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Sample Sizes for Inland Lake Habitat and Lakeshore Development Metrics

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*Abstract.–*Sample sizes for two inland lake habitat, and three lakeshore development, metrics were evaluated for eight southern Michigan lakes, three large lakes, and three impoundments. Habitat metrics were index of vegetation cover and counts of submerged trees. Lakeshore development metrics were dwelling and dock counts, and percentage of shoreline armored. Metrics were sampled from a boat cruising parallel to the shoreline. Boat transects were 1,000 ft in length, as measured using a handheld Global Positioning System (GPS) unit. The entire shoreline was sampled for each lake or impoundment. For the eight southern Michigan lakes, bootstrapping techniques indicated that sampling 5 transects captured most of the variation for each metric. Only minimal increases in measured variation occurred by sampling 10 transects. Two additional levels of precision were considered using parametric methods. First was the sample size needed to detect maximum change in the mean value for each metric. Maximum change for vegetation cover was ±1 (change to an entirely different category), count of submerged trees was ±4, dwelling counts was ±10, dock counts was ±6, and percentage of shoreline armored was ±50%. Second was sampling effort required to detect relatively small changes in the mean where additional sampling would provide only modest improvements in precision. To detect maximum change for the eight southern Michigan lakes, a sample size of 2 transects was necessary for the index of vegetation, 1 for submerged trees counts and for dwelling counts, 4 for dock counts, and 2 for estimating the percentage of shoreline armored. Sampling effort required to detect relatively small changes in the mean was 15 transects for index of vegetation and submerged trees; and 20 for dwelling counts, dock counts and percentage of shoreline armored. Index of vegetation was not sampled for the three large lakes or the three impoundments. To detect maximum change for the three large lakes, a sample size of 1 transect was necessary for submerged trees counts, 3 for dwelling counts, 4 for dock counts, and 2 for estimating the percentage of shoreline armored. Sampling effort required to detect relatively small changes in the mean was 10 for submerged trees counts, 20 for dwelling counts, 25 for dock counts, and 20 for percentage of shoreline armored. To detect maximum change for the three impoundments, a sample size of 18 transects was necessary for submerged tree counts, 1 for dwelling counts, 3 for dock counts, and 2 for percentage of shoreline armored. Sampling effort required to detect relatively small changes in the mean was 30 for submerged tree counts, 15 for dwelling counts, 25 for dock counts, and 20 for percentage of shoreline armored. The finite population correction (fpc) term was not included in previously given sample size evaluations. An example of fpc benefit is presented; inclusion of fpc greatly increased the precision of mean dwelling count for the eight southern Michigan lakes. Measurement error introduced by GPS was evaluated for transect lengths of 100–2,000 ft. For a 1,000-ft transect, error was ±9.8% of transect length (±98 ft). Inclusion or exclusion of a metric unit (e.g., dock) in a transect is associated with lake lot width. For a minimum lot width of 60 ft, greatest reduction in edge effect was achieved with a transect length of 500 ft and only minimal improvements occurred for transects over 1,000 ft. For our study, a boat transect of 1,000 ft sampled a mean shoreline of 1,320.4 ft. Shoreline sampled per 1,000 ft boat transect was not significantly different between eight southern Michigan lakes, three large lakes, or three impoundments ($P = 0.63$). Similarly, shoreline sampled and lake circumference were not significantly correlated ($P = 0.88$), and shoreline sampled and shoreline development index were not significantly correlated ($P = 0.29$). Shoreline sampling for most Michigan lakes takes a minimal amount of time. Twenty-six transects can be sampled in ~1 h. Recommendations of this study are that the entire shoreline should be sampled for all lakes and impoundments less than 3,500 acres. For lakes and impoundments greater than 3,500 acres, a minimum of 30 randomly selected shoreline transects should be sampled, and additional transects should be sampled whenever possible.

Introduction

Human activities can negatively affect inland lake ecosystems through alterations in water quality and physical habitat. For example, increased nutrient loadings from septic seepage and lawn fertilizers can increase primary production, increase algae and aquatic vegetation to nuisance levels, and decrease concentrations of dissolved oxygen when excess algae and vegetation decompose. In addition, the quantity and quality of physical habitat available to fishes in the littoral zone can be altered by removal of coarse woody debris, by an increase or decrease (via chemical or mechanical removal) of aquatic macrophytes, and by homogenization of the shoreline through erosion control efforts (e.g., rip-rap and sheet piling). Such changes in water quality and habitat features have been shown to negatively impact fish growth (Schindler et al. 2000), limit natural reproduction of certain fish species (Rust et al. 2002), and reduce fish species richness and shift assemblage structure towards more tolerant species (Jennings et al. 1999). Consequently, monitoring, assessing, and regulating the influence of human activities on the condition of inland lake systems is necessary for sound management of these resources.

A primary goal of the Michigan Department of Natural Resources' Lakes Status and Trends Program (Hayes et al. 2003) is to monitor and assess the impacts of human activities on inland lakes. However, few guidelines are available for setting appropriate sample sizes for measuring human impacts, especially to assess status and detect trends for a large number of lakes distributed across the State. The allocation of sampling effort must strike a balance between collecting quality data for individual lakes and being able to rapidly assess conditions in a relatively large number of lakes.

The objective of this study was to evaluate sample sizes for characterizing littoral zone habitat and human lakeshore development for Michigan inland lakes. Metrics for this study were visually estimated vegetation and coarse woody debris abundance, counts of dwellings and docks, and estimates of the percentage of shoreline armoring. The goals of this study were to determine sample sizes required to characterize these metrics and to estimate sample sizes for varying levels of precision.

Methods

Study Site Habitat Characteristics

Eight southern Michigan lakes.–Eight southern Michigan lakes were selected for shoreline sampling (Table 1). Lakes varied in size from 29 to 796 acres. Shoreline development index (SDI) was measured for each lake using methods found in Orth (1983). Lakes were sampled during July and August during 2002 or 2003. These lakes are all found at approximately the same latitude (thus share similar annual temperature variation), have similar physical and limnological characteristics, and have similar fish species composition. Consequently, these lakes were considered similar and comparison of shoreline metrics appropriate.

Three large lakes and three river impoundments.–To further evaluate variability of the metrics measured in the eight southern Michigan lakes, all of which were less than 1,000 acres in size, three additional lakes (two of which were >1,000 acres in size) and three large river impoundments (two of which were >1,000 acres in size) were selected for sampling (Table 1). Shoreline development index was measured for each. Lakes and impoundments were sampled during July and August 2004. Characteristics of these three lakes and three river impoundments are quite different. They are found at different latitudes, physical and limnological characteristics are not similar, and fish species composition is quite variable. Consequently, placement of these water bodies in a single class would not be appropriate. The purpose in evaluating each metric's variability was to determine if variability was associated with lake size and characteristics. Specifically, this study compared sample size estimates for smaller lakes with lakes and impoundments that were quite different.

Data Collection

Lake habitat and lakeshore development metrics were visually assessed by boating during daylight hours. Data were recorded in 1,000-ft intervals and each transect was completed in ~2 minutes. Sampling crews consisted of 2–3 members and each person was responsible for collection of specific data. Handheld Global Positioning System (GPS) units (Garmin Map 76S) were used to measure transects within each lake. During data collection, the boat traveled approximately 100–200 ft from shore. The boat paralleled the shore with limited movement in and out from shore. Deviation from this path was done only to avoid structures such as docks.

Two habitat and three development metrics were selected for shoreline sampling. The habitat metrics were index of vegetation cover and counts of submerged trees (e.g., logs). The index of vegetation provided a measure of the percentage of the littoral zone that was occupied by aquatic macrophytes (emergent, submergent, and floating), and was estimated using five abundance categories (0% = 1, 1–25% = 2, 25–50% = 3, 50–75% = 4, and 75–100% = 5). The number of submerged trees large enough to provide fish habitat (>3 inches diameter) were counted as the boat moved along the shoreline. Any submerged trees visible between the boat and the lakeshore were counted. No effort was made to locate and count trees that were too deep to be readily visible from the boat.

Dwellings having obvious lake frontage were counted within each transect. Criteria for obvious lake frontage included: contiguous lawn from near edge of a dwelling to the near edge of the lake, and no road separation between a dwelling and the lake. Only dwellings located immediately along the shoreline were counted, visible dwellings occurring behind other shoreline dwellings were not counted.

Docks extending from the shore were counted. Docks piled on the shore and not in obvious use were not counted. Size of docks and number of hoists or mooring positions were not evaluated.

Percentage of shoreline, within a 1,000-ft transect, having armoring was visually estimated to the nearest 10% by each crew member and then averaged to the nearest 10% to obtain an estimate for the entire lake. Bank (shoreline) armoring included wood or steel sheet pilings, cement walls, or gabions positioned along the shoreline in a vertical or sloping position to prevent erosion. Loosely placed cobble with no structural support were considered armoring if it appeared that these structures were more than just a decorative border.

Sample Size Analysis

Two analyses of sample size (i.e., number of 1,000-ft transects) were completed for each metric. For the eight southern Michigan lakes, the number of samples necessary to provide an efficient estimate of metric means precision was determined. This was defined as the point at which the greatest gains in precision (reduction in SE) had occurred and additional sampling resulted in small gains in precision. For the eight southern Michigan lakes, three large lakes, and three impoundments, sample sizes were estimated to attain varying levels of relative precision (mean ± proportion of that mean). This provided an estimate of our ability to detect some given change in metric mean for each lake or impoundment.

Efficient Estimate of Precision

This analysis was done for the eight southern Michigan lakes only. Sample sizes necessary to provide efficient estimates for each lake-metric mean were calculated using bootstrapping techniques (Efron and Tibshirani 1993). Number of transects sampled varied from 1 to 30 per lake and metric. While only one of the sample lakes (Wamplers Lake) had circumference greater than 30,000 ft, the variation seen within this group of lakes was assumed to be representative of lakes found in Michigan. Following traditional bootstrapping techniques, sampling was done with replacement and up to 30 transects were considered for each lake.

The mean $\bar{x}_{l,m}$ for lake *l* and metric *m* was estimated as:

$$\bar{x}_{l,m} = n^{-1} \sum_{k=1}^{n} \left(\frac{\sum_{i=1}^{j} x_{l,m,i}}{j} \right), \tag{1}$$

with *j* transects sampled and *n* equal to 2,000 iterations. The standard error *SE* was estimated from the bootstrap standard deviation (Efron and Tibshirani 1993; Manly 1997) for mean $\bar{x}_{l,m}$ as:

$$SE_{l,m} = \left((n-1)^{-1} \cdot \sum_{k=1}^{n} \left[\theta_{l,m} - \left(\sum_{i=1}^{j} x_{l,m,i} \Big/ j \right) \right]^2 \right)^{0.5}, \tag{2}$$

with data set mean $\theta_{l,m}$. For each metric then, the coefficient of variation of the mean $CV_{\bar{x}l,m}$ was:

$$CV_{\bar{x}l,m} = \frac{SE_{l,m}}{\bar{\theta}_{l,m}}. \tag{3}$$

To provide relative measures for each metric, $CV_{\bar{x}}$ for each metric were averaged across lakes for each sample size (transects sampled).

Ability to Detect Change

A sample size equation for proportions was used to estimate sampling effort (number of 1,000 ft transects) required to detect specified changes in the mean value (i.e., precision) for each metric in each lake with 95% confidence. This analysis was done for all eight southern Michigan lakes, three large lakes, and three impoundments. Sample sizes $N_{l,}$ for each lake *l* and metric *m* were estimated as (Snedecor and Cochran 1989:52):

$$N_{l,m} = t^2 \frac{S_{l,m}^2}{L_{l,m}^2}, \tag{4}$$

with Student's *t* of 1.96 (α = 0.05) and standard deviation *S*. Approximate normality of data was assumed. The relative error *L* for precision *p* was:

$$L_{l,m} = \theta_{l,m} \, p, \tag{5}$$

with levels of precision p from 1% to 377%. For this analysis we selected a maximum detectable change in the mean value for each metric. This maximum detectable change represented a relatively large proportional difference in the mean (and low precision) and consequently required a low level of sampling to detect. For each metric we calculated sampling effort required to detect this maximum change in the mean and to detect 14 progressively smaller changes in the mean (Table 2). Progressively smaller values of detectable change represent increasingly higher levels of precision and consequently require larger sample sizes. Maximum detectable change in vegetation index was set at 1. A change of 1 in the index would mean that the index status shifted to a different category. Maximum detectable change was set at 4 for submerged trees, 10 for dwellings, 6 for docks, and 50% for armored shoreline.

Sample sizes were averaged for the eight southern Michigan lakes, for the three large lakes, and for the three impoundments. Underestimates of sample sizes from equation (4) were corrected following tables and methods given in Kupper and Hafner (1989). Detectible change and sample size were plotted for each metric. The inflection point for these plots represents the minimum sampling effort required to obtain relatively high levels of precision.

Finite Population Correction Term

The standard deviation S for each lake l and metric m was calculated for independent samples as:

$$S_{l,m} = \sqrt{\frac{\sum_{i=1}^{j}\left(y_{l,m,i} - \bar{y}\right)^2}{\left(j_{l,m} - 1\right)}} \quad , \tag{6}$$

with j transects sampled and y_i being the i^{th} sample. Excluded from our estimate of S for estimates of sample size was the finite population correction term (fpc). Including the fpc, equation (6) becomes:

$$S_{l,m} = \left(1 - \frac{j_{l,m}}{J_{l,m}}\right)\sqrt{\frac{\sum_{i=1}^{j_{l,m}}\left(y_i - \bar{y}\right)^2}{\left(j_{l,m} - 1\right)}} \quad , \tag{7}$$

with total number of transects J for lake l. Equation (7) then, provides an estimate of S that accounts for the proportion of the entire shoreline that is sampled. Additional evaluations and effect of inclusion of fpc (i.e., equation (7)) were conducted for a sample data set with mean 1.0 and $S^2 = 10$, and for dwelling counts at the eight southern Michigan lakes with varying proportions of shoreline sampled. The goal of the sample data set was to estimate the number of transects necessary to achieve a relative standard error (RSE) less than or equal to 1.0 for lakes of sizes 25, 124, 247, 1,236, 2,471, and 12,355 acres with and without the fpc. Relative standard error is the standard error relative to the mean (SE/mean). For the dwelling counts, comparisons were made between lakes with fpc equal to 1.0 and fpc equal to 0.1 (i.e., 90% of population sampled).

Evaluation of Shoreline Transect Length

Sources of variation.–To evaluate shoreline transect length we considered two potential sources of variation. The first was the variation associated with our GPS unit. For this study we used a 2002-03 Garmin model Map 76S (Garmin International Inc.). Variation introduced by the GPS unit (V_{GPS}) was expressed as a percentage with manufacturer's reported unit error rate e and transect length l:

$$V_{GPS} = 100 \cdot \frac{2e}{l}. \tag{8}$$

Potential variation introduced by the GPS unit considered estimation of the beginning and ending points of a transect and transect length from 100 to 2,000 ft evaluated in 100-ft intervals.

Second, we considered the judgment error associated with including or excluding a metric unit in a count transect. Specifically, we evaluated lot width w relative to transect length expressed as a percentage:

$$V_w = 100 \cdot \frac{2w}{l}. \tag{9}$$

Lot width effect was considered for both the beginning and the ending of a transect. With rare exceptions, minimum lake lot width on inland Michigan lakes is 60 ft (i.e., lots wide enough to accommodate a dwelling). As lot width increases, metrics such as dwellings or docks are more widely dispersed within a transect and less likely to fall on a transect edge. Consequently we only considered lot widths of 60 ft.

Estimate of actual shoreline sampled.–Sampling of habitat and development metrics was done by traversing each lake parallel to the shoreline approximately 100–200 ft from the shore. Since the circumference of the boat path was less than the circumference of the lake, our boat transects represented greater shoreline transects. To estimate shoreline transects, we compared total boat transect circumference to lake circumference for each lake. We evaluated effects of lake size (acreage), circumference, and SDI on estimated shoreline transects.

Results

Study Site Habitat Characteristics

Eight southern Michigan lakes.–Shoreline development index varied from 1.18 at Round Lake to 2.11 at Half-Moon Lake (Table 1). Number of 1,000-ft transects varied from 5 at Chenango Lake to 26 at Wamplers Lake. Mean vegetation index for individual lakes varied from 1.00 at Round Lake to 5.00 at Chenango Lake (Table 3). Vegetation index was not measured at Sand Lake. Five of seven lakes had mean vegetation indices less than 2. Mean number of submerged trees varied from 0.22 at Round Lake to 4.00 at Crooked Lake. Submerged trees were not counted at Sand Lake. Three of seven lakes had less than 1 tree per 1,000-ft transect. Shoreline dwellings varied from 0.20 per 1,000 ft at Chenango Lake to 13.74 at Sand Lake. Four of eight lakes had more than 10 dwellings per 1,000 ft of shoreline. Mean number of docks per 1,000 ft of shoreline varied from 0.40 at Chenango Lake to 12.39 at Sand Lake. Six of eight lakes had mean dock counts of 5 or more. Percentage of armored shoreline varied from 0.00% at Chenango Lake to 63.46% at Wamplers Lake. Two of eight lakes had more than 50% of their shoreline armored.

Three large lakes and three river impoundments.–Shoreline development index was more varied for this group. For the three large lakes, SDI varied from 1.50 at Houghton Lake to 4.26 at Lobdell Lake (Table 1). Shoreline development index was greater for all impoundments and varied from 3.30 at Croton to 8.59 at Moores Park. Number of 1,000-ft transects sampled per lake varied from 45 at Missaukee Lake to 145 at Houghton Lake. Number of transects sampled at the impoundments varied from 65 at Croton to 91 at Moores Park.

Vegetation index was not collected for any of the three large lakes or the three impoundments (Table 3). Mean number of submerged trees varied from 0.09 at Missaukee Lake to 1.09 at Lobdell Lake. Houghton Lake was similar to Missaukee Lake and had a mean tree count of 0.10. Submerged trees were not counted at Moores Park. Croton had 3.37 trees per 1,000 ft of shore line and Kent had 4.70. Shoreline dwellings varied from 10.69 per 1,000 ft at Missaukee Lake to 15.47 at Houghton Lake. Lobdell Lake was similar to Missaukee Lake with 10.81 dwellings per 1,000 ft of shoreline. For the impoundments, Kent had the fewest number of dwellings (0.01) and Croton the greatest (6.80). Mean number of docks per 1,000 ft of shoreline varied from 6.98 at Missaukee Lake to 11.53 at Lobdell Lake. Houghton Lake was similar to Lobdell Lake with 10.38 docks per 1,000 ft of shoreline. Croton had greatest number of docks (7.03/1,000 ft) for any of the impoundments, while Kent and Moores were similar at 0.21 and 1.50, respectively. Percentage of armored shoreline varied from 25.67% at Missaukee Lake to 86.69% at Houghton Lake. Lobdell Lake was similar to Houghton Lake with 72.23% of shoreline armored. For the impoundments, Kent had the least percentage of its shoreline armored (14.00%) and Croton the greatest (43.69%). Moores Park had 30.25% of its shoreline armored.

Sample Size

Efficient estimate of precision for eight southern Michigan lakes.–For all metrics, the greatest improvement in precision of means occurred between 1 and 5 transects sampled (Figure 1). Only minimal improvements occurred when more than 10 transects were sampled.

Vegetation index required the least sampling effort to provide precise estimates of means. With 5 transects sampled, mean CV was 15.4%, and by 30 transects, sampled CV decreased to 6.1%. Submerged tree counts was the most variable metric when few transects were sampled. With 5 transects sampled, mean CV was 68.0% and decreased to 28.0% with 30 transects sampled.

Precision of dwelling and dock counts, and percentage of shoreline armored were similar. With 5 transects sampled, mean CV values were 38.5% (dwellings), 38.6% (docks), and 43.3% (armoring). Similarly, with 30 transects sampled mean CV values were 15.4% (dwellings), 15.5% (docks), and 17.3% (armoring).

Ability to detect change for eight southern Michigan lakes.–For these lakes, the average number of transects needed to detect our predetermined levels of maximum change with 95% confidence was 2 for the index of vegetation (maximum detectable change = 1) (Figure 2), 1 for counts of submerged trees (4) (Figure 3), 1 for dwelling counts (10) (Figure 4), 4 for docks (6) (Figure 5), and 2 for shoreline armoring (50%), (Figure 6). The average number of transects required to detect relatively small changes in the mean (as determined from the inflection points in Figures 2-6) varied from 15 for the index of vegetation (detectable change = ±0.39) and counts of submerged trees (±1.23), to 20 for dwellings (±2.93), docks (±2.65) and percent shoreline armoring (±15.70%).

Three large lakes and three river impoundments.–Index of vegetation was not sampled at any of the three large lakes or three impoundments.

For the three large lakes, the average number of transects needed to detect our predetermined levels of maximum change with 95% confidence was 1 for counts of submerged trees (Figure 7), 2 for dwelling counts (Figure 8), 3 for docks (Figure 9), and 2 for shoreline armoring (Figure 10). The average number of transects required to detect relatively small changes in the mean (inflection points in Figures 7-10) varied from 10 for counts of submerged trees (detectable change = ±0.67), to 20 for dwellings (±3.65), 25 for docks (±2.35), and 20 for percent shoreline armoring (±15.02%).

For the three impoundments, the average number of transects needed to detect our predetermined levels of maximum change with 95% confidence was 18 for counts of submerged trees (Figure 11), 1 for dwelling counts (Figure 12), 2 for docks (Figure 13), and 2 for shoreline armoring (Figure 14). The average number of transects required to detect relatively small changes in the mean (inflection points in Figure 11-14) was 30 for counts of submerged trees (detectable change = ±3.07), 15 for dwellings (±2.06), 25 for docks (±1.87), and 15 for percent shoreline armoring (±18.50%).

Finite population correction term.–When the finite population correction term (fpc) was not included, for the 25- and 124-acre sample lakes a relative standard error (RSE) of less than 1.0 was not achievable (Table 4). For the larger lakes (247, 1,236, 2,471, and 12,355 acres), a RSE of 0.95 was achieved with 11 shoreline transects. Relative standard error decreased with increasing number of transects sampled. Most precise estimate from this example (RSE = 0.35) was for the 12,355-acre lake with 80 transects sampled.

Inclusion of fpc provided RSE less than 1.0 for all lakes (Table 5). The 25-acre lake required that the entire shore (assuming 1,000 ft transects) be sampled, while the remaining lakes required less than complete enumeration of the shoreline. Relative standard error for the four lakes varying in size from 124 to 2,471 acres was acceptable (≤1.0) with 8 transects; the largest lake had an acceptable RSE (0.89) with 11 transects.

Excluding fpc decreased precision of dwelling counts for all eight of the southern Michigan lakes (Figure 15). As a result, dwelling estimates had lower power to distinguish differences among lakes. Inclusion of fpc, in our example fpc equal to 0.1, improved precision and statistical power to distinguish differences among lakes (Figure 16).

Shoreline Transect Length

Sources of variation.–Manufacturer's documentation indicated that the GPS unit used in this study had on average 49 ft of measurement error. Error introduced by the GPS unit was minimal with a 400-ft transect length (Figure 17). This error was reduced to 14% of transect length with a 700-ft transect. That is, a GPS measured transect length of 700 ft was probably from 602 to 798 ft in length. At 2,000 ft, GPS error was less than 5% of transect length and a 2,000 ft GPS measured transect length was 1,902–2,098 ft in length.

Similar to GPS error, greatest reduction in lot size effect was achieved with 500-ft transect (Figure 17). With transects of 700, 1,000 and 2,000 ft, 82.9, 88 and 94%, respectively, of the transects were occupied with uninterrupted lots.

Estimate of actual shoreline sampled.–Mean actual shoreline sampled per 1,000-ft transect was 1,310.8 ft (S = 129.9) for the eight southern Michigan lakes, 1,276.6 ft (S = 167.2) for the three large lakes, and 1,389.9 ft (S = 184.4) for the three impoundments (Table 1). Grand mean for all 14 water bodies was 1320.4 ft (S = 142.2). Boat transects represented 75.7% (1,000/1,320.4) of actual shoreline. Actual shoreline sampled was not significantly different between the three groups of water bodies (ANOVA, df = 13, F = 0.477, P = 0.633).

Circumference and SDI did not have a significant effect on actual shoreline sampled. Actual shoreline sampled regressed on circumference was not significant (df = 13, F = 0.026, P = 0.876) and actual shoreline sampled regressed on SDI was not significant (df = 13, F = 1.215, P = 0.292).

Discussion

The purpose of Fisheries Division's Status and Trends Program is to characterize metrics associated with classes of lakes. These characterizations will allow statewide measures of status and trends, and provide a management framework for comparisons of individual lakes to appropriate clusters sharing physical and chemical characteristics.

Essential to any sampling program is the reliable measure of the metrics used to create classification strata. Reliable measures depend on three key components. First, selected metrics must be appropriate measures of lake physical or chemical attributes. The metrics used in this study have been shown to be important in determining the ecological potential of inland lakes (Jennings et al. 1999; Schindler et al. 2000; Rust et al. 2002). For example, submerged trees and vegetation cover can influence fish survival and growth by providing critical feeding areas that offer refugia from predation. Because human development can adversely affect water quality and the quantity of nearshore habitat, measures of the intensity of human activity (e.g., number of dwellings and docks) should help explain biotic and abiotic differences observed among lakes.

Second, any sampling program must provide randomly selected samples of a given metric. Non-random samples, such as quota or convenience samples, are problematic in that they give measures that are not representative of the population being estimated (Peterson et al. 1999); they do not provide measures that may be expanded to a larger area (Thompson et al. 1998); the extent of bias (that is, error) introduced is not known (Snedecor and Cochran 1989); and the use of basic statistical formulas, theory, and inferences are not applicable (Remington and Schork 1970; Ferguson 1976; Cochran 1977). Pollock et al. (1994) noted that:

"A sampling procedure must be consistent with sound statistical principles or it will be impossible to establish the properties of the estimators obtained from the sample in terms of bias, precision, and accuracy. Samples drawn subjectively to cut costs or to be vaguely representative are useless."

Third, a sample must be large enough to reliably characterize the true population metric (Wiley et al. 1997). From a practical standpoint, a sample of 1 or 2 drawn from a population of, say, 50 has a low probability of reliably reflecting that population mean (assuming that the population does not have a uniform distribution). Assuming unbiased sampling, as the number of samples increases the probability of the sample mean reliably reflecting the population mean increases. When an estimate is based on a sample of 1, the standard deviation cannot be calculated and the precision of that sample is unknown. Continuing then, if an estimate is based on a sample of 2, the standard deviation can be calculated but is based on minimal information. That is, the observed variability may not reliably represent the total variation (e.g., Wiley et al. 1997). Total variation is the sum of two components, the sample variation observed from a given sample size and the unsampled variation from the remainder of the population. As sample sizes increase, the proportion of unsampled variation decreases. Since the entire shoreline from each of our eight southern Michigan lakes was sampled, we were able to estimate the total variation associated with sample sizes for each metric. Results of bootstrapping estimates of coefficient of variation indicate that a minimum of 5 randomly selected 1,000-ft transects must be sampled to characterize each of the metrics sampled, assuming that the fpc is negligible. Sampling fewer than 5 transects will provide unreliable estimates of each metric and would certainly produce unreliable estimates of the variation associated with each.

For any estimate to be useful, the proportional variation of that estimate must be efficient given some optimal level of sampling effort. Variability of an estimate may be due to clustering of individuals or rarity of individuals. Stratification of sampling will effectively reduce estimate variability but requires a priori data and stratification by one metric may not be appropriate for another (e.g., Lockwood 1999). Estimates of rarely occurring individuals or features typically require substantial sampling effort or specialized sampling techniques such as adaptive cluster sampling (Thompson et al. 1998). However, even imprecise estimates of rare individuals or features indicate their rareness and slight (even doubling) changes may not be noteworthy. For most lake-metric estimates, greatest reduction in variability occurred with samples of approximately twenty 1,000-ft transects.

Estimated precision of the three large lake and three impoundment metrics, and consequently sample size, were similar to that of the eight southern Michigan lakes. Sample size methods and assumptions for the eight southern Michigan lakes appear to be quite robust and applicable across Michigan inland lakes.

Our estimates of sample size for given levels of precision do not take into account the effect of the finite population correction term (fpc). In fact, since the entire shoreline of each lake or impoundment was sampled, the estimated *SE* for each lake and metric was 0.0. Our guidelines for sample size are designed to be conservative, particularly since most Michigan lakes are small enough to allow complete shoreline enumeration. Wamplers Lake (797 acres), for example, took approximately 1 h to sample. Houghton Lake, the largest inland lake in Michigan at 20,075 acres took 8 h to sample. Interpolating then, a 3,500-acre lake would take 2 h to sample. Michigan has 5,944 lakes greater than 10 acres and only 28 lakes greater than 3,500 acres.

For this study 1,000-ft shoreline transects were sampled to estimate each metric and handheld GPS units were used to measure each transect. Two sources of potential edge-effect error were considered and the shoreline transect length was scaled to minimize each error source. First was the error introduced by the GPS unit. Greatest reduction in error was realized at a shoreline transect length of 400 ft. Reduction in GPS-introduced error was 1% per 100 ft increase in shoreline transect at 1,000 ft and only minimal reductions in error were realized with additional shoreline transect length. Consequently, GPS measurement error was considered inconsequential by 1,000 ft. Second was the judgment error associated with including or excluding a metric unit in a count transect. Similar to GPS introduced error, greatest reduction in error was realized by a shoreline transect of 500 ft. Reduction in error per 100 ft of shoreline was 1.5% at 1,000 ft with only minimal decreases for additional 100-ft increments.

Actual shoreline length was greater than boat transect length due to distance our sampling boats traveled from shore. Distance from shore was consistent across water bodies and actual shoreline length was not related to circumference or SDI. However, we recommend reporting each metric by boat transect and actual shoreline transect. When the entire shoreline is sampled actual shoreline transect length may be directly determined. When random samples of shoreline are taken, we recommend using 1,320.4 ft as the estimated shoreline sampled per 1,000-ft boat transect.

Recommendations

We recommend that all Michigan lakes and impoundments be sampled with procedures based on area. Estimated mean for each of the metrics proved reliable with 5 transects sampled. Evaluations of precision for each metric indicated variation of estimates stabilized with 20–30 transects sampled per lake. Shoreline sampling for most lakes takes a minimal amount of time. Wamplers Lake with 26 transects sampled required ~1 h and 99.5% of all Michigan lakes should take less than 2 h.

1. For small-medium lakes (<3,500 acres) we recommend sampling the entire shoreline.
   When the circumference of a lake is large (>3500 acres) or sampling time limited, we recommend a single systematic sampling design (Cochran 1977; Thompson et al. 1998). This design is easy to execute and provides an unbiased estimate of the mean (Cochran 1977:206). Therefore, the following recommendations are made:
2. All shoreline boat transects should be 1,000 ft in length.
3. All metric information should be recorded for each 1,000-ft boat transect.
4. All metric information should be reported per 1,000 ft of boat travel and actual (or estimated using 1,320.4 ft) shoreline sampled.
5. For lakes exceeding 3,500 acres, sample 30 transects starting from a randomly selected shoreline position with necessary spacing between transects to end equidistance from the starting location.

Example

A lake is 3,600 acres in size with circumference of 88,785 ft. Since the boat transect circumference will be less than the actual shoreline circumference, multiplying the actual circumference by 75.7% yields boat transect circumference of 67,210 ft (rounded to the nearest foot). Randomly pick an integer between 1 and 67,210. Suppose that integer is 2,130. With 30,000 ft to be sampled, 37,210 ft will be unsampled. Dividing 37,210 ft by 30 gives 1,240.3 ft of unsampled boat transect between each 1,000 ft transect. For this example then: (1) randomly select direction of travel from the launch site (e.g., coin toss to determine clockwise or counter clockwise direction of travel); (2) from the launch site travel 2,130 ft, sample 1,000 ft of shoreline, skip 1,240.3 ft of shoreline, sample 1,000 ft of shoreline, and continue until all 30 transects have been completed.

Note: all 1,000-ft transects along a lake's shoreline may be sampled (even though acreage is >3,500) if time is available and/or the crew determines that it is easier or more efficient to sample the entire shoreline rather than a portion of it. The length of the last transect sampled will no doubt be unequal to 1,000 ft. In this situation record the length of the last transect for each of the metrics.

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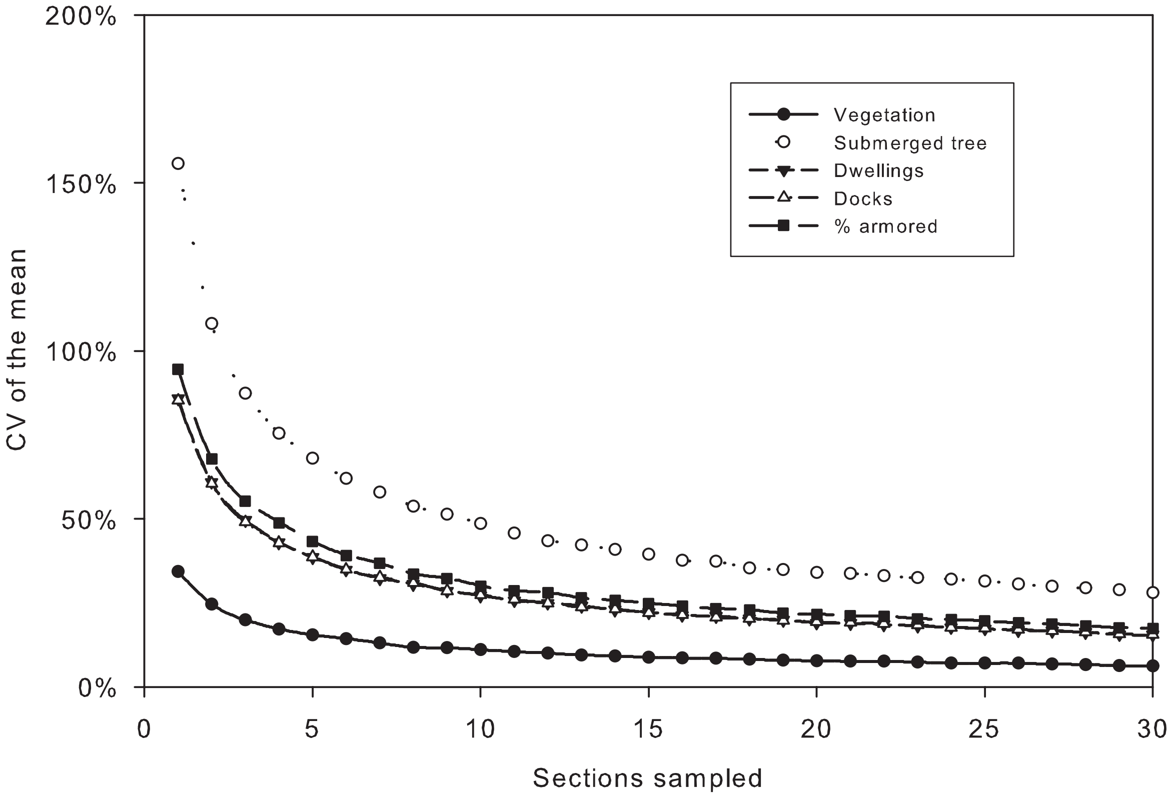

Figure 1.−Bootstrap estimates of coefficient of variation of the mean ($CV_{\bar{x}}$) for two habitat and three shoreline development metrics in relation to number of 1000-ft transects sampled. $CV_{\bar{x}}$ for each metric and transects sampled were averaged across lakes to provide relative measures of precision.

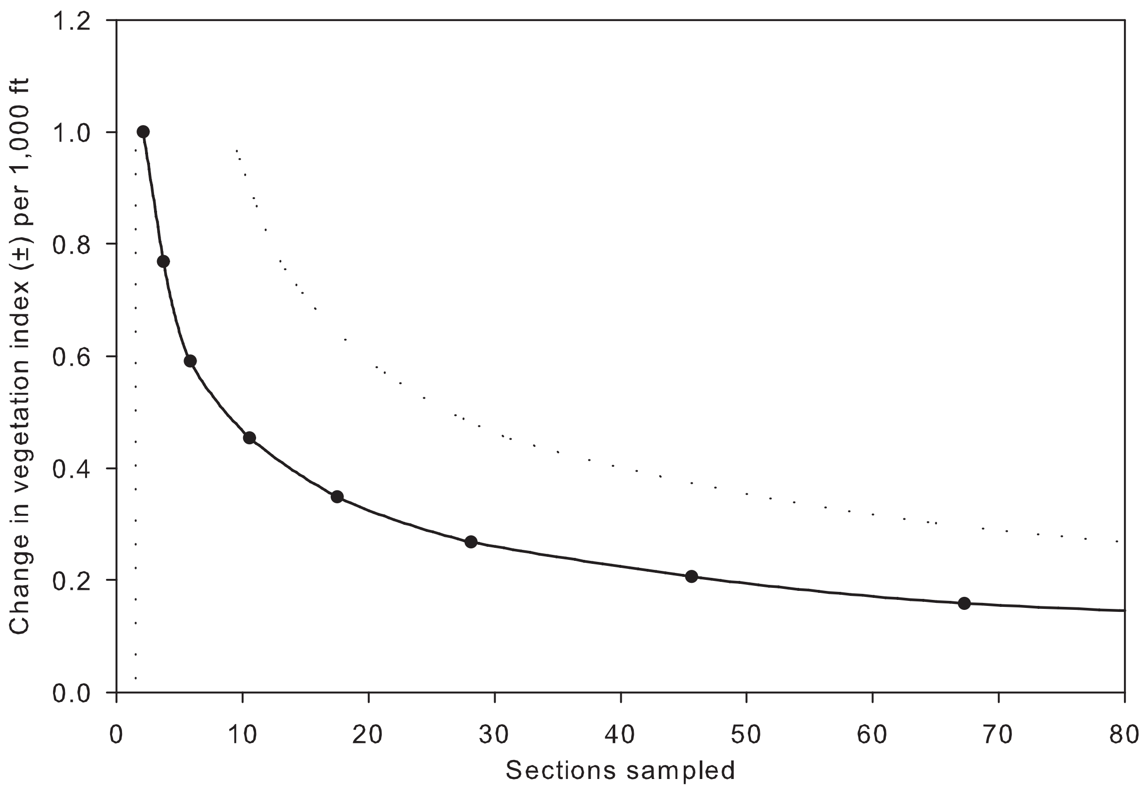

Figure 2.−Detectable change in mean vegetation index by sections sampled (1,000-ft transects) for seven southern Michigan lakes (vegetation index was not measured at Sand Lake). Sample size estimates were averaged across lakes for a given level of change. Estimates of precision are for α = 0.05. Dotted lines represent minimum and maximum values from individual lakes. The minimum dotted line has been offset to improve visual perception.

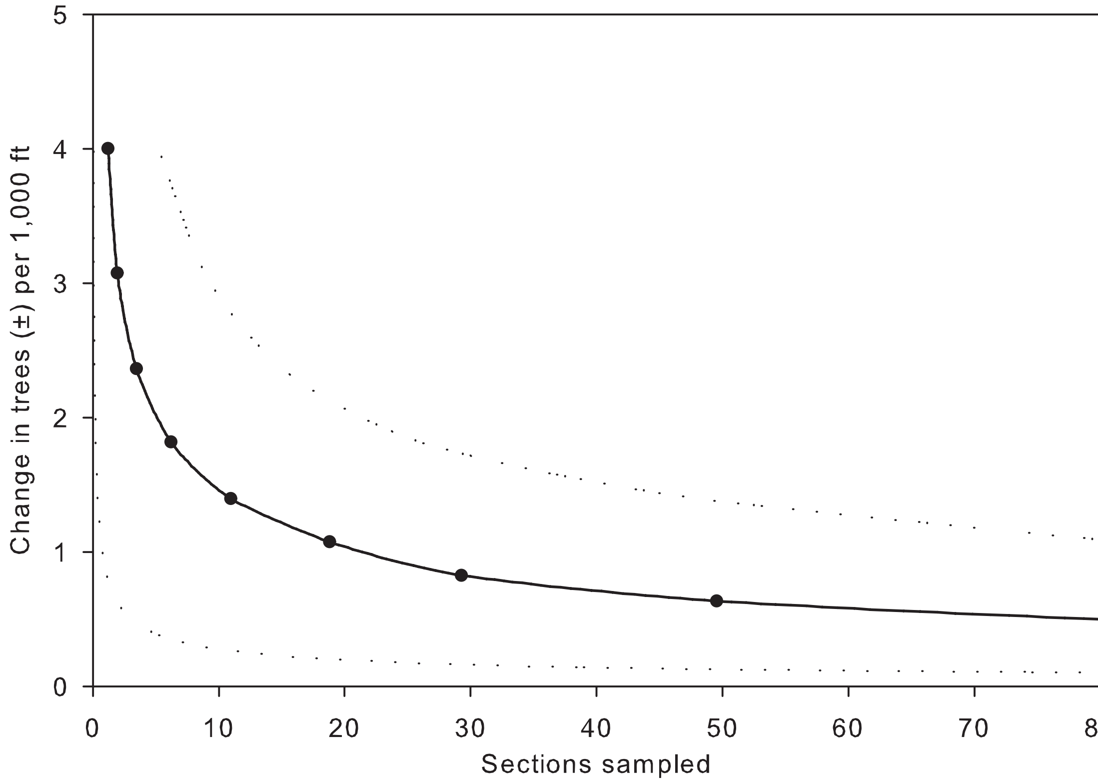

Figure 3.−Detectable change in mean submerged tree counts by sections sampled (1,000-ft transects) for the southern Michigan lakes. Sample size estimates were averaged across lakes for a given level of change and all eight lakes were sampled. Estimates of precision are for α = 0.05. Dotted lines represent minimum and maximum values from individual lakes.

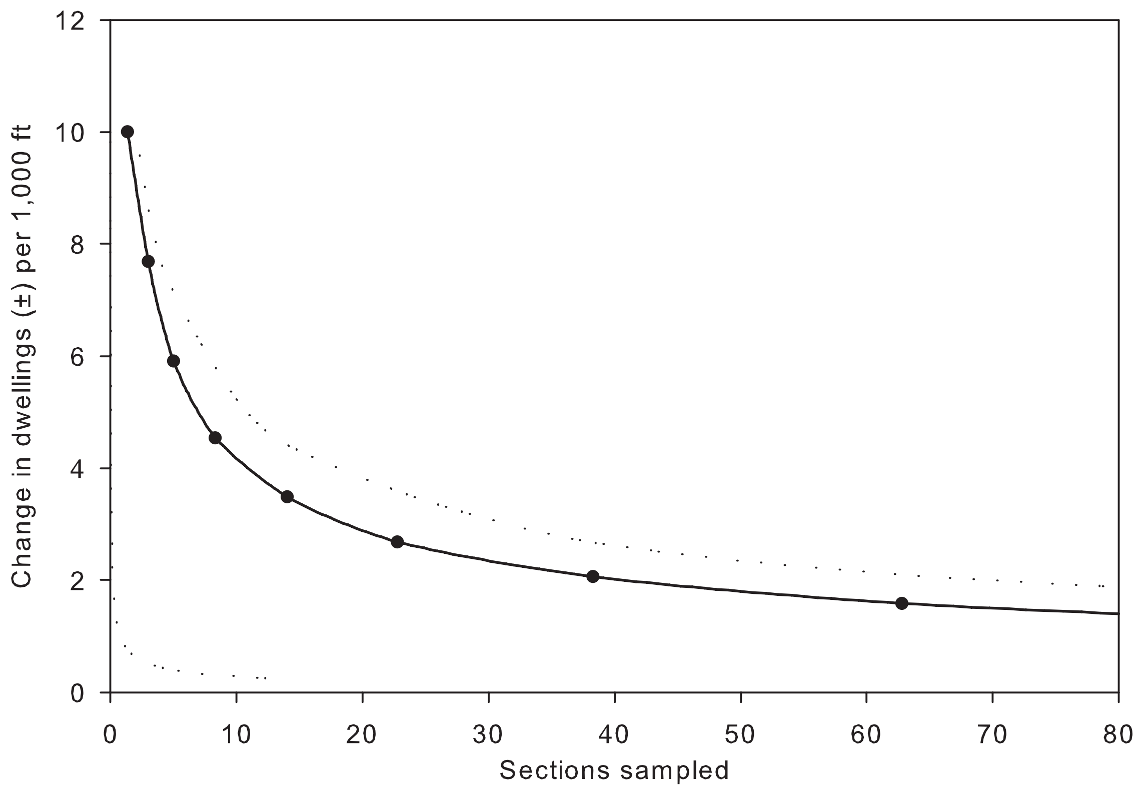

Figure 4.−Detectable change in mean dwelling counts by sections sampled (1,000-ft transects) for the southern Michigan lakes. Sample size estimates were averaged across lakes for a given level of change and all eight lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

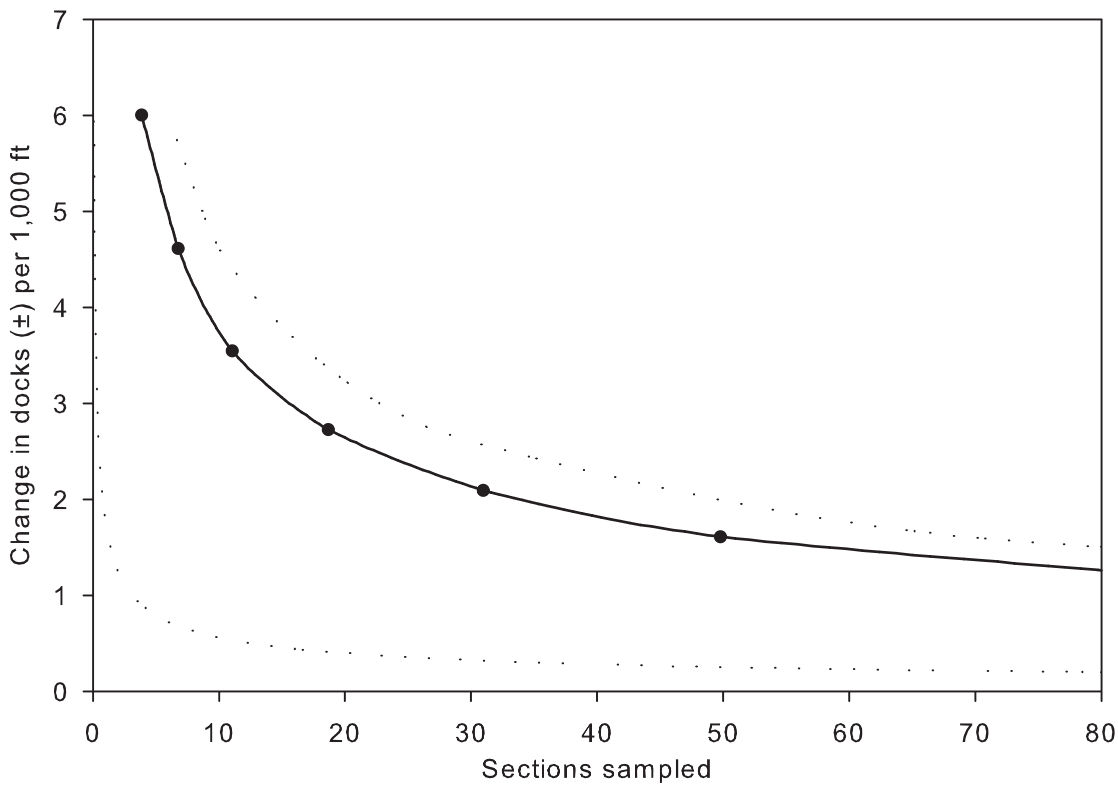

Figure 5.–Detectable change in mean dock counts by sections sampled (1,000-ft transects) for the southern Michigan lakes. Sample size estimates were averaged across lakes for a given level of change and all eight lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

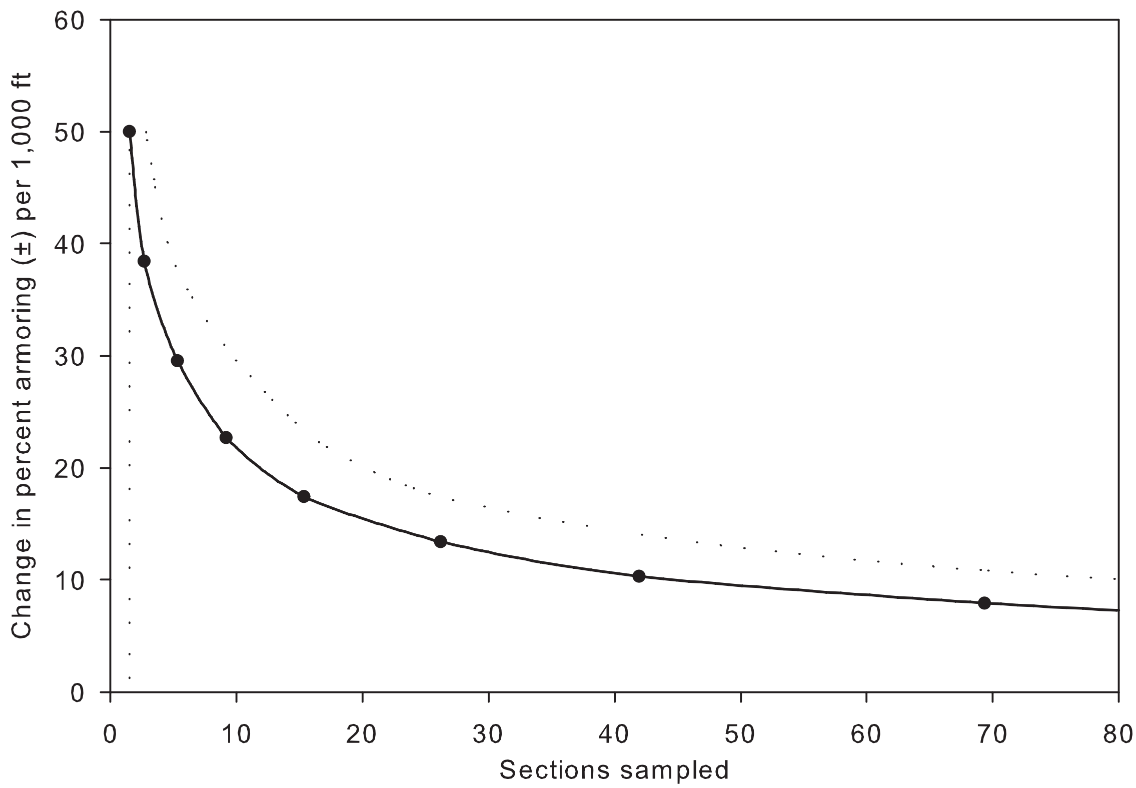

Figure 6.−Detectable change in mean shoreline armoring counts by sections sampled (1,000-ft transects) for the southern Michigan lakes. Sample size estimates were averaged across lakes for a given level of change and all eight lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes. Minimum dotted line is actually 0 sections sampled for all changes, but has been offset to improve visual perception.

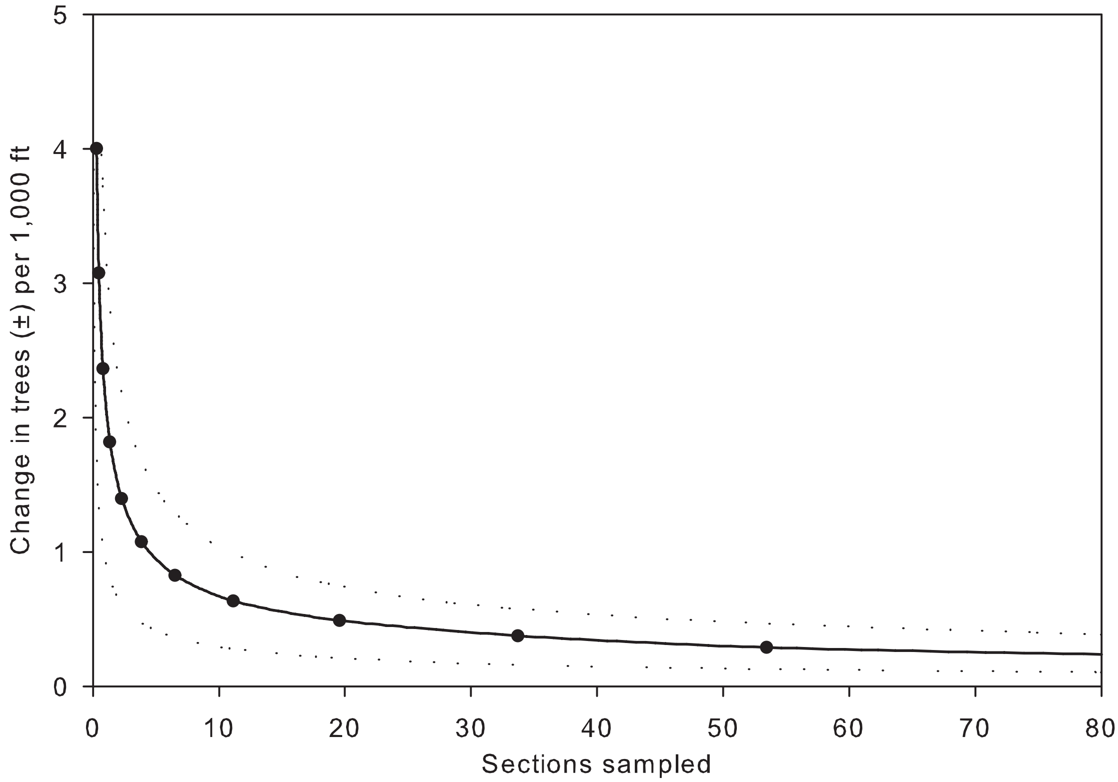

Figure 7.−Detectable change in mean submerged tree counts by sections sampled (1,000-ft transects) for selected Michigan large lakes. Sample size estimates were averaged across lakes for a given level of change and all three lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

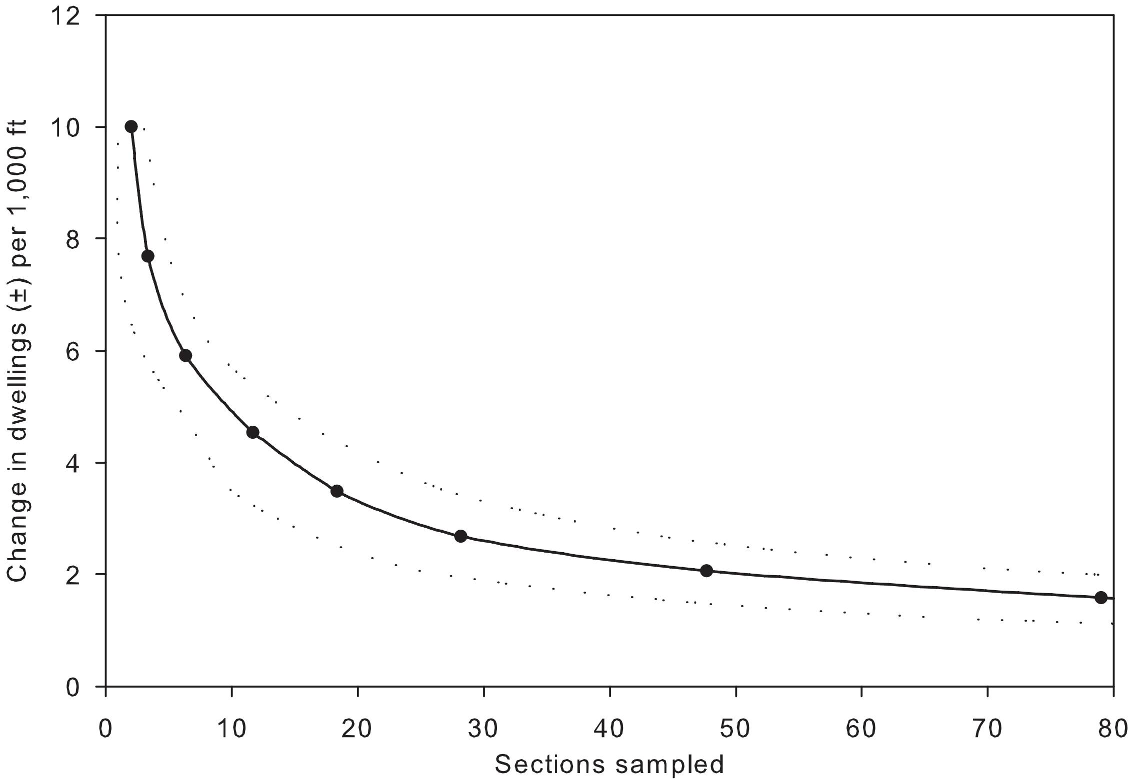

Figure 8.−Detectable change in mean dwelling counts by sections sampled (1,000-ft transects) for selected Michigan large lakes. Sample size estimates were averaged across lakes for a given level of change and all three lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

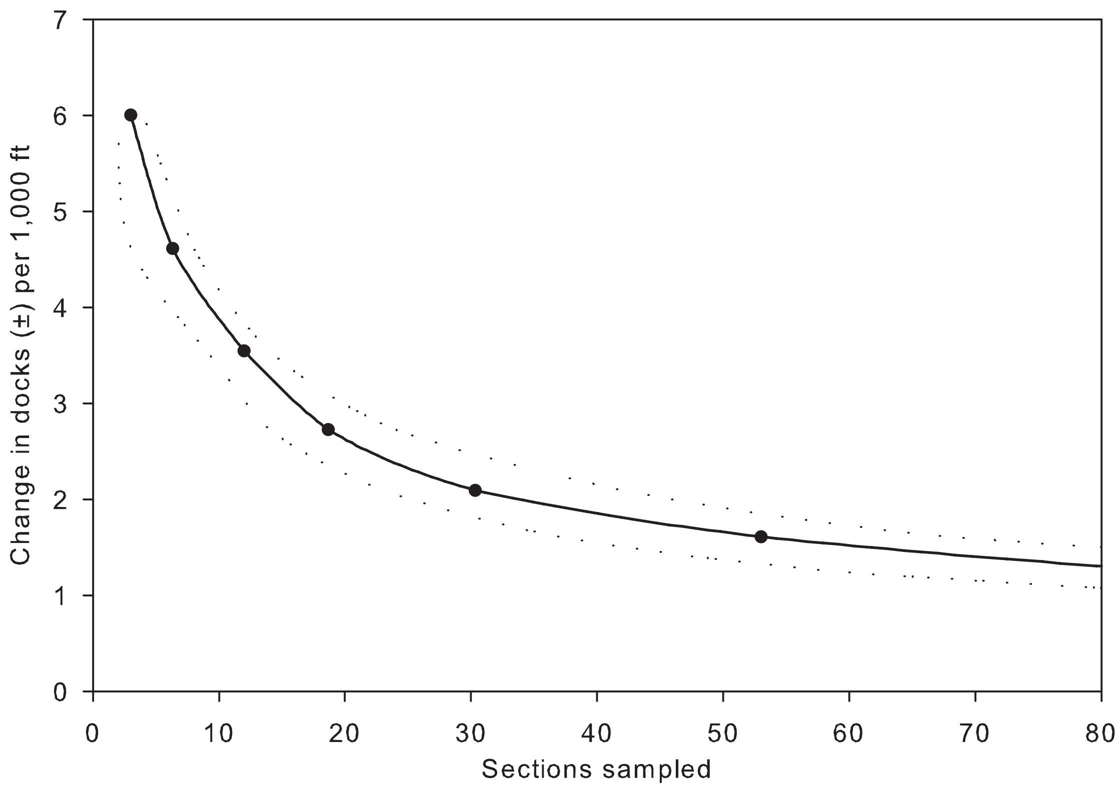

Figure 9.−Detectable change in mean dock counts by sections sampled (1,000-ft transects) for selected Michigan large lakes. Sample size estimates were averaged across lakes for a given level of change and all three lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

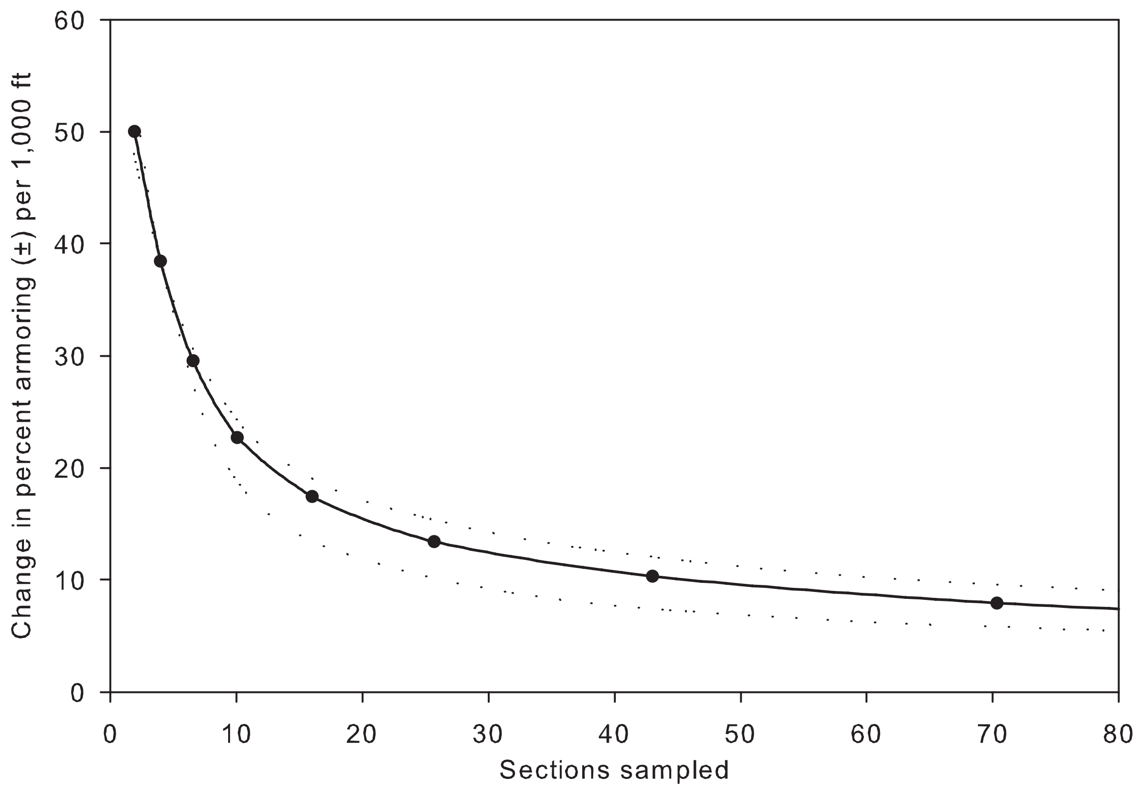

Figure 10.–Detectable change in mean shoreline armoring counts by sections sampled (1,000-ft transects) for selected Michigan large lakes. Sample size estimates were averaged across lakes for a given level of change and all three lakes were sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual lakes.

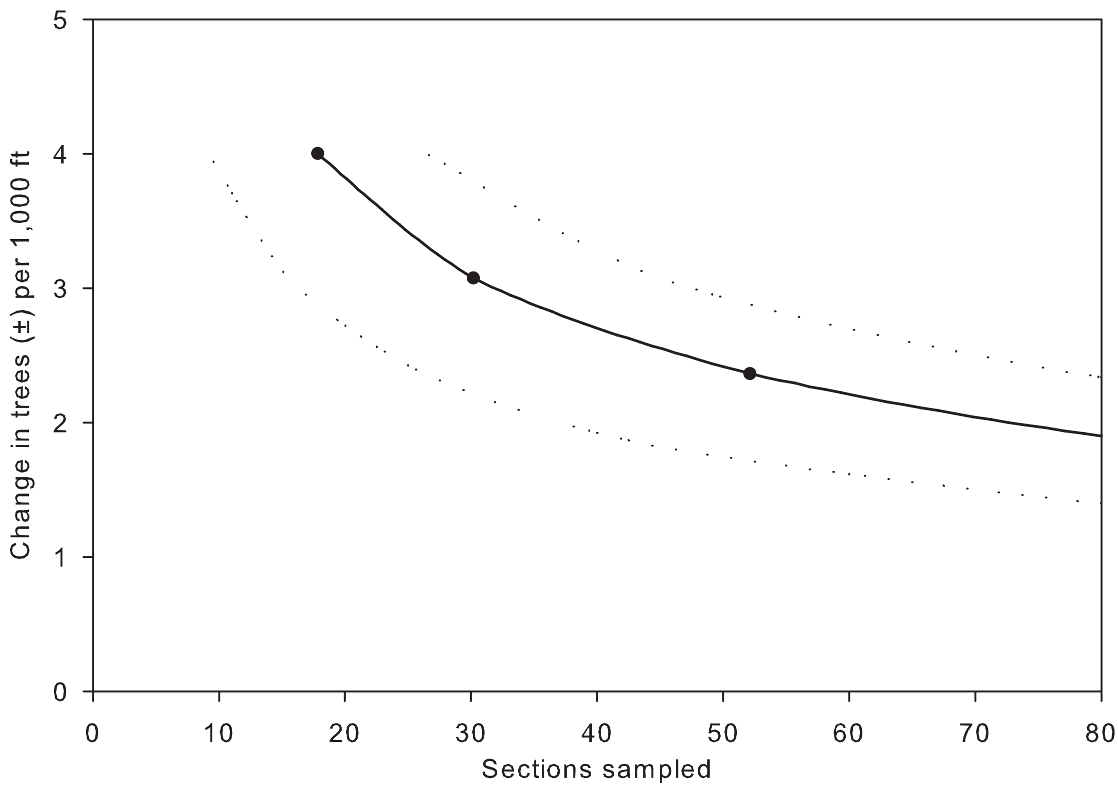

Figure 11.−Detectable change in mean submerged tree counts by sections sampled (1,000-ft transects) for two Michigan impoundments (Moores Park impoundment was not sampled). Sample size estimates were averaged across impoundments for a given level of change. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual impoundments.

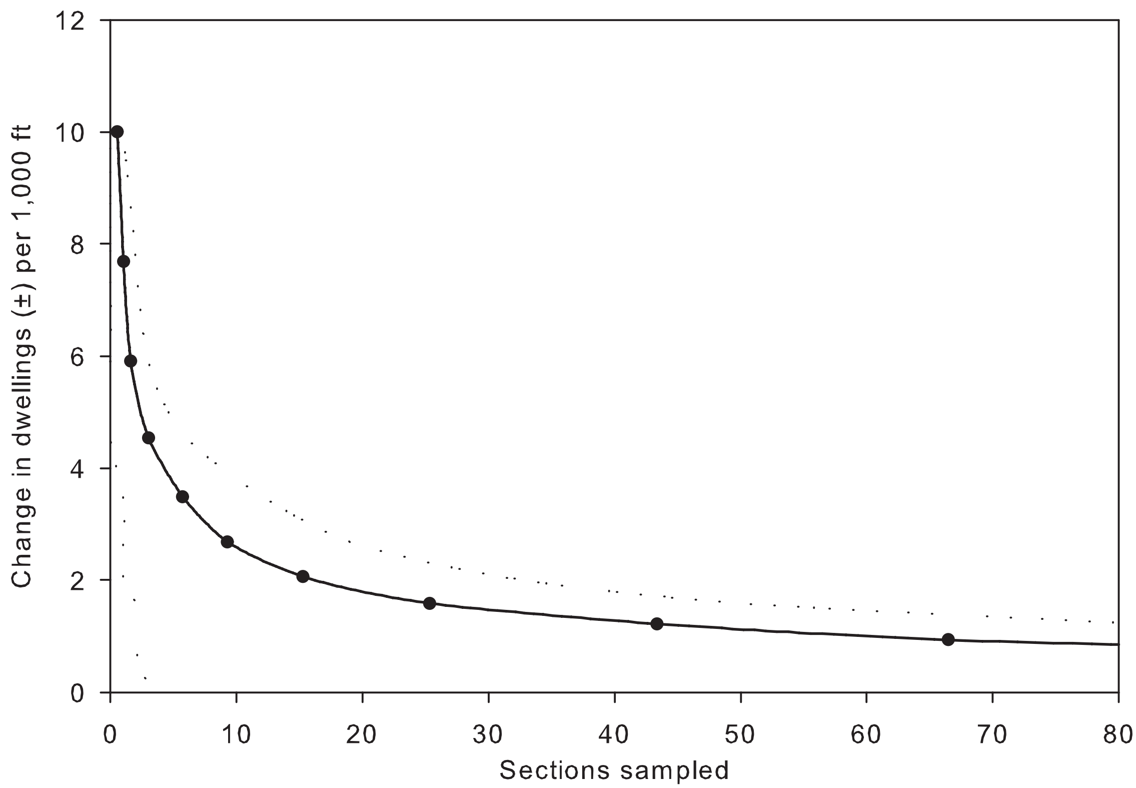

Figure 12.−Detectable change in mean dwelling counts by sections sampled (1,000-ft transects) for selected Michigan impoundments. Sample size estimates were averaged across impoundments for a given level of change and all three impoundments were sampled. Estimates of precision are for α = 0.05. Dotted lines represent minimum and maximum values from individual impoundments. Minimum dotted line has been offset to improve visual perception.

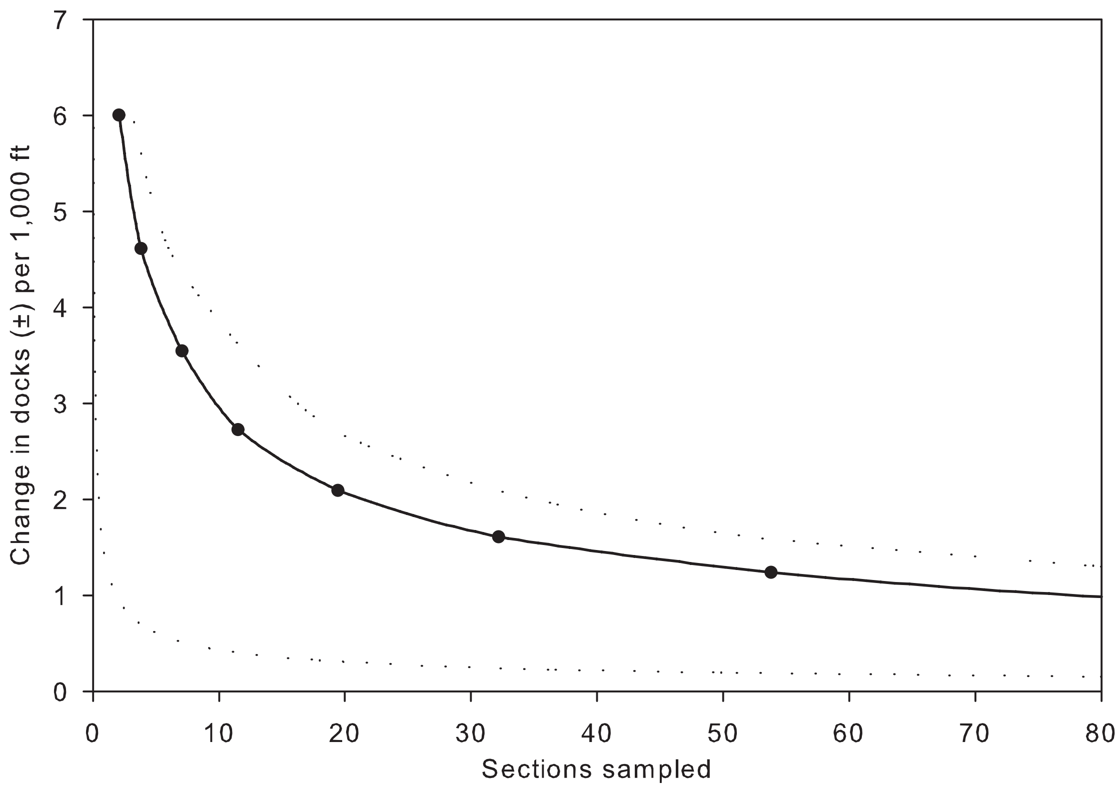

Figure 13.−Detectable change in mean dock counts by sections sampled (1,000-ft transects) for selected Michigan impoundments. Sample size estimates were averaged across impoundments for a given level of change and all three impoundments were sampled. Estimates of precision are for α = 0.05. Dotted lines represent minimum and maximum values from individual impoundments.

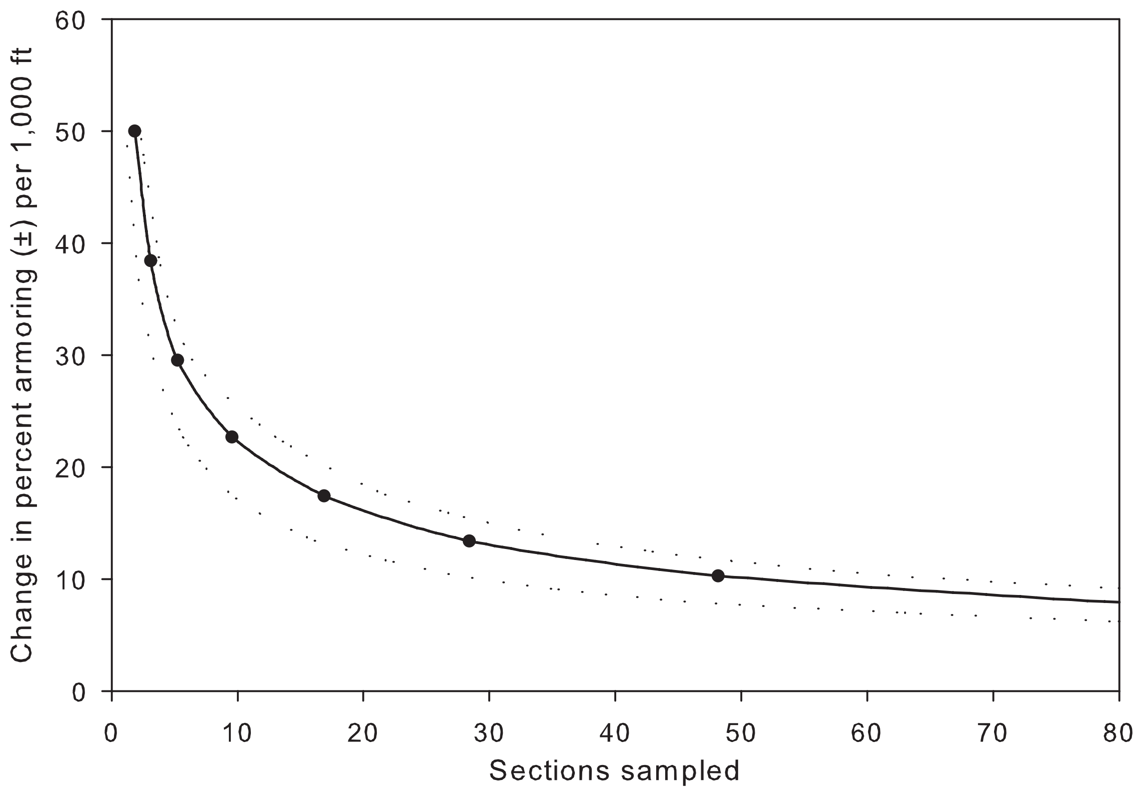

Figure 14.−Detectable change in mean shoreline armoring counts by sections sampled (1,000-ft transects) for selected Michigan impoundments. Sample size estimates were averaged across impoundments for a given level of change and all three impoundments sampled. Estimates of precision are for $\alpha = 0.05$. Dotted lines represent minimum and maximum values from individual impoundments.

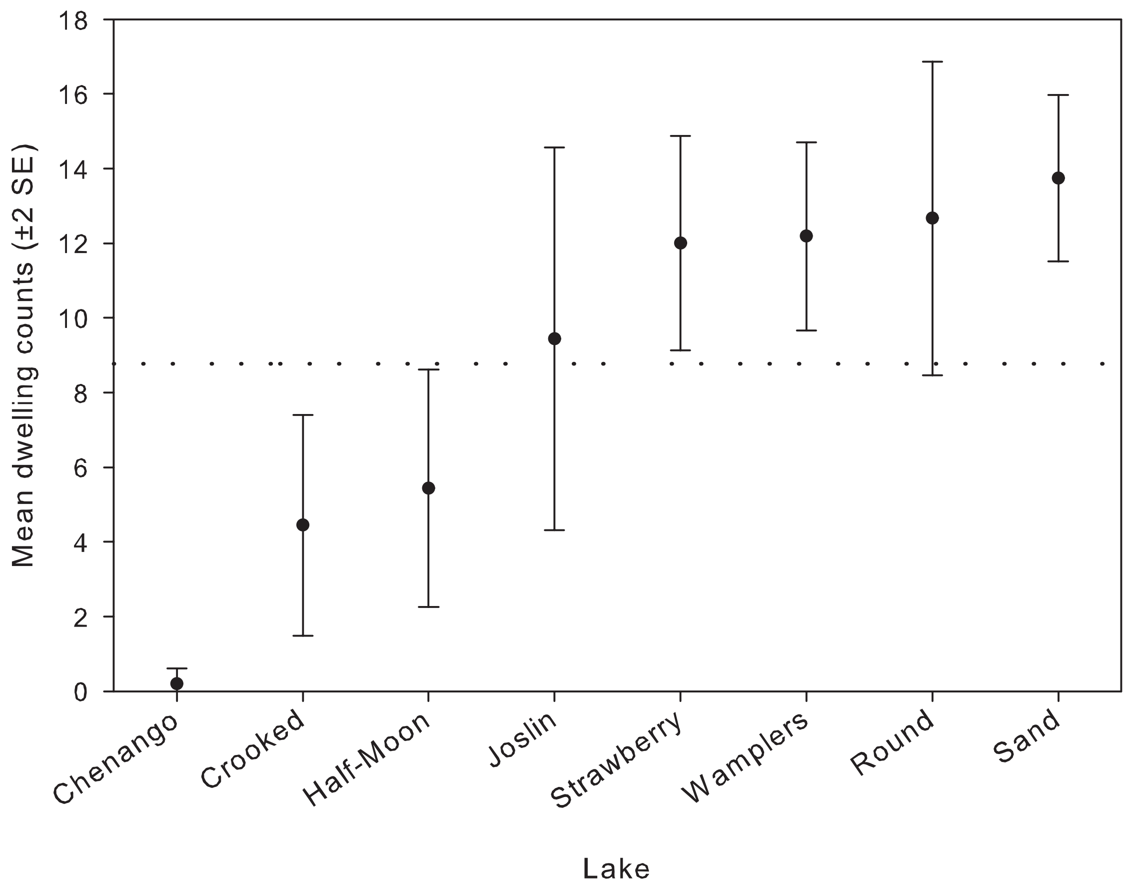

Figure 15.−Mean dwelling counts (±2 SE) for selected southern Michigan lakes. Dotted horizontal line is the across lakes mean (8.8 dwellings per 1,000 ft of shoreline). Error bars were estimated using fpc = 1 (i.e., population was infinite).

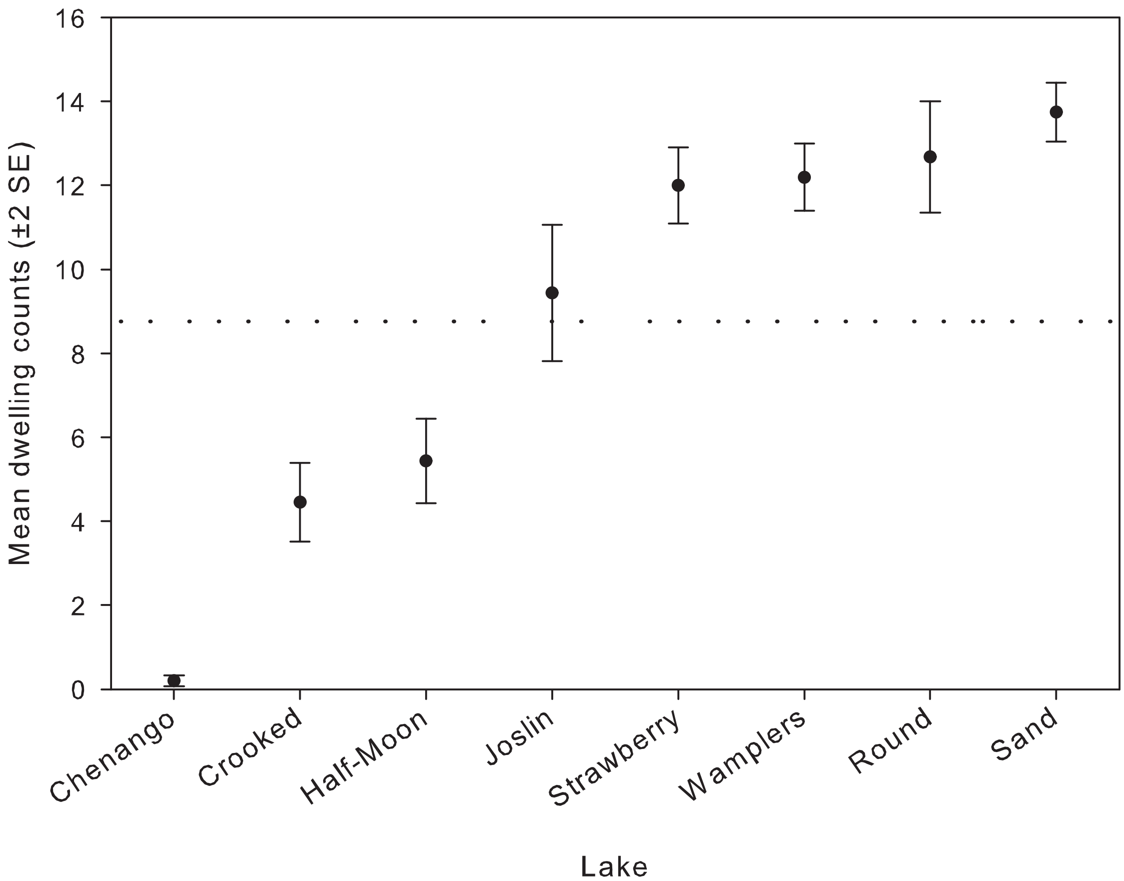

Figure 16.−Mean dwelling counts (±2 SE) for selected southern Michigan lakes. Dotted horizontal line is the across lakes mean (8.8 dwellings per 1,000 ft of shoreline). Error bars were estimated using fpc = 0.1 (i.e., 90% of the population was sampled).

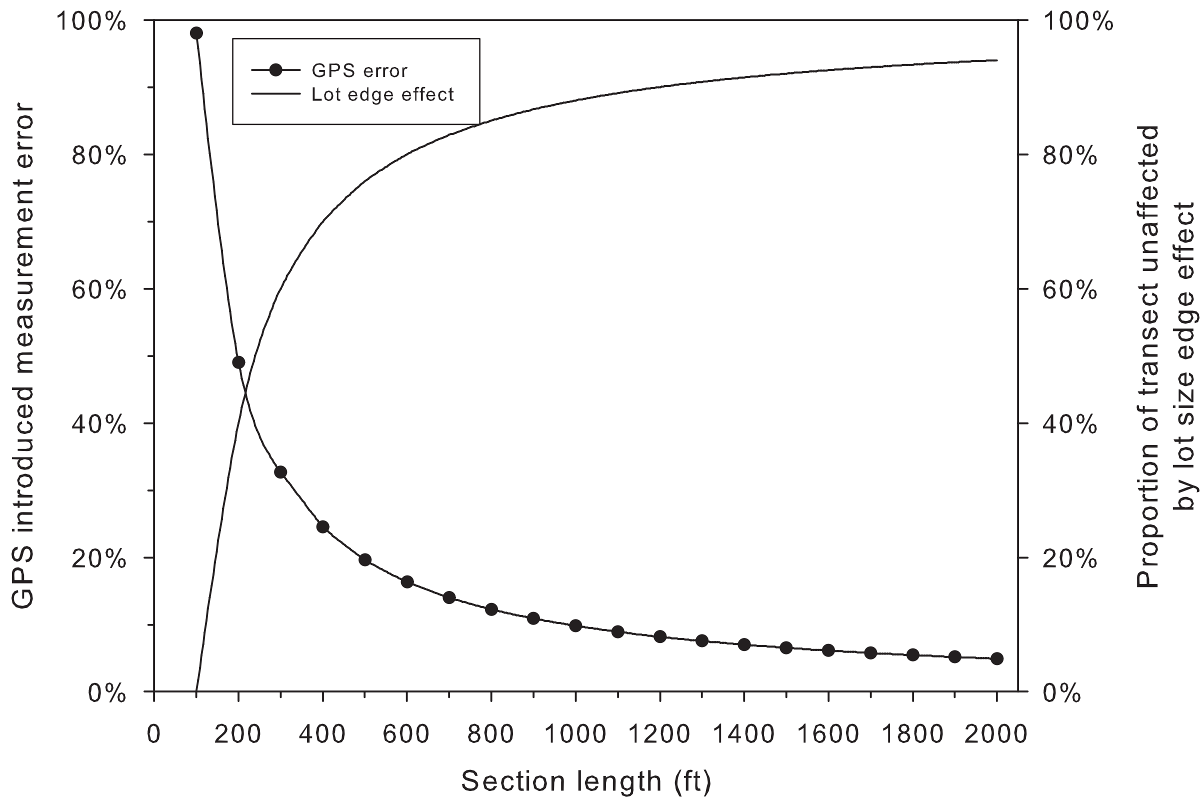

Figure 17.−Global positioning system (GPS) introduced error and percent of transect unaffected by lot width effect. For lot width evaluation, lot width was 60 ft.

Table 1.–Study lake or impoundment name, location, size, circumference, shoreline development index (SDI), number of 1,000-ft sample transects, and estimated shoreline transect length.

Group/Name	Latitude	Longitude	Size (acres)	Circumference (ft)	SDI	Transects	Estimated shoreline transect length
Eight Southern Michigan Lakes							
Crooked	42.32491	84.11448	113	13,744	1.75	11	1,249.5
Wamplers	42.07237	84.14054	797	34,447	1.65	26	1,324.9
Round	42.08536	84.46997	151	10,735	1.18	9	1,192.8
Chenango	42.50591	83.89668	29	5,584	1.40	5	1,116.8
Joslin	41.41425	84.06902	194	12,648	1.23	9	1,405.3
Half-moon	42.41597	84.00462	241	24,276	2.11	18	1,348.7
Sand	42.04952	84.12685	546	29,247	1.69	19	1,539.3
Strawberry	42.45205	83.84898	261	23,567	1.97	18	1,309.3
Three Large Lakes							
Houghton	44.31977	84.76460	20,075	157,251	1.50	145	1,084.5
Lobdell	42.78504	83.83321	546	73,622	4.26	53	1,389.1
Missaukee	44.33978	85.22469	1,880	61,027	1.83	45	1,356.2
Three Impoundments							
Croton (Muskegon River)	43.43955	85.66593	1,129	82,014	3.30	65	1,261.8
Kent (Huron River)	42.52374	83.64515	1,015	128,097	5.43	80	1,601.2
Moores Park (Grand River)	42.72114	84.58642	350	118,901	8.59	91	1,306.6

Table 2.–Levels of detectable change for estimating sample sizes for two habitat and three shoreline development metrics based on survey data from selected Michigan lakes. Each change, for individual metrics, represents a 23.16% improvement in precision from previous value.

	Vegetation index	Submerged trees	Dwellings	Docks	Percentage of shoreline armored
Maximum change	1.0000	4.0000	10.0000	6.0000	50.0000
	0.7684	3.0737	7.6842	4.6105	38.4209
	0.5905	2.3619	5.9047	3.5428	29.5233
	0.4537	1.8149	4.5372	2.7223	22.6862
	0.3486	1.3946	3.4865	2.0919	17.4325
	0.2679	1.0716	2.6791	1.6074	13.3954
	0.2059	0.8235	2.0587	1.2352	10.2933
	0.1582	0.6328	1.5819	0.9491	7.9095
	0.1216	0.4862	1.2156	0.7293	6.0778
	0.0934	0.3736	0.9341	0.5604	4.6703
	0.0718	0.2871	0.7177	0.4306	3.5887
	0.0552	0.2206	0.5515	0.3309	2.7576
	0.0424	0.1695	0.4238	0.2543	2.1190
	0.0326	0.1303	0.3257	0.1954	1.6283
Minimum change	0.0250	0.1001	0.2502	0.1501	1.2512

Table 3.–Empirical data for each habitat and development metric for selected Michigan lakes. Statistics for each include mean, standard deviation (S), and number of 1,000-ft transects sampled (N).

Group Sample year	Name	Statistics	Vegetation (%)	Submerged trees	Shoreline dwellings	Docks	Armored shore (%)
Eight Southern Michigan Lakes							
2002	Crooked	Mean	1.70	4.00	4.45	3.91	10.91
		S	1.06	1.90	4.91	4.06	15.78
		N	10	11	11	11	11
2003	Wamplers	Mean	1.61	0.42	12.19	10.92	63.46
		S	1.08	0.99	6.43	6.15	39.29
		N	23	26	26	26	26
2002	Round	Mean	1.00	0.22	12.67	11.44	56.67
		S	0.00	0.44	6.30	5.62	30.00
		N	9	9	9	9	9
2003	Chenango	Mean	5.00	2.00	0.20	0.400	0.00
		S	0.00	1.58	0.45	0.89	0.00
		N	5	5	5	5	5
2003	Joslin	Mean	2.78	0.33	9.44	7.33	40.00
		S	1.09	0.71	7.68	5.85	42.72
		N	9	9	9	9	9
2002/03	Half-Moon	Mean	1.33	3.44	5.44	5.39	15.00
		S	0.48	4.67	6.73	6.30	27.49
		N	18	18	18	18	18
2003	Sand	Mean	–	–	13.74	12.39	49.47
		S	–	–	4.86	5.07	37.49
		N	0	0	19	18	19
2003	Strawberry	Mean	1.33	1.06	12.00	9.83	45.00
		S	0.59	2.18	6.10	5.82	34.17
		N	18	18	18	18	18
Three Large Lakes							
2004	Houghton	Mean	–	0.10	15.47	10.38	86.69
		S	–	0.66	6.12	4.26	20.98
		N	–	145	145	145	145
2004	Lobdell	Mean	–	1.09	10.81	11.53	72.23
		S	–	1.67	4.47	5.29	30.44
		N	–	53	53	53	53
2004	Missaukee	Mean	–	0.09	10.69	6.98	25.67
		S	–	0.47	8.25	6.29	38.75
		N	–	45	45	45	45
Three Impoundments							
2004	Croton	Mean	–	3.37	6.80	7.03	43.69
		S	–	6.17	5.21	5.42	38.22
		N	–	65	65	65	65
2004	Kent	Mean	–	4.70	0.01	0.21	14.00
		S	–	10.50	0.11	0.69	27.54
		N	–	80	80	80	80
2004	Moores Park	Mean	–	–	2.99	1.50	30.25
		S	–	–	4.05	5.43	36.62
		N	–	–	91	90	91

Table 4.–Relative standard error (RSE) for Michigan lakes varying in size from 25 to 12,355 acres. Shoreline development factor is 1.3 for each lake. Metric mean is 1 and variance of the sample (S^2) is 10. Each boat transect length is 1,000 ft resulting in 1,320.4 ft of shoreline sampled. Finite population correction term (fpc) is ignored (i.e., fpc = 1).

Lake size	Circumference	Transects		RSE										
(acres)	(ft)	possible	Transects=	2	3	8	11	15	20	25	36	50	75	80
25	4,780	3		2.24	1.83									
124	10,689	8		2.24	1.83	1.12								
247	15,118	11		2.24	1.83	1.12	0.95							
1,236	33,806	25		2.24	1.83	1.12	0.95	0.82	0.71	0.63				
2,471	47,808	36		2.24	1.83	1.12	0.95	0.82	0.71	0.63	0.53			
12,355	106,909	80		2.24	1.83	1.12	0.95	0.82	0.71	0.63	0.53	0.45	0.37	0.35

Table 5.–Relative standard error (RSE) for Michigan lakes varying in size from 25 to 12,355 acres. Shoreline development factor is 1.3 for each lake. Metric mean is 1 and variance of the sample (S^2) is 10. Each boat transect length is 1,000 ft resulting in 1,320.4 ft of shoreline sampled. Finite population correction term (fpc) is included in estimation of SE.

Lake size	Circumference	Transects		RSE										
(acres)	(ft)	possible	Transects=	2	3	8	11	15	20	25	36	50	75	80
25	4,780	3		1.29	0.00									
124	10,689	8		1.94	1.44	0.00								
247	15,118	11		2.02	1.56	0.58	0.00							
1,236	33,806	25		2.14	1.71	0.92	0.71	0.52	0.32	0.00				
2,471	47,808	36		2.17	1.75	0.99	0.79	0.62	0.47	0.35	0.00			
12,355	106,909	80		2.21	1.79	1.06	0.89	0.74	0.61	0.52	0.39	0.27	0.09	0.00

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