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[Article]

Point Sampling by Boat Electrofishing: A Test of the Effort Required to Assess Fish Communities

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Abstract.—Point sampling by electrofishing is often used to study fishes in large rivers and lakes whereby a specific location is electrofished without moving the anode. Short (1–5-s) samples are taken under the belief that many small samples are preferred over a few large ones for statistical analyses. However, this typically results in relatively little time spent sampling fishes compared with time spent measuring abiotic factors and traveling among sites. We evaluated the optimal sampling duration and number of replicates per site to balance sample size and number for community-level studies. In 2004, 165 point samples were taken from shallow Canadian waters of the Detroit River. Sites were continuously electrofished for 2 min (eight 15-s intervals), and a second replicate of 2 min was taken after a pause. Subsets of the data were used to compare various designs of sampling duration and number of replicates. A sampling design of two replicates of 1 min appeared to be ideal because it balanced a large gain of information with a small increase in effort. This design would allow 35–50 sites to be sampled per day, depending on the detail of abiotic measurements. Compared with data from the first 15-s interval only, sampling for two replicates of 1 min resulted in fewer null (no fishes captured) samples (19% instead of 53%). The number of common (found at >5% of samples) species also increased from 12 to 19. By increasing the effort for point sampling by electrofishing at each site, a better understanding of the fish assemblage was obtained. This allows for more complete analyses of community composition and habitat preference.

Much of the fisheries research in large rivers is restricted to shallow waters, owing to the difficulty of sampling deep, flowing waters. Several electrofishing techniques exist for sampling shallow waters, each of which is suited to particular objectives. Point abundance sampling by electrofishing (PASE; Nelva et al. 1979) is used to determine fish densities, to examine population structure, and to study the habitat preferences of fishes (e.g., Fladung et al. 2003). For PASE, a site is approached quietly and the anode (along with a dip net beneath it) is swiftly immersed for 1 to 5 s. The anode and net are then lifted, capturing any fishes stunned above the net (Copp et al. 1994). Point abundance sampling, developed by Blondel et al. (1970) for the study of bird populations, is based on the premise that more precise results are obtained from many small samples than from a few large ones. However, current methods for PASE may not be ideal for the study of the microhabitat preferences of juvenile and adult fishes because sampling duration is short and relatively little information is obtained about the fish assemblage at a site.

During PASE, field time may be spent in three ways: (1) collecting and processing fishes (e.g., identification, measurements), (2) measuring environmental variables, and (3) traveling between sites. Fish processing time will increase with abundance (which increases with the length of time a site is electrofished), while time spent measuring abiotic factors and traveling remains constant. Even if most environmental variables are estimated qualitatively and travel time is short, little time is actually spent sampling fishes if 1- to 5-s samples are taken (as with PASE).

It is difficult to determine exactly how long to electrofish because although species richness will continue to increase with effort, the rate of increase will diminish rapidly. The first direct test of sampling duration (the length of time a site is electrofished) for PASE was performed by Scholten (2003) who caged fishes in the vicinity of the anode and determined that sites should be electrofished for 10 s to ensure all fishes are captured. However, his tests were performed in 20 cm of water with low turbidity, a condition rarely met in large rivers. Additional replicates per site (point)

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have never been considered for PASE. However, if several minutes have been spent measuring environmental variables for a site, it may be worthwhile investing time in a second replicate provided this replicate is expected to yield additional information.

A design of many small samples provides relatively accurate estimates of the densities of common fishes, but most rare species are not captured, which leads to an incomplete picture of community structure (McCune and Lesica 1992). In general, a compromise between sample size and number is recommended for community-level analysis (McCune and Grace 2002). Such studies can provide information on the ecology of several species simultaneously and help to identify important habitats in need of conservation or restoration.

Our objective was to determine the optimal sampling design (sampling duration and number of replicates) to balance sample size and number for community-level studies.

Methods

Site description and selection.—The Detroit River is 51 km long and follows the Michigan–Ontario border, connecting Lake St. Clair to Lake Erie. The width of the river ranges between 600 m in the north and as much as 5 km in the south. Average flushing time and discharge are 19 h and 5,300 m^3/s, respectively (Bolsenga and Herdendorf 1993). Although 83 fish species have been reported in the Detroit River (N. W. R. Lapointe, unpublished data), many of these have only been observed in larval form, are seasonal migrants, are found only in the deep waters of the channel, or may be extirpated; therefore, 50–65 species were likely available for capture by electrofishing. Stratified random sampling was used to select 60 sites from shallow (<2.5-m) Canadian waters for a related project examining fish–habitat associations (Lapointe 2005). Sites were chosen using randomization macros in ArcMap 8.3 (ESRI 2003). To reduce the effects of spatial autocorrelation among sites, a minimum distance of 200 m between sites was arbitrarily selected.

Sampling.—Sites were electrofished using a Smith-Root 5.0 GPP boat electrofisher with a single anode array and pulsed DC (60 Hz, high voltage 1–1000 V). The percent of range setting was altered by site between 40% and 60% to maintain a current of 8 A. Sites were sampled in spring (June), summer (August), and fall (October) 2004 between 07:00 and 19:00. The boat was anchored over the site, which was then continuously electrofished for 2 min (eight 15-s intervals). A second continuous 2-min replicate was taken after a pause, during which environmental variables (depth, slope, flow, substrate, macrophytes, turbidity, conductivity, and water temperature; measurement details in Lapointe [2005]) were measured. This pause lasted 5–10 min, the amount of time required to measure all environmental variables. Each replicate was divided into eight 15-s intervals by placing the fishes captured during each interval into a separate container. A ninth container labeled "after" was used for fishes captured after a replicate was completed. All 60 sites were sampled in spring, but only 51 sites were sampled in summer and 54 in fall; a total of 165 samples.

To test if additional sampling time or replicates were required to significantly improve estimates of richness and abundance, 10 of the 60 sites were then sampled more intensively in October 2004. Five replicates were taken at each of the ten sites, each replicate a continuous 5-min period with a 5-min nonsampling period between replicates. Each replicate was divided with a timer into ten 30-s intervals. For all sampling, all fishes were identified to species, and the total length of up to 30 individuals of each species was measured at each site. All fishes were released after the final replicate.

Analysis.—Cumulative species curves (CSC) were generated from the 2-min data to determine if subsets of the sampling design were sufficient to sample the fish community (PC-ORD 4.14, McCune and Mefford 1999). Alternative sampling designs were simulated by using subsets of the 2-min data. These were compared with a CSC for the full data (two 2-min replicates). The richness captured and the second-order jackknife estimate of total species richness were calculated at the same time as the CSC. To determine which sampling design was most efficient, we determined the Pearson rank correlation between richness captured by each alternative design and richness captured by the full data.

A direct comparison was made between the 5- and 2-min data sets using the same 10 sites sampled by each method in October 2004. The average richness was calculated for a subset of alternative sampling designs from both data sets. To examine the relationship between environmental variables and the time of detection (the sampling duration before a species is first captured at a site), we used canonical correspondence analysis (CCA; CANOCO 4.53, Ter Braak and Smilauer 2004). A matrix of 165 samples containing the number of new species detected in each of the 18 (including "after") time intervals was created. Proportional environmental variables were arcsine square root transformed, and all other environmental variables were log + 1 transformed to improve normality (McCune and Grace 2002). We chose biplot scaling

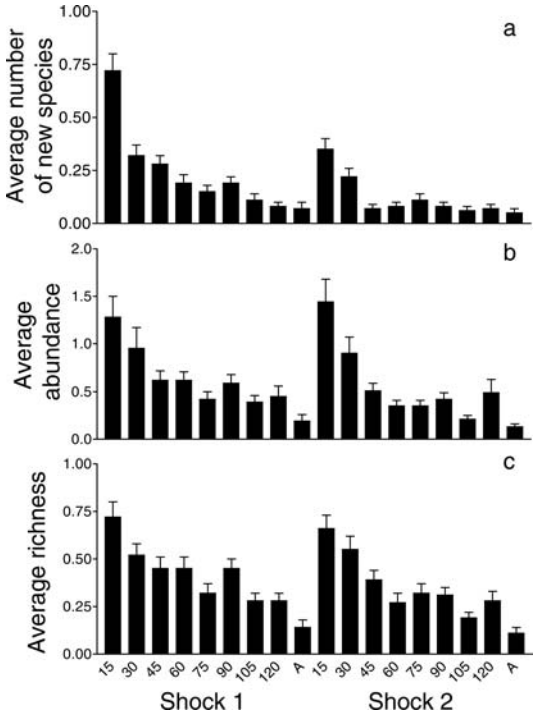

FIGURE 1.—Average (+SE) number of **(a)** new species, **(b)** abundance, **(c)** and richness captured in each 15-s interval for both replicates of the 2-min sampling design. Labels along the *x*-axis represent the sampling duration (in seconds) at the end of each interval (replicates presented separately); A = after (fishes that remained stunned and were netted after the sample was complete), $N = 165$.

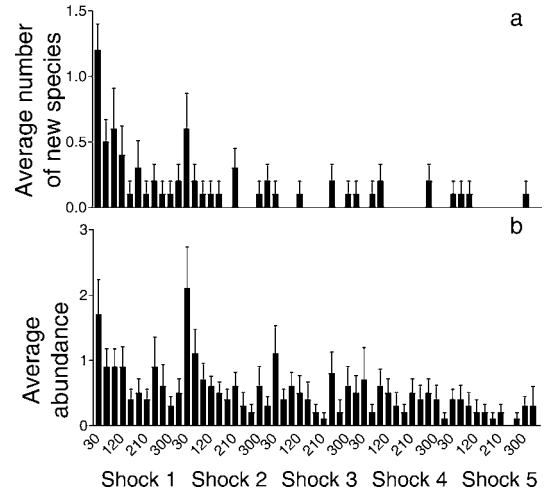

FIGURE 2.—Average (+SE) number of **(a)** new species and **(b)** abundance captured in each 15-s interval for all replicates of the 5-min sampling design in fall 2004. Labels represent the sampling duration (in seconds) at the end of each interval (replicates presented separately); A = after, $N = 10$.

focused on interspecies distances and manual stepwise selection of environmental variables. Monte Carlo permutations (9,999 permutations) were used to test the stepwise significance of adding microhabitat variables to the model and, therefore, their usefulness in determining the time of detection data (Ter Braak and Smilauer 1998).

Results

A total of 1,705 fishes was captured in the 2-min samples, representing 39 species in 14 families. A total of 334 fishes was captured in the 5-min samples, representing 23 species in 11 families. When only the first 15 s of the first replicate was considered, fishes were captured at 78 of 165 samples (47%). This increased to 134 (81%) when the first 60 s of each replicate was considered. Catches were dominated by cyprinids, centrarchids, and yellow perch *Perca flavescens* (scientific and common names of fishes according to Nelson et al. [2004]), all of which are all abundant in the river. Benthic species, such as round goby *Neogobius melanostomus*, were rarely captured despite being abundant in the river (MacInnis and Corkum 2000).

Water temperature (11–27°C), turbidity (Secchi disk: 15–225 cm), current velocity (0–1.4 m/s), mean depth (32.7–254 cm), and slope (0–23.3%) measurements varied throughout the sampling period. Each substrate class varied between 0% and 100% composition by site. Macrophytes were classed as either simple (i.e., grassy, such as *Vallisneria americana*) or complex (i.e., branching, such as *Potamogeton* spp.). Both complex and simple macrophytes varied between 0% and 100% cover among sites. Conductivity data were deemed unreliable because of equipment malfunction and measurement errors and were omitted from analysis.

The number of species captured in an interval but not captured in a previous interval (or replicate) was termed "new species richness." For the 2-min data, the highest number of new species, abundance, and species richness was captured in the first two replicates of each interval and generally continued to decline in later intervals (Figure 1). For the 5-min data, high abundance was captured in the first interval of the first three replicates (Figure 2). The greatest number of new species was captured in the first interval of the first two replicates, but few new species were captured by the third replicate (Figure 2).

Of the alternative sampling designs, the greatest number of species was captured at the fastest rate by the two replicates of 1-min design (Figure 3). This

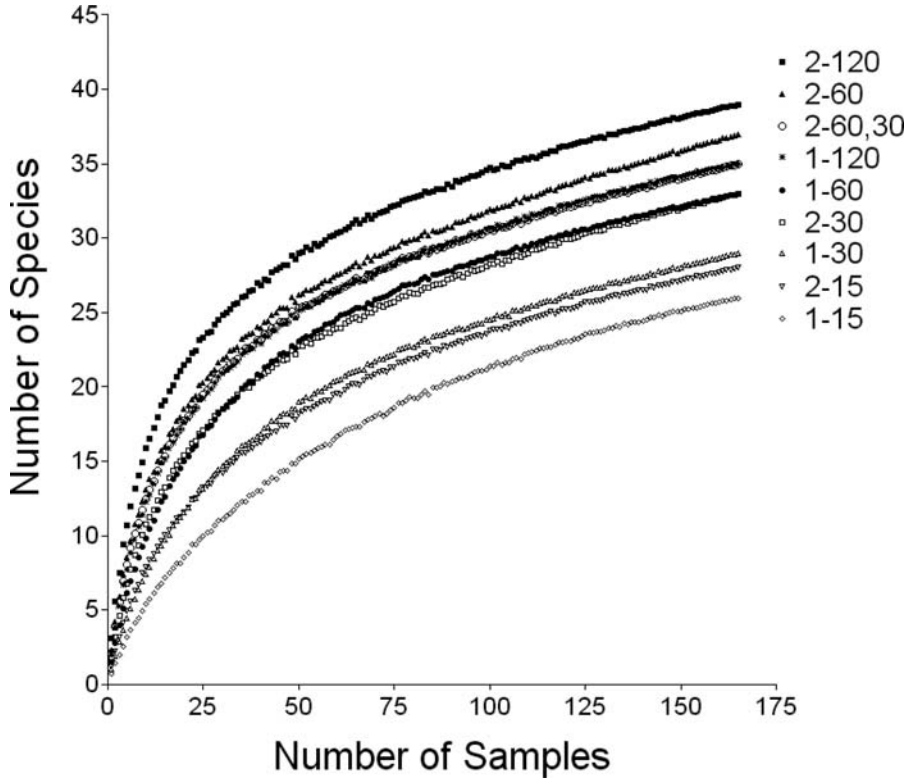

FIGURE 3.—Cumulative species curves for a selection of simulated sampling designs using subsets of the 2-min data. The legend represents the number of replicates–number of seconds simulated for each subset; $N = 165$.

design resulted in a second-order jackknife estimate of species richness that closely matched historical records for the sampling area (Table 1). Of all the alternative sampling designs, two replicates of the 1-min design was most strongly correlated with the full two replicates of the 2-min design.

TABLE 1.—Total richness (S), second order jackknife estimate of richness (J); and Pearson rank correlation with two 2-min replicates; (R) of simulated sampling designs. The "60, 30" entry here and in Table 2 denotes a design where only the first 60 s of the first replicate and the first 30 s of the second replicate were considered ($N = 165$).

Number of replicates	Seconds per replicate	S	J	R
1	15	26	38.9	0.6
	30	29	47.8	0.71
	60	33	47.9	0.82
	120	35	48.9	0.89
2	15	28	42.9	0.63
	30	33	47.9	0.78
	60	37	59.8	0.89
	60, 30	35	52.9	0.89
	120	39	51.9	1

A design of two replicates of 1 min each resulted in only 19% null samples, compared with 53% null samples when only the first 15-s interval was considered. When only the first 15-s interval was considered, 12 species occurred in more than 5% of samples. This increased to 19 species when the sampling design was increased to two replicates of 1 min each.

By comparing the 10 sites sampled by both 2- and 5-min designs in October 2004, we observed sharp increases in richness with increases in sampling time until the two replicates of 1 min was reached (Table 2). Adding additional sampling time or replicates resulted in relatively minor increases in species richness compared with the increase in effort.

The relationship between environmental variables and the time of detection was weak (Table 3). Only water temperature explained a significant ($p = 0.03$) portion of the variation in detection data. Turbidity was nearly significant ($p = 0.07$), but was included because it is known to reduce the effectiveness of electrofishing (Casselman et al. 1990). In general, it took longer to detect new species when waters were cool and turbid (Figure 4).

TABLE 2.—Average richness of simulated sampling designs calculated from actual data collected at 10 sites sampled in October 2004 by both 2-min and 5-min sampling methods.

Data set (min)	Number of replicates	Seconds per replicate	Total time (sec)	Average richness	Standard deviation
5	5	300	1,500	6.6	1.8
	5	60	300	4.1	1.1
	4	60	240	3.8	1.1
	3	60	180	3.7	1.1
	2	60	120	3.2	1.3
	1	60	60	1.7	0.8
2	2	120	240	4.4	1.7
	2	60	120	3.5	1.6
	2	60, 30[a]	90	3.1	1.3
	2	30	60	2.8	1.0
	2	15	30	1.9	1.1
	1	120	120	2.9	1.6
	1	60	60	1.9	1.4
	1	30	30	1.5	1.1
	1	15	15	0.9	0.7

[a] See Table 1.

Discussion

A sampling design of two replicates of 1 min appeared to balance a large gain of information with a small increase in effort. This design would allow 35–50 sites to be sampled per day, depending on the detail of abiotic measurements. Although Garner (1997) estimated that 150 samples could be taken per day (25/h) with measurement of environmental variables, this estimate seems excessive because sampling, processing, abiotic measurements, and travel must all be completed in 2.4 min per site. In practice, Carter et al. (2004) reported completing about 40 PASE samples/d, which seems more realistic based on our results.

Increasing sampling time will reduce the number of null (no fish captured) samples. Short-duration (1–5 s) samples often result in high percentages (~50%) of null samples that may be discarded prior to analysis (e.g., Copp et al. 1994). If null samples are discarded, the remaining sample size may be similar whether many sites were electrofished instantly or fewer sites were electrofished for an extended period. Given comparable sample sizes, extensive samples will be more valuable because they provide more information about the fish assemblage. Such additional information helps reduce the 0-truncation problem (Beals 1984) where sites lacking a species are all given equal weight (for that species) in multivariate analysis, regardless of whether habitat is very or marginally poor. When samples are not extensive, there is an additional risk that species will not be detected in preferred habitats. The frequency of occurrence of a species is also important for multivariate analysis because species found in less than 5% of samples (or similar criteria)

TABLE 3.—Results of CCA between the number of new species detected in each interval, and the corresponding environmental data ("species" refers to the 18 sampling intervals and units are the number of new species captured in each interval).

Statistic	Axis 1	Axis 2
Eigenvalues	0.077	0.060
Species–environment correlations	0.500	0.392
Cumulative percentage variance		
Species data	1.4	2.6
Species–environment relations	56.1	100.0

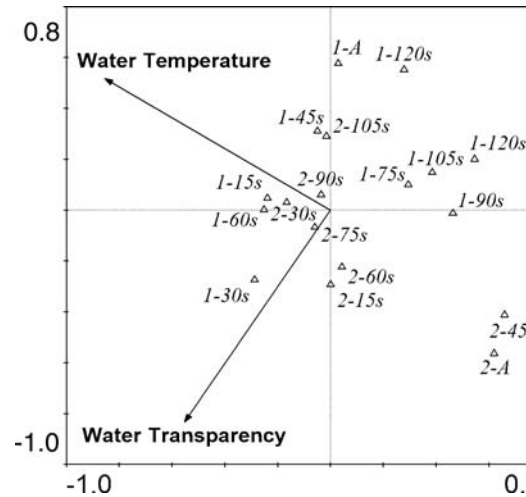

FIGURE 4.—Canonical correspondence analysis biplot of correlations between environmental variables and the number of new species detected in each interval. Turbidity is presented as water transparency because high values represent high Secchi disk readings. Triangles represent intervals (replicate number – sampling duration in seconds at the end of each interval); A = after, $N = 165$.

are often discarded (Gauch 1982). Increasing the effort per site will increase the frequency of occurrence across sites (especially for benthic or other species–size-classes with low catchability), allowing a more complete analysis of the fish assemblage.

The 5-min sample showed that a third replicate added little information. However, our 5-min sample size is small ($N = 10$), and depletion is a serious concern. At some point, the fish population surrounding a site may be depleted, and the fishes remaining in the area likely exhibit lower catchability (Bohlin and Cowx 1990). In our study, depletion is shown by the decrease in abundance over 25 min, even with pauses allowing recolonization. By the third replicate in our 5-min samples, the site has been depleted by 10 min of electrofishing and, therefore, catches in a third replicate may be higher if it is preceded by replicates of only 1 min. This concern may also be applied to the 2-min sampling design where the importance of a second replicate has likely been underestimated because of depletion from the second minute of the first replicate.

Fishes captured after the first 15 s may have been stunned instantly but only observed at a later interval, or may have moved into range after electrofishing began. It is appropriate to include these data in analyses of microhabitat preferences because the surrounding area likely contains similar microhabitat to the site itself. All stunned fishes should be collected, including those observed stunned after electrofishing ceases.

In general, it took longer to detect new species at sites with high turbidity and low water temperatures, although only a small amount of the variability in time of detection was explained by these factors. Conductivity would have likely explained a significant portion of the variation in detection data as well. Stunned fishes are less buoyant in cold water, which has lower conductivity (Reynolds 1996); therefore, more time is required for detection when cold, turbid waters are sampled. Scholten (2003) found that differences in conductivity can change the effective fishing range up to 50 cm in large rivers, and that the effective fishing range was highest over sandy substrates and lowest over mud. This can result in an area of attraction that is twice as large in the main channel of a large river compared with the floodplain (Scholten 2003).

For PASE, sites are traditionally selected by "a point of the finger with eyes closed" (Copp 1992) because computer generated sites would (at the time the strategy was created) have been impossible to locate in the field. However, with the development of geographical information system and Global Positioning System technologies, sites can be selected at random prior to field sampling. This is more objective than a point of the finger and allows temporal habitat use patterns to be examined by resampling exact locations at a later date (Lapointe 2005).

Recommendations

Further research is required to determine if a third (or more) replicate is worthwhile. Sampling efficiency could be maintained under a three-replicate sampling design by measuring half of the environmental variables during each pause. Additionally, our recommendations should be tested in other large rivers or lakes because the effort required to detect a given portion of the species richness depends on the total richness of the system (Meador 2005). Based on our results, we recommend a design of two replicates of 1 min each for assessing fish community composition and the microhabitat preferences of juvenile and adult fishes.

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