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Evaluation of Michigan Creel Survey Catch Rate Estimator

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Abstract.–Access-site creel surveys are conducted at numerous Great Lakes ports and on inland waters each year in Michigan to estimate angling effort and catch. Estimated catch is the product of estimated angler hours and catch rate. Catch rate has been determined by averaging angler party catch per hour by species, angling mode, and time period. This method for calculating catch rate is not weighted by number of anglers in the party or by length of fishing trip which could lead to biases in estimates. Effects of bias on accuracy and precision of catch per hour estimates were measured using Monte Carlo sampling techniques on 132 data sets from Michigan access-site creel surveys. Each data set was considered a discrete population and population catch rate parameters were compared with sample catch rate estimates. Estimated mean catch rate by angler party was significantly greater, $P_{\alpha} \leq 0.05$, than population catch rate parameters in 82 data sets and significantly less in 49 others. Due to trip length and angler party size bias, the sample confidence limits were incorrectly represented in 123 of 132 data sets. Biases associated with averaging angling party catch rates were found to be prevalent in Michigan access-site creel surveys. I concluded that averaging angler party catch rates is inappropriate for Michigan access-site creel surveys. Calculating catch rate by dividing total catch by total hours from angler interviews eliminates the bias.

Introduction

Michigan Department of Natural Resources (MDNR), Fisheries Division conducts creel surveys on inland and Great Lakes waters of Michigan to evaluate status and trends in fish populations, changes in sportfishing regulations, trends in angling effort, success of fish plantings, and success of other management practices (Ryckman and Lockwood 1985; Rakoczy and Lockwood 1988; Alexander et al 1979; Schneider and Lockwood 1979; Beyerle 1984; and Galbraith and Schneider 1984). In 1994, some 16,000 angling parties fishing Lake Michigan (G. Rakoczy, MDNR, personal communication) and over 2,000 angling parties fishing six inland lakes and Southern Michigan's Rogue River (Lockwood 1995) were interviewed.

Michigan creel surveys are best described as access-site creel surveys (Malvestuto 1983) and follow a stratified design using structured random sampling within strata (Fabrizio et al 1991). These access-site creel surveys consist of two separate sampling components, angler counts and angler party interviews. Angler counts are made at each site or lake and averaged by angling mode and time period (Ryckman 1981; Ryckman and Lockwood 1985). Mean counts are then expanded by hours sampled in a given time period to estimate total angling effort. Angling parties are interviewed as they leave a site (completed trip interview) or prior to leaving while they are still actively fishing (incompleted trip interview). Individual creel surveys consist of mostly, or entirely, completed trip interviews or incompleted trip interviews. For example, all Great Lakes interviews collected in 1994 were completed trip interviews (G. Rakoczy, MDNR, personal communication) as were all 1994 inland lake interviews. The 1994 Rogue River survey was comprised primarily of incompleted trip interviews (85%).

Angler success is estimated by catch rates which are determined from interviews. Several methods exist for calculating catch rates. Crone and Malvestuto (1991) assessed five methods for calculating catch rates and report that substantial differences in catch rate estimates existed between methods as did variability (determined by the coefficient of variation) associated with each method. For Michigan creel surveys, catch rate for each species (i) is calculated as a mean of ratios ($\overline{R}_i$):

$$\overline{R}_i = \frac{\sum_{j=1}^{n}\left(\frac{c_{i,j}}{h_j}\right)}{n}, \qquad (1)$$

where

i = species,
c = total catch of angler party j,
h = total hours fished by angler party j,
n = total angler parties interviewed.

Pollock et al. (1994) recommends using this estimator with incomplete trip interviews recorded by individual angler. Mean-of-ratios estimator can be correctly used when there is no bias due to angler trip length or angler party size (Hayne 1991), and averaging daily catch rates over many days is appropriate for calculating mean daily catch rates (Malvestuto 1983). Jones et al. (1995) showed effects of trip length bias on the mean-of-ratios estimator, and its variance, using a creel survey of summer flounder *Paralichthys dentatus* anglers in Virginia. Bias concerns allied with using the mean-of- ratios estimator for completed trip interviews have also been noted by Jessen (1956) and Hayne (1991).

Neuhold and Lu (1957), Malvestuto (1983), Hayne (1991) and Pollock et al. (1994) recommend a ratio-of-means ($\hat{R}_i$) estimator with completed trip interviews:

$$\hat{R}_i = \frac{\sum_{j=1}^{n} c_{i,j} \big/ n}{\sum_{j=1}^{n} h_j \big/ n}, \qquad (2)$$

where

i = species,
c = catch of angler party j,
h = total hours fished by angler party j,
n = total number of interview records.

Ryckman (1983) utilized angler count and interview data sets from several Michigan creel surveys in an attempt to predict sampling levels necessary to minimize bias and maximize precision of estimated angling pressure and catch per hour (CPH_i). Sample CPH_i was calculated using the mean-of-ratios estimator, $\overline{R}_i$ in (1), and was compared with total catch per hour of the data set, $\hat{R}_i$ in (2). That study indicated that while precision of sample CPH_i improved with increased sampling, biases existed in particular data sets which showed no apparent trend nor magnitude in relation to sample CPH_i estimates or sample size. Sample CPH_i was lower (negative bias) than total CPH_i in some data sets and greater (positive bias) in others. Also, sign and magnitude of sample CPH_i bias that existed at low levels of sampling (e.g., 20% of the population) remained when sampling was increased to as much as 90% of the population.

I selected 132 data sets from Michigan creel surveys to further evaluate catch rate biases associated with a mean-of-ratios estimator and determine if a ratio-of-means estimator is more appropriate for use in Michigan. Variability of these data sets was also evaluated to ascertain appropriate sampling levels for future Michigan creel surveys.

Methods

Selection of Data Sets

Interview data sets were chosen for analysis which represented five modes of angling and 13 species of freshwater fish (Table 1). These data sets were assumed to characterize the diverse sport fisheries that exist in Michigan and to replicate fishery types (Great Lakes or inland, angling mode, and species harvested). Individual data sets contained 50-1,148 interview records and only completed trip interviews were analyzed. Interviews portrayed catch by angling party and party size varied from 1-6 anglers. None of the interviews were originally collected for use in this study, but were gathered in conjunction with independent management or research projects. Catch by species in each instance was harvest by species; no catch-and-release data were included.

Sampling Techniques

Each of the selected data sets was treated as a finite population to be sampled. Monte Carlo sampling techniques were used to sub-sample the data sets and then calculate estimates. Sampling levels (k) for each data set were 1-10% (at 1% intervals), 15%, 20%, 30%, 50%, 70% and 90% of the available records. Extra sampling was done at lower levels since most surveys sample <20% of the anglers (Ryckman 1983). Greater sampling levels (>20%) were done since it was assumed that as a greater proportion of a population is sampled, the more likely the sample estimate is to correctly represent the population parameter. Each sampling level was replicated 500 times and records were randomly selected without replacement for each replication.

Catch Rate Estimators

For each data set the true catch per hour (Θ) was calculated using equation (2) and all interview records in a data set. This is considered the correct measure of catch per hour by species because in a true census:

$$C_i = \frac{\sum_{j=1}^{P} C_{i,j}}{\sum_{j=1}^{P} H_j} \bullet \sum_{j=1}^{P} H_j , \qquad (3)$$

where

i = species,
C = total catch of species i by angler party j,
H = total hours fished by angler party j,
P = number of angler parties in population,

accurately determines total catch. The goal of Michigan creel surveys is to accurately estimate C_i.

Mean-of-ratios ($\overline{R}_i$) and ratio-of-means ($\hat{R}_i$) catch rates were calculated, by species for each replication and sampling level (k). Estimate of $\overline{\overline{R}}_{i,k}$ then was:

$$\overline{\overline{R}}_{i,k} = \frac{\sum_{j=1}^{N} \overline{R}_{i,k,j}}{N} , \qquad (4)$$

where

i = species,
k = sampling level,
$\overline{R}$ = mean of ratios for replication j,
N = number of replications.

The variance of the $\overline{\overline{R}}_{i,k}$, ($\hat{\text{var}}(\overline{\overline{R}})_{i,k}$), was calculated as:

$$\hat{\text{var}}\left(\overline{\overline{R}}\right)_{i,k} = \frac{\sum_{j=1}^{N} \left(\overline{R}_{i,k,j} - \Theta_i\right)^2}{N(N-1)} , \qquad (5)$$

where

i = species,
k = sampling level,
$\overline{R}$ = mean of ratios for replication j,
Θ = data set catch per hour of species i, in equation (2),
N = number of replications.

Estimate of $\bar{\hat{R}}_{i,k}$ then was:

$$\bar{\hat{R}}_{i,k} = \frac{\sum_{j=1}^{N} \hat{R}_{i,k,j}}{N}, \qquad (6)$$

where

i = species,
k = sampling level,
$\hat{R}$ = ratio of means for replication j,
N = number of replications.

The variance of $\bar{\hat{R}}_{i,k}$, ($\hat{\mathrm{var}}(\bar{\hat{R}})_{i,k}$), was calculated as:

$$\hat{\mathrm{var}}\left(\bar{\hat{R}}\right)_{i,k} = \frac{\sum_{j=1}^{N}\left(\hat{R}_{i,k,j} - \Theta_i\right)^2}{N(N-1)}, \qquad (7)$$

where

i = species,
k = sampling level,
$\hat{R}$ = ratio of mean for replication j,
Θ = data set catch per hour of species i, in equation (2),
N = number of replications.

Variance formulas (5) and (7) are derived from Hammersley and Handscomb (1964) and Hall (1992), and represent the total variation associated with estimated $\hat{\Theta}$ (either $\bar{\bar{R}}$ or $\bar{\hat{R}}$):

$$\hat{\mathrm{var}}(\hat{\Theta}) = S^2\hat{\Theta} + (Bias\hat{\Theta})^2, \qquad (8)$$

where

$S^2\hat{\Theta}$ = variation due to sampling,
$Bias\hat{\Theta}$ = estimated bias.

Statistical Tests

Estimates of catch rate and 95% confidence limits at the 90% sampling level for each estimator ($\bar{\bar{R}}_i$ and $\bar{\hat{R}}_i$) were compared to actual catch per hour (Θ_i). With 90% of a given population sampled, error due to sampling is minimized and biases associated with an estimator are readily apparent. Differences were considered significant when Θ_i fell outside the 95% confidence limits for a particular estimator (Hammersley and Handscomb 1964). Bias was measured as the difference between Θ_i and the 90% sampling level catch rate mean for $\bar{\bar{R}}_i$ or $\bar{\hat{R}}_i$. Bias was calculated for each data set and influence of bias on estimated confidence limits for a given data set was calculated as:

$$\frac{\hat{B}_i}{\hat{\sigma}_i}, \qquad (9)$$

where

$\hat{B}_i$ = bias associated with estimator $\bar{\bar{R}}_i$ or $\bar{\hat{R}}_i$,
$\hat{\sigma}_i$ = estimated standard deviation from $\hat{\mathrm{var}}(\bar{\bar{R}})_i$ or $\hat{\mathrm{var}}(\bar{\hat{R}})_i$.

Confidence limits were considered misrepresented when $\hat{B}_i / \hat{\sigma}_i > 0.20$ (Cochran 1977).

Stepwise linear regression was used to measure influence of angler party size and length of fishing trip on individual angler party catch rate in each data set. Variables were considered significant and included in regression equations at $P_\alpha = 0.05$. Regression analysis was done using SPSS for Windows (Version 6.0, SPSS Inc., 1993).

Multiple regression analysis was used to evaluate sampling levels (number of party interviews sampled) for future access-site creel surveys. Number of angler party interviews from the Monte Carlo simulation was regressed on coefficient of variation (CV) expressed as a percentage (Fowler and Cohen 1990) and $\bar{\hat{R}}_i$.

Results

Monte Carlo Sampling

Replications were varied from 2-500 on a sample data set to determine appropriate number of replications (Figures 1 and 2). Bias and CV associated with each estimator stabilized at 50 replications and remained similar out to 500 replications. As a result, 500 iterations was considered satisfactory for each Monte Carlo simulation.

Mean of Ratios

Mean-of-ratios estimator [$\overline{\overline{R}}_i$] was significantly different from actual catch per hour [Θ_i] in 131 of the 132 comparisons (Tables 2-14). $\overline{\overline{R}}_i$ over estimated Θ_i for 82 data sets and under estimated Θ_i for 49 others. Only for a walleye pier fishery at Holland on Lake Michigan was $\overline{\overline{R}}_i$ not significantly different from Θ_i (Table 13). $\overline{\overline{R}}_i$ under or over estimated Θ_i by ≥20% on 67 occasions; ≥30% on 44 occasions; ≥40% on 30 occasions; and ≥50% on 21 occasions (Figure 3). Confidence limits associated with this method were misrepresented for 123 of 132 data sets. Bias was quite variable and under or over estimated Θ_i by 0.36-285.50%.

Length of fishing trip was a significant factor affecting $\overline{R}_i$ in 33 data sets (Tables 15 and 16). Of these 33, catch rate declined as length of fishing trip increased for 7 data sets and increased as length of fishing trip increased for 26 data sets. Similarly, number of anglers in a fishing party significantly affected $\overline{R}_i$ in 24 data sets. Catch rate declined as number of anglers in a fishing party increased for 23 data sets, and increased as number of anglers in a party increased for only one data set.

Ratio of Means

Estimator $\overline{\hat{R}}_i$ was significantly different from Θ_i in only 1 of the 132 comparisons (Table 4). Bias was insignificant and $\overline{\hat{R}}_i$ under estimated Θ_i by 0.71% in that one instance. In 59 comparisons, $\overline{\hat{R}}_i$ was identical to Θ_i and maximum deviation of $\overline{\hat{R}}_i$ was an over-estimation of 3.33%. Confidence limits were never misrepresented.

Estimation of Sampling Levels

As a result of analyzing bias, only sampling levels for catch rate estimator $\overline{\hat{R}}_i$ were considered. $\overline{\hat{R}}_i$ in the 132 data sets analyzed ranged from 0.0003-4.3892. Monte Carlo sampling of the original 132 data sets resulted in the creation of 2,112 $\overline{\hat{R}}_{i,k}$ and $\hat{\mathrm{var}}(\overline{\hat{R}})_{i,k}$ values. A data base was developed containing these estimates. Each record in the data base included $\overline{\hat{R}}_{i,k}$, $CV_{i,k}$ (based on $\hat{\mathrm{var}}(\overline{\hat{R}})_{i,k}$) and the number of angler parties, which ranged from 1-1,033, sampled at level k.

A natural log-linear multiple regression model was developed to evaluate sampling intensities of the 2,112 Monte Carlo records (Figure 4). Transformation of sample size (number of angler party interviews) was regressed on transformations of $CV_{i,k}$ and $\overline{\hat{R}}_{i,k}$. Variation in regression coefficients accounted for 83% of the variation (R=0.91) in number of angler party interviews and was significant at $P_\alpha \leq 0.01$. As catch rate increased and CV declined, sampling levels were reduced (Figure 4). Sampling levels at a given CV are quite similar when $\overline{\hat{R}}$ ≥0.07. However, when $\overline{\hat{R}}$ <0.07 substantially more interviews are required to achieve similar precision. CV of 20%, when $\overline{\hat{R}}$ =0.07, is attainable with 98 angler party interviews and attainable with 78 angler party interviews when $\overline{\hat{R}}$ =0.13. When $\overline{\hat{R}}$ =0.01, however, 200 interviews are needed for a CV=20%.

Discussion

Fisheries Division, of the then Michigan Conservation Department, began conducting creel surveys in 1927 (Tait 1953). These first surveys were true censuses, that is all anglers fishing on a particular lake were counted and interviewed. Partial censuses were conducted during following years, however they were not conducted using any specific survey design. By the early 1950s, sampling designs were incorporated and Tait (1953) conducted the first evaluation of Michigan's creel survey methods. Several conclusions were drawn from Tait's study and help to explain reliance on mean-of-ratios estimator used in Michigan to date.

Only two sources of catch-per-hour bias were recognized in Tait's (1953) evaluation. First, methods for developing a sampling schedule may be biased, and second, a creel clerk might not randomly select angling parties to interview. Also, catch rate by individual angler was assumed to be equal to catch rate of angling parties. Both ratio of means and mean of ratios estimators were given as alternatives for calculating catch rate. Mean-of-ratios estimator was selected for use in Michigan creel surveys rather than ratio-of-means estimator for two reasons. First, a method or methods for calculating variance of ratio of means was unknown. Second, it was known that distribution of catch rates by anglers is highly skewed and mean-of-ratios estimator tended to normalize this distribution.

Potential bias problems associated with mean-of-ratios estimator were inadvertently suggested by Tait (1953). Due to intense sampling effort of some of these early creel surveys, Tait (1953) was able to compare taking mean-of-ratios catch rate for a season with mean-of-ratios catch rate for each hour sampled. Individual hourly catch rates were weighted by that hour's angling pressure. Resulting catch rates from these two methods differed by 3.0-20.8%. My evaluation of catch rate estimators shows that calculating hourly catch rates for the duration of an angling trip would compensate for the length of trip bias.

Bias concerns associated with averaging angler or angler party catch rates have been noted for many years following Tait's (1953) study (Jessen 1956, Hayne 1991). Jones et al (1995) evaluated bias associated with fishing trip length and its effect on confidence intervals, and found that bias significantly affected estimates of catch rates. Ryckman (1983) showed that trip length bias was present in six Michigan creel surveys and that sign of trip length bias was not consistent between surveys.

My current analysis of mean-of-ratios estimator showed that biases associated with fishing trip length and angler party size, and effects of these biases on confidence intervals, were significant. Linear regression analysis showed that catch rates of longer fishing trips tended to be greater, while catch rates tended to decrease with increasing angler party size. Length of trip and angler party size biases existed in both inland and Great Lakes creel surveys, for each of the five angling modes, and for each species of fish. These findings confirm those of Ryckman (1983) and Jones et al (1995), and show that these biases are prevalent throughout Michigan creel surveys. Biases similar to those attributed to the mean-of-ratio estimator were not detected for the ratio-of-means estimator. Angler party size and length of trip are both accounted for using estimator $\hat{R}_i$.

Bias effects associated with mean-of-ratios estimator are further magnified by their inconsistent nature. For example, mean-of-ratios estimator suggests that catch rate of walleye by boat anglers at Menominee (which was underestimated by 20.93%) is only 8.51% greater than at Muskegon (which was overestimated by 84.31%; Table 13). However, catch rate is actually 152.94% greater at Menominee than at Muskegon. Similarly, mean-of-ratios estimator for Chicagon Lake in 1994 (which was overestimated by 7.54%) incorrectly showed a 48.90% reduction from 1993 (which was overestimated by 57.56%), while actual catch rate in 1994 was only 25.09% less. If biases were similar between sites or years, trend information would remain reliable. Consistent biases would characterize long term changes even though estimates for individual time periods or sites are inaccurate. This additional inconsistent variation also confounds an investigator's ability to correctly interpret results of angler catch estimates. Apparent differences or similarities between estimates are masked by these inconsistent biases.

Representative confidence limits are essential to correct interpretation of estimated harvest from creel survey estimates. Biases associated with mean-of-ratios catch rate estimator altered associated confidence limits. These biases were great enough to warrant concern over their interpretation (Cochran 1977).

$\hat{R}_i$ and $\overline{R}_i$ actually estimate two different catch rates. $\hat{R}_i$ estimates total catch per hour while $\overline{R}_i$ estimates total catch per hour per angler party. Michigan creel surveys are generally designed to collect either complete trip interviews or incomplete trip interviews. Complete trip interviews are collected when a clerk remains at a survey site or area much longer (~8h) than the length of an average trip (~3.5h), thus complete trip interviews are collected with approximate equal probability. Incomplete trip interviews however, are collected when the clerk spends a shorter period of time (<3.5h) at a location. Incomplete trip interviews are collected proportional to trip length - anglers that remain at a location longer are more likely to be interviewed. Results of this study show when $\overline{R}_i$ is used to estimate $\hat{R}_i$ two sources of bias are of concern. If catch rates increase with length of trip, $\overline{R}_i$ will under estimate $\hat{R}_i$ and if catch rates decrease with length of trip, $\overline{R}_i$ will over estimate $\hat{R}_i$. Similarly, if catch rates increase with angler party size, $\overline{R}_i$ will under estimate $\hat{R}_i$ and if catch rates decrease with party size, $\overline{R}_i$ will over estimate $\hat{R}_i$.

Jones et al (1995) showed that when anglers are sampled with equal probability, complete trip interviews, $\hat{R}_i$ multiplied by an independent estimate of effort produces an unbiased estimate of catch. When anglers are sampled proportional to their trip length (incomplete trip interviews) $\overline{R}_i$ (calculated per angler - not per angler party) multiplied by an independent estimate of effort produces an unbiased estimate of catch. However, given the current procedure of collecting incomplete-trip interviews by angling party (not by angler), angler party size bias remains a problem.

Estimating sample size necessary for a given level of precision in catch rate provides an investigator with two pieces of information. First, the investigator is able to determine if the chosen precision is in fact attainable at a given level of certainty. Second, the investigator is able to determine how much sampling effort is required to collect the necessary information. Sampling effort (number of interviews collected) is often a function of the number of creel clerks used for a particular survey.

Over sampling results in collecting adequate data at an inflated cost, while under sampling results in collection of expensive inadequate data. Subsampling of anglers from some prior survey at a representative location or time period, will allow the investigator to use the sampling level model developed in this study. Recognizing appropriate sampling effort will help prevent costly mistakes.

Recommendations

For Michigan access-site creel surveys utilizing completed-trip interviews, calculate catch-per-hour rates using the ratio-of-means estimator $\hat{R}_i$. Catch rate information may be collected by angler or angler party since $\hat{R}_i$ correctly accounts for party size. The appropriate formula for calculating variance of a ratio of means is given by Cochran (1977). For creel surveys utilizing incomplete-trip interviews, catch information should be collected by individual angler. Catch-per-hour rates of incomplete-trip interviews are calculated using the mean-of-ratios estimator $\overline{R}_i$. Variance of $\overline{R}_i$ is calculated as for any set of independent samples. These methods correspond with the recommendations of Pollock et al (1994) and are consistent with the findings of Jones et al (1995).

The sampling level model described should prove to be a practical tool for use in designing future creel surveys. From preliminary data collections and historical data sets, appropriate sampling levels for future surveys may be determined for desired catch rate precision. Determination of acceptable sample sizes for large-scale creel surveys in particular will allow design of more cost effective surveys.

Acknowledgments

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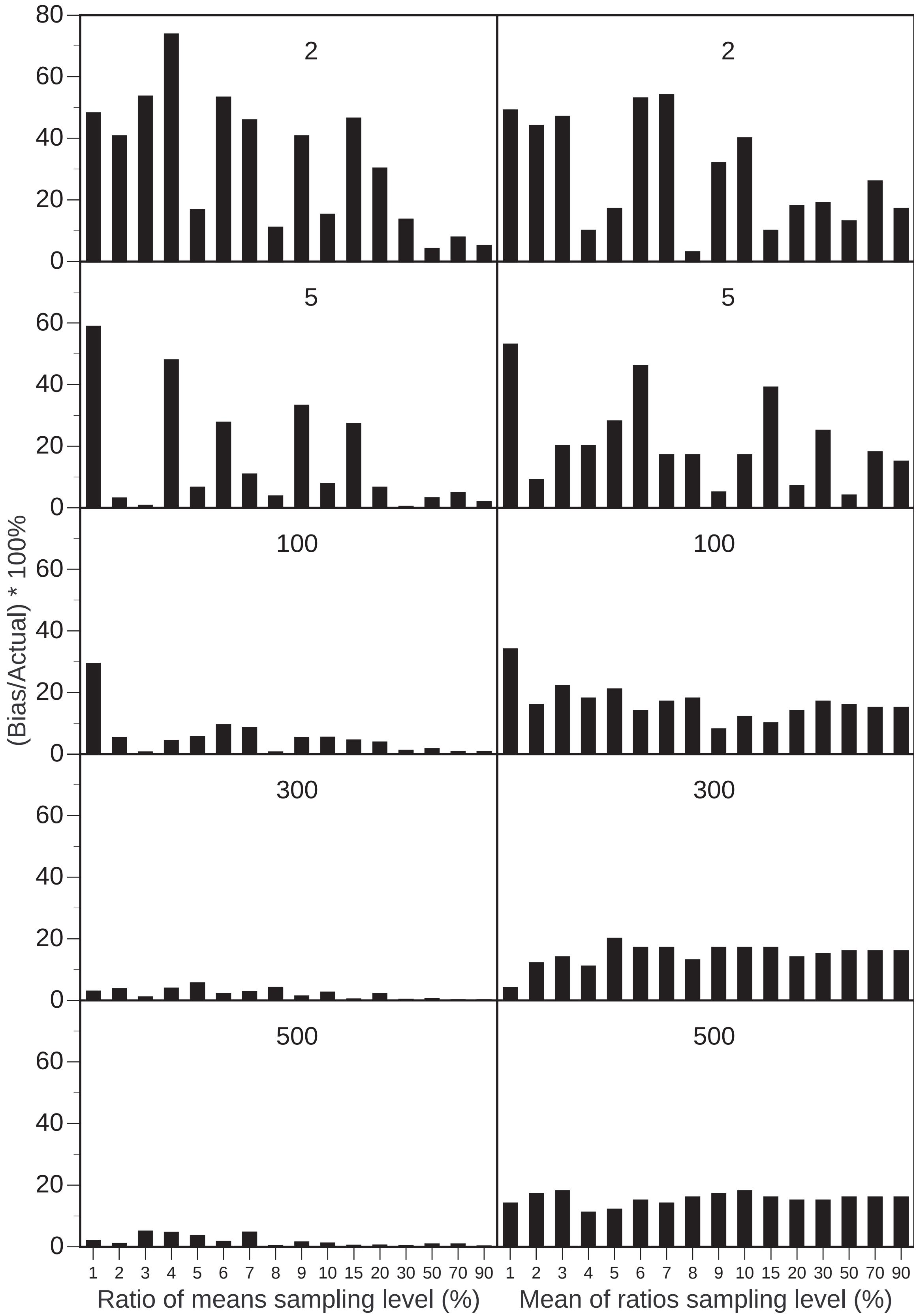

Figure 1.–Bias diversity for ratio-of-means and mean-of-ratios estimators at 2, 5, 100, 300, and 500 iterations. Boat angler interviews are from Hagerman Lake walleye fishery.

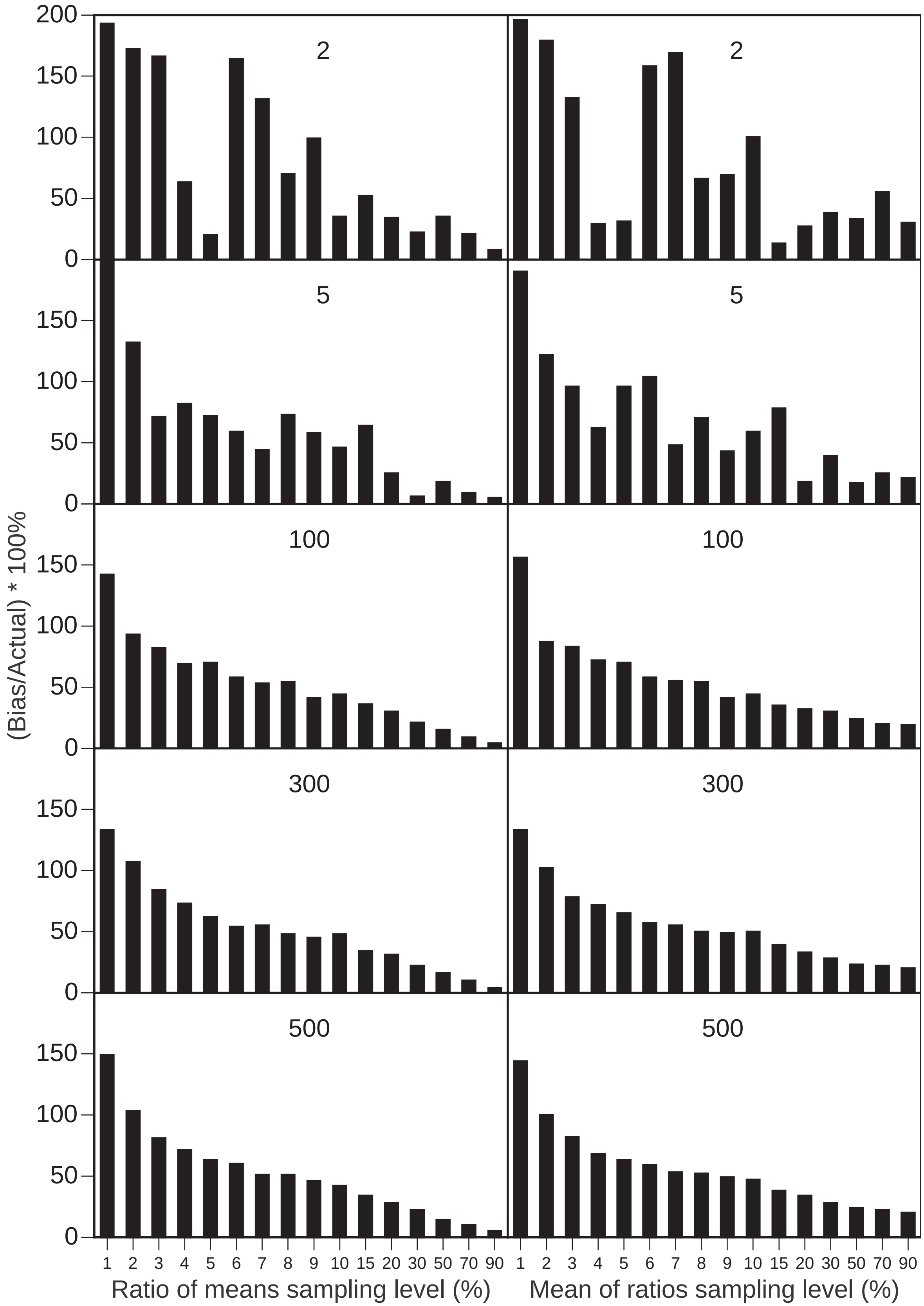

Figure 2.–Coefficient of variation diversity for ratio-of-means and mean-of-ratios estimators at 2, 5, 100, 300, and 500 iterations. Boat angler interviews are from Hagerman Lake walleye fishery.

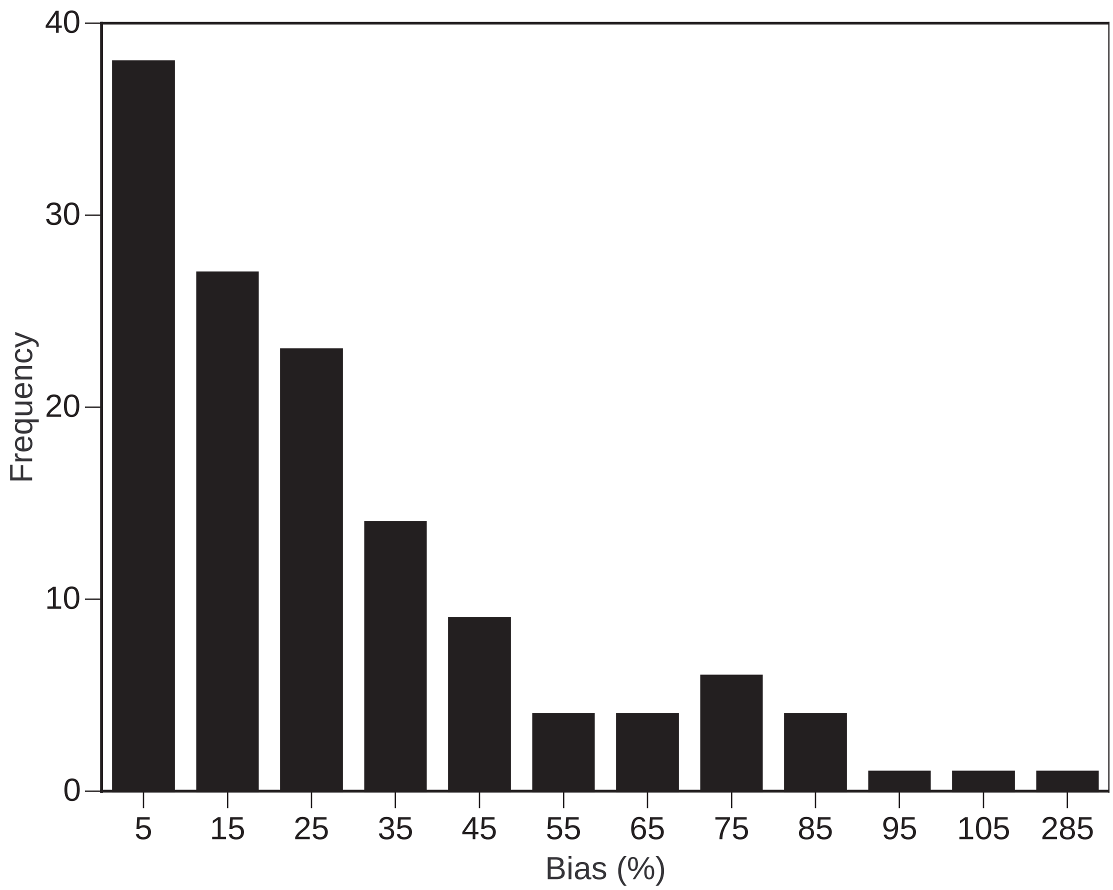

Figure 3.–Frequency of absolute value of bias based on under or over estimation of Θ by estimator $\overline{\overline{R}}$.

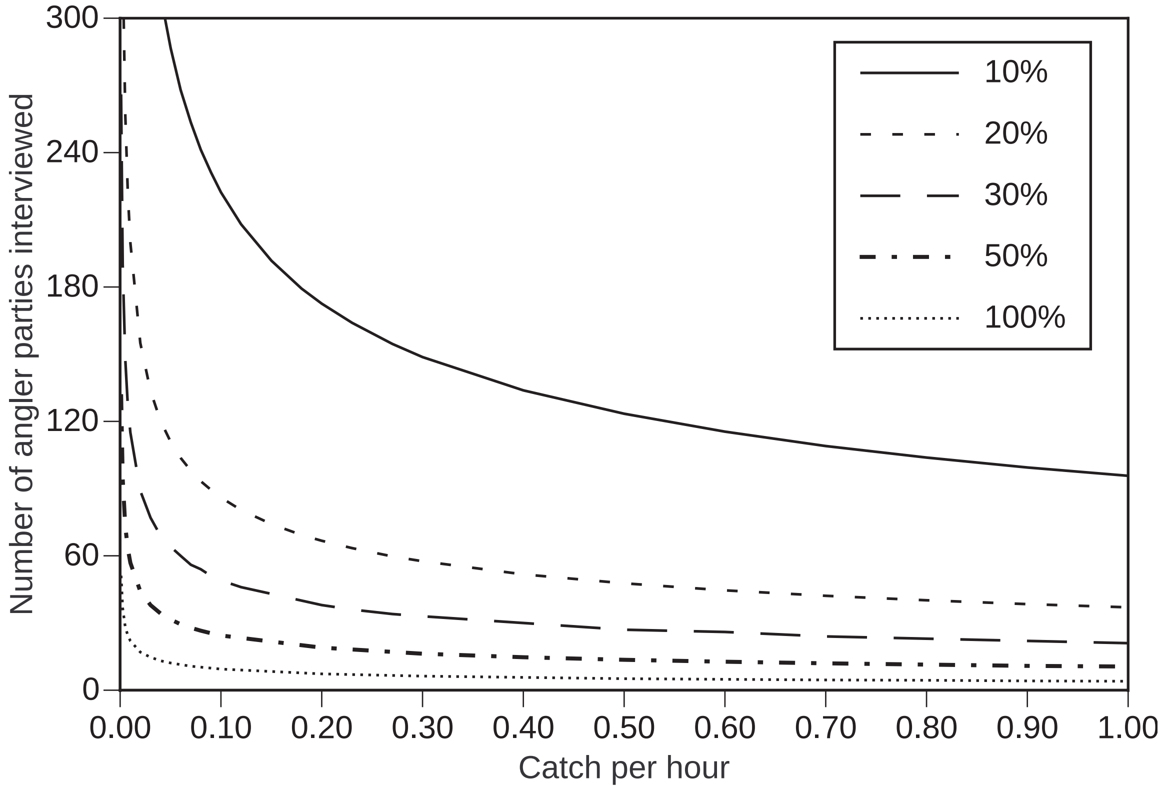

Figure 4.–Sample size determination. Sampling quantities (q) vs. angler party catch per hour rates (CPH) and coefficient of variation (CV). Regression coefficients are: ln(q)=7.7168-[ln(CPH)*0.3659]-[ln(CV)*1.3701].

Table 1.–List of freshwater fish species evaluated in study.

Common name	Scientific name
Brown trout	*Salmo trutta*
Steelhead	*Oncorhynchus mykiss*
Lake trout	*Salvelinus namaycush*
Round whitefish	*Prosopium cylindraceum*
Coho salmon	*Oncorhynchus kisutch*
Chinook salmon	*Oncorhynchus tshawytscha*
Northern pike	*Esox lucius*
Smallmouth bass	*Micropterus dolomieui*
Sunfish	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Black crappie	*Pomoxis nigromaculatus*
Walleye	*Stizostedion vitreum vitreum*
Yellow perch	*Perca flavescens*

Table 2.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from inland black crappie fisheries. Significantly different estimators (P_{α}=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Pomeroy	58	0.2568	-18.93	0.91*	0.2082*	0.08	0.01	0.2570
Duck	102	0.2465	-5.72	0.63*	0.2324*	-0.49	0.07	0.2477
Open Ice								
Fletcher	321	0.1055	41.80	0.99*	0.1496*	0.19	0.03	0.1057
Ice Shanty								
Fletcher	336	0.0610	5.08	0.46*	0.0641*	0.00	0.00	0.0610

Table 3.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from inland bluegill fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\hat{\overline{R}}$
Boat								
Pomeroy	58	0.0479	-33.82	0.91*	0.0317*	-0.04	0.01	0.0478
Duck	102	0.2427	39.23	0.97*	0.3379*	0.37	0.05	0.2436
Open Ice								
Fletcher	321	0.3517	25.87	0.97*	0.4427*	-0.03	0.02	0.3514
Ice Shanty								
Fletcher	336	0.3030	8.91	0.86*	0.3300*	-0.03	0.01	0.3029

Table 4.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan brown trout fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Stoney Point	75	0.0662	22.96	0.85*	0.0814*	-0.15	0.01	0.0661
Jutison Point	132	0.0069	5.80	0.18	0.0073*	1.45	0.04	0.0070
Cedar River	237	0.0707	16.47	0.19	0.0823*	0.00	0.00	0.0707
Yuba Creek	319	0.0563	23.98	1.01*	0.0698*	-0.71	0.18	0.0559*
Muskegon	383	0.0087	6.90	0.27*	0.0093*	0.00	0.00	0.0087
Manistee	959	0.0489	45.40	0.99*	0.0711*	-0.20	0.04	0.0488
Frankfort	1,111	0.0199	29.15	0.86*	0.0257*	0.00	0.00	0.0199
Shore								
Jutison Point	72	0.0177	15.82	0.63*	0.0205*	0.00	0.00	0.0177
Lighthouse Point	90	0.0285	20.00	0.64*	0.0342*	-0.35	0.02	0.0284
Elk Rapids	279	0.0235	35.32	0.93*	0.0318*	0.00	0.00	0.0235
Pier								
Menominee	79	0.0599	8.51	0.57*	0.0650*	0.17	0.01	0.0600
Jutison Point	138	0.0671	-3.13	0.31*	0.0650*	0.15	0.02	0.0672
Holland	220	0.0336	14.29	0.72*	0.0384*	0.60	0.09	0.0338
Grand Haven	302	0.0571	-15.41	0.98*	0.0483*	0.00	0.00	0.0571
Ludington	437	0.0258	5.43	0.63*	0.0272*	0.00	0.00	0.0258
Manistee	668	0.0421	-4.28	0.80*	0.0403*	0.24	0.04	0.0422

Table 5.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan chinook salmon fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Petoskey	73	0.0100	49.00	1.10*	0.0149*	0.00	0.00	0.0100
Escanaba	105	0.0009	44.44	0.36*	0.0013*	0.00	0.00	0.0009
Menominee	151	0.0268	-11.19	0.67*	0.0238*	0.00	0.00	0.0268
Lighthouse Point	197	0.0215	6.51	0.63*	0.0229*	-0.01	0.04	0.0214
Holland	330	0.0278	-9.35	1.16*	0.0252*	0.36	0.04	0.0279
Ludington	1,036	0.0206	-8.68	0.94*	0.0188*	0.28	0.08	0.0207
Shore								
Bear River	52	0.0348	72.73	0.63*	0.0601*	0.00	0.00	0.0348
Elk Rapids	80	0.0120	38.60	0.94*	0.0166*	0.53	0.01	0.0121
Jutison Point	258	0.0160	-7.50	0.54*	0.0148*	0.00	0.00	0.0160
Pier								
Frankfort	121	0.0191	-20.94	0.89*	0.0151*	-0.52	0.04	0.0190
South Haven	167	0.0026	50.00	0.58*	0.0039*	0.00	0.00	0.0026
Manistee	185	0.0019	94.74	0.80*	0.0037*	0.00	0.00	0.0019
Holland	220	0.0053	-35.85	0.85*	0.0034*	0.00	0.00	0.0053
Benton Harbor	328	0.0035	-31.43	0.49*	0.0024*	0.00	0.00	0.0035

Table 6.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan coho salmon fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Portage	114	0.0252	-7.14	0.80*	0.0234*	0.00	0.00	0.0252
Benton Harbor	165	0.0348	30.46	0.95*	0.0454*	-0.29	0.04	0.0347
New Buffalo	203	0.0586	50.85	0.95*	0.0884*	-0.68	0.09	0.0582
Manistee	385	0.0086	-15.12	0.58*	0.0073*	0.00	0.00	0.0086
Ludington	894	0.0056	-8.93	0.56*	0.0051*	0.00	0.00	0.0056
South Haven	1,148	0.0020	45.00	1.01*	0.0029*	0.00	0.00	0.0020
Shore								
Bear River	52	0.0087	63.22	0.82*	0.0142*	1.15	0.04	0.0088
Pier								
Grand Haven	105	0.0022	77.27	0.76*	0.0039*	0.00	0.00	0.0022
South Haven	167	0.0337	-31.16	0.94*	0.0232*	0.30	0.02	0.0338
Frankfort	194	0.0065	66.15	0.96*	0.0108*	1.54	0.09	0.0064
Benton Harbor	328	0.1131	33.16	0.99*	0.1506*	-0.09	0.02	0.1130
Grand Haven	492	0.0035	2.86	0.11	0.0036*	0.00	0.00	0.0035

Table 7.–Bias attributed to mean-of-ratios estimator ($\bar{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan lake trout fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\bar{\bar{R}}$	Bias(%)	B/σ	$\bar{\hat{R}}$
Boat								
Benton Harbor	167	0.0166	20.48	0.76*	0.0132*	0.60	0.04	0.0165
Petoskey	200	0.0958	27.66	0.99*	0.1223*	-0.21	0.04	0.0956
Holland	307	0.0490	-10.20	1.12*	0.0440*	0.00	0.00	0.0490
Manistee	535	0.0142	-28.87	0.92*	0.0101*	0.00	0.00	0.0142
South Haven	816	0.0194	-4.64	0.40*	0.0185*	0.00	0.00	0.0194
Frankfort	1,111	0.0278	1.80	0.14	0.0283*	0.00	0.00	0.0278

Table 8.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Inland northern pike fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Open Ice								
Fletcher	321	0.0219	-2.74	0.27*	0.0213*	0.00	0.00	0.0219
Ice Shanty								
Fletcher	336	0.0188	25.00	1.05*	0.0235*	0.00	0.00	0.0188

Table 9.–Bias attributed to mean-of-ratios estimator ($\bar{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan round whitefish fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\bar{\bar{R}}$	Bias(%)	B/σ	$\bar{\hat{R}}$
Boat								
Portage Lake	137	0.0025	68.00	0.76*	0.0042*	0.00	0.00	0.0025
Ludington	218	0.0049	40.82	0.89*	0.0069*	0.00	0.00	0.0049
Elk Rapids	319	0.0100	15.00	0.67*	0.0115*	0.00	0.00	0.0100
Pier								
Ludington	81	0.0193	-73.06	1.05*	0.0052*	-2.59	0.07	0.0188
Frankfort	136	0.0088	-80.68	1.06*	0.0017*	-1.14	0.04	0.0087
Manistee	185	0.0624	-1.44	0.13	0.0615*	0.48	0.04	0.0627

Table 10.–Bias attributed to mean-of-ratios estimator ($\bar{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan smallmouth bass fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\bar{\bar{R}}$	Bias(%)	B/σ	$\bar{\hat{R}}$
Boat								
Jutison Point	84	0.0209	29.19	0.91*	0.0270*	-0.48	0.04	0.0208
Escanaba	103	0.0011	-27.27	0.27*	0.0008*	0.00	0.00	0.0011
Old Coast Guard Station	163	0.0032	78.12	1.12*	0.0057*	0.00	0.00	0.0032
Cedar River	187	0.0255	-29.41	1.12*	0.0180*	-0.39	0.04	0.0254
Frankfort	538	0.0003	100.00	0.27*	0.0006*	0.00	0.00	0.0003
Shore								
Cedar River	54	0.0429	-62.00	0.99*	0.0163*	-0.70	0.03	0.0426
Elk Rapids	110	0.0395	17.22	0.76*	0.0463*	-0.51	0.04	0.0393
Jutison Point	397	0.0041	41.46	0.76*	0.0058*	2.44	0.09	0.0042
Pier								
Manistee	76	0.0030	-43.33	0.58*	0.0017*	3.33	0.09	0.0031
Grand Haven	95	0.0042	-30.95	0.58*	0.0029*	0.00	0.00	0.0042
Holland	102	0.0082	6.10	0.22*	0.0087*	-2.44	0.09	0.0080

Table 11.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from Lake Michigan steelhead fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Old Coast Guard Station	82	0.0045	-8.89	0.36*	0.0041*	0.00	0.00	0.0045
New Buffalo	145	0.0164	17.68	0.65*	0.0193*	0.00	0.00	0.0164
Portage Lake	178	0.0207	14.01	0.65*	0.0236*	-0.48	0.04	0.0206
Grand Haven	194	0.0148	10.14	0.67*	0.0163*	0.00	0.00	0.0148
Holland	330	0.0214	-15.42	0.74*	0.0181*	0.00	0.00	0.0214
Manistee	959	0.0179	-37.43	1.00*	0.0112*	0.00	0.00	0.0179
Frankfort	1,111	0.0320	-13.44	0.96*	0.0277*	0.00	0.00	0.0320
Shore								
Yuba Creek	51	0.0952	1.47	0.13	0.0966*	0.11	0.01	0.0953
Lighthouse Point	90	0.0665	5.71	0.57*	0.0703*	0.00	0.00	0.0665
Elk Rapids	279	0.0242	19.42	1.05*	0.0289*	0.00	0.00	0.0242
Jutison Point	334	0.0073	73.97	0.80*	0.0127*	0.00	0.00	0.0073
Pier								
Muskegon	73	0.0114	-21.93	1.12*	0.0089*	-0.88	0.04	0.0113
South Haven	212	0.0033	-36.36	0.54*	0.0021*	0.00	0.00	0.0033
Grand Haven	302	0.0069	-4.35	0.27*	0.0066*	0.00	0.00	0.0069
Manistee	422	0.0045	-26.67	0.54*	0.0033*	0.00	0.00	0.0045
Benton Harbor	713	0.0197	-2.03	0.18	0.0193*	0.00	0.00	0.0197

Table 12.–Bias attributed to mean-of-ratios estimator ($\overline{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from inland sunfish spp fisheries. Significantly different estimators ($P_{\propto}$=0.05) and bias (B/σ>0.20) are noted with an '*'.

			Mean of Ratios			Ratio of Means		
Mode/Site	n	θ	Bias(%)	B/σ	$\overline{\overline{R}}$	Bias(%)	B/σ	$\overline{\hat{R}}$
Boat								
Duck	102	0.1118	72.99	0.89*	0.1934*	-0.54	0.04	0.1112
Open Ice								
Fletcher	321	0.0403	83.13	1.00*	0.0738*	0.00	0.00	0.0403
Ice Shanty								
Fletcher	336	0.0412	24.51	0.90*	0.0513*	0.24	0.02	0.0413

Table 13.–Bias attributed to mean-of-ratios estimator ($\bar{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from walleye fisheries. Significantly different estimators (P_{α}=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\bar{\bar{R}}$	Bias(%)	B/σ	$\hat{\bar{R}}$
Inland								
Boat								
Pomeroy	58	0.0413	29.06	0.89*	0.0533*	-0.48	0.04	0.0411
Hagerman	202	0.1330	-15.79	0.94*	0.1120*	-0.08	0.01	0.1329
Stanley	328	0.0205	11.22	1.03*	0.0228*	0.00	0.00	0.0205
Chicagon (1993)	598	0.0549	57.56	1.01*	0.0865*	0.18	0.04	0.0550
Chicagon (1994)	801	0.0411	7.54	0.69*	0.0442*	0.24	0.04	0.0412
Burt	1,044	0.1254	12.84	1.03*	0.1415*	-0.08	0.04	0.1253
Open Ice								
Chicagon (1993)	58	0.0233	45.92	0.96*	0.0340*	0.00	0.00	0.0233
Lake Michigan								
Boat								
Menominee	51	0.0129	-20.93	0.60*	0.0102*	0.00	0.00	0.0129
Muskegon	120	0.0051	84.31	0.96*	0.0094*	1.96	0.04	0.0052
Tacoosh River	225	0.1350	4.37	0.53*	0.1409*	0.15	0.03	0.1352
Jutison Point	305	0.2029	10.55	0.96*	0.2243*	0.10	0.04	0.2031
Escanaba	528	0.1205	1.24	0.34*	0.1220*	0.00	0.00	0.1205
Shore								
Cedar River	95	0.0271	-19.56	0.79*	0.0218*	0.00	0.00	0.0271
Jutison Point	535	0.0714	21.43	0.98*	0.0867*	0.00	0.00	0.0714
Pier								
Holland	131	0.0155	-0.65	0.04	0.0154	0.65	0.04	0.0156
Menominee	190	0.0072	18.06	0.58*	0.0085*	0.00	0.00	0.0072
Jutison Point	282	0.0054	22.22	0.54*	0.0066*	-1.85	0.09	0.0053

Table 14.–Bias attributed to mean-of-ratios estimator ($\bar{R}$) and ratio-of-means estimator ($\hat{R}$). Monte Carlo sampling techniques (500 replications) were used with 90% of the population sampled. Results are from yellow perch fisheries. Significantly different estimators (P_α=0.05) and bias (B/σ>0.20) are noted with an '*'.

Mode/Site	n	θ	Mean of Ratios			Ratio of Means		
			Bias(%)	B/σ	$\bar{\bar{R}}$	Bias(%)	B/σ	$\bar{\hat{R}}$
Inland								
Boat								
Stanley	328	0.3893	2.31	0.45*	0.3983*	0.10	0.02	0.3897
Chicagon (1993)	598	0.2785	6.28	0.87*	0.2960*	0.14	0.04	0.2789
Chicagon (1994)	801	0.2607	24.86	1.00*	0.3255*	-0.04	0.01	0.2608
Open Ice								
Chicagon (1993)	58	0.5404	-9.70	0.78*	0.4880*	-0.48	0.07	0.5378
Fletcher	321	0.2731	11.83	0.96*	0.3054*	-0.11	0.03	0.2728
Ice Shanty								
Fletcher	336	0.2914	19.11	0.96*	0.3471*	0.00	0.00	0.2914
Lake Michigan								
Boat								
Menominee	89	0.0200	285.50	0.95*	0.0771*	1.00	0.04	0.0202
Cedar River	134	0.6871	33.30	0.97*	0.9159*	-0.29	0.04	0.6851
Tacoosh River	225	0.0194	87.11	0.94*	0.0363*	-0.52	0.04	0.0193
Yuba Creek	319	0.0703	27.88	0.88*	0.0899*	0.14	0.01	0.0704
Escanaba	647	0.0986	1.72	0.25*	0.1003*	0.30	0.07	0.0989
Ludington	853	0.2486	34.63	0.99*	0.3347*	-0.08	0.02	0.2484
South Haven	1,148	4.3892	17.18	0.99*	5.1432*	0.01	0.01	4.3898
Shore								
Elk Rapids	115	0.1002	52.20	0.90*	0.1525*	0.00	0.00	0.1002
Jutison Point	138	0.0120	-27.50	0.74*	0.0087*	0.00	0.00	0.0120
Pier								
Muskegon	50	0.4630	-15.94	0.87*	0.3892*	0.28	0.03	0.4643
Menominee	169	1.1192	-7.46	0.85*	1.0357*	0.33	0.06	1.1229
Jutison Point	243	0.6372	-0.36	0.09	0.6349*	0.14	0.03	0.6381
Manistee	422	0.0185	-5.95	0.49*	0.0174*	1.08	0.09	0.0187
Holland	669	0.6684	-14.51	0.96*	0.5714*	-0.01	<0.01	0.6683
Grand Haven	906	0.8632	-1.09	0.28*	0.8538*	-0.20	0.06	0.8615

Table 15.–Significant ($P_{\propto}$=0.05) stepwise regression coefficients from boat and ice shanty interviews. Non-significant coefficients are noted as "ns".

				Slope	
Mode/Site	Species	n	Intercept	Hours	Anglers
		Inland			
Boat					
Chicagon (1993)	Walleye	598	0.2163	ns	-0.0615
Chicagon (1994)	Walleye	801	0.0744	ns	-0.0146
Burt	Walleye	1,044	0.2589	ns	-0.0547
Chicagon (1994)	Yellow Perch	801	0.4553	-0.0388	ns
Pomeroy	Black Crappie	58	-0.3406	0.1435	ns
Ice Shanty					
Fletcher	Northern Pike	336	0.0572	ns	-0.0182
		Lake Michigan			
Boat					
Petoskey	Lake Trout	200	0.2374	ns	-0.0529
Holland	Lake Trout	307	0.0108	0.0072	ns
Manistee	Lake Trout	535	-0.0054	0.0018	0.0033
New Buffalo	Coho	203	0.2398	-0.0337	ns
Manistee	Coho	385	0.0015	0.0031	-0.0038
Ludington	Coho	894	0.0005	0.0010	ns
South Haven	Coho	1,148	0.0087	-0.0012	ns
Petoskey	Chinook	73	0.0584	ns	-0.0198
Menominee	Chinook	151	0.0020	0.0041	ns
Holland	Chinook	330	0.0070	0.0040	ns
Ludington	Chinook	1,036	0.0139	0.0035	-0.0050
Yuba Creek	Brown Trout	319	0.1284	-0.0144	ns
Manistee	Brown Trout	959	0.1625	ns	-0.0423
Frankfort	Brown Trout	1,111	0.0624	-0.0030	-0.0087
Menominee	Yellow Perch	89	0.4001	ns	-0.1204
Cedar River	Yellow Perch	134	2.4827	ns	-0.6438
Yuba Creek	Yellow Perch	319	0.1705	0.0456	-0.1300
Ludington	Yellow Perch	853	0.7940	ns	-0.1989
South Haven	Yellow Perch	1,148	10.2242	-0.4891	-1.1236
Jutison Point	Walleye	305	0.3349	0.0235	-0.0872
Escanaba	Walleye	528	0.1547	0.0110	-0.0379
Holland	Steelhead	330	0.0014	0.0037	ns
Manistee	Steelhead	959	-0.0139	0.0059	ns
Frankfort	Steelhead	1,111	-0.0048	0.0065	ns
Cedar River	Smallmouth Bass	187	-0.0001	0.0059	ns

Table 16.–Significant ($P_{\propto}$=0.05) stepwise regression coefficients from open ice, shore and pier angler interviews. Non-significant coefficients are noted as "ns".

Mode/Site	Species	n	Intercept	Slope	
				Hours	Anglers
		Inland			
Open Ice					
Fletcher	Bluegill	321	0.8413	ns	-0.1977
Fletcher	Sunfish	321	0.2185	ns	-0.0721
Fletcher	Black Crappie	321	0.3667	ns	-0.1082
		Lake Michigan			
Shore					
Cedar River	Walleye	95	-0.0156	0.0219	ns
Jutison Point	Walleye	535	0.1409	ns	-0.0319
Cedar River	Smallmouth Bass	54	-0.0528	0.0395	ns
Pier					
Benton Harbor	Coho	328	0.2290	-0.0253	ns
Jutison Point	Brown Trout	138	-0.0011	0.0233	ns
Menominee	Yellow Perch	169	-0.0282	0.4914	ns
Holland	Yellow Perch	669	0.0542	0.2665	ns
Grand Haven	Yellow Perch	906	0.9072	0.1292	-0.3024
Muskegon	Steelhead	73	-0.0102	0.0068	ns
Manistee	Steelhead	422	-0.0012	0.0015	ns
Ludington	Round Whitefish	81	-0.0319	0.0153	ns
Frankfort	Round Whitefish	136	-0.0060	0.0026	ns
Manistee	Round Whitefish	185	0.0685	0.0297	-0.0606

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