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Lake Superior's Coastal Ecosystems: How "Pristine" Are They?

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Shorelines are complex and variable habitats that attract both humans and a diverse community of plants and animals. Use of our shorelines and coastal waters for residences, commercial development and recreation has increased substantially as towns and cities have cleaned up areas abandoned by heavy industries. While industrial discharges have been eliminated or reduced, diffused pollution from roads, storm sewers, and failed septic systems have increased.

Interested in predicting the health of this ecosystem, the U.S. Environmental Protection Agency put out a "call for proposals" in 1999 to develop indicators of condition for the United State's coastal waters, including the Great Lakes. The University of Minnesota Duluth's Natural Resources Research Institute was awarded one of five $6 million grants in a highly competitive application led by Dr. Gerald Niemi and 27 investigators from across the Great Lakes Basin. The project's goal was "to develop efficient, economic, and effective indicators to monitor the condition, integrity, and long-term sustainability of the basin," with a focus on the coast and the nearshore aquatic habitat out to around 32 feet in depth.

Much like the Consumer Confidence Index is used to forecast the strength of the economy and body temperature is used as an indicator of our own health, we developed indicators of the status of the ecosystem by examining relationships among the plants, animals, water quality, habitat quantity and quality, and human activities (such as farming, urban development, industrial discharges) that can negatively affect these ecosystems.

Teams of investigators involved in the project visited more than 300 sites across the U.S. side of the Great Lakes Basin; over 150 were visited by the "fish and invertebrate" team, with 38 sites in Lake Superior (Figure 1). While sampling was finished in 2003, analysis and writing continues. A special issue of the Journal of Great Lakes Research will be released next year covering results from the entire project. This article will summarize some of the findings for Lake Superior from the fish and invertebrate team.

What was sampled?

Anyone boating on the Great Lakes can see the enormous diversity of shoreline habitats, although that diversity is difficult to see from land. Most fish spend at least some part of their life occupying the shallower waters along the coast because of that diversity, and because it's more productive than the deeper waters of Lake Superior. We sampled five different types of coastal ecosystem types. Fish were sampled using a fyke net array consisting of two small and two large mesh nets set in about two to three feet of water. A total of 100 species were identified and released across the entire basin, 57 of which were captured from Lake Superior. Altogether, more than 100,000 fish were handled for the study. Across each site detailed habitat infor mation was collected describing depth, vegetation type and density, substrate composition, and water quality characteristics. Other observations included the types of pollution or disturbances observed at, or adjacent to the site.

What we measured: Birds and frogs, wetland vegetation, fish and invertebrates, microscopic algae known as diatoms, and physical characteristics of the sites were sampled over two years from 2002-2003. Indicators for two unique types of contaminants—endocrine disrupting chemicals, and UV-activated polycyclic aromatic hydrocarbons (PAH's)—also were investigated at a limited number of locations across the Basin. Sampling took place on only the U.S. side of the Basin, due to the funding source, which was the U.S. Environmental Protection Agency.

An extensive database detailing the land use, soils, roads, population density, and other "stressors" was compiled for the entire U.S. side of the Great Lakes Basin. These data are combined into a "stressor gradient". That gradient was used to select sampling locations that represented the full range of environmental conditions across the basin, from the best to the worst.

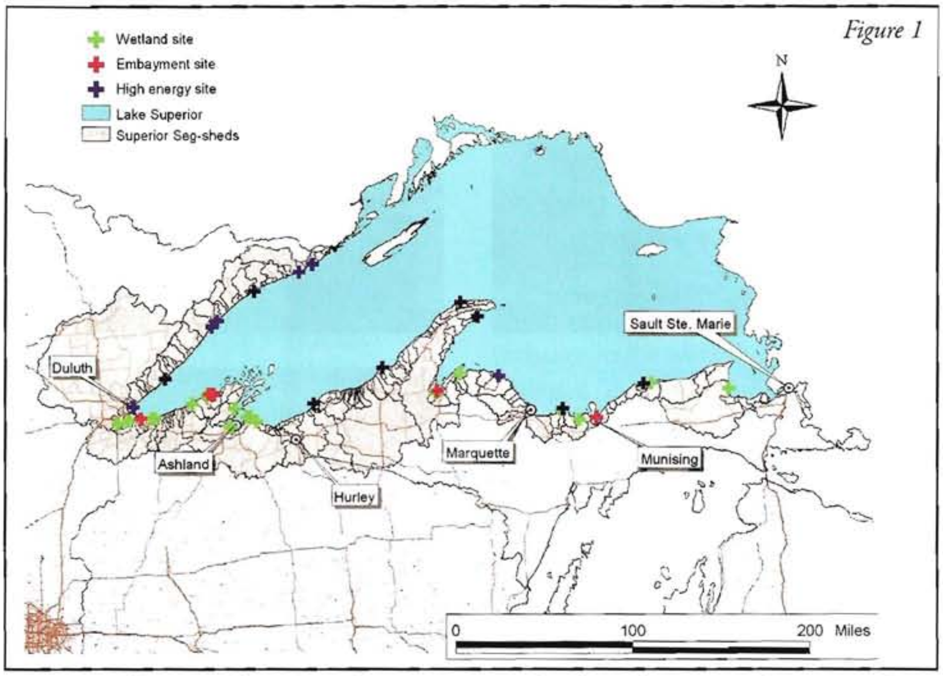

Figure 1

Watersheds and Habitats

We started on land, examining differences in land use, vegetation and human activity to determine potential pollutants and disturbances that could affect the shoreline. We found that Lake Superior watersheds of high energy sites are smaller and contain more upland forest, but are similar to wetland watersheds in terms of road and population density, and number of pollution discharge permits. The wetland watersheds contain higher proportions of forested wetlands and marshland.

Exposure to wave action determines the shoreline structure and vegetation. The types of human activities that are found on the shore also vary with topography and exposure. There is a higher density of residential development as well as upland forest on the shorelines at high energy sites and bays compared to the wetlands in the areas we sampled. The coastal wetlands on Lake Superior are not as developed since they tend to have more marshy shorelines with shrubby or forested vegetation, deeper and finer sediments with more organic matter.

Riverine wetland plants and animals are exposed to flowing water, whose quality is determined by conditions in the watershed. Depending on the structure of the river mouth, those wetlands can also be influenced by seiche or wind tides, which increase mixing of lake and river water. The aquatic vegetation in those and the protected wetlands is very diverse. Cattails, reeds, sedges, water lilies and other emergent or floating vegetation are common in the shallower waters, while many species of pondweed, water cabbage, and coontail inhabit the deeper waters. Open coastal wetlands, the least common wetland type in the Lake Superior coastal region, support erect sedges and ribbon-like floating vegetation.

The rocky, high energy shorelines and bay sites, in contrast, have sand to boulder bottoms with little organic matter. Unlike the lower lakes, only two of our sampled sites had artificially armored shorelines (riprap). Aquatic vegetation is rare, unless protected from intense wave activity, such as in the calmer waters of bays and behind islands, where vegetation is a reed or a plant whose narrow leaves float to the surface. Because the water does not stagnate, temperatures and water chemistry closely mirror those of the lake. Bays and open coastal wetlands share many habitat characteristics.

The Fish Community

Ten fish species were found exclusively in high energy sites, ten were exclusive to riverine wetlands, and one each were found exclusively in protected and open coastal wetlands. Riverine wetlands had the largest number of species, while bays had the largest number of non-native (exotic) species. In Table 1 we summarize characteristics of the fish community across ecosystem types. All species commonly found in the protected wetlands were also common in the riverine wetlands; similarly, most of the species encountered in the open coastal wetlands were also found in the bays. Fish community characteristics varied across the five ecosystem types we studied (Table 2). In general, wetlands contained more species tolerant of turbidity and warmer temperatures, exhibited nest-guarding behavior, were top carnivores or vegetarian, and had a majority of species that grow to large body sizes (>24 inches). Nest guarding fish (e.g., bluegills, crappie; black bullhead) were frequently most abundant in open coastal wetlands and protected wetlands, although they also occurred in riverine wetlands. The high energy shoreline habitats, in contrast, supported species that tended to have smaller body sizes and were bottom-feeders.

The "indicator concept"

Anglers know through experience that each fish species has an optimal temperature range, and characteristic habitat

Examples of the shoreline ecosystem types sampled: Clockwise from upper left: Open coastal wetland located within a bay, in northern Lake Michigan- note low water conditions; Lake Superior high energy shoreline, near Hovland, MN; Au Train River, MI; Protected wetland, Lake Superior Basin, location unknown.

preference, reproductive behavior, and body size. We use those "traits," along with information about the community as a whole (such as the total number of species encountered, and the number of individuals of native versus non-native species) to assess environmental conditions. We compare the communities and environmental variables at sites that we know are minimally disturbed ("reference sites") to other sites. The extent of disturbance can be deduced by how different they are from the reference sites.

"Minimally disturbed" is a relative term. Since conditions in the upper Great Lakes differ fundamentally in terms of depth (and temperature), nutrient status, and the geology of the surrounding basin, it is useful to define reference conditions separately for the upper versus the lower Great Lakes. If reference sites were compared across the entire basin, few sites would be considered "reference" in the south versus the north, simply due to the higher level of disturbance across those basins, and the inherently warmer and more productive conditions in the lakes themselves. Indicators of disturbance are ultimately identified by statistically relating those things we measure in the field to the disturbances that we measure at both the site and within the watershed. Those indicators can then be used to help managers determine the status of the coastal environment and the causes of any impairment.

From our analysis of the amount of disturbance in the watersheds, only one potential "degraded" site (a high energy site off of the City of Duluth) was among the 38 sampled sites on Lake Superior. The habitat and biota also showed signs of degradation. Table 3 contrasts that site with a reference site, which is vastly different in its watershed development patterns and adjacent land use. Indicators of degradation include the habitat structure (extensive riprap, evidence of trash and pollution), and the structure of the fish community. In the degraded site one of the two most abundant species is the non-native

Table 1. Fish community structure in the shoreline ecosystems of Lake Superior. Species common to the two broad shoreline types--the high energy shorelines and bays versus the wetlands are listed, along with the fish that were found exclusively in those ecosystems, species found in "reference" ("least disturbed") sites, and those found exclusively in the "non-reference" sites. Non-reference sites are the sites that are not included in either the "reference" or "degraded" sites. Reference sites were identified as those sites with the lowest amount of human disturbance; in our case defined as the best 20% of all sites in the northern Great Lakes. Degraded sites were the worst 20%.

Community Characteristics	**Coastal Ecosystem Type**	
	High Energy & Bays	**Wetlands**
Common species (* = exclusive to ecosystem types in each column)	Burbot, eastern longnose sucker*, eastern slimy sculpin, lake chub, burbot*, rainbow trout, troutperch, white sucker	Golden shiner*, blackchin shiner, blacknose shiner, bluntnose minnow*, bluegill sunfish*, Johnny darter, yellow, brown, and black bullhead, northern pike*, pumpkinseed sunfish*, white sucker, yellow perch
Found in a single habitat type	High Energy: alewife, brook trout, eastern longnose sucker, green sunfish, northern hogsucker, northern pugnose shiner, northern redbelly dace, rainbow trout Bays: none	Riverine wetland: brassy minnow, central mudminnow, freshwater chum, largemouth bass, least darter, pugnose minnow, river darter, silver redhorse, stonecat, warmouth Protected wetland: black crappie Open coastal: yellow bullhead
Reference Sites Only	Northern redbelly dace, brassy minnow, brook trout	Northern brook silverside
Non-Reference Sites Only	alewife, blacknose dace, chinook salmon, coho salmon, fathead minnow, green sunfish, three spine stickleback, white bass	black crappie, blacknose dace, European carp, golden shiner, largemouth bass, silver redhorse, stonecat, tadpole madtom, three spine stickleback, walleye, yellow bullhead

Table 2. Comparison between a "degraded" and "reference" high energy site. The community traits reflect the relative abundance of fish with those characteristics.

	Downtown Duluth waterfront	Gogebic County, Michigan
Environmental Features		
Watershed Composition	47% Urban; 16% forest; road density = 0.0004 mi/mi²; population density = 443 / mi²	<1% Urban; 97% forest/ wetland/ grassland; road density = 0.0004 mi/mi²; population density = 0 / mi².
Shoreline Composition and Condition	70% riprap on shore; 100% commercial and residential; recreational boating, trash present	100% rocky shore; 100% forest; 1 structure.
Water Column Characteristics	Transparent to 16.5'; dissolved oxygen levels saturated	Transparent to 33'; dissolved oxygen levels saturated
Habitat Structure	Open water 100%; sediment organic content: very low; substrate comp: sand to boulder	Open water 100%, sediment organic content: very low; substrate comp: sand to boulder
Community composition		
Total # species (# non-native species*)	12 (1)	13 (1)
Dominant species	Northern rockbass, Eurasian ruffe*.	Lake chub, longnose dace, spottail shiner, eastern longnose sucker
Subdominant species	Bluegill sunfish, eastern longnose sucker	Blacknose shiner, rainbow trout, white sucker
Community Traits		
% Omnivorous	90%	79%
% Intolerant	7%	22%
% Non-native	26%	< 1%
% Nestguarding	52%	1%

Eurasian ruffe. In addition, species such as green sunfish and spottail shiner with high tolerances for degraded water quality are present. Furthermore, the community is almost entirely composed of fish species that are omnivorous ("omni" = everything, that is, they do not require specialized food resources). In contrast, a "healthy" ecosystem generally has species that occupy a range of different "niches" and have slightly different food and habitat preferences. When the entire community is composed of omnivorous species, it generally indicates that habitat diversity is low. As an example of this, the healthy sites across the basin contained a greater proportion of bottom-feeders (white and longnose sucker, burbot) compared to the degraded site, although omnivores were abundant in both types of sites across the basin.

Wetlands seem to fare better. None were identified as potentially degraded based on the watershed data; however, among the non-reference sites identified, several wetlands showed signs of moderate disturbance. The Pokegama River wetland contained a high proportion of invasive vegetation—the water was turbid and showed signs of oxygen stress; a quarter of its fish species and 5% of all the fish were non-natives. Fish abundance was relatively low and was dominated by black crappie, with subdominants being black bullhead, pumpkinseed and bluegill sunfish. Turbidity-tolerant species made up 13% of the total abundance. In contrast, the Middle River wetland, also in Wisconsin, had similar amounts of urban land use and forest in the watershed, yet had few invasive plants, high fish species diversity (17 species), and high fish abundance. Its fish community was dominated by northern mimic shiner, blacknose shiner, black bullhead and tadpole madtom. Subdominants included emerald shiner, troutperch, white sucker and Eurasian ruffe. Overall, wetlands and bays with deep, organic sediments have fewer species per site, and fewer native species.

Table 3. Dominant fish groups sampled from each habitat type visited on Lake Superior. Included are references to thermal preference, parental care and spawning habitat.

Habitat Type	Dominant Groups (total # species)	Thermal Preference	Parental Care	Spawning Habitat
High Energy shoreline	Minnows, Suckers, Trout Perch (31)	Cool / Cool Warm	Non-guarders (no care)	Stony substrate and broadcast
Bays	Minnows, Suckers, Sticklebacks, Trout Perch, Sunfishes (32)	Cool/Warm	Mostly non-guarders	Stony substrate, Broadcast and nests
Coastal Wetlands	Sunfishes, Perches, Catfishes (13)	Cool/Warm	Guarders	Nests and vegetation
Riverine Wetlands	Catfishes, Perches, Sunfishes, Minnows (48)	Cool/Warm	Mostly guarders	Nests, vegetation and stony substrate
Protected Wetlands	Catfishes, Sunfishes, Suckers, Perches (29)	Cool/Warm	Mostly guarders	Nest, stony substrate and vegetation

Demonstrating the use of a "transparency tube" for measuring water clarity.

Higher proportions of non-native species were found where water was more turbid.

In general, human activity and disturbance at a site correlates with the amount of suspended solids in the water. When suspended solids were high, water column transparency is low and emergent vegetation such as cattails and bur-reed dominate. These habitat types support more non-native fish species such as Eurasian ruffe, and European carp, and species tolerant of turbidity such as northern pike, northern mimic shiner, fathead minnow, and central mud minnow among others.

How "pristine" is Lake Superior?

Our watershed data tells us that the U.S. side of the Lake Superior Basin has less human disturbance than the other Great Lakes. How else does Lake Superior fare in terms of their coastal ecosystems? Altogether, Lake Superior had more "intolerant" species and more individuals of species that are considered intolerant than any of the other lakes combined. In particular, there are a larger number of species considered intolerant of high turbidity. The specific contrasts for the different lakes and ecosystems types are summarized in Table 4. As evidenced by the few "degraded" sites found in the basin, Lake Superior is still the healthiest of the Great Lakes. There is, however, evidence of severe degradation at specific locations, and when implemented in a monitoring program, the indicators we have identified may help to determine where and why sites are degraded so that appropriate actions can be taken to eliminate or minimize the stress and restore the site.

What's Next

Indicators are only one of the products of the Great Lakes Environmental Indicators project. Other products include 1) methods for quantifying "human disturbance" for watersheds, 2) determining "least impacted" and "most degraded" sites, 3) calibrating a fish Index of Biotic Integrity (IBI) to determine the underlying cause of degradation, 4) an index of condition that uses a measure of dominance of

Table 4. Comparison of indicator across the Great Lakes and coastal ecosystems. The community traits reflect the relative abundance of fish with particular characteristics. Abbreviations: < = less than; > = greater than; RW = riverine wetland, HE = high energy shore, CW = open coastal wetland, PW = protected wetland, B = bay.

	Compared to all Great Lakes combined	Compared to other Great Lakes taken individually	Compared to similar ecosystem types in all Great Lakes combined	Compared to similar ecosystem types in other Great Lakes
Community Composition				
# Intolerant Species	Superior >	Superior >>Michigan , Erie, Ontario	RW: Superior > PW: Superior > HE: Superior >	RW: Superior >> Michigan, Erie, Ontario
# Non-native Species		Superior < Erie		
Community Traits				
% Intolerant Individuals	Superior >	Superior > Erie	RW: Superior >	RW: Superior > Michigan
% Tolerant Individuals				HE: Superior < Huron
% Turbidity Intolerant	Superior >	Superior > Erie	RW: Superior >	
% Non-native		Superior < Erie		RW: Superior < Erie
% Nestguarding		Superior < Ontario	CW: Superior > B: Superior <	

invasive plants, 5) an index that uses the human disturbance gradient, rather than a "reference condition" approach, and many individual measurements based on diatoms, plants, invertebrate, and water quality measures. A big challenge will be to integrate the indicators developed by the different groups into a single set of measurements that can provide information about the health of all parts of the coastal ecosystem—from the deeper waters to the upland.

Many of our methods and indicators are currently being evaluated by several of the Lake-wide Area Management Plan organizations in the Great Lakes (especially Lake Erie and Lake Superior) for inclusion in their monitoring plans. Efforts are also underway to incorporate indicators that have been developed by other investigators. A meeting will take place in Duluth in January to work out a strategy for choosing the "best" indicators for Great Lakes wetlands. For more information on the Great Lakes Environmental Indicators project, see http://glei.nrri.umn.edu.

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