, and paper birch; and potential suitable environments for alpine communities will “all but disappear.” It should be noted that these predictions cannot be applied directly to ISRO because they are for mainland areas only and do not account for the moderating effects of Lake Superior. Currie (2001) predicted the long-term change in richness (number of species within a community) of trees under a scenario of doubling of CO_2 and found that short-term changes are likely to be negative, but tree richness will increase in cooler climates and mountainous areas.

A more recent assessment using a similar approach found a smaller magnitude of changes. McKenney et al. (2007) examined the predicted range response of 130 tree species in the conterminous U.S. They used the concept of climate envelope, which simply means that the climatic boundaries of a species today probably indicate the conditions it can endure in the future. Using this approach (which ignores many possible interactions that may manifest and influence where a species thrives in the future) they determined that 72 species would show a decrease in the size of their range within the conterminous U.S. Many of the more northerly distributed species will increase dramatically in Canada (McKenney et al. 2007), and this is the general expectation for the boreal forest type in the U.S. The authors ranked species based on the magnitudes of the reduction in the size of the climate envelope assuming no dispersal and the northward shift in the climate envelope latitude. No ISRO species were in the top 20% of the first category, but five species (sugar maple, yellow birch, northern red oak, eastern white pine, and mountain maple) were in the top 20% of the second (range shift). The extent of the northern range shift varies depending on which GCM model is used and the migration rate of a species. For example, sugar maple could have its range move northward as little as 3.3 degrees of latitude or as much as 8.9 degrees. Classic boreal species (paper birch, white spruce, balsam fir) were not predicted to change as much in this assessment.

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

Projected Impacts on Animal Communities

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

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

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

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

Overall Impacts at ISRO

Davis et al. (2000) noted that “the Western Great Lakes parks…” (including ISRO) “…are important reservoirs of biologic diversity in a landscape that has been altered by logging, mineral extraction, agriculture, and urbanization.” The accumulated pollen record over the Holocene suggests that ISRO’s location on Lake Superior may buffer it from temperature changes, at least temporarily, and allow it to serve as a refuge for plants and animals that cannot survive farther inland. However, that same location may jeopardize plants and animals because it is more subject to precipitation extremes than inland sites (Davis et al. 2000).

Given current climate change scenarios, biologically significant changes will likely occur in plant species ranges, species abundance, community composition, and many ecosystem properties. Novel assemblages may form, creating many challenges because we will not know the outcome of interactions like competition, nor will we know the successional pathways some communities will take. ISRO's isolation may magnify some effects on species by increasing extinction and limiting new arrivals. Species' capacity for and method of dispersal will take on an even more important role than on the mainland. Under current climate change projections, it is almost certain that some species that are disjunct populations with an alpine affiliation, or are near the southern limit of their range, will disappear. During roughly the same time period, an unknown (probably smaller) number of novel plant species will expand northward and appear at ISRO. Species that are scattered and uncommon (not limited to threatened or endangered species), have limited genetic variation (e.g., wolves), or rely on specialized pollinators will be more vulnerable to local extinction. It is likely that mammalian richness will decrease, but avian richness will not. It is unknown how important groups like the arthropods, amphibians, and fungi will respond, but clearly there will be important ecologic changes if and when the climatic regime, and the plant composition and abundance, change.

Conclusions and Recommendations

NPS has developed conceptual ecosystem models for long-term ecologic monitoring in Great Lakes nearshore and coastal wetland areas, inland lakes, wetlands, and northern forests (Gucciardo et al. 2004). Each ecosystem has a set of vital signs, defined as "…attributes that are determined to be the best indicators of ecologic condition, or respond to natural or anthropogenic stresses in a predictable or hypothesized manner, or have high value to the park or the public…" (Route and Elias 2006). We have used those vital signs to evaluate the condition of ISRO ecosystems; unless a source is listed under "Condition," the rankings are our own. We also added indicators using our professional judgment (Table 31–Table 35). The current and potential impacts of major stressors have also been identified (Table 36).

In addition to specific recommendations below, we recommend a review of the three recent reports by Schlesinger et al. (2009), Crane et al. (2006), and Lafrancois and Glase (2005), which make detailed monitoring and management recommendations for ISRO.

Lake Superior

Although Lake Superior has the greatest surface area of any freshwater lake in the world and is an ultra-oligotrophic lake (LSBP 2006a), it is still susceptible to anthropogenic stress. Atmospheric deposition of contaminants and their resulting trophic bioaccumulation is an area of significant concern for Lake Superior (Table 32, Table 33). Deposition of chlordane, dioxin, mercury, and PCBs is reflected in fish consumption advisories for many species, especially for larger fish. Aquatic invasive species are also of significant concern; sea lamprey, threespine stickleback, spiny water flea, and dreissenid mussels have been found at ISRO.

Vital signs with a ranking of "caution" include Lake Superior water levels, which have been below long-term averages, and a trend toward increasing water temperature and nitrate concentration. Exotic cattails and reeds were found in a recent survey of coastal wetlands. The aquatic pathogen VHSv has recently been detected in the lake. Coaster brook trout populations remain low, and the fish community is strongly (and perhaps irrevocably) influenced by introduced species.

Nearshore water quality data were not found for ISRO. Major data gaps exist for the vital signs of sediment analysis, toxic concentrations in sediments, and benthic invertebrates. Metrics were unavailable for the vital signs of algae, nutrient dynamics and biogeochemistry, geomorphology, primary productivity, zooplankton, and indices of biological integrity.

Major existing stressors for Lake Superior are atmospheric deposition and exotic species (Table 36). Other potential problems are Great Lakes shipping and recreational boating, which could be sources of fuel spills or discharges of human wastes and other contaminants. Wastewater disposal and soil and groundwater contamination are small-scale sources that appear to be adequately addressed as they are discovered. Climate change may affect all ISRO resources in ways not yet understood. For Lake Superior, effects could include changes in water levels, water chemistry, and biotic communities.

Along with Lafrancois and Glase (2005), we recommend bathymetric assessments, habitat mapping, and biological inventories (including nearshore fish surveys) of Lake Superior nearshore waters, and we add a recommendation for baseline core and advanced water quality testing. We endorse the recommendation of Kallemeyn (2000) to frequently monitor nearshore waters and bays for invasive species, especially dreissenid mussels. Given the importance of the remnant coaster brook trout populations at ISRO, we recommend continued study and evaluation of any threats to this population. Further genetics investigations of lake trout are necessary to determine if there are different stocks around the island and if potential over-exploitation could be possible due to low numbers of some stocks (Lafrancois and Glase 2005).

We acknowledge the challenge of addressing threats to park resources that originate far beyond park boundaries; perhaps a mechanism should be set up in NPS to address this challenge, if one does not already exist.

Inland Lakes, Rivers, and Wetlands

No vital signs were ranked as significant concerns for ISRO inland waters (Table 34). However, many vital signs received a rank of "caution," often because data were limited in geographic scope and collected some time ago. Very limited data suggest changes in the water chemistry of some lakes, including increases in major ions, specific conductance, pH, and chlorophyll–*a*. Some lakes exceed nutrient criteria for their ecoregion; this finding seems unusual for lakes in a wilderness setting, but does not by itself indicate a problem. In general, ISRO inland waters appear to be of good quality and free of local anthropogenic influences. Because ISRO is isolated from mainland impacts and mostly protected as wilderness, water quality monitoring activities can serve as valuable datasets to assess long-term effects of atmospheric deposition or global warming. Thus, it is important that the monitoring programs already in place be continued.

Aggressive exotic plants were found in a recent survey of inland lakes and wetlands. Fish in some inland lakes have consumption advisories for mercury. Little is known about certain groups of organisms such as benthic invertebrates, algae, zooplankton, or freshwater sponges. Little is known about water levels on inland water bodies, and the only long-term gaging station on ISRO, located on Washington Creek, was recently deactivated.

Atmospheric deposition is considered an existing problem for inland waters because of the fish consumption advisories (Table 36). To date, exotic animals have not been detected, but have the potential to be introduced through visitor use. Climate change is a potential threat to inland water levels, water chemistry, and biotic communities.

ISRO's wetlands inventory is incomplete (Crane et al. 2006), and inventories for wetland biota other than plants are generally lacking. We recommend a more thorough look at ISRO wetlands, using the 1999 Vegetation Mapping Program (TNC 1999) and Meeker et al. (2007) as starting points. Inland lake fish assessments should be conducted on a regular basis, especially because some inland coregonid populations (such as those in Lake Desor) may be vulnerable to the effects of climate change (Lafrancois and Glase 2005).

Terrestrial Resources

The plant composition of ISRO is quite valuable for its diversity. At least two plant communities (the white cedar–yellow birch forest and the boreal calcareous seepage fen) are globally rare (TNC 1999). The greatest botanic value of the park lies in its disjunct populations, most of which are found along the Lake Superior shoreline (Judziewicz 1995, 1997, 2004) and on Passage Island. This group contains 21 arctic and alpine species and 12 species whose ranges are centered in the western U.S. (Judziewicz 1995). The range of community types, large number of species of concern, and minimal incidence of exotics, coupled with minimal human impact during the settlement era, make ISRO a suitable reference condition for other protected areas in the region (Schlesinger et al. 2009).

No vital signs were ranked as significant concerns for ISRO forests (Table 35). Some woody species (white pine, tamarack, and Canada yew) have declined since approximately 1860, largely due to human activities. Nutrient deposition could affect nutrient cycling, decomposition, nitrogen availability, and the availability and leaching of cations in the future. Concerns exist about fluctuating moose and wolf populations and lack of genetic diversity among wolves, but bird communities appear to be in good condition and are similar to mainland bird communities. Priority should be given to monitoring and evaluating the mammalian community, since it has limited dispersal capacity and so is vulnerable to stressors such as climate change.

Metrics have not been defined for the vital signs of special habitats; biotic diversity; trophic relations; health, growth, and reproductive success; lichens and fungi; or primary productivity.

We recommend continuation, and expansion if necessary, of monitoring for exotic plants along trails and in other human use areas. Schlesinger et al. (2009) further encouraged the analysis and integration of current monitoring of changes in vegetation. They suggested that synthesizing several large datasets could allow insight into the role of moose, climate, and soils in controlling the composition and dynamics of vegetation and providing a baseline for understanding the role of moose and/or climate change in future vegetation changes. In addition, detailed studies of the understory are needed to assess the differences between forest types and their conservation value. More information is needed on the status of the ISRO boreal forest and the abundance of each successional stage relative to its historic range and variability. Further monitoring and mapping of the possible presence and abundance of exotic earthworms in the various forest types should be considered.

We endorse the recommendations of Schlesinger et al. (2009) to monitor atmospheric deposition, especially for nitrogen, and to assess impacts on aquatic and terrestrial components of the ISRO ecosystem. Similarly, Swackhamer and Hornbuckle (2004) recommended research to evaluate the relative impact of local versus regional or global sources of atmospheric contaminants at ISRO. Lafrancois and Glase (2005) supported the continuation of Stottlemyer’s work in additional scattered ISRO watersheds with particular attention to how climate warming may affect the cycling of nutrients and organic carbon in ISRO watersheds.

Table 31. Condition summary for general resources, Isle Royale National Park.

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Light pollution	Not defined	UNRANKED	Originates from residential areas within ISRO and Thunder Bay to the north (page 129).	Good
Soundscapes	Not defined	UNRANKED	Inventory completed for Wilderness and Backcountry Management Plan (NPS 2005) (page 129).	Fair
Land use/land cover coarse scale	Conversion rate of non-developed land to developed and of nonforest to forest.	GOOD	Lowest conversion rate of non-developed land to developed and highest conversion rate of nonforest to forest of all Great Lakes from 1992 to 2001 (USEPA and Environment Canada 2007).	Good
Land use/land cover fine scale	Area and percent land cover change per year Types and frequency of disturbance Patterns of connectivity and fragmentation Changes in road and building density	GOOD	99% of ISRO is managed as wilderness.	Good
Phenology	Dates that flowering and growth are initiated	CAUTION	Regional changes are occurring (Walther et al. 2002), but not documented for ISRO (page 143).	Poor
Weather/ meteorologic data	Not defined	CAUTION	Summer temperatures are trending upward (page 7).	Good

Table 32. Condition summary for air quality, Isle Royale National Park.

Metric	Condition	Data Summaries or References	Quality of data
Air quality for Class I area	GOOD	Met NPS goal of stable or improving air quality for ozone, $PM_{2.5}$, and SO_2 (NPS 2006).	Good
Ozone	UNRANKED	Insufficient data (NPS 2006).	Poor
Visibility–clear days	CAUTION (NPS rank)	No trend, 1996–2005 (NPS 2006).	Good
Visibility–hazy days	CAUTION (NPS rank)	No trend, 1996–2005 (NPS 2006).	Good
Sulfate in precipitation	CAUTION (NPS rank)	Degrading trend, but not statistically significant, 1996–2005 (NPS 2006). Emissions of SO_2 within 250 km of ISRO decreased 8% from 1996–2002 (page 102).	Good
Nitrate in precipitation	SIGNIFICANT CONCERN (NPS rank)	No trend, 1996–2005 (NPS 2006). Inorganic N deposition was 0.52–1.42 kg/ha/summer from 1985–2006; estimated to be 3.5 kg ha^{-1} yr^{-1} by extrapolation from station at Hovland, MN (page 104).	Good
Ammonium in precipitation	SIGNIFICANT CONCERN (NPS rank)	Degrading trend, but not statistically significant, 1996–2005 (NPS 2006).	Good
pH of precipitation	CAUTION	Mean pH has varied from 4.35 in 1992 to 5.38 in 2006, with notably lower values in 2004 and 2005 (page 106).	Good
Mercury and persistent organic pollutants	CAUTION	Long-range atmospheric transport continues to be the main source of these compounds at ISRO; emissions within the basin are decreasing (page 101).	Good

Table 33. Condition summary for Lake Superior, Isle Royale National Park.

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Plant exotics	Presence/abundance	CAUTION	Cattails and reeds found on 1.2% of shoreline (page 23).	Good
Animal exotics	Presence/abundance	SIGNIFICANT CONCERN	Sea lamprey, threespine stickleback, spiny water flea, and invasive mussels present (page 132).	Good
Core water quality suite	Water clarity	GOOD	Good and unchanged, 1992–2002 (USEPA 2006).	Fair
	Temperature	CAUTION	Trend toward increasing temperatures, 1979–2006 (page 37).	Fair
	Specific conductance	GOOD	No apparent trend, 1996–2008 (page 37).	Fair
	Dissolved oxygen	GOOD	All but one of 1,108 samples met standard (page 36).	Fair
	pH	GOOD	All of 653 samples met standard (page 37).	Fair
Threatened and endangered species	Presence/abundance	GOOD	ISRO has unique habitats and is home to many species threatened elsewhere in their ranges.	Fair
Water level fluctuations	Measurement of water levels over time	CAUTION	Lake Superior water levels are controlled, but have been below long-term average since 1998.	Good

Table 33. Condition summary for Lake Superior, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Advanced water quality suite	Major ions	GOOD	Values low, but some parameters are missing and proportions cannot be calculated (page 37).	Poor
	Dissolved silica	GOOD	Considered sufficient for diatom production (page 34).	Fair
	Alkalinity	GOOD	Sufficient to buffer acid rain (page 37).	Fair
	Dissolved organic carbon	UNRANKED	Lake Superior is limited by organic carbon (page 34).	Poor
	Chlorophyll-*a*	GOOD	In oligotrophic range (page 34).	Fair
	Nutrients	CAUTION	TP is below the upper limit of 5 µg L^{-1}; NO3-N is increasing (page 33).	Fair
Aquatic and wetland plant communities	Not defined	CAUTION	Inventory recently completed; some AIS found (page 23).	Good
Fish communities	Not defined	CAUTION	Inventory recently completed; coaster brook trout populations remain low; fish community is strongly influenced by the presence of introduced species (page 25).	Good

Table 33. Condition summary for Lake Superior, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data References or Summaries	Quality of Data
Trophic bioaccumulation	Monitoring and assessing methylmercury and organic contaminants in yellow perch, northern pike, and dragonfly larvae at three year intervals	SIGNIFICANT CONCERN	The Michigan waters of Lake Superior have fish consumption advisories for chlordane, dioxin, mercury, and PCBs (page 41).	Good
Mussels and snails	Not defined	GOOD	Healthy mussel population found in very limited sampling in McCargoe Cove (Nichols et al. 2001a).	Fair
Sediment analysis	Not defined	UNRANKED	No data found.	Poor
Toxic concentrations in sediments	Presence of toxics at levels exceeding standards	UNRANKED	No data found.	Poor
Toxic concentrations in water	Presence of toxics at levels exceeding standards	FAIR (SOLEC ranking)	Low levels of numerous toxics have been found in Lake Superior waters (page 39).	Fair
Benthic invertebrates	Not defined	UNRANKED	No data found.	Poor
Aquatic pathogens	Presence/absence	CAUTION	VHSv recently found in Lake Superior, and 28 fish species are vulnerable (page 134).	Fair

Table 33. Condition summary for Lake Superior, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data References or Summaries	Quality of Data
Algae	Not defined	UNRANKED	USEPA annual surveys (page 33).	Fair
Nutrient dynamics/ biogeochemistry	Not defined	UNRANKED	USEPA annual surveys (page 33).	Fair
Aeolian, lacustrine geomorphology	Not defined	UNRANKED	No data found on condition.	Poor
Primary productivity	Not defined	UNRANKED	USEPA annual surveys (page 33).	Fair
Index of biological integrity (IBI)	Numerous indices in development (see page 31**Error! Bookmark not defined.**).	UNRANKED	No indices have been applied to ISRO to date.	Poor
Zooplankton	Not defined	UNRANKED	USEPA annual surveys (page 33).	Fair

Table 34. Condition summary for inland lakes, rivers, and wetlands, Isle Royale National Park.

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Plant exotics	Presence/abundance	CAUTION	Aggressive exotic species detected in broad survey of inland lakes and wetlands (Meeker et al. 2007).	Good
Animal exotics	Presence/abundance	GOOD	No nonnative fish species detected in lakes during most recent survey (Kallemeyn 2000).	Good
Core water quality suite	Water clarity	GOOD	Recent comparison of several lakes suggests normal variation in clarity (Kallemeyn 2000).	Fair
	Temperature	GOOD	No long-term change in lake temperature detected (Kallemeyn 2000, Elias 2009).	Fair
	Specific conductance	CAUTION	Comparison from lakes suggests slight increase in conductance (Figure 29).	Fair
	Dissolved oxygen	CAUTION	Hypolimnion of stratified lakes was below USEPA criterion on some dates; Lake Richie became anoxic below 5 m (page 71).	Fair
	pH	CAUTION	Limited long-term sampling, but one pH reading exceeded USEPA criterion (page 71).	Fair
Bird communities	Not defined	GOOD	Trends of ISRO bird populations are similar to mainland bird communities (page 86).	Good

Table 34. Condition summary for inland lakes, rivers, and wetlands, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Threatened and endangered species	Presence/abundance	CAUTION	Desor, Ritchie, Sargent, and Siskiwit Lakes are designated as “cisco lakes” (page 93).	Good
			ISRO supports at least two populations of threatened coaster brook trout (page 27).	Good
			Communities of freshwater sponges and mussels are present but relatively unstudied in many lakes (Nichols et al. 2002, Meeker et al. 2007).	Poor
Water level fluctuations	Measurement of water levels over time.	CAUTION	Limited data exist for water level on inland water bodies (GLKN now measures index lakes three times per year); a long-term gaging station on Washington Creek was recently deactivated (Crane et al. 2006).	Fair
Advanced water quality suite	Major ions	CAUTION	Increases in some major ions noted by comparing samples from 1995–1996 to 2007–2008 (Figure 29 and page 71).	Fair
	Dissolved silica	CAUTION	Limited data suggests that silica is variable but within range necessary for aquatic organisms (page 73).	Fair
	Alkalinity	GOOD	Alkalinity in lakes is within acceptable range and unchanged between recent surveys (Figure 29).	Fair
	Dissolved organic carbon	GOOD	DOC is within acceptable range and unchanged between recent surveys (Figure 29).	Fair

Table 34. Condition summary for inland lakes, rivers, and wetlands, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Advanced water quality suite (continued)	Chlorophyll-*a*	CAUTION	Chlorophyll-*a* concentration can be variable, but many lakes show increase between recent surveys (page 74).	Fair
	Nutrients	CAUTION	Several lakes exceeded USEPA reference criteria for the ecoregion during recent survey (page 75).	Fair
Aquatic and wetland plant communities	Not defined	GOOD	Native communities appear stable despite some exotic, aggressive species; Native species previously undocumented were found by Meeker et al. (2007).	Good
Amphibians and reptiles	Presence/distribution	GOOD	Apparent broad distribution of native salamanders, snakes, and turtle (page 67).	Fair
Fish communities	Change in native communities over time	GOOD	Few changes in the species composition of ISRO lakes from early 1900s to 1990s (Kallemeyn 2000).	Good
Trophic bioaccumulation	Concentration in organisms exceeding recommended levels/benchmarks	CAUTION	Mercury concentration in fish is above recommended levels in several lakes (page 110).	Fair
		GOOD	Organic compound and heavy metals were detected in mussels at ‘levels well below any concentration of concern’ (Nichols et al. 2001a).	Fair

Table 34. Condition summary for inland lakes, rivers, and wetlands, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Toxic concentration in sediments	Presence of toxics at levels exceeding standards	UNRANKED	No data found.	Poor
Toxic concentrations in water	Presence of toxics at levels exceeding standards.	GOOD	Some data exceeded USEPA criteria in Washington Creek between 1965 and 1974, but subsequent readings were normal (Table 23).	Good
Health, growth and reproductive success	Not defined	GOOD	Eagle and osprey population increasing (NPS ca. 2003) and populations of aquatic organisms apparently stable.	Good
Benthic invertebrates	Not defined	CAUTION	Limited sampling of invertebrate communities from Siskiwit and Sargent Lake did not raise concern (Whitman et al. 2000).	Fair
Aquatic pathogens	Presence	CAUTION	VHS has not been detected in inland waterways on ISRO, but has been found in Lake Superior (page 134).	Fair
Algae/Phytoplankton	Not defined	CAUTION	Samples from Siskiwit and Sargent Lake between 1997 and 1999 did not report unusual community composition (Whitman et al. 2000).	Fair
Nutrient dynamics/biogeochemistry	Not defined	GOOD	Early concerns regarding acidic precipitation indicate that acidity is buffered and has not significantly altered aquatic systems (page 110).	Fair
Zooplankton	Not defined	GOOD	Zooplankton communities from ISRO lakes are similar to nearby mainland lakes, but regular monitoring efforts have been recommended (Whitman et al. 2000).	Fair

Table 35. Condition summary for forest resources, Isle Royale National Park.

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Plant exotics	Distribution/abundance	GOOD	Judziewicz 1997.	Fair
Animal exotics	Distribution/abundance	GOOD	No data found to support the presence of animal exotics.	Fair
Terrestrial plants	Abundance, number of populations	UNRANKED	Judziewicz 1997.	Fair
Bird communities	Not defined	GOOD	Trends of ISRO bird populations are similar to mainland bird communities (page 86).	Good
Problem species (white-tailed deer)	Presence/abundance	GOOD	White tailed deer are not present on ISRO.	Good
Problem species (exotic earthworms)	Presence/abundance of key taxa (e.g., *Lumbricus terrestris*)	UNKNOWN (GOOD?)	Significant differences in invasion potential in ISRO forests (page 140).	Poor
Threatened and endangered species	Number and distribution of populations	CAUTION	Judziewicz 2004 listed many plant species of concern, especially disjunct species, mainly along the Lake Superior shoreline (page 78).	Good
Mammal communities	Number of species; population density of wolf	CAUTION	NPS records and Peterson 1999.	Good
Uncommon inland community types	TNC Community types 1, 16, 22, 31, 37, 44, and 48	CAUTION	Judziewicz 1997, TNC 1999.	Good

Table 35. Condition summary for forest resources, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Plant species that have declined since approximately 1860	Decline in population from historic levels	CAUTION	Eastern white pine, larch, and Canada yew populations have declined, in part due to past harvesting (Janke et al. 1978).	Fair
Special habitats	Not defined	UNRANKED		Unknown
Harvested species	Not defined	GOOD	No species are harvested in ISRO.	Good
Mercury concentration	Concentration in soil solution or associated with organic matter	UNRANKED	Cannon and Woodruff 2000, Grigal 2003.	Poor
Terrestrial pests and pathogens	Presence, damage	GOOD	None are known to be a major issue (page 137).	Fair
Succession	Abundance of each boreal forest successional stage relative to historic range and variability	CAUTION	Hansen et al. 1973, FIA data (page 80).	Fair to Poor
Biotic diversity	Not defined; may be covered by other metrics	UNRANKED		Unknown
Trophic relations	Not defined	UNRANKED		Unknown

Table 35. Condition summary for forest resources, Isle Royale National Park (continued).

Vital Sign	Metric	Condition	Data Summaries or References	Quality of Data
Soils, soil organic matter	Carbon/nitrogen ratio, concentration of nitrogen	CAUTION	Deposition rates suggest that nitrogen levels in soil could be rising (page 110).	Poor
Health, growth and reproductive success	Not defined	UNRANKED	These types of metrics tend to be ambiguous and require long-term intensive monitoring to have much potential as indicators.	Unknown
Lichens and fungi	Not defined	UNRANKED		Unknown
Nutrient dynamics/biogeochemistry	Concentration of sulfate and potassium ions in soil solution, ammonium immobilization rate	CAUTION	Stottlemyer and Hanson 1989, Stottlemyer and Toczydlowski 1999a.	Poor
Primary productivity	Not defined	UNRANKED		Unknown

Table 36. Impact of stressors on aquatic and upland resources in Isle Royale National Park.

Stressor/Resource	Lake Superior and coastal wetlands	Inland lakes	Streams	Interior wetlands	Upland resources	Lowland forests
Atmospheric Deposition	existing problem	existing problem	potential problem; insufficient information	potential problem; insufficient information	potential problem; insufficient information	potential problem; insufficient information
Nutrient Enrichment	potential problem	potential problem	potential problem; insufficient information	potential problem; insufficient information	potential problem; insufficient information	potential problem; insufficient information
Altered Disturbance Regime - Fire Exclusion	--	--	--	--	not a known problem	not a known problem
Soil and Groundwater Contamination	potential problem	not a known problem	not a known problem	not a known problem	not a known problem	not a known problem
Wastewater Disposal	potential problem	not a known problem	not a known problem	not a known problem	not a known problem	not a known problem
Great Lakes Shipping	existing problem	not a known problem	not a known problem	not a known problem	--	--
Commercial And Recreational Fishing	not a known problem	not a known problem	not a known problem	--	--	--
Recreational Boating	potential problem	potential problem	not a known problem	--	--	--
Visitor Use	potential problem	potential problem	not a known problem	not a known problem	potential problem; insufficient information	not a known problem
Climate Change	potential problem	potential problem	potential problem	potential problem	potential problem	potential problem
Exotic Species	existing problem	potential problem	potential problem	potential problem	potential problem	potential problem

(red hexagon) =existing problem; (yellow hexagon) =potential problem; (green hexagon) =not a known problem; (grey box) =insufficient information

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Appendices

Appendix A. Sources of data for base map and notes on map content development.

All maps and associated geoprocessing were done with the ArcGIS 9.3 software by Environmental Systems Research Institute, Inc., Redlands, CA (2009). Maps are shown in the NAD 1983 UTM Zone 16N coordinate system. Spatial data obtained in other datums or coordinate systems were re-projected using ArcGIS.

Park boundaries (lines and areas), hydrography (streams, lakes, shorelines), and terrain (DEM elevation grids and hillshading) were typical base map features used on many of the report maps. The overall park boundary and area defined as the 4.5 mile extension onto Lake Superior is the Isle Royale NP Park Boundary (parkbnd) layer (MTU 1993). The boundary and areas for the main and included islands are based on the shoreline features (FCode 56600 L. Superior Coastline) from the National Hydrography Dataset (NHD) - High Resolution (USGS 2008) obtained from Ulf Gafert, NPS Ashland, WI Center on 06/19/2008. The NHD was also the source for the ISRO stream/river flowline features (FTypes 33400-Connectors, 46003-Intermittent, 46006-Perennial, and 55800-Artificial Path) and lake/pond waterbody features (FTypes 39004-Perennial and 39009-Perennial with stage; also included Big Siskiwit River outlet FType 46006). Elevation data was obtained from NPS-Ashland, WI (Ulf Gafert, 06/24/2008), as 2 m DEMs from bare earth LIDAR data. North and south DEMs were combined, irregularities fixed, and fitted to the island boundaries noted above. The hillshade layer was created with the standard ArcGIS hillshading tool applied to the final 2 m DEM.

Regional scale maps included layers for state and county (province and upper tier municipal unit for Ontario), that were created by merging detailed layers from Michigan (MI Center for Geographic Information, 2008, Michigan Geographic Framework ver 8a; http://www.mcgi.state.mi.us/mgdl accessed 2/5/2009), Wisconsin (WDNR, 1992, Wisconsin County Boundaries, Madison, WI), Minnesota (MNDNR, 2003, Minnesota County Boundaries; http://deli.dnr.state.mn.us accessed 7/7/2008), Ontario (ESRI Canada, 2004, Ontario Base Map Delivery Website, Upper Tier Municipal; http://www.geographynetwork.ca/website/obm/viewer.htm accessed 6/30/2008), and the park boundary noted above. Edge problems were fixed and closure lines added as needed.

Sources for other content on individual maps are noted in the figure caption. Digital versions (GIS-ready) of the source data were used when possible. When GIS layers were not available, new layers were developed from available spatial information (see below). Layer symbolization represents our interpretation or application of the data. Figures that are direct copies from other reports (not our GIS product) are noted as “from” (Figure 2 and Figure 3), and figures that are GIS reproductions of the original report figure are noted as “after” (Figure 8 and Figure 47).

Figure 7, Lake Superior bathymetry and soundings, is based on water depth information (sounding points, shoreline, and shallow depth contours) from NOAA electronic navigation charts (ENCs), primarily chart 14961 for Lake Superior and chart 14976 for Isle Royale. Additional sounding point data was also obtained as needed from charts 14962–14969 and 14973–14974. A 50 m depth grid for the ISRO area and a 200 m grid for Lake Superior were developed from the ENC data using ArcGIS and Golden Software's Surfer interpolation tools along with manual contouring and detailing. The bathymetry shading layer was made with the ArcGIS hillshading tool. A masking layer to cover landward extents of the bathymetry interpolation was also developed by utilizing the general Lake Superior coastline from ENC 14961 and the ISRO coastline from ENC 14976.

Figure 8, Lake Superior currents, was created by on-screen digitization of Figure 7 in the Lake Superior Lakewide Management Plan (LSBP 2006a).

Figure 13 (USEPA open water sampling sites), Figure 33 (air quality monitoring sites), and Figure 34–Figure 40 (regulated facilities and emissions for criteria air pollutants), were made using published lat/long coordinates from the noted sources. The air direction roses for the air emission maps were based on 2007-2008 averages for Rock of Ages and Passage Island sites (NBDC 2009a,b). Figure 34, regulated facilities, also displays a distance overlay from ISRO, created by buffering the base map park boundary (water extent).

Watershed delineations shown on Figure 21–Figure 23 were made using the ArcGIS watershed tool and the 2 m DEM discussed above. Some manual fine adjustments were made to smooth the junction of watersheds and to best represent outlet areas.

Figure 24, Lake types by canonical correspondence analysis, utilized a subset of the base map waterbody layer. The canonical correspondence grid position for each target lake was obtained from the referenced source and the lake symbolized based on a continuous gradient of colors developed for the analysis grid.

The wetland figures (Figure 25–Figure 27) utilized a subset of the vegetation layer (TNC 1999, USGS 2000a). As described in the report in the Inland Aquatic Resources section, the wetland communities in Ecologic Groups 3 and 4 were grouped into seven types, an attribute field was added to the veg layer for this classification, and the maps symbolized on this field. Figure 28, river-associated wetlands, also uses this wetland subset of the vegetation layer. In this case, the contiguous polygons with the same wetland grouping were dissolved and unioned with the stream layer in order to quantify wetland areas adjacent to streams. This river-associated wetlands analysis also utilized 10 and 100 m buffers of the base map stream layer and a subset of the stream layer representing the intersection of the stream and veg based wetland layer.

Figure 46, Lake Superior shipping lanes, is based mostly on the Lake Superior ENC chart 14961 for the Lake Superior coastline and the recommended ship routes. The ENC's navigation line feature was symbolized by type and direction, and a point direction (arrowhead) layer was created from the navigation line orientation field. Some additional ferry route segments were obtained from ENC charts 14964, 14968, and 14976.

Figure 47, location of mines, reproduces the original report map in a new GIS format. In addition to the original report figure as a general guide, mine site locations were obtained from the Mine and Mine Related Point Features of Isle Royale National Park (ISROMIN) layer (NPS 2004d), and mine sites noted on the DRG available for ISRO as noted below.

Although not used directly on any maps, digital version of the USGS topographic maps (DRGs) and airphotos (DOQs) were used to verify other data, serve as a base for digitization, and as a general reference for locating features. A composite of 1:24k DRG quads and a 2005 NAIP color photo mosaic, both in .sid format, were obtained from the NPS Ashland Center on 06/24/2008.

A complete list of GIS layers, sources, and available metadata is included as Appendix B.

Appendix B. Description of GIS layers, sources, and metadata for maps used in the preparation of this report.

Layer	Type	Source	Description	Metadata File
Air_Canada2007	point	Environment Canada 2009	facilities on the Canadian national pollutant release inventory	Air_Canada2007.xls
Air_Monitoring_Sites	point	various-see text	air quality monitoring stations pertinent to the ISRO area	ISROAirSites.xls
Air_US2002	point	USEPA 2009c	facilities on the USEPA AIRS/AFS air release list for the MN, WI, and MI area	Air_US2002.xls
APIS	polygon		Apostle Islands National Lakeshore area from previous Coastal Assessment report	
Bathymetry_mask	polygon	NOAA 2007a,d	land area polygon mask to cover landward extent of the bathymetry grids	NOAA_ENC_download.txt
CCA_Axes	line	new (legend)	the central axes for the CCA_Grid layer	
CCA_Grid	polygon	new (legend)	a canonical correspondence grid to match values in CCA_Lakes	
CCA_Lakes	polygon	USGS 2008, Carlisle 2000	a subset of the Hydro_Lakes layer for lakes with canonical correspondence analysis available	see Carlisle 2000
DEM2I	grid	Ulf Gafert, NPS, 06/24/2008	2 m DEM (integer centimeter) for ISRO	
DEM50I	grid	see DEM2I	50 m DEM (integer centimeter) resampled from DEM2I	
EPA_Sensitivity	line	USEPA Region 5 2000	shoreline type and sensitivity classification extracted for ISRO shorelines	Inland_Sensitivity_Atlas.HTM, UPMESI.txt, UPMESI.pdf
Geology	polygon	NPS 2004c	geologic units of ISRO; a geologic group attibute field was added for mapping	isroglg.shp.xml
Hillshade2	grid	derived	Ground surface elevation hillshade created in ArcGIS using the DEM2I layer	
Hillshade50	grid	derived	Ground surface elevation hillshade created in ArcGIS using the DEM50I layer	
Hydro_Coast	line	USGS 2008	NHD feature type 566 (Lake Superior coastline)	National Hydrography Dataset (NHD) - High-resolution.htm

Shading indicates modification, attribute editing, or significant geoprocessing of source GIS data

Appendix B. Description of GIS layers, sources, and metadata for maps used in the preparation of this report (continued).

Layer	Type	Source	Description	Metadata File
Hydro_Flow	line	USGS 2008	NHD feature types 334 (connectors), 460 (intermittent and perennial streams), and 558 (artificial paths)	National Hydrography Dataset (NHD) - High-resolution.htm
Hydro_Flow_200Corridor	polygon	derived	a 100 m buffer around the Hydro_Flow layer	
Hydro_Flow_Wetlands	line	USGS 2008	subset of ISRO rivers and streams (Hydro_Flow) that intersect wetland vegetation	
Hydro_Lakes	polygon	USGS 2008	NHD feature type 390 (perennial waterbodies)	National Hydrography Dataset (NHD) - High-resolution.htm
Hydro_Marsh	polygon	USGS 2008	NHD feature type 466 (undifferentiated swamp/marsh)	National Hydrography Dataset (NHD) - High-resolution.htm
Hydro_Named_Lakes	polygon	USGS 2008	subset of Hydro_Lakes for named lakes	National Hydrography Dataset (NHD) - High-resolution.htm
ISRO_Bath_Hillshade	grid	derived	50 m Lake Superior depth hillshade for the ISRO vicinity created in ArcGIS using the ISRO_Bathymetry grid	
ISRO_Bath_HS_comb	grid	derived	50 m hillshade combination of ISRO_Bath_Hillshade (L Superior) and Hillshade50 (ISRO land area)	
ISRO_Bathymetry	grid	NOAA 2007a,b,c,d	50 m integer grid of Lake Superior water depth in the vicinity of ISRO	NOAA_ENC_download.txt
ISRO_veg	polygon	USGS 2000a, TNC 1999	vegetation mapping used for upland and wetland analysis; wetland group added to attributes	USGS_ISRO_Spatial_Veg_Data_Metadata.txt, NatureConservancyVegClass.pdf, PhotoInterpretationReport.pdf
ISRO_veg_area	polygon	USGS 2000a, TNC 1999	the extent of the ISRO_veg layer	
ISRO_veg_wetlands_7grps	polygon	USGS 2000a, TNC 1999	subset of the ISRO_veg layer for wetland types; dissolved on seven major wetland groups	
ISRO_veg_wetlands_20corridor	polygon	USGS 2000a, TNC 1999	subset of ISRO_veg for wetlands within a 20 m corridor along rivers and streams	
ISRO_veg_wetlands_200corridor	polygon	USGS 2000a, TNC 1999	subset of ISRO_veg for wetlands within a 200 m corridor along rivers and streams	

Shading indicates modification, attribute editing, or significant geoprocessing of source GIS data

Appendix B. Description of GIS layers, sources, and metadata for maps used in the preparation of this report (continued)
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Layer	Type	Source	Description	Metadata File
L_Superior	polygon	see Region_Counties	Lake Superior boundary created from Region_Counties	
L_Superior_ENC	polygon	NOAA 2007a	Lake Superior area from NOAA ENC 14961 depth area features	NOAA_ENC_download.txt
L_Superior_ENC_arc	line	NOAA 2007a	Lake Superior boundary from NOAA ENC 14961 depth line features for coastlines	NOAA_ENC_download.txt
L_Superior_Surface_Current_Dir	point	LSBP 2006a	digitized Lake Superior surface current vector direction indicators	see LSBP 2006a
L_Superior_Surface_Currents	line	LSBP 2006a	digitized Lake Superior surface current vectors	see LSBP 2006a
L_Superior_Vertical_Currents	polygon	LSBP 2006a	digitized Lake Superior areas of upwelling and downward water movement	see LSBP 2006a
LS_Bath_Hillshade	grid	derived	200 m Lake Superior depth hillshade created in ArcGIS using the LS_Bathymetry grid	
LS_Bathymetry	grid	NOAA 2007a,b,c,d	200 m integer grid of Lake Superior water depth	NOAA_ENC_download.txt
LS_sample_sites	point	USEPA 2006, USEPA 2008a	Lake Superior water quality sampling sites in the ISRO area	GLENDA WQ Data.xls
LS_Soundings	point	NOAA 2007a,b,c,d	compilation of sounding point features from available NOAA ENCs	NOAA_ENC_download.txt
Mines	point	NPS 2004d, DRGs Karamanski et al. 1988	location of historic mines on ISRO	isromin.shp.xml
Park_arc	line	see Park_poly	ISRO land and water boundaries created from Park_poly	
park_buffers	polygon	derived	Five buffer zones, 50 km each, extending from the ISRO water park boundary (Park_poly layer)	
Park_poly	polygon	MTU 1993, USGS 2008	ISRO park areas created from the NPS park boundary feature and the Hydro_Coast line features	parkbnd.xml, National Hydrography Dataset (NHD) - High-resolution.htm

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Appendix B. Description of GIS layers, sources, and metadata for maps used in the preparation of this report (continued).

Layer	Type	Source	Description	Metadata File
PIRO	polygon		Pictured Rocks National Lakeshore area from previous Coastal Assessment report	
Region_Counties	polygon	MNDNR 2003	regional county level map created from Mn, WI, MI, and Ontario layers	MN_county_boundaries.htm
		WDNR 1992		WI_county_boundaries.htm
		MCGI 2008		MI_Geographic_Framework.html
		ESRI Canada 2004		Ontario Base Map Data Delivery Website.htm
Region_State_Land_Boundaries	line	see Region_States	regional state land boundary map created from Region_States	
Region_States	polygon	see Region_Counties	regional state level map created from Region_Counties	
Shipping_Lanes	line	NOAA 2007a,b,c,d	navigation line features from four NOAA ENC charts 14961, 14964, 14968, 14976	NOAA_ENC_download.txt
Shipping_Lanes_Direction	point	derived	direction of recommended track lines based on description and orientation in the Shipping_Lanes layer	
SLBE	polygon		Sleeping Bear Dunes National Lakeshore area from previous Coastal Assessment report	
Watershed_arc	line	derived	arc version of the Watershed_poly layer	
Watershed_poly	polygon	derived	the ISRO main island subdivided into watersheds for principal streams, drainages, and coastal areas, based on DEM2I layer	

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