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Calculation of Catch Rate and Total Catch in Roving Surveys of Anglers

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SUMMARY

To estimate the total catch in a sport fishery sampled by a roving creel survey, we multiply an estimate of the total fishing effort by the estimated catch rate (i.e., catch per unit of fishing effort). While the statistical theory for estimating the fishing effort from instantaneous or progressive counts is well established, there is much confusion about the appropriate way to estimate the catch rate. Most studies have used the ratio of means or the mean of the ratios of individual catches and efforts. We analyzed the properties of these estimators of catch rate under the assumption that fishing is a stationary Poisson process. The ratio of means estimator has a finite second moment, while the mean ratio estimator has infinite variance. Simulation studies showed that the mean of ratios estimator tends to have high and unstable mean squared error relative to the ratio of means estimator and this is in accordance with empirical observations. We also studied the properties of the mean of ratios estimator when all interviews with people fishing for less than ϵ minutes duration were disregarded for values of ϵ up to 60 minutes. There was typically a marked reduction in mean squared error when the shorter trips were not included. We recommend that the mean of ratios estimator, with all trips less than 30 minutes disregarded, be used to estimate catch rate and hence total catch under the roving creel survey design. It has the correct expectation (at least approximately after the truncation) and almost always had smaller mean squared error than the ratio of means estimates in our simulations.

1. Introduction

Fishery managers frequently conduct creel (angler) surveys to estimate the total catch, fishing effort or activity, and catch rate for a given body of water. One creel survey method consists of estimating the total fishing effort in a day (or portion of a day) and the average catch rate. For example, the total effort might be estimated in angler-hours and the catch rate in fish per angler-hour. The total catch is then estimated as the product of the estimates of total effort and average catch rate. Thus, *total catch = total effort × catch rate.*

The total fishing effort can be estimated from an instantaneous count of all anglers present at a randomly selected moment (or at several moments) during the day. The count provides an unbiased estimate of the mean number of anglers fishing during the day. The product of the estimated mean

Key words: Angler surveys; Length-biased sampling; Length of stay bias; Mean of ratio estimator; Model-based sampling; Ratio of means estimator; Success rate estimation; Truncation of short trips.

number of anglers and the duration of the day provides an estimate of the angler-hours of effort (see Neuhold and Lu, 1957; Hoenig et al., 1993). Alternatively, the total effort can be estimated from a progressive count, in which the survey agent counts all anglers encountered while roving through the fishery in a specified manner (see Robson, 1961; Hoenig et al., 1993).

In addition to wanting an estimate of catch rate for estimating the total catch, fisheries biologists may want to look at the distribution of catch rates among anglers. For example, it might be of interest to see how well the "average" angler is doing on a particular day. Also, angler catch rate has been used as an index of fish abundance on the assumption that more fish are caught per fishing hour when fish are abundant than when they are scarce. However, angler catch rates also depend on angler skills and environmental conditions (e.g., availability of prey for the fish; see Lux and Smith, 1960) and, even if these factors could be controlled, there is no guarantee that angling success rate would be a linear function of fish abundance. Fisheries agencies often prefer to monitor fish abundance under more controlled conditions using designed research surveys and optimal sampling gear. For these reasons, we do not consider further the use of catch rates as an indicator of fish abundance.

While the statistical theory for estimating the total effort is well established, the proper procedure for estimating the overall catch rate in a roving creel survey is the object of much confusion (van den Avyle, 1986; Crone and Malvestuto, 1991; Pollack, Jones, and Brown, 1994). The two estimators commonly used in fisheries work are the ratio of the means and the mean of the ratios of individual catches and efforts. The ratio of means estimator has been advocated for roving creel surveys by Neuhold and Lu (1957), von Geldern and Tomlinson (1973), Malvestuto, Davies, and Shelton (1978), Phippen and Bergersen (1991), Dent and Wagner (1991), and Orsatti, Daniels, and Lester (1991), among others. In contrast, the mean of ratios estimator has been advocated by Sigler and Sigler (1990) and Hayne (1991) among others.

In evaluating the performance of these estimators, it is necessary to recognize that the probability of the survey agent encountering a given angler in the roving survey is proportional to the length of time that the angler fishes. This is because the agent travels through the fishery and interviews anglers while they are in the act of fishing. Thus, anglers fishing a long time are more likely to be encountered than those fishing a short time. Also, the catch rate calculation is based only on the catch up to the time of interview (incomplete trip) and the length of the complete trip is typically unknown. These complications are dealt with by adopting a model-based approach to sampling.

In Section 2, we present two estimators for catch rate and establish notation and relationships for various quantities of interest. In Section 3, we present analytical expressions for the asymptotic expected values and discuss variances of these estimators. These results motivate the computer simulations of the estimators presented in Section 4. The performance of the estimators in a roving creel survey in Minnesota is considered as an example in Section 5. Section 6 is a general discussion section that includes a recommendation on which estimator to use.

2. Catch Rate Estimators

Consider the problem of estimating the overall catch rate in a given day. A closed-circuit route is laid out from which the entire fishery can be viewed. The survey agent conducts interviews of all anglers encountered while traveling at a constant speed through the survey area beginning at a randomly selected starting point, traveling in a randomly selected direction (e.g., either clockwise or counterclockwise), and ending at the same place at the end of the survey day. The survey agent records the number of fish caught and the amount of time fished up to the time of the interview. We assume that the anglers are stationary or, if they move while fishing, they travel at a rate that is slower than the travel speed of the survey agent.

This is the simplest sampling design and serves to illustrate the basic relationships. The results are easily applied to variations of this design, e.g., when only a portion of the day or a portion of the fishery is surveyed in a day.

Let C_j be the catch of angler j up to the time of interview, L_j be the length of the trip (hours) to the time of interview, and L_j^* be the total length of the trip (unknown). Also, let the number of anglers interviewed in the day be denoted by n. We now present two estimators of the catch rate.

2.1 *Ratio of Means Estimator*

This method of estimating the catch rate involves dividing the total observed fish caught by the total observed effort. Thus,

$$\hat{R}_1 = \frac{\sum_{j=1}^{n} C_j}{\sum_{j=1}^{n} L_j} = \frac{\sum_{j=1}^{n} C_j/n}{\sum_{j=1}^{n} L_j/n}. \tag{2.1}$$

The equation can also be viewed as the ratio of mean catch $(\Sigma_{j=1}^{n} C_j/n)$ to mean effort $(\Sigma_{j=1}^{n} L_j/n)$.

2.2 *Mean of Ratios Estimator*

The second method is to calculate the average of the individual catch rates for all anglers interviewed on a given day. Thus,

$$\hat{R}_2 = \frac{1}{n}\sum_{j=1}^{n}\frac{C_j}{L_j}. \tag{2.2}$$

2.3 *Notation and Some Basic Relationships*

To begin with, we make the assumption that, for each angler j, fishing is a stationary Poisson process with parameter λ_j and that the fishing rate does not vary with the angler's starting time or with the length of the fishing trip. Because the interviewer interrupts the angler during the fishing trip, the data obtained on catch and effort provide only an estimate of the actual catch rate for the completed trip. An additional factor to consider is that the probability of encountering an angler is proportional to the angler's trip length and that, on average, the angler will be intersected midway through the fishing trip. Hence, it is assumed that, on average, half the catch is also seen and the catch rate up to the interview is similar to that after the interview. These ideas are formalized in the notation and relationships which follow. Let

T = number of hours in the fishing day = time required for the survey agent to make one complete circuit through the fishery;
N = number of anglers fishing during the day;
λ_j = Poisson catch rate (# fish/hour) of an individual angler j $(j = 1, \ldots, N)$;
L_j = length of the trip (hours) up to the time of interview of angler j $(j = 1, \ldots, N)$; L_j is defined to be 0 if the angler is not interviewed;
L_j^* = total trip length (hours) of angler j $(j = 1, \ldots, N)$;
L^* = total hours of fishing in the day, $L^* = \Sigma_{j=1}^{N} L_j^*$;
$\mathbf{L}$ = vector of the trip lengths up to the time of interview, L_j;
C_j = catch of angler j at the time of interview $(j = 1, \ldots, N)$. C_j is defined to be 0 if the angler is not interviewed;
C_j^* = catch of angler j at the completion of the fishing trip $(j = 1, \ldots, N)$;
$\mathbf{C}^*$ = vector of catches from all of the completed fishing trips, C_j^*;
n = number of anglers interviewed;
δ_j = an indicator variable where $\delta_j = 0$ if angler j is not intercepted and $\delta_j = 1$ if angler j is intercepted and interviewed by the survey agent, $n = \Sigma_{j=1}^{N} \delta_j$; and finally,
δ = vector of the indicator variables δ_j.

Given the sampling design and the assumption of Poisson processes, we can easily establish some basic relationships. First, the probability of interviewing a given angler is proportional to the length of time the angler fishes (see Robson, 1961; Hoenig et al., 1993, Appendix 2), so that

$$P(\delta_j = 1 \mid L_j^*) = L_j^*/T. \tag{2.3}$$

This implies that δ_j is a Bernoulli random variable with expectation and variance given by

$$\mathrm{E}(\delta_j \mid L_j^*) = L_j^*/T \quad \text{and} \quad V(\delta_j \mid L_j^*) = (L_j^*/T)(1 - L_j^*/T). \tag{2.4}$$

The length of time an angler fishes before being interviewed by the survey agent (given that the angler is interviewed) is a uniform random variable, and thus

$$L_j \sim U(0, L_j^*) \quad \text{given } \delta_j = 1. \tag{2.5}$$

Therefore, from the properties of the uniform distribution

$$\mathrm{E}(L_j \mid L_j^*, \delta_j = 1) = L_j^*/2 \quad \text{and} \quad V(L_j \mid L_j^*, \delta_j = 1) = L_j^{*2}/12. \tag{2.6}$$

Equation (2.5) also implies that the expected value and variance of the reciprocal of trip length at the time of interview (given the completed trip length and the fact that $\delta_j = 1$) are infinite.

The expected catch at the time of interview, given that an angler is interviewed when the fraction L_j/L_j^* of the trip is over, is simply the total catch for the trip times the fraction of the trip completed. Thus,

$$\mathrm{E}(C_j \mid L_j, C_j^*, L_j^*, \delta_j = 1) = C_j^* L_j / L_j^* \tag{2.7}$$

and

$$V(C_j \mid L_j, C_j^*, L_j^*, \delta_j = 1) = C_j^*(L_j/L_j^*)(1 - L_j/L_j^*).$$

This follows from the assumption that fishing is a Poisson process, i.e., that catch rate does not vary over time. On average, an angler will be intercepted halfway through the fishing trip and one half of the trip's catch will have been taken at the time of interview. Thus,

$$\mathrm{E}(C_j \mid C_j^*, L_j^*, \delta_j = 1) = C_j^*/2 \tag{2.8}$$

and

$$V(C_j \mid C_j^*, L_j^*, \delta_j = 1) = C_j^*(1 + C_j^*/2)/6.$$

Equation (2.8) follows from equation (2.7) using equation (2.5).

Equations (2.7) and (2.8) are conditional on an angler's catch for the whole trip. The catch per trip on any given day arises from a Poisson process so that the expected catch in a trip is

$$\mathrm{E}(C_j^* \mid L_j^*) = \lambda_j L_j^* \tag{2.9}$$

and the variance is

$$V(C_j^* \mid L_j^*) = \lambda_j L_j^*.$$

Taking expectation and variance of C_j and C_j^* gives

$$\mathrm{E}(C_j \mid L_j^*, \delta_j = 1) = \lambda_j L_j^*/2 \tag{2.10}$$

and

$$V(C_j \mid L_j^*, \delta_j = 1) = \lambda_j L_j^*/2 + (\lambda_j L_j^*)^2/12.$$

For the rest of this paper, conditionality on L_j^* will be assumed implicitly and dropped from the notation.

3. Asymptotic Expected Values and Variances

3.1 *Ratio of the Means Estimator*

The expected value of this catch rate estimator can be approximated as follows. Let $\hat{R}_1$ be written

$$\hat{R}_1 = \frac{\sum_{j=1}^{N} \delta_j C_j}{\sum_{j=1}^{N} \delta_j L_j}.$$

To facilitate finding an analytic solution, assume that the sample size is large enough that the expectation of the ratio is approximately equal to the ratio of the expectations. This assumption is verified in the simulations described in Section 4. The approximate expected value of the estimator is then

$$\mathrm{E}(\hat{R}_1 \mid \mathbf{C}^*) \simeq \frac{\sum_{j=1}^{N} \mathrm{E}(\delta_j C_j \mid C_j^*)}{\sum_{j=1}^{N} \mathrm{E}(\delta_j L_j)} = \frac{\sum_{j=1}^{N} P(\delta_j = 1)\mathrm{E}(C_j \mid \delta_j = 1, C_j^*)}{\sum_{j=1}^{N} P(\delta_j = 1)\mathrm{E}(L_j \mid \delta_j = 1)}.$$

Using result (2.4),

$$\mathrm{E}(\hat{R}_1 \mid \mathbf{C}^*) \simeq \frac{\sum_{j=1}^{N} (L_j^*/T)\mathrm{E}(C_j \mid \delta_j = 1, C_j^*)}{\sum_{j=1}^{N} (L_j^*/T)\mathrm{E}(L_j \mid \delta_j = 1)}.$$

Using result (2.8) for the numerator and (2.6) for the denominator,

$$\mathrm{E}(\hat{R}_1 \mid \mathbf{C}^*) \simeq \frac{\sum_{j=1}^{N} L_j^* C_j^*/2}{\sum_{j=1}^{N} L_j^* L_j^*/2} = \frac{\sum_{j=1}^{N} L_j^{*^2} (C_j^*/L_j^*)}{\sum_{j=1}^{N} L_j^{*^2}}. \tag{3.1}$$

Therefore, the approximate expectation of $\hat{R}_1$ is a weighted average of the individual catch rates with the weights being the squares of the completed trip lengths. Equation (3.1) gives the expected value of the estimator for a realization of the stochastic fishing process, i.e., for a particular day. If we take the expectation of C_j^* over the superpopulation, we obtain the corresponding expression

$$\mathrm{E}(\hat{R}_1) \simeq \frac{\sum_{j=1}^{N} L_j^{*^2} \lambda_j}{\sum_{j=1}^{N} L_j^{*^2}}. \tag{3.2}$$

These expressions show that $\hat{R}_1$ does not provide an estimate of catch rate that can be used with an independent estimate of total effort (L^*) to provide an unbiased estimate of total catch except in the unrealistic case where λ is constant over all anglers.

Using the relationships developed in Section 2.3 and the Taylor series method, we can show that the asymptotic variance of $\hat{R}_1$ is finite. The form of the variance, while obtainable, is not of practical use because it contains the unknown completed trip lengths; it will not be presented here.

3.2 *Mean of the Ratios Estimator*

The mean of ratios estimator can be written

$$\hat{R}_2 = \frac{\sum_{j=1}^{N} \delta_j (C_j/L_j)}{\sum_{j=1}^{N} \delta_j}.$$

Again assume that the expectation of the ratio is approximately the ratio of the expectations. Then

$$\mathrm{E}(\hat{R}_2 \mid \mathbf{C}^*) \simeq \frac{\sum_{j=1}^{N} \mathrm{E}[\delta_j (C_j/L_j \mid C_j^*)]}{\sum_{j=1}^{N} \mathrm{E}(\delta_j)} = \frac{\sum_{j=1}^{N} P(\delta_j = 1)\mathrm{E}(C_j/L_j \mid \delta_j = 1, C_j^*)}{\sum_{j=1}^{N} P(\delta_j = 1)}.$$

Using results (2.3) and (2.7),

$$\mathrm{E}(\hat{R}_2 \mid \mathbf{C}^*) \simeq \frac{\sum_{j=1}^{N} (L_j^*/T)(C_j^*/L_j^*)}{\sum_{j=1}^{N} L_j^*/T} = \frac{\sum_{j=1}^{N} C_j^*}{\sum_{j=1}^{N} L_j^*}. \tag{3.3}$$

In this case, the approximate expectation is simply the ratio of total catch to total effort. Thus, the mean of the ratios estimator, $\hat{R}_2$, provides us with a theoretically correct estimator for calculating catch per unit effort in the roving creel method.

We can average (3.3) over realizations of the stochastic process. Taking the expectation of C_j^* over the superpopulation yields

$$\mathrm{E}(\hat{R}_2) \simeq \frac{\sum_{j=1}^{N} L_j^* \lambda_j}{\sum_{j=1}^{N} L_j^*}. \tag{3.4}$$

Using the relationships developed in Section 2.3 and the Taylor series method, we can show that the asymptotic variance of $\hat{R}_2$ is infinite. The reason for the infinite variance is that L_j can get very close to zero and $\mathrm{E}(1/L_j)$ is infinite. This result relies on the assumption that fishing is a Poisson process, which is just an approximation to the real world. Nonetheless, we might find in practice that the variance of $\hat{R}_2$ can be reduced if a lower bound is placed on L_j by eliminating short incomplete trips when we calculate the mean of ratios. In Section 4, we use simulation to study how the amount of truncation influences the bias and mean squared error.

4. Simulation Studies

4.1 *The Simulation Model*

The expected values and variances derived in Section 3 are approximations that were derived for a specific model. We developed a simulation model to evaluate these results and explored the performance of the catch rate estimators under more realistic conditions (Greene et al., 1995). The simulations were patterned after and simplified from those developed by Wade et al. (1991) to evaluate estimators of fishing effort in roving creel surveys.

A population of 50 angler trips was generated for each 8-hour simulated day. Each trip had the following attributes: fixed geographic location of the angler, starting time, trip duration, and fishing rate parameter for the angler. The fishing rate parameter was then used to generate a catch history of the angler consisting of the time each fish was caught.

A random starting location was picked for the survey agent. Note that the agent's direction of travel did not need to be randomized because the anglers were stationary (see Hoenig et al., 1993). The agent then traveled at constant speed along the route and completed the route after 8 hours. Whenever an angler was encountered, the catch and fishing effort at the time of interview were recorded.

In all simulations, the anglers were distributed regularly over space. The starting time was fixed at 1 hour after the start of the day for all anglers. In most of the simulations, half of the anglers fished for 3 hours and half for 6 hours, with trip lengths alternating over space. In the simplest simulations, the distribution of λ was drawn from a gamma distribution with parameters $\alpha = 1$ and $\beta = 2$ such that on average the anglers had a catch rate of $\alpha\beta = 2$ fish per hour with variance $\alpha\beta^2 = 4$.

We simulated five types of scenarios:

1) Baseline conditions—the fishing rate parameter varied among anglers but did not vary with length of trip or elapsed time since the beginning of the trip. In this scenario, the assumptions under which the equations in the text were derived are met.

2) Trip-length dependent catch rate—the catch rate for anglers fishing for 6 hours was doubled so that, on average, they had catch rates twice as high as those fishing for 3 hours.

3) Learner model—initial catch rate was drawn from the gamma (1, 2) distribution as before but was multiplied by 2 when the angler caught the first fish. This is meant to mimic the angler finding a patch of fish and then staying with the patch.

4) Fish are caught in clusters—instead of individual fish being caught, fish are caught in clusters. At the time each fish is caught, a Poisson random variable with mean 1.0 is generated to determine how many additional fish are caught. This is meant to mimic cases where several fish may be simultaneously scooped up in a net or where several lines may be trolled from a boat and when a school of fish is encountered several fish may be caught simultaneously.

5) Trip-length dependent catching of clusters—this is the same as scenario 4 except that anglers fishing for 6 hours catch larger clusters of fish than anglers fishing for 3 hours.

For each scenario, the two catch rate estimators were applied to all of the interview data. In addition, the mean of ratios estimator was applied to the truncated portion of the data for which the time at interview was at least ϵ minutes after the start of the fishing trip, for $\epsilon = (0, 1, 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60$ minutes). This prevented division by very small numbers and should stabilize the variance (which according to our approximation is infinite without truncation). Note that the expected number of usable interviews declines linearly with increases in minimum fishing time.

4.2 *Simulation Results*

For each of the five scenarios described in Section 4.1, we present results in terms of the percentage bias and the mean squared error of each total catch estimator (*total catch* = *total effort* × *catch rate*). Total effort (225 hours) is assumed known exactly.

Baseline conditions. In the first set of simulations, each angler had a constant catch rate parameter that was independent of the length of the trip. All of the estimators had negligible bias (under 0.2%). The ratio of means estimator $\hat{R}_1$ had a mean squared error of 12,000. When all interviews were used, the mean of ratios estimator $\hat{R}_2$ had a mean squared error of 14,000. $\hat{R}_2$ was also calculated from those interviews where the angler had fished for a minimum period of ϵ minutes prior to the interview. Mean squared error decreased steadily from 14,000 for $\epsilon = 0$, to 10,000 for $\epsilon = 20$ minutes, and then rose to 11,000 for $\epsilon = 60$ minutes (Figure 1, top).

Effort-dependent model. We considered a model in which the anglers fishing for 6 hours had twice the catch rate, on average, of those fishing for 3 hours. The ratio of means estimator had a bias of 8%, while the mean of ratios estimator had a bias of under 0.2% when all interviews were used and 3% or less for all other values of minimum fishing time. The ratio of means estimator had a mean squared error of 45,000, while the mean of ratios estimator had mean squared errors that declined from 33,000 for $\epsilon = 0$ to 27,000 for $\epsilon = 7.5$, and then increased to 33,000 for $\epsilon = 60$ (Figure 1, second panel).

Note that for this scenario we can predict the simulation results using equations (3.2) and (3.4). The ratio of means estimator has expectation 3.60 fish/hr, while the mean of ratios estimator has expectation 3.33 fish/hr. Multiplying by 225 hours of fishing effort gives predicted catches of 810 fish for the ratio of means and 750 fish for the mean of ratios estimators. The simulation results are in good agreement, with 809 fish for the ratio of means and 749 fish for the mean of ratios estimators.

Learner model. For this set of simulations, the angler's catch rate parameter increased as soon as the angler caught the first fish. All of the estimators had negative biases (Table 1) ranging from −2.7% (ratio of means) to −8.2% (mean of ratios with no truncation). The mean squared error of $\hat{R}_2$ (37,000 to 41,000) was uniformly better than that of $\hat{R}_1$ (44,000) (Figure 1, third panel).

Cluster models. Results for these models were qualitatively the same as for the other models (Figure 1, fourth and fifth panels). As the minimum interview time was increased, the mean squared error for $\hat{R}_2$ declined to a minimum and then increased; for values of ϵ ranging from 7.5 to 60 minutes, the mean squared error for $\hat{R}_2$ was lower than for $\hat{R}_1$. In all cases, the bias was small. The ratio of means estimator had a 1% bias for the cluster model and a 4% bias for the

Table 1

Bias in the estimated total catch under the learner model. The catch rate parameter for each angler is initially a constant drawn from a G(1, 2) distribution. Catch rate is doubled as soon as the first fish is caught. The average actual total catch in 12,000 simulations was 857 fish. ϵ is the minimum fishing time (at the time of interview) for the interview to be used for estimating catch rate.

	Bias (%)	
ϵ	$\hat{R}_1$	$\hat{R}_2$
0	−2.69	−8.24
1	—	−8.03
5	—	−7.40
15	—	−6.33
30	—	−5.13
60	—	−3.60

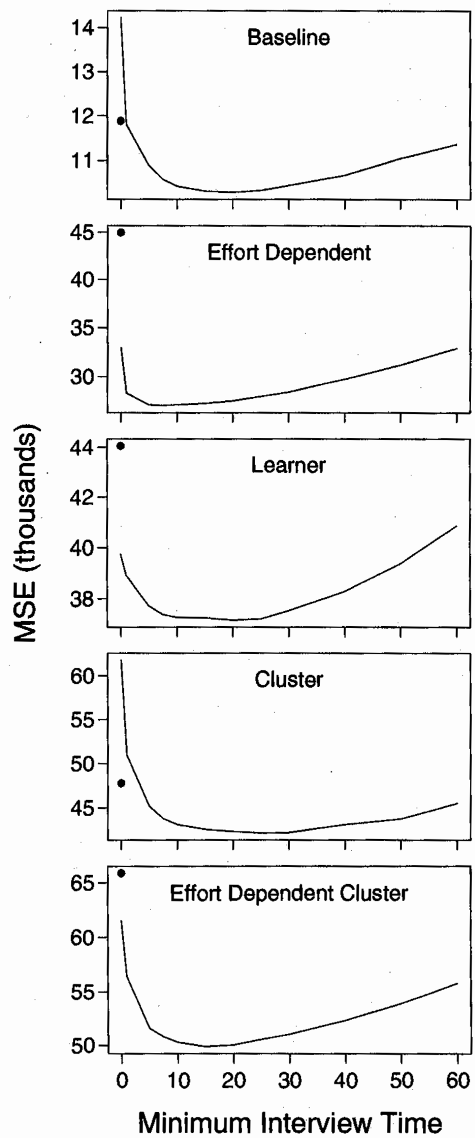

Figure 1. Mean squared error for the mean of ratios estimator (solid line) with various minimum fishing times and for the ratio of means estimator (large dot). Top: baseline conditions—catch rate parameters drawn from a G(1, 2) distribution; second panel: effort-dependent model—anglers fishing for 6 hours had twice the catch rate on average as those fishing for 3 hours; third panel: learner model—catch rate for each angler doubled as soon as the first fish was caught; fourth panel: cluster model—anglers encounter clusters of fish (every time a fish is caught a P(1.0) random variable is generated to see how many additional fish are caught); fifth panel: trip-length dependent cluster model—every time a fish is caught a P(0.67) or P(1.33) random variable is generated if trip length is 3 or 6 hours, respectively, to determine how many additional fish are caught.

effort-dependent cluster model. In contrast, the mean of ratios estimators always had biases of 1.5% or less.

5. Example

The simulation results suggest that the two estimators should give similar results on average, that truncation does not lead to appreciable bias, and that the mean squared error for the mean of ratios estimator may be higher than that of the ratio of means estimator when there is no truncation and lower when there is moderate truncation on the order of half an hour. In an actual creel survey, we might expect to see similar comparative results when estimates are made for a series of days.

We examined interview data collected from May through August of 1994 during a roving creel survey on Ottertail Lake in West Central Minnesota. From 2 to 35 interviews were obtained on 32 days. We consider the data on catch of walleye (*Stizostedion vitreum vitreum*) and time fished at the time of interview. The catch includes both kept and released fish.

For each of the 32 days, we computed the ratio of means estimate and the mean of ratios estimate with truncation of 0, 0.50, 0.75, and 1.0 hours (Figure 2). The average of the ratio of means estimates was 1.39 fish/hr, while the averages of the mean of ratios estimates were 1.33, 1.33, 1.37, and 1.47, respectively. Thus, the first prediction is met: the two estimators gave similar estimates on average. The results for the mean of ratios estimator increased with the degree of truncation, but the estimates with 1.0 hour truncation were only 11% higher than the estimates with no truncation or 0.5 hour truncation.

The day-to-day variability in the estimates reflects variability among and within days. However, both types of estimator were applied to identical data so that the difference in variance was due to differences in performance of the estimators. The variance of the ratio of means estimator was 0.86. With no truncation, the mean of ratios estimator had a variance of 0.91; with truncation of 30 minutes, the variance dropped to 0.80—less than the ratio of means estimator. With truncation of 45 and 60 minutes, the mean of ratios estimator had variances of 0.84 and 1.00, respectively. The third prediction is also met: as truncation increased, the variance of the mean of ratios estimator dropped to below the variance of the ratio of means estimator and then increased. There were 417 interviews. Truncation of a half hour resulted in the loss of 10 interviews; for 0.75 and 1.0 hours truncation, the number of interviews discarded were 42 and 68, respectively.

It should be noted that there were no interviews with extremely short fishing times. The three smallest fishing times were 0.30, 0.38, and 0.40 hours. Thus, for this data set, truncation of data of less than 0.30 hours would have no effect. Furthermore, the catch rates associated with the shortest fishing times are not extreme. Nonetheless, the truncations lead to estimators with lower variance.

6. Discussion

In this paper, we have used large sample results on mean and variance plus simulation to compare different estimators of catch rate under roving interview designs. The primary purpose of calculating catch rate in these designs is usually to obtain total catch using the equation *total catch* = *total effort* × *catch rate*. Both the theoretical results and empirical observations (e.g., Kavanaugh, 1986; Eades, 1987; Crone and Malvestuto, 1991) suggest that the mean ratio estimator $\hat{R}_2$ has large variance. The simulation results are somewhat equivocal in that the mean of ratios estimator without truncation had higher variance than the ratio of means estimator for the baseline conditions and clustered fish model, but the reverse was the case for the other scenarios. However, this is a misleading result because the variance of the mean of ratios estimator without truncation was not stable in the simulations. It appears that the greater the number of simulations, the greater the chances of obtaining an interview with an angler who fished for an extremely short period of time and who caught a fish, thus yielding an extremely high catch rate estimate. It appears from the simulation results that the variance can be greatly reduced, without inducing an appreciable bias, by the simple device of eliminating interviews for those anglers who fished for less than a certain short period of time at the time of the interview. However, if the minimum fishing time criterion for accepting an interview is set too high, the number of acceptable interviews will be small and can even be zero. For example, if the trip lengths are all 4 hours, then a minimum fishing time of 0.5 hours means that one eighth of the interviews will be unusable on average. This is because the fishing time at the time of interview is a uniform random variable on $(0, L_j^*)$. In contrast, if the fishing trips last 1 hour, then half the interviews will be discarded when a minimum fishing time of 0.5 hours is used.

We recommend that the mean of ratios estimator $\hat{R}_2$ be used with truncation of short trips (say, less than 20–30 minutes). The advantages of this estimator are that it has approximately the correct expectation even when truncated and that it appears to have smaller mean squared error than the competing ratio of means estimator ($\hat{R}_1$). The disadvantages of this estimator are that there is some degree of arbitrariness in the level of truncation used and the truncation causes the number of usable interviews to be reduced. We do not feel these limitations outweigh the advantages of the estimator, but we note that some care is needed in picking the level of truncation to ensure that not too many interviews are discarded.

Survey methods utilizing interviews for incomplete trips are based on the assumption that the fishing process (expected catch rate) is stationary over time. The learner model simulations indicate

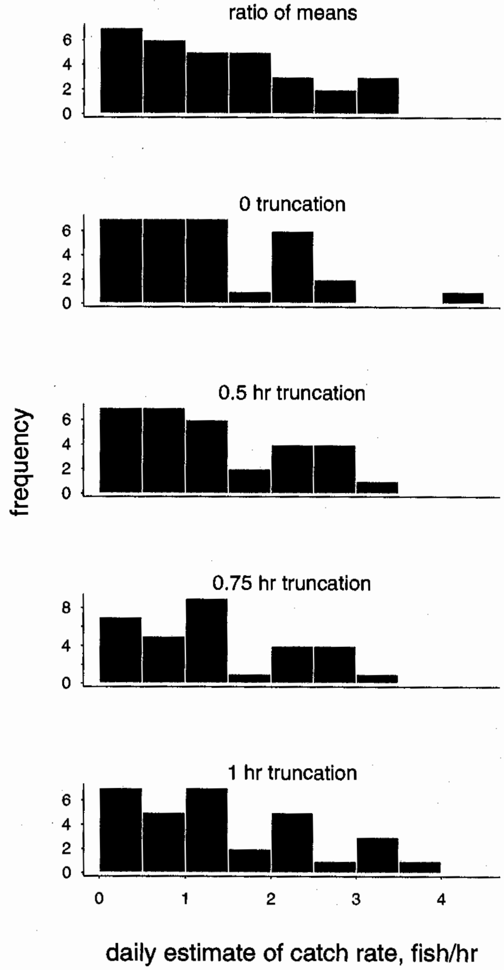

Figure 2. Catch rate estimates of walleye on Ottertail Lake for each of 32 days in 1994. Top panel: ratio of means estimator; bottom four panels: mean of ratios estimator with various levels of truncation. Note that the range and variance of the estimates first decrease and then increase as the level of truncation increases.

that failure of this assumption leads to biased estimates. Further simulations for specific situations would be helpful in determining if this is likely to be a significant problem. It is instructive to consider the failure of this assumption in more detail. Under the learner model, the catch rate for the second half of an angler's trip is expected to be higher than that for the first half. Therefore, for any particular angler, the observed catch rate at the time of interview tends to underestimate the effective catch rate over the whole trip. Eliminating interviews for people who fished less than a few minutes at the time of interview eliminated anglers who tended to have low catch rates; this decreased the bias.

If we wanted to see how the average angler is doing, then we would recommend obtaining completed trip information for some anglers from an access point survey (where all anglers have equal probability of being intercepted) and using $\hat{R}_2$. We did not explore this further because we do not see estimation of average catch rate for the population as an important objective in most angler surveys.

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Résumé

Pour estimer la prise totale d'une pêche sportive par un échantillon de pêcheurs à la ligne on multiplie l'effort total de la pêche par une estimation du taux de prise (à savoir la prise par unité d'effort de pêche). Bien que le théorie statistique pour estimer l'effort de pêche à partir de comptages instantanés ou progressifs soit bien établie, il y a une grande confusion sur la manière ad hoc pour estimer le taux de prise. La plupart des études ont employé le rapport des moyennes ou la moyenne des rapports des prises et des efforts individuels. Nous analysons les propriétés de ces estimateurs du taux de prise sous la supposition que le processus sous-jacent est poissonnien et stationnaire. Le rapport de l'estimateur des moyennes a un moment du second ordre fini alors que l'estimateur de la moyenne du rapport a une variance infinie. Des études de simulation ont montré que l'estimateur de la moyenne rapports a tendance à avoir un carré moyen de l'erreur élevé et instable par rapport à l'estimateur du rapport des moyennes, et ceci est cohérent avec les observations empiriques. Nous étudions aussi les propriétés de l'estimateur de la moyenne des rapports quand toutes les interviews des personnes pêchant pendant un temps inférieur à e minutes sont séparées des valeurs allant de e jusqu'à 60 minutes. Il y a une nette diminution du carré moyen de l'erreur quand les séquences les plus courtes ne sont pas incluses. Nous recommandons que la moyenne de l'estimateur des rapports, avec toutes les séquences de moins de 30 minutes omises, soit utilisée pour estimer le taux de prise et donc de la prise totale dans le plan d'échantillonnage de pêcheurs à la ligne. Son espérance est correcte (au moins approximativement après troncature) et possède presque toujours un carré moyen de l'erreur plus petit que celui du rapport des estimateurs des moyennes dans nos simulations.

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