

## Relationships between Recapture Rates from Different Gears for Estimating Walleye Abundance in Northern Wisconsin Lakes

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**Abstract.**—Maximizing sampling efficiency and reducing sampling costs are desirable goals for fisheries management agencies. Expensive and labor-intensive methods (such as mark–recapture) are commonly used to estimate the population abundance of walleye *Sander vitreus*, but more efficient methods may be available. We compared recapture rates from surveys and harvests to evaluate the efficiency of currently used recapture gears and the potential for using gears that require less effort. To evaluate the usefulness of walleye harvest as mark–recapture samples, we used errors-in-variables models to determine whether recapture rates differed between fyke-netting and spearing, electrofishing and spearing, and electrofishing and angling. We found no significant differences between fyke-netting and adult walleye electrofishing recapture rates or between spearing and adult walleye electrofishing recapture rates. In contrast, we found that recapture rates from angling and electrofishing differed significantly in lakes with and without minimum length limits. We concluded that the lack of significant differences between the slopes of some harvest and survey recapture rates may allow the use of harvest recapture rates to estimate walleye abundance, but the biases associated with each gear should be considered. We also concluded that more attention should be given to understanding the biases of recapture gears.

Mark–recapture studies are expensive and time-consuming (Seawell and Hevel 1979), so minimizing sampling effort to estimate abundance by mark–recapture should be a goal of fisheries agencies. If current mark–recapture sampling overlaps with other population sampling methods (such as creel surveys or fishing tournaments), then these other fishery samples may be useful as marking or recapture samples. Reducing effort by using alternative methods to collect mark–recapture data are tempting, but care must be taken to assure that mark–recapture assumptions are not violated, thereby leading to biased abundance estimates. Mark–recapture assumptions in closed populations include closure to additions or losses to the population, equal capture probability of marked and unmarked individuals, and that marks are not lost

or overlooked by observers (see Ricker 1975 and Pollock et al. 1990). A major concern when attempting to replace current protocols with more efficient methods is violating the assumption of equal capture probability between marked and unmarked populations.

Equal capture probability between marked and unmarked populations may be violated due to behavioral responses by fish or sampling biases (Ricker 1975). Different gears are often used to mark and recapture fish to reduce the potential of behaviors (e.g., “trap-happy” or “trap-shy” responses), affecting, in turn, capture probability (Ricker 1975). For example, when common carp *Cyprinus carpio* were marked and recaptured by different gears, estimates of population abundance were more accurate than when they were marked and recaptured by the same gear (Beukema and De Vos 1974). Designs for mark–recapture experiments commonly include random sampling to prevent unequal capture probabilities between marked and unmarked populations. Random sampling during marking or recapture periods will lead to unbiased population estimates (Ricker 1975), but variability in catchability using randomly fished gear may bias population estimates. For example,

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recapture rates of brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* differed between angling and electrofishing gears because the gears sampled different habitats and, therefore, different populations were vulnerable to each gear (Favro et al. 1986). Favro et al. (1986) concluded that anglers and electrofishing sampled different portions of each population and that estimates from different gears may apply to different segments of the population. Lastly, recapture rates of common carp marked in fyke nets differed between angling and seining because fish avoided angling and were prone to seining (Beukema and De Vos 1974). When multiple recapture gears are used in mark–recapture studies, recapture rates of the gears should be compared to determine if mark–recapture assumptions are violated, and if methods that require less effort or cost can be used in place of current methods.

Our objective was to determine whether harvest recapture rates by spearing and angling fisheries could be used in place of survey recapture rates by fyke-netting and electrofishing to reduce the sampling effort required to monitor populations of walleyes *Sander vitreus* in northern Wisconsin lakes. Walleye abundance was estimated annually in 22–43 lakes during 1990–2000 by marking in fyke nets and electrofishing recapture. Spearing and angling harvest was then quantified on the same lakes, thereby permitting comparisons of recapture rates between fyke-netting and spearing, electrofishing and spearing, and electrofishing and angling. We expected to find significant differences between fyke-netting and spearing recapture rates, and between electrofishing and spearing recapture rates because marked and unmarked fish were not homogeneously distributed and recapture effort was not random in fyke-netting or spearing. We expected to find a significant linear relationship between angling and electrofishing recapture rates because recapture effort was random for both gears.

### Methods

**Abundance estimates.**—Walleye abundance was estimated annually by mark–recapture on 22–43 lakes/year during 1990–2000 by the Wisconsin Department of Natural Resources (WDNR). Adult walleyes were captured for marking with 0.5-in-mesh (1 in = 2.54 cm) fyke nets shortly after ice-out in late spring, usually mid-April (Hansen et al. 1991; Beard et al. 1997; Hansen et al. 2000). In northern Wisconsin, male walleyes usually mature at a length of 12 in and females at a length of 15

in, so adults were defined as all fish for which sex could be determined and all fish of unknown sex longer than 15 in (Beard et al. 1997; Hansen et al. 2000). Each fish was marked by removal of a portion of one or more fins, and lengths were recorded. Ten percent of the mature walleyes in each lake were targeted for marking (Hansen et al. 2000). A recapture sample was collected 1–2 d after marking (during peak walleye spawning) by electrofishing the entire lakeshore to estimate the ratio of marked fish in the adult population (Hansen et al. 2000). Marked and unmarked adult walleyes were assumed to have equal capture probability because of the short interval between marking and sampling, and because the entire shoreline was sampled (Hansen et al. 2000). All unmarked walleyes captured during the adult abundance sample were marked by removal of a portion of one or more fins to estimate total walleye abundance. A second electrofishing recapture sample was collected 14–17 d after the first recapture, which allowed time for subadults to move inshore to estimate the ratio of marked fish in the entire walleye population (Hansen et al. 2000). Electrofishing recapture surveys took place at night, and electrofishing crews attempted to net all fish they saw.

**Spearing harvest.**—Tribal spearing took place in early spring during the walleye spawning season. The number of tribal members on each lake each night was determined from the estimated nightly quota for that lake and the number of interested individuals (U.S. Department of the Interior 1991; Hansen et al. 2000). Each spearer was given a nightly quota for a specific landing on a specific lake (Hansen et al. 2000). Spearers tended to harvest their quotas as quickly as possible, so time spent spearing was related to adult walleye density in the area being speared (Hansen et al. 2000). The maximum length of walleyes speared was limited by allowing only one fish of the nightly bag limit to be between 20 and 24 in, plus one fish of any length (Hansen et al. 2000). Great Lakes Indian Fish and Wildlife Commission (GLIFWC) clerks recorded the starting and ending times of each spearing trip, the number of fish speared, fish lengths, and the number of marked fish in each spearer's harvest (Hansen et al. 2000).

**Angler harvest.**—The WDNR estimated angler effort and harvest by creel survey on the same lakes that were randomly selected for walleye population estimates during 1990–2000 (Staggs et al. 1990). Creel surveys were conducted from the first Saturday in May through March 1 of the following year, which is the legal angling season for walleyes

in most Wisconsin waters (Beard et al. 1997). Surveys were conducted following a random stratified roving access design (Pollock et al. 1994; Beard et al. 1997, Rasmussen et al. 1998). Days were stratified into weekdays and weekend days, and all weekend days and one to three randomly selected weekdays were sampled each week (Beard et al. 1997). During the open-water season, days were divided into two periods of equal length and surveys were conducted during randomly selected periods. During the ice fishing season, entire days were sampled due to shortened daylight (Beard et al. 1997). Creel surveys were not conducted during November because of dangerous ice conditions and low angler effort (Beard et al. 1997). Clerks recorded the number of fish caught, lengths, and the number of marked fish caught in selected angler harvests.

*Data analysis.*—Relationships between recapture rates by harvest gears ( $h$  = spearing or angling) and recapture rates by survey gears ( $s$  = fyke-netting or electrofishing) were modeled by means of the linear regression

$$\frac{R_h}{C_h} = b_0 + b_1 \frac{R_s}{C_s} + \varepsilon,$$

where  $R$  is the number of marked walleyes in the recapture sample and  $C$  is the number of walleyes captured in the recapture sample. Harvest and survey recapture rates were both measured with error; thus, ordinary least-squares regression estimates were biased (Ricker 1975). We incorporated measurement errors into our analysis by estimating the slope  $b_1$  and intercept  $b_0$  for each relationship using an errors-in-variables model

$$\hat{\beta}_1 = \frac{m_{YY} - \delta m_{XX} + \sqrt{(m_{YY} - \delta m_{XX})^2 + 4\delta m_{XY}^2}}{2m_{XY}},$$

where  $\beta_1$  is the slope of the relationship,  $m_{YY}$  is the variance in harvest recapture rate,  $\delta$  is the measurement error ratio,  $m_{XX}$  is the variance in survey recapture rate, and  $m_{XY}$  is the covariance between harvest and survey recapture rates (Fuller 1987; Quinn and Deriso 1999). Measurement error ratios (MER;  $\delta$ ) were estimated with the equation

$$\delta = \frac{CI(R_h/C_h)}{CI(R_s/C_s)},$$

where CI is the difference between the exact upper and lower 95% confidence limits for  $R/C$  for the harvest and survey recapture methods, which were calculated with formulas presented by Zar (1999).

The slope estimate was tested for a significant difference from one, and the intercept estimate was tested for a significant difference from zero to test the null hypothesis that harvest recapture rates and survey recapture rates were not significantly different ( $P \leq 0.05$ ).

Spearing harvests could take place any time during the marking or recapture periods, so spearing recapture rates were compared with fyke-netting and electrofishing recapture rates, depending on when spearing took place, to ensure that the number of marked fish in the population ( $M$ ) was constant. Spearing recapture rates were compared with fyke-netting recapture rates during the fyke-netting season when both samples took place in the same day because  $M$  changed daily. Fyke-netting recapture rates were estimated by the ratio of marked fish ( $R_s$ ) to total fish ( $C_s$ ) in each day's fyke-net catch (approximately 24-h soak period). Spearing recapture rates were estimated by the ratio of marked fish ( $R_h$ ) to total fish ( $C_h$ ) for each day's spearing harvest from data provided by GLIFWC (Ngu and Kmiecik 1993; Ngu 1994, 1995, 1996; Krueger 1997, 1998, 1999, 2000, 2001). Spearing recapture rates were compared with electrofishing recapture rates for adult abundance when spearing occurred after fyke-netting and prior to adult walleye electrofishing recapture sampling to ensure  $M$  was equal for both gears. Electrofishing recapture rates were estimated by the ratio of marked fish ( $R_s$ ) to total fish ( $C_s$ ) captured during the electrofishing recapture. Spearing recapture rates were modeled as a linear function of fyke-netting recapture rates during 1997–2000 ( $N = 52$ ) and electrofishing recapture rates during 1992–2000 ( $N = 35$ ).

Angling recapture rates were compared with electrofishing recapture rates from total population estimates for lakes without minimum length limits and with electrofishing recapture rates of walleyes 15 in and larger from adult electrofishing samples for lakes with a 15-in minimum length limit ( $N = 39$  and 123, respectively). Angling recapture rates were calculated by dividing the number of marked fish harvested by anglers ( $R_h$ ) by the number of total fish harvested by anglers ( $C_h$ ) from creel survey observations. Recapture rates from the angling fishery were modeled as a linear function of electrofishing recapture rates during 1990–2000.

## Results

Spearing recapture rates were positively related to fyke-net recapture rates and adult electrofishing recapture rates (Figures 1, 2). Spearing and fyke-

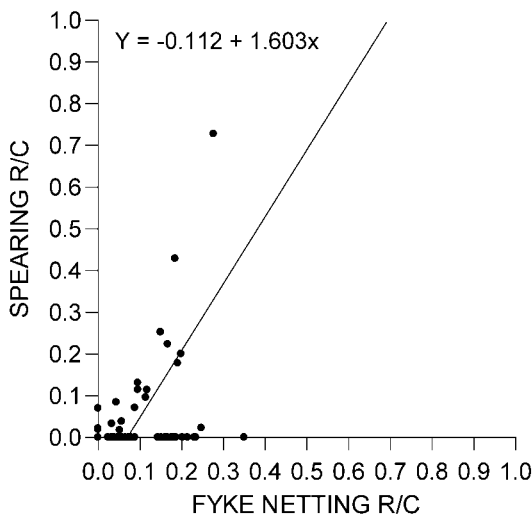


FIGURE 1.—Relationship between spearing recapture rates ( $R/C$ , where  $R$  is the number of marked walleyes recaptured and  $C$  is the total number of walleyes recaptured) and fyke-net recapture rates ( $R/C$ ) of adult walleyes in northern Wisconsin lakes during 1997–2000.

net recapture rates were not significantly different because the slope of the relationship between spearing and fyke-netting recapture rates did not differ significantly from 1.0 ( $t = 1.01$ ;  $df = 50$ ;  $P = 0.32$ ), and the intercept did not differ significantly from 0.0 ( $t = 1.72$ ;  $df = 50$ ;  $P = 0.09$ ). Measurement errors from spearing harvest data were greater than from fyke-net survey data ( $\delta = 1.92$ ). The mean spearing recapture rate was 0.05, and the mean fyke-net recapture rate was 0.10 (Figure 1). Spearing and adult walleye electrofishing recapture rates did not differ significantly because the slope of the relationship between spearing and adult electrofishing recapture rates did not differ significantly from 1.0 ( $t = 0.63$ ;  $df = 33$ ;  $P = 0.53$ ), and the intercept did not differ significantly from 0.0 ( $t = -0.88$ ;  $df = 33$ ;  $P = 0.38$ ). Measurement errors from spearing harvest data were greater than from electrofishing survey data ( $\delta = 2.65$ ). During the electrofishing sample used to estimate adult abundance, the mean spearing recapture rate was 0.25 and the mean electrofishing recapture rate was 0.31 (Figure 2).

Angling and electrofishing recapture rates differed significantly in lakes with and without 15-in minimum length limits (Figures 3, 4). In lakes with 15-in minimum length limits, the slope of the relationship between angling and adult walleye electrofishing recapture rates differed significantly from 1.0 ( $t = -5.25$ ;  $df = 121$ ;  $P < 0.01$ ), but the

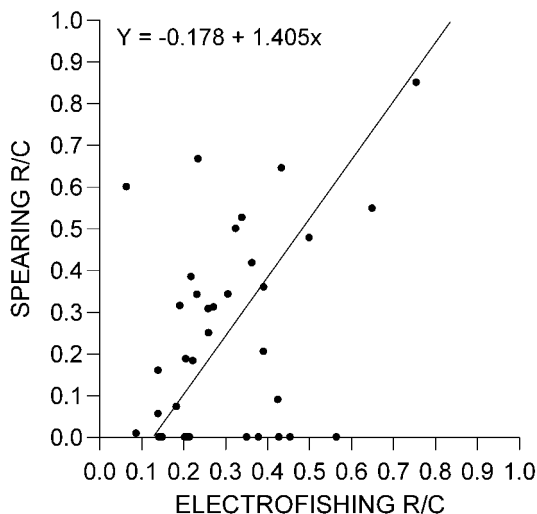


FIGURE 2.—Relationship between spearing recapture rates ( $R/C$ ) and electrofishing recapture rates ( $R/C$ ) of adult walleyes in northern Wisconsin lakes during 1992–2000.

intercept did not differ significantly from 0.0 ( $t = 1.75$ ;  $df = 121$ ;  $P = 0.08$ ). Measurement errors were greater from angling harvest data than from electrofishing survey data ( $\delta = 1.35$ ). The mean angling recapture rate was 0.20, and the mean adult electrofishing recapture rate was 0.32 (Figure 3). In lakes without length limits, the slope of the relationship between angling and total walleye

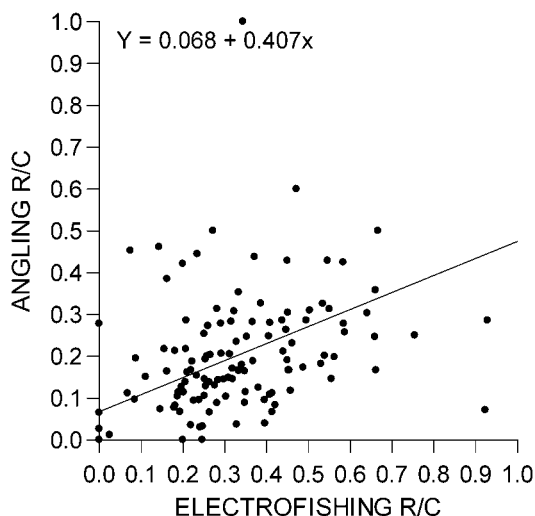


FIGURE 3.—Relationship between angling recapture rates ( $R/C$ ) and electrofishing recapture rates ( $R/C$ ) of adult walleyes in northern Wisconsin lakes with 15-in minimum length limits during 1990–2000.

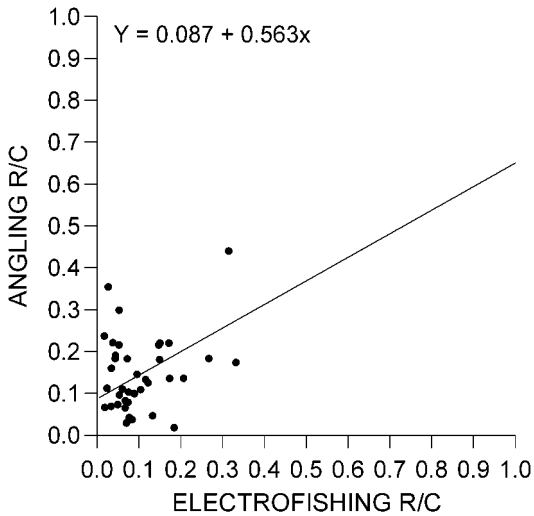


FIGURE 4.—Relationship between angling recapture rates ( $R/C$ ) and electrofishing recapture rates ( $R/C$ ) of all walleyes in northern Wisconsin lakes without minimum length limits during 1990–2000.

electrofishing recapture rates did not differ significantly from 1.0 ( $t = -1.23$ ;  $df = 37$ ;  $P = 0.23$ ), but the intercept differed significantly from 0.0 ( $t = 2.20$ ;  $df = 37$ ;  $P = 0.03$ ). Measurement errors were greater from angling harvest data than from total electrofishing survey data ( $\delta = 2.46$ ). During the electrofishing sample used to estimate total walleye abundance, the mean angling recapture rate was 0.15 and the mean electrofishing recapture rate was 0.10 (Figure 4).

### Discussion

The lack of significant differences between spearing and fyke-netting recapture rates and spearing and electrofishing recapture rates was unexpected because we assumed that fyke-netting and spearing effort were both nonrandom. Marked and unmarked fish did not likely have time to mix before early recapture sampling, so we expected nonrandom placement of fyke nets and spearers to violate the assumption of equal mixing or random sampling effort. In contrast, we assumed that electrofishing effort was random because the entire shoreline was sampled to compensate for the short time between marking and recapture (which was not expected to permit time for fish to mix; Hansen et al. 2000). A lack of significant differences between these gears suggests that nonrandom placement of fyke-netting and spearing effort were not biased towards unmarked or marked fish and that recapture rates from all of these gears provide

equally reliable recapture rates of marked adult walleyes.

The differences between angling and electrofishing recapture rates were surprising because we assumed that both gears sampled randomly. We assumed that angling effort was random because marked and unmarked fish had time to mix prior to the opening of the angling season. We also assumed that electrofishing effort was random because the entire shoreline was sampled. However, when  $R/C$  was low, angling  $R/C$  was higher than electrofishing  $R/C$  (indicated by a positive  $y$ -intercept, which was significant in lakes without minimum length limits but not in lakes with 15-in minimum length limits). We cannot explain why angling  $R/C$  may have been too high, but electrofishing  $R/C$  may have been too low because of differential vulnerability of marked and unmarked fish due to relocation where electrofishing is inefficient, as was shown for largemouth bass *Micropterus salmoides* (Lewis and Flickinger 1967; Parker and Hasler 1959; Van Den Avyle 1976). In contrast, when  $R/C$  was high, angling  $R/C$  was lower than electrofishing  $R/C$  (indicated by a slope less than 1.0, which was significant in lakes with 15-in minimum length limits but not in lakes without minimum length limits). We cannot explain why electrofishing  $R/C$  may have been too high, but angling  $R/C$  may have been too low because of recruitment of unmarked fish that were not vulnerable to capture during marking due to growth or location, as was shown for largemouth bass (Parker and Hasler 1959; Lewis and Flickinger 1967; Van Den Avyle 1976), or because of behavioral changes of marked fish after marking, as was shown for walleye (Johnson 1969; Serns and Kempinger 1981).

Recapture rates were probably not biased by additions to or losses from the population because most walleye populations in northern Wisconsin were closed to immigration and emigration. Lake chains only represent 15–20% of the acreage of off-reservation lakes in northern Wisconsin, though more than 50% of postspawning walleyes moved among lakes within such lake chains (Rasmussen et al. 2003). In interconnected lakes, recapture rates from fyke-netting, spearing, and adult electrofishing samples were not likely biased because of the short period between marking and recapture, although angling recapture rates may have been biased by movement if marked and unmarked walleyes emigrated at different rates or if unmarked walleyes immigrated into lakes sampled. Seawell and Hevel (1979) recommended less than one week between marking and recapture of largemouth bass to avoid biases due to migration.

Recapture rates were probably not violated by loss of tags or missed marks because fish were marked with fin clips (Beard et al. 1997; Hansen et al. 2000) and fins did not have time to regenerate between marking and recapture by fyke-netting, spearing, and electrofishing. Fin regeneration may have increased the likelihood of missing marks captured by angling, although fins tend to regrow with recognizable mutations (Churchill 1963), which should have been noticeable to trained survey clerks who were instructed to look for marks.

Recapture rates were probably not violated by unequal capture probability of marked and unmarked fish because different gears were used for marking and recapturing to reduce the likelihood of a behavioral response to capture (Pollock et al. 1990). Similarly, recapture rates were not likely biased due to preferential spearing or angling harvest because spearers were unlikely to see fin clips and were required to report all harvested fish, and anglers were unlikely to prefer marked fish over unmarked fish. Similarly, spearing harvest rates of an estuarine river bream *Acanthopagrus berda* were not different between tagged and untagged individuals in South African estuaries (Robertson 1997). Equal catchability was also not likely affected by stress responses due to marking because handling was minimal in comparison with other tagging methods (e.g., anchor tags).

### Management Implications

Assuring that assumptions are satisfied is one of the most difficult aspects of using mark-recapture methods (Van Den Avyle 1993). The lack of significant differences between recapture gears that we studied indicated that recapture samples from some harvest gears might be used to estimate walleye abundance in northern Wisconsin lakes. Recapture rates from spearing were similar to recapture rates from fyke-netting and electrofishing but should be used cautiously because spearing samples nonrandomly and could lead to biased recapture rates, depending on the distribution of marked and unmarked fish in relation to the sampling location. Electrofishing and angling were expected to violate the fewest assumptions, but significant differences between recapture rates suggested that some biases existed. Significant differences between electrofishing and angling recapture rates in lakes with 15-in minimum length limits suggested that electrofishing and angling may have sampled different portions of the same population. The relationship between electrofishing and angling in lakes without minimum length limits suggested

that angling recaptures could be used in place of electrofishing recaptures, but the intercept was significantly different from zero, suggesting biased recapture rates may be estimated. In cases when we found no significant differences between recapture rates, our results showed high variability between recapture rates, suggesting that caution should be used when substituting recapture rates from different gears.

Electrofishing seemed to violate few assumptions and therefore may provide the most accurate sampling method for estimating adult walleye abundance. We recommend continuing the use of electrofishing for recapture sampling in northern Wisconsin lakes. Adult walleye abundance estimates, using electrofishing recaptures, in northern Wisconsin during 1990–2000 generally had coefficients of variation ( $CV = 100 \times SD/mean$ ) less than 0.40 (median, 0.110; range, 0.016–0.620) and were therefore considered reliable (Hansen et al. 2000). Further support for using population estimates from electrofishing comes from a recent evaluation of Wisconsin's mixed walleye fishery which showed that Wisconsin's walleye fisheries have not exceeded exploitation targets based on abundance estimates using electrofishing recaptures (Beard et al. 2003). The lack of a significant relationship between electrofishing and angling recapture rates was unexpected. Grinstead and Wright (1973) recommended using angling recaptures to avoid electrofishing biases because anglers were likely to sample the total population by targeting areas where electrofishing is inefficient. Angling recapture rates have provided accurate estimates of largemouth bass populations in southern reservoirs (Hickman and Hevel 1976; Seawell and Hevel 1979), but adult walleye behavior and vulnerability to angling may not allow angling harvest to serve as a recapture sample. Conclusions from our study were based on specific gears and mark-recapture methods in northern Wisconsin, but our results indicated the importance of considering potential biases of sampling gears used for mark-recapture experiments under other circumstances. We suggest further study to quantify vulnerability of the entire adult walleye population to angling and electrofishing, which would allow managers to ensure that sampling effort is randomly distributed throughout the population and that abundance can be estimated accurately.

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