National Park Service
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Structure and Function of Coastal Shoreline Fish Assemblages of Lake Michigan at the Indiana Dunes National Lakeshore

GLRI #94 Task Agreement #J 6300100405 Final Report

ON THE COVER

From upper left to bottom right: Beach seining at West Beach; Banded killifish, *Fundulus diaphanus* (used with permission NYDEC); Indiana Dunes National Lakeshore, Lake Michigan from Mt. Baldy; Backwater lagoon forming off of Mt Baldy coastal shoreline; Spottail shiner, *Notropis hudsonius* (used with permission Joseph Tomelleri); and Central Beach showing beach width and natural shoreline Photographs by: Thomas P. Simon

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GLRI #94 Task Agreement #J 6300100405

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Abstract

The southern Lake Michigan coastal shoreline represents critical habitat for many Great Lake fishes and is particularly important to conserving and restoring native species diversity. We describe the spatial variation in the composition and abundance of fishes along coastal shoreline reaches in southern Lake Michigan, and relate these to variation in littoral drift type. Fish collections were made using a 6x50 ft. bag seine with 1/8 inch mesh. Historically, 71 fish species have been documented from the study area, species documented from historical collections prior to 1950 include 26 species, 59 species collected from 1995-2005, and an additional 12 species collected during 2010-2011. During the 2010-2011 sampling 22,924 individuals from 31 species were collected. Three native species dominated—Yellow perch, Spottail shiner, and Brook silverside—with another 4 species occurring commonly represented by Alewife, Sand shiner, Mimic shiner, and Round goby. Prior to 1950, native species comprised 96.2% of the species composition, while during the recent past (1995-2005) native species comprised declined to 74.6%, and currently (2010-2011) native species richness comprises only 63.6%. In the current collections 22 native species comprised 92.3% of the total individuals collected, 5 non-indigenous species comprised 7.32%, and 4 exotic species comprised 0.39%. Significant differences in fish community structure between erosion and stable littoral drift and accretion littoral drift was observed in only the number of salmon species (Friedman ANOVA 7,1 =2.667, p = 0.102). The percentage of omnivores ($z_{17, 7}$=-2.221, *P=0.14)*, herbivores ($z_{17, 7}$= -2.20292, *P=0.14)*, detritivores ($z_{17, 7}$= *1.644, P=<0.0001*), insectivores ($z_{17. 7}$ = 1.644, *P* = 0.023), and carnivores ($z_{17, 7}$=*1.645. P=0.023*) was significantly greater in the accretion littoral drift reaches compared to erosion and stable reaches. No difference was observed between the number of obligate Lake habitat species or the percent individuals as Great Lake obligates. No statistical difference was seen in exotic species use of accretion or erosion littoral drift types. No significant difference in the catch-per-unit-effort was observed between accretion and erosion reaches.

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Introduction

Existing data indicate that the number of native species in the Lake Michigan watershed, including coastal Lake Michigan, has declined by 22% since the onset of European settlement (Simon and Stewart 1999). Few remnants of natural fish communities exist and it is difficult to reconstruct the native assemblage of Lake Michigan. The coastal shoreline habitats of southern Lake Michigan are poorly known; however, native biodiversity areas that resemble historical conditions of southern Lake Michigan occur principally in the palustrine and riverine wetlands. The highest biological species richness occurs in the ponds of Miller Woods, the Grand Calumet Lagoons, and the Little Calumet River (Spacie 1988; Simon 1998; Simon and Stewart 1998; Simon et al. 2000). These communities have maintained a relatively diverse assemblage of fishes despite large-scale anthropogenic disturbances in the area, including channelization, massive river redirection, fragmentation, habitat alteration, exotic species invasions, and the introduction of toxic chemicals (Simon et al. 1989; Simon and Moy 2000). Degradation of habitats has caused an increase in numbers and populations of species able to tolerate and flourish when confronted with hydrologic alteration. Simon and Stewart (1998) found that fish communities on public lands in northwest Indiana generally are of lower biological integrity, in terms of structure and function, than those on private lands and are not acting as refugia for native fish populations.

One intention of the US Water Pollution Control Act of 1972 was to restore the biological integrity of the nation's waters (Hocutt 1981). Similarly, one of the main tenets of the National Park Service Organic Act of 1916 was "to conserve … the wildlife therein … for the enjoyment of future generations." Knowledge of biological diversity in most areas is poor (Allen and Flecker 1993), and our national parks are not an exception (Stohlgren et al. 1995). Karr and Dudley (1981) defined biological integrity as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region." In order to quantify the decline of biological integrity (Hocutt 1981, Karr and Dudley 1981) in a system, reference conditions and multimetric indices must be designed and calibrated for assessment (Davis and Simon 1995).

The Lake Michigan basin should be classified as coldwater or coolwater. Typically, this thermal type comprises fewer individuals and has lower biomass than similar sized warmwater systems of the Central Corn Belt Plain (Mundahl and Simon 1998). Simon (1991) developed expectations for fish community structure and function in the streams and rivers of the Lake Michigan basin of the Central Corn Belt Plain. Simon (1998) also evaluated palustrine wetlands of that region; however, few studies have examined the nearshore of Lake Michigan, precluding the development of an indicator of integrity for this area (Meek and Hildebrand 1910; T. Simon, unpubl. data). The health of a stream ecosystem depends on the surrounding watershed (Maughan and Nelson 1980, Menzel et al. 1984, Bain et al. 1988). Land-use practices in the watershed can negatively impact the water body and its resident fish populations. Wetlands in northwest Indiana have been extensively drained, rivers channelized and reversed, river mouths filled, and rivers contaminated (Moore 1959; EPA 1985; Simon 1989; Simon and Moy, 2000). The rivers of the Lake Michigan region have experienced some of the most destructive alterations known.

Extensive restoration work in northwest Indiana has identified and restored plant communities (Choi and Pavlovic 1994, 1995), examined fire effects on Karner blue butterflies *(Lycaeides melissasamuelis* Nabokov; Kwilosz and Knutson 1999, Knutson et al. 1999), and gathered information necessary for restoring wetlands (Stewart et al. 1997). Except for stocking of game fish (including nonindigenous species) for recreational fisheries, none of this restoration activity includes native fish communities. It is necessary to measure the departure of native fish community structure and function from historical conditions if the natural biological dynamics of these communities is to be restored (Williams et al. 1989).

Restoration and maintenance of native fish communities along the coastal shoreline of Lake Michigan must overcome significant obstacles (e.g., disruption of littoral drift causing sand starvation impacts and presence of nonindigenous species). To determine the effectiveness of national parks as refugia, it is essential to examine the fish fauna from several perspectives. (1) Is the fish community at Indiana Dunes representative of native fish populations prior to extensive industrial development? (2) Do the Indiana Dunes National Lakeshore fish communities serve as a "least impacted" area or reference condition for the Lake Michigan drainage? (3) How have exotic or nonindigenous species influenced native fish populations along the coastal shoreline? (5) What additional information needs to be gathered prior to initiating a native fish population restoration and creation of an assessment indicator for coastal Lake Michigan?

Methods

Study Area

The southern Lake Michigan drainage (Figure 1) in the Calumet Region of northwest Indiana has a complex geological history (Chrzastowski and Thompson 1992). This includes a series of declines in Lake Michigan water levels that contributed to the build-up of dune and swale topography. This landscape includes rows of ponds that parallel the Lake Michigan shore. The drainage also contains several large wetlands and water bodies between the rows of dunes (e.g., the ponds of Miller Woods and West Beach, the Great Marsh, and Long Lake). This area also includes riverine systems such as the Grand Calumet and Little Calumet Rivers and tributaries, Trail Creek, and the Galien River. These aquatic features provide important habitat for both resident and transient species that occupy the shoreline of Lake Michigan.

The Indiana Dunes National Lakeshore (lakeshore) was established in 1966 to offer recreational opportunities for the public and to serve as an area for protection of native biota. The coastal shoreline of Lake Michigan represents 43 miles along Indiana's portion with the lakeshore comprising 15 miles, or nearly a third of the total natural shoreline. The coastal zone is represented by shallow depths typically averaging 6 m (Simon et al. in press) and includes fine sorted substrates (Simon and Morris 2012). Three littoral drift types provide sand nourishment that maintains beach and shoreline morphology. Accretion, erosion, and dynamically stable littoral drift are characterized by areas of deposition, loss, and balanced sand, respectively.

The coastal shoreline includes habitat heterogeneity characterized by a variety of substrates from fine silt, sand, and larger flat coarse materials (Simon and Morris 2012). Available habitat structure is a result of wind and wave driven processes. The filling of Lake Michigan shoreline,

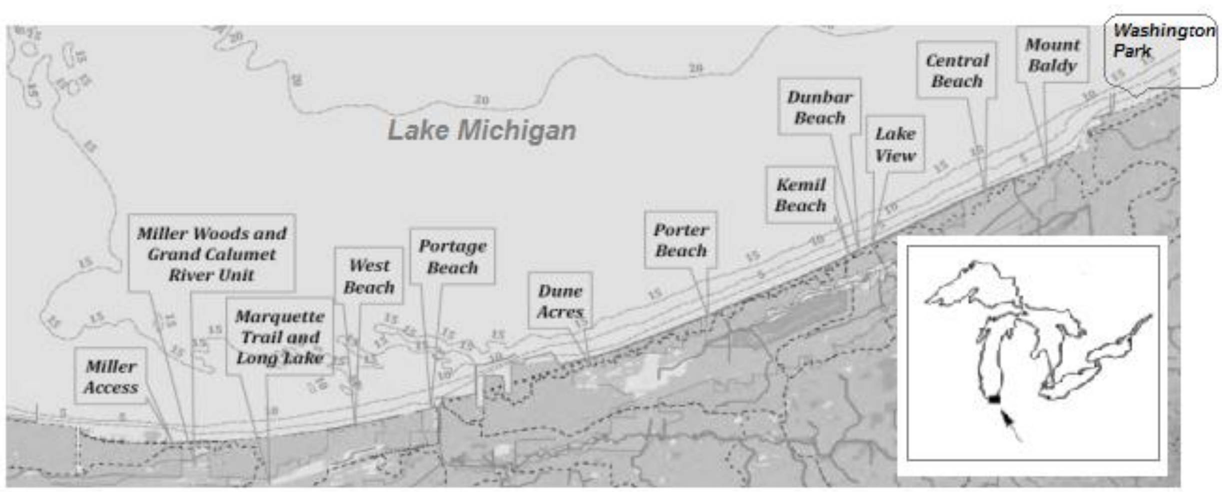

Figure 1. Location of the Indiana Dunes National Lakeshore showing important watersheds associated with the coastal shoreline of Lake Michigan (Simon et al. 2012).

wetland draining, construction of piers, harbors, and armoring of the shoreline destroyed habitat stability by reducing and constricting the amount of sand movement. These changes to the natural shoreline caused major impairments to the structure and function northwest Indiana's aquatic habitats. In addition, channelization, water quality degradation, addition of toxins and agrochemicals, agricultural sedimentation, drainage, deforestation, and the addition of nonindigenous species has further impaired the Lake Michigan fish community (U.S. Environmental Protection Agency 1985, Simon et al. 1989, Sly 1991, Hartig and Zarull 1992, Jude et al. 1995).

Sample Collection

Fish community structure and function in Lake Michigan coastal shorelines were determined from daytime inventories conducted between June and October from 1985 to 1996 (recent past) and from 2010 to 2011 (recent). Complete community sampling was required to characterize sites and determine long-term patterns in fish community dynamics. For each site, representative samples were collected to document species diversity and relative abundance (Hocutt et al. 1974). All habitats within a sample area were surveyed relative to their frequency (Ohio EPA 1989). Longitudinal sampling distances parallel to shore included a minimum sampling distance of 300 m and a maximum of 500 m (recent past sampling). Data collected prior to 1950 were based on published information. Methods were based on seining techniques; however, the seine and mesh sizes were not specified (Meek and Hildebrand 1910; Shelford 1911).

Three techniques were used for Lake Michigan sampling. Recent past collections included beach seining, visual transect surveys by SCUBA, and boat-mounted electrofishing. Current Lake Michigan sampling included only beach seining, which was found to provide the best estimate of species composition in the coastal shoreline. Beach seining included a 15.24 m (50 foot) bag seine with 3.125-mm mesh. Seines were waded to depths of 1.6 m and then pulled into shore along 300 m of shoreline using 10 hauls. Sample distances were recorded along with the bench height of the swash zone. Visual transects by SCUBA estimates involved two divers swimming a perpendicular transect for 1000 m from shore, then proceeding every 50 m along a serpentine series of transects parallel to shore. All fish encountered were visually identified and counted. Electrofishing in Lake Michigan was done by fishing parallel to shore for minimum distances of 500 m for at least 2,300 seconds (Simon and Stewart 1999).

All habitats encountered were sampled including depressions, rip-rapped sea walls and breakwaters, and beaches. Surf and littoral zones of beaches were sampled by dragging the electrosphere in the water along the shoreline. Stunned fish were netted and placed into a live well for identification, enumeration, and batch weighing. Fish were inspected for gross external deformities, eroded fins, lesions, and tumors (DELT) and released. Smaller species such as minnows, darters, and sculpins were preserved in 10% formalin. Preserved specimens were identified in the laboratory using standard taxonomic references (Gerking 1955, Smith 1979, Becker 1983, Simon 2011); scientific and common names follow Simon et al. (1992) and Simon (2011).

Reference Conditions

Reference condition expectations for the Lake Michigan drainage of northwest Indiana has been developed for riverine systems (Simon 1991) and drowned river mouth coastal wetlands (Simon et al. 2006a, b); however, no indicator has been developed for the coastal shoreline. Pristine sites (i.e., those that could represent reference sites) do not exist in northwest Indiana. Therefore, a range of habitats were sampled in order to characterize the "least-impacted" conditions to estimate the best remaining areas (Simon 1991; Stoddard et al. 2006). Unfortunately, very few least-impacted areas remain and the system seems to be responding in a universal manner, thus no single area would be representative of past conditions. Subtle patterns of the reference condition can emerge from the cumulative data, which allows the reconstruction of fish community characteristics (Davis and Simon 1995). Littoral drift of sand materials may be the driving factor in determining stable fish assemblages in the Lake Michigan coastal littoral habitats. These reference conditions can be the basis for calibration of an indicator of Lake Michigan fish structure and function (after Karr et al. 1986).

Simon et al. (2006a,b) defined species that are considered tolerant and intolerant, assigned trophic and reproductive guild designations, and listed obligate lake and Great Lake species. Tolerant species are those that increase under degraded conditions (Simon 1991; Simon 1999; Simon et al. 2006a), while intolerant species are those that are sensitive to changes in water quality and habitat modification. The percentage of obligate Great Lake species functions as a measure of the permanence of large lake habitats and decrease in the proportion of hydrologic alteration (Simon and Stewart 2006, Simon et al. 2006a). Functional feeding guilds were defined by Goldstein and Simon (1999) and applied by Simon et al. (2006b). Reproductive guilds were alternative metrics proposed by the Ohio Environmental Protection Agency for streams and rivers (Ohio Environmental Protection Agency 1989) and further defined by Simon (1999). This characteristic of lentic fish communities replaces the percentage of hybrid species (Karr et al. 1986). Destruction of reproductive habitat causes the loss of species that need clean sand and gravel substrates. The loss of open lake wetland function for fish habitat and reproduction was directly measured by the percentage of simple lithophils and phytophilic species. Catch-per-unit-effort (CPUE) is commonly used as an estimate of abundance in an area. Although CPUE is a poor abundance Index when data are combined across species (Richards and Schnute 1986), we believed it was adequate for relative abundance comparisons between our sites. The percentage of deformities, eroded fins, lesions, and tumors (DELT) increases at the lowest extreme of biological integrity (Karr et al, 1986). The health of fish possessing DELT anomalies is poor and is associated with degraded water and habitat quality (Sanders et al. 1999).

Statistical Analysis

Statistical analyses were carried out on structural (e.g., total number of species; number of minnow species; number of darter species; number of sunfish species; number of obligate Great Lakes species; number of obligate lake species; number of salmon species; percentage of tolerant species; and number of intolerant species) and functional (e.g., percentage of omnivores, insectivores, and carnivores; percentage of pioneer species; percentage of simple lithophils; CPUE; and percentage of DELT) attributes of fish communities by standard methods (Zar 1984).

Differences between fish community characteristics were examined by performing a Friedmann nonparametric ANOVA for means for structural attributes and a Z-test for unequal observations for functional attributes comparing various littoral drift types. Results are reported at a significance level of $P < 0.05$.

Results and Discussion

Historical Fish Communities

Fish assemblage species composition includes 71 species that have been known to inhabit the coastal shoreline of southern Lake Michigan (Table 1). Species documented from historical collections prior to 1950 include 26 species (Meek and Hildebrand 1910), while recent past species richness increased known species to 59 as a result of the increase in non-indigenous and exotic species (Simon and Stewart 1999, Simon unpublished data). Current species richness includes 31 species (Table 1). Prior to 1950, native species comprised 96.2% of the species composition, while during the recent past (1995-2005) native species comprised declined to 74.6%, while current (2010-2011) native species richness comprises 63.6% (Table 1).

The presettlement fish community of the Indiana Dunes is difficult to reconstruct since only a few studies describing fish community composition were published prior to 1950 (Table 1). Coastal Lake Michigan fish communities were studied by Meek and Hildebrand (1910) and Simon and Stewart (1999). A large decline in native fish species has been observed in Lake Michigan with the increasing biodiversity resulting from increases in the number of exotic or nonindigenous species introductions and colonization (Morman 1979, Edsall et al. 1995, Simon and Stewart 1999). Better sampling methods and more intensive collection efforts have led to the collection of a greater number of species during recent past and current periods (Table 1).

The number of native species in the Lake Michigan watershed, including coastal waters of southern Lake Michigan, has declined since European settlement (Table 2). Taxa including the Blackfin cisco *(Coregonus nigripinnis)* and Shortnose cisco *(C. reighardi),* have been declared extinct (Miller et al. 1989, Sommers et al. 1981). The Longnose dace *(Rhinichthys cataractae;* Gilbert and Shute 1980), Trout perch *(Percopsis omiscomaycus;* Gilbert and Lee 1980), and Lake chub *(Couesius plumbeus;* Wells 1980) were also once more common along the coastal shoreline of Lake Michigan (Gilbert and Lee 1980, Gilbert and Shute 1980, Wells 1980). Lake-dwelling coregonid species have declined substantially, with only the Lake herring *(Coregonus artedii)* and bloater *(C. hoyi)* either increasing or maintaining their distributions (Smith and Todd 1992). Keystone predators, such as Lake trout *(Salvelinus namaycush),* Lake whitefish *(Corogonus clupeaformis)*, Muskellunge *(Esox masquinongy)*, and Northern pike *(E. lucius)*, have been either eliminated or drastically reduced in the coastal areas of southern Lake Michigan (Table 2). Bowfin *(Amia calva)* and Burbot *(Lota lota)* have been reduced or eliminated by the alteration and destruction of spawning and nursery areas primarily from the loss of open lake aquatic macrophytes or due to warming temperatures. Benthic species are particularly declining with the increase in Round goby. Species such as Mottled sculpin, Slimy sculpin, and Deepwater sculpin have been eliminated from the coastal zone and perhaps the nearshore.

Table 1. Species composition of southern Lake Michigan coastal fish assemblages based on historical (Meek and Hildebrand 1910), recent past (1995-2005), and current (2010-2011) studies in the vicinity of Indiana Dunes National Lakeshore. Common and scientific names follow Simon (2011). Status: N=native, NI=non-indigenous, E=Exotic. Ex=Extinct, X=present.

Family/Common Name	Scientific Name	Status	Meek & Hildebrand 1910	Simon 1995-2005	Current study 2010-211
PETROMYZONTIDAE					
Silver lamprey	*Ichthyomyzon unicuspis*	N	X		
Sea lamprey	*Petromyzon marinus*	NI		X	X
ACIPENSERIDAE					
Lake Sturgeon	*Acipenser fulvescens*	N	X	X	
LEPISOSTEIDAE					
Longnose gar	*Lepisosteus osseus*	N			X
AMIIDAE					
Bowfin	*Amia calva*	N	X		
CLUPEIDAE					
Alewife	*Alosa psuedoharengus*	NI		X	X
Skipjack herring	*Alosa chrysocloris*	NI		X	
Gizzard shad	*Dorosoma cepedianum*	NI		X	X
SALMONIDAE					
Coho salmon	*Oncorhynchus kisutch*	NI		X	
Rainbow trout	*Oncorhynchus mykiss*	NI		X	X
Chinook salmon	*Oncorhynchus tshawytscha*	NI		X	X
Brown trout	*Salmo trutta*	E		X	X
Lake trout	*Salvelinus namaycush*	N	X	X	
Lake cisco	*Coregonus artedii*	N	X	X	
Lake whitefish	*Coregonus clupeaformis*	N	X	X	
Kiyi	*Coregonus kiyi*	N	X		
Blackfin cisco	*Coregonus nigripinnis*	N	Ex		
Shortnose cisco	*Coregonus reighardi*	N	Ex		
CYPRINIDAE					
Carp	*Cyprinus carpio*	E	X	X	X
Goldfish	*Carassius auratus*	E		X	X
Common shiner	*Luxilus cornutus*	N		X	
Golden shiner	*Notemigonus crysoleucas*	N		X	X
Emerald shiner	*Notropis atherinoides*	N	X	X	X
Spottail shiner	*Notropis hudsonius*	N	X	X	X
Silver shiner	*Notropis photogenis*	N			X
Sand shiner	*Notropis stramineus*	N		X	X
Mimic shiner	*Notropis volucellus*	N		X	X
Bluntnose minnow	*Pimephales notatus*	N	X	X	X
Fathead minnow	*Pimephales promelas*	N		X	X
Longnose dace	*Rhinichthys cataractae*	N		X	X
CATOSTOMIDAE					
Longnose sucker	*Catostomus catostomus*	N	X	X	
White sucker	*Catostomus commersonii*	N	X	X	X
Spotted sucker	*Minytrema melanops*	N		X	
ICTALURIDAE					
Black bullhead	*Ameiurus melas*	N		X	X
Yellow bullhead	*Ameiurus natalis*	N		X	
Brown bullhead	*Ameiurus nebulosus*	N		X	
Channel catfish	*Ictalurus punctatus*	N		X	X

Tadpole madtom	*Noturus gyrinus*	N		X	
UMBRIDAE					
Central mudminnow	*Umbra limi*	N		X	
ESOCIDAE					
Grass pickerel	*Esox americanus vermiculatus*	N		X	
Northern pike	*Esox lucius*	N		X	
Muskellunge	*Esox masquinongy*	N	X		
ANGUILLIDAE					
American eel	*Anguilla rostrata*	N	X		
GADIDAE					
Burbot	*Lota lota*	N	X		
PERCOPSIDAE					
Trout perch	*Percopsis omiscomaycus*	N	X	X	
FUNDULIDAE					
Banded killifish	*Fundulus diaphanus*	N	X		X
GASTEROSTEIDAE					
Brook stickleback	*Culaea inconstans*	N		X	
Ninespine stickleback	*Pungitius pungitius*	NI		X	
Threespine stickleback	*Gasterosteus aculeatus*	NI		X	
ATHERINIDAE					
Brook silverside	*Labidesthes sicculus*	N			X
MORONIDAE					
White perch	*Morone americana*	NI		X	X
Striped bass hybrid	*Morone saxatilis x chrysops*	NI		X	
CENTRARCHIDAE					
Rock bass	*Ambloplites rupestris*	N		X	
Green sunfish	*Lepomis cyanellus*	N	X	X	
Orangespotted sunfish	*Lepomis humilis*	N		X	
Pumpkinseed	*Lepomis gibbosus*	N	X	X	
Warmouth	*Lepomis gulosus*	N		X	
Bluegill	*Lepomis macrochirus*	N		X	X
Smallmouth bass	*Micropterus dolomieu*	N		X	X
Largemouth bass	*Micropterus salmoides*	N		X	X
White crappie	*Pomoxis annularis*	N		X	
Black crappie	*Pomoxis nigromaculatus*	N	X	X	
PERCIDAE					
Yellow perch	*Perca flavescens*	N	X	X	X
Scaly darter	*Etheostoma eulepis*	N		X	X
Logperch	*Percina caprodes*	N		X	
Walleye	*Sander vitreus*	N		X	
COTTIDAE					
Mottled sculpin	*Cottus bairdii*	N	X	X	
Slimy sculpin	*Cottus cognatus*	N		X	
Deepwater sculpin	*Myoxocephalus thompsonii*	N		X	
GOBIIDAE					
Round goby	*Neogobius melanostomus*	E		X	X
SCIAENIDAE					
Freshwater drum	*Aplodinotus grunniens*	N	X	X	X
	Total number of species		26	59	31

Table 2. Distribution and status of native fish species among habitat types in southern Lake Michigan. RR=range reductions, EP=extirpated from study area, and Ex= extinction.

		Habitat Type	
Species	**Status**	**Coastal**	**Nearshore**
Lake sturgeon	RR	X	X
Bowfin	RR	X	
Lake whitefish	RR		X
Blackfin cisco	Ex		X
Kiyi	RR		X
Shortnose cisco	Ex		X
Lake trout	RR	X	X
Lake chub	EP	X	
Longnose dace	RR	X	
Longnose sucker	RR	X	
Northern pike	EP	X	
Muskellunge	EP	X	
Burbot	RR	X	X
Trout perch	RR	X	X
Iowa darter	EP	X	
Deepwater sculpin	RR		X
Mottled sculpin	EP	X	
Slimy sculpin	EP	X	

Associations between Grain Size and Coastal Shoreline Habitat

Simon and Morris (2012) recognized two clusters based on using the Ward's cluster method and Euclidean distance rotation (Figure 2) to associate coastal shorelines with sediment particle size. Littoral drift in the study area is generally in an east to west direction, with some changes occurring as a result of wind direction and currents. Thus, the Indiana Dunes are an important sand source for the natural coastal processes associated with southern Lake Michigan. The first cluster included Mt. Baldy (East and West), Central Beach, and Dunbar. These sites would have been identified as erosion-dynamically stable reaches (Simon and Morris 2012). A second cluster was comprised of Portage Lakefront, West Beach, Dune Acres, and Washington Park, with a secondary cluster comprising Lake Street and Beach House Blowout. This second cluster is considered accretion littoral drift reaches (Simon and Morris 2012). We used this cluster analysis as a surrogate for habitat and evaluated fish assemblage structure, function, relative abundance and individual health among these two coastal conditions.

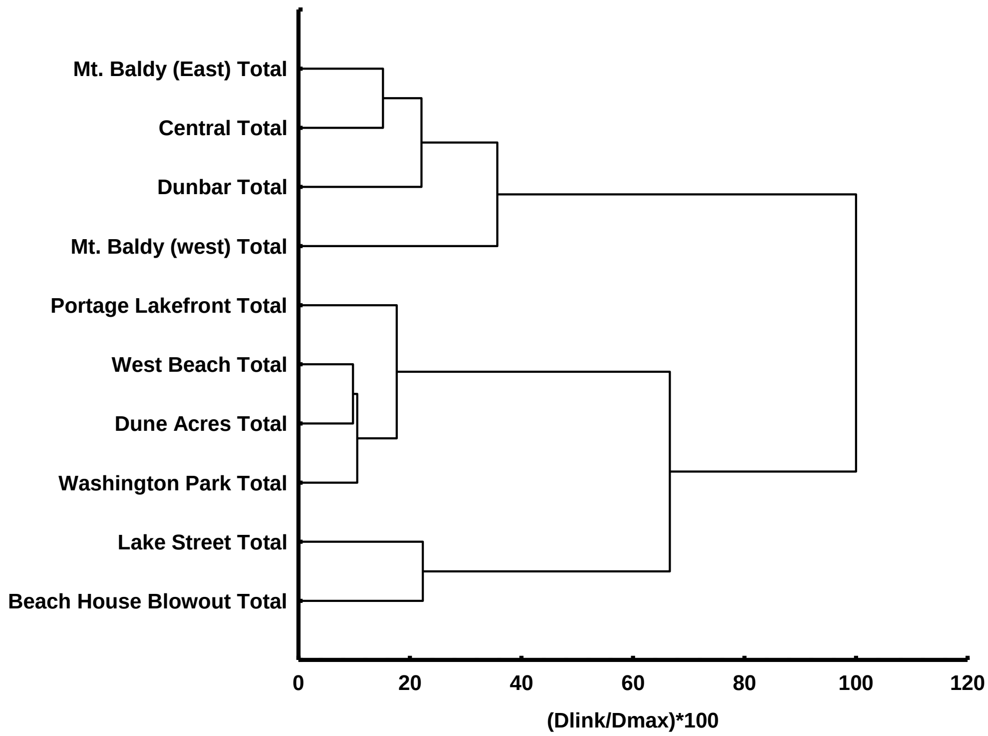

Figure 2. Dendogram illustrating the relationship among Lake Michigan coastal shoreline reaches and grain size attributes using an Euclidean distance similarity matrix.

Structural Characteristics of Fish Communities

Three native species dominated current species composition—Yellow perch, Spottail shiner, and Brook silverside—with another 4 species occurring commonly represented by Alewife, Sand shiner, Mimic shiner, and Round goby. Structural attributes of accretion and erosion littoral drift types did not show significant statistical difference between most of the natural conditions depicted in regional fish communities (Table 3). Only the number of salmon species was significantly different (Friedman ANOVA $_{7,\,1}$ =2.667, p = 0.102) between accretion and erosion littoral drift. Darters and sculpins are absent from erosion and stable substrates, while sunfish and salmon are absent from accretion habitats. The invasion of exotic and non-indigenous individuals has changed the pre-1995 fish assemblages.

Table 3. Structural attribute means and ranges for fish communities along Lake Michigan coastal shorelines based on two littoral drift types. P-value refers to Friedman ANOVA test comparison of multiple dependent samples.

Attribute	Accretion (N=7)	Erosion/Stable (N=19)	p-values
Total number spp.	6.71±1.62	6.35±1.56	0.560
Number DMS spp.	0.14±0.42	0.00±0.00	0.320
Number minnow spp.	3.57±1.26	2.76±1.15	0.102
Number intolerant spp.	1.14±0.42	1.00±0.00	0.317
Number sunfish spp.	0.00±0.00	0.06±0.31	0.157
Number salmon spp.	0.00±0.00	0.29±0.67	0.045
Percent tolerant spp.	1.71±1.15	0.59±0.81	0.102

p-value from t-test comparison of means

Functional Characteristics of Fish Communities

Functional characteristics of Lake Michigan fish communities are influenced by trophic guild, reproductive, habitat needs, and tolerance. In our data, the mean percentage of omnivores ($z_{17, 7}$*=-2.221, P=0.14)*, herbivores ($z_{17, 7}$*= -2.20292, P=0.14)*, detritivores ($z_{17, 7}$*= 1.644, P=<0.0001*), insectivores ($z_{17. 7}$ = 1.644, *P* = 0.023), and carnivores ($z_{17, 7}$*=1.645. P=0.023*) was significantly greater in the accretion littoral drift reaches compared to erosion and stable reaches (Table 4). Fish communities were not significantly different between littoral drift types for planktivore trophic guilds. Accretion beaches showed a wider amount of variation than erosion or stable beaches.

No difference was observed between habitat guilds including the number of obligate Lake habitat species or the percent individuals as Great Lake obligates (Table 4), while no statistical difference was seen in exotic species use of accretion or erosion littoral drift types.

Table 4. Functional characteristics, abundance, and individual health attributes of coastal Lake Michigan fish communities from Indiana Dunes National Lakeshore during 2010-2011. P-value is based on z-test two sample for means.

Attribute	**Accretion (N=7)**	**Erosion/Stable (N=19)**	**P-value**
% Omnivore	0.62±0.89	0.04±0.17	0.014
% Herbivore	0.34±0.56	0.00±0.00	0.014
% Detritivore	98.84±1.11	65.82±36.18	<0.0001
% Planktivore	20.42±36.52	15.09±34.55	0.361
% Invertivore	77.75±37.06	55.64±37.91	0.085
% Carnivores	0.12±0.23	0.05±0.10	0.022
# Lake Habitat spp	3.42±0.50	3.5±1.09	0.499
% Great Lake obligate spp	1.86±0.74	1.58±0.67	0.11
% Exotic spp	20.45±37.54	11.43±33.07	0.275
% Open substrate phytolithophil	20.80±36.60	44.37±37.83	0.074
% Brood hiding lithophil	0.00±0.00	0.03±0.09	<0.0001
% Nest polyphil	0.12±0.23	0.01±0.04	0.005
% Open substrate phytophil	20.20±37.78	1.46±3.01	0.081
% Open substrate pelagophil	0.54±1.58	0.04±0.11	0.133
Catch-per-unit-effort	553.3±562.5	1120.5±1315.1	0.049
% DELT	0.007+0.00001	0.00+0.00	0.001

Among reproductive guilds significant differences were observed between the percent of brood hiding lithophils ($z_{17,7}$ = *-3.965, P=<0.*001), percent nesting polyphils ($z_{17,7}$ = *-2.591, P=0.*005), percent open substrate phytophils ($z_{17,7}$ = *-1.401, P=0.*081), while the percent open substrate pelagophil and percent brood hiding lithophils were not statistically different between littoral drift class (Table 4). Accretion types had no brood hiding lithophils and exhibited greater variation than erosion and stable littoral types. Degradation by the accretion of sediment in the littoral drift habitats probably caused the disruption of trophic and reproductive guilds, and increased populations of those species able to tolerate fine substrates when confronted with littoral drift alteration.

Abundance and Individual Health of Fish Communities

No significant difference in the number catch-per-unit-effort was observed between accretion and erosion reaches (Table 4). Native species represent 92.3% of the individuals, non-indigenous species comprise 7.32% of the individuals, and exotic species include 0.39% of total relative abundance. The total number of deformities, eroded fins, lesions, and tumors (DELT) anomalies included 16 individuals. This represents an incidence rate of 0.07% DELT anomalies among the 22,924 individuals collected during the current study. This is less than the minimum observed number of DELT anomalies anticipated from regional studies in the Lake Michigan basin (Simon 1991). Individual health of Lake Michigan coastal fish populations is generally healthy and disease is anticipated to not exceed 7 in 10,000 individuals.

Influence of Exotic and Nonindigenous Species

Large-scale disturbance has enabled exotic and non-indigenous species to colonize and disperse into modified habitats (Fox and Fox 1986; Orians 1986; Mills et al. 1993; Simon and Stewart 1999). Within the study areas, non-indigenous species comprised 11 species, while exotic species included as many as 4 species (Table 1). Compared to historical data prior to 1950, native species comprised 96.2% of the species composition, while during the recent past (1995-2005) native species declined to 74.6%, and current (2010-2011) native species richness comprises 63.6%. The mean number of exotic species in erosion and stable drift types was 11.4 individuals per collection, while accretion drift types include 20.5 individuals. The presence of exotic and non-indigenous species has altered the natural function of fish assemblages (Elton 1958, Mooney and Drake 1986, Vitousek 1986, Meng et al. 1994, Krueger et al. 1995, Moyle and Light 1996). Simon and Stewart (1999) indicated that more than 50% of the individuals in the catch were exotic or non-indigenous species from samples collected between 1986 and 1996.

Information Needs for Indictor Development and Restoration

The southern Lake Michigan coastal shoreline represents critical habitat for many Great Lake fishes and are particularly important to conserving and restoring native species (Goodyear et al. 1982; Simon and Stewart 1999). The former open lake coastal wetland complexes associated with southern Lake Michigan have been irreplaceably lost and drowned river mouth coastal wetlands associated with the Grand Calumet River, Trail Creek and other tributaries draining into Lake Michigan have been altered and made into marinas or international shipping ports. The seawalls and artificial structures associated with these entrances have created accretion areas that act as sediment constriction points that reduce littoral drift.

Coastal shoreline restoration is needed to enhance native species recovery. Sediment particle size preferences of dominant species associations are needed to evaluate beach and shoreline nourishment objectives and to provide sufficient heterogeneity for species. In addition, the movement of fine grain materials and stability of coarse fraction material are important for spawning, nesting, and nursery habitat. The complexity afforded within the swash zone is among the most important habitat along the coastal shoreline.

In order to develop an indicator of Lake Michigan condition, additional fish assemblage information is needed, especially from accretion and erosion habitats. These two littoral drift types are the two extremes of Lake Michigan condition and will provide needed information for management of beach nourishment projects. Especially important would be the evaluation of early life history stages of fishes in the swash zone. Surprisingly, the dominant species in the coastal shoreline is Yellow perch. The dominance of young Yellow perch in the swash zone provides important food, dissolved oxygen, and thermal conditions that promote rapid growth. As Yellow perch increase in size and move offshore into nearshore habitats, additional recruitment models could be developed to predict year class strength and trophic web dynamics.
Development of a standard method of data collection and seasonal evaluation of fish assemblage structure and function would be important for determining the stability of resident native species,

while also providing an important early warning measure for invasive nonindigenous and exotic species increase and colonization.

Evaluation of attributes of Lake Michigan coastal fish assemblages would need further evaluation to determine impacts associated with natural and anthropogenic disturbance associated with industrial, electric generating facilities, and habitat modifications in the offshore waters. Attributes of fish assemblages would require testing and modification to create a suite of indicators capable of measuring changes in biological condition, water quality, and recruitment.
Lastly, stocking of nonindigenous species should be evaluated to enable the restoration of native fish communities on public lands (Simon et al. 2004). Habitat quality requires restoration and land-use modifications to decrease or reverse declines in native fish communities. The stocking of nonindigenous species for recreational opportunities must be evaluated in light of native species recovery. Species formerly abundant on the Lake Michigan coastal shoreline, such as Lake chub, Trout perch, Longnose sucker, Mottled sculpin, Scaly darter, and Longnose dace have declined precipitously and have experienced significant range reduction; while other native predators such as Burbot, Lake trout, coastal Brook trout, and native whitefish species have been reduced or extirpated from the Lake Michigan basin. Recovery of native top carnivores should be the priority for restoration of the Lake Michigan basin.

Conclusions

The Lake Michigan drainage once possessed important wetland habitats and features that served as spawning and nursery areas to resident and transient fish communities (Goodyear et al. 1982). Native fish populations in tributary watersheds have declined by 67% in the Illinois River and by 44% in the Maumee River (Karr et al. 1985). Fish communities have been altered due to anthropogenic changes in the landscape, including drainage of wetlands, channelization, introduction of toxins, and the addition of nonindigenous species (Simon 1991). These threats along with over-fishing have led to historical changes in Great Lakes fish communities (Hartman 1988).

Our comparison of historic and current studies suggested that the number of native fish species in Lake Michigan watershed has increased as a result of nonindigenous and exotic species introductions, but that the native species populations have declined 32.6% from pre-1950 conditions. We believe that population densities have also been altered; however, little background data exist to support such a conclusion. Few areas in northwest Indiana, including most sites on public lands, qualify as “least-impacted." We found that in terms of the structure and function of fish communities, public lands in southern Lake Michigan region may be serving as refugia for native fish populations in northwest Indiana.

Stocking programs exist for nonindigenous salmonids in Lake Michigan. To restore the native fish communities on public lands, stocking of nonindigenous species needs to be evaluated to ensure that these communities are not adversely affecting native species recovery. Recent estimates suggest that 139 nonindigenous species occur in the Great Lakes Basin, including 25 fish species (Mills et a1. 1993, Edsall et al. 1995). The increase of exotic species has contributed to the decline of native species. Our study demonstrates that greater numbers of nonindigenous and exotic species dispersal into aquatic habitats on public lands but they have not become well established as a result of natural habitats and lack of armored structures. The percentage of exotic species found in our study was highest in accretion habitats of coastal Lake Michigan and lowest in the erosional and stable littoral drift habitat types. Improvements in native species richness and biological integrity will require increased monitoring and assessment of Lake Michigan coastal condition and development of coastal biological indicators to achieve a goal of "no net loss of species." The ecological integrity of coastal shoreline habitats of Lake Michigan are showing signs of universal loss and deterioration of natural habitats and requires further evaluation to develop models for restoration efforts, especially native species habitat, and critical restoration of nursery habitat and spawning areas. Habitat quality including sediment heterogeneity needs to be managed to restore coastal shoreline land use changes resulting from anthropogenic disturbance. In addition, Lake Michigan must be protected against introductions of exotic and nonindigenous species. Without a commitment to native species restoration, continued decline in the native fish communities of Lake Michigan is inevitable.

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