GREAT LAKES ISLANDS: BIODIVERSITY ELEMENTS AND THREATS

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INTRODUCTION

The origin of this report lies in the transfer of nearly 100 islands from the U.S. Bureau of Land Management to the State of Michigan in the late 1980s. At that time there was almost no assembled information nor a state policy regarding Great Lakes islands. Officials disagreed about what to do with these islands. Some thought we should ignore or sell them because they were remote and isolated. Others thought we should build campgrounds with outhouses and boat access. Still others thought we should establish wildlife sanctuaries. Questions grew as to on what basis we should make these decisions. Years later, a barebones policy was drawn up for Michigan islands, undoubtedly the first one in the basin. But there were still many more questions than could be answered in the few files drawers of information spread throughout the Michigan Department of Natural Resources in 1988.

In 1995, with a grant from the Michigan Coastal Management Program, thirty-five people gathered for a three-day workshop in Roscommon, Michigan. Papers were invited from as many island experts as could be identified, the first gathering of its kind. The workshop led to the first assemblage of information about the islands as a collection, including recognization of the global significance of their biological diversity (biodiversity). Proceedings were published as the *State of the Great Lakes Islands* [Vigmostad (ed.) 1999; for executive summary see www.greatlakesislands.org/Execsummary2003.pdf]. Around the same time, a significant island effort was started by the U.S. Fish and Wildlife Service's Great Lakes Basin Ecosystem Team that continues and the team leader is on this project team (see www.fws.gov/midwest/greatlakes/gli.htm).

In December 2003, the Great Lakes Program Office of the U.S. EPA hosted a second Great Lakes forum in Chicago. This time over 100 people gathered and we became known as the Collaborative for the Conservation of Great Lakes Islands. The second forum led to successful grant-writing effort and the project underlying this report. Again, it was the GLNPO that had a funding mechanism that could support *binational* projects with basinwide implications. As described in *Acknowledments*, the Colloborative formed a small binational project team from government, academic, and nonprofit sectors. Other experts have been called on throughout the project to enhance team efforts.

While we knew of the islands' global significance due to work of Susan Crispin, Judy Soule, and others, in some ways we were starting from scratch. For example, we didn't know how many islands there were, how to classify, rank, or define "island", or, most importantly, which islands were the most important to conserve. So we have been putting into place these pieces that are necessary if we are to conserve the full variety of life on these islands in perpetuity.

Because of the scale of this project, it was necessary to create a geographic information system (GIS). Team members developed the structure and assembled GIS data for Ontario's islands. More and more partners joined the Collaborative, such as the Ontario Ministry of Natural Resources, enabling our resources to multiply. In the mean time, a ranking paper was published, 14 papers were given during a special island session at the 2004 International Association for

Great Lakes Research, and island indicators were submitted to the 2006 State of the Lakes Ecosystem Project.

This report describes the biodiversity elements of the islands of the Great Lakes and details threats to that biodiversity. This information is fundamental to a comprehensive, science-based understanding of the features and significance of these islands. The more we learn about this collection of islands, the more we appreciate just how extraordinary and fragile they are. We have been able to innovate and carry out GIS analysis for the Ontario islands by coastal environments and island groupings. For U.S. islands, we did create the island polygons so we could count and locate islands. Presently we are working out agreements with the five states with islands to finish assembling data layers necessary to do a complete assessment to identify binational Priority Island Conservation Areas: those islands areas with extraordinary species, communities, or habitat, facing threats, and not yet adequately conserved. Of the 31,407 islands, it will be the PICAs that will need our foremost and greatest stewardship.

The Islands of the Great Lakes

Great Lakes Islands: Biodiversity Elements

This section provides information and perspectives on the biodiversity of Great Lakes islands—the largest collection of freshwater islands in the world—to complement and update previous reviews of Great Lakes island biodiversity (Soule 1993; Soule *in* Vigmostad 1999). This effort is not intended to be a complete review of Great Lakes island biodiversity literature (see Soule 1993 for a comprehensive island research bibliography for Michigan); rather it provides background information to help focus and create a framework for island conservation programs.

Great Lakes islands: Abiotic features

The physical setting of Great Lakes islands is well described by Soule (1993):

> Sprinkled across all five of the Great Lakes, thousands of islands form a landscape unique in the world. Nowhere else does the combination of vast, interconnected, mid-continental bodies of freshwater and such a number and variety of islands occur.

Found from 49^0 to 41^0 North and 92^0 to 76^0 West, the islands occur in different climatic zones and thus support a wide range of species and natural communities. The biological diversity and distinctiveness of Great Lakes islands is due to the interaction of several factors including: (1) island size, (2) isolation of an island from the mainland and other islands, (3) island latitude and longitude, (4) bedrock (e.g., metamorphic, igneous, sandstone, and limestone) and surface soils of the island (e.g., silt, glacial till, and sand; see Boerner 1984), (5) island exposure to wave action, (6) influence of nearshore bathymetry, (7) effects of fluctuating water levels on islands, (8) climate, current and historical, especially microclimates generated by the Great Lakes (see Eichenlaub 1979), and (9) amount of time islands have been isolated from the mainland.

Climates and refugia

Lake Erie islands and the Apostle Islands (Lake Superior), like many other Great Lakes islands, tend to have warmer winters, later springs, cooler summers, and longer lasting autumns than adjacent mainland areas. These effects are especially pronounced for islands furthest from the mainland (Heredendorf and Stuckey 1977, Judziewicz and Koch 1993; see Eichenlaub 1979). Consequently islands serve as refugia, or "safe havens," for many species and communities during periods of environmental stress, as they have in the past and may in the future. Davis et al. (2000) noted that,

> The contrast in reconstructed temperatures at Voyageurs and Isle Royale national parks indicates that the ameliorating effect of the Great Lakes on temperatures has been in effect throughout the Holocene and presumably will continue in the future, thus reducing the potential for species loss caused by future temperature extremes....If future temperature changes, like those in the past, are buffered by lake effects, lakeside parks will continue to serve as temporary refuges for animals and plants that may not be able to survive at inland sites. Of course, large

and continuing regional changes in temperature will eventually be felt in lakeside parks as well.

GEOLOGICAL HISTORY

The 31,407 islands of the Great Lakes are geologically recent, having appeared only in the last 15,000 to 2,500 years (see Dorr and Eschman 1970). Because of their isolation and complex history (e.g., islands have at various times been submerged or connected with the mainland, varied in size and degree of isolation), many islands lack species common on the mainland, support other species in great abundance, or harbor species largely restricted to islands given their land area. This unusual species composition, including Great Lakes endemic species and communities (species and communities restricted to the Great Lakes ecoregion), results in island biotas that are globally distinctive and therefore of great importance (Soule 1993).

ISLANDS: BIOTIC PATTERNS OF DISTRIBUTION AND MODES OF DISPERSAL

Patterns of distribution

Biological diversity patterns have been generally described for islands: (1) larger islands tend to be more species rich than smaller islands, (2) less isolated islands tend to be more species rich than more isolated islands, (3) species richness is lower on small, isolated islands than on large, less-isolated islands due to higher extinction rates and slower colonization rates (MacArthur and Wilson 1963, 1967), (4) high rates of endemism are found on islands, especially islands that have been isolated for long time periods (tens of thousands to millions of years) and (5) some species are absent or disproportionately abundant on islands. Many of these concepts best apply to oceanic islands, but these principles apply to other islands, including Great Lakes islands and islands of terrestrial habitat.

In addition, islands may support (1) relict species and plant communities, (2) unusual or high-quality plant communities due to the absence of some biota (e.g., some herbivores or invasive species), (3) high concentrations of migrating and nesting birds, perhaps migratory bats and other taxa (e.g., snakes), and (4) important spawning areas for fishes in offshore shoals (Manny and Kennedy 2004). These characteristics are among the properties that define island biotas and thus their importance for conservation purposes.

Modes of dispersal

The biota of an island is dynamic. On islands once part of the mainland, species composition includes the original suite of species that has persisted plus those species that have dispersed to the island. Mechanisms that bring species to islands include flotsam, air transport (e.g., seeds carried to the island via birds or bats), swimming to or walking over ice from the mainland, deliberate or accidental anthropogenic introductions, and wind (see Scharf 1973; Morton and Hogg 1989). For example, all but 6.5 percent of approximately 210 plant species on Barrier Island (Lake Huron), Ontario, have adaptations for dispersal by water or birds (Morton and Hogg 1989). It has been hypothesized that certain reptiles and amphibians arrived on some Great Lakes islands via flotsam (see Hatt et al. 1948) or simply were carried by water currents to island shorelines. Gulls are thought to transport seeds of plants on their feathers and feet and via disgorged pellets when they fly from mainland feeding sites to island nesting areas (Hogg and Morton 1983). Migratory birds visit islands frequently during migration and some remain to breed (see Scharf 1973). Mammals, such as black bears are known to cross water barriers of at least several kilometers to visit islands (Corin 1976; see Appendix 2 for list of common and scientific names). Non-hibernating mammals, such as coyotes, wolves, and cervids (e.g., deer, moose, caribou, elk), travel to islands over the ice (Judziewicz 2001; Peterson 1995) thereby increasing their chances of colonization, even if they remain for short periods of time .

Anthropogenic activities may be increasingly important mechanisms for dispersing species to islands. Some introductions are deliberate, including introduction of white-tailed deer to islands in the Beaver Island archipelago (Lake Michigan; Hatt et al. 1948), while other introductions are almost certainly accidental, such as the arrival of garlic mustard on Washington Island in Lake Michigan (Judziewicz 2001). Possibly all but the smallest islands have received new species through either direct or indirect anthropogenic activity and this trend is likely increasing. Non-native, invasive species occur on all the Apostle islands (Lake Superior; Judziewicz and Koch 1993), Isle Royale (Lake Superior; Slavik and Janke 1993), all islands of the Grand Traverse archipelago (Lake Michigan; Judziewicz 2000) and on relatively small, isolated islands of the Beaver Island archipelago (Lake Michigan; Whately et al. 2005).

GREAT LAKES ISLANDS: BIOTIC FEATURES

The biota of Great Lakes islands is almost entirely a subset of the regional biota (Lomolino 1994, Hecnar et al. 2002). Although plants and animals on islands are most similar to the immediate Great Lakes mainland shoreline, Great Lakes islands have an extremely diverse biota including endemic species on Lake Erie islands (i.e., a subspecies of snail, *Anguispira kochi strontiana* found on Green Island (Life Line 2006); Herdendorf and Stuckey 1977), and even some species, such as the Lake Erie watersnake, whose populations are concentrated on islands. Distinctive plant communities composed of many rare species, including refugia for boreal and other communities, characterize many islands. Canadian islands, for example, support 100 percent of Canadian populations of 35 species and 18 communities, and over 50 percent of the Canadian distribution of 113 species and 38 communities (Mary Harkness, personal communication; see Appendix 3 for affiliations of those cited as a personal communication).

It is likely that populations of animal and plant species, especially those resident on islands, will diverge from their mainland counterparts. The Lake Erie watersnake, which evolved from the Northern watersnake, is a striking example of this divergence, as is the relatively high incidence of melanistic Eastern garter snakes on western Lake Erie islands (see King et al. 1997). Deer mice on the Grand Traverse Islands (Lake Michigan) have smaller cranial measurements than those on the mainland (Long 1978). Other island populations, including black bears on the Apostle Islands (Lakes Superior; Belant et al. 2002) differ genetically from mainland populations.

Island populations also differ from mainland populations ecologically. Southern red-backed voles occupy ecological niches on Poverty Island (Lake Michigan) that are distinct from the mainland (Judziewicz 2001). Although some differences between island and mainland populations have occurred, there are also examples where this has not been the case, such as the pollination system of the bird’s-eye primrose (Larson and Barrett 1998).

Great Lakes islands are important conservation areas that support distinctive flora and fauna (Soule 1993, Soule *in* Vigmostad 1999) and, with time, even more distinctive flora and fauna are likely to evolve. In short, the freshwater islands of the Great Lakes support a globally important set of diverse flora, fauna, and natural communities. The wide latitudinal and longitudinal distribution of the islands and the range of underlying bedrock and surficial glacial deposits create the foundation for a rich biotic community. Given the complexity of interactions that govern dispersal and survival of organisms, and the vast array of islands distributed over the Great Lakes region, it is no surprise that the flora and fauna of Great Lakes islands are so complex and diverse.

SPECIES RICHNESS AND SUSCEPTIBILITY TO CHANGE AS A FUNCTION OF ISLAND SIZE

Species richness and island size and isolation

Species richness of islands is reduced when compared to plants and animals on the adjacent mainland; this observation is consistent with relatively small islands elsewhere in the world. For example, the Beaver Island archipelago (Lake Michigan) supports only 62 percent of the mainland amphibian fauna, and 60, 66, 87, and 39 percent of the snake, turtle, bird and mammal faunas, respectively (Hatt et al. 1948). The relatively low species richness for taxa on islands relative to the mainland has also been described for Isle Royale (Lake Superior), Michigan (*in* National Park Service 1998), the Apostle Islands (Lake Superior; Belant and Van Stappen 2002), Grand Traverse archipelago (Lake Michigan; Long and Long 1976, Long 1978), Huron Islands (Lake Superior; Corin 1976), South Manitou Island (Lake Michigan; Scharf 1973), and islands in Lake Erie (Herdendorf and Stuckey 1977).

Large Great Lakes islands tend to have higher species richness than small islands. Plant species richness, for example, is positively correlated with island size on the Grand Traverse islands in Green Bay (Lake Michigan; Judziewicz 2001), Apostle Islands in Lake Superior (Judziewicz and Koch 1993) and the Beaver Island archipelago (Lake Michigan; Whately et al. 2005). Larger numbers of mammal species are associated with larger islands on the Grand Traverse islands (Lake Michigan) where there are as few as three species of mammals on the 198-hectare (490-acre) Little Summer Island, but 12 species on 5,664-hectare (14,000-acre) Washington Island (Long 1978). Similarly, there are fewer mammal species on small islands than large islands on the Apostle Islands (Lake Superior; Belant and Van Stappen 2002). Island area and winter activity of mammal species were the primary determinants of species composition on this archipelago. Island isolation was not a key factor affecting mammal distribution on the Apostle Islands although the islands are close to the mainland and each other. Similarly, non-volant (non-flying) mammal species richness (Lomolino 1994) and amphibian and reptile species richness (Hecnar et al. 2002) appear to be less associated with island isolation than island size.

Species richness on islands is not only a function of size and isolation but probably also reflects time since isolation and availability and diversity of habitats. Hazlett (1988) *in* Voss (2001) noted that for recently formed islands, the amount of habitat diversity, itself a result of topographic, edaphic (relating to soil), and other factors, may be an important determinant of plant-species richness. In addition, human activities have influenced species richness through extirpation (removed or destroyed) (see Hatt et al. 1948) and species introductions.

Susceptibility to change

The relatively small size and isolation of islands favors the potential for rapid change (Judziewicz 2001) and make islands especially vulnerable to alteration by natural processes and human-induced activities. For example, rapid ecological changes on islands have occured as a result of (1) fluctuating water levels that may inundate islands or alter shoreline habitat for birds and plants (e.g., Cuthbert 1985), (2) increases in deer density (Judziewicz 2001) following natural dispersal or planned introductions, and (3) in response to the colonization and abandonment of an island by colonial nesting birds (Hogg and Morton 1983, Hebert et al. 2005). Finally, impacts on communities and entire ecosystems have been well documented as a result of colonization of aquatic and terrestrial systems by numerous invasive species in the Great Lakes, and islands may be particularly at risk. These observations confirm that extra care be exercised, for example, to avoid bringing non-native species to islands, perhaps especially small islands. However, given the generally small landmass and isolation of most Great Lakes islands, eradication programs can be especially successful, as has been demonstrated on islands worldwide (see Veitch and Clout 2002).

SPECIES AND COMMUNITY COMPOSITION ON GREAT LAKES ISLANDS

No island is the same

Although a very few species may be found on many islands throughout most of the Great Lakes, most species have a patchy distribution on islands. This patchy distribution can be seen at large scales (e.g., among archipelagos) and small scales (e.g., islands within an archipelago). Although virtually each island, even islands close to each other, has a unique assemblage of species, some species appear to be quite widespread on islands and other species are consistently absent from Great Lakes islands even when present on the closest mainland areas.

Some species, whose range includes all or much of the Great Lakes basin, are also commonly found on islands in each of the Great Lakes. Examples include a diverse set of taxa including the American toad (see Hatt et al. 1948, Long and Long 1976, Scharf 1973, Corin 1976, National Park Service 1998), Eastern garter snake (see Hatt et al. 1948, Scharf 1973, Long and Long 1976, Corin 1976 , Herdendorf and Stuckey 1977, National Park Service 1998, Tiessen 2003), song sparrow (see Hatt et al. 1948, Scharf 1973, Corin 1976, Cadman et al. 1987, Peterjohn and Rice 1991, Apostle Islands National Lakeshore annual research, monitoring and restoration report 2004, Penskar et al. 2001), and woodland deer mouse (Burt 1948, Hatt et al. 1948, Scharf 1973, Corin 1976, Long 1978). Why these species are typically found on islands is largely unknown, but each is common, has broad geographical ranges, and appears to be ecologically resiliant. At least one of these species, the song sparrow, is common in habitat fragments (Crooks et al. 2004), which have as much edge as do many islands. Other taxa, such as the American redstart, are frequent on islands (see Hatt et al. 1948, Corin 1976, see map in Cadman et al. 1987; Peterjohn and Rice 1991, Apostle Islands National Lakeshore annual research, monitoring and restoration report 2004, Penskar et al. 2001). This species, also common along many mainland forested shorelines, may select islands because of the relative abundance of aquatic-dependent volant (flying) insects (Ewert, Hamas and Smith, unpublished data).

By contrast, some species are typically absent from islands except perhaps for the very largest islands such as Manitoulin (Lake Huron) or Isle Royale (Lake Superior). Ruffed grouse, short distance flyers, and large, wide ranging mammals such as black bear are among the species frequently absent from islands, especially relatively small and isolated islands, except where introduced. However, black bears have prospered on Stockton Island (Apostle Islands, Lake Superior; Peggy Burkman, personal communication) after swimming to the island and occur on some large islands close the mainland, such as Drummond Island (Lake Michigan; Baker 1983). Even many species of small rodents and others such as cottontail rabbits are frequently absent from islands. For example, common mammals on the mainland, such as white-footed mouse, cottontail rabbit, American beaver, American badger, long-tailed weasel, mink, and black bear, are largely absent from Lake Michigan's Grand Traverse (Long 1978) and Beaver Island archipelagos (Hatt et al. 1948), except where introduced. Clearly dispersal ability and seasonal activity patterns strongly influence species compostion on islands.

Island archipelagos differ in species composition. The mammal fauna of two archipelagos in the same Great Lake at the same latitude reveals interesting contrasts. For example, Lake Michigan's Grand Traverse islands lack Eastern chipmunks, but they are abundant on the Beaver Island archipelago (Hatt et al. 1948) barely 60 miles away. Conversely, red squirrels are absent from the Beaver Island archipelago, but occur on most Grand Traverse islands (Long 1978) as well as Lake Superior's Isle Royale and Apostle islands (Hatt et al. 1948). However, the boreal fauna is similar between the Grand Traverse and Beaver island groups (Long 1978). Additionally, the Apostle Islands also lack Eastern chipmunks, but support red squirrels (see Smith and Maragi 2004) while the Huron Islands (Lake Superior) have neither red squirrels nor Eastern chipmunks (Corin 1976). Distribution knowledge of these two species of squirrels highlights the idiosyncratic distribution patterns of species on Great Lakes islands.

At finer scales, species distribution and species-specific ecology also vary on islands within an archipelago. The distribution of mammals on islands in Green Bay (Lake Michigan; Long 1978) illustrates how diverse the mammalian fauna may be from island to island within an archipelago while revealing patterns common to the islands and other island archipelagoes. Only two species, white-tailed deer and coyote, which can disperse over ice, were found on all islands; no two islands had the same mammalian fauna (the range of similarity was 16 to 86 percent) even though no island was more than 10 kilometers (6 miles) from another island. Species that hibernate or are less likely to disperse over ice tend to be absent from or have restricted ranges on islands as in the Apostle Islands (Lake Superior; Belant and Van Stappen 2002). However, when a species reaches an island without competitors it may expand its niche and become abundant. A number of investigators have reported this pattern, including Long (1978) for deer mice and Southern red-backed voles on some Grand Traverse islands, Hatt et al. (1948) for woodland deer mice on some islands in the Beaver Island archipelago (Lake Michigan), and Smith and Maragi (2004) for Southern red-backed voles on Devil's Island (Apostle Islands, Lake Superior).

GREAT LAKES ISLANDS: SUPERABUNDANCE AND CHANGE OVER TIME

Islands, in large part because of their relatively small size and isolation, often lack keystone predators or herbivores (those species having disproportionate effects on an ecosystem) so some species become disproportionately abundant, which affects biological interactions, stability of ecological systems and landscape characteristics. This results in distinctive ecological systems that arise from both natural processes and processes set in motion by human activity. Isle Royale (Lake Superior), famous for the intensively studied relationships between moose and Eastern timber wolves, differs from similar mainland systems with large fluctuations and high densities of moose populations (Peterson 1995). Some islands in lakes Michigan and Erie support high densities of watersnakes and Eastern garter snakes, perhaps a reflection of the absence of mesopredator mammals (mid-level predators like a raccoon) or even ants (see Hatt et al. 1948). Ground-nesting songbirds have been reported as relatively abundant on the Apostle Islands (Lake Superior; Apostle Islands National Lakeshore annual research, monitoring and restoration report 2004). Additionally, colonial nesting waterbirds are concentrated on islands throughout the basin (UMVGLP 2005), especially where mid-size mammalian predators such as raccoon, gray fox, and red fox are absent and there is suitable nesting substrate. Further, because ground nesting colonial waterbirds tend to occupy islands with relatively little vegetation and low relief, the distribution of nesting colonies varies with water level as some islands may be flooded during high-water periods or the birds may abandon a site for other reasons. The result can be large fluctuations in numbers of birds over time as environmental conditions change.

Populations of some plant species can remain abundant, perhaps similar to presettlement conditions, where herbivores are absent. Canada yew, which has declined dramatically on the mainland due to deer browsing (Jalava et al. 2005; Whately et al. 2005), occurs in dense colonies on islands, or portions of islands, where deer or moose are absent or scarce (Table 2). The distribution of Canada yew has been greatly reduced so that the species has a relict distribution analogous to species restricted to specific microclimate or edaphic (soil) conditions. In this case, however, the relict distribution of yew is a consequence of accessibility of the species to deer rather than change in climate or other abiotic (non-living physical or chemical) factors. For example, when deer swim to islands with yew, populations of yew may decline (Peggy Burkman, personal communication). The status of yew on any island is dynamic and contingent upon the ability of deer to colonize an island.

Table 1. Some Great Lakes islands with significant Canada yew populations. Data from Corin (1976), Hatt et al. (1948), Jalava et al. (2005), Judziewicz (2001), Judziewicz and Koch (1993) Judziewicz and Kopitzke (1999), Mike Grimm (personal communication), Slavik and Janke (1993), and Whately et al. (2005).

Island	Archipelago	Great Lake	State/Province
Birch	Les Cheneaux	Huron	Michigan
Thunder Bay	Thunder Bay	Huron	Michigan
High	Beaver	Michigan	Michigan
Hog	Beaver	Michigan	Michigan
Poverty	Grand Traverse	Michigan	Michigan
St. Martin	Grand Traverse	Michigan	Michigan
Trout	Beaver	Michigan	Michigan
Au Train	No named archipelago	Superior	Michigan
East Huron	Huron Islands	Superior	Michigan
Huron	Huron Islands	Superior	Michigan
Outlying islands	Isle Royale	Superior	Michigan
Many islands	Georgian Bay	Huron	Ontario
Adventure	Grand Traverse	Michigan	Wisconsin
Cat	Apostles	Superior	Wisconsin
Devils	Apostles	Superior	Wisconsin
Eagle	Apostles	Superior	Wisconsin
Green	Grand Traverse	Michigan	Wisconsin
Ironwood	Apostles	Superior	Wisconsin
Michigan	Apostles	Superior	Wisconsin
North Twin	Apostles	Superior	Wisconsin
Otter	Apostles	Superior	Wisconsin
Outer	Apostles	Superior	Wisconsin
Raspberry	Apostles	Superior	Wisconsin
Sand	Apostles	Superior	Wisconsin
York	Apostles	Superior	Wisconsin

Because overbrowsing on Canada yew provides highly visible and measurable impacts, it may be an easily monitored indicator of island plant-community composition and integrity relative to one threat: deer browsing. Many other plant species, including orchids, lilies, and white cedar appear to have been severely overbrowsed as well (Judziewicz and Kopitzke 1999, Juziewicz 2001, Rooney et al. 2002). Islands without deer, due to their relative small size and isolation, may be prime areas to protect both rare and once common ecological systems because of the pervasive threat of overabundant deer in most of the upper Midwestern landscape (see Whately et al. 2005). Furthermore, deer can be removed from islands and thus permit vegetation recovery as has been done on Chambers Island (Lake Michigan), Wisconsin.

Introductions of species, deliberately or accidentally, are a special case of island colonization. There have been many cases of deliberate introductions, especially ruffed grouse (see Brewer et al. 1991), white-tailed deer, and game or fur-bearing mammals. Hatt et al. (1948) reported that raccoons, striped skunk, Eastern gray squirrel, Eastern fox squirrels, American beaver and muskrat have all been deliberately introduced to the Beaver Island archipelago (Lake Michigan) while other species, such as Norway rat and house mouse, were introduced to islands unintentionally. The Grand Traverse archipelago (Lake Michigan) also has had intentional mammal introductions, such as striped skunk and Eastern gray squirrel, and unintentional introductions including the house mouse (Long 1978). At least some species have failed to persist, including raccoons and Norway rats on South Manitou Island (Lake Michigan) (Hatt et al. 1948, Scharf 1973).

Fish have also been introduced to many lakes on Great Lakes islands and surrounding shoal areas. Walleye have been repeatedly introduced to some inland lakes on islands, such as Lake Genesrath on Beaver Island (Lake Michigan; Michigan Department of Natural Resources); bluegill, small mouth bass and largemouth bass to Barney's Lake on Beaver Island (Lake Michigan); and bluegills to Echo Lake on Grand Island (Lake Superior). Lake trout, brook trout, northern pike, and walleye have all been planted on shoal areas near islands (Michigan Department of Natural Resources). However, the ecological consequences of these introductions are largely undocumented. Based on currently available information it is uncertain if or how many lakes are or were fishless.

Islands with human development, especially larger islands with many landowners [e.g., Manitoulin (Lake Huron), Beaver (Lake Michigan), South Bass (Lake Erie), and Mackinac (Lake Huron)], have a steady flow of ornamental plants for private landowner landscaping purposes.

The most common means of plant colonization on islands is probably by indirect means. For example, colonization of Great Lakes islands by plant species not native to the Great Lakes region and/or North America appears pervasive, even on fairly remote islands with little human traffic. Virtually every island that has been botanically surveyed has non-native species (see Judziewicz and Koch 1993, Judziewicz 2001). The proportion of non-native plant species on an island ranges from six to 48 percent on the Apostle Islands (Lake Superior) averaging about 21 percent; the highest proportion of non-native species (48 percent) occurred on Gull Island, a major waterbird colony site in this archipelago (Judziewicz 2001). On Hog Island, a relatively remote island in the Beaver Island archipelago (Lake Michigan), 12 percent of the flora was identified as non-native. These species may have been brought to the island by animals or humans even though human visits to the island are rare (Wakely et al. 2005). On Isle Royale (Lake Superior) approximately 15 percent of the flora is non-native (Judziewicz 1995). Although the ecological consequences of these non-native species are often uncertain, the spread of invasive species is of high concern to conservationists and land managers (Judziewicz 2001, Voss 2001). Examples of species that are threatening the integrity of island communities include timothy grass in open areas, European helleborine and garlic mustard in forests, Eurasian water-milfoil in aquatic systems, glossy buckthorn and European marsh thistle in wetlands, spotted knapweed on dunes, common hound's tongue on dolomite cliffs, and gold-moss stonecrop on shoreline wetlands. At least some of these species, such as garlic mustard, may be inadvertently transported to islands by hikers (Judziewicz 2001).

GREAT LAKES ISLANDS, A SPECIAL CASE: RELICT AND DISJUNCT DISTRIBUTION

Some species and communities on islands are relict (surviving from an earlier time) or disjunct (populations in widely separated regions and that are absent from areas in between) communities. Most likely, these were species or communities that were more widespread in the region historically. It is widely believed that as climate changed, selected organisms became restricted to small, isolated areas with microclimates and edaphic (soil) conditions that favored their survival. For example, northern species, such as caribou, have an isolated population on the Slate Islands (Lake Superior), Ontario (Peterson 1966, Great Lakes Heritage Coast 2000). Additionally, over 20 species of arctic-alpine disjunct plant species, including bird's-eye primrose and common butterwort, occur on islands in Lake Superior (Slavik and Janke 1993, Albert et al. 1997, see Judziewicz and Koch 1993) and the mainland shoreline as well, and range south and east to both the mainland and islands in northern Lake Huron and northern Lake Michigan (*in* Judziewicz and Koch 1993; Guire and Voss 1963, Great Lakes Heritage Coast 2000). Many of these plants hug the shoreline where the cool and moist summer climate allows these northern species to persist (Given and Soper 1981 *in* Judziewicz and Koch 1993). At least 30 plant species, such as mooseberry on Isle Royale (Lake Superior) and North and South Manitou islands (Lake Michigan) reach their southern limits on Great Lakes islands (Anthony Reznicek, personal communication). On some islands, as well as some mainland sites, krummholz communities (wind-swept sites with stunted trees) exist on exposed areas near the shoreline (Judziewicz and Koch 1993; Albert et al. 1997)

Other species, such as prairie dropseed and prairie smoke, are disjunct from prairie regions to the west (Brownell and Riley 2000). Another group of plant species from the mountains of the western United States and Canada is now concentrated around Lake Superior. At least three western cordilleran disjunct plant species (species whose principal range are in the western mountains of North America with disjunct populations east of the Rocky Mountains and Black Hills) are on the Slate Islands (Lake Superior), Ontario; eleven on Isle Royale (Lake Michigan), Michigan; and three on the Apostle Islands (Lake Superior), Wisconsin (*in* Judziewicz and Koch 1993).

Still other species, though not with a relict distribution, have colonized islands from other regions. Both the Eastern redbud and yellow-breasted chat, species typically found south of the Great Lakes region, have their largest, northern populations in Canada on Pelee Island in Lake Erie (Tiessen 2003, Cadman et al. 1987). The timber rattlesnake, which has been extirpated from Lake Erie islands (Herdendorf and Stuckey 1977), is another species whose northern limits of distribution included Great Lakes islands.

BIOTA ENDEMIC OR LARGELY LIMITED TO THE GREAT LAKES REGION

Although very few subspecies, species, or communities are restricted to Great Lakes islands, some endemic (found exclusively in one ecoregion) or limited-range (primarily in one ecoregion, but extends to one or two other ecoregions) species and communities occur disproportionately on islands (see Table 2; by ecoregion we mean large areas defined by influences of shared climate and geology). Further, a disproportionate number of locations with endemic or limited species or communities are found on Great Lakes islands (Soule 1993). For some species, such as lakeside daisy, dwarf lake iris, and Pitcher's thistle, some of the largest populations in the Great Lakes, and thus in the world, are found on islands (Environment Canada, Species at Risk 2007; Brownell and Riley 2000, U.S. Fish and Wildlife Service 2002).

Table 2. Species and communities endemic or largely limited to the Great Lakes region identified in the Great Lakes Ecoregional Plan: A First Interation (The Nature Conservancy 1999) where ten or more element occurrences (EOs) are on Great Lakes islands (Mary Harkness, personal communication).

Species/community	Distribution	Percent of EOs on Great Lakes islands
Dwarf lake Iris	Endemic	24
Michigan monkey flower	Endemic	12
Lakeside daisy	Endemic	44
Houghton's goldenrod	Endemic	16
Pitcher's thistle	Endemic	27
Snail (Triodopsis albolabris goodrichi)	Endemic	100
Snail (Anguispira kochi strontiana)	Endemic	100
Lake Huron locust	Endemic	11
Eastern fox snake	Endemic	16
Lake Erie watersnake	Endemic	65
Piping plover (Great Lakes population)	Endemic	34
Kirtland's warbler	Endemic	0 percent breeding; migrant on some islands
Great Lakes Limestone bedrock lakeshore	Endemic	26
Great Lakes shoreline cattail-bulrush marsh	Endemic	18
Lakeplain wet-mesic oak openings	Endemic	22
Great Lakes pine barrens	Endemic	20
Great Lakes alkaline cobble/gravel shore	Endemic	12
Great Lakes granite/metamorphic cliff	Endemic	11
Prairie dunewort (fern)	Limited	20
Ram's head lady's slipper	Limited	20
Auricled twayblade	Limited	17
Hill's pondweed	Limited	18
Eastern massassauga	Limited	12
Tufted hairgrass wet alvar grassland	Limited	23
White cedar alvar savanna	Limited	67
Alvar nonvascular pavement	Limited	11
Juniper alvar pavement	Limited	17

In addition to species and communities that are endemic and largely restricted to the Great Lakes ecoregion, some plant communities have a distinctive composition on islands. For example, the forests on Lake Erie islands have a relatively diminished shrub layer and smaller proportion of species whose seeds are dispersed by animals compared to the mainland. This difference is attributed to an interaction between elevation and insular, topographic, edaphic (soil), and historical factors (Boerner 1984).

GREAT LAKES ISLANDS, A SPECIAL CASE: COLONIAL NESTING WATERBIRDS

Islands in the Great Lakes are important sites for globally significant populations of colonial nesting waterbirds. For example, 80 to 94 percent of the world's breeding population of ring-billed gulls and perhaps as much as 28 percent of the world's population of breeding double-crested cormorants occur in the Great Lakes, mostly on islands. Additionally, as many as 60 percent of the North American population of breeding herring gulls nest in the Great Lakes, mostly on islands (UMVGLP 2005). Also of interest is high species richness of colonial waterbirds found on some islands in the Great Lakes. For example, West Sister Island (Lake Erie) was used for nesting by eight waterbird species in the late 1990s (Wires and Cuthbert 2001). The islands provide refuge from mammalian and avian predators (e.g., great horned owls) due to their isolation. In addition, shoals and nearshore shallow coastal waters are used by many species as important foraging sites. Although most colonial nesting waterbirds are found in lakes Michigan, Huron, Erie, and Ontario, islands in oligotrophic Lake Superior also host colonial nesting waterbirds (Wires and Cuthbert 2001). The marsh-nesting black and Forster's terns are locally concentrated along the Great Lakes shorelines, especially in and near protected coastal bays such as the Les Cheneaux islands in Lake Huron and islands in the St. Marys River and Lake St. Clair (Wires and Cuthbert 2001).

Colonial nesting waterbirds often nest in very high densities on islands. Guano (droppings) produced by the birds creates nutrient-rich water around islands and also kills plants on land through excessive levels of nitrogen. At one ring-billed gull colony on South Manitou Island (Lake Michigan), Shugart (1976) documented high mortality of creeping juniper, common juniper, poison ivy, choke cherry, and sand cherry within approximately five years of establishment of the nesting colony. On Knife Island (Lake Superior) the number of plant species, especially trees and forbs (non-woody flowering plants), declined between 1971 and 2004, apparently as a result of guano deposition from nesting herring gulls and double-crested cormorants; Canada yew also declined dramatically (Anderson et al. 2005). Despite these examples, once a colony is abandoned, there can be rapid recovery to native plant species even though soil conditions are changed (Hogg and Morton 1983). Consequently, potentially distinctive, nutrient-rich terrestrial and near shore aquatic systems may characterize islands with colonial nesting waterbirds.

GREAT LAKES ISLANDS, A SPECIAL CASE: STOPOVER SITES FOR MIGRANTS

The islands of the Great Lakes are harbors of refuge for migrating landbirds. Large concentrations of landbird migrants have been noted from the western Lake Erie islands (Campbell 1968, Herdendorf and Stuckey 1977, Anderson et al. 2002, Kelleys Island Audubon Club 2005, Bird Studies Canada 2006a, b); northern Lake Michigan islands (Scharf *in* Vigmostad 1999); Lake Superior's Apostle islands, especially Outer Island (Van Stappen and Doolittle 1993), and Isle Royale (Peet 1908); and some Lake Huron islands including Bois Blanc Island (Penskar et al. 2001), the Les Cheneaux islands (David Ewert et al., unpublished data), and Mackinac Island (White 1893). Migrants caught over the lakes at dawn may use islands as the nearest and/or only readily available habitat (Scharf 1999, see Diehl et al. 2003).

Consequently, Great Lakes islands are essential refuge for many migrants, especially during storms. Although rigorous studies of migrants on islands are limited, observations suggest that islands may be used extensively as stopover sites by migrating birds (Scharf 1999) and perhaps bats.

NEARSHORE WATERS AROUND ISLANDS

The characteristics of nearshore waters around islands vary with substrate, bedrock, exposure to waves, and other features, and are probably similar to mainland nearshore waters. Although most known biotic (living) features of islands are terrestrial, there may also be differences in the aquatic biota although this has been much less studied. Pollution-intolerant species, including amphipods, mayflies, and caddisflies, were noted by Herdendorf and Stuckey (1977) to be more abundant around islands than mouths of major rivers in Lake Erie. The shoals and reefs offshore of the Lake Erie islands are used extensively by fish, including spawning and nursery areas (see Trautman 1981), and by double-crested cormorants and other waterbirds, during the breeding and immediate non-breeding season (Stapanian and Waite 2003). The nearshore waters of islands with colonial nesting waterbirds may be distinct from nearshore waters of the mainland and other islands, due to the nutrient enrichment of the water from guano produced by the birds. This may produce distinctive nearshore communities of biological significance.

DISTINCTIVE PROPERTIES OF GREAT LAKES ISLANDS THAT SERVE TO BUFFER ISLANDS

At least two factors may play a disproportionately important role in buffering islands from some types of change, or at least rates of change. First, islands, especially small islands relatively isolated from the mainland, have microclimates that can be highly modified by the surrounding waters of the Great Lakes. This effect will modify the magnitude and rate of climate change on these islands. Ultimately, climate change may also result in large changes of biota. Because there may be a lag effect compared to most mainland areas, islands may provide at least temporary refugia for a number of species if temperatures of Great Lakes waters change more slowly than temperatures of the land.

Second, the isolation of islands may also buffer islands from other changes as well. Non-anthropogenic dispersal by all species to islands, including pathogens and introduced species, will be reduced compared to most mainland sites. The reduction in dispersal to islands results in a relatively low richness of biota, especially for fairly isolated, small islands, but also may result in higher biotic integrity to the extent that introduced species do not reach islands. Further, human activity on islands is often relatively low [e.g., the high expense and difficult logistics of timber removal (Jalava et al. 2005)].

CONCLUSION

Great Lakes islands, the largest collection of islands in any freshwater lake system in the world, support globally rare species and natural communities. They also are home to distinctive communities composed of species able to colonize islands or, for those islands that once were part of the mainland, were able to persist on islands following isolation. The net result is a rich biological legacy that includes colonial nesting waterbirds, species and communities endemic to the Great Lakes region, disjunct species, critical stopover sites for migratory birds, rich reptile faunas on some island archipelagos, and important fish spawning and nursery areas. Islands may also provide important refugia for species sensitive to climate change and perhaps be buffered from colonization by invasive species, especially small islands with little human activity. Consequently, protection of islands to conserve native species and communities is of particular importance.

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ASSESSING THREATS TO GREAT LAKES ISLANDS BIODIVERSITY

CONTEXT

Since Europeans first arrived in the early 1600s, the Great Lakes islands have changed substantially. After the last glaciers receded from the Great Lakes region—scouring out islands from resistant bedrock and leaving landmasses isolated by huge lakes—plants began to flourish (USEPA 2003). Eventually, wetland, beach, and forested climax communities developed on most islands. When settlers first arrived on many of the islands, the trees were harvested for use in building ships and homes for the new islanders and land was quickly converted from forest and wetland to agriculture (GINews.net 2005, Wilds of Pelee 2003, Hatt et al. 1948). The tempering effect of the lakes provided a longer growing season for crops, and was especially favorable for growing fruits, including grapes, particularly in the southern lakes (GINews.net 2005, Wilds of Pelee 2003, Hatt et al. 1948). Beginning in the mid 20th century, vacation cottages and second homes became more popular, and the islands became a destination spot for tourism and recreation, and this trend continues today on many Great Lakes islands (Soule *in* Vigmostad 1999). Islands characterized by significant agriculture were quickly populated by homes leading to secondary construction of roads, airports, marinas, hotels, stores, and restaurants. Increased development, coupled with the strong natural forces of the lakes, resulted in shoreline modifications to protect structures, which in turn resulted in loss of additional natural areas. To facilitate development, bridges to islands were sometimes constructed, resulting in loss of the isolation that defines the very character of islands (GINews.net 2005). In the absence of bridges, airports, car ferries, and high-speed passenger ferries were built to improve the efficiency with which visitors could access some islands [e.g., South Bass Island, Kelleys and Pelee islands (Lake Erie), Washington and Beaver islands (Lake Michigan), Mackinac Island (Lake Huron)]. Additionally, sensitive nearshore habitat was degraded when channels were dredged near and around islands to further accommodate access and provide for shipping needs (Barr and Gora 2004, LaPan et al. 2002). With this increased access came more people, more cars, and the potential for more non-native plants, animals, and seeds to become established on the islands and compete with the plants and animals that had for so long been isolated with limited competition.

The 1952 Grand Island Centennial Book (GINews.net 2005) chronicled the history of Grand Island, NY (Niagara River) and included the following descriptions of the progression of the island from a forested wilderness to a productive agricultural community, and eventually to a residential haven:

The farmers who purchased land in 1849 or a little later had to clear it before crops could be planted. This was a difficult job, involving the felling of trees, the pulling out of the stumps with the aid of oxen and then the burning of the brush… Once the land was cleared, it produced abundant crops of hay, wheat and grains. Mr. Lewis F. Allen reported that in the year 1860 he produced 350 tons of hay on his farm. The island soil was excellent for fruit trees. It is said that the first peach orchards in this area were on Grand Island. The Northern Spy apple was the variety found in many orchards as well as Greenings and Baldwins. Cherries, both sweet and sour, as well as Bartlett, Flemish Beauty and Seckle pears grew abundantly… As the metropolitan areas of Buffalo, Niagara Falls and Tonawanda expanded, the sylvan quietude of the island became very attractive to city dwellers… Island residents marked the opening of the bridges [Between Buffalo, NY, Grand Island, NY and Niagara Falls, ON] with a celebration on July 13, 1935… Since the opening of the bridges Grand Island has been in a state of transition from a rural to a suburban area. Many subdivisions have been developed such as Sandy Beach, Grandyle Village, East Park and Coldbrook Manor. The population of the town has increased from less than 1,000 in the early 1930's to almost 4,500 in 1952, and is growing steadily.

Island ecosystems, like mainland ecosystems, are composed of specialized habitats determined by physical conditions such as geologic composition, soils, temperatures, and weather events (USEPA 2003). Based on these unique features, only select plants can grow on islands; additionally, only those animals that can survive within the range of physical conditions and specific flora will naturally occur on islands. These ecosystems, or combinations of physical features and biotic communities, have evolved together over thousands of years and are interdependent on each other for survival. When one or more ecosystem component is removed, all other remaining components are affected in some way. Several hypotheses describe the relationship between species diversity and ecological stability. The "redundancy hypothesis" (Walker 1991) and the "rivet-popper hypothesis" (Ehrlic and Ehrlic 1981) generally agree that most healthy ecosystems can tolerate some level of loss and still function effectively, although the extent of loss that can be tolerated is difficult to quantify and varies by ecosystem type. Further, at some point loss of native biodiversity reaches a level at which the impacts on the remaining components are significant, and the ecosystem ceases to function as it has in the past.

Although some species can still persist in changed ecosystems, many of the most sensitive species cannot, and may eventually become rare or extinct within the ecosystem. Island species are particularly vulnerable to extinction for several reasons: due to the finite boundaries of islands, there is a limit to the number of species that can persist on a given island; further, the dispersal power of species that occur on islands is generally reduced compared to similar mainland species (MacArthur and Wilson 1967). It is generally true that on smaller islands the extinction process is accelerated (MacArthur and Wilson 1967). Additionally, once habitat for a species or group of species has been lost, there is no place for the species to migrate to because of the very finite boundaries of islands. In general, the relatively small size and isolation of islands create the potential for rapid change (Judziewicz 2001). This may result in islands being especially vulnerable to biological change or, on a more positive note, elimination of species injurious to island biota. A corollary of this observation is that re-colonization may be difficult once change has occurred (Jalava et al. 2005). This hypothesis suggests that extra care be exercised, for example, to avoid transporting non-native species to islands, perhaps especially small islands. However, because re-colonization of islands is hindered, it also means that eradication programs can be successful, as has been demonstrated on islands around the world (Taylor and Thomas 1989, North et al. 1994, Cowen 1992).

This assessment of threats to the biodiversity of the Great Lakes islands is a first attempt to identify, define, and assess the impacts of current and future threats within the Great Lakes island ecosystem. This analysis will be used in conjunction with assessments of the biodiversity value of island areas to identify high-quality islands most in need of conservation action. The Collaborative for the Conservation of Great Lakes Islands (Collaborative) plans to identify specific actions that can be taken to alleviate these threats and, in turn, preserve the native biodiversity of Great Lakes island ecosystems.

TYPES OF THREATS FACED BY GREAT LAKES ISLANDS

This assessment identifies threats or stressors to Great Lakes island biodiversity, as well as sources of these stressors. A general assessment is illustrated in Table 3 followed by detailed descriptions of the five foremost threats to island biodiversity: habitat loss and fragmentation, overharvest, toxic substances, invasive species, and climate change. Borrowing from The Nature Conservancy's *Conservation by Design: A Framework for Mission Success* (1996), which describes the identification of systems, stresses, and sources of stress, the following definitions are provided:

Systems: "The focal conservation targets and their key ecological attributes." For the purposes of this assessment, the systems of concern are Great Lakes island native plant, animal, and nearshore communities.

Stresses (threats): "The most serious types of destruction or degradation affecting the conservation targets or key ecological attributes." There are six major human-induced stresses that this project has identified within the Great Lakes system that contribute substantially to the loss of biodiversity: habitat loss; fragmentation; overharvesting; toxic substances; invasive species; and climate change. Notably, these threats are nearly identical to the "six classes of human interference" that threaten the biospatial hierarchy worldwide, as described by Soulé (1991).

Sources of Stress: "The causes or agents of destruction or degradation." The stressors or threats listed above are caused by a wide variety of sources such as development, transportation, or recreation. Most can be traced back to larger issues including economic development, anthropocentrism, human population growth within the island environment, and cultural transitions. The loss of biodiversity and the causes of this loss observed at a microscale on Great Lakes islands are similar to patterns of biodiversity loss throughout the world (Soulé 1991).

Scope: "The geographic scope of impact to the conservation target expected within 10 years under current circumstances." The scope of each of the identified threats varies significantly. While some threats, such as global climate change and associated changes in water levels, are expected to impact island biodiversity throughout the entire Great Lakes, other threats, such as local overharvesting, may only affect biodiversity at a local level.

Severity: "The level of damage to the conservation target over at least some portion of the target occurrence that can reasonably be expected within 10 years under current circumstances." Some threats, such as conversion of a forested habitat to a residential subdivision, may completely eliminate segments of biodiversity. Other threats, such as the introduction of a non-native species that displaces some of the original species while others persist, may only result in limited impacts to biodiversity.

Irreversibility: "The reversibility of the stress caused by a source of stress." While The Nature Conservancy uses the term "irreversibility," we have used the term "reversibility" for ease of understanding and clarity, but with essentially the same meaning. The reversibility of each of these stresses varies considerably. Many of the stresses are permanent. Once an invasive species becomes established in the Great Lakes system, it is unlikely it will ever be completely removed. On the other hand, with effort lost habitat can sometimes be restored to its former state.

Table 3. General assessment of stresses and sources of stresses to Great Lakes islands biodiversity, watershed-wide.

Stress/Threat	Sources	Scope	Severity	Reversibility
Habitat Loss and Fragmentation	Agriculture, residential/commercial development, roads, shoreline modifications, inappropriate land management, dredging, mining, marinas, light/noise pollution, dams, water level management, erosion, timber harvest, recreational development	High	High	Moderate
Overharvest	Commercial fishing, subsistence fishing, recreational fishing, eradication programs, illegal collecting, poaching	Low	Moderate	Moderate
Toxic substances	Industry, sediments, lighthouses	Moderate	Moderate	Moderate
Invasive Species	Ballast water, aquariums/pets, exotic fish markets, hydrological modifications, accidental transport of seeds via animals, purposeful introductions, horticulture industry	High	High	Low
Climate Change	Greenhouse gases from power plants, vehicles, burning fossil fuels, deforestation	High	High	Low

Below is a detailed description of each threat and some of the most common sources.

Threat: Habitat loss and fragmentation

As described under "Context," public and private island owners typically manage island properties similar to mainland areas. Islands have been farmed, grazed, timbered, and developed with little consideration of impacts to the native plant and animal communities that inhabited these unique areas. In recent times, islands are quickly being developed to provide vacation resorts or second homes, complete with golf courses, lawns, hotels, restaurants, shopping centers, airports, and other amenities typical of a mainland community (Soule *in* Vigmostad 1999). Even those areas set aside as parks in some cases are dominated by mowed grass. Because island species are potentially at a disadvantage to compete due to loss of dispersal power and because islands typically have accelerated extinctions compared to mainland areas (MacArthur and Wilson 1967), loss and fragmentation of island habitat may have magnified impacts on biodiversity when compared to similar actions on the mainland. As previously mentioned, the relatively small size and isolation of islands include the potential for rapid change (Judziewicz 2001), which may result in islands being especially vulnerable to biological change.

We define habitat fragmentation as the loss of connectivity between parcels of natural habitat. Human-constructed obstacles that often cause fragmentation include homes, lawns, roads, parking lots, and buildings. This can lead to small, isolated pockets of natural habitat separated from other areas of natural habitat. In effect, humans are creating “islands” of natural habitat surrounded by a “sea” of development. Often native species cannot successfully cross through developed areas to reach other isolated parcels of habitat. Species that cannot move between these parcels will have fewer opportunities to forage and mate, and will have only a limited area within which to find suitable habitat and all the resources needed to survive (USEPA 2003). Fragmentation can result in direct loss of biodiversity. For example, road-kill mortality has been documented in juvenile Lake Erie watersnakes as individuals attempt to move between summer habitat on the shoreline and hibernation areas inland (USFWS 2003). Fragmentation can also cause indirect loss of biodiversity by limiting opportunities for foraging and mating to only those resources within the isolated parcel.

Source: Accessibility

Islands, by their nature, are isolated from other landmasses. This isolation is part of what defines island habitat and is a main reason why only certain plants and animals have colonized these unique habitats. Each island has evolved in relative isolation from other landmasses, and its native communities reflect this isolation (MacArthur and Wilson 1967). When an island becomes easily accessible to humans, plants, and animals through an artificial connection to another landmass, significant changes can occur to the island’s ecosystem. Accessibility can take many forms. Public transportation such as bridges, ferries, airports, and marinas all promote increased accessibility to islands. With human access comes an increased potential for arrival of new animal and plant species. The implications of new organisms arriving on an island can vary substantially. Generally, however, disturbance to the native ecosystem usually occurs. Examples are discussed below.

Source: Agriculture

Agriculture can reduce native biodiversity by converting natural landscapes to heavily managed single-crop species, or monocultures. Aside from direct loss of natural island habitat, other common agricultural practices include installation of drainage tiles or ditches; applications of fertilizers, herbicides, and pesticides; and soil disturbances associated with planting and harvesting crops. These activities can have significant impacts on native biodiversity. Drainage facilitates loss of wetlands that are typically high-biodiversity areas. Additionally, it leads to higher rates of runoff and sedimentation and does not allow for normal nutrient absorption (USEPA 2003). Furthermore, soil disturbances can alter the typical soil horizons, adversely impacting plant species that rely on historic soils and disturbing the native seed bank within the soil. Modern agricultural practices call for an array of chemicals to maximize yield. Fertilizers, if not correctly applied, can lead to excess levels of nitrogen, phosphorus, and potassium in adjacent water bodies. Under these circumstances, chemicals can cause overgrowth of algae, known as eutrophication, which negatively impacts aquatic species and their habitats (USEPA 2003). Pesticides are intended to kill a variety of both native and non-native insects that prey on crops, while herbicides target both native and non-native plants that compete with crops. Therefore biodiversity can be directly impacted by herbicide and pesticide use.

Source: Development

Because of isolation and close proximity to water and recreational opportunities, islands are often romanticized as vacation areas or tourist destinations. Put-in-Bay (Lake Erie), Mackinac Island (Lake Huron), Thousand Islands (St. Lawrence River), Apostle Islands (Lake Superior), and Georgian Bay Islands (Lake Huron) are well-known destinations and all contribute to local economies. Islands are also targeted locations for second homes or vacation cottages. As island ecosystems are developed with homes and the associated infrastructure necessary to support human communities, loss of biodiversity is eminent. Habitat is lost to the footprint of development and fragmented into smaller and smaller parcels by roads, maintained lawns, parking lots, and other structures (USEPA 2003). Development brings humans and their perceptions of certain native wildlife as "nuisances" and native plants as "weeds." These species are then targeted for eradication (e.g., USFWS 2003). The wide range of human intentional and unintentional actions brought on by development, when considered collectively and cumulatively, can and has had substantial impacts on the native species of Great Lakes islands.

Source: Dredging

Dredging of submerged sediments is a tool commonly used to deepen lake and river bottoms to allow for boat access. Historically, dredging has occurred within the Great Lakes and connecting channels and also in coastal wetland areas to allow for boat access and dockage. For example, in 1960 a large coastal wetland on Middle Bass Island (Lake Erie) was dredged to create a sheltered open water marina (Barr and Gora 2004). Similarly, from 1907 to 1916, the Detroit River was virtually dewatered to dredge the 12-mile Livingstone Channel in the lower reaches of the river among several of the 21 Detroit River islands. The blasting, scouring, and removal of the river bottom to create this 300-feet wide and 22-feet deep canal was a major factor leading to the collapse of the lake whitefish fishery (U.S. Geological Survey undated; Bruce Manny, personal communication).

Coastal wetlands and nearshore areas that support submerged aquatic vegetation, sandy or rocky substrate, shoals, or reefs are extremely important for fish spawning and nursery habitat (Goodyear et al. 1982) and provide high-quality nesting and foraging habitat for a diversity of birds including shorebirds and waterfowl. Additionally, these areas are extremely productive for aquatic insects such as mayflies *(Hexagenia* spp.) which provide important food sources for other wildlife (Edsall 2001). Loss of coastal wetlands and productive nearshore habitats can result in a decrease in important habitat for fish, wildlife, and plants, as well as declines in local populations.

Source: Erosion

Erosion, the loss of landmass due to the forces of water, wind, or ice, is both a natural and human-induced threat. Erosion due to wave action and ice scour is common on islands, particularly those composed of sedimentary rock (e.g., sandstone, limestone) or unconsolidated sediments (e.g., sand, silt), and is less common on islands characterized by harder rock (granite). Although erosion is typically due to natural factors, human actions can significantly exacerbate erosion. Such actions often include 1) removal of native shoreline vegetation which destabilizes soils and facilitates quicker erosion than if the vegetation remained (USEPA 2003); and 2) modification of shoreline/nearshore habitats such as shoreline armoring, beach nourishment, jetty construction, dredging, and filling. When structures are added to or removed from the shoreline and nearshore areas, the natural processes that deposit sand and other fine-grained sediments are often disrupted or changed. In general, the shape of the island shoreline results from the combined effects of erosion and accretion. Anthropogenic influences have disrupted these natural patterns resulting in the alteration of shoreline and nearshore habitat.

Source: Hydrological modifications

Hydrological change, or changes in the water regime of a specific area, may impact biodiversity in significant ways. Examples of hydrological changes include installation of dams; changes to flow patterns or flood regimes; draining of wet areas; rerouting, channelizing, and culverting of streams; and increasing impervious surfaces such that rates of stream flow are significantly impacted (USEPA 2003). Many of the most significant threats to islands in the St. Lawrence River are closely related to impacts from the creation, use, and maintenance of the St. Lawrence Seaway navigation channel and associated locks and dams used for navigation and power generation. Damming and flooding of sections of the river has raised the water level of portions of the river significantly, covering some islands and shoals completely, and increasing scour areas and erosion on other islands (LaPan et al. 2002). Upstream of the Moses-Saunders Power Dam lies Lake St. Lawrence. Based on the water needs of the hydroelectric facility, water levels here are subject to extreme changes [up to 2 meters (6.6 feet)] at any time of year (R.E. Grant and Associates, undated). While wetland and backwater areas created by flooding could provide suitable habitat, the unpredictable and dramatic water level fluctuations impede use by many aquatic species (LaPan et al. 2002). Dredging of the navigation channel has resulted in significant island habitat loss. La Pan et al. (2002) note that seaway construction and maintenance activities in the Red Mills, New York, and Cardinal, Ontario, area destroyed Galop Rapids and altered the physical location and connectivity of a complex of 11 nearby islands.

Source: Light pollution

The impacts of a bright nighttime sky on fish, wildlife, and plants may at first glance not seem significant, but research is revealing that artificial lighting in natural habitats can significantly impact the behavior of many different species. Plants, animals, and humans have all evolved in an environment of regular dark and light periods. These cycles of darkness and light influence circadian rhythm (patterns of activity and rest), metabolism, and even hormone production in some species (Guynup 2003). Research has shown that redback salamanders will not emerge to feed and reproduce when light brighter than a full moon is present (Harder 2004). Some tree frogs will not call when exposed to light, and if the males do not call they cannot attract females to mate (Harder 2004, Guynup 2003). Nocturnal snakes are absent from regions of California where they once occurred and suitable habitat still exists. Lights from nearby cities shine brightly at these locations (Harder 2004). Lights can attract migrating birds, causing them to fly off course or collide with artificial structures. Zooplanktons typically rise to the surface to feed on algae. Research shows that when these tiny organisms are exposed to lighted conditions at night movement up to the surface to feed is reduced (Harder 2004). This change in behavior could lead to substantial algal blooms. Many nocturnal insects are attracted to certain types of light. This behavior may draw them out of their natural habitats and into developed areas, where the animals that depend on the insects as a food source will not have access to them.

Source: Mining

Due to the geological composition of Great Lakes islands, they historically and currently provide a source of economically valuable raw materials such as limestone, sand, and gravel. An active quarry on Kelley's Island (Lake Erie) produces more than one million tons of limestone per year (Lafarge North America Inc. 2004). Removal of sand and gravel in the nearshore areas of islands, which often provide substrate necessary for fish spawning and nursery habitat, could impact local fish, mussel, and benthic invertebrate populations. A mined area at the head of the St. Clair River was historically a spawning area for lake sturgeon (Goodyear et al. 1982). Major deposits of sand and gravel have been identified in Lake Ontario near Niagara, Hamilton, Toronto, and Wellington, and mining has occurred on the Niagara Bar at the mouth of the Niagara River, a nursery area for at least one species of fish (Goodyear et al. 1982). Strawberry Island (Niagara River) is a five-acre island that shelters a 400-acre area of vegetated shallows from the erosive forces of the river and has been designated a "Significant Coastal Fish and Wildlife Habitat" by the New York State Department of Environmental Conservation. Due to the impacts of gravel mining within areas on and adjacent to the island, a habitat restoration project on this island was recently funded (Office of the Governor of New York 1996). Depending on the extent of mining, a few acres of habitat or an entire island could be lost to these practices, while indirect impacts to species and their habitats from erosion, runoff, and noise could also occur.

Source: Noise Pollution

Sources of noise pollution that could impact island wildlife populations include recreational vehicles such as all-terrain vehicles (ATVs), off-road vehicles (ORVs), snowmobiles, aircraft, boats, automobiles, and large construction machinery. Study of animal response to noise is very broad including characteristics of the noise and duration, life-history characteristics of the species, habitat used, season and current activity of the animal, sex and age, previous exposure and whether other physical stressors (e.g., drought) are present (Manci et al. 1988). The responses to noise stimuli may include heart-rate acceleration and behavioral responses such as avoidance, while exposure to persistent noise can cause changes in metabolism, hormone balance, chronic stress, and physical damage to auditory systems (Fletcher 1990). Considered cumulatively with other threats, noise pollution can further stress already troubled species and contribute to a decline in biodiversity.

Source: Recreation

The rapid development of Great Lakes islands for recreational use has been well documented. Often, local, state, provincial, Federal, or Crown governments create recreational areas to provide opportunities for visitors to enjoy the natural beauty of islands. While some activities (e.g., hiking, photography, wildlife viewing) typically have only minimal impacts on island biodiversity, other more intensive uses (e.g., ATVs, ORVs, snowmobile trails, campgrounds, fishing, hunting) can have negative impacts on biodiversity if island dynamics are not considered. Intense recreational development can result in habitat loss when excessive public activity tramples or destroys vegetation, introduces pollution, injures or kills wildlife (especially smaller species), or disturbs some of the more sensitive species or habitats. Careful evaluation of proposed recreational uses prior to implementation can often alleviate this threat by identifying the most sensitive resources that should be avoided and the more resilient areas that may be minimally impacted by proposed activities. If public-use areas are designed and managed to promote native island biodiversity, this threat may not be large. Ultimately, the significance of this source of stress will depend on the sensitivity of the resources to be impacted and the intensity of use.

Source: Shoreline modification:

Island shoreline accounts for a significant portion of total Great Lakes shoreline. GIS mapping by the Collaborative indicates that there are 31,407 Great Lakes islands (3,081 U.S. and 28,326 Canadian) comprising a total of 15,623 kilometers (9,708 miles) of shoreline [3822 kilometers (2374 miles) in U.S. and 11,801 kilometers (7334 miles) in Canada]. Historically, the shoreline of the Great Lakes has been dynamic due to precipitation, storms, isostatic rebound, glaciers, waves, water-flow patterns, and a variety of other natural processes. Since Europeans first settled on the shores of the lakes, hardening of the shoreline has been a tried and true method to stabilize the location of the shoreline and protect land and property from storms, waves, ice, and erosion. Shoreline hardening includes installation of large rock breakwaters, steel-sheet piling, concrete shore walls, and various other structures. While shoreline hardening may protect human habitat, the loss of natural shoreline habitat is a threat to many coastal species including the binationally endangered piping plover (USFWS 1996), the Federally (U.S.) threatened Houghton’s Goldenrod (USFWS 1997) as well as other native coastal plants and animals. Furthermore, the natural processes of erosion and deposition form various habitat types along the shoreline that provide essential wildlife habitat buffer the upland areas from storm surges, and contribute sand to the littoral system. Armored shorelines do not provide such benefits.

Source: Timber Harvest

Timber has been a source of economic prosperity for the Great Lakes region since the early 1800s. Much of the Great Lakes vast forested landscape was cleared of trees for lumber and to facilitate urban and agricultural expansion (USEPA 2003). The islands have in the past and now continue to face similar threats. Woody plant communities historically dominated many of the permanent islands in the Great Lakes Basin. On Pelee Island (Lake Erie), more than 2,181 hectares (5,390 acres) of the 2,869 hectares (7,090 acres) were harvested for timber by 1982 (Wilds of Pelee 2003). Hatt et al. (1948) describe South Manitou Island (Lake Michigan) in the late nineteenth and early twentieth centuries:

> Because of its fine harbor and good forests, South Manitou was among the first of the islands settled…Cordwood (at $1.75 a full cord) was widely cut, and only scattered patches of forest skirting the dunes escaped the ax. The effect on the flora and hence on the fauna was, of course, cataclysmic, and the forest fires, of which there were several in this period, increased the transformation of the forests.

The vegetative and animal communities associated with the islands are dependent on the forested systems for their survival. Forested areas provide critical stopover sites for migratory birds as they travel between their nesting and wintering grounds, and various islands or groups of islands, such as the Western Lake Erie islands, have been identified as key stopover sites for migratory birds (Ewert et al. 2005). Timber harvest, if conducted at too large a scale or without using sustainable practices, can result in a significant threat to the persistence of biodiversity on the islands through the elimination of native habitat and lack of potential for regeneration.

Source: Towers and Turbines

Telecommunication towers serve a variety of purposes including transmitting television or radio waves or phone signals, monitoring weather conditions, and notifying people of emergency situations. The Federal Aviation Administration requires towers over 200 feet (61 meters) to be lighted for aviation safety. Such tall towers, especially when lighted with supporting guy wires, have been documented to kill birds particularly during foggy nights in the migration season (Avery et al. 1980, Weir 1976). Many of the Great Lakes islands have been specifically identified as significant areas for birds as migration stopover sites for Neotropical migrants, nesting areas for colonial waterbirds, or as permanent habitat for many resident species of birds (Ewert et al. 2005, Wires and Cuthbert 2001). These birds could be threatened by construction and operation of towers on islands.

Wind power is a rapidly expanding form of clean energy, generally harnessed by constructing large turbines up to 400 feet (122 meters) tall in areas with suitable wind resources. This form of energy produces no emissions and requires very little input to produce a useable form of energy. President Bush’s 2006 Energy Initiative calls for an increase in renewable energy, and the U.S. Department of Energy supports the development of 20 percent of U.S. energy from wind power. This would necessitate a total of 325,000 megawatts of wind energy, or approximately 216,000 average-size wind turbines (USDOE 2007). However, wind turbines in a few specific locations have been documented to kill large numbers of birds and bats (Barclay et al. 2007, Tuttle 2004). Mortality rates of up to 42.7 bats per turbine per year and 9.33 birds per turbine per year (when corrected for scavenging and searcher efficiency) have been detected at sites in West Virginia (Kerns and Kerlinger 2004, Kerns et al. 2005) and Tennessee (Tennessee Valley Authority 2002, Fiedler 2004), respectively.

The geography of the Great Lakes favors significant wind-energy production over the water and in coastal areas, making wind-power development very attractive in these locations. Wolfe Island (Lake Ontario), Ontario, has been designated a globally significant Important Bird Area by Nature Canada and Bird Studies Canada due to its large congregations of waterfowl (specifically Greater Scaup and Canvasback) and hawks and owls (Bird Life International undated). Wolf Island has also been proposed as an area to support 86 wind turbines (Canadian Hydro Developers Inc. 2006). Placement of wind turbines on islands—which provide vital and unique open-water shelter to wildlife—has the potential to injure or kill large numbers of birds and bats, and the impacts on other species such as insects has yet to be determined.

Threat: Overharvest
Overharvest of fish and other wildlife and plants, whether for commercial or recreational purposes, has the potential to reduce biodiversity of Great Lakes islands and surrounding habitats, particularly on small and/or isolated islands. Unregulated commercial harvest of Great Lakes fish in the nineteenth and early twentieth centuries resulted in catastrophic population declines of some fish, for example the lake trout, formerly the Great Lake's top predator (Hansen and Peck 1995). Despite basin-wide reintroduction efforts over the past 60 years, as well as bag limits and control of sea lamprey, an invasive species that contributed to the trout's decline, the lake trout has yet to achieve natural reproduction at a sustainable level in three of the five lakes (Hansen and Peck 1995). While overharvest has been somewhat abated by fishing regulations, licenses, and quotas, some fish species, including the lake trout, still require stocking programs to survive angling pressure. Intentional overharvest of some other wildlife species has been widespread and contributed to population declines. For example, as the western basin Lake Erie islands were developed with homes and recreational opportunities, the island-endemic Lake Erie watersnake became the target of eradication efforts. These illegal activities eventually resulted in this species being listed as a Federal threatened species in the U.S. and a national endangered species in Canada (USFWS 2003). In another example, Hatt et al. (1948) describe the fur trade eliminating beaver and caribou and possibly other large mammals from the eastern Lake Michigan islands.

Source: Poaching/Illegal Collecting
Poaching of fish and game and illegal collecting of native plants can have significant impacts on native island biodiversity. In general, most states and provinces have established regulations for the harvest of fish and game and, in some instances, plants. These harvests and populations are carefully monitored to ensure harvests are sustainable. Poaching and illegal collection of plants sidesteps regulations leading to harvests that may not be sustainable. Poaching and illegal collecting can impact small and fragile island populations to such an extent that the populations are no longer able to survive and reproduce and become extirpated from the island.

Threat: Toxic Substances
Toxic substances are "any substance which can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions or physical deformities in any organism or its offspring, or which can become poisonous after concentration in the food chain or in combination with other substances" (GLWQA 1987). The Great Lakes Binational

Toxics Strategy (USEPA and Environment Canada 1997) identify two levels of persistent toxic substances, which include the following (among others): aldrin/dieldrin; benzo(a)pyrene {B(a)P}; chlordane; DDT (+DDD+DDE); hexachlorobenzene (HCB); Alkyl-lead; mercury and mercury compounds; mirex; octachlorostyrene; PCBs; PCDD (dioxins) and PCDF (furans); and toxaphene. Toxicity sources and symptoms vary widely with several examples discussed below. Lead is a toxic substance commonly found in older paints, gasoline, and in lead shot. Lead exposure can have lethal and sublethal effects in both humans and wildlife, including reproductive impairment, inhibited fetal development, and damage to the central nervous system (Eisler 1988). Mercury is a contaminant introduced into the ecosystem primarily through burning of fossil fuels and wastes and can cause damage to the nervous, excretory, and reproductive systems of piscivorous (fish-eating) birds and mammals (Wolfe et al. 1998). Polychlorinated biphenyls (PCBs) and organochlorine compounds (e.g., chlordane, hexachlorobenzene, dioxins, furans, mirex, and DDT/DDD/DDE) are known to bioaccumulate in the fat cells of fish, mammals, birds, and reptiles, contributing to "adversely affected patterns of survival, reproduction, growth, metabolism, and accumulation" (Eisler and Belisle 1996). Methyl mercury, toxaphene, and PCBs are the primary toxic substances responsible for fish-consumption advisories throughout the Great Lakes, and they can harm humans as well as wildlife (USEPA and Environment Canada 1997).

Toxic substances typically occur within the Great Lakes, on islands, and in nearshore sediments as byproducts from industry, lighthouses, military operations, and paint, among others. Historic sources of PCBs in the Great Lakes Basin include the pulp and paper and steel industries (Bruce Kirschner, personal communication). Fish-eating birds such as the bald eagle and colonial nesting waterbirds are often susceptible to contamination and adverse effects from these contaminants. In general, the impacts of toxic substances on biodiversity include a decline in habitat suitability and decreased fitness, survival, and reproduction in local populations of animals and humans.

Source: Dredging

Dredging of submerged sediments is a tool commonly used to deepen lake and river bottoms to allow for boat access. Dredging may re-suspend toxic substances that have been buried in sediment and redistribute them into the water column. This makes them available for uptake by aquatic organisms where they can bioaccumulate and transfer toxic residues up through the food chain to fish, birds, wildlife, and humans (Willford et al. 1987).

Source: Industry

Industrial discharges into the Great Lakes region water and air during the industrial era of the mid-20th Century are responsible for much of the contamination still found in sediments, the water column, and fish and wildlife throughout the basin today. The electric industry, paper and pulp, and steel mills historically discharged PCBs; mercury is emitted as a byproduct of burning fossil fuels and waste; and organochlorine compounds were commonly used as pesticides and flame retardants (USEPA 2006a). Industrial discharges may occur directly to the land or water, but are often discharged into the air, carried long distances, and then deposited during precipitation.

Source: Lighthouses

Mercury was commonly used in the lenses of the lights in old lighthouses that dot the island landscape throughout the Great Lakes region (Wikipedia 2007). Mercury is toxic to wildlife and humans, causing neurological and other problems. High concentrations of mercury in Great Lakes fish are one of the main reasons for human fish-consumption advisories throughout the Great Lakes**.** All islands with lighthouses should be examined to determine if mercury is still present, and if so, it should be properly removed and disposed.

Source: Sewers

As Great Lakes islands become more populated, sewage issues must be addressed. Disposal of human waste on islands has typically been addressed by installation of individual septic systems or package sewer plants. However, as island communities grow and become more densely populated, large-scale collection and treatment systems may become necessary. Furthermore, the shallow soils on many islands are not suited for effective septic systems. An island-wide outbreak of gastrointestinal illness occurred in at least 1,450 visitors to South Bass Island (Lake Erie), Ohio, in the summer of 2004, and was attributed to island drinking water that had been contaminated with coliforms and *E. coli* from septic systems, among other sources (Ohio Dept. of Health 2004). Similar outbreaks on other islands could affect both human and wildlife populations. Furthermore, due to the shallow soils and high water tables on many islands, these locations are often not well suited for effective septic systems (Bruce Kirschner, personal communication).

Threat: Invasive species

An "invasive species" is a plant or animal that is alien to the Great Lakes ecosystem. Once established, invasive species are likely to cause economic, human health, and/or environmental damage in the Great Lakes ecosystem (USEPA 2007). Invasive species impact native biodiversity by altering established food webs, competing with native species for habitat and food, degrading the quality of some habitats, and displacing many types of native plants (USEPA 2003). Some of the most well-documented invasive species in the Great Lakes basin include brown carp, round goby, zebra mussel, quagga mussel, spiny water flea, purple loosestrife, *Phragmites* spp., reed canary grass, sea lamprey, alewife, and eurasian river ruffe. The impacts these species have on native biodiversity are dependent on the degree of infestation. Impacts vary significantly depending on the nature of the invasive species and those species that are impacted by it. However, the consequences of some invasives have been well documented. The sea lamprey, the earliest recorded invasive native to the Atlantic coast of Europe and the Americas, decimated native populations of lake trout *(Salvelinus namaycush)* after the construction of the Welland Canal in 1921, significantly impacting commercial and recreational fisheries (USFWS undated). Currently, tributaries where sea lampreys spawn must be treated regularly with a lampricide (a pesticide targeted to kill sea lamprey) to ensure that sea lamprey populations are controlled and native fish can persist. Kolar and Lodge (2002) used two risk-assessment models to predict which alien fish species were most likely to become established, spread, and become nuisances within the Great Lakes. Their results indicated that 26 species were likely to become established in the Great Lakes, if introduced (intentionally or unintentionally); of these, six species were likely to become nuisances (Kolar and Lodge 2002).

Source: Ballast Water

The ballast water carried in ocean-going vessels is widely implicated in the introduction of many non-native and invasive species to the Great Lakes from around the world. USEPA (2006b) indicates that ballast water is the source of 30 percent of invasive species in the Great Lakes. The State of the Lakes Ecosystem Conference Report (Environment Canada and U.S. Environmental Protection Agency 2001) estimates an increase of one new species per year introduced into the Great Lakes system, and states that 50 percent of all aquatic non-natives introduced into the Great Lakes region have been reported in the St. Lawrence River, the connecting channel that brings international ships into the Great Lakes system.

Source: Hydrological Modifications

Significant hydrological modifications to the Great Lakes system have occurred over the years. These include the creation of the Chicago Shipping and Sanitary Canal, which connected the Great Lakes system to the Illinois River and Mississippi River drainage, and the establishment of the Great Lakes-St. Lawrence Seaway, which made the St. Lawrence River and Great Lakes navigable by ocean-going freighters by eliminating former navigation barriers such as the Niagara Falls. These modifications have allowed invasive species to pass between formerly isolated aquatic systems. For example, great attention has been given to two species of Asian carp (Bighead and Silver), which are voracious predators moving up the Illinois River toward Lake Michigan**.** Significant efforts and dollars have been put forward to construct barriers to try to prevent these species from entering the Great Lakes due to the potential for impacts to native aquatic species (USEPA 2006c).

Source: Purposeful Introduction of Non-native and Native Species

Occasionally, well-meaning or ill-advised people purposefully introduce non-native species and native species not found on an island into the Great Lakes or onto Great Lakes islands. Documented cases include fish released from aquariums and live fish markets; pigs introduced to the Lake Erie islands in the 1800s to control snake populations (McDermott 1947); pigs and raccoons introduced on islands in lakes Michigan and Huron in the early 2000s to control cormorant populations (Francesca Cuthbert, personal communication); pheasants released on Pelee Island (Lake Erie) in 1918 for hunting that later became a nuisance to corn farmers due to their large numbers (Wilds of Pelee 2003); deer introduced to South Fox Island (Lake Michigan) around 1915 by the landowner for hunting (Hatt et al. 1948); and plants frequently brought to islands for landscaping purposes that then spread into natural areas. Furthermore, domestic animals can have significant impacts on local plant and wildlife populations. Feral cats are thought to kill millions of birds, reptiles, and small mammals each year. The American Bird Conservancy's (undated) fact sheet on domestic cat predation on wildlife states that, "domestic cats are considered primarily responsible for the extinction of eight island bird species, and the eradication of over 40 bird species from New Zealand islands alone." Some introduced species can bring diseases that impact local wildlife, compete with native animals for resources, destroy native vegetation, or kill or injure native wildlife. Deer introduced to North Manitou Island (Lake Michigan) in 1926 browsed so heavily on herbaceous vegetation and certain species of trees that the forest composition changed over the years: conifers decreased while maple and beech increased (Flaspohler and Hurley 2004). Compared to South Manitou where no deer were present, nearby North Manitou had seven times less herbaceous and fern coverage and four times more sapling coverage (Flaspohler and Hurley 2004). In other cases the impact of the introduction is not felt as strongly. The significance of the threat to the system will vary depending on the sensitivity of the habitats to disturbance, the type of disturbance, the invasibility (the susceptibility of an environment to the colonization and establishment of individuals from species not currently part of the resident community) of the introduced species, and the size of the island.

Threat: Climate change

Changes in global climate patterns due to trapping of greenhouse gases, particularly carbon dioxide, within the atmosphere are being widely predicted by scientists all over the world (IPCC 2007a). Climate change is expected to bring increased temperatures, altered distribution patterns of precipitation, greater intensity of storm events, melting of glaciers, and changes in local water levels (IPCC 2007a). Several models of climate change within the Great Lakes region provide possible scenarios for weather and precipitation should carbon dioxide levels double within the coming years. These models predict that doubled carbon dioxide in the atmosphere could increase air temperature between 2.6 and 9.1° Celsius (4.7 and 16.4° Fahrenheit), increase water temperature, alter precipitation, reduce snowfall and lake ice cover, increase evapotranspiration rates, and lower lake levels and connecting channel flow by 0.2 to 2.5 meters (0.66 to 8.2 feet) (Mortsch and Quinn 1996, Magnuson et al. 1997). The impacts of such climate change on Great Lakes island biodiversity would be wide in scope and extremely difficult to predict. Decreases in Great Lakes water levels, which define the boundaries of islands, can lead to increases in the area of an island exposed, expansion or loss of coastal wetland habitat (depending on elevation and topography), connection of some islands to the mainland, changes in extent and/or composition of island shoreline habitat, and changes in erosion and accretion patterns. Even slight changes in average or maximum/minimum temperatures and the associated alterations of precipitation can impact the life cycles and distribution of some plant and animal species. For example, it has been predicted that in portions of Canada climate change could replace moist boreal forests with transitional grasslands and cool temperate forests (Rizzo and Wilken 1992). Likewise, changes in precipitation, lake levels, runoff, and soil moisture are likely to result in a reduction in wetland coverage and an increase in incidences of fire and drought. Any of the predicted climate-change impacts could significantly alter plant and animal composition (Magnuson et al. 1997) on the already vulnerable Great Lakes islands.

The ramifications of global climate change on aquatic species that rely on the nearshore island environment are also potentially significant. Because different species of fish are dependent on specific seasonal temperature regimes, some will be affected in unique ways. For example, warmer water temperatures in the lakes will result in an extended growing season for fish that depend on warmer water for growth and development, but is also expected to result in less available oxygen (and potentially anoxic conditions) in the cooler, deeper portions of the lake that cool water fish species need to survive (Magnuson et al. 1997).

Because climate change is a global issue likely to affect all Great Lakes islands and because most prevention and mitigation efforts must be addressed at a global level, this threat will not be specifically addressed within individual lake-by-lake island assessments still being compiled by the Collaborative. Consequently, our recommendations to address the threat of global climate change are:

Recommendation 1*: At an international level, work with other countries to devise policies, measures, and instruments to mitigate climate change, as suggested by the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007b).*

Recommendation 2*: Take steps at a national (U.S. and Canada) level to a) reduce carbon dioxide emissions into the atmosphere from fossil-fuel burning, particularly from power plants and vehicles and b) create incentives and venues for offset credits for the public and private sector.*

Recommendation 3*: At a local, state, and provincial level, limit carbon dioxide emissions from regulated industry sources, and provide incentives for vehicles that do not emit carbon dioxide.*

Recommendation 4*: Because large-scale deforestation contributes to increased carbon dioxide in the atmosphere, use timber-management practices that promote rapid regeneration and encourage reforestation of previously disturbed areas.*

Lack of Knowledge as a Significant Threat

In addition to the threats described above, our lack of knowledge about the islands as a collection, the plants and animals that inhabit these unique ecosystems, and the significant impact that typical daily human activities have on these delicate systems further contribute to loss of biodiversity. Without this knowledge, we are ill equipped to identify and prioritize conservation efforts to ensure that the most representative conservation targets are afforded permanent protective status. Prior to undertaking this study, the unknowns included the number and location of the islands, which island areas are of most ecological significance, what Great Lakes island-specific conservation targets would be, and the overall conservation status of the islands. The Collaborative took up the challenge to address these questions, having to start from scratch by defining just what constitutes an “island.” But as the Collaborative continues to identify, collect, analyze, and report on island science, policy, management, and conservation activities, we remain ill equipped to make intelligent management decisions and to prioritize conservation efforts for the islands as a binational collection. Hence opportunities to preserve the significant biodiversity of the Great Lakes islands are slipping away each day. The Collaborative will continue efforts to ensure the conservation of Great Lakes islands in perpetuity through our efforts to increase and share island-specific knowledge.

Implications for Conservation

Although islands may be isolated in one sense, ecologically they are linked to the lakes, other islands, the mainland, and the globe through the movement of species, weather, and water. Strong cultural drivers are in place that foster the development of islands for human purposes to such an extent that our ability to conserve the globally significant non-human life that they hold is often restricted. To ensure the protection of biodiversity on Great Lakes islands, bold measures are needed by island residents, local, state/provincial, and federal governments, and citizens to halt and reverse threats that result in the most significant losses. Island owners and land managers will need to address loss and fragmentation of high-quality island habitats at a local level. Land managers should ensure that island management and recreation are compatible with native species and habitats. Regionally, resource managers need to prevent over-harvest of native plants and animals. Efforts to remediate contaminated sites need to continue and even increase, and the introduction of new chemicals into island environments must be done appropriately or when necessary be avoided. Nationally, governments need to take legislative action to halt the spread of invasive species by regulating ballast water releases and blocking existing sources of new invasive species, for example through the Chicago shipping and sanitary canal. Globally, governments must take legislative action to halt or reverse human-induced climate change stemming from the release of greenhouses gases into the atmosphere. Threats to the living resources of Great Lakes islands are wide in source, scope, and severity. Without focused conservation efforts to address specific threats to Great Lakes islands, they, like ecosystems throughout the world, face increasing and irreversible loss of biodiversity.

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FORTHCOMING EFFORTS

The Collaborative's focus is on creating a lasting framework for the binational conservation of the Great Lakes islands. The framework will be based in science and point to the most vital conservation needs and opportunities. The team will continue to assemble data, literature, and expert advice about the biodiversity and features of the islands throughout 2007. By early 2008, we will distribute a framework document for peer and public review. Presently that document is being written (see Appendix 5 for the Lake Huron prototype of profiles we are developing for the islands by lake and connecting channel). We welcome ideas, information, and questions via email at info@greatlakesislands.org, or by contacting the teams members identified in *Acknowlegments*. Information will be posted on www.greatlakesislands.org as it becomes available.

Islands hold intense alure as places of rest, retreat, and romance. Often due to this unique appeal, islands face particular threats while lacking the innate ability to counter them. Islands by their very nature are fragile and cannot be treated like mainland areas. We hope that once this is understood, people throughout the basin will actively work to ensure that island activities are appropriate and sustainable. With 31,407 globally unique Great islands, it will take hundreds or even thousands of people from all walks of life to give the Great Lakes islands the special attention they require if we are to enjoy their beauty, life, and resources today and into the future. The world's largest collection of freshwater islands are a one-time irreplaceable gift, and we welcome participation in the efforts of the Collaborative to conserve them in perpetuity.

APPENDIX 1: OTHER PROJECT DELIVERABLES

- Creating a binational Great Lakes Islands geographic information system that led to, among other things:
    - Tabulation and mapping of the 31,407 Great Lakes islands
    - "Finding" numerous islands in the lakes that heretofore had not been counted

- Developing the first freshwater island classification system

- Providing support for the 2005 publication of *The Biological Ranking Criteria for Conservation of Islands in the Laurentian Great Lakes* by Ewert et al. that underlies this project (see http://www.greatlakesislands.org/USFWS%20Island%20Ranking%20Rpt.pdf)

- Developing and submitting island indicators to SOLEC 2006 (see Appendix 4)

- Convening a one-day session that drew 14 papers on the Islands of the Great Lakes at the 2004 International Association for Great Lakes Research Conference in Waterloo, Ontario

- Organizing six *Great Lakes Islands Workshops* during July and August 2006 in Thunder Bay, Ontario; Traverse City and Grosse Ile, Michigan; Clayton, New York; and two in the Georgian Bay, Ontario with radio, television, and newspaper coverage

APPENDIX 2: SPECIES COMMON AND SCIENTIFIC NAMES

Common	Scientific
PLANTS	
Auricled twayblade	Listera auriculata
Bird's-eye primrose	Primula mistassinica
Canada yew	Taxus canadensis
Choke cherry	Prunus virginiana
Common butterwort	Pinguicula vulgare
Common hound's tongue	Cynoglossum officinale
Common juniper	Juniperus communis
Creeping juniper	Juniperus horizontalis
Dwarf lake iris	Iris lacustris
Eastern redbud	Cercis canadensis
Eurasian water-milfoil	Myriophyllum spicatum
European helleborine	Epipactus helleborine
European marsh thistle	Cirsium palustre
Garlic mustard	Alliaria petiolata
Glossy buckthorn	Rhamnus frangula
Gold-moss stonecrop	Sedum acre
Hill's pondweed	Potamogeton hillii
Houghton's goldenrod	Solidago houghtonii
Lakeside daisy	Hymenoxys herbacea
Michigan monkey flower	Mimulus glabaratus michiganensis
Mooseberry	Viburnum edule
Pitcher's thistle	Cirsium pitcheri
Poison ivy	Toxidendron radicans
Prairie dropseed	Sporobolus heterolepis
Prairie dunewort (fern)	Botrychium campestre
Prairie smoke	Geum triflorum
Purple loosestrife	Lithrum salicaria
Reed canary grass	Phalaris arundinacea
Ram's head lady's slipper	Cypripedium arietinum
Sand cherry	Prunus pumila
Spotted knapweed	Centaurea biebersteinii
Timothy grass	Phleum pratense
White cedar	Thuja occidentalis
MOLLUSCS	
Quagga mussel	Dreissena bugensis

Zebra mussel	Dreissena polymorpha
Snail	Triodopsis albolabris goodrichi
Snail	Anguispira kochi strontiana
CRUSTACEANS	
Spiny water flea	Bythotrephes cederstroemi
INSECTS	
Lake huron locust	Trimerotropis huroniana
FISH	
Alewife	Alosa pseudoharengus
Bighead carp	Hypophthalmichthys nobilis
Bluegill	Lepomis macrochirus
Brook trout	Salvo fontinalis
Brown carp	Carpiodes cyprinus
Eurasian river ruffe	Gymnocephalus cernuus
Lake trout	Salvelinus namaycush
Lake whitefish	Coregonus clupeaformis
Largemouth bass	Micropterus salmoides
Northern pike	Esox lucius
Round goby	Neogobius melanostomus
Sea lamprey	Petromyzon marinus
Silver carp	Hypophthalmicthys molitrix
Smallmouth bass	Micropterus dolomieu
Walleye	Sander vitreus
AMPHIBIANS	
American toad	Bufo americanus
REPTILES	
Eastern fox snake	Elaphe vulpina gloydi
Eastern garter snake	Thamnophis sirtalis
Eastern massassauga	Sistrurus catenatus
Lake Erie watersnake	Nerodia sipedon insularum
Northern watersnake	Nerodia sipedon sipedon
Timber rattlesnake	Crotalus horridus

BIRDS	
American redstart	Setophaga ruticilla
Bald eagle	Haliaeetus leucocephalus
Black tern	Chlidonias niger
Double-crested cormorant	Phalacrocorax auritus
Forster's tern	Sterna forsteri
Great horned owl	Bubo virginianus
Herring gull	Larus argentatus
Kirtland's warbler	Dendroica kirtlandii
Piping plover	Charadrius melodus
Ring-billed gull	Larus delawarensis
Ruffed grouse	Bonasa umbellus
Song sparrow	Melospiza melodia
Yellow-breasted chat	Icteria virens
MAMMALS	
American badger	Taxidea taxus
American beaver	Castor canadensis
Black bear	Ursus americanus
Caribou	Rangifer tarandus
Cottontail rabbit	Sylvilagus floridanus
Coyote	Canis latrans
Deer mouse	Peromyscus maniculatus gracilis
Eastern chipmunk	Tamias striatus
Eastern fox squirrel	Sciurus niger
Eastern gray squirrel	Sciurus carolinensis
Eastern timber wolf	Canis lupus
Gray fox	Urocyon cinereoargenteus
House Mouse	Mus musculus
Long-tailed weasel	Mustela frenata
Mink	Mustela vison
Moose	Alces alces
Muskrat	Ondatra zibethicus
Norway Rat	Rattus norvegicus
Raccoon	Procyon lotor
Red fox	Vulpes vulpes
Red squirrel	Sciurus vulgaris
Red-backed vole	Clethrionomys gapperi
Striped skunk	Mephitis mephitis

White-footed mouse	Peromyscus leucopus
White-tailed deer	Odocoileus virginianus
Woodland deer mouse	Peromyscus maniculatus

APPENDIX 3: AFFILIATIONS OF INDIVIDUALS CITED IN PERSONAL COMMUNICATIONS

Peggy Burkman, Apostle Islands National Lakeshore (Lake Superior)
Francesca Cuthbert, University of Minnesota
Mike Grimm, The Nature Conservancy
Mary Harkness, The Nature Conservancy
Bruce Kirschner, Great Lakes Regional Office, International Joint Commission
Bruce Manny, Great Lakes Science Center, U.S. Geological Service
Anthony Reznicek, University of Michigan

APPENDIX 4. FIRST REPORTING OF ISLAND INDICATORS FOR SOLEC 2006

Extent, Condition and Conservation Management of Great Lakes Islands
Indicator #8129

Overall Assessment

Status:	**Mixed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	**The Framework for Binational Conservation of Great Lakes Islands will be completed in 2007. The following results reflect detailed analysis from Canadian islands and preliminary results from the US. This project has created the first detailed binational map Great Lakes islands. This includes the identification of 31,407 island polygons with a total coastline of 15,623 km.** **This project has established baseline information that will be used to assess future trends.**

Lake by Lake Assessment

Lake Superior

Status:	Good
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 2,591 island polygons. St. Mary's River has 630 island polygons. Canadian islands in Lake Superior have the lowest threats score in the basin. A high proportion of these islands are within protected areas and conservation lands. Overall condition is good. These islands include a high number of disjunct plant species.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis not completed. Total of 329 island polygons.

Lake Huron

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 23,719 island polygons (includes Georgian Bay). These islands tend to be more threatened in the south compared to the north. A large number of protected areas and conservation lands occur in the northern region. Southern regions are more developed, and under increasing pressures from development. These islands include high number of globally rare species and vegetation communities.

Lake Erie

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 1,724 island polygons. Other island polygons with Lake St. Clair/ St. Clair River (339), Detroit River (61) and Niagara River (36). These islands include a mix of protected areas and private islands. Islands in the western Lake Erie basin have some of the highest biodiversity values of all Great Lakes islands.

Lake Ontario

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 2,591 island polygons (including upper St. Lawrence River). Many of these islands have high threat index scores and a long history of recreational use. One of the highest building point counts. Few areas have been protected.

Purpose

•To assess the status of islands, one of the 12 special lakeshore communities identified within the nearshore terrestrial area.

Ecosystem Objective

To assess the changes in area and quality of Great Lakes islands individually, and as an ecologically important system; to infer the success of management activities; and to focus future conservation efforts toward the most ecologically significant island habitats in the Great Lakes.

State of the Ecosystem

Background

There are 31,407 islands that have been idnetified in the Great Lakes (Figure 1). The islands range in size from no bigger than a large boulder to the world's largest freshwater island, Manitoulin, and often form chains of islands known as archipelagos. Though not well known, the Great Lakes contain the world's largest freshwater island system, and are globally significant in terms of their biological diversity. Despite this, the state of our knowledge about them as a collection is quite poor.

By their very nature, islands are vulnerable and sensitive to change. Islands are exposed to the forces of erosion and accretion as water levels rise and fall. Islands are also exposed to weather events due to their 360-degree exposure to the elements across the open water. Isolated for perhaps tens of thousands of years from the mainland, islands in the past rarely gained new species, and some of their resident species evolved into endemics that differed from mainland varieties. This means that islands are especially vulnerable to the introduction of non-native species, and can only support a fraction of the number of species of a comparable mainland area.

Some of the Great Lakes islands are among the last remaining wildlands on Earth. Islands must be considered as a single irreplaceable resource and protected as a whole if the high value of this natural heritage is to be maintained. Islands play a particularly important role in the "storehouse" of Great Lakes coastal biodiversity. For example, Michigan's 600 Great Lakes islands contain one-tenth of the state's threatened, endangered, or rare species while representing only one-hundredth of the land area. All of

Michigan's threatened, endangered, or rare coastal species occur at least in part on its islands. The natural features of particular importance on Great Lakes islands are colonial waterbirds, neartic-neotropical migrant songbirds, endemic plants, arctic disjuncts, endangered species, fish spawning and nursery use of associated shoals and reefs and other aquatic habitat, marshes, alvars, coastal barrier systems, sheltered embayments, nearshore bedrock mosaic, and sand dunes. New research indicates that nearshore island areas in the Ontario waters of Lake Huron account for 58% of the fish spawning and nursery habitat and thus are critically important to the Great Lakes fishery. Many of Ontario's provincially rare species and vegetation communities can be found on islands in the Great Lakes.

Pressures

By their very nature, islands are more sensitive to human influence than the mainland and need special protection to conserve their natural values. Proposals to develop islands are increasing. This is occurring before we have the scientific information about sustainable use to evaluate, prioritize, and make appropriate natural resource decisions on islands. Island stressors include development, invasive species, shoreline modification, marina and air strip development, agriculture and forestry practices, recreational use, navigation/shipping practices, wastewater discharge, mining practices, drainage or diversion systems, overpopulation of certain species such as deer, industrial discharge, development of roads or utilities, abandoned landfills, and disruption of natural disturbance regimes.

Management Implications

Based on the results of assessments of island values, biological significance, categorization, and ranking, the Binational Collaborative for the Conservation of Great Lakes Islands will soon recommend management strategies on Great Lakes islands to preserve the unique ecological features that make islands so important. In addition, based on a proposed threat assessment to be completed in 2005, the Collaborative will recommend management strategies to reduce the pressures on a set of priority island areas.

Comments from the author(s)

The Great Lakes islands provide a unique opportunity to protect a resource of global importance because many islands still remain intact. The U.S. Fish and Wildlife Service's Great Lakes Basin Ecosystem Team (GLBET) has taken on the charge of providing leadership to coordinate and improve the protection and management of the islands of the Great Lakes. The GLBET island initiative includes the coordination and compilation of island geospatial data and information, developing standardized survey/monitoring protocols, holding an island workshop in the fall of 2002 to incorporate input from partners for addressing the Great Lakes Island indicator needs, and completion of a Great Lakes Island Conservation Strategic Plan.

A subset of the GLBET formed the Binational Collaborative for the Conservation of Great Lakes Islands. Recently, the Collaborative received a habitat grant from the Environmental Protection Agency's Great Lakes National Program Office (GLNPO) to develop a framework for the binational conservation of Great Lakes islands. With this funding, the team has developed:

1) An island biodiversity assessment and ranking system (based on a subset of biodiversity parameters) that will provide a foundation to prioritize island conservation;
2) A freshwater island classification system; and
3) A suite of indicators that can be monitored to assess change, threats, and progress towards conservation of Great Lakes islands biodiversity.

To date, the Collaborative has tentatively proposed ten state, five pressure, and two response indicators. We anticipate developing additional response indicators and may be able to incorporate existing Great Lakes response indicators. The island indicators are still being evaluated and are not final. Final selection of indicators will take place in 2005-2006, and will be based on relevance, feasibility, response variability, and interpretation and utility. The Collaborative is currently drafting the Framework for the Binational Conservation of Great Lakes Islands, which is expected to be submitted for public and peer review in the fall of 2006.

The information conveyed by a science-based suite of island indicators will help to focus attention and management efforts to best conserve these unique and globally significant Great Lakes resources.

Acknowledgments
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List of Tables

Also see draft Framework for Binational Conservation of Great Lakes Islands

List of Figures

Last updated
August 31, 2006

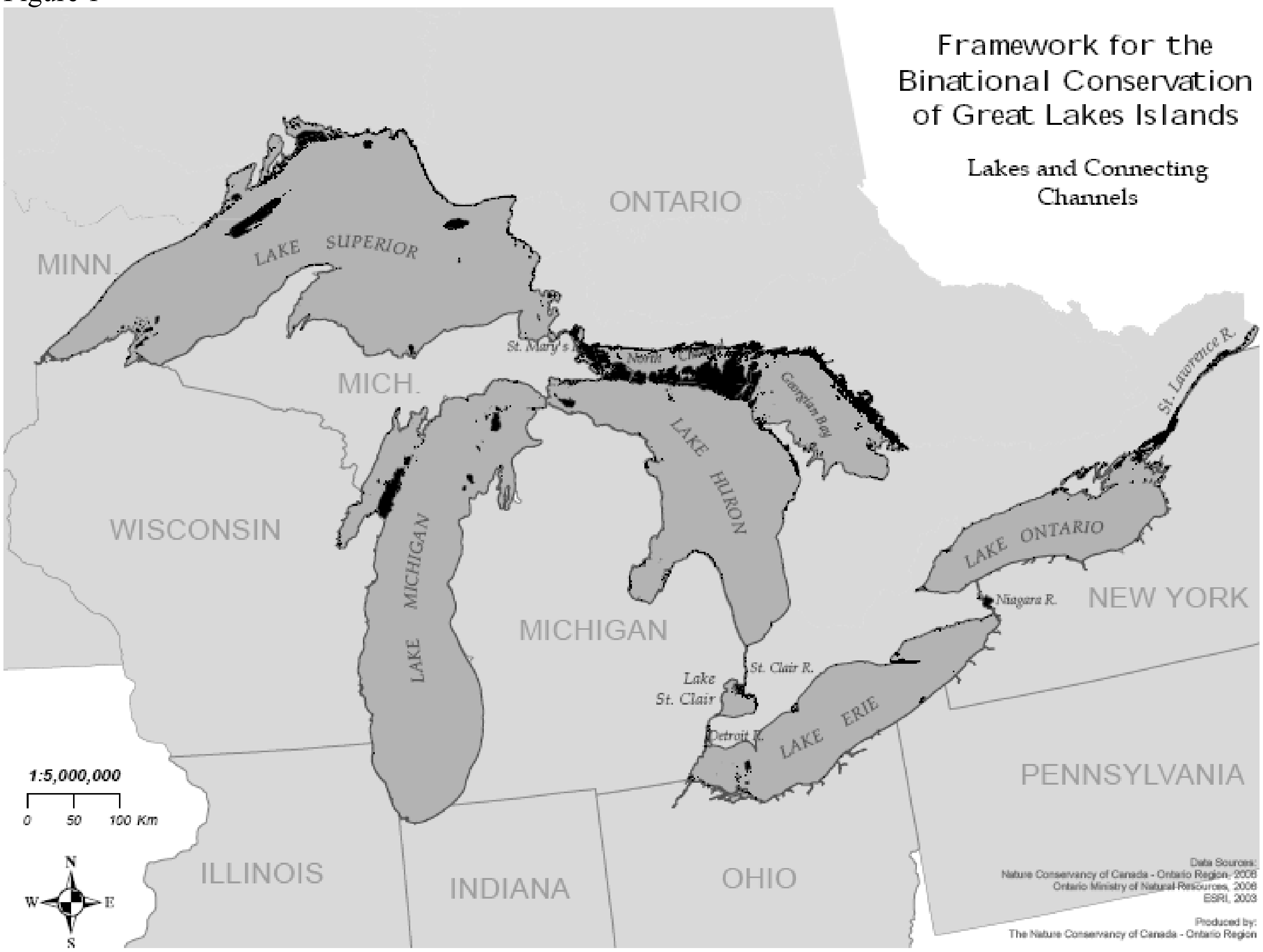
Permissions and Links
YES

http://greatlakesislands.org/

Table 1
Biodiversity and Threats Scores for Great Lakes Islands (Canada only), by coastal environment.

Costal Environment	No. Individual Islands	No. Islands/ Complexes	Biodiversity Score		Threat Score	
			Mean	Range	Mean	Range
Georgian Bay 1	3992	595	85.2	0-345	1.3	0-65
Georgian Bay 2	17615	848	90.2	0-290	11.8	0-52
Georgian Bay 3	38	22	93.9	57-244	8.2	1-46
Georgian Bay 4	36	18	95.8	47-195	5.7	1-33
Georgian Bay 5	290	90	103.6	39-300	4.0	1-44
Georgian Bay 6	225	119	92.8	46-401	9.7	1-581
Lake Erie 1	0	0	0	0	0	0
Lake Erie 2	15	15	151.7	87-388	11.2	1-88
Lake Erie 3	2	2	92.5	91-94	1.0	1
Lake Erie 4	66	13	198.9	154-340	4.8	1-32
Lake Erie 5	2	2	90.5	87-94	2.0	1-3
Lake Erie 6	1461	30	203.4	81-333	9.7	1-41
Lake Erie 7	21	18	88.4	57-143	7.7	1-42
Lake Erie 8	17	4	144.5	96-164	2.3	1-6
Lake Huron 1	887	173	103.4	39-490	8.2	1-179
Lake Huron 2	31	19	85.0	57-137	3.4	1-22
Lake Huron 3	8	5	127.0	114-145	2.8	1-4
Lake Ontario 1	0	0	0	0	0	0
Lake Ontario 2	9	7	108.6	90-148	2.3	1-5
Lake Ontario 3	34	13	127.0	86-190	7.0	1-27
Lake Ontario 4	74	32	131.5	83-231	3.3	1-22
Lake Ontario 5	603	171	114.1	44-302	3.7	1-143
Lake Superior 1	167	117	84.6	39-290	2.2	1-25
Lake Superior 2	1228	459	81.2	37-288	2.0	1-40
Lake Superior 3	495	160	71.7	40-195	2.4	1-28
Lake Superior 4	77	28	97.2	57-253	3.3	1-26
Lake Superior 5	246	45	93.6	49-275	8.8	1-138
St. Clair 1	21	11	119.7	84-187	22.1	1-46
St. Clair 2	234	25	162.2	92-336	9.2	1-68
St. Clair 3	53	11	160.3	102-239	6.0	1-36
St. Clair 4	1	1	116	116	2	2
St. Clair 5	41	14	162.1	79-231	11.5	1-36
St. Lawrence 1	337	111	92.4	44-211	19.5	1-81

Figure 1


Framework for the
Binational Conservation
of Great Lakes Islands
Lakes and Connecting
Channels
ONTARIO
MINN.
LAKE SUPERIOR
MICH.
St. Mary's
North
Georgian Bay
LAKE HURON
WISCONSIN
LAKE MICHIGAN
MICHIGAN
St. Lawrence R.
LAKE ONTARIO
Niagara R.
NEW YORK
St. Clair R.
Lake
St. Clair
Detroit R.
LAKE ERIE
PENNSYLVANIA
1:5,000,000
0
50
100 Km
N
W
E
S
ILLINOIS
INDIANA
OHIO
Data Sources:
Nature Conservancy of Canada - Ontario Region, 2006
Ontario Ministry of Natural Resources, 2006
ESRI, 2003
Produced by:
The Nature Conservancy of Canada - Ontario Region

APPENDIX 5: LAKE HURON PROTOTYPE FOR ISLAND-BY-LAKE PROFILES

The Collaborative is currently compiling a binational summary of islands within each of the individual Great Lakes and connecting channels for inclusion in the final Framework report. To date we have assembled more than 100 pages of information detailing the significance of, threats to, and conservation status of the biodiversity of islands in each of the lakes and connecting channels. This has required significant effort because the data has never before been compiled for the Great Lakes islands either nationally or binationally.

As of 2007, we have a complete GIS database for Canadian/Ontario islands, while development of a similar database for the U.S. islands has been hindered by collecting and standardizing data from eight individual states. The document below, "Biodiversity and Conservation of Lake Huron's Islands," is a prototype upon which we will base our binational island-by-lake profiles. Because this document was prepared for journal publication, our format will vary somewhat and we plan to incorporate more detail on intriguing location-specific topics. However, the basic information presented here will be included for each of the lakes and connecting channels in a more fulsome framework report sometime within the next 12 months that will be peer reviewed and identify Priority Island Conservation Areas (PICAs) .

Biodiversity and Conservation of Lake Huron's Islands

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Abstract
Lake Huron includes the largest collection of freshwater islands in the world. These islands are a significant contributor to the biodiversity of the region. This project provides the most comprehensive biodiversity assessment of islands in the Lake Huron to date, and has assembled mapping of over 23,000 island units. The number, extent and configuration of many islands, particularly small, low-lying systems, is very dynamic depending on lake-levels. Islands in Lake Huron can be divided into 3 broad groups: 1) limestone and dolostone islands associated with Manitoulin and Drummond Islands and the Bruce Peninsula, and hundreds of smaller surrounding islands, 2) dense archipelagos of small nearshore

Precambrian Shield islands in eastern Georgian Bay and the North Channel and, 3) the small group of islands low-erodible islands in Saginaw Bay that supports vast areas of Great Lakes marshes.

These islands are important for colonial nesting waterbirds, endemic species and communities and migratory birds. The rich and diverse set of species and communities on Lake Huron islands which have been somewhat buffered from anthropogenic change due to their isolation. Consequently, many islands remain undeveloped and in good condition ecologically.

The primary threats to islands include development and invasive species, and are generally greater in many of the southern island regions where fewer islands are protected. Priorities for conservation include the identification and protection of key sites with globally rare community types and ecosystem functions.

Introduction

Of the five Great Lakes, Lake Huron, more than any other, embodies the biodiversity of the basin. Stretching over 350 km from Ontario's "Carolinian" zone at the mouth of the St. Clair River north to the boreal transition forests along the North Channel, Lake Huron includes a multitude of climatic, geological and biogeographical zones. This second largest of the Great Lakes, Lake Huron contains more shoreline than any other lake. Its deep bays, meandering shoreline and thousands of islands represent the longest freshwater coast in the world. These coastal areas are critical for biological diversity, and many of the Great Lakes basin's endemic, disjunct and globally rare species occur near the shoreline. In addition to species, coasts of Lake Huron harbor many community types that, while poorly documented, are known to be very rare and range restricted. Eastern Georgian Bay for example contains a minimum of 19 globally rare vegetation communities (Nature Conservancy of Canada 2006).

Islands are an integral part of the biophysical character of Lake Huron. From the intricate archipelagos of the eastern Georgian Bay, to Manitoulin Island (the world's largest freshwater island) to the low-lying, erodible islands of Saginaw Bay, islands harbour many of the unique biodiversity features characteristic of Lake Huron. Due to their isolation, strong coastal influence and unique geology, many of these islands support, and include ecological systems, vegetation communities, and species that are found nowhere else in the world. In addition, these islands support ecosystem functions and phenomena unique to the Great Lakes and important for maintaining the biodiversity of the region. Some of the specialized biodiversity found on islands includes colonial nesting waterbirds, landbird stop-over sites, fish habitat and species and communities of conservation concern (Ewert et. al 2004). In addition, many islands harbour plant and animal communities that are different from the mainland due to their isolation.

The islands of Lake Huron are relatively young. Many were part of, or connected to, the mainland following the last period of glaciation when water levels were lower. However, during the Lake Nipissing stage (approximately 4000 years ago) because of isostatic rebound and changes in outflows, the water level rose about 8 m above present-day levels before receding again (Karrow and Calkin 1985). Islands with lower relief would have been submerged, and then emerged as water levels receded to present day levels. In most regions of Lake Huron, islands are still slowly emerging as the land continues to rebound from glaciation and as water levels drop. Colonization of most islands from mainland flora and fauna has therefore occurred in the last few thousand years. Many lower islands are subject to repeated episodes of colonization from pioneer species as water levels fluctuate and these islands are subject to periodic inundation.

While the importance of islands to biodiversity in the Great Lake basin has long been recognized, this full collection of islands has not been studied. This project provides the most comprehensive biodiversity assessment of islands in the Lake Huron and the Great Lakes to date. Here we describe preliminary results of this analysis for islands in Lake Huron in both Canada and the United States.

Methods

The initial step in this project was the creation of the first bi-national map of Lake Huron islands from national, provincial and state digital mapping. This islands layer includes island polygons and rocks/reefs. For US islands, some of the existing polygons were very coarse, and re-digitized to better capture the true size and shoreline diversity.

Different analytical methods were used for the Ontario and US islands. A more comprehensive and accurate island data layer in Ontario, and complete datasets of island attributes allowed for an automated analysis with Geographical Information Systems (GIS) relatively early on in the project. These results were then supplemented with detailed information from the literature. In the US, the need to update the island layer and assemble island attributes from a variety of state sources has delayed a detailed automated analysis. For islands in the US, basic island information extracted from the data was supplemented with a literature review. Fortunately most of the US islands in Lake Huron have detailed studies available that could be used to assess biodiversity and conservation needs. The following provides a more detailed summary of the approaches used in this study.

Ontario Islands

In order to create manageable units for the analysis, islands were analyzed based on their Great Lakes coastal environment (Owens 1979). Coastal environments are based on relief, geology, fetch, wave exposure, ice conditions, and availability and transport of sediment. This divides some larger islands (e.g. Manitoulin) into different zones to reflect distinctive coastal characteristics.

Within each coastal environment large islands and island complexes were identified. Large islands were extracted based on the range of sizes and maintained as a single unit of analysis.
Portions of the Great Lakes (e.g. eastern Georgian Bay) contain thousands of islands, many of which are very small and have similar characteristics, and often function as a unified landscape unit. Clusters of small islands were grouped into island complexes based on proximity (within 200 m of each other and without any intervening land) and similar geology. The analysis was then done on the island complex, rather than small individual islands.

Islands and island complexes were assigned scores based on three categories: 1) biodiversity values, 2) potential threats, and 3) existing conservation progress. The criteria from Ewert et al. (2004) were modified and used as a basis to build a scoring method that could use an automatic approach to assess the biodiversity of islands. Biodiversity criteria included measures for biological diversity, physical diversity, size and distinctiveness.

The analysis of threats considered direct potential threats, such as boat launches, anchorages, residences, cottages, building density, invasive species, pits, quarries and lighthouses. Indirect potential threats considered included distance to mining claims, road density and percent of the island occupied by cropland.

Conservation progress was also assessed for each island and island complex. Parks, protected areas, conservation lands and existing recognition of biodiversity values were categorized into four categories to reflect the general type of associated conservation. Existing conservation progress scores did not directly contribute to the biodiversity or threat scores, but the proportion of these conservation lands on each island and island complex were assessed to provide further insight into island values and identify potential conservation gaps and needs.

Highest scoring islands for biodiversity and threats within each coastal environment were identified based on the natural breaks (Jenks) method provided in ArcGIS software (Environmental Systems Research

Institute Inc. 2002). Along with the protection gap analysis, potential priority islands and island complexes for conservation can be identified.

US Islands
This project created the first comprehensive dataset of islands within the US portion of Lake Huron, and increased the number of documented islands from 200 (Soule 1999) to almost 600. Many of these islands have been inventoried by Michigan Natural Features Inventory (see Penskar et. al 2002; Penskar et. al 2000) and priorities for colonial nesting waterbirds have been identified (Wires and Cuthbert 2001). Basic island metrics have been developed for the shoreline units of Lake Huron (based on Reid et al. 2001). The islands were assessed based on these information sources, the Great Lakes ecoregion plan in the United States (The Nature Conservancy 1999), data on endangered, threatened, and special concern species available from the Michigan Natural Features Inventory, information from the Michigan chapter of The Nature Conservancy and Michigan Nature Association, and other published and unpublished descriptions of biodiversity. The protected status of islands in the Michigan portion of Lake Huron was determined from a newly developed data layer, CARL (Conservation and Recreational Lands database) and a review of threats to islands in Lake Huron derived from expert opinion and other sources (e.g. Vigmostad 1999, Wires and Cuthbert 2001).

Scores comparable to those developed in Ontario have not yet been developed as the databases needed to derive these scores were just becoming available as this paper was written. We anticipate being able to score islands in Michigan similar to those in Ontario in the near future.

Results
Biodiversity of Lake Huron Islands
This study has mapped over 23,000 island polygons within Lake Huron (Figure 1). These islands range in size from less than a few square metres to Manitoulin Island at 2,766 km^2. The vast majority of these islands occur within the northern and eastern portion of Georgian Bay, while large areas in the southern part of Lake Huron have very few islands (Table 1). Within the Great Lakes, almost 75% of all islands occur in Lake Huron. The number and density of islands of Lake Huron far surpass the number of freshwater islands known from other regions.

Collectively, Lake Huron islands are important sites for nesting colonial waterbirds (Wires and Cuthbert 2001), species and communites endemic to or largely limited to the Great Lakes, disjunct species and communities, especially from western North America (Guire and Voss 1963) and the Atlantic coastal plain (Jalava et al. 2005), and important areas for wide ranging animals (e.g., stopover sites for migratory birds and spawning and nursery areas for fish). Although islands are rarely free of introduced species, some islands have relatively low numbers of introduced species and thus provide excellent examples of communities characteristic of the Great Lakes region.

The islands of Lake Huron are highly variable, but can be generally grouped into three major groups, based on their underlying substrate, with each of these groups having different biodiversity features.

The northernmost Lake Huron islands within northern and eastern Georgian Bay are on metamorphic rock of the Canadian (Laurentian) shield. This is also the largest group of islands, not only in Lake Huron, but the Great Lakes. This region is generally characterized by dense archipelagos of low, small islands. These islands are noted for supporting granite rock barrens, colonial nesting waterbirds, disjunct flora from the arctic and western cordillera, and, in southern Georgian Bay, harbour Atlantic coastal plain plant communities as well as northern populations of many reptiles and amphibians, including the globally rare eastern foxsnake (*Elaphe gloydi*) and eastern massassauga (*Sistrurus catenatus*) (Henson and Brodribb 2005).

The northern coast of Lake Huron is mantled by a discontinuous archipelago of resistant limestone and dolostone islands that extends from the scattered islands off the southern Bruce Peninsula west to Manitoulin Island, St. Joseph Island, the Les Cheneaux islands and the Mackinac and Bois Blanc islands. These islands are especially important for concentration of globally rare species and communities endemic to the Great Lakes, ranging from species such as dwarf lake iris (*Iris lacustris*), lakeside daisy *Hymenoxys herbacea)* and Pitcher's thistle (*Cirsium pitcheri*) to communities such as Great Lakes alkaline cobble/gravel shore, limestone bedrock lakeshore, wooded dune and swales and alvars (The Nature Conservancy 1999). Lake Huron islands particularly noteworthy for the concentration of species and communities associated with limestone and dolostone bedrock include Manitoulin Island, Ontario and Drummond Island, Michigan, and smaller islands associated with these two large islands. Some of the highest quality alvars and best sites for lakeside daisy and dwarf lake iris in the world are found on these islands and island complexes (Reschke et al. 1999).

Finally, the small group of Lake Huron islands in Saginaw Bay, Michigan supports vast areas of Great Lakes marshes that, together with the adjacent mainland, provide cover and food resources for large numbers of migrating waterfowl and shorebirds. Nearshore waters around these islands support spawning and nursery areas for many species of fish. Some beach ridges also support distinctive prairie and savanna communities.

Threats

Perhaps the two most significant threats to Lake Huron islands are (1) development, especially in the Les Cheneaux and eastern Georgian Bay region, which results in habitat loss, including fragmentation, and loss of natural processes in shoreline stretches and near shore waters (Soule 1993) (2) spread of invasive species and particularly in Saginaw Bay where islands under public ownership are being invaded by non-native animal and plant species such as Phragmites, zebra mussel, and Eurasian carp that may alter ecological and trophic-level dynamics in the Great Lakes, including Lake Huron. Other threats to many islands include loss of vegetation and thus modification of ecological communities due to overbrowsing by deer, and potential effects of climate change. More locally, threats related to recreation mining, shoreline hardening, alteration of substrate in nearshore waters due to dredging, and contaminants all may have consequences to the biota and processes that maintain biota on islands in Lake Huron.

Conservation Status

There is great variation in the threats and conservation status to the islands of Lake Huron. In general, islands in the southern areas tend to have less protection and greater competing land uses than regions in the north. For example, while almost 50% of the islands of central and northern Georgian Bay are within regulated protected areas, almost none of the islands in the East Christian Island Peninsula and Nottawasaga Bay region to the south are protected. Within Ontario, the most threatened island regions include the eastern coast of Georgian Bay and the northern coast of Lake Huron along the Bruce Peninsula and Manitoulin Island.

In contrast to Ontario, many islands in the southern Lake Huron portion of Michigan are protected. Most islands in Saginaw Bay, the southernmost islands on the US portion of Lake Huron, are under State of Michigan or US government ownership. In addition, many islands of the Thunder Bay region, near Alpena, Michigan, are protected as part of the Michigan Islands National Wildlife Refuge or by Michigan Nature Association. In the northern Lake Huron portion of Michigan, a smaller proportion of islands (or parts of islands) are under public or non-governmental ownership. This reflects the much larger number of islands in that region. Approximately 10% of all islands in the US side of Lake Huron are partially or completely protected (Soule 1993). Round Island, near Mackinac Island, is a designated Wilderness area by the US federal government.

Discussion
Islands are a key component of the Lake Huron's biodiversity. The islands are diverse in terms of size, isolation, geology, climate and biology. The three major groups of islands described in this paper, defined largely by substrate and to some degree, latitude, support distinctive plant and animal communities whose expression has been shaped by the relatively recent, geologically speaking, lake level and climate fluctuations, and historic distribution of species. The result has been the development of a rich and diverse set of species and communities on Lake Huron islands which have been somewhat buffered from anthropogenic change due to their isolation. Consequently, many islands remain undeveloped and in good condition ecologically.

Relative to the Lake Huron shoreline, islands are disproportionately valuable as colonial nesting waterbird sites, as sites that support Great Lakes endemic flora, fauna and communities characteristic of limestone and dolomite, and for concentrations of communities such as granite rock barrens in Georgian Bay and Great Lakes marshes in Saginaw Bay. And from a Great Lakes-wide perspective, the Lake Huron islands also emerge as globally significant sites.

Protection of Lake Huron islands, or portions of the large islands such as Manitoulin and Drummond Islands, is progressing but much more needs to be done. This study has identified some of the priority islands for biodiversity within Lake Huron for Ontario (see Table 2), and will shortly have completed a parallel analysis for the US. Remaining protection is needed to focus not only on the species and communities of concern, but also the ecological processes needed to maintain these islands. Islands need to be integrated into both regional and local conservation and land use planning to recognize the distinctive needs and high importance of these unique systems.

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Figure 1. Islands of Lake Huron

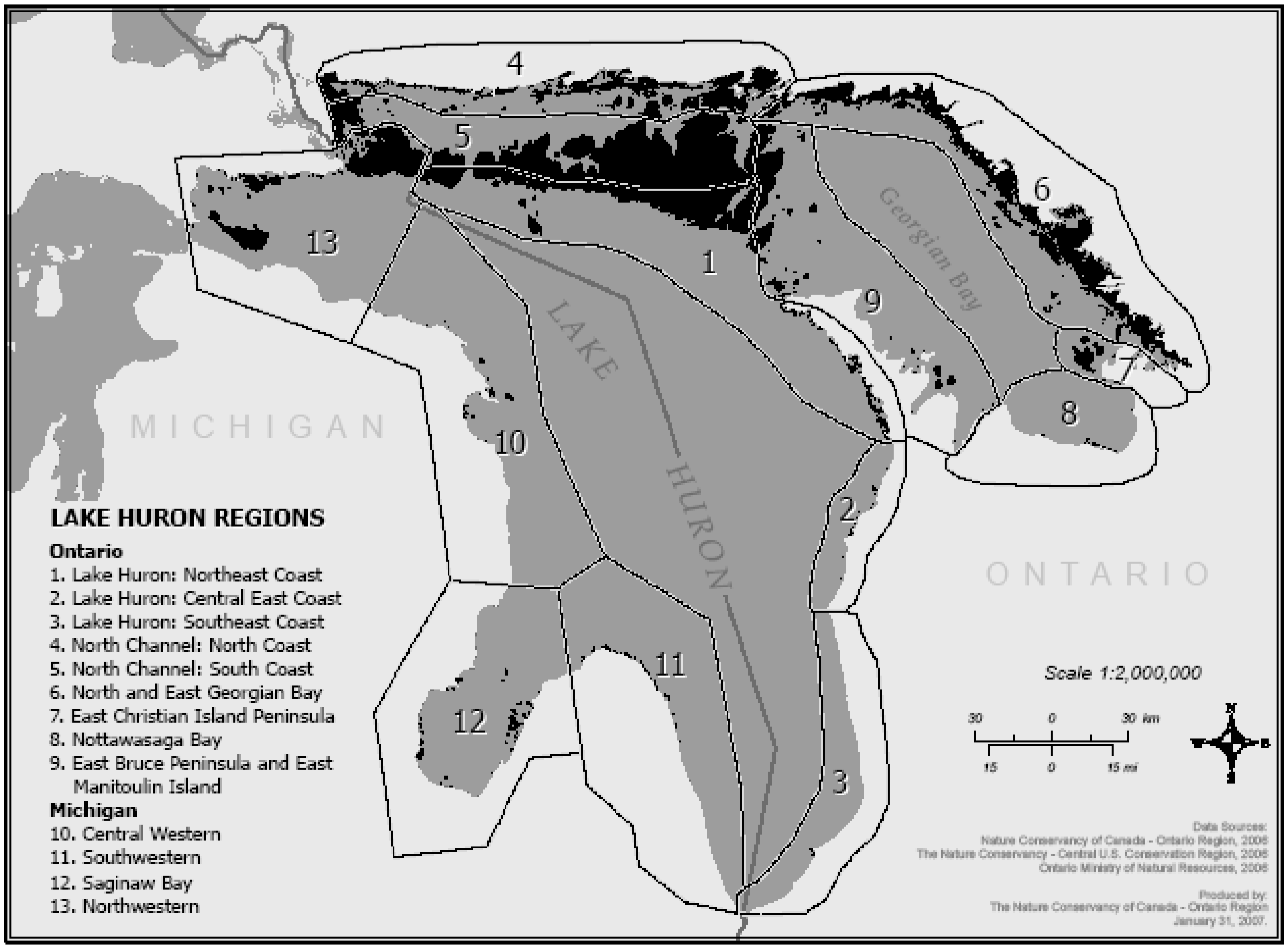

Table 1: Summary of Lake Huron Islands

Lake Huron Region	Number of Island Polygons	Total Area of Islands (ha)	Island Coastline (km)
Ontario			
1. Lake Huron: Northeast Coast	887	97,209.8	585.6
2 & 3. Lake Huron: Central East & Southeast Coast	39	25.5	8.3
4. North Channel: North Coast[1]	3,992	33,258.04	1,347.9
5. North Channel: South Coast	225	206,965.16	599.3
6. North & East Georgian Bay[2]	17,615	37,944.79	4,050.9
7 & 8. East Christian Island Peninsula and Nottawasaga Bay	74	5,400.62	69.5
9. East Bruce Peninsula and East Manitoulin Island	290	30,161.17	283.1
Ontario Summary	**23,122**	**410,965.08**	**6,944.6**
Michigan			
10. Central Western	81	347.56	39.63
11. Southwestern	140	31.17	34.00
12. Saginaw Bay	135	795.02	112.72
13. Northwestern	243	43,488.62	533.84
Michigan Summary	**599**	**44,662.37**	**720.19**
Lake Huron Summary	**23,721**	**455,627.45**	**7,664.79**

Notes:
(1): Some larger islands in Ontario are divided by coastal environments (e.g. Manitoulin Island) and are included in more than one region.
(2): Many of the island polygons mapped in the Georgian Bay region may appear as several smaller islands if observed in the field. The configuration and numbers of these islands varies greatly based on water levels.

Table 2. Priority Islands for Biodiversity Conservation in Lake Huron (Ontario)

Northeast Coast	
Island Name	***Key Biodiversity Values***
Cockburn Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Great Duck Island	High biological diversity. Distinctive compared to other islands in the region.
Western Duck Island	Isolated compared to other islands in the region.
Central East & Southeast Coast	
Island Name	***Key Biodiversity Values***
Chantry Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Baie du Dore Island Complex	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Kettle Point Island Complex	Large number of ecological systems and high biological diversity. Important site for colonial nesting waterbirds.
North Channel North Coast	
Island Name	***Key Biodiversity Values***
Great La Cloche Island	Large number of ecological systems and high biological and physical diversity. Distinctive compared to other islands in the region.
Clapperton Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
St. Joseph Island	Large number of ecological systems.
North Channel South Coast	
Island Name	***Key Biodiversity Values***
Barrie Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Strawberry Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Browning Island Complex	High physical diversity. Distinctive compared to other islands in the region.
North & East Georgian Bay	
Island Name	***Key Biodiversity Values***
Parry Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Philip Edward Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Beausoleil Island	High biological diversity. Distinctive compared to other islands in the region.
East Christian Island Peninsula and Nottawasaga Bay	
Island Name	***Key Biodiversity Values***
Christian Island	Large number of ecological systems and high biological and physical diversity. Distinctive and isolated compared to other islands in the region.
Hen and Chicken Island	Large number of ecological systems and high biological and physical diversity. Important site for colonial nesting waterbirds. Distinctive and isolated compared to other islands in the region.
Beckwith Island	Large number of ecological systems and high biological diversity. Distinctive and isolated compared to other islands in the region.
East Bruce Peninsula and East Manitoulin Island	
Island Name	***Key Biodiversity Values***
Manitoulin Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Fitzwilliam Island	Large number of ecological systems and high biological diversity. Distinctive compared to other islands in the region.
Cove Island	Large number of ecological systems and high biological diversity

Ontario priorities based on the top 5 highest scoring islands/ island complexes from each coastal environment.

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