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Spatial Patterns of Fish Communities in Lake Michigan Tributaries

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Abstract

Understanding spatial patterns in freshwater fish communities is critical for the successful management of natural resources as well as a vital component for understanding aquatic ecosystems. Spatial patterns of species similarity of freshwater fish assemblages can be affected by dispersal processes and environmental conditions. We hypothesized that as distance increased between study systems, species similarity would decrease. We sampled 15 drowned river mouths (DRMs) connected to Lake Michigan by conducting 10-minute electrofishing transects (n = 5-6 per DRM) parallel to the shoreline in each DRM to characterize littoral fish assemblages. At each transect, we also characterized environmental conditions (e.g., specific conductivity or number of houses/buildings along shoreline). We captured 3,080 individual fish representing 45 species across the 15 DRMs, with catch among DRMs ranging from 115 to 358 individuals per system and species richness ranging from 11 to 26 species per system. The most abundant species in the catch were yellow perch *Perca flavescens* (13.9%), pumpkinseed *Lepomis gibbosus* (10.9%), and bluegill *Lepomis macrochirus* (9.8%). We found a weak positive correlation between species similarity and distance between each pair of DRMs (R^2 = 0.03), which did not support our hypothesis that species similarity would decrease with distance, even though we found evidence of spatial autocorrelation of environmental variables. A potential explanation for our findings is related to gear selectivity associated with boat electrofishing. We suggest that sampling fish with additional gear or approaches is necessary to more rigorously test for the spatial pattern of species similarity among DRMs.

Introduction

Although freshwater is a small component of the Earth's surface (Bernardi 2013), freshwater fishes comprise nearly half of all fish species (Carpenter et al. 2011; Vega & Wiens 2012). Freshwater fish are extremely important to humans, especially from a cultural and economic standpoint. Extensive alterations, such as hydrologic flow modification, land-use change, chemical inputs, non-native species, and harvest, are reaping harmful repercussions upon these extremely valuable freshwater ecosystems (Carpenter et al. 2011). Therefore, recognizing the spatial patterns in freshwater fish communities is critical to successful natural resource management and is an essential component for understanding aquatic ecosystems.

To further understand freshwater ecosystems, it is vital to identify the species change across spatial gradients. An approach to examine such spatial gradients in biological communities is to assess species similarity, which is the degree of similarity in species composition among sites (Nekola & White 1999). A common spatial pattern is for species similarity to decrease with increasing geographic distance (known as "distance decay"), which has been found in terrestrial plants (Nekola & White 1999), snails and birds (Steinitz et al. 2006), and freshwater fish (Drakou et al. 2009; Araújo et al. 2013). Distance decay can be affected by environmental conditions and dispersal processes (Nekola & White 1999). Species composition is often affected by environmental conditions because interspecific competition can lead to scenarios where only the best-suited species persist in a particular area given those specific conditions. Additionally, environmental conditions are often affected by geographic distance because sites in closer proximity generally have more similar environmental conditions than sites that are further apart (Koenig 2002). The combination of environmental conditions and geographic distance can lead to the pattern of distance decay in species similarity. Dispersal also plays a role in the occurrence of distance decay because dispersal of biota is limited by geographic distance (Steinitz et al. 2006). Sites closer together can have a greater exchange of organisms via dispersal, therefore increasing species similarity. Thus, environmental conditions and dispersal processes can both result in the pattern of distance decay.

In this project, we evaluated whether the pattern of distance decay was discernable in fish assemblages among drowned river mouths connected to eastern Lake Michigan (i.e., drowned river mouths are essentially lakes that connect a tributary to a large lake). Since the drowned river mouths are linked directly to Lake Michigan, the dispersal of fish species can occur. We expected to find a pattern of distance decay among drown river mouths (Janetski & Ruetz 2014), and we hypothesized that both geographic distance between drowned river mouths (LaRue et al. 2011) and environmental conditions (Uzarski et al. 2005; Janetski & Ruetz 2014) would be important underlying mechanisms. Our goal was to disentangle the contribution of geographic distance and environmental conditions in driving spatial patterns of fish assemblages. Specifically, we wanted to (1) test for the spatial pattern of distance decay among fish assemblages in Lake Michigan drowned river mouths, and (2) assess the relative contribution of environmental conditions and dispersal processes in driving spatial patterns.

Methods

To test the distance decay hypothesis, we sampled 15 drowned river mouths (Table 1) that are directly connected to eastern Lake Michigan using boat electrofishing during daylight hours, which is a common method for sampling littoral (i.e., depth < 2 m) fish communities in lakes (Ruetz et al. 2007). We conducted five 10-minute (pedal time) electrofishing transects parallel to the shoreline in each lake. If less than 110 fish were captured across the initial five transects, then a sixth 10-minute transect was sampled (which only occurred at Portage Lake). Electrofishing transects were randomly sampled by dividing the shoreline boundary (physically represented as a GIS polyline file) of each individual lake into sequentially-numbered, 750-m line segments using ESRI ArcGIS 10.2 (a geographic information system). The GIS-determined range of these uniquely numbered line segments were then processed through a random number generator (random.org) to select five individual line segments (i.e., transects) for sampling in each lake. A map was generated in ArcGIS for each lake, using the five randomly derived transects (including geographic coordinates representing the physical location of each transect) and digital orthophotography with geographic position system (GPS) coordinates to navigate to the sample locations. We also randomly selected five "back-up" sampling transects for cases where a transect was deemed too difficult to sample (e.g., too deep). No two sampling transects overlapped in space, and if the lake's shoreline was sufficiently large, adjacent line segments were not sampled. At each sampling transect, two individuals standing at the front of the electrofishing boat netted fish, which were kept in a holding tank until the 10-minute electrofishing transect was completed. The electrofishing boat was equipped with a

Smith-Root 5.0 generator-powered pulastor control box (pulsed DC, 220 volts,~7 amp). Each captured fish was identified to species, measured for total length, and released.

To determine the relationship between fish community structure and environmental factors, we measured a suite of environmental variables at each transect. Many of these environmental variables were found to be associated with fish community structure in drowned river mouths (Bhagat & Ruetz 2011; Janetski & Ruetz 2014). We measured organic sediment depth by pushing a 1-cm diameter rod into the sediment to the bottom of the soft organic layer and recording the depth (Nelson et al. 2009). We visually estimated the percentage of submerged aquatic vegetation (SAV) along each transect. We measured water temperature (°C), specific conductivity (µS/cm), total dissolved solids (TDS, g/L), pH, oxidation reduction potential (ORP, mV), turbidity (NTU), and dissolved oxygen concentration (DO, mg/L) at the middle of the water column using a YSI multiprobe meter (Model 6600-V2 data sonde). We also measured water clarity (hereafter Secchi depth) via a turbidity tube (length: 126 mm, diameter: 45 mm).

To assess distance decay, we calculated community similarity and distance between each pair of drowned river mouths. We calculated the distance between each pair of drowned river mouths by measuring the distance from its center to the nearest drowned river mouth via Lake Michigan. The distances between each pair of lakes were added together to calculate the distance between nonadjacent drowned river mouths (e.g., $distance_{A-C} = distance_{A-B} + distance_{B-C}$). We measured fish community similarity using Morisita's Index (*M*), which ranges from 0 (no similarity) to 1 (complete similarity; Krebs 1999).

Results

We captured 3,080 individual fish representing 45 species across the 15 drowned river mouths (Table 2). Catch ranged from 115 individuals in Betsie Lake to 358 in Pere Marquette Lake (Figure 1). Species richness was lowest in Bass Lake (11 species) and highest in Pentwater Lake (26 species; Figure 1). Yellow perch (13.9% of overall catch) was the most abundant species in the catch, followed by pumpkinseed (10.9%) and bluegill (9.8%; Table 2). Together, these three species made up 34.6% of the individuals sampled. Four of the 45 species caught were non-native: alewife, common carp, round goby, and white perch, contributing to 11.9% of the overall catch. Rare species each representing <1% of the overall catch were a large portion of the species pool (27 of the 45 total species; Table 2).

We did not find evidence of distance decay among our drowned river mouths. The association between species similarity and distance was not strong (Figure 2). The relationship between species similarity and distance also was analyzed in drowned river mouths that possessed maintained navigational channels (i.e., all drowned river mouths except Bass, Stony, Duck, and Mona lakes), as opposed to natural channels without human modification. This was to guard against the possibility that dispersal could be higher among drowned river mouths with maintained navigational channels. The relationship between species similarity and distance was not strong for the drowned river mouths with a maintained navigational channel (Figure 3). Finally, we assessed the relationship between geographic distance and species similarity for four drowned river mouths (i.e., Pentwater, White, Muskegon, and Kalamazoo lakes) that previously were found to display a pattern of distance decay among littoral fish assemblages based on fyke netting (see Janetski & Ruetz 2014) and found no evidence for a negative relationship (Figure 4).

Although we did not find evidence of distance decay in our study system, environmental conditions were not homogenous across the drowned river mouths (Table 3). There was high variability in environmental conditions, especially in specific conductivity and the number of docks and houses/buildings (Table 3), among drowned river mouths. We found a weak positive association between the difference in mean specific conductivity and distance (Figure 5), suggesting that environmental conditions were more similar between drowned river mouths in close geographic proximity than those further apart. The number of docks and houses/buildings present along the shoreline also varied among drowned river mouths (Figure 6).

Discussion

We hypothesized that as distance increased between drowned river mouths, the species similarity would decrease, thereby resulting in the spatial pattern of distance decay. A significant, negative slope (i.e., species similarity decreases with increasing geographic distance between drowned river mouths) would be interpreted as distance decay. However, we found a slightly positive correlation between species similarity and distance, which did not support the hypothesis of distance decay based on our electrofishing sampling of littoral fish assemblages (Figure 2). Even when we only included lakes with strong connections to Lake Michigan through a maintained navigational channel, distance decay was not evident (Figure 3).

Janetski and Ruetz (2014) sampled six drowned river mouths and found a significant negative correlation between species similarity and increasing geographic distance. Therefore, their data showed evidence of distance decay. Four of the six lakes sampled by Janetski and Ruetz (2014) were included in our study (i.e., Pentwater, White, Muskegon, and Kalamazoo); yet, when analyzed, the four lakes did not yield a negative correlation (Figure 4). Once again, the hypothesis of distance decay was not supported with our electrofishing data. A possible explanation for the difference in the findings of our study and Janetski and Ruetz (2014) could be related to the spatial scale of the study and spatial autocorrelation in environmental variables. However, we found evidence of spatial autocorrelation in environmental conditions (at least in terms of mean specific conductivity), which should have resulted in distance decay in species similarity.

An additional factor that could have affected our ability to detect distance decay in species similarity is the type of sampling gear we used in this study (i.e., boat electrofishing). Janetski and Ruetz (2014) sampled fish assemblages with fyke nets, as opposed to our method of boat electrofishing. Ruetz et al. (2007) found that fyke netting selects for small-bodied fish species, while boat electrofishing selects for large-bodied species. Since we utilized a sampling method that is biased towards larger, more mobile species (Chick et al. 1999), our observations on drowned river mouths may be skewed by gear selectivity. This could be an important factor of why we were unable to detect distance decay in species similarity. In the future, sampling these drowned river mouths with complimentary gear would be beneficial and better represent littoral fish assemblages (Ruetz et al. 2007).

There are alternative approaches to sampling fish to obtain a greater range of species other than the one we used in this study. Increasing the sampling effort by performing a second pass at each transect can obtain more species than obtained in a single pass (Meador 2005). Apart from performing multiple passes, we also could have increased the number of transects sampled at each drowned river mouth. With more passes or transects, we likely would have gotten a better representation of the full species richness of littoral fish assemblages. Sampling each lake at night also could have yielded greater species richness. Typically, more species are caught at night while boat electrofishing (Paragamian 1989). A completely different sampling method that could be employed is the use of environmental-DNA to detect which fish species are present in a water body (Takahara et al. 2012), which may provide a more cost-effective approach to better characterize the littoral fish assemblages in drowned river mouths compared to traditional sampling methods.

Our finding that species similarity between drowned river mouths did not follow the spatial pattern of distance decay contrasts with previous studies on freshwater fish (Drakou et al. 2009; Araújo et al. 2013; Janetski & Ruetz 2014). We suggest that sampling fish with additional gear or approaches is necessary to more rigorously test for the spatial pattern of distance decay in species similarity among drowned river mouths. Based on our findings in this study, we are unsure if the lack of a spatial pattern of distance decay was due to the sampling gear we used (i.e., daytime boat electrofishing) or because such a spatial pattern was not present in littoral fish assemblages among drowned river mouths of Lake Michigan.

Plans for dissemination

We plan to share our findings with the scientific community via publications and presentations at conferences. We will submit this report to Grand Valley State University's Institutional Repository, ScholarWorks. We also plan to submit a manuscript to a peer-reviewed journal that summarizes our main findings. Although we have not decided on a journal for submission at this time, we expect the *Journal of Great Lakes Research* or *Ecology of Freshwater Fish* would be suitable venues for such a submission. In the fall of 2014, Samantha will present a poster at the West Michigan Regional Undergraduate Science Research Conference. Samantha also will give an oral presentation at the Michigan Chapter of the American Fisheries Society in the winter of 2015 (exact dates for this conference have not been released yet) and at Grand Valley State University's Student Scholars Day on April 8, 2014. Finally, Carl and Samantha will attend the annual meeting of the Society for Freshwater Science (SFS) in Milwaukee, Wisconsin (May 17-21, 2015) where Samantha either will give a poster or oral presentation at the conference. The SFS conference attracts scientists from around the globe.

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Table 1. Names and locations (i.e., Michigan County) of drowned river mouths as well as distance (km) to the adjacent drowned river mouth via Lake Michigan. Drowned river mouths are listed from north to south. Distance is reported for the drowned river mouth immediately to the south (e.g., 16.18 km refers to the distance between Betsie Lake and Arcadia Lake).

Lake	**County**	**Distance (km)**
Betsie Lake	Benzie	16.18
Arcadia Lake	Manistee	13.83
Portage Lake	Manistee	13.67
Manistee Lake	Manistee	34.39
Pere Marquette Lake	Mason	13.53
Bass Lake	Mason	5.73
Pentwater Lake	Oceana	25.09
Stony Lake	Oceana	21.98
White Lake	Muskegon	3.96
Duck Lake	Muskegon	13.88
Muskegon Lake	Muskegon	12.66
Mona Lake	Muskegon	12.66
Spring Lake	Ottawa	31.86
Macatawa Lake	Ottawa	10.71
Kalamazoo Lake	Allegan	--

Table 2. Fish species caught and percentage of overall catch across all 15 drowned river mouths.

Scientific Name	Common Name	% of overall catch
Perca flavescens	yellow perch	13.86
Lepomis gibbosus	pumpkinseed	10.94
Lepomis macrochirus	bluegill	9.81
Moxostoma erythrurum	golden redhorse	8.12
Micropterus salmoides	largemouth bass	8.05
Morone americana	white perch	7.21
Pimephales notatus	bluntnose minnow	5.71
Ambloplites rupestris	rock bass	4.84
Micropterus dolomieu	smallmouth bass	4.84
Alosa pseudoharengus	alewife	3.15
Catostomus commersoni	white sucker	2.89
Fundulus diaphanus	banded killifish	2.08
Moxostoma macrolepidotum	shorthead redhorse	1.82
Carpiodes cyprinus	northern quillback	1.62
Ameiurus nebulosus	brown bullhead	1.56
Moxostoma anisurum	silver redhorse	1.53
Notropis hudsonius	spottail shiner	1.30
Cyprinus carpio	common carp	1.10
Dorosoma cepedianum	gizzard shad	0.84
Amia calva	bowfin	0.81
Notropis stramineus	sand shiner	0.78
Notropis volucellus	mimic shiner	0.78
Labidesthes sicculus	brook silverside	0.71
Aplodinotus grunniens	freshwater drum	0.65
Esox lucius	northern pike	0.62
Notemigonus crysoleucas	golden shiner	0.62
Cyprinella spiloptera	spotfin shiner	0.49
Luxilus cornutus	common shiner	0.49
Minytrema melanops	spotted sucker	0.49
Neogobius melanostomus	round goby	0.39
Ictalurus punctatus	channel catfish	0.36
Sander vitreus	walleye	0.32
Lepomis gulosus	warmouth	0.23
Moxostoma valenciennesi	greater redhorse	0.23
Moxostoma carinatum	river redhorse	0.16
Pomoxis nigromaculatus	black crappie	0.16
Oncorhynchus tshawytscha	Chinook salmon	0.10
Erimyzon sucetta	lake chubsucker	0.06
Lepisosteus osseus	longnose gar	0.06
Notropis atherinoides	emerald shiner	0.06
Esox americanus	grass pickerel	0.03
Etheostoma nigrum	johnny darter	0.03
Ichthyomyzon castaneus	chestnut lamprey	0.03
Noturus gyrinus	tadpole madtom	0.03
Oncorhynchus mykiss	rainbow trout	0.03

Table 3. Environmental conditions across all 15 drowned river mouths. The mean and range were calculated across all transects (*n* = 15).

Environmental variable	**Mean**	**Range**
Temperature (°C)	20.9	16.3 - 26.6
Specific conductivity (µS/cm)	386	215 - 621
Total dissolved solids (g/L)	0.251	0.152 - 0.403
Turbidity (NTU)	6.5	2.6 – 20.7
Dissolved oxygen (mg/L)	9.38	5.41 – 16.51
% submerged aquatic vegetation	37	0 - 100
Secchi depth (cm)	99.4	46.2 - 120
Organic sediment depth (cm)	10.3	6.1 - 19.1
# of docks (per transect)	6	0 - 37
# of houses/buildings (per transect)	5	0 - 21

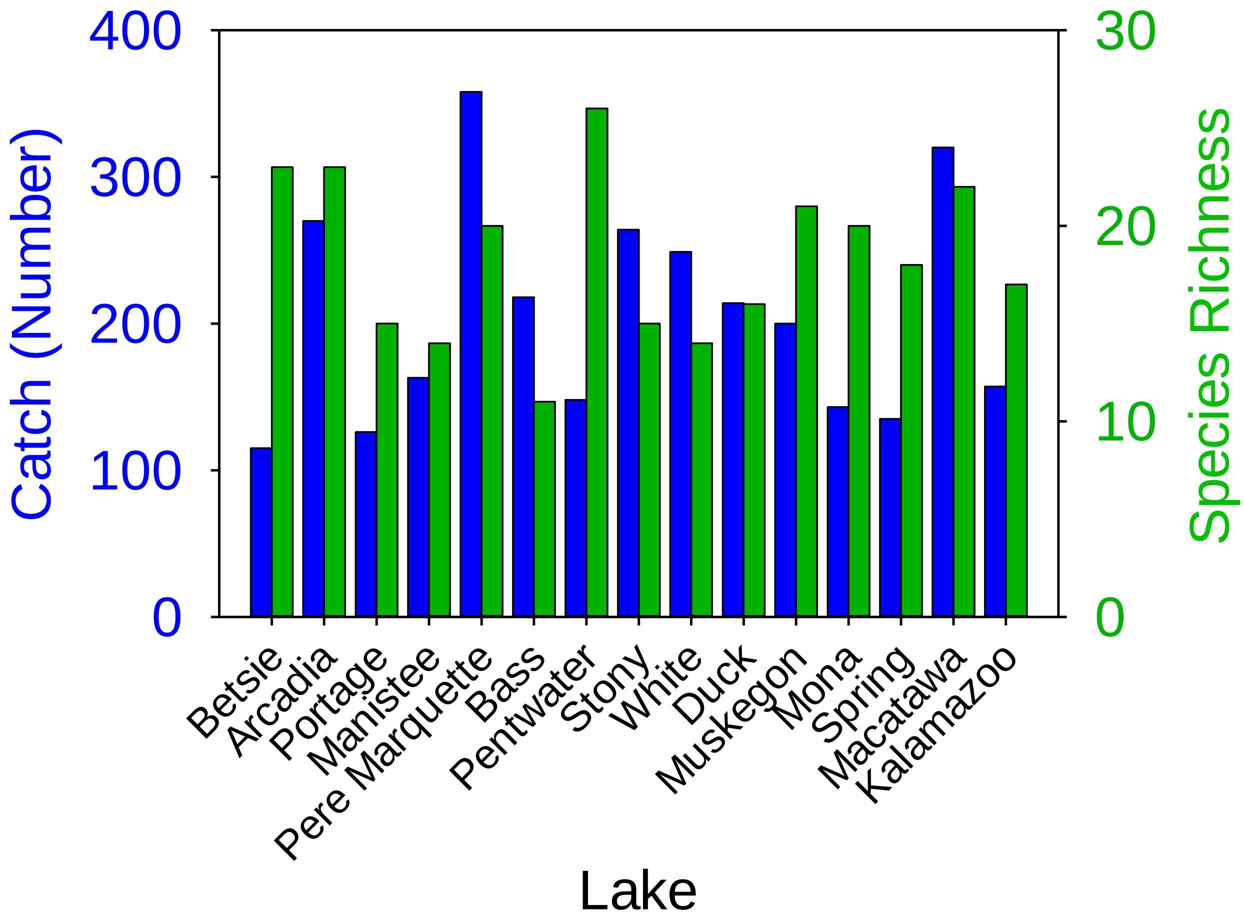

Figure 1. Catch and species richness in each drowned river mouth.

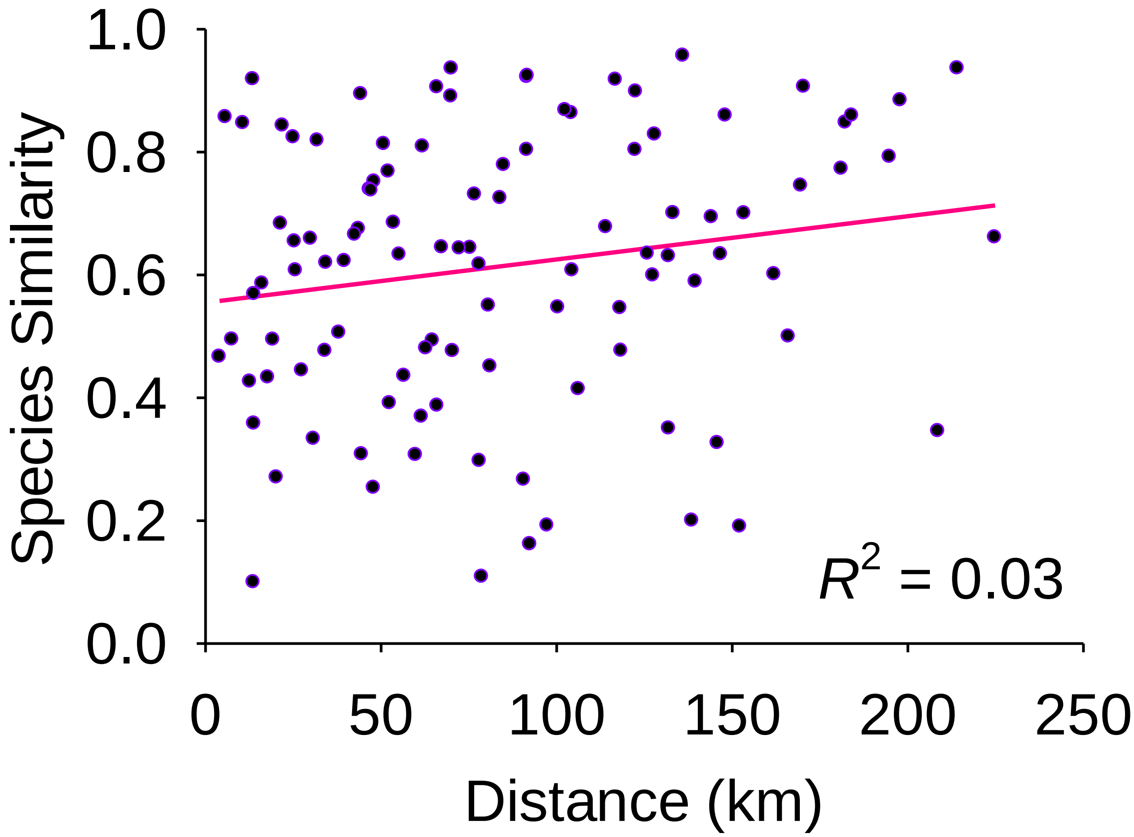

Figure 2. Species similarity versus distance between each pair of drowned river mouths.

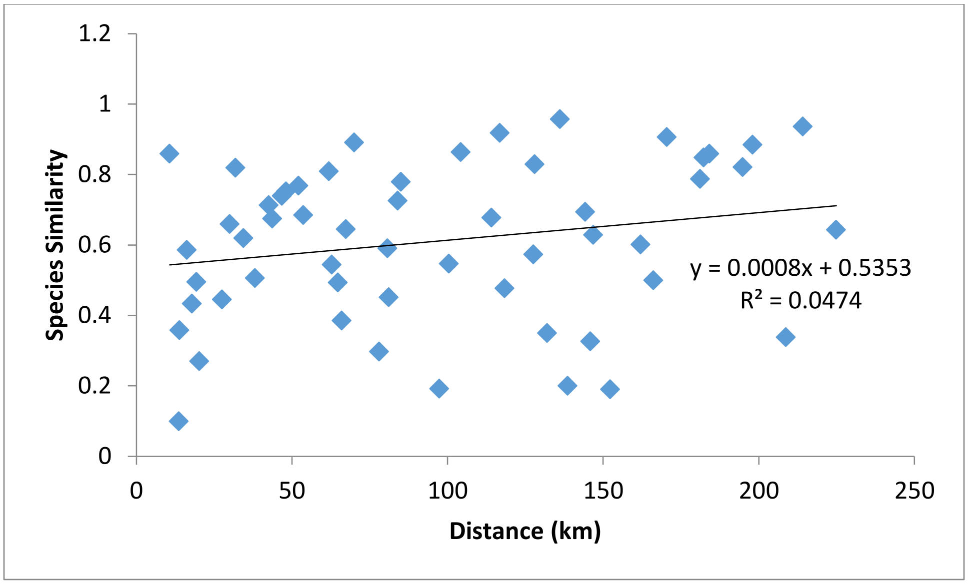

Figure 3. Species similarity versus distance between drowned river mouths with maintained navigational channels (all drowned river mouths except Bass, Stony, Duck, and Mona lakes).

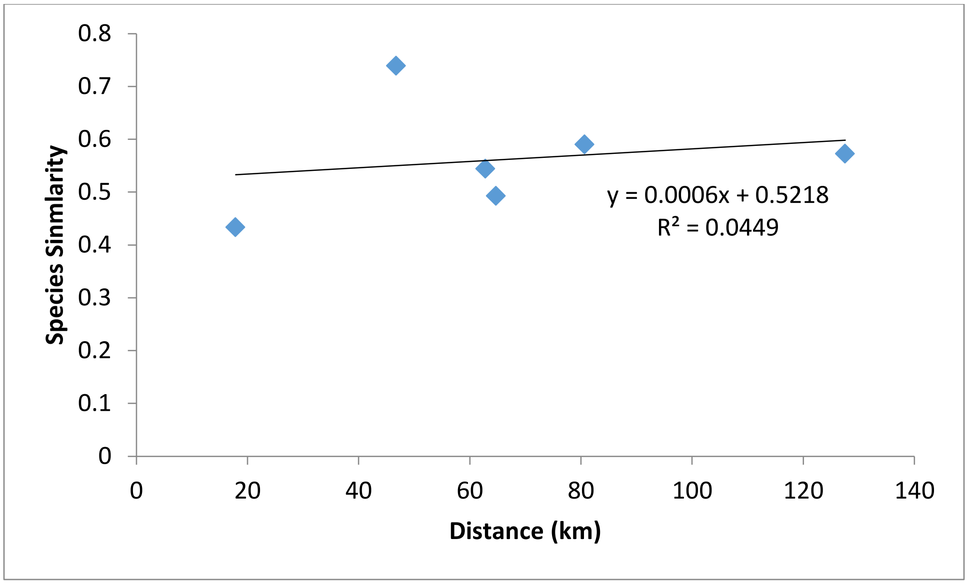

Figure 4. Species similarity versus distance between drowned river mouths sampled in study performed by Janetski and Ruetz (2014), which included Pentwater, White, Muskegon, and Kalamazoo lakes.

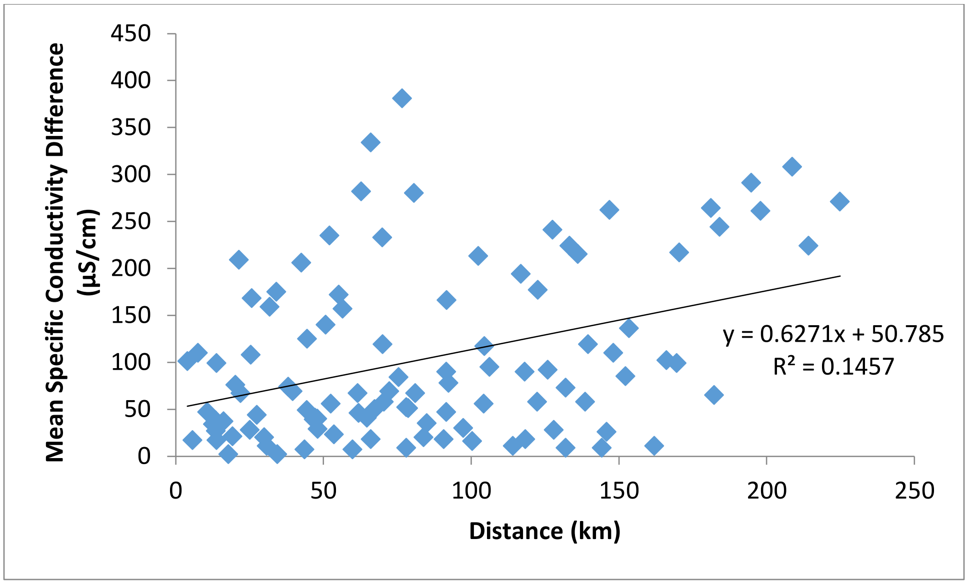

Figure 5. Difference between mean specific conductivity versus distance across all drowned river mouths.

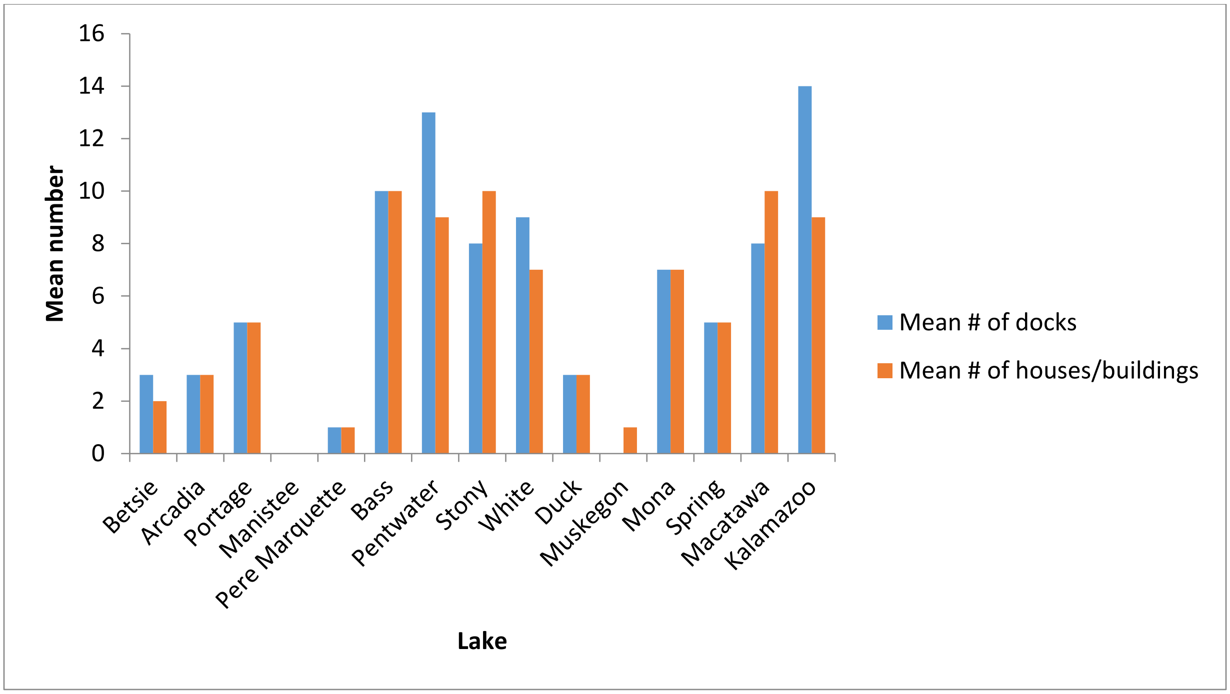

Figure 6. Mean number of docks and houses/buildings present along the shoreline of each drowned river mouth, which are listed from north to south.