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Catch Rate Estimation for Roving and Access Point Surveys

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Abstract.—Optimal designs of recreational angler surveys may require complemented surveys, in which different contact methods are used to estimate effort and catch. All common methods of estimating catch involve on-site interviews that may either be based on access (complete trip) or roving (incomplete trip) interviews. In roving surveys, anglers to be interviewed on a given day are intercepted with a probability proportional to the length of their completed fishing trip, whereas in access surveys, anglers are intercepted as they leave the fishery and are intercepted with the same probability regardless of the length of their completed fishing trip. There are four complemented survey designs which use interviews at access points (mail–access, telephone–access, aerial–access, and roving–access); there are four corresponding designs which use roving interviews (mail–roving, telephone–roving, aerial–roving, and roving–roving). For all of these surveys, total catch is estimated as the product of total effort and catch rate. We show that, when access interviews are used, the appropriate catch rate estimator is the ratio of means estimator (i.e., mean catch from interviews divided by mean effort); whereas when roving interviews are used, the appropriate estimator is the mean of the individual ratios of catch divided by effort for each angler. In the roving method, it is necessary to ignore short trips of less than about 0.5 h duration when calculating the mean of the ratios. This stabilizes the variance of the estimates and does not appear to cause any appreciable bias. A bias occurs in the estimates of catch rate and total catch from roving interviews when anglers are subject to a bag limit. This bias can be substantial if the bag limit is effective in limiting the catch.

Pollock et al. (1994) described in detail how to estimate total effort and total catch from recreational angler surveys. In general, there are two basic strategies. The first is to observe a portion of the fishery, determine the catch and effort in that portion, and then expand the observations to the whole fishery by dividing by the fraction of the fishery observed. For example, a lake might have a single access point, and a survey agent (creel clerk) might monitor all fishing effort and catch occurring on a random sample of 10% of the days in the season. The seasonal totals would then be obtained by multiplying the observed catch and effort by 10. This is the traditional access point design. The second strategy is to estimate the total fishing effort and the catch per unit of fishing effort (catch rate). The total catch is then estimated as total catch = total effort × catch rate. For example, in a given day, the fishing effort might be estimated by making one (or more) instantaneous count(s) for the number of anglers fishing at one (or more) randomly selected instant(s) (see Hoenig et al. 1993 for a discussion of such methods). The instantaneous counts provide an estimate of the average number of anglers fishing during the day. The product of the average number of anglers fishing multiplied by the length of the day is an estimate of the fishing effort in angler-hours and can be multiplied by an estimate of the catch per angler-hour to estimate the total catch in the day. This is the idea behind the traditional roving creel design.

There is a controversy dating back at least 30 years over the proper catch rate estimator, and this is the focus of our paper. First, we review the types of creel survey designs in which catch rate data need to be collected. Pollock et al. (1994) suggested that reference to angler surveys for effort and catch (or catch rate) estimation with common generic names such as telephone, mail, access, roving, or aerial is inadequate and confusing. Practical survey methods may require that a different method be used for each parameter. Such approaches are termed complemented or combined surveys. Consider, for example, a fishery encompassing a large geographic area, such as a chain of large lakes or along a stretch of coastline. It may be that a relatively precise estimate of fishing effort can be obtained by making a series of aerial counts. It may also be the case that the area is too large for a roving survey and there are so many access points, each of low usage, that estimates of catch, effort, and catch rate from an access point creel survey will necessarily be imprecise. In this case, one might decide that the best course of action is to use the precise estimate of effort from the aerial survey and the imprecise estimate of catch rate from the access point interviews.

In their notation for combination designs, Pollock et al. (1994) give the method for effort estimation first, then (after a dash) the method for catch (or catch rate) estimation. For example, the aerial survey for effort estimation and access survey for catch rate estimation described above would be denoted "aerial–access." The notation does not indicate a sequence in time; for example, catch rate may be estimated on-site before effort is estimated off-site. The set of all design complements is presented in Table 1, together with a subjective assessment of their importance. One important aspect to notice is that all the common methods of estimation of catch involve on-site interviews. Fisheries agencies are often reluctant to rely on off-site interviews where the catch cannot be examined (Essig and Holliday 1991; Pollock et al. 1994), whereas agencies sometimes use off-site interviews for estimating fishing effort (e.g., the U.S. National Marine Fisheries Service's telephone survey, Essig and Holliday 1991).

An important distinction among the complemented designs which use on-site interviews is whether they use interviews obtained at access points (complete trips) or obtained by roving (incomplete trips). There are four complemented designs which use complete trip interviews to estimate catch (effort × catch rate); these are mail–access, telephone–access, aerial–access, and roving–access. There are also four complemented designs which use incomplete trip interviews to estimate catch (effort × catch rate); these are mail–roving, telephone–roving, aerial–roving, and roving–roving. In terms of analysis, aerial–access and roving–access are equivalent designs, and aerial–roving and roving–roving are also equivalent designs. This is because an aerial instantaneous count is treated the same way as any other kind of roving instantaneous or progressive count.

TABLE 1.—Complemented survey designs for effort and catch estimation; yes = commonly used design, (yes) = possible but rarely used design, and no = inappropriate design. Designs on the diagonal use the same method for both effort and catch estimation. Reproduced from Pollock et al. (1994).

Effort estimation	Catch estimation: Telephone	Mail	Access	Roving	Aerial
Telephone	(Yes)	No	Yes	(Yes)	No
Mail	No	(Yes)	(Yes)	(Yes)	No
Access	No	No	Yes	No	No
Roving	No	No	Yes	Yes	No
Aerial	No	No	Yes	Yes	No

Pollock et al. (1994) noted that incomplete trip interviews from roving surveys have a different sampling probability structure (sampling design) than complete trip interviews from access surveys. In the roving surveys anglers to be interviewed on a given day are intercepted with a probability proportional to the length of their completed fishing trip (an angler fishing for only a few minutes is not likely to be intercepted by the survey agent). In access surveys, anglers are intercepted as they leave the fishery and are intercepted with the same probability regardless of the length of their completed fishing trip. This has important implications for choosing the appropriate catch rate estimators. Hoenig et al. (1997) have considered this issue in a theoretical paper dealing with roving survey interviews. Below we give recommendations for analyzing data obtained from both roving and access point interviews. Our recommendations agree with the intuitive recommendations given in Pollock et al. (1994; chapter 15).

Recently, Jones et al. (1995) discussed a special sampling design that resembles the traditional roving creel survey. In their design, a survey agent roves through the fishery collecting incomplete-trip interview data. However, their design also requires that there be follow-ups to the interviews to determine the completed-trip durations. In traditional roving surveys, the completed-trip lengths are unknown. Their conclusions are not relevant to the traditional access point and roving creel surveys considered here.

We present the assumptions and develop the notation necessary for comparing the two main competing estimators of catch rate. These estimators are the ratio of the means of catch and trip length at the time of interview ($\hat{R}_1$) and the mean of the ratios of catch divided by trip length for each angler interviewed ($\hat{R}_2$). We define these estimators for the access and roving designs. Then, we present some basic results on expectations and variances for the two estimators for access (complete trip) and roving (incomplete trip) interviews and consider the possibility of truncating (i.e., ignoring) short incomplete trips under the roving interview design. Also, we consider the effect of a bag limit on the performance of the different estimators. Finally, we conclude with a general discussion that includes our recommendations on which estimates to use for access (complete) and roving (incomplete) interviews.

Survey Design and Assumptions

Consider the problem of estimating the average catch rate in a given day. We use either an access point or roving angler survey to obtain interviews. For the access point interviews, the survey agent is positioned at one access point and conducts interviews of all anglers encountered while they are leaving the fishery. The total number of fish caught and the amount of time fished are recorded for each completed trip interview. To obtain interviews by the roving method, a closed circuit route is laid out which traverses the entire fishery. The survey agent conducts interviews of all anglers encountered while traveling through the survey area; the agent begins at a randomly selected starting point on the route, travels in a randomly selected direction, and arrives back at the starting point 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 each interview. For both designs, variations are easily accommodated when only a portion of the day is surveyed. Also, it is possible for only a portion of the fishery area to be sampled in a day according to some probability sampling design.

We make the assumption that each angler has a specific catch rate parameter which is constant over time and does not depend on the angler's starting time or the duration of the angler's trip. Technically, we assume that fishing is a stationary Poisson process, which means that the number of fish caught per hour is a Poisson random variable.

For the roving design, because the agent 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. Also, note that the probability of encountering an angler is proportional to the angler's trip length (an angler fishing for only a few minutes being unlikely to be encountered by the survey agent). 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 presented more formally in the appendix.

By contrast, in the access point design the agent gets complete trip information, and the probability of encountering an angler does not depend on the length of the fishing trip.

The Two Ratio Estimators

Ratio of Means Estimator

This method of estimating the catch rate involves dividing the total number of fish reported in the interviews by the total fishing effort recorded. Thus, for the access method, the estimator is

$$\hat{R}_{1a} = \frac{\sum_{j=1}^{n} C_j^*}{\sum_{j=1}^{n} L_j^*}, \tag{1}$$

and for the roving method, the estimator is

$$\hat{R}_{1r} = \frac{\sum_{j=1}^{n} C_j}{\sum_{j=1}^{n} L_j}, \tag{2}$$

where C_j (C_j^*) is the incomplete (complete) catch for the jth angler and L_j (L_j^*) is the incomplete (complete) trip length for the jth angler.

Mean of Ratios Estimator

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

$$\hat{R}_{2a} = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{C_j^*}{L_j^*}\right), \tag{3}$$

and for the roving method, the estimator is

$$\hat{R}_{2r} = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{C_j}{L_j}\right), \tag{4}$$

with symbols defined as above.

Results

Large Sample Expected Values

Ratio of the means estimator.—The expected value of this catch rate estimator is found as follows for the access design. Let $\hat{R}_1$ be written

$$\hat{R}_{1a} = \frac{\sum_{j=1}^{N} \delta_j C_j^*}{\sum_{j=1}^{N} \delta_j L_j^*},$$

where δ_j is the indicator random variable that indicates that angler j was interviewed at the end of his or her fishing trip ($\delta_j = 1$ if the angler was interviewed and equals 0, otherwise) and N is the total number of anglers fishing in the day. Assume that the sample size is large enough that the expectation of the ratio is approximately equal to the ratio of the expectations. The approximate expected value of the estimator is then

$$E(\hat{R}_{1a}) \approx \frac{\sum_{j=1}^{N} C_j^* E(\delta_j)}{\sum_{j=1}^{N} L_j^* E(\delta_j)} \approx \frac{\sum_{j=1}^{N} C_j^* P(\delta_j = 1)}{\sum_{j=1}^{N} L_j^* P(\delta_j = 1)}.$$

The only random variable is δ_j, and the $P(\delta_j = 1)$ is a constant (all anglers have equal probability of being sampled) so that

$$E(\hat{R}_{1a}) \approx \frac{\sum_{j=1}^{N} C_j^*}{\sum_{j=1}^{N} L_j^*}. \tag{5}$$

Therefore, the approximate expectation of $\hat{R}_{1a}$ is the appropriate ratio of total catch over total effort, which is used with an independent estimate of total effort to provide an approximately unbiased estimator of total catch (i.e., total catch = total effort × catch rate).

The expected value of the ratio of means catch rate estimator for the roving design is derived by using a similar but more complex argument developed in Hoenig et al. (1997). For this design the estimator can be written

$$E(\hat{R}_{1r}) \approx \frac{\sum_{j=1}^{N} \delta_j C_j}{\sum_{j=1}^{N} \delta_j L_j}.$$

But now $P(\delta_j = 1) = L_j^*/T$, and C_j and L_j are also random variables. The final result is

$$E(\hat{R}_{1r}) = \frac{\sum_{j=1}^{N} L_j^{*2}(C_j^*/L_j^*)}{\sum_{j=1}^{N} L_j^{*2}}. \tag{6}$$

Therefore, the approximate expectation (or average value) of $\hat{R}_{1r}$ is a weighted average of the individual catch rates, with the weights being the squares of the completed trip lengths. This expression 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.

Mean of the ratios estimator.—The mean of ratios estimator can be written as follows for the access design:

$$\hat{R}_{2a} = \frac{\sum_{j=1}^{N} \delta_j(C_j^*/L_j^*)}{\sum_{j=1}^{N} \delta_j}.$$

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

$$E(\hat{R}_{2a}) \approx \frac{\sum_{j=1}^{N} (C_j^*/L_j^*)E(\delta_j)}{\sum_{j=1}^{N} E(\delta_j)}$$

$$\approx \frac{\sum_{j=1}^{N} (C_j^*/L_j^*)P(\delta_j = 1)}{\sum_{j=1}^{N} P(\delta_j = 1)}.$$

The only random variable is δ_j, and the $P(\delta_j = 1)$ is some constant so that

$$E(\hat{R}_{2a}) \approx \frac{\sum_{j=1}^{N} (C_j^*/L_j^*)}{N}. \tag{7}$$

Therefore, the approximate expectation of $\hat{R}_{2a}$ is the average catch rate of individual anglers in the population. This is not the appropriate expectation

TABLE 2.—Properties of the two catch rate estimators for access point and roving designs. Bold expressions have the correct expected value for estimating total catch as the product of catch rate × total effort and are the recommended estimators.

Estimator	Access	Roving
	Expected values	
$\hat{R}_1$	$\boldsymbol{\sum_{j=1}^{N} C_j^* / \sum_{j=1}^{N} L_j^*}$	$\sum_{j=1}^{N} C_j^* L_j^{*2} / \sum_{j=1}^{N} L_j^{*2}$
$\hat{R}_2$	$\sum_{j=1}^{N} (C_j^*/L_j^*)/N$	$\boldsymbol{\sum_{j=1}^{N} C_j^* / \sum_{j=1}^{N} L_j^*}$
	Variances	
$\hat{R}_1$	Finite	Finite
$\hat{R}_2$	Finite	Infinite[a]

[a] Under the roving design, the untruncated estimator has infinite variance, but the truncated version has finite variance.

for an estimator to be used in total catch estimation. (It might, however, be of interest if one were interested in an index of fishing quality, i.e., how well the "average" angler is doing.)

The mean of ratios estimates can be written as follows for the roving design:

$$\hat{R}_{2r} = \frac{\sum_{j=1}^{N} \delta_j (C_j/L_j)}{\sum_{j=1}^{N} \delta_j},$$

but now $P(\delta_j = 1) = L_j^*/T$, and C_j and L_j are also random variables. Hoenig et al. (1997) show that the final result is

$$E(\hat{R}_{2r}) = \frac{\sum_{j=1}^{N} C_j^*}{\sum_{j=1}^{N} L_j^*}. \qquad (8)$$

In this case, the approximate expectation is simply the ratio of total catch to total effort. Thus, the mean of the ratios estimator, $\hat{R}_{2r}$ provides us with the theoretically correct estimator for calculating catch per unit effort and hence total catch in the roving method. A summary of these results is given in Table 2.

Large Sample Variances

Another factor to consider in assessing whether an estimator is likely to be useful in practice is the properties of its variance compared with those of its competitor. Here we present results on large sample variances based on Taylor series arguments (Seber 1982:8). This is based on similar work explored in more detail by Hoenig et al. (1997) for the roving design.

Ratio of means estimators.—With the methods mentioned previously, it is possible to show that $\hat{R}_{1a}$ and $\hat{R}_{1r}$ have finite large sample variances. This is important in that it does not rule out use of either estimator on the grounds of its having infinite variance.

Mean of ratios estimators.—By using the methods described earlier, it is possible to show $\hat{R}_{2a}$ has finite large sample variance, whereas $\hat{R}_{2r}$ does not have finite large sample variance (Hoenig et al. 1997). The intuitive reason is that this estimator involves dividing by L_js from very short incomplete trips, which can cause the estimator to get very large. Theoretically, it can be shown that the $E(1/L_j|L_j^*)$ is infinite (from Appendix equation A.3), which is used in the variance derivation and is another way of saying the estimator can get very large. In the next section we consider a modification to $\hat{R}_{2r}$ that ensures it has finite large sample variance.

Mean of ratios estimators ignoring short trips.—To prevent the expected value $E(1/L_j|L_j^*)$ from being infinite in the roving survey, it is necessary to keep L_j from getting too close to 0, and this is conceptually easy to do. We just insist that some minimum incomplete trip length be achieved before an interview to obtain catch (C_j) and incomplete trip length (L_j) be carried out. If this is done, then $E(1/L_j|L_j^*)$ is finite and the large sample variance of $\hat{R}_{2r}$ modified in this way is finite. Hoenig et al. (1997) investigated this by simulation for minimum fishing times ranging from 1 to 60 min (see Greene et al. 1995 for computer program listing the documentation). Hoenig et al. (1997), found that ignoring (or truncating) short trips when calculating $\hat{R}_{2r}$ induced negligible bias and that its mean squared error was usually smaller than $\hat{R}_{1r}$, whereas the untruncated version of $\hat{R}_{2r}$ usually had larger mean squared error than $\hat{R}_{1r}$. The degree of truncation appropriate was less well defined, but something in the neighborhood of 20–30 min appears reasonable. A summary of the properties of the variances is given in Table 2.

Discussion and Recommendations

We recommend that for access-based interviews, the appropriate catch rate estimator to use (when the objective is to estimate total catch [total effort × catch rate]) is the ratio of means estimator ($\hat{R}_{1a}$). This estimator has expectation equal to total catch divided by total effort for the population of anglers. If we wanted to use the catch rate estimator to measure how well the average angler is doing, then it would be appropriate to use the mean of ratios estimator ($\hat{R}_{2a}$), which has expectation equal to average catch rate for the population of anglers (Table 2).

We recommend that for roving-based interviews the appropriate catch rate estimator to use (when the objective is to estimate total catch [total effort × catch rate]) is the mean of ratios estimator with truncation of short trips ($\hat{R}_{2r}$). This estimator has the appropriate approximate expectation of total catch divided by total effort for the population of anglers. The truncation of short trips is necessary to lower the variance of the estimates, and it appears to induce negligible bias (Greene et al. 1995; simulations of Hoenig et al. 1997). If we wanted the catch rate estimator to ascertain how the average angler is doing, then we need an estimator weighted by the completed trip lengths, which are typically unknown. Therefore, if estimation of the mean of the individual angler catch rates is important, the roving survey design for obtaining interviews should not be used.

Finally, we consider situations for which roving interviews do not work well and for which it may be necessary to obtain completed trip interviews. Consider the effect of a bag limit on the estimation of catch rate and total catch. If the bag limit is very high relative to the expected catch (e.g., a 30 fish/d limit when the average catch is 1 fish/d), then the bag limit will have virtually no effect on the estimated catch rate. Suppose, however, we have the opposite extreme, and the bag limit is 1 fish/d. Then, assume that as soon as an angler catches a fish, the angler leaves the fishery. Consequently, the roving-survey agent will only encounter anglers who have not caught any fish, and the measured catch rate will always be zero. Clearly, this causes a negative bias in the estimated catch rate and catch and also in the estimated variance of these quantities. Estimates will also be biased, but not necessarily negatively, for bag limits greater than one. The bias decreases as the bag limit increases.

Alternatively, consider the case of a low bag limit, roving interviews, and anglers who continue to fish after catching their bag limit in order to replace fish in their creel with bigger fish. In this case, the catch rate will decline as the trip progresses because catch stays the same and effort increases. In statistical terms, the catch rate is nonstationary, which violates the assumption of the roving survey. In this case, the direction of bias is unpredictable without further information because the bias depends on the relationship between trip length and catch rate.

As an example, we simulated a fishery with 50 anglers, spaced regularly around the perimeter of a lake. Each angler began fishing 1 h into an 8-h day. Half the anglers fished for 3 h, and these alternated in space with anglers fishing for 6 h. Each angler's catch followed a Poisson process (number of fish caught per hour is a Poisson random variable, so that the time until the next fish is caught is an exponential random variable). The individual angler's Poisson catch rate parameter was drawn randomly from a gamma distribution with $\alpha = 1$ and $\beta = 2$, so that the expected catch was $\alpha\beta = 2$ fish/h, with a variance of $\alpha\beta^2 = 4$. The survey agent began at a randomly selected location and traveled around the lake at uniform speed, such that the entire shoreline was traveled in the 8-h day. For every angler encountered, the catch and effort at the time of interview were obtained. The estimated catch rate was then multiplied by the total effort (assumed known) to estimate catch. We ran this simulation with no bag limit and with bag limits of from two to five fish. We assumed anglers stopped fishing when the bag limit was caught. Program details are given in Greene et al. (1995). All of the estimators were virtually unbiased (less than 0.2% bias) when there was no bag limit; additionally, the mean of ratios estimator had considerably lower mean squared error (variance + bias^2) than the ratio of means estimator when trips with a duration of 5–40 min were discarded (Figure 1, bottom row). When a bag limit was imposed, the ratio of means estimator had a negative bias ranging from −15% for a bag limit of five fish to −36% for a bag limit of two fish (Figure 1, first column). The mean squared error was considerably larger for the mean of ratios estimator than for the ratio of means estimator when the minimum fishing time for interviews was small; however, when the minimum fishing time was set at 30 min or more, the mean ratios estimator had almost as low mean squared error as the ratio of means estimator (Figure 1, third column). Note that the mean squared error of the ratio of means estimator decreases as the bag limit is reduced. This occurs because the bag limit keeps catches and efforts small. The relative error of the estimators, expressed as the square root of the mean squared error divided by the true value of the average daily catch, increases as the bag limit decreases. Thus, estimation of catch rate from roving interviews may be inappropriate if a low bag limit is in place, and further work is necessary to study the performance of the estimators in partic-

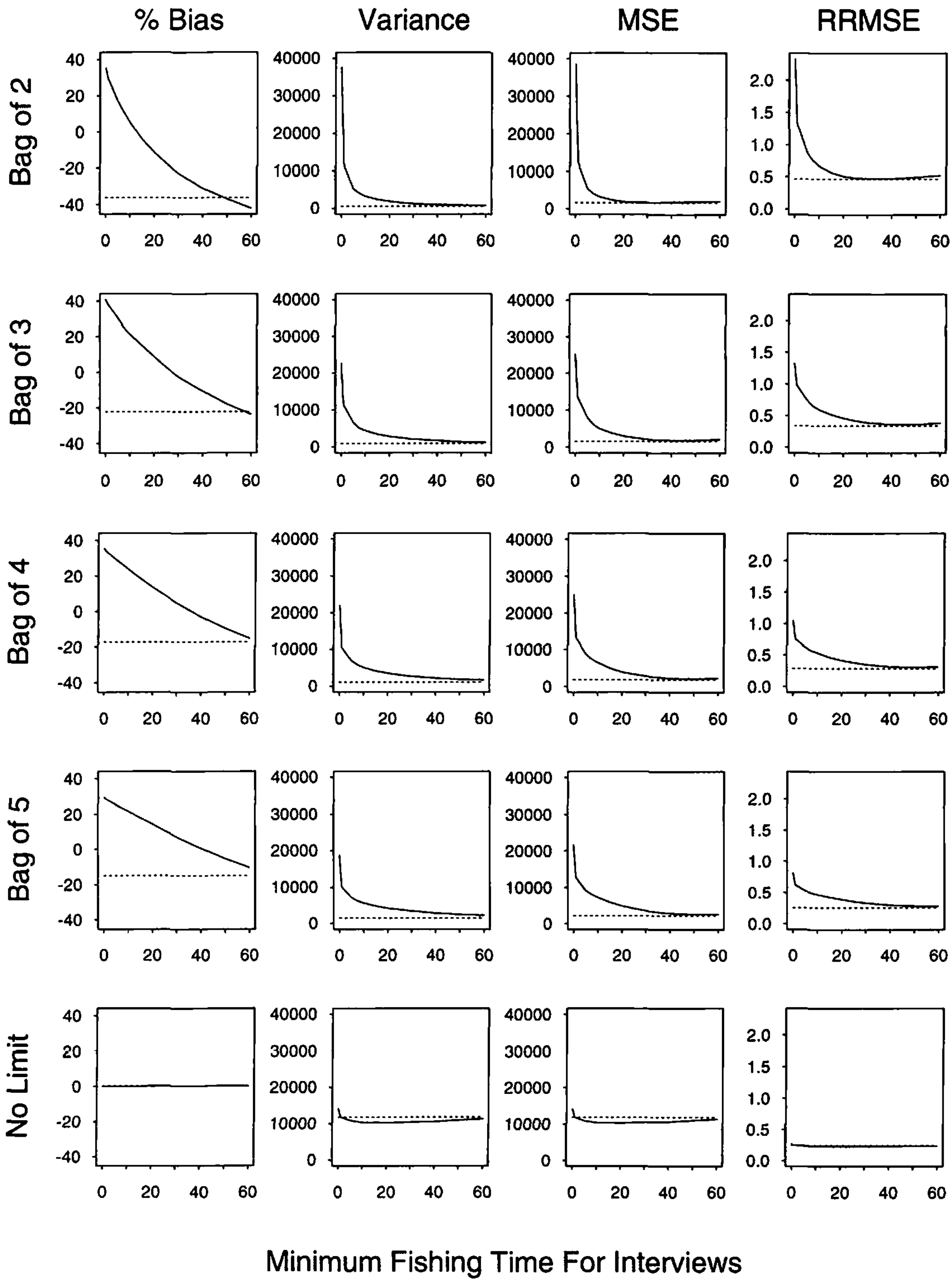

FIGURE 1.—Simulation results for a roving creel survey. Dashed line refers to the ratio of means estimator; solid line to the mean of ratios estimator. Abscissa specifies the minimum amount of fishing time for an interview to be used. Rows correspond to bag limits of 2, 3, 4, 5, and infinity (no bag limit). Columns give percentage bias, variance, mean squared error (MSE), and relative root mean squared error (RRMSE).

ular situations to justify the use of roving interviews.

The imposition of a bag limit poses no problem for catch rate estimation based on access point interviews. This is because only anglers who have completed their trips are interviewed and the probability of an angler being interviewed does not depend on the angler's success or trip length.

Another situation in which roving surveys for catch rate may not work well is when catch rates change over the course of a trip (i.e., catch rates are nonstationary). For example, it may take anglers some time to find a good location to catch fish but, once one is found, catch rate might be consistently high. This situation was studied by Hoenig et al. (1997) with a modification of the simulation program described above. They found that for all of the estimators, nonstationary catch rates result in biased estimates. This is because the interviewer obtains information on only a part of the trip which is not necessarily similar to the rest of the trip. Simulation studies for specific situations would be helpful for determining how important this is likely to be. Also, catch rates obtained from incomplete trips should be compared to the completed trip catch rates to see if there is a systematic difference. Note that the comparison is not meaningful unless equivalent quantities are compared. Thus, the ratio of means estimator for complete trips should be compared to the mean of ratios estimator (with appropriate truncation) for incomplete trips. A more efficient way to detect differences between incomplete and complete trip catch rates is to measure both on the same sample of anglers. That is, anglers can be intercepted while fishing and the same anglers can be interviewed again as they leave the fishery. Then, for valid use of the roving method, a plot of the incomplete trip catch rates versus the corresponding complete trip catch rates should be consistent with a straight line passing through the origin with a slope of unity.

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Appendix: Some Basic Relationships for Roving Creel Survey Interviews

In this appendix, we justify the intermediate results presented in the second section of the paper for the roving creel survey design. These results are needed to establish whether or not the two basic estimators for the roving creel design have finite variance. We use the following notation throughout the paper:

T = number of hours in the fishing day = time required for the survey agent to make one complete circuit through the fishery in the roving design;

N = number of anglers fishing during the day;

λ_j = Poisson catch rate (number of fish/h) of an individual angler j ($j = 1, \ldots, N$);

L_j = length of the trip (h) up to the time of interview in the roving design j ($j = 1, \ldots, N$); and L_j is defined to be 0 if the angler is not interviewed;

L_j^* = total trip length (h) of angler j ($j = 1, \ldots, N$);
L^* = total hours of fishing in the day, $L^* = \Sigma_{j=1}^{N} L_j^*$;
$\underline{L}$ = vector of the trip lengths up to the time of interview L_j, in the roving design;
C_j = catch of angler j at the time of interview in the roving design ($j = 1, \ldots, N$); and 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 ($j = 1, \ldots, N$);
$\underline{C}^*$ = vector of catches from all of the completed fishing trips;
n = number of anglers interviewed for the access or the roving design;
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, $n = \Sigma_{j=1}^{N} \delta_j$. Then $E(\delta_j) = P(\delta_j = 1)$;
$\underline{\delta}$ = vector of the indicator variables δ_j.

Given the sampling designs and the assumption of Poisson processes, we can easily establish six basic relationships. First, the probability of interviewing a given angler in a roving design is proportional to the length of time the angler fishes:

$$P(\delta_j = 1|L_j^*) = L_j^*/T. \quad \text{(A.1)}$$

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

$$E(\delta_j|L_j^*) = L_j^*/T, \ V(\delta_j|L_j^*) = (L_j^*/T)(1 - L_j^*/T). \quad \text{(A.2)}$$

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,

$$L_j \sim U(O,L_j^*) \text{ given } \delta_j = 1. \quad \text{(A.3)}$$

Therefore,

$$E(L_j|L_j^*, \delta_j = 1) = L_j^*/2,$$

and

$$V(L_j|L_j^*, \delta_j = 1) = L_j^{*2}/12.$$

Equation (A.3) 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,

$$E(C_j|L_j, C_j^*, L_j^*, \delta_j = 1) = C_j^* \ L_j/L_j^*, \quad \text{(A.4)}$$

and

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

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 one-half of the way throughout the fishing trip, and one-half of the trip's catch will have been taken at the time of interview. Thus,

$$E(C_j|C_j^*, L_j^*, \delta_j = 1) = C_j^*/2, \quad \text{(A.5)}$$

and

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

Equation (A.5) follows from equation (A.4) by using equation (A.3).