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[Article]

Evaluating Assumptions of Mark–Recapture Studies for Estimating Angling Exploitation of Walleyes in Northern Wisconsin Lakes

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Abstract.—To test for violations of the assumptions of mark–recapture studies used to estimate angling exploitation rates of walleye *Sander vitreus* in northern Wisconsin lakes, we estimated the recapture rate (*R/C*) of walleyes previously marked for each month of the angling year for five length categories: all lengths combined, less than 12 in, 12–15 in, 15–20 in, and 20 in or larger. The recapture rate declined significantly during the year for all walleye length-classes combined and for all length-classes except walleyes 12–15 in long. The *R/C* ratio in May increased with length. We conclude that fin regeneration, which contributed to lack of mark recognition, or higher mortality due to marking, may have reduced the number of marks in the *R/C* ratio and therefore may have biased estimates of walleye angling exploitation rates.

Knowledge of the exploitation rate of fish is necessary for management of any fishery (Ricker 1956; Serns and Kempinger 1981). Often, mark–recapture methods are used to estimate the exploitation rate (Ricker 1956). The simplest mark–recapture method for a closed population involves capturing, marking, and releasing M animals from a population of N animals and then resampling the population to obtain a second sample of C animals, of which R animals were previously marked (Ricker 1975). Mark–recapture exploitation rate estimates are based on the assumption that the proportion of marked animals to recaptured animals, R/C, represents the same ratio in the population, M/N, namely,

$$R/C = M/N.$$

From this, the exploitation rate, u, can be estimated as the rate of recapture of marked fish (Ricker 1975), that is,

$$u = R/M.$$

Mark–recapture surveys must meet the assumptions that (1) the population is closed to additions (births and immigrants) and deletions (deaths or emigrants) between marking and recapture, (2) marked and unmarked animals are equally vulnerable to capture, and (3) all marked individuals are identified (marks are not lost or overlooked by observers; Pollock et al. 1990; Guy et al. 1996; Van Den Avyle and Hayward 1999). Any violation of these assumptions can alter the proportion of marked animals to total animals in the recapture sample, thereby biasing estimates of exploitation rate; for example, any factor that overrepresents marked animals in the recapture sample will cause overestimation of exploitation rate, as when marked animals are more vulnerable to capture than unmarked animals (Van Den Avyle and Hayward 1999). Conversely, any factor that underrepresents marked fish in the recapture sample will cause underestimation of exploitation rate, as when marks are lost (e.g., fin regeneration) or when marked animals die at a higher rate than unmarked animals (Van Den Avyle and Hayward 1999).

A widely accepted marking technique for fish is full or partial fin removal (Guy et al. 1996). Fin-clipping is appropriate when recognition of individuals is not required, but this technique can affect growth, lower survival of marked fish, and fins may regenerate to cause marks to be unrecognized (McNeil and Crossman 1979). Fin-clipping can

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slow growth (Shetter 1950; Coble 1967), but in the majority of cases does not significantly affect growth (Armstrong 1949; Shetter 1951; Churchill 1963; Brynildson and Brynildson 1967; Coble 1971; Nicola and Cordone 1973; McNeil and Crossman 1979). The effect of fin removal on survival is mixed; it can either lower survival of marked fish (Coble 1971; Nicola and Cordone 1973) or not significantly affect survival (Shetter 1951; Churchill 1963). Fin regeneration has been documented in walleye *Sander vitreus*, coho salmon *Oncorhynchus kisutch*, Atlantic salmon *Salmo salar*, and brook trout *Salvelinus fontinalis*, depending on the fin removed and length of time between marking and recapture (Hale 1954; Eipper and Forney 1965; Coombs et al. 1990; Thompson and Blankenship 1997). In general, fin regeneration is greater among spiny-rayed fishes than soft-rayed fishes, among small fishes than large fishes, and in warm water than cool water (Ricker 1956). In addition, median fins tend to regenerate more quickly and perfectly than paired fins. Closely cut fins are less likely to regenerate (Ricker 1956).

Our objective was to determine whether violations of the assumptions of mark–recapture studies might have caused bias in estimates of exploitation rates of walleyes in northern Wisconsin. The Wisconsin Department of Natural Resources (WDNR) uses mark–recapture methods to estimate walleye angling exploitation rates in northern Wisconsin; however, the assumptions of mark–recapture surveys have not been evaluated for these methods. To examine the potential for loss of marks as a result of fin regeneration, lack of mark recognition, or higher mortality of marked fish, we examined trends in *R/C* during the walleye angling season (May–February). If a loss of marks was biasing estimates of exploitation rates, we expected to see a declining trend in the *R/C* ratio during the year; however, a declining trend in the *R/C* ratio may also be caused by a slowed growth of marked fish, which would cause unmarked fish to recruit to a higher length-class more quickly than marked fish, or cause those unmarked fish not susceptible to the capture gear in spring to recruit to a size vulnerable to angling. To examine this potential problem, we also examined trends in the *R/C* ratio during the angling season for different length categories of walleyes: less than 12 in, 12–15 in, 15–20 in, and 20 in or larger. If a loss of marks biased estimates of exploitation rates, we expected to see a declining trend for all length categories. In contrast, if unmarked fish recruited out of one length-class more quickly than marked fish (perhaps because of slowed growth caused by fin-clipping), we expected to see an increasing trend in the *R/C* ratio for the length-class losing unmarked fish and a declining trend in the *R/C* ratio for the length-class gaining unmarked fish. If no problem existed with mark recognition, we expected to see no trend in the *R/C* ratio across the angling season for any length-class.

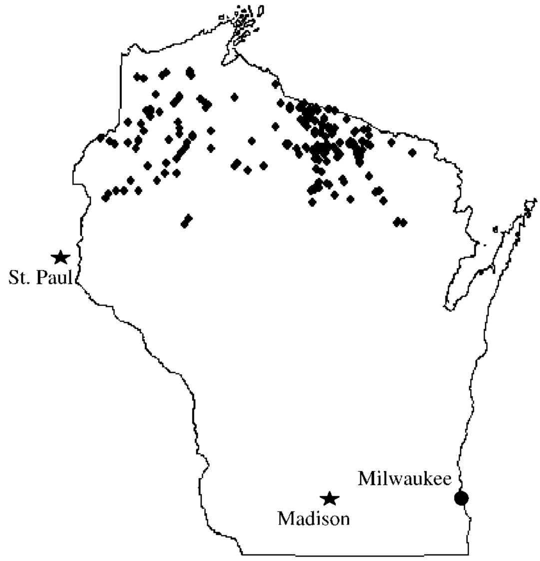

FIGURE 1.—Map showing the locations of 192 northern Wisconsin lakes where data on walleye recapture rates were collected through creel surveys from May to February during 1991–2002.

Methods

Study area.—The lakes in our analysis are located in northern Wisconsin (Figure 1). Lake surface areas ranged from 22 to 15,300 acres with walleye densities of 1 to 100 fish/acre (U.S. Department of the Interior 1991; Hansen et al. 2000). The fisheries in northern Wisconsin generate estimated revenues of US$340 million/year for Wisconsin's economy (Staggs et al. 1990).

Fishery surveys.—Mark–recapture surveys were used to estimate angling exploitation rates of walleyes in about 25 lakes/year during 1991–2002. Adult walleyes were captured with 0.5-in-mesh fyke nets and leads of 50–100 ft shortly after ice-out in late spring (usually April) as they moved inshore to spawn on shallow reefs (Beard et al. 1997; Hansen et al. 2000). Because male walleyes usually mature at 12 in and female walleyes usually mature at 15 in in northern Wisconsin, adults were defined as all fish for which sex could be determined and all walleyes of unknown sex longer than 15 in (Beard et al. 1997). Mature and immature walleyes were marked by partial removal of one or more fins, at which time lengths were recorded and dorsal spines were removed from a subsample of 5–10 fish/0.5-in length-class to estimate age. Ten percent of mature walleyes in each lake were targeted for marking (Hansen et al. 2000).

The numbers of walleyes harvested and numbers of marked walleyes harvested (used to estimate exploitation rate) were collected with the use of creel surveys. Creel surveys that followed a random-stratified roving-access design were conducted during the legal walleye angling season (Pollock et al. 1994; Beard et al. 1997; Rasmussen et al. 1998).

Data analysis.—During 1991–2002, creel surveys were conducted on 192 different lakes, at which time 169,282 complete-trip interviews were obtained. First, we estimated the *R/C* ratio for each month from May to February by dividing the total number of recaptures estimated across all years and interviews by the total harvest estimated across all years and interviews (Newman et al. 1997; Beard et al. 2003) for all lengths of walleyes. For each monthly estimate of the *R/C* ratio, we estimated 95% confidence intervals using the relationship between the *F* distribution and the binomial distribution (Zar 1999). To determine whether the *R/C* ratio declined during the angling season, we fit a negative exponential model to the data, that is,

$$R/C = \alpha X^{-\beta},$$

where X is the month of the angling season, α is the *R/C* ratio in May, and β is the rate at which the *R/C* ratio decreases by month. Parameters were estimated with linear regression on the $\log_e$ transformed model, that is,

$$\log_e(R/C) = \log_e\alpha - \beta X + \varepsilon.$$

To determine whether recruitment caused a systematic change in the *R/C* ratio during the angling season, the same model described above was fit to the *R/C* ratio for four length-classes: less than 12 in, 12–15 in, 15–20 in, and 20 in or larger.

To test for significant bias in estimates of exploitation rates, the number of recaptures in a year, *R*, was estimated as the sum of the product of the *R/C* ratio and harvest in each month (Rasmussen et al. 1998) and compared with estimates of recaptures in each year that were estimated by applying the *R/C* ratio in May to all months with paired *t*-tests ($P < 0.05$). We compared estimates of *R* because the denominator of exploitation rate is the same for both biased and unbiased estimates of *R*; therefore, bias detected in estimates of *R* is the same as bias in estimates of exploitation rate. We used the *R/C* ratio in May because the effects of fin regeneration, higher mortality due to marking, and recruitment of other fish would be negligible compared with other months with a longer amount of time between marking and recapture. We therefore assumed May most accurately reflected the *R/C* ratio expected throughout the angling season. Bias was reported as the percentage change in the estimate of *R*, or the mean difference between the estimate of *R* based on the *R/C* ratio in each month and the *R/C* ratio in May applied to all months, divided by the estimate based on the *R/C* ratio in May applied to all months and multiplied by 100.

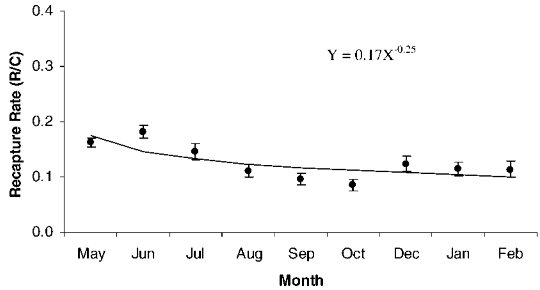

FIGURE 2.—Recapture rate (±95% confidence intervals) of walleyes sampled during complete-trip interviews of creel surveys conducted in northern Wisconsin lakes from May to February during 1991–2002.

Results

The *R/C* ratio generally declined from May to February and increased with walleye length in northern Wisconsin lakes. For walleyes of all lengths combined, the *R/C* ratio declined significantly ($F_{1,7} = 7.78$; $P = 0.03$), from a value of $\alpha = 0.174$ in May at a rate of $\beta = -0.249$ (Figure 2). The *R/C* ratio also declined significantly for walleyes less than 12 in long ($F_{1,6} = 16.72$; $P = 0.01$), 15–20 in long ($F_{1,7} = 19.15$; $P = 0.003$), and 20 in long or larger ($F_{1,7} = 8.14$; $P = 0.02$), but not for walleyes 12–15 in long ($F_{1,7} = 5.00$; $P = 0.060$; Figure 3). The decline in *R/C* ratios from May to February was steeper for walleyes less than 12 in long ($\beta = -0.888$) than for longer walleyes ($\beta = -0.250$ to -0.283; Figure 3). The *R/C* ratio in May increased with length, from $\alpha =$

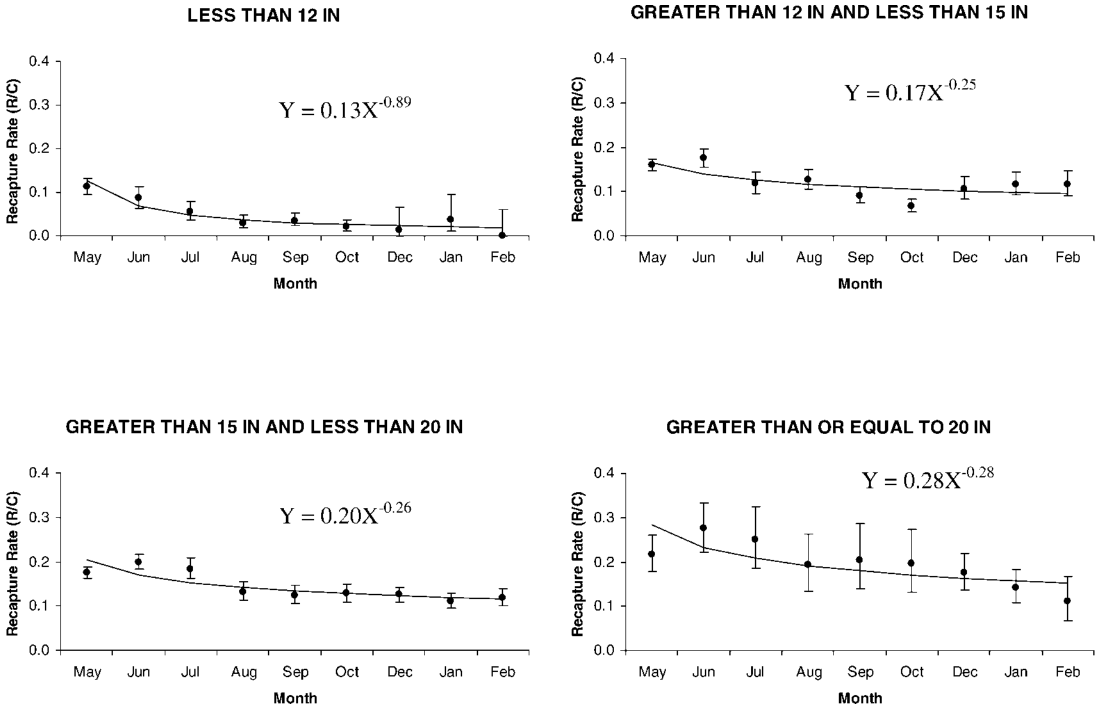

FIGURE 3.—Recapture rate (±95% confidence intervals) of walleyes in four length-classes sampled during complete-trip interviews of creel surveys conducted in northern Wisconsin lakes from May to February during 1991–2002.

0.126 for walleyes less than 12 in long to α = 0.284 for walleyes 20 in long or larger (Figure 3).

Estimates of R based on the R/C ratio for each month were significantly lower than the R/C ratio from May applied to all months ($t = -3.95$; df = 255; $P < 0.01$). Bias was negative in all years except 1993 and 2001 and ranged from −41% in 2000 to 36% in 2001 (Figure 4).

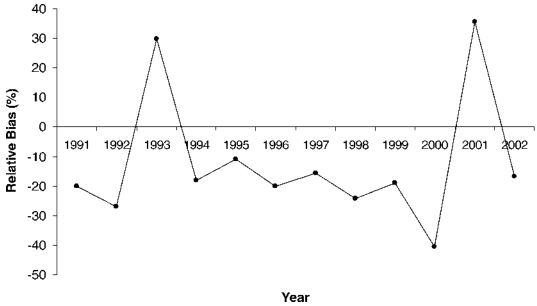

FIGURE 4.—Percentage bias in estimates of recaptured walleyes in northern Wisconsin lakes during 1991–2002 using the R/C ratio in each month, as opposed to using the R/C ratio in May for all months.

Discussion

We found that the recapture rate declined significantly during the angling season for all lengths of walleyes combined and for all length-classes (except for walleyes 12–15 in long), which suggests that recruitment of unmarked fish throughout the angling season or slowed growth due to fin-clipping were not significant problems and that factors such as fin regeneration, lack of mark recognition, or a decrease in survival due to marking may have reduced the number of marks in the R/C ratio as in several other studies (Hale 1954; Coble 1971; Nicola and Cordone 1973; Coombs et al. 1990; Thompson and Blankenship 1997). For example, survival of rainbow trout *O. mykiss* marked by removal of the dorsal, adipose, anal, right ventral, left pectoral, or right pectoral fin was significantly less than unmarked fish after 1 year in Castle Lake, California (Nicola and Cordone 1973). Similarly, survival of age-0 smallmouth bass *Micropterus dolomieu* marked by removal of the left pectoral, right ventral, both ventral, or anal fin was significantly less than unmarked fish after 1 year in 8 experimental ponds in Boone County, Missouri, and survival varied among fin clips (Coble 1971). In addition, adult walleyes marked with half-pectoral fin clips and held in an experimental pond in New York exhibited nearly complete regeneration after 6 months (Eipper and Forney 1965). In Washington, 23% of coho salmon marked by removal of the top or back two-thirds of the adipose fin exhibited complete regeneration after 21 months (Thompson and Blankenship 1997). For Atlantic salmon held in experimental tanks in New Brunswick, Canada, 0.2% of adipose fins showed signs of regeneration 3 months after initial marking, whereas 46.4% of left pelvic fins and 53.4% of right pelvic fins almost completely regenerated over the same period (Coombs et al. 1990). For fingerling brook trout, 28.8% marked by removal of pelvic fins exhibited complete regeneration after 10 months in an experimental trough and 44.5% exhibited considerable regeneration (Hale 1954).

We found that the slope of the relationship between the *R/C* ratio and month of the angling season was steepest for the smallest length-class of walleyes (<12 in), which might be a result of the propensity of young (small) fish to regenerate fins more quickly than old (large) fish. For example, Slater (1949) concluded that younger fish regenerate clipped fins more quickly, but that speed of regeneration decreased with size and age. In addition, Ricker (1956) noted that regeneration was more common and more complete among smaller fish.

We found that the *R/C* ratio in May increased with length, probably because fyke nets select for longer fish, as was found in other studies (Latta 1959; Forney 1961; Hamley and Regier 1973; Laarman and Ryckman 1982; Kraft and Johnson 1992). Fyke-net selectivity increased with length and changed systematically with mesh size for yellow perch *Perca flavescens* in Green Bay, Lake Michigan (Kraft and Johnson 1992). Trap-net selectivity increased with length for rock bass *Ambloplites rupestris*, walleyes, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, yellow perch, and pumpkinseed *Lepomis gibbosus* in Manistee Lake, Michigan (Laarman and Ryckman 1982). Similarly, the percentage of marked fish recaptured with trap nets increased with length for bluegill, rock bass, yellow bullhead *Ameiurus natalis*, and white sucker *Catostomus commersonii* in Fife, Whitmore, Fine, and Sugarloaf lakes, Michigan (Latta 1959). Trap-net selectivity also increased with length for walleyes in Dexter Lake, Ontario (Hamley and Regier 1973). Size selectivity of fyke nets is probably a result of some size-specific fish behavior (Latta 1959; Laarman and Ryckman 1982; Beamesderfer and Rieman 1988).

Management Implications

The declining trends in *R/C* ratios that we observed may have led to underestimation of angling exploitation rates of walleyes in northern Wisconsin lakes. Percent changes in estimates of exploitation rate at the levels we estimated could lead managers to conclude that exploitation rates are at sustainable levels, when, in fact, they are not. Because fin-clipping is a widespread marking technique, this problem may also exist in other fisheries. Therefore, management agencies should evaluate their marking protocol to ensure that fin clips are recognizable for the duration of the recapture period and do not affect survival. Such an evaluation could be accomplished through either a dual-marking study or an experiment in a controlled environment. Our findings also provide some evidence that the rate of regeneration or decrease in survival may be greater for younger fish. Therefore, research should also account for the fact that young (small) fish are able to regenerate fins more quickly than old (large) fish and may respond differently to the marking procedure.

In cases where creel surveys are used to collect recapture data, creel clerk performance may also affect estimates. For example, two clerks conducting a stratified roving creel survey on Kentucky Lake, Tennessee, on the same days at the same times of day from July 1988 to December 1988 reported significantly different catch rates and mean weights of largemouth bass *M. salmoides* and white crappies *Pomoxis annularis* (O'Bara 1991). O'Bara (1991) concluded that clerk performance was affected by experience. Periodic training may help to ensure that creel clerks know how to recognize partially regenerated fins and to reiterate the importance of mark recognition. Alternatively, creel clerks could be scheduled to rotate among several different water bodies during the angling season, which would help prevent boredom and complacency, especially on lakes with low angling effort.

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