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[Management Brief]

Effect of Measurement Error on Tests of Density Dependence of Catchability for Walleyes in Northern Wisconsin Angling and Spearing Fisheries

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Abstract.—We sought to determine how much measurement errors affected tests of density dependence of spearing and angling catchability for walleye *Sander vitreus* by quantifying relationships between spearing and angling catch rates (catch/h) and walleye population density (number/acre) in northern Wisconsin lakes. The mean measurement error of spearing catch rates was 43.5 times greater than the mean measurement error of adult walleye population densities, whereas the mean measurement error of angling catch rates was only 5.6 times greater than the mean measurement error of adult walleye population densities. The bias-corrected estimate of the relationship between spearing catch rate and adult walleye population density was similar to the ordinary-least-squares regression estimate but differed significantly from the geometric mean (GM) functional regression estimate. In contrast, the bias-corrected estimate of the relationship between angling catch rate and total walleye population density was intermediate between ordinary-least-squares and GM functional regression estimates. Catch rates of walleyes in both spearing and angling fisheries were not linearly related to walleye population density, which indicated that catch rates in both fisheries were hyperstable in relation to walleye population density. For both fisheries, GM functional regression overestimated the degree of hyperdepletion in catch rates and ordinary-least-squares regression overestimated the degree of hyperstability in catch rates. However, ordinary-least-squares regression induced significantly less bias in tests of density dependence than GM functional regression, so it may be suitable for testing the degree of density dependence in fisheries for which fish population density is estimated with mark–recapture methods similar to those used in our study.

Determining the density dependence of catchability is essential for effective management of inland recreational fisheries, but this determination is complicated because both the catch rates and densities of target species are measured with error. Models used to estimate catchability of inland recreational fisheries often rely on linear regression methods (Peterman and Steer 1981; Hansen et al. 2000; Newby et al. 2000). For example, the most common formulation of the catchability model assumes that catch rate is a linear function of population density (Ricker 1975), which can be modified to test for a nonlinear relationship between catch rate and population density (Peterman and Steer 1981). In either case, model parameters are usually estimated by linear regression, which relies on the assumption that estimates of fish population size are measured without error (Sokal and Rohlf 1994). Because fish abundance is usually estimated with error, the assumption of no error in estimates of population density is violated whenever fish density or abundance is used as the independent variable in linear regression.

Methods for dealing with measurement error have been well established in the statistical literature (Fuller 1987) but are often ignored when estimating parameters of fisheries models. Ricker (1975) recommended the use of geometric mean (GM; functional) regression whenever the independent variable in linear regression was measured with error. Hilborn and Walters (1992) suggested the use of Monte Carlo methods to evaluate the bias associated with parameter estimates whenever the independent variable in linear regression was measured with error. Quinn and Deriso (1999) suggested the use of measurement error models for estimating parameters of linear models described by a single pair of dependent and independent variables that are based on models developed to account for independent variables that were measured with error (Fuller 1987).

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Our objective was to determine how much measurement errors affected tests of density dependence of catchability of spearing and angling fisheries for walleye *Sander vitreus* in northern Wisconsin lakes. We previously analyzed this problem with a GM functional regression (Hansen et al. 2000), which assumes that measurement errors of the *x*-variable (i.e., walleye population density) are similar to measurement errors of the *y*-variable (i.e., spearing or angling catch rate; Sokal and Rohlf 1994). More recently, based on analyses of sampling gears for walleyes in northern Wisconsin lakes (Rogers et al. 2003; Hansen et al. 2004), we grew concerned that our treatment of measurement errors may not have allowed us to accurately estimate catchability or to test for density dependence of spearing and angling capture fisheries for walleyes in northern Wisconsin. Therefore, in this analysis we compared the use of ordinary-least-squares and GM functional regressions with Monte Carlo simulation and measurement error models for estimating catchability and its density dependence for walleye spearing and angling fisheries in northern Wisconsin lakes.

Methods

We evaluated the following relationship between spearing and angling catch rates (C/f) and walleye population density (N/A), in which catchability (q) is often assumed to be constant (Ricker 1975):

$$\frac{C}{f} = q\left(\frac{N}{A}\right). \tag{1}$$

To evaluate whether q is constant, equation (1) can be modified into a power function, where β expresses the degree of curvature in the relationship between C/f and N/A, and α provides an estimate of q when C/f and N/A are near the origin (Peterman and Steer 1981), that is,

$$\frac{C}{f} = \alpha\left(\frac{N}{A}\right)^{\beta+1}. \tag{2}$$

As in our previous analysis of this problem, we used data gathered as part of a multiagency effort to monitor walleye populations and associated spearing and angling fisheries in the northern third of Wisconsin (Hansen et al. 1991; Beard et al. 1997). Lakes were randomly selected each year from among those lakes containing walleye that were subjected to state-licensed angling and tribe-licensed spearing (Hansen et al. 1991).

We had previously analyzed data gathered during 1990–1997 (Hansen et al. 2000), so we expanded the present analysis to also include data gathered during 1998–2003. Tribal spearing targeted sexually mature walleyes that were attempting to spawn during a few weeks in spring (usually April), so numbers of sexually mature walleyes were estimated during the spawning period for comparison with spearing catch rates. In contrast, angling occurred from the first Saturday in May through 1 March the following year, when mature and immature walleyes were intermingled; therefore, total numbers of walleyes were estimated 2–3 weeks after spawning, when immature and mature fish were mixed into the total population, and compared with angling catch rates. Our previous analysis of catchability for these two fisheries did not explicitly account for measurement errors of mark–recapture estimates (Hansen et al. 2000), so we used Monte Carlo methods to estimate the true relationship between fisheries catch rates and walleye population densities. Area dependence of catchability is not confounded by measurement error of area, which is known with virtually no error, so we did not repeat that analysis here. In addition, we did not model catchability as a function of walleye population density because catchability was not estimated independently; therefore, a spurious negative self-correlation was probably induced between catchability and walleye population density (Shardlow et al. 1985).

Because methods of data collection were described by Hansen et al. (2000) and methods of statistical analysis were described by Rogers et al. (2003) and Hansen et al. (2004), both are only briefly characterized here. Spearing catch rates were computed from nightly censuses of spearing harvest and effort on each lake conducted in the springs of 1990–2003 (Kmiecik 1991; Kmiecik and Ngu 1992; Ngu and Kmiecik 1993; Ngu 1994, 1995, 1996; Krueger 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004). Angling catch rates were estimated from creel surveys conducted during the walleye angling season in Wisconsin, which began on the first Saturday in May during 1990–2003 and continued through 1 March the following year (Beard et al. 1997; Rasmussen et al. 1998). Abundance of adult (sexually mature) walleyes and all walleyes (immature and mature) were estimated in the spring of each year during 1990–2003 with the use of Chapman's modification of the Petersen estimator (Ricker 1975). To determine whether the catchability of walleyes to spearing and angling varied with density, we modeled spearing harvest/h (C/f) as a function of adult walleyes/acre (N/A)

TABLE 1.—Parameter estimates (α and $\beta + 1$, along with upper and lower 95% confidence limits) for the relationship $C/f = \alpha(N/A)^{\beta+1}$ between mean yearly catch per hour in spearing and angling fisheries (C/f) and numbers of adult and total walleyes per acre (N/A) in northern Wisconsin lakes sampled during 1990–2003. Parameter estimates are shown for the ordinary-least-squares regression, geometric mean (GM) functional regression, and bias-corrected regression models.

	α			$\beta + 1$		
Estimator	Estimate	Lower	Upper	Estimate	Lower	Upper
			Spearing			
Ordinary least squares	6.718	5.596	8.066	0.639	0.493	0.785
GM functional regression	3.273	2.726	3.930	1.310	1.164	1.455
Bias-corrected regression	6.579	5.626	7.694	0.659	0.513	0.805
			Angling			
Ordinary least squares	0.035	0.029	0.043	0.772	0.679	0.864
GM functional regression	0.023	0.018	0.028	0.998	0.906	1.091
Bias-corrected regression	0.032	0.026	0.038	0.825	0.732	0.917

and angling catch/h (C/f) as a function of total walleyes/acre (N/A).

Results

Spearing data were available for 240 lakes for which adult walleye abundance was estimated by mark–recapture and the median coefficient of variation (CV) was smaller than 0.40. The median CV for estimates of adult walleye abundance was 0.083 (range, 0.022–0.300), the median spearing catch rate was 14.85 walleyes/h (range, 0.50–60 walleyes/h), and the median density of adult walleyes was 3.13 walleyes/acre (range, 0.43–15.45 walleyes/acre). Measurement error of spearing catch rates was 43.5 times greater than measurement error of adult walleye population densities. The bias-corrected estimate of the relationship between spearing catch rate and adult walleye population density did not differ significantly from the ordinary-least-squares regression estimate, but differed significantly from the GM functional regression estimate (Table 1). Catch rates of walleyes in the spearing fishery were not linearly related to adult walleye population density (Figure 1) because the bias-corrected slope of the relationship was significantly less than one (Table 1):

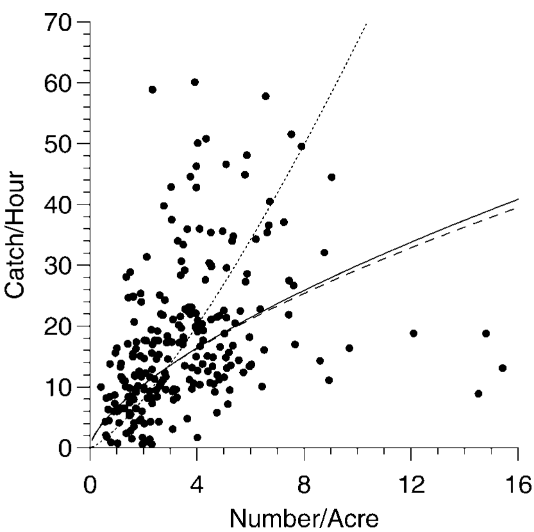

FIGURE 1.—The mean yearly catch per hour in walleye spearing fisheries versus the number of adult walleyes per acre in 240 northern Wisconsin lakes sampled during 1990–2003. The geometric mean functional regression line (dotted line), bias-corrected regression line (solid line), and ordinary-least-squares regression line (dashed line) are shown as curves. Observed values are shown as black dots.

$$\frac{C}{f} = 6.579\left(\frac{N}{A}\right)^{0.659}. \quad (3)$$

A hyperstable relationship between spearing catch rate and adult walleye population density was indicated by bias-corrected and ordinary-least-squares methods, but a hyperdepletive relationship was indicated by the GM functional regression method (Table 1).

Angling data were available for 185 lakes for which total walleye abundance was estimated by mark–recapture and the median CV was smaller than 0.40. The median CV for estimates of total walleye abundance was 0.221 (range, 0.068–0.400), the median angling catch rate was 0.18 walleyes/h (range, 0.006–1.53 walleyes/h), and the median density of total walleyes was 7.76 walleyes/acre (range, 0.45–43.32 walleyes/acre). Measurement error of angling catch rates was only 5.6 times greater than measurement error of adult walleye population densities. The bias-corrected estimate of the relationship between angling catch

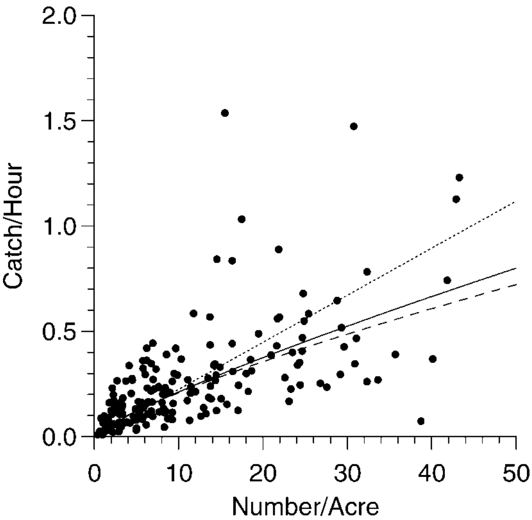

FIGURE 2.—The mean yearly catch per hour in walleye angling fisheries versus the number of total walleyes per acre in 185 northern Wisconsin lakes sampled during 1990–2003. The geometric mean functional regression line (dotted line), bias-corrected regression line (solid line), and ordinary-least-squares regression line (dashed line) are shown as curves. Observed values are shown as black dots.

rate and total walleye population density did not differ significantly from either ordinary-least-squares or GM functional regression estimates (Table 1). Catch rates of walleyes in the angling fishery were not linearly related to total walleye population density (Figure 2) because the slope of the bias-corrected relationship was significantly less than one (Table 1):

$$\frac{C}{f} = 0.0318\left(\frac{N}{A}\right)^{0.825}. \tag{4}$$

A hyperstable relationship between angling catch rate and total walleye population density was indicated by bias-corrected and ordinary-least-squares methods, but a proportional relationship was indicated by the GM functional regression method (Table 1).

Discussion

We found that tests of density dependence of walleye spearing and angling fisheries in Wisconsin lakes were biased by use of GM functional regression. Our previous analysis of these fisheries (which relied on GM functional regression) indicated hyperdepletion for the spearing fishery and proportionality for the angling fishery (Hansen et al. 2000), whereas our present analysis (which relied on Monte Carlo simulation of measurement errors for walleye population density) indicated hyperstability for both spearing and angling fisheries. Therefore, for both fisheries, GM functional regression overestimated the degree of hyperdepletion in catch rates and ordinary-least-squares regression overestimated the degree of hyperstability in catch rates. Because ordinary-least-squares regression induced significantly less bias in tests of density dependence than GM functional regression, it may be suitable for testing the degree of density dependence in fisheries for which fish population density is estimated when following methods similar to those used in our study. Similarly, when walleye population density was estimated by mark–recapture, bias-corrected estimates were similar to ordinary-least-squares estimates for relationships between fyke netting and electrofishing catch rates of adult walleyes (Rogers et al. 2003) and electrofishing catch rates of age-0 walleyes (Hansen et al. 2004).

We found that catchability of walleyes to spearing and angling was hyperstable, as has been found for numerous other capture fisheries (Arreguin-Sanchez 1996). For example, Staggs et al. (1990) found that spearing fishery catch rates of adult walleyes in northern Wisconsin lakes changed little with population density, which suggested that catchability was hyperstable (as we found in the present study). Similarly, catchability of angling fisheries was hyperstable for lake trout *Salvelinus namaycush* in Ontario, Canada (Shuter et al. 1998), and Chinook salmon *Oncorhynchus tshawytscha* in the Pacific Northwest, USA (Peterman and Steer 1981). In contrast, walleye angling catch rate has generally been found to be proportional to population density, which indicates constant catchability that is independent of population density (Thorn 1984; Isbell and Rawson 1989; Staggs et al. 1990; Beard et al. 1997), though none of these studies accounted for measurement errors of population density. Last, we found that hyperstability was stronger for the spearing fishery than for the angling fishery because the density-dependent coefficient ($b_1 = \beta + 1$) was further from 1.0 for the spearing fishery ($b_1 = 0.659$) than for the angling fishery ($b_1 = 0.825$), though 95% confidence intervals for the β-coefficients of the two fisheries overlapped.

We found that capture efficiency of adult walleyes in the spearing fishery was more than 200 times greater than capture efficiency of all walleyes in the angling fishery in northern Wisconsin lakes, which is about 4 times higher than we previously found for these two fisheries (Hansen et al. 2000). In our previous analysis of these fisheries, catchability at low population density (i.e., α parameter) was more than 50 times higher for the spearing fishery (α = 1.121 walleyes · h^{-1} · acre^{-1}) than for the angling fishery (α = 0.021 walleyes · h^{-1} · acre^{-1}; Hansen et al. 2000). In contrast, in this analysis we found that catchability at low population density was more than 200 times higher for the spearing fishery (α = 6.579 walleyes · h^{-1} · acre^{-1}) than for the angling fishery (α = 0.032 walleyes · h^{-1} · acre^{-1}). Differences in relative efficiency between the two fisheries were largely caused by differences in analytical approaches, because GM functional regression used by Hansen et al. (2000) underestimates the slope ($b_0 = \log_e\alpha$) of the log–log relationship whenever the measurement error ratio (δ) is larger than 1:1 (δ = 43.5 for the spearing fishery and δ = 5.6 for the angling fishery).

In Wisconsin, active management of the walleye spearing fishery was warranted because the spearing fishery was highly efficient and not self-regulating, whereas passive management of the walleye angling fishery was warranted because the angling fishery was inefficient and self-regulating (Staggs et al. 1990). Our findings confirm both of these observations for the spearing fishery, which suggests that active management of the spearing fishery is warranted. Our findings also confirm that the angling fishery is much less efficient than the spearing fishery; however, our findings also suggest that angling may not be as self-regulating as previously thought, so passive management of the angling fishery may not be as safe as previously assumed. Active management of angling fisheries has only recently received attention (Cox and Walters 2002; Beard et al. 2003; Cox et al. 2003; Pereira and Hansen 2003; Radomski 2003). Active management of the walleye angling fishery in Wisconsin may be warranted if further study shows that angling catch rates remain high as walleye stock density declines to levels where recruitment overfishing is possible.

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