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Catch Rates and Catchability of Walleyes in Angling and Spearing Fisheries in Northern Wisconsin Lakes

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Abstract.—We examined relationships between angling and spearing catch rates (catch/h) and walleye population density (number/acre) in 118 northern Wisconsin lakes to determine if walleye catchability in these fisheries was density dependent. The densities of both adult and total walleye populations were unrelated to lake surface area. Similarly, the catchability of walleyes in angling and spearing fisheries was unrelated to lake surface area. Angling catch rates of walleyes were linearly related to total walleye population density, whereas spearing catch rates of walleyes were exponentially related to adult walleye population density. Walleye catchability in the angling fishery was not significantly related to population density, whereas walleye catchability in the spearing fishery was inversely related to population density. We conclude that walleye angling is density independent and is therefore self-regulating, whereas walleye spearing is density dependent and is therefore not self-regulating.

An understanding of the portion of a fish population that is removed by a single unit of fishing effort, defined as the catchability coefficient (q), is central to an understanding of fishery dynamics and effective fishery management (Ricker 1975; Gulland 1988; Hilborn and Walters 1992; Quinn and Deriso 1999). The catchability of fishes is often assumed to be a constant fraction of the population caught by each unit of fishing effort. This relationship has most often been formulated as the basic catch equation

$$C/f = qN/A; \tag{1}$$

C = catch, f = fishing effort, N = fish abundance, and A = area occupied by the fish stock (Gulland 1969; Ricker 1975). In equation (1), C/f is a linear function of N/A, with constant slope q. In some fisheries, however, q may increase as N/A decreases (Cushing 1981; Peterman and Steer 1981; Bannerot and Austin 1983; Hilborn and Walters 1992; Arreguin-Sanchez 1996). An inverse relationship between q and N/A must be known for fishery harvest regulation to be effective because effort needs to be controlled more severely than if q was unrelated to N/A (Peterman and Steer 1981). Density dependence in the relation between q and N/A is most likely caused by nonrandom searching behavior of fishermen and schooling behavior of fish (Peterman and Steer 1981).

Catchability may also increase as the area occupied by the fish stock decreases. Most often, however, the dependence of catchability on area has been ignored because it is assumed that the area occupied by the fish stock is constant (Winters and Wheeler 1985). This assumption is probably reasonable for some fish species, such as anadromous salmonids, that are intercepted as they return to natal streams (Peterman and Steer 1981). For other species, such as pelagic marine species, that occupy areas of different size that are proportional to the total number of individuals in the population, catchability may vary inversely with area (Winters and Wheeler 1985). Similarly, inland species that occupy lakes of varying size may be exploited more effectively in small lakes (Ryder et al. 1974). For such pelagic marine and inland fish species, the inverse relationship between catchability and area may falsely give the appear-

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ance of density-dependent catchability, if not taken into account.

We wished to determine if catch rates and catchability of walleyes in angling and spearing fisheries in northern Wisconsin lakes varied with walleye population density or lake surface area. We relied on data that has been collected since 1990 in Wisconsin as part of a stock assessment program that was designed to determine long-term effects of spearing and angling on walleye populations in Wisconsin. Annual surveys of walleye populations and angling and spearing fisheries have been conducted each year on about 25 randomly selected lakes. Lakes ranged in size from about 100 acres to more than 10,000 acres, and walleye populations ranged from about 1.0 fish/acre to nearly 100 fish/acre, thereby permitting comparisons of angling and spearing catch rates over a wide range of walleye population densities and lake sizes.

Methods

We analyzed data gathered as part of a multiagency effort to monitor walleye populations and associated fisheries in the northern third of Wisconsin (Hansen et al. 1991; Beard et al. 1997). Lakes were selected at random each year during 1990–1997 from among those lakes containing walleyes that were subjected to state-licensed angling and tribe-licensed spearing (Hansen et al. 1991). Tribal spearing occurs during a few weeks in spring (usually April) when sexually mature walleyes are attempting to spawn, whereas angling occurs from the first Saturday in May through the first of March of the following year. Tribal spearing is targeted on spawning walleyes, so numbers of sexually mature walleyes were estimated during the spawning period. In contrast, angling occurs when mature and immature walleyes are intermingled, so total numbers of walleyes were estimated 2–3 weeks after spawning, when immature and mature fish were mixed into the total population.

Walleye abundance.—Abundance of adult (sexually mature) walleyes and all walleyes (immature and mature) were estimated during spring of each year during 1990–1996 using Chapman's modification of the Petersen estimator (Ricker 1975). Walleyes were captured for marking in fyke nets that were set shortly after ice-out when mature walleyes were congregated inshore for spawning (Hansen et al. 1991; Beard et al. 1997). Ten percent of the mature walleyes in each lake were targeted for marking. Mature walleyes were defined as all fish for which the sex could be determined, plus all fish longer than 15 in for which the sex could not be determined (the length at which males and females were likely to be sexually mature). All fish were marked by partial removal of a fin. To estimate adult walleye abundance, fish were recaptured 1–2 d after netting while adult walleyes were still congregated inshore. Because the interval between marking and recapture was short, the entire shoreline was electrofished to ensure that marked and unmarked fish were equally vulnerable to capture. Immature and mature fish that were present during the first electrofishing recapture run, but that had not been previously marked, were marked by removal of one or more fins for estimating the total number of walleyes in the population. To estimate total walleye abundance, fish were captured about 2–3 weeks after the first recapture sample. Again, the entire shoreline of each lake was electrofished to ensure marked and unmarked fish were equally vulnerable to capture. Marked fish from the fykenetting and first electrofishing runs were combined as the marked sample, while the ratio of marked fish in the population was estimated from the second electrofishing run.

Abundance and variance were estimated for four length-classes (0–11.9 in, 12–14.9 in, 15–19.9 in, and $\geq$20.0 in) then summed to estimate adult and total abundance and variance for each lake. Before estimating abundance, walleyes that were speared after the start of the marking period were subtracted from the number of marked fish at large during the recapture period. These fish were then added to the number of fish estimated to have been present at the time of marking for the populations of interest (spawning population or total population). Abundance estimates with a coefficient of variation (CV = estimate/SD) larger than 0.40 were considered unreliable and were eliminated from further use. Of 232 lakes with estimates of adult walleye abundance, 13 lakes (5.6%) were dropped because the CV of the estimate was larger than 0.40 (median = 0.101, range = 0.016−0.578). Of 157 lakes with estimates of total walleye abundance, 37 lakes (23.6%) were dropped because the CV of the estimate was larger than 0.40 (median = 0.272, range = 0.067−0.690).

Spearing catch rates.—Spearing catch rates were computed from nightly censuses of spearing harvest and effort on each lake in spring 1990–1996 (Kmiecik 1991; Kmiecik and Ngu 1992; Ngu and Kmiecik 1993; Ngu 1994; 1995; 1996; Krueger 1997; 1998). Spearing is permitted for only a limited number of tribal members on each lake each night, based on the estimated nightly quota for that lake and the number of interested individuals (U.S. Department of the Interior 1991). Each spearer is allowed a quota for the evening (commonly, 25 fish per spearer), which must be landed at a specified location on each lake. Spearing is pursued to take the allotted quota in as little time as possible, so time spent spearing is a function of fish density in the area speared. In addition, spearing is only effective in spring, when walleyes are congregated in shallow water for spawning. Consequently, spearing is not used at other times of year when walleyes are offshore. Clerks record the starting and ending times of each spearing trip, count all fish speared, and record the length of each fish. Maximum length of walleyes speared is limited by allowing only one fish of the nightly bag limit to be between 20 and 24 in and one additional fish of the nightly bag limit to be of any length. Catchability of walleyes in the spearing fishery was estimated by dividing the mean annual catch rate by the density of adult walleyes for each lake (rearranging equation 1, $q = CA/fN$). Spearing data were available for 93 of the 219 lakes on which adult walleye abundance was estimated by mark–recapture and that had a CV smaller than 0.40.

Angling catch rates.—Angling catch rates were estimated from creel surveys that were conducted during the angling season for walleye in Wisconsin from 1990 to 1996; the season began on the first Saturday in May and continued through 1 March of the following year (Beard et al. 1997). Creel surveys followed a random stratified roving-access design (Pollock et al. 1994; Rasmussen et al. 1998). Each month, all weekend days (including holidays) and 2–3 randomly selected weekdays were sampled each week from 0.5 h before sunrise to 0.5 h after sunset. Clerks worked 5 d per week. During the open-water season, the day was divided into two nonoverlapping clerk shifts, and clerk shifts were randomly selected each day. During the ice-fishing season, the entire day was sampled because of short daylight hours. Creel surveys were not conducted in November because of dangerous ice conditions and low angling effort.

Angling catch rates were estimated from catch and effort data collected during interviews of anglers as they completed fishing each day. Data were stratified by month and day type (weekdays, weekends). The walleye catch rate for each stratum was calculated as the total number of walleyes caught divided by the total number of hours fished for walleyes (i.e., targeted effort). Monthly estimates were calculated as means of each stratum estimate, weighted by the angling effort for walleyes within that stratum. The mean annual walleye catch rate for each lake was calculated as the weighted mean of the monthly estimates. Variance was estimated using the same weighting. Catchability of walleyes in the angling fishery was estimated by dividing the mean annual catch rate by the density of all walleyes for each lake (rearranging equation 1, $q = CA/fN$). Angling data were available for 111 of the 120 lakes on which total walleye abundance was estimated by mark–recapture and that had a CV smaller than 0.40.

Area dependence of angling and spearing catchability.—To determine if average walleye density varied with lake surface area, we modeled numbers of both adult and total walleyes as nonlinear functions of lake surface area:

$$N = \alpha A^{\beta+1}; \qquad (2)$$

β expresses the degree of curvature in the relationship between N and A and α expresses the average density (N/A) when $\beta = 0$. Parameters were estimated from the transformed model,

$$\log_e(N) = b_0 + b_1 \log_e A; \qquad (3)$$

the intercept $b_0 = \log_e\alpha$, and the slope $b_1 = \beta + 1$. In equation (3), N/A is constant at all lake sizes when the slope, b_1, is one ($\beta = 0$), and N/A is inversely related to lake size when the slope, b_1, is less than one ($\beta < 0$). Because lake surface area is measured with little error, the parameters in equation (3) are unbiased when estimated by simple linear regression.

To determine if catchability of walleyes in angling and spearing fisheries varied with lake surface area, we then modeled walleye angling and spearing q as nonlinear functions of lake surface area (A):

$$q = \alpha A^{-\beta}; \qquad (4)$$

q is independent of area (constant) when $\beta = 0$ and changes in direct proportion to stock area when $\beta = 1$ (Winters and Wheeler 1985). Parameters in equation (4) were estimated by linear regression on the transformed model:

$$\log_e q = b_0 - b_1 \log_e A; \qquad (5)$$

the intercept $b_0 = \log_e\alpha$ and the slope $b_1 = \beta$. Equation (5) is not fraught by errors in variables, so β (b_1) can be estimated by simple linear regression (Winters and Wheeler 1985). We judged the degree of area dependence in equation (5) from the significance of β for the nonlinear form of the model (equation 4).

Density dependence of angling and spearing catchability.—To determine if catchability of walleyes in angling and spearing fisheries varied with walleye density, angling and spearing catch rates (C/f) were modeled as nonlinear functions of walleye population density (N/A):

$$C/f = \alpha(N/A)^{\beta+1}; \qquad (6)$$

β expresses the degree of curvature in the relation between C/f and N/A and α provides an estimate of q when $\beta = 0$ (Peterman and Steer 1981). Parameters were estimated from the transformed model:

$$\log_e(C/f) = b_0 + b_1\log_e(N/A); \qquad (7)$$

the intercept $b_0 = \log_e\alpha$ and the slope $b_1 = \beta + 1$. We tested the degree of nonlinearity in the relation between C/f and N/A (i.e., density dependence) by determining if the slope ($b_1 = \beta + 1$) differed significantly from one ($\beta = 0$; Peterman and Steer 1981; Shardlow et al. 1985). However, the parameters in equation (7) are biased when estimated by linear regression because N was estimated with error (Peterman and Steer 1981; Shardlow et al. 1985). We therefore estimated parameters for the functional (geometric mean) regression of $\log_e(C/f)$ on $\log_e(N/A)$ (Ricker 1975; Sokal and Rohlf 1981).

Dividing equation (1) by N/A allows walleye angling and spearing q to be modeled as nonlinear functions of N/A:

$$q = (C/f)/(N/A) = \alpha(N/A)^{\beta}; \qquad (8)$$

q is constant at all population densities when $\beta = 0$, decreases with population density when $\beta < 0$, and increases with population density when $\beta > 0$. Parameters in equation (8) were estimated for the transformed model

$$\log_e q = b_0 + b_1\log_e(N/A); \qquad (9)$$

the intercept $b_0 = \log_e\alpha$ and the slope $b_1 = \beta$. As with catch rates, we estimated parameters for equation (9) from the functional (geometric mean) regression of $\log_e(q)$ on $\log_e(N/A)$ because these parameters are biased when estimated by linear regression (Ricker 1975; Sokal and Rohlf 1981).

The statistical significance of β in equation (9) cannot be tested directly because N appears on both sides of the equation (i.e., $q = CA/fN$; Peterman and Steer 1981; Shardlow et al. 1985). Therefore, we used equation (9) only to describe the functional relationship between q and N/A and tested for density dependence from the slope of equation (7), the relation between C/f and N/A (Peterman and Steer 1981; Shardlow et al. 1985). When estimated by linear regression, β is the same in equations 7 ($\beta = b_1 - 1$) and 9 ($\beta = b_1$), so the significance of β ($b_1 - 1$) in equation (7) is equivalent to the significance of β (b_1) in equation (9). However, the same algebraic equivalence does not hold when β is estimated by functional regression because b_1 is always greater in both equations (7) and (9) than when estimated by linear regression (Sokal and Rohlf 1981). For example, when estimated by functional regression, a slope in equation (7) that is significantly greater than one indicates a slope in equation (9) that is significantly less than zero. We interpret such a result as indicating density dependent catchability ($\beta < 0$). In contrast, when estimated by functional regression, a slope in equation (7) that is not significantly different from one may indicate a slope in equation (9) that is not significantly different from zero. We interpret such a result as indicating density independent (constant) catchability ($\beta = 0$).

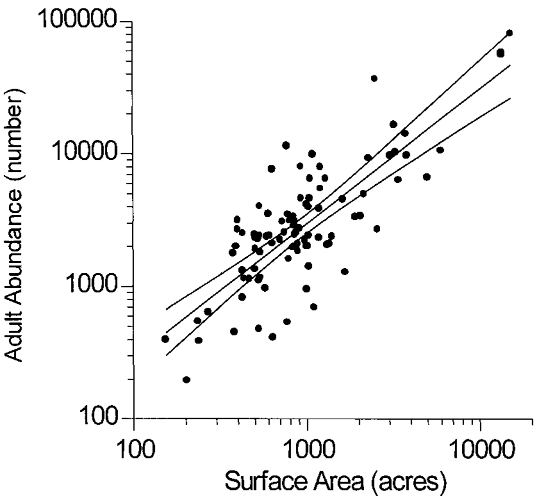

FIGURE 1.—Adult walleye abundance, estimated by mark–recapture, versus surface area in 93 northern Wisconsin lakes sampled in 1990–1997. Upper and lower lines depict 95% confidence intervals.

Results

Area Dependence of Angling and Spearing Catchability

Population density did not vary with lake surface area for either adult walleyes or all walleyes. Total walleye abundance was linearly related to lake surface area (Figure 1) because the slope of

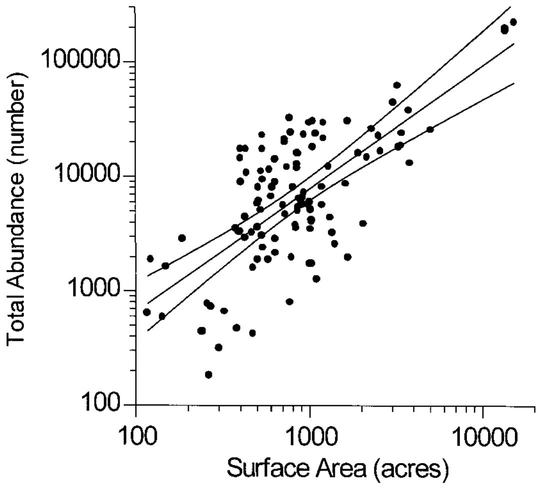

FIGURE 2.—Total walleye abundance, estimated by mark–recapture, versus surface area in 111 northern Wisconsin lakes sampled in 1990–1997. Upper and lower lines depict 95% confidence intervals.

the relation was not significantly different from 1.0 (t = 0.708; df = 109; P = 0.48):

$$N = 4.636A^{1.074}.$$

Total walleye density in 111 northern Wisconsin lakes averaged 4.6 fish/acre (95% confidence interval = 1.1–18.8/acre) and did not vary significantly with lake surface area. Adult walleye abundance was also linearly related to lake surface area (Figure 2) because the slope of the relation was not significantly different from one (t = 0.776; df = 91; P = 0.94):

$$N = 2.825A^{1.006}.$$

Adult walleye density in 93 northern Wisconsin lakes averaged 2.8/acre (95% confidence interval = 0.9–8.4/acre) and did not vary significantly with lake surface area.

Catchability of walleyes in angling and spearing fisheries was unrelated to lake surface area. In the angling fishery, catchability of all walleyes was unrelated to lake surface area (Figure 3) because the slope of the relation was not significantly different from zero (t = −0.658; df = 109; P = 0.51):

$$q = 0.030A^{-0.043}.$$

Catchability of all walleyes in the angling fishery in 111 northern Wisconsin lakes averaged 0.030 (95% confidence interval = 0.012–0.071) and did not vary significantly with lake surface area. In the spearing fishery, catchability of adult

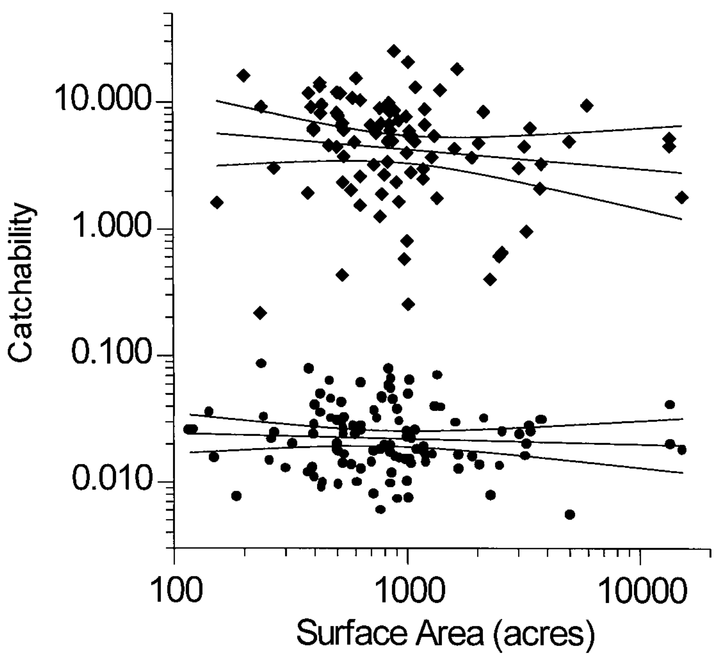

FIGURE 3.—Lake surface area versus walleye catchability in angling and spearing fisheries in 118 northern Wisconsin lakes sampled in 1990–1997. Diamonds show the relation between lake surface area and spearing catchability (93 lakes). Dots show the relation between lake surface area and angling catchability (111 lakes). Upper and lower lines depict 95% confidence intervals.

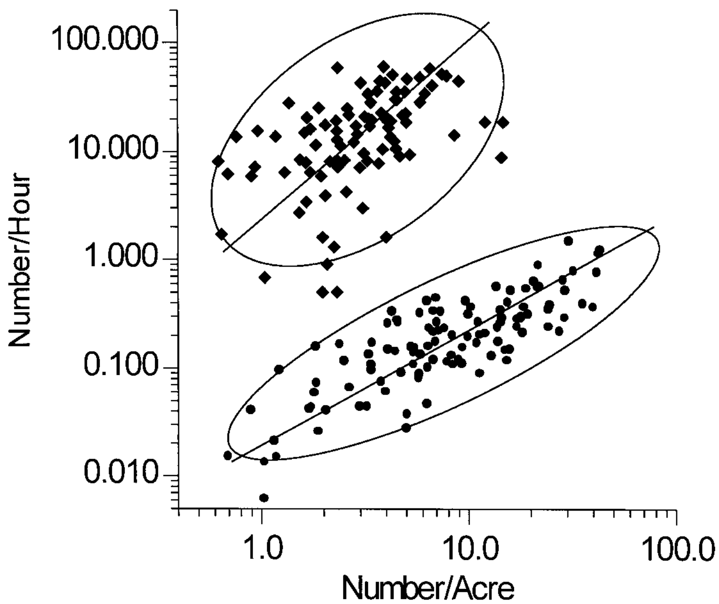

FIGURE 4.—Number of walleyes per acre versus the mean yearly catch per hour in angling and spearing fisheries in 118 northern Wisconsin lakes sampled in 1990–1997. Diamonds show the relation between number of adult walleyes per acre and spearing catch per hour (93 lakes). Dots show the relation between total number of walleyes per acre and angling catch per hour (111 lakes). Ellipses enclose 95% of the data points for each bivariate relation.

walleyes was also unrelated to lake surface area (Figure 3) because the slope of the relation was not significantly different from zero ($t = -1.321$; df = 91; $P = 0.19$):

$$q = 12.321A^{-0.154}.$$

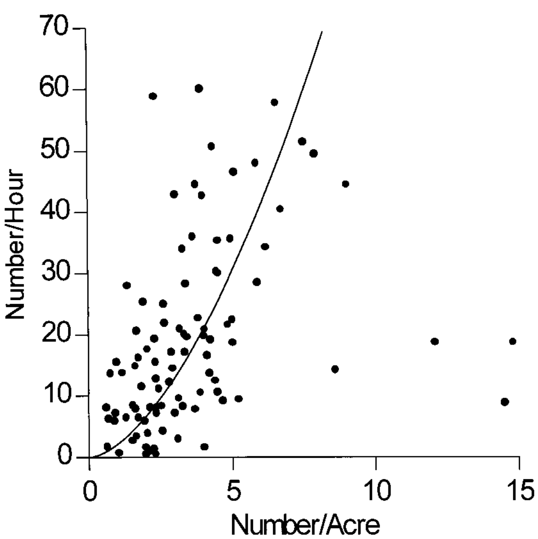

FIGURE 5.—Number of adult walleyes per acre versus the mean yearly catch per hour in spearing fisheries in 93 northern Wisconsin lakes sampled in 1990–1997.

Catchability of adult walleyes in the spearing fishery in 93 northern Wisconsin lakes averaged 12.3 (95% confidence interval = 2.5–60.9) and did not vary significantly with lake surface area (Figure 3). The spearing fishery for adult walleyes was therefore 416 times more efficient than the angling fishery for all walleyes in northern Wisconsin lakes (95% confidence interval = 202–857 times).

Density Dependence of Angling and Spearing Catchability

Catch rates of walleyes in angling and spearing fisheries increased in relation to walleye population density (Figure 4). Catch rates of walleyes in the spearing fishery increased exponentially with adult walleye population density (Figure 5) because the slope of the functional regression was significantly larger than one ($t = 4.253$; df = 91; $P \leq 0.01$):

$$C/f = 2.121(N/A)^{1.652}.$$

This suggests that catchability of adult walleyes in the spearing fishery in northern Wisconsin varied significantly with walleye population density. In contrast, catch rates of walleyes in the angling fishery were linearly related to total population density (Figure 6) because the slope of the func-

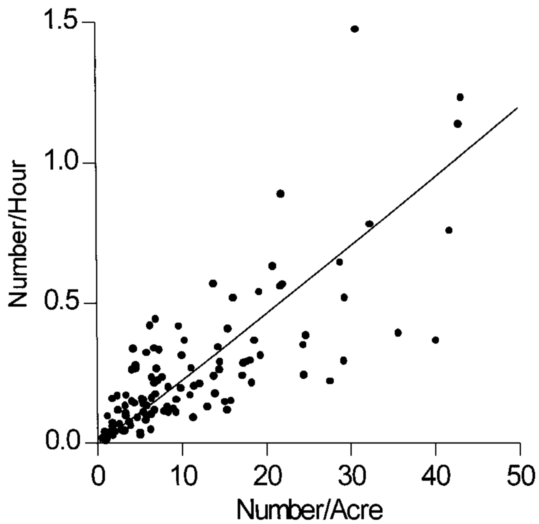

FIGURE 6.—Number of total walleyes per acre versus the mean yearly catch per hour in angling fisheries in 111 northern Wisconsin lakes sampled in 1990–1997.

tional regression was not significantly different from one ($t = 0.652$; df = 109; $P = 0.52$):

$$C/f = 0.021(N/A)^{1.038}.$$

This suggests that catchability of all walleyes in the angling fishery in northern Wisconsin did not vary significantly with walleye population density.

The catchability of all walleyes in the angling fishery and adult walleyes in the spearing fishery appeared to decline as population density increased (Figure 7). The catchability of walleyes in the spearing fishery was inversely related to adult walleye population density (Figure 8):

$$q = 21.249(N/A)^{-1.480}.$$

The inverse relation between spearing catchability and adult walleye density indicates significant density dependence because the slope of the relationship between spearing catch rates and adult walleye population density was significantly greater than one. The catchability of walleyes in the angling fishery also appeared to be inversely related to total walleye population density (Figure 9):

$$q = 0.079(N/A)^{-0.626}.$$

However, the relation between angling catchability and total walleye density indicates density independence because the slope of the relationship

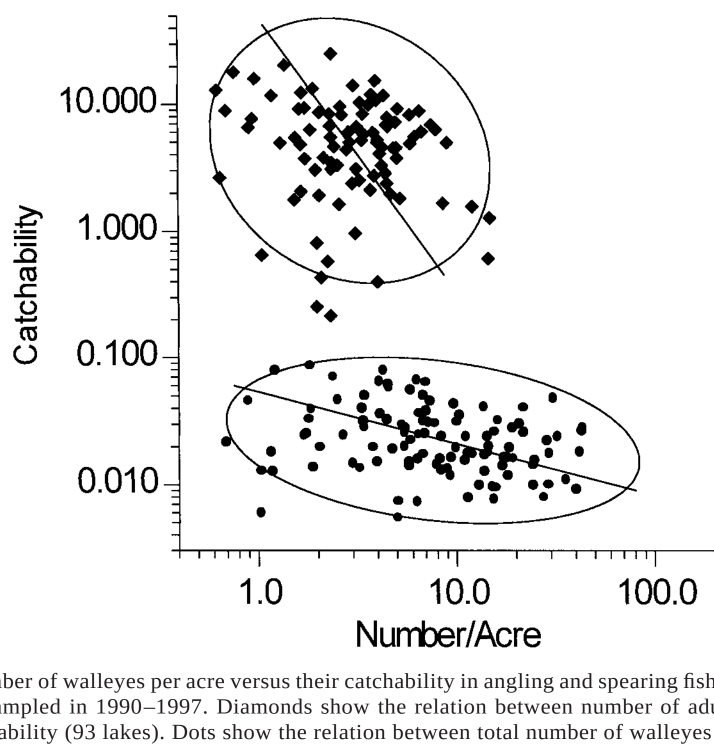

FIGURE 7.—Number of walleyes per acre versus their catchability in angling and spearing fisheries in 118 northern Wisconsin lakes sampled in 1990–1997. Diamonds show the relation between number of adult walleyes per acre and spearing catchability (93 lakes). Dots show the relation between total number of walleyes per acre and angling catchability (111 lakes). Ellipses enclose 95% of the data points for each bivariate relation.

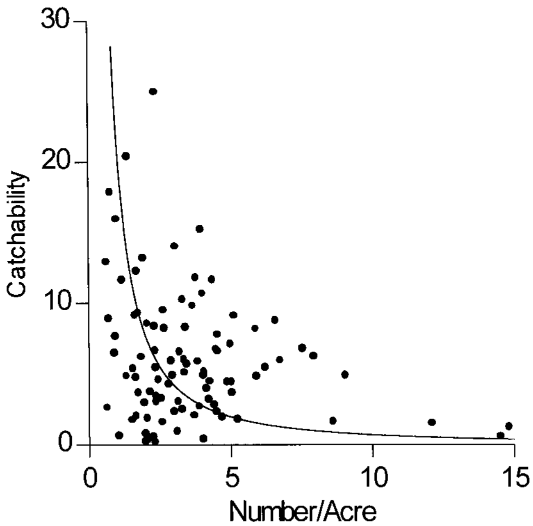

FIGURE 8.—Number of adult walleyes per acre versus their catchability in spearing fisheries in 93 northern Wisconsin lakes sampled in 1990–1997.

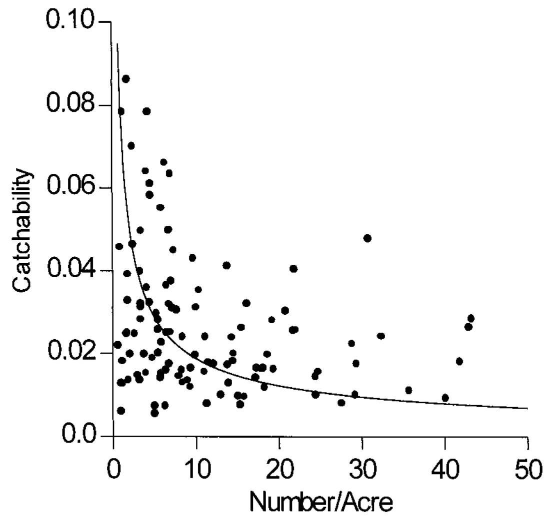

FIGURE 9.—Number of total walleyes per acre versus their catchability in angling fisheries in 111 northern Wisconsin lakes sampled in 1990–1997.

between angling catch rates and total walleye density was not significantly different from one.

Discussion

Angling catch rates were linearly related to total walleye population density in northern Wisconsin lakes, which agreed with the results of several other studies of walleye angling catch rates (Thorn 1984; Isbell and Rawson 1989; Staggs et al. 1990; Beard et al. 1997). Catchability of walleyes in the northern Wisconsin angling fishery appeared to decline with population density, but the decline was not significant within the range of variation in angler catch rates and walleye population density. In addition, our estimate of the density dependent coefficient for walleye angling catchability ($\beta = -0.626$) was lower than all but one of those summarized by Peterman and Steer (1981). We therefore conclude that catchability of walleyes by angling is not density dependent and agree with Staggs et al. (1990) that angling is relatively self-regulating (i.e., catch rates are linearly related to population density and catchability does not change as a function of fish density).

Angling appears to be self-regulating when examined across a broad spatial scale, such as in our analysis. However, we do not mean to imply that self-regulation will lead to quality walleye angling in terms of catch rates or average size of fish caught. Walters and Cox (in press) showed that anglers for rainbow trout *Oncorhynchus mykiss* in British Columbia lakes tended to homogenize catch rates across the region by moving to lakes with higher catch rates. Angler movement across the landscape thereby reduced angling quality by targeting lakes with high catch rates and created a landscape in which no lake stood out from the rest (Walters and Cox, in press). The self-regulation of angling fisheries may therefore ensure mediocrity in regional fisheries that is maintained by angler movement patterns. Regulation of angling effort will be necessary to control this homogenization of angling catch rates.

Spearing catch rates increased exponentially as adult walleye population density increased in northern Wisconsin lakes, which contradicts an earlier analysis that found spearing catch rates were not significantly related to walleye population density (Staggs et al. 1990). The apparent contradiction in our results may be due to the fact that Staggs et al. (1990) analyzed data from only 25% as many lakes ($n = 24$) as were included in our analysis ($n = 97$). In addition, mark–recapture estimates of adult walleye abundance analyzed by Staggs et al. (1990) were obtained in 1986–1988, before sampling designs were standardized in 1990. The lack of a significant association between catch rates and walleye density that Staggs et al. (1990) found might therefore have been an artifact of small sample size or biased estimates of adult walleye abundance. In addition, our estimate of the density dependent coefficient for walleye spearing catchability ($\beta = -1.480$) was higher than all but one of those summarized by Peterman and Steer (1981). We agree with the conclusion of Staggs et al. (1990) that spearing is more likely to harvest walleyes when populations are low and therefore that walleye spearing is not self-regulating.

Catchability of walleyes in angling and spearing fisheries was unrelated to lake surface area, which contradicts other studies that suggested small lakes were fished more effectively than large lakes (Goddard et al. 1987). Most other studies were based on yield per unit area rather than catchability, but all suggested that yield per unit area increased as lake size decreased (Rounsefell 1946; Oglesby 1977; Goddard et al. 1987). It has generally been argued that small lakes either produce more fish per unit area or are simply easier to exploit (Goddard et al. 1987). We found no evidence of such area dependence in the vulnerability of walleyes to angling or spearing in northern Wisconsin lakes. However, the lakes we evaluated encompassed a relatively narrow range of surface area and a similar analysis of larger lakes (e.g., $>$10,000 acres) may suggest greater area dependence than in our analysis. Walleyes in inland lakes of the sizes included in our analysis seem to be different from pelagic marine species that occupy greater or lesser total area as their abundance changes (Winters and Wheeler 1985).

Management Implications and Recommendations

Regulation of most angling fisheries relies on daily creel limits, size limits, seasonal restrictions, closed areas, and gear restrictions (Noble and Jones 1993). Such regulations only indirectly limit the total harvest, and therefore rely on the fact that the fishery is self-regulating (Beard et al. 1997). By self-regulating, we mean that catch rate is directly proportional to population density and catchability does not change with population density. However, angling catchability may be inversely related to stock density (Peterman and Steer 1981; Bannerot and Austin 1983), which suggests some angling fisheries are not self-regulating. Based on our analysis of the angling fishery for walleyes in northern Wisconsin, catchability was not significantly related to population density over the range of fish densities we examined. Nonetheless, we recommend further study of the density-dependence of walleye angling catchability in northern Wisconsin lakes, particularly in lakes with low population densities. Intensive evaluation of walleye angling catchability in low-density lakes would complement our extensive evaluation of many lakes.

Regulation of spearing fisheries in northern Wisconsin relies on individual nightly quotas, length limits, and a census of the entire harvest (U.S. Department of the Interior 1991). These restrictive regulations were instituted because spearing was highly efficient and was not self-regulating (Staggs et al. 1990). Our results confirm both of these early observations of spearing, and therefore confirm that the spearing fishery needs to be tightly regulated. Spearing catch rates are two to three orders of magnitude higher than angling catch rates, and catchability is inversely related to adult walleye population density, which suggests that spearing cannot be effectively regulated with the indirect methods that are used to regulate angling. However, spearing catch rates may be biased by nightly quotas, which may have altered the true relationship with population density. To verify the relationship between spearing catch rates and adult walleye population density, experimental spearing without nightly bag limits would need to be conducted. Such an experiment is not currently allowed under federal court-mandated regulations and could jeopardize affected fish stocks.

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References

Arreguin-Sanchez, F. 1996. Catchability: a key parameter for fish stock assessment. Reviews in Fish Biology and Fisheries 6:221–242.

Bannerot, S. P., and C. B. Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Transactions of the American Fisheries Society 112:608–617.

Beard, T. D., Jr., S. W. Hewett, Q. Yang, R. M. King, and S. J. Gilbert. 1997. Prediction of angler catch rates based on walleye population density. North American Journal of Fisheries Management 17: 621–627.

Cushing, D. H. 1981. Fisheries biology, a study in population dynamics. University of Wisconsin Press, Madison.

Goddard, C. I., D. H. Loftus, J. A. MacLean, C. H. Olver, and B. J. Shuter. 1987. Evaluation of the effects of fish community structure on observed yields of lake trout (*Salvelinus namaycush*). Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2): 239–248.

Gulland, J. A. 1969. Manual of methods for fish stock assessment, part 1, fish population analysis. Food and Agriculture Organization of the United Nations, Rome.

Gulland, J. A., editor. 1988. Fish population dynamics, 2nd edition. Wiley, New York.

Hansen, M. J., M. D. Staggs, and M. H. Hoff. 1991. Derivation of safety factors for setting harvest quotas on adult walleyes from past estimates of abundance. Transactions of the American Fisheries Society 120:620–628.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Isbell, G. L., and M. R. Rawson. 1989. Relations of gillnet catches of walleyes and angler catch rates in Ohio waters of western Lake Erie. North American Journal of Fisheries Management 9:41–46.

Kmiecik, N. 1991. Spear fishery of the Lake Superior tribes of Chippewa Indians, spring 1990. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 91-4, Odanah, Wisconsin.

Kmiecik, N., and H. H. Ngu. 1992. Open water spearing and netting in northern Wisconsin by Chippewa Indians during 1991. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 92-8, Odanah, Wisconsin.

Krueger, J. 1997. Open water spearing in northern Wisconsin by Chippewa Indians during 1996. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 97-02, Odanah, Wisconsin.

Krueger, J. 1998. Open water spearing in northern Wisconsin by Chippewa Indians during 1997. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 98-01, Odanah, Wisconsin.

Ngu, H. 1994. Open water spearing and netting in northern Wisconsin by Chippewa Indians during 1993. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 94-1, Odanah, Wisconsin.

Ngu, H. 1995. Open water spearing and netting in northern Wisconsin by Chippewa Indians during 1994. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 95-03, Odanah, Wisconsin.

Ngu, H. 1996. Open water spearing in northern Wisconsin by Chippewa Indians during 1995. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 96-01, Odanah, Wisconsin.

Ngu, H., and N. Kmiecik. 1993. Open water spearing and netting in northern Wisconsin by Chippewa Indians during 1992. Great Lakes Indian Fish and Wildlife Commission, Administrative Report 93-4, Odanah, Wisconsin.

Noble, R. L., and T. W. Jones. 1993. Managing fisheries with regulations. Pages 383–402 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Oglesby, R. T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34:2271–2279.

Peterman, R. M., and G. J. Steer. 1981. Relation between sport-fishing catchability coefficients and salmon abundance. Transactions of the American Fisheries Society 110:585–593.

Pollack, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their application to fisheries management. American Fisheries Society, Special Publication 25, Bethesda, Maryland.

Quinn, T. J., II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Rasmussen, P. W., M. D. Staggs, T. D. Beard, Jr., and S. P. Newman. 1998. Bias and confidence interval coverage of creel survey estimators evaluated by simulation. Transactions of the American Fisheries Society 127:469–480.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rounsefell, G. A. 1946. Fish production in lakes as a guide for estimating production in proposed reservoirs. Copeia 1946:29–40.

Ryder, R. A., S. R. Kerr, K. H. Loftus, and H. A. Regier. 1974. The morphoedaphic index, a fish yield estimator—review and evaluation. Journal of the Fisheries Research Board of Canada 31:663–688.

Shardlow, T., R. Hilborn, R. M. Peterman, G. J. Steer, and M. J. Bradford. 1985. Density-dependent catchability coefficients. Transactions of the American Fisheries Society 114:436–440.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry: the principles and practice of statistics in biological research. Freeman, New York.

Staggs, M. D., R. C. Moody, M. J. Hansen, and M. H. Hoff. 1990. Spearing and sport angling for walleye in Wisconsin's ceded territory. Wisconsin Department of Natural Resources, Administrative Report 31, Madison.

Thorn, W. C. 1984. Effects of continuous fishing on the walleye and sauger population in Pool 4, Mississippi River. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 378.

U.S. Department of the Interior. 1991. Casting light upon the waters: a joint fishery assessment of the Wisconsin ceded territory. U.S. Department of the Interior, Bureau of Indian Affairs, Minneapolis, Minnesota.

Walters, C., and S. Cox. In press. Maintaining quality in recreational fisheries: how success breeds failure in management of open-access sport fisheries. Proceedings of the international conference on the future of recreational fishing. University of British Columbia, Fisheries Centre, Vancouver.

Winters, G. H., and J. P. Wheeler. 1985. Interaction between stock area, stock abundance, and catchability coefficient. Canadian Journal of Fisheries and Aquatic Sciences 42:989–998.