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ARTICLE

Comparison of Electrofishing Techniques and Effort Allocation across Diel Time Periods, Seasons, Sites, and Habitat in the Ohio Coastal Waters of Western Lake Erie

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Abstract
Coastal (<3-m depth) and nearshore (3–15-m depth) zones of large freshwater lakes are generally rich in complex habitats that are important for fisheries, but they are often highly degraded and understudied. We identified spatial and temporal sampling efficiencies for monitoring coastal fish communities in a large freshwater lake by use of electrofishing. During 2011 and 2012, we sampled 21 coastal sites in Lake Erie's western basin via daytime and nighttime electrofishing with multiple replicates throughout the summer sampling season. Nighttime electrofishing captured more species and more individuals with less effort than daytime electrofishing; nighttime electrofishing conducted early in the season (i.e., late spring and early summer) was more efficient than that conducted late in the season (i.e., late summer and early fall). A sampling design based on 500 m of shoreline per site required fewer sites and person-hours to attain 65% and 75% of total species richness (6 and 11 sites, respectively) than a design that used 100 m/site. A 300-m/site design was more efficient at targeting 90% of total species richness. Targeting of wetland habitat increased the number of species captured but missed species that were only found at other habitat types. A sampling design that targeted 11 sites (75% of species richness) sufficiently described fish community metrics (e.g., number of tolerant species) since the design captured nearly all fish species that were relevant to each metric. This study provides the foundation for a coastal monitoring program in western Lake Erie and serves as a starting point for program development in other large freshwater lakes.

Recreational and commercial fisheries (e.g., Walleye *Sander vitreus* and Yellow Perch *Perca flavescens*) in the Laurentian Great Lakes provide economic benefits (USFWS and USCB 2006) but are likely to be compromised by environmental stressors that reduce fish recruitment (Gilliers et al. 2006) and alter fish distributions (Goforth and Carman 2009). Some stressors include poor water quality (e.g., nutrient enrichment, thermal pollution, sediment turbidity, and heavy metals; Allan et al. 2013), habitat degradation (e.g., shoreline alteration; Allan et al. 2013), harmful algal blooms, and invasive species (e.g., Round Goby *Neogobius melanostomus*). Coastal areas are especially affected by environmental stressors because human activities have a direct impact in these habitats. The coastal area (<3-m depth; Mackey 2012) of Lake Erie has one of the highest human population densities in the Laurentian Great Lakes region (Crossett et al. 2004) and has been

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subjected to many of the stressors that are found throughout the Great Lakes basin.

The coastal area is a distinct habitat along the shoreline that connects to the nearshore (3–15-m depth; Mackey 2012) and offshore (>15-m depth; Mackey 2012) zones and provides a crucial link between tributaries and open water. In addition, coastal areas supply important habitat for all life stages of many fish species (Goodyear et al. 1982; Peterson et al. 2000; Roseman et al. 2005). The nearshore and coastal zones of western Lake Erie are managed as a diverse coolwater fish community, with the Walleye as the top predator (Ryan et al. 2003). Managers strive to maintain a high number of native and forage species while minimizing the number of nonnative or tolerant species.

The fish community of the coastal area is not well monitored. Across the Great Lakes, there are more than 25 monitoring programs focused on individual fish species and lower trophic levels (GLC 2006). Although these programs have resulted in a greater understanding of factors affecting offshore fisheries (e.g., Madenjian et al. 2000; Ludsin et al. 2001; Manning et al. 2013), few of the monitoring programs capture changes in coastal zone fish communities (GLC 2006). Our goal was to develop a sampling design for use in the long-term monitoring of Lake Erie coastal fish communities by the Ohio Department of Natural Resources' (ODNR) Division of Wildlife. The addition of a coastal monitoring program will complement sampling efforts in the nearshore and offshore areas to provide a lakewide perspective on fish communities. Furthermore, sampling in the coastal area will help to relate environmental stressors to fish community changes, and such information can be used to guide restoration and mitigation efforts (Mackey and Goforth 2005).

Designing a monitoring program is challenging because habitat use (Hatzenbeler et al. 2000) and catchability (Schoenebeck and Hansen 2005) vary among seasons and among fish life stages. A preferred methodology would capture a high proportion of all fish species that use the coastal area and would do so at a relatively low cost. Maximizing the number of species (i.e., species richness) detected ensures a thorough description of the coastal fish community and increases the likelihood of detecting rare or newly invasive species. Therefore, factors that are likely to affect the number of sampled species and the number of sampled individuals representing a given species should be evaluated. For example, due to diel migrations or gear avoidance, many fish species are more vulnerable to nighttime sampling than to daytime sampling (Paragamian 1989; Sanders 1992; Copp and Jurajda 1993; Dumont and Dennis 1997; Thoma 1999; Bonar et al. 2009). Water clarity and habitat complexity also affect catch rates and species detection (e.g., Bonar et al. 2009). Water clarity in Lake Erie's coastal zone can vary greatly on a weekly basis; for example, Secchi depths in Maumee Bay can range from 0.3 to 2.0 m throughout the summer (J. E. Ross, University of Toledo, unpublished data). Furthermore, a monitoring program must have a survey design that specifies the number of sites to visit and the sampling intensity to implement at each site. Sampling more sites will provide better spatial coverage, increase the precision of population estimates, and increase the ability to detect trends, but it will also likely increase travel time and project cost. Similarly, sampling multiple times per year allows for the description of intra-annual trends but again is associated with increases in cost. Therefore, a comparison of the number of species captured with different sampling protocols across a range of water clarity levels and habitat types will be vital for determining an appropriate standardized sampling methodology.

To develop an appropriate fish community monitoring design for coastal Lake Erie, our specific objectives were to (1) determine whether nighttime or daytime electrofishing captured the greatest number of species, (2) determine a sampling period between May and October that would yield the greatest number of species, (3) determine trade-offs between the use of fewer large sites versus more small sites in terms of capturing the greatest number of species, (4) determine whether targeting particular habitat types during sampling can maximize the number of species captured with electrofishing, and (5) determine the effect sizes of fish community metrics between years and the accumulation of species within each metric to further support the decision of sampling design selection.

METHODS

*Site selection.—*We sampled 21 sites spanning portions of the coastal zone in Ohio waters of Lake Erie's western basin (Figure 1). Sites were selected based on a hierarchical approach, which included sampling a range of geomorphic shoreline types nested within dominant summer plume zones. Geomorphic shoreline types (i.e., clay, bedrock, bluff/bank, sand, and wetland) were classified using guidelines developed by the U.S. Army Corps of Engineers (USACE 2004). The Lake Erie plume zones were derived with an ordination of water quality and summer lake currents to partition the lake by tributary influences (Lake Erie GIS database; Michigan Department of Natural Resources, Institute for Fisheries Research, Ann Arbor). These plume zones include the Maumee River, the Detroit River, the Sandusky River, the Sandusky subbasin, and the central basin's south shore. Although these categories are broad, they allow coverage of a wide water quality range that may impact the catchability of fish species.

Once we arrived at a site, the exact location sampled was then selected to maximize the number of local habitat types (e.g., beach, riprap, bedrock, and emergent vegetation) within the site. For logistical and safety purposes, selected sites were located within 10 km of a boat ramp, with at least two sites accessible from each boat ramp. Sites were sampled as wind direction and intensity dictated; northern winds typically prevented sampling.

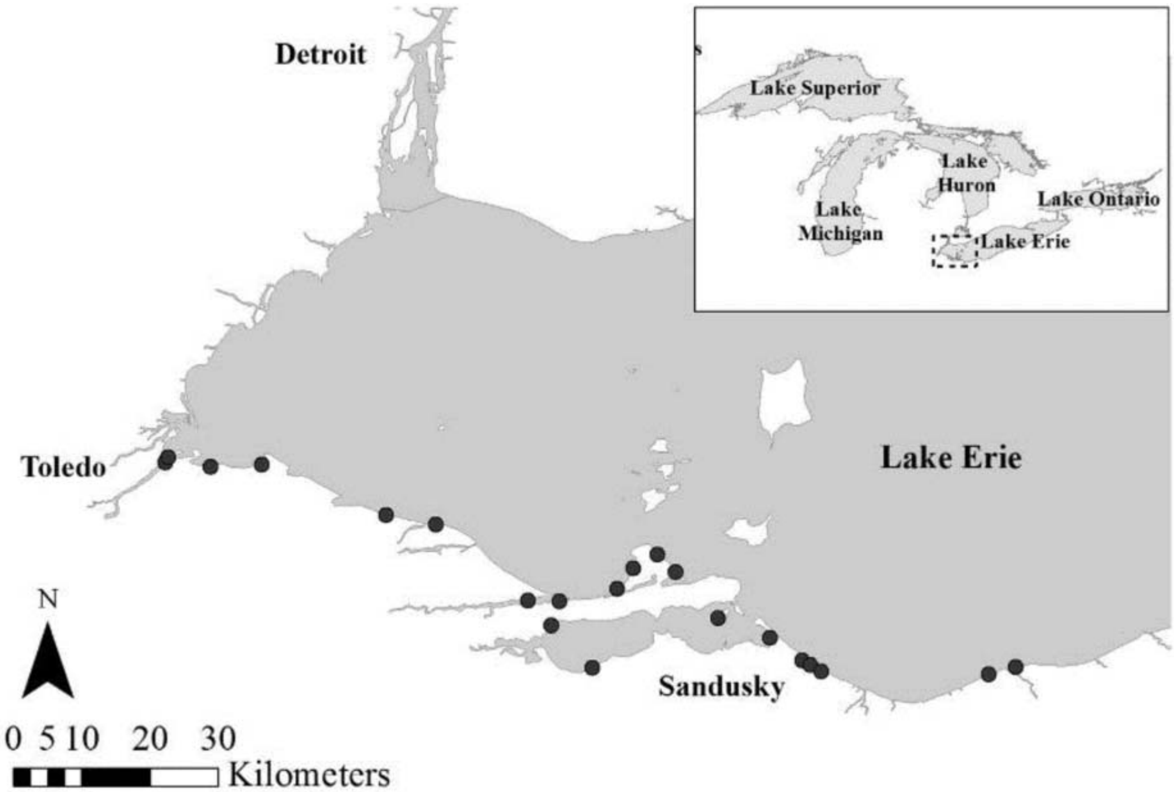

FIGURE 1. Coastal sampling locations in Ohio waters of Lake Erie's western basin, where electrofishing was conducted during 2011 and 2012. The sites spanned a range of major summer plume zones and geomorphic shoreline types.

Comparison of sampling methods.—Sites were sampled via electrofishing through a collaborative effort by the Ohio Environmental Protection Agency, the ODNR Division of Wildlife, and researchers at the University of Toledo. Sampling occurred from June 6 to August 18, 2011, and from May 30 to September 12, 2012. We chose electrofishing because (1) it is an active sampling method that is appropriate for the water depths along the shoreline (<2 m); (2) it can sample a majority of habitat types in the coastal area; and (3) it was shown to be an efficient sampling method within western Lake Erie (Francis et al. 2014). Fish were sampled during the day and night to determine which period maximized the number of species captured.

Sites consisted of 500-m transects situated parallel and adjacent (within 7 m) to the shoreline; along each transect, fish were sorted every 100 m for analysis within sites. Sites were sampled by driving the boat in a combination of zig-zags and nosing the anodes into the shoreline and existing habitat features (e.g., vegetation, riprap, logs, and boulders). Daytime electrofishing was performed between 30 min after sunrise and 30 min before sunset, whereas nighttime electrofishing was limited to between 30 min after sunset and approximately 0300 hours.

All electrofishing was performed with similarly configured aluminum boats and three-person crews (one driver and two netters) in water depths ranging from the shoreline to approximately 2 m. The electricity was produced by 120-V, 5,000-W generators operated with a Smith-Root 5.0 GPP (generator-powered pulsator) electrofishing system that was set at pulsed DC with 60 pulses/s and approximately 5–6 A. Power was adjusted for varying conductivity conditions to maintain a target amperage generally ranging from 40% to 60%. On each boat, electricity was transferred through the water by two 1.2-m-circumference sphere anodes and eight 1.8-m cathodes. The anodes were suspended approximately 5 cm below the water surface from 2.6-m booms and were separated by about 3.7 m. The cathodes were positioned with four on the starboard side and four on the port side of the boat and were spaced approximately 1.6 m apart.

During fish sorting, we identified all fish to species and counted all individuals. Fish that could not be definitively identified in the field were preserved in a 70% solution of ethanol and were keyed to species in the laboratory. We also preserved approximately 30 individual "minnow-like" fish to verify proper fish identification. Fish of each species were grouped according to length and were weighed to estimate biomass.

The mean numbers of species and individuals captured at each site via nighttime and daytime electrofishing in 2011 and

2012 were compared by using paired *t*-tests. Count data were $\log_{10}$ transformed to stabilize the variance. Statistical analyses were performed using R software (R Foundation for Statistical Computing; www.r-project.org).

Sampling effort.—To determine a period that maximized the number of species captured, we sampled two periods within the summer season: early (late spring and early summer) and late (late summer and early fall). The catchability of fish species can vary through time due to movement patterns (e.g., spawning migrations) that are affected by water temperature. Therefore, the peak in mean weekly surface water temperature during 2011 and 2012 was used to delineate the early season period versus the late-season period. We chose only two time periods because it is difficult for agencies to commit to smaller time frames. This approach did result in few sites being replicated within each summer period. However, we ensured that sampling was not aggregated in certain areas or habitat types between seasons, as we wanted to avoid creating bias toward a single plume zone or a single geomorphic shoreline type since these habitats may encompass different fish communities (Wei et al. 2004; ODNR Division of Wildlife 2011). Within each sampling period, we combined years to generate sample-based rarefaction curves (Mao et al. 2005) using EstimateS software (Colwell 2013) with 50 randomizations. Sample-based rarefaction curves use sites (as opposed to individual fish) as the independent variable to build the curve, and they account for the spatial patterns of fish rather than assuming that the fish are evenly distributed. We also calculated SDs for each rarefaction curve to allow for comparisons between early season and late-season sampling efficiencies.

Sample-based rarefaction curves were also constructed to identify the amount of effort—in terms of both the number of sites and the distance sampled per site—that would be necessary to track fish community changes. Nighttime electrofishing samples with both years combined were used to build the rarefaction curves. Since fish were processed every 100 m, we built rarefaction curves for multiple distances of shoreline sampled within a site (i.e., 100, 200, 300, 400, and 500 m), thereby permitting comparison of the number of sites needed for each distance sampled. This was done in the order of sampling for the 100-m segments.

The species pool (100% of total species richness) was estimated by pooling the nighttime electrofishing samples from 2011 and 2012 and using Chao's (1987) asymptotic richness estimator. In our study, the targeted percentages of total fish species richness used within the species rarefaction curves were 65, 75, and 90%. The 75% and 90% targets were used for comparability with the work of Trebitz et al. (2009), whereas the 65% target was added to provide a lower-cost sampling comparison. These targets allowed for a comparison of effort required by each sampling design and also offered a variety of approaches by which managers could increase sampling efficiencies.

To determine trade-offs between sampling fewer sites with a longer distance per site and sampling more sites with a shorter distance per site, we compared the amount of effort for multiple sampling designs. We calculated the number of person-hours associated with each sampling design to reach the targeted 65, 75, and 90% from the previous rarefaction curve generated in this study. If a sampling design did not reach a targeted percentage of species richness, we used the Colwell et al. (2012) method and EstimateS software to extrapolate an estimated number of sites required to reach the target. Time logs that were maintained throughout the 2012 sampling season were used to quantify the number of person-hours required for different scenarios. The recorded time categories included truck travel, boat travel, and sampling time. Average truck travel time was calculated based on round-trip travel to a single boat ramp. Total sampling time was calculated for all sampling activities per 100-m distance per site, averaged across all sampling events. Sampling designs were compared based on a crew of three people, two sites sampled per day, and truck travel to a single boat ramp.

To determine whether targeted sampling at certain geomorphic habitat types would increase the number of species encountered, we constructed a contour plot using a random drawing of nighttime electrofishing samples from each habitat type (Trebitz et al. 2009) to allocate sampling. Since a contour plot can be constructed with only three habitat variables, we combined the geomorphic habitats into three groups: hard substrate, soft substrate, and wetland. Hard substrates included bedrock and bluff/bank; soft substrates included sand and clay; and wetlands included coastal wetlands and flooded river mouths. However, only the percentages of hard substrate and wetland were displayed on the contour plot; the percentage of soft substrate was equal to 100% minus the combined percentages of hard substrate and wetland at any point on the plot. We used R software to randomly select 0, 2, 4, 6, 8, and 10 samples from each habitat. Samples from each habitat were combined with those from other habitats in all possible combinations summing to 10 sites, and the proportion of sites allocated to each habitat were generated. For each combination of samples, the numbers of species captured from each habitat type were summed, and the contour plots were then constructed.

Fish community metrics.—To examine changes in the fish community, we compared the number of native, forage, nonnative, and tolerant fish species between the two study years. These metrics were identified as important characteristics of the Lake Erie fish community (Ryan et al. 2003) to ensure desirable and sustainable fisheries. Fish species included in each metric were drawn from Thoma (1999), with the exception of forage species. In our comparison, the forage species were the Brook Silverside *Labidesthes sicculus*, Bluntnose Minnow *Pimephales notatus*, Emerald Shiner *Notropis atherinoides*, Ghost Shiner *Notropis buchanani*, Gizzard Shad *Dorosoma cepedianum*, Golden Shiner *Notemigonus crysoleucas*, Logperch *Percina caprodes*, Mimic Shiner *Notropis volucellus*, Spotfin Shiner *Cyprinella spiloptera*, and Spottail Shiner *Notropis hudsonius*. A paired *t*-test and power analysis

(Cohen 1988) were performed in R to test for significant differences in metrics between 2011 and 2012 for 18 paired sites. An a priori-based power analysis was conducted using the "pwr" package (Champely 2012) in R software to compare the effect size index (Cohen's *d*; Cohen 1988) to the number of sites, assuming an α value of 0.05 and a statistical power value of 0.80. Generally, a Cohen's *d*-value of 0.2 is considered small, 0.5 is moderate, and 0.8 is large (Cohen 1988). Comparison of Cohen's *d* with the a priori analysis was conducted to allow for a better understanding of the effect sizes and values that may require management actions. Sample-based rarefaction curves were constructed to determine whether the number of sites resulting from our evaluation of objective 3 (fewer large sites versus more small sites) was adequate to monitor fish community metrics. Rarefaction curves were built by using the species within each metric and combining both study years.

RESULTS

Comparison of Sampling Methods

We collected nearly 25,000 individual fish during 132 sampling events (Table 1). The White Perch was the most abundant species (~27% of total individuals), followed by the Emerald Shiner (~16%) and Gizzard Shad (~11%). At nearly all sites, nighttime electrofishing captured significantly ($P < 0.05$) more fish species (Figure 2) and more individual fish than daytime electrofishing. Northern Hog Suckers, Silver Chub, Northern Pike, and Rainbow Trout were only captured at night, whereas Flathead Catfish *Pylodictis olivaris* and Trout-perch *Percopsis omiscomaycus* were only captured during the day.

During 2011, nighttime electrofishing captured, on average, four more fish species per site ($t = -2.36$, df = 18, $P = 0.029$; power = 0.87) and 127 more individual fish per site ($t = -3.70$, df = 18, $P = 0.002$; power = 0.99) than daytime electrofishing. Similarly, in 2012, nighttime electrofishing captured, on average, three more species per site ($t = -2.80$, df = 17, $P = 0.012$; power = 0.79) and 165 more individuals per site ($t = -4.09$, df = 17, $P = 0.0007$; power = 0.99) than daytime electrofishing.

Sampling Effort

Because nighttime electrofishing consistently captured more species and more individuals than electrofishing during the day, we only included nighttime electrofishing in the comparison of sampling effort between seasonal time frames. The cutoff between early season and late-season periods occurred during week 31 at 27.8°C (J. E. Ross, University of Toledo, unpublished data); therefore, samples collected before week 31 were considered the early season samples (June 6–July 20, 2011; May 30–July 27, 2012), while those collected during or after week 31 were deemed the late-season samples (July 27–August 18, 2011; July 30–September 12, 2012). Sample-based rarefaction curves showed that early season sampling captured more fish species with less effort than late-season sampling (Figure 3). On average, early season sampling required nearly half the sampling effort to acquire a given number of species and was associated with a lower SD for the interpolated rarefaction curve than late-season sampling. However, the SDs of the early season and late-season rarefaction curves overlapped. In addition, Black Redhorses, Northern Pike, and Silver Chub were only captured during the early season period, whereas Rainbow Trout and Northern Hog Suckers were only captured during the late-season period. Therefore, sampling by nighttime electrofishing during only the early or late portion of the season could miss some fish species.

Comparison of rarefaction curves indicated that the various sampling designs (i.e., distance sampled per site) differed in their ability to capture 65, 75, and 90% of the estimated total fish species richness (Figure 4). Based on Chao's (1987) richness estimator, 49.28 fish species were estimated to occur in the coastal area of western Lake Erie. The sampling design with 100 m of shoreline per site required more sites to attain the 65% and 75% targets (14 and 25 sites, respectively) than the designs that used 200 m (9 and 17 sites), 300 m (8 and 15 sites), 400 m (7 and 13 sites), or 500 m (6 and 11 sites) per site. However, rarefaction curves began to merge near 90% such that the number of sites required to attain the target became more similar among sampling designs. For all sampling approaches, the number of sites required to capture 90% of the extrapolated species pool was more than triple the number of sites needed to obtain 75% of the species pool.

The mean number of person-hours spent during nighttime electrofishing included 2.32 h of truck travel per boat ramp, 1.29 h of boat travel per site, and 0.38 h of sampling per 100 m of shoreline. Mean person-hours were applied to the mean number of sites across the two study years to reach the total species richness targets of 65, 75, and 90% (Table 2). The number of sites was always rounded up. The sampling design that required the fewest person-hours to reach the 65% target consisted of six 500-m nighttime electrofishing sites, which required approximately 26 person-hours. The most cost-effective design for attaining the 75% target comprised eleven 500-m sites, which were sampled with 148 person-hours. Conversely, the 300-m design required the fewest person-hours to capture 90% of total species richness (561 person-hours), as all rarefaction curves began to merge near the 90% target.

Contour plots using randomly selected samples collected from hard substrate, soft substrate, and wetland habitats illustrated that allocating more than 50% of nighttime electrofishing sampling to wetland habitat could increase the number of species captured with 10 total samples (Figure 5). Allocating 100% of nighttime electrofishing samples to wetland habitat resulted in the highest number of sampled fish species (41 species). Sampling only the soft substrate or hard substrate resulted in the lowest number of captured species.

TABLE 1. Summary of the fish species captured with nighttime electrofishing across coastal habitat types in the western basin of Lake Erie, 2011–2012. Habitat types were generated by combining the geomorphic habitat features into three categories: hard substrate (bedrock and bluff/bank); soft substrate (sand and clay); and wetland (coastal wetland and flooded river mouths).

Species	Hard substrate	Soft substrate	Wetland
Bigmouth Buffalo *Ictiobus cyprinellus*	3	6	2
Black Bullhead *Ameiurus melas*	0	3	3
Black Crappie *Pomoxis nigromaculatus*	5	7	9
Black Redhorse *Moxostoma duquesnei*	1	0	0
Bluegill *Lepomis macrochirus*	177	570	532
Bluntnose Minnow *Pimephales notatus*	0	38	147
Bowfin *Amia calva*	0	0	3
Brook Silverside *Labidesthes sicculus*	129	295	22
Brown Bullhead *Ameiurus nebulosus*	89	23	32
Channel Catfish *Ictalurus punctatus*	14	44	42
Common Carp *Cyprinus carpio*	135	190	206
Emerald Shiner *Notropis atherinoides*	1,014	1,390	874
Freshwater Drum *Aplodinotus grunniens*	199	313	111
Ghost Shiner *Notropis buchanani*	0	9	6
Gizzard Shad *Dorosoma cepedianum*	396	1,120	183
Golden Redhorse *Moxostoma erythrurum*	2	4	2
Golden Shiner *Notemigonus crysoleucas*	3	3	10
Goldfish *Carassius auratus*	6	49	124
Green Sunfish *Lepomis cyanellus*	0	17	4
Largemouth Bass *Micropterus salmoides*	137	475	257
Logperch *Percina caprodes*	56	47	6
Longnose Gar *Lepisosteus osseus*	5	0	2
Mimic Shiner *Notropis volucellus*	35	287	218
Northern Hog Sucker *Hypentelium nigricans*	1	0	0
Northern Pike *Esox lucius*	0	0	1
Orangespotted Sunfish *Lepomis humilis*	0	74	66
Pumpkinseed *Lepomis gibbosus*	4	265	221
Quillback *Carpiodes cyprinus*	47	29	15
Rock Bass *Ambloplites rupestris*	10	16	23
Round Goby *Neogobius melanostomus*	18	26	23
Shorthead Redhorse *Moxostoma macrolepidotum*	27	1	10
Silver Chub *Macrhybopsis storeriana*	0	1	0
Silver Redhorse *Moxostoma anisurum*	1	1	0
Smallmouth Bass *Micropterus dolomieu*	42	20	26
Smallmouth Buffalo *Ictiobus bubalus*	35	65	1
Spotfin Shiner *Cyprinella spiloptera*	36	77	48
Spottail Shiner *Notropis hudsonius*	23	347	92
Spotted Sucker *Minytrema melanops*	0	16	4
Rainbow Trout *Oncorhynchus mykiss*	0	0	5
Walleye *Sander vitreus*	6	2	1
White Bass *Morone chrysops*	89	210	42
White Crappie *Pomoxis annularis*	5	21	8
White Perch *Morone americana*	2,016	3,220	377
White Sucker *Catostomus commersonii*	3	2	0
Yellow Bullhead *Ameiurus natalis*	21	19	22
Yellow Perch *Perca flavescens*	4	15	27

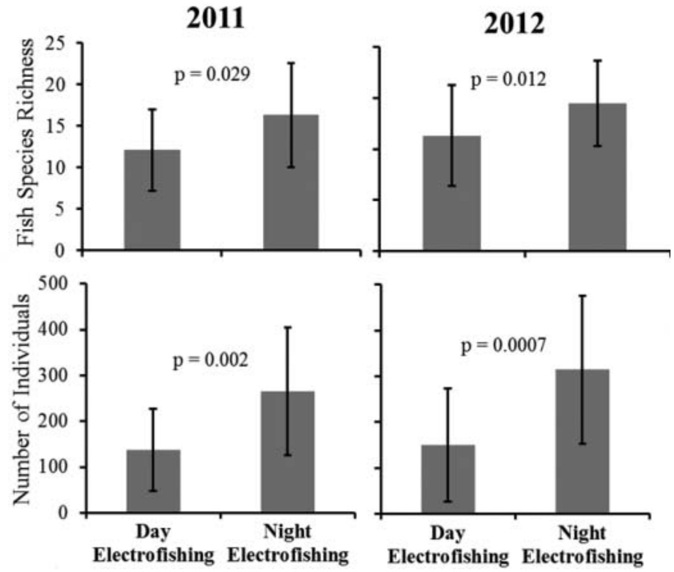

FIGURE 2. Mean (±SD) number of fish species captured and number of individuals captured during nighttime and daytime electrofishing in coastal waters of Lake Erie's western basin, 2011–2012. During both years and across sites, nighttime electrofishing captured significantly more species and more individuals than daytime electrofishing ($P < 0.05$; results of paired t-tests are shown on each panel).

Short-Term Changes in the Fish Community

For all fish community metrics, there was a slight decrease between 2011 and 2012 (Table 3), but Cohen's d was low (<0.2) in all cases. One metric (the number of nonnative species) significantly decreased between 2011 and 2012, but this comparison had low statistical power ($t = 2.53$, df = 17, $P = 0.02$; power = 0.31). According to the a priori-based power analysis (Figure 6), Cohen's d-values of approximately 1.7,

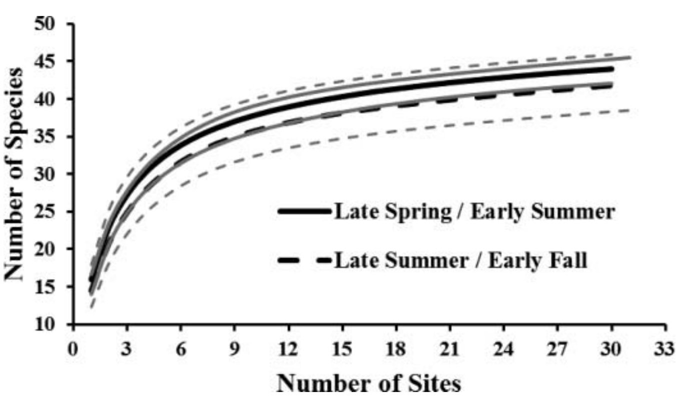

FIGURE 3. Sample-based rarefaction curves (±SD in gray) that were used to compare nighttime electrofishing samples between the early season (late spring and early summer) and late-season (late summer and early fall) periods in coastal waters of Lake Erie's western basin. Early season sampling accumulated species with fewer sites than late-season sampling, but variation overlapped.

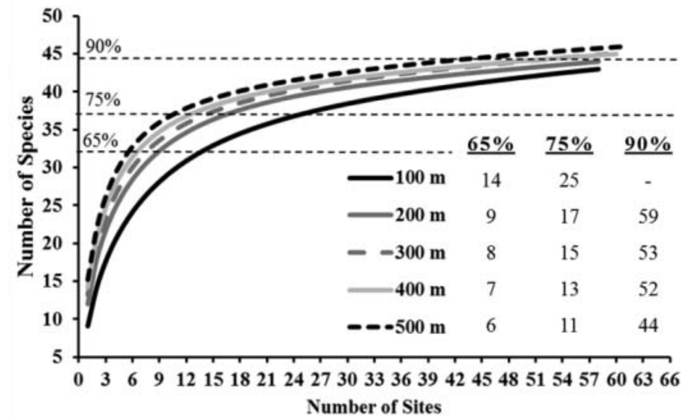

FIGURE 4. Sample-based rarefaction curves for the different sampling designs (distance [m] sampled per site) using nighttime electrofishing in coastal waters of Lake Erie's western basin. The numbers next to the legend reflect the number of sites that were required to capture 65, 75, and 90% of total fish species richness for each sampling distance. To attain the targeted percentages of species richness, fewer sites were required with the 500-m/site sampling design than with the 100-m/site design. Chao's (1987) richness estimator produced a total fish species richness estimate of 49.28 species for the coastal area of western Lake Erie.

0.9, and 0.4 would be required for sufficient statistical power to detect a significant difference with 6, 11, and 44 sites (i.e., the number of sites required to capture 65, 75, and 90% of total species richness). Rarefaction curves for fish community metrics indicated that the sampling of six sites to achieve 65% of total species richness did not capture all species within a given metric and resulted in high variability (Figure 7). Sampling of 11 sites to capture 75% of total species richness also generated high variability in community metric rarefaction curves but captured nearly all species in the metrics for nonnative, forage, and tolerant fishes. Sampling of 44 sites (to target 90% of total species richness) captured nearly 100% of the species in each metric and exhibited low variability; the exception was the metric for the number of native species, which maintained high variability and did not reach an asymptote when fewer than 60 sites were sampled.

DISCUSSION

We assessed the efficiency of multiple electrofishing scenarios by comparing various strategies for the spatial and temporal allocation of sampling effort so as to improve a coastal fish community survey for a large freshwater lake. Greater catchability of species and individuals during night than during the day can be explained by diel migrations and visual detection and avoidance of the gear (Paragamian 1989; Sanders 1992; Copp and Jurajda 1993; Dumont and Dennis 1997; Thoma 1999), which are driven by water clarity (Kocovsky and Stapanian 2011). Some studies recommend sampling during the day if Secchi depths are less than 1 m and sampling during the night

TABLE 2. Estimated effort (person-hours) and number of sites (in parentheses) for each sampling design (distance [m] sampled per site) to achieve the targeted species richness in coastal waters of Lake Erie's western basin. Person-hours were estimated based on the individual tasks listed in the results. The numbers of sites required to achieve 65, 75, and 90% of total fish species richness were determined from the rarefaction curves presented in Figure 4. Two sites were sampled per boat ramp; sampling was conducted with a three-member crew. Sampling designs that required the fewest hours of effort are shown in bold italics.

	Sampling design				
Percentage of total richness	100 m	200 m	300 m	400 m	500 m
65	119 (14)	90 (9)	86 (8)	87 (7)	***79 (6)***
75	216 (25)	168 (17)	166 (15)	159 (13)	***148 (11)***
90	603 (71)[a]	573 (59)	***561 (53)***	621 (52)	576 (44)

[a]Species richness was estimated using the method of Colwell et al. (2012).

if Secchi depths exceed 1 m (e.g., Bonar et al. 2009). However, switching from daytime to nighttime sampling at the 1-m Secchi depth threshold (e.g., Bonar et al. 2009) in a highly variable habitat would result in single sites being sampled using both criteria, which would reduce comparability. Due to the spatial and temporal variability in water clarity within Lake Erie coastal zones, the use of only nighttime electrofishing would maintain the ability to directly compare sites.

Differences in sampling efficiency between early season and late-season time periods may have been impacted by migration patterns. Fish aggregate in coastal margins for reproduction or foraging during spring and early summer, whereas they disperse when temperatures reach 20°C during mid-summer (Hall and Werner 1977). The selection of only early season sampling would reduce the ability of the nighttime electrofishing survey to describe seasonal use of habitat; for instance, detection of young-of-the-year fish in coastal zones will be greater during the late-season period (e.g., Knight and Vondracek 1993). Limiting the timing of sample collection may reduce the ability to relate environmental stressors to changes in the coastal zone fish community. For example, algal blooms in Lake Erie tend to occur during late summer (Depew et al. 2011; Stumpf et al. 2012; Bridgeman et al. 2013) and may affect fish community composition and abundance in coastal areas (Manning et al. 2013). Additionally, sampling in only the early season period or the late-season period may result in missing those species that are only present during one time period. Therefore, the final decision about sample timing or sample replication in a particular coastal system should include consideration of the specific questions that the monitoring program is intended to address.

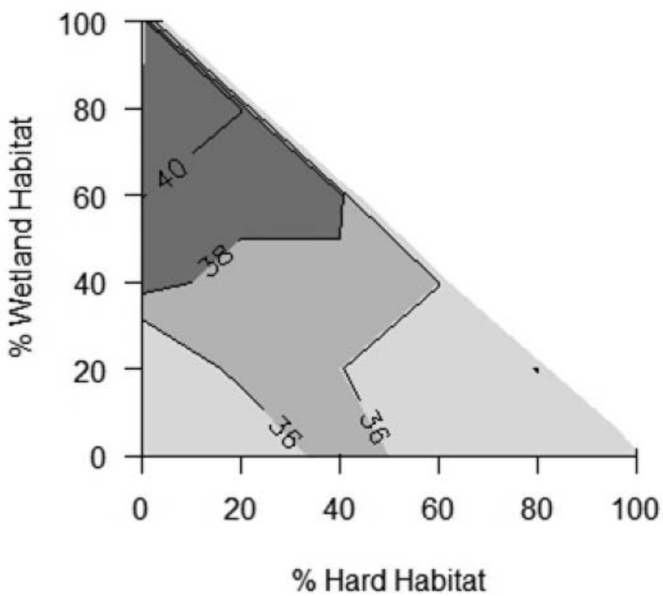

FIGURE 5. Contour plots of the total fish species richness obtained with 10 samples randomly drawn from a combination of samples collected from hard substrate, soft substrate, and wetland habitats in coastal waters of Lake Erie's western basin. The percentages of sites sampled from hard substrate and wetland habitats are shown on the axes; the percentage of sites representing soft substrate is therefore equal to 100% minus the combined hard substrate and wetland percentages at any point on the plot. Contours represent species richness; contours with darker shading reflect a greater number of fish species.

We chose the percentage of total fish species richness as a primary index of our monitoring program's ability to describe the coastal fish community, but the selection of specific metrics as well as target levels for a given metric should depend on the system of interest and the goals of the monitoring program. For example, the number of 500-m sites required to capture 75% of total species richness in our study was lower than the number of samples required in the St. Louis River/Duluth–Superior Harbor system (Trebitz et al. 2009). However, the 200-m/site design in our study was most similar to the Trebitz et al. (2009) findings based on multiple gear types. Therefore, our study and that of Trebitz et al. (2009) provide a starting point for others interested in improving sampling efficiency in a coastal fish community monitoring program.

Sampling enough sites in a large lake often requires a significant amount of travel time that can be expensive and can become unsafe, especially when the travel occurs at night. The coastal zone in Lake Erie, as in many lakes, contains structures such as boulders, logs, or sand bars that are not visible during the night and therefore can damage equipment or cause injury

TABLE 3. Results of *t*-tests and power analyses comparing fish community metrics between sampling years (2011 and 2012) based on 18 paired sites in coastal waters of Lake Erie's western basin (Cohen's d = effect size index). Only one metric (number of nonnative species) significantly decreased between years, but the comparison had low statistical power.

Metric	Mean (2011, 2012)	SD (2011, 2012)	Cohen's d	t	P	Power
Number of native species	12.47, 11.30	5.05, 3.19	0.28	1.05	0.31	0.20
Number of nonnative species	3.61, 3.07	1.59, 1.35	0.37	2.53	0.02	0.31
Number of forage species	4.53, 4.44	2.13, 1.87	0.04	0.17	0.86	0.05
Number of tolerant species	2.56, 2.37	1.37, 1.46	0.13	0.75	0.47	0.08

to personnel if a collision occurs. Furthermore, sampling for extended periods during the night increases personnel fatigue and can cause truck travel to become dangerous. In this study, truck travel time was the major factor that resulted in the sampling of fewer sites with longer distances per site as a less-time-consumptive strategy. Therefore, reducing truck travel time may be the most effective approach for decreasing effort and costs while creating safer working conditions.

Sampling fewer sites with longer distances per site does have drawbacks. First, it reduces spatial resolution and may result in the exclusion of specific habitat types. The use of fewer sites results in low statistical power, as adjacent 100-m segments within a site should not be considered independent replicates; however, this problem can be mitigated by sorting fish every 100 m along the transect within a site and employing a nested or blocked statistical design to examine the association between the fish community and coastal habitats. Indices of biotic integrity have been developed for 100-m sites (e.g., Minns et al. 1994). Therefore, maintaining 100-m units may be advisable to (1) increase spatial coverage and resolution (Palmer and White 1994), (2) simplify statistical analysis, (3) increase the ability to detect differences (Paller 1995), and (4) allow for addressing other hypotheses related to environmental stressors. Hence, maintaining shorter sampling distances within a site appears to be important, especially when the number of sites is limited by cost.

Targeting of wetland habitat in preference to soft substrate or hard substrates maximized the number of species captured via nighttime electrofishing. In Lake Erie, much of the wetland habitat occurs near river mouths or harbors that are frequented by freighters and recreational boats. Vessels often harbor nonnative species in their ballast water, which has been a major vector facilitating the spread of nonnative species (Grigorovich et al. 2003). Targeting of wetland may be beneficial in the early detection of these nonnative species, but monitoring that is focused solely on coastal wetland could result in missing species that are found in other habitat types. Use of a

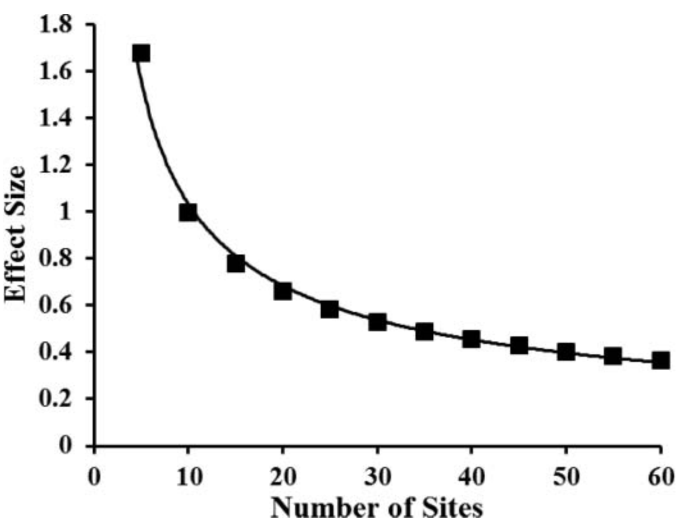

FIGURE 6. Relationship between the number of nighttime electrofishing samples (sites) and the effect size index (Cohen's d; Cohen 1988) assuming a power value of 0.80 and an α value of 0.05.

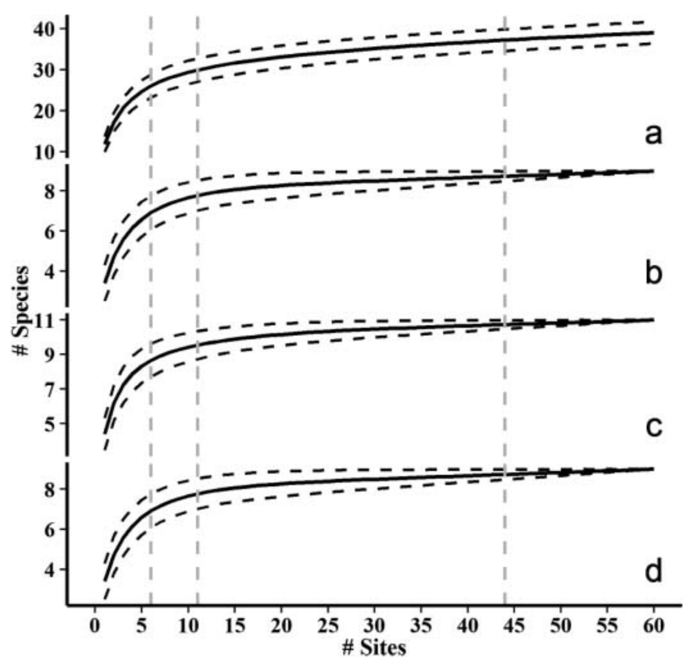

FIGURE 7. Rarefaction curves for important fish community metrics as measured from sampling in coastal waters of Lake Erie's western basin: **(a)** number of native species, **(b)** number of nonnative species, **(c)** number of forage species, and **(d)** number of tolerant species. Black dashed lines represent ±1 SD of the rarefaction curve; the gray dashed vertical lines indicate the number of samples required to capture 65, 75, and 90% of the total species richness (as depicted in Figure 4).

balanced sampling design that incorporates all habitat types will allow a complete representation of the coastal fish community in western Lake Erie. After the initial years of sampling with a balanced design, researchers will be able to evaluate whether the targeting of a specific habitat can meet the specific goals of an existing or new monitoring program.

Targeting 75% of total species richness (i.e., 11 sites in the present study) with nighttime electrofishing was sufficient for describing fish community metrics, as this design captured nearly all fish species that were relevant to each metric except for the number of native species. The native species rarefaction curve did not reach an asymptote, indicating either that our sampling effort was not enough to capture all species or that our effort did capture several species on single occasions. Single capture events for multiple species may be attributable to the presence of species that are rarely found in the coastal zone (i.e., normally found in other depth zones). Collating the data from all depth zones would allow a lakewide description of fish community status in Lake Erie and would support managers' ability to make informed decisions based on metric statuses.

Sampling of at least 11 sites will ensure that statistical power is sufficient to allow comparisons among years when large interannual differences exist. However, we observed Cohen's *d*-values less than 0.2 for fish community metric comparisons, and over 60 sites would have been required to achieve the appropriate statistical power. Interannual variability in species abundances and community structure can be related to water quality (Karr 1981; Ludsin et al. 2001; Drake and Pereira 2002; Drake and Valley 2005), shoreline alteration (Jennings et al. 1999; Toft et al. 2007), and changes in lake levels (Gertzen et al. 2012). The Great Lakes Fishery Commission and partnering agencies have recognized the importance of monitoring stressors and have been monitoring the lower trophic levels (Thomas et al. 2014) and habitat (Weimer et al. 2015) in coastal and nearshore zones. Additional years of data collection will be required to understand differences in the natural variability in community structure between years and changes related to environmental stressors.

An understanding of the manner in which sampling efficiency varies through space and time is important when developing fisheries monitoring programs. We hope to provide agencies with a starting point to optimize sampling efficiency for coastal fish community monitoring programs in the Great Lakes. We identified the most cost-effective design as one that encompassed nighttime electrofishing along 500 m of shoreline per site during late spring and early summer, with a target of approximately 75% of total fish species richness. However, sampling of 11 sites (75% target) allowed only for the detection of large effect sizes. Targeting of wetland habitat could increase the number of species encounters within a set number of samples but at the expense of focusing solely on one habitat type. Given that large-vessel monitoring is expensive, the addition of a less-expensive survey, such as a coastal monitoring program, to complement monitoring in other depth zones can provide additional information about fish community structure, thus allowing agencies to make more informed management decisions.

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