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FEATURED PAPER

Sample Size Estimation for On-Site Creel Surveys

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Abstract
Conducting sample size analysis is important to ensure that sample sizes are adequate to meet objectives for precision but not so large that valuable resources are wasted. When simple survey designs are used, sample size analysis is straightforward. However, creel surveys often follow complex designs that can make sample size estimation difficult. The objectives of this study were to provide sample size estimators for commonly used creel survey designs and investigate sample size requirements to achieve varying levels of precision. For estimates of angling effort, the average sample size among fisheries required to achieve relative 95% confidence intervals of 40% (i.e., coefficient of variation of approximately 0.2) was 16 d (range = 7–40 d). To estimate mean catch rate with the same level of precision, 43 survey days (range = 8–95 d) were required when the daily catch rate estimator was used, and 11 d (range = 3–30 d) were required when the multi-day estimator was used. Fifty-five days (range = 14–89 d) and 57 d (range = 19–140 d) were required to estimate total catch with relative 95% confidence intervals of 40% when the daily and multi-day estimators were used, respectively. Although absolute precision will vary among fisheries, our results suggest that approximately 30 d of surveying may serve as a reasonable starting point for planning creel surveys when no prior information is available on expected sample variance, as relatively large increases in sample size beyond 30 d were needed to achieve relatively small increases in precision.

Creel surveys produce estimates of angler effort, catch rate, and catch that are regularly used by governmental agencies to better manage recreational fisheries for the benefit of the angling public. Additionally, the value of on-site creel surveys, with regard to public perception, extends beyond simply gathering quantitative catch and effort data to inform management decisions. However, creel surveys can be labor intensive and expensive to conduct. Often, decisions are made to limit the number of survey days within a fishery or the number of fisheries that can be surveyed. Thus, an understanding of how intensively creel surveys need to be conducted to achieve the desired precision in effort, catch rate, or catch estimates is important.

Development of general sample size requirements for creel surveys is not a new concept (e.g., Parkinson et al. 1988; Lester et al. 1991; Malvestuto and Knight 1991). However, with fisheries and wildlife agencies across North America experiencing constrained budgets (e.g., Archibald et al. 2014), there is a renewed interest in refining the sample sizes that are needed to achieve acceptable levels of precision in estimates of angler effort, catch rate, and harvest (Deroba et al. 2007; McCormick et al. 2013; McCormick 2015). Determining sample size for creel surveys a priori is difficult because creel survey designs are often complex and commonly lack replication of sampling units within a day (e.g., only one shift or count is conducted daily; Su and Clapp 2013). Catch and effort are frequently estimated as the product of multiple random variables (e.g., effort, catch rate, and party size), which means that obtaining large sample sizes will not necessarily result in precise estimates. Angler effort, catch rate, and catch can also vary considerably among years, waters, and target species (Betsill and Pitman 2002; Mallison and Cichra 2004; Vølstad et al. 2006). Consequently, target

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precision levels may not be met for every species in every year as a result of such variation. In addition, there are several different sample sizes that need to be considered when designing creel surveys, including the number of angler counts when applicable, the number of interviews to conduct, and the number of days to sample. Selecting the number of days to sample is the primary focus of this study.

Besides the issue of sample size in creel surveys, another consideration affecting estimates of catch and catch rates (and their variance) involves whether to use the daily or multi-day catch rate estimator. See Rasmussen et al. (1998), Lockwood et al. (1999), and Su and Clapp (2013) for detailed descriptions of the differences between daily and multi-day estimators. The difference hinges on how angler interviews are treated. When the daily estimator is used, mean catch rate is calculated daily (Malvestuto et al. 1978), whereas data from several days are used to calculate mean catch rate when using the multi-day estimator (Rasmussen et al. 1998). Because days are usually selected as the primary sampling unit in creel surveys, sampling theory suggests that the daily estimator should be used where estimates of effort, catch, and catch rate should first be estimated at the day scale and then averaged or expanded over multiple days (i.e., a stratum). However, it can be difficult or cost-prohibitive to obtain an adequate sample size of angler interviews for each surveyed day. Consequently, estimates of variance for catch or catch rate may be unreliable at low sample sizes (Jones et al. 1995; Lockwood et al. 1999) or unobtainable when only one angler or no anglers are surveyed (McCormick 2015). To circumvent this problem, several authors have advocated for the use of a multi-day or stratum estimator when estimating catch rate (Rasmussen et al. 1998; Su and Clapp 2013; McCormick 2015). The multi-day estimator treats all interviews from a stratum as if they were random samples from the stratum. This estimator ignores the daily structure of commonly used creel survey designs where days are first selected as the primary sampling unit and could be considered pseudoreplication when such designs are used (Hurlbert 1984). Although the multi-day estimator may have more desirable statistical properties (e.g., less bias and smaller mean-square error) than the daily estimator under certain circumstances (Rasmussen et al. 1998), it can also produce biased point and variance estimates under other conditions (Su and Clapp 2013). The preferred estimator likely varies depending on the characteristics of the fishery and sampling design (Su and Clapp 2013). As pointed out by Lockwood et al. (1999), comparative performances of the daily and multi-day estimators over a range of fisheries are lacking, and such comparisons would be useful when deciding which estimator to use.

Lester et al. (1991) provided equations to estimate sample sizes for roving creel surveys and conducted sample size analyses for Lake Trout *Salvelinus namaycush* fisheries in Ontario, Canada. The objectives of this research were to build on the work of Lester et al. (1991) by providing sample size estimators for creel surveys employing commonly used alternative designs (e.g., stratified designs lacking within-day replication) and catch rate estimators (i.e., daily and multi-day). In addition, we investigated sample size requirements to achieve varying levels of precision for several existing creel survey data sets from Idaho and Oregon.

METHODS

When conducting sample size analyses, an analyst must first decide on the level and form of the precision metric to be used (e.g., SE or coefficient of variation [CV]). For this study, precision was expressed as the width of confidence intervals (CIs). The formulas presented are therefore appropriate when an analyst asks, "How large should my sample size be to estimate population parameters, such as effort, catch rate, or catch, with CIs of plus or minus a desired amount?" Sample size analyses are generally parameterized by conducting a pilot study or using historical data to provide an estimate of the sample variance of the metric of interest.

Variance estimators differ depending on the design used to estimate population parameters. As such, the formulas presented below apply to only a subset of commonly used creel survey designs. It was assumed in these analyses that the creel surveys followed a multi-stage design where days were identified as the primary sampling units and a single portion of the day (i.e., a shift or cluster) was sampled. For creel surveys in Idaho and Oregon, it is common to select either the first or the second half of the day as the shift (see Pollock et al. 1994; Rasmussen et al. 1998). Times of day of the instantaneous effort counts—which in this study varied between one and four depending on the survey—are then randomly selected within shifts when estimating effort, and either all anglers are contacted or a sample of anglers is randomly selected for interview when estimating angler catch rates. It was also assumed that days were stratified by weekdays (Monday–Friday) or weekend days, which also included holidays, and there was no angler-type stratification (e.g., boat, bank, or gear type).

General Sample Size Estimation Methods

Two methods were used to evaluate sample sizes required to estimate creel survey metrics with a desired level of precision. The first method was to analytically derive sample sizes by solving the variance equations (and resulting CIs) for the sample size (i.e., sample days, number of angler counts, and number of angler interviews; Scheaffer et al. 2006). The equations for point estimates of effort, catch rate, and catch are presented below along with the variance, CI, and sample size equations.

Due to the complexity of several of the variance equations, some sample sizes were derived using iterative empirical methods (i.e., bootstrapping). When these methods were used, existing data were sampled with replacement, the metric of interest (i.e., effort, catch rate, or catch) was estimated, and the process was repeated 5,000 times. This resulted in a sampling distribution (Thompson 2012) of 5,000 estimates of effort, catch rate, or catch. The SD of this distribution was calculated and represents the empirical SE of the estimate (Efron and Tibshirani 1993). A 95% CI was then calculated by multiplying the empirical SE by 1.96. The entire process was repeated for incrementally larger sample sizes until a relationship was developed between sample size and the expected 95% CI. Empirical and analytical sample size estimators should be nearly identical. For demonstration purposes only, analytical and empirical sample sizes were calculated for Priest Lake (Idaho) effort estimates (Figure 1). For this exercise, daily estimates of effort within each stratum were sampled with replacement, averaged, then multiplied by the number of days in the stratum. Estimates were then summed among strata to develop the distribution of the 5,000 estimates of effort, with one estimate of season-long effort for each iteration. Example R code (R Development Core Team 2009) for calculating the analytical and empirical sample sizes used in this example is provided in Supplement A (available in the online version of this article).

Estimating Angling Effort

Total angling effort in angler-hours on day d ($\hat{E}_d$) is estimated as

$$\hat{E}_d = T_d \bar{I}_d, \tag{1}$$

where T_d is the total number of hours in the fishing day and $\bar{I}_d$ is the mean of the angler counts conducted on day d. If only one instantaneous count is conducted, then the variance of daily effort cannot be estimated (Rasmussen et al. 1998; Su and Clapp 2013). Additionally, if only a single shift is sampled within a day, as was assumed in this study, there is no exact daily variance estimator

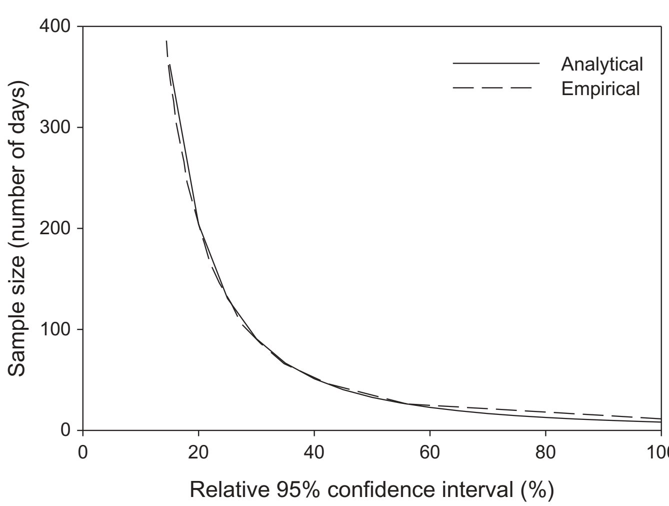

FIGURE 1. Comparison of analytical and empirical (i.e., iterative methods) sample size estimates for estimating angling effort in Priest Lake, Idaho.

because among-shift variability cannot be accounted for. Daily variance of effort can be estimated if multiple counts within a day are conducted, and if the sampling period is set to the entire day or if multiple shifts are surveyed. Variance estimators and sample size estimators for simple random designs or cluster designs are described by Scheaffer et al. (2006).

Angling effort ($\hat{E}_k$) for the kth stratum is estimated as

$$\hat{E}_k = N_k \frac{\sum_{d=1}^{n_k} \hat{E}_d}{n_k}, \tag{2}$$

where N_k is the number of days in the stratum and n_k is the number of days surveyed in the stratum. Estimates of effort among strata can be summed to estimate effort ($\hat{E}$) over the duration of the fishing season or time period of interest. The variance estimator for equation (2) depends on the estimate of within-day variance, which cannot be calculated when only one count is made or when only one shift is sampled. However, the within-stratum variance ($\hat{V}[\hat{E}_k]$) can be approximated (Pollock et al. 1994; Scheaffer et al. 2006; Su and Clapp 2013) as

$$\hat{V}(\hat{E}_k) = N_k^2 \left(\frac{s_{\hat{E}_k}^2}{n_k} \right), \tag{3}$$

where $s_{\hat{E}_k}^2$ is the sample variance, which is calculated as

$$s_{\hat{E}_k}^2 = \frac{\sum_{d=1}^{n_k} (\hat{E}_d - \bar{E}_k)}{n_k - 1}, \tag{4}$$

where $\bar{E}_k$ is the average daily effort estimate over the stratum. Similar to the point estimate, the overall season variance ($\hat{V}[\hat{E}]$) is calculated as the sum of the estimated stratum variances. A CI for estimated angling effort over the sampling period ($\text{CI}_{\hat{E}}$) is estimated as

$$\text{CI}_{\hat{E}} = \hat{E} \pm Z_{\alpha/2} \sqrt{\hat{V}(\hat{E})}, \tag{5}$$

where $Z_{\alpha/2}$ is the desired critical value for the CI (e.g., 1.96 for a 95% CI).

When planning a creel survey, an analyst can estimate the number of days to sample (n) in order to achieve a desired CI as

$$n = \frac{N^2 (Z_{\alpha/2})^2}{\text{CI}_{\hat{E}}^2} \sum_{k=1}^{L} \left(\frac{N_k}{N} \right)^2 \frac{s_{\hat{E}_k}^2}{w_k}, \tag{6}$$

where w_k is the proportion of the sample that will be allocated to stratum k; N is the total number of days for all strata; and L is the total number of strata. The sample variance (equation 4) is used as an approximation for the population variance, which will not be known beforehand. Rather, it is approximated from a pilot study or by using historical data, or a range of values can be evaluated to investigate how sample size changes with variance. In addition, if multiple species are of interest, sample sizes can be evaluated for each species. The one-sided width (i.e., plus or minus the $\mathrm{CI}_{\hat{E}}$ value) of the CI is supplied by the analyst and represents the desired precision. Equation (6) allows an analyst to approximate how many days need to be sampled to achieve a CI of a desired width.

Daily Estimator

Estimating catch rate.—Mean angler catch rate using the daily estimator in fish per angler-hour on day d ($\hat{R}_d$) is estimated as

$$\hat{R}_d = \frac{\sum_{i=1}^{j_d} c_{d,i}}{\sum_{i=1}^{j_d} h_{d,i}}, \tag{7}$$

where j_d is the total number of anglers interviewed on day d; $c_{d,i}$ is the number of fish caught by the ith angler on day d; and $h_{d,i}$ is the total number of hours fished by the ith angler on day d. Similar to daily effort estimates, variance cannot be estimated for catch rate when only one shift is sampled within a day. Su and Clapp (2013) recommended that catch rate for the stratum ($\hat{R}_k$) be estimated as

$$\hat{R}_k = \sum_{d=1}^{n}\left(\hat{E}_d \Big/ \sum_{d=1}^{n}\hat{E}_d\right)\hat{R}_d. \tag{8}$$

Estimates of $\hat{E}_k$ and $\hat{R}_k$ can be substituted for $\hat{E}_d$ and $\hat{R}_d$, respectively, to generate a season catch rate estimate. Because of the complexity of the approximate variance equation for the catch rate estimate for the stratum or season, the sample size estimation equation is also complex and depends on the daily variance of both effort and catch rate and on effort over the stratum or season. Thus, we used iterative methods to evaluate sample sizes for estimating catch rate over the duration of the sampling period by using the daily estimator. For this exercise, days within each stratum of the existing data sets were sampled with replacement, and total observed catch was divided by total observed hours fished from all interviews conducted from both strata. This process was repeated 5,000 times for each sample size, and the CI was estimated based on the resulting sampling distribution. Example R code to do so is presented in Supplement B.

Estimating catch.—Catch on day d ($\hat{C}_d$) using the daily estimator is estimated as

$$\hat{C}_d = \hat{R}_d\hat{E}_d. \tag{9}$$

There is no exact variance estimator for daily catch under the sampling conditions assumed in this study. However, if multiple angler counts are conducted and if the entire day is sampled, then daily catch variance can be estimated as the variance of the product of catch rate and effort (Goodman 1960).

Catch for the stratum ($\hat{C}_k$) is estimated as

$$\hat{C}_k = N_k \frac{\sum_{d=1}^{n}\hat{C}_d}{n_k}. \tag{10}$$

Estimated catch among strata is then added to estimate season catch. Similar to effort, approximate variance for the stratum can be estimated using equation (3), with catch sample variance substituted for effort variance (estimated using equation 4). Stratum variance is then summed to estimate season catch variance and CIs, and sample sizes can be estimated using equations (5) and (6), respectively, with catch metrics substituted for effort metrics.

Multi-Day Estimator

Estimating catch rate.—Multi-day catch rate in stratum $k\left(\hat{R}_{2k}\right)$ is estimated as

$$\hat{R}_{2k} = \frac{\sum_{i=1}^{j_k} c_i}{\sum_{i=1}^{j_k} h_i}, \tag{11}$$

where j_k is the total number of anglers interviewed in the stratum. Stratum variance of the multi-day catch rate ($\hat{V}\left[\hat{R}_{2k}\right]$) is estimated as

$$\hat{V}\left(\hat{R}_{2k}\right) = \frac{1}{\left(\bar{h}_k\right)^2 j_k} S^2_{\hat{R}_{2k}}, \tag{12}$$

where $\bar{h}_k$ is the mean number of hours fished by all anglers who were interviewed; and $S^2_{\hat{R}_{2k}}$ is the sample variance, estimated as

$$S^2_{\hat{R}_{2k}} = \frac{\sum_{i=1}^{j}\left(c_i - \hat{R}_{2k}h_i\right)^2}{j-1}. \tag{13}$$

Little to no guidance in the literature exists on estimating catch rate at the season scale (i.e., among strata) when using a stratified creel survey design. Unlike catch and effort, the catch rate is not additive among strata. Two stratified ratio estimators have primarily been suggested in the sampling literature: combined and separate (Cochran 1977; Scheaffer et al. 2006). However, both estimators require knowledge of the total number of sampling units (i.e., the number of anglers), something that is rarely known in on-site creel surveys. One option for estimating season catch rate is estimating season catch (below) and dividing by estimated effort.

Alternatively, Malvestuto and Knight (1991) found no difference in catch rate among weekday and weekend strata and suggested that stratification by day type is not necessary when creel surveys are focused on estimating catch rate. If day-type stratification is not used, catch rate ($\hat{R}_2$) and its variance ($\hat{V}\left[\hat{R}_2\right]$) can be estimated using equations (11) and (12), where the strata (k) are ignored. A CI for mean catch rate ($CI_{\hat{R}_2}$) over the sampling period using the multi-day estimator can then be constructed as

$$CI_{\hat{R}_2} = \hat{R}_2 \pm Z_{\alpha/2}\sqrt{\hat{V}(\hat{R}_2)}. \quad (14)$$

Equation (14) can then be solved for j to provide an estimate of the number of angler interviews to conduct over the sampling period to achieve a desired CI:

$$j = \frac{S^2_{\hat{R}_2} \times (Z_{\alpha/2})^2}{(\bar{h})^2 CI^2_{\hat{R}_2}}. \quad (15)$$

Estimating catch.—Catch in stratum k using the multi-day estimator ($\hat{C}_{2k}$) is estimated as the product of stratum effort and catch rate,

$$\hat{C}_{2k} = \hat{E}_k \hat{R}_{2k}. \quad (16)$$

Variance of catch for the stratum is estimated as the variance of a product (Goodman 1960):

$$\hat{V}(\hat{C}_{2k}) = \hat{E}^2_k \hat{V}(\hat{R}_{2k}) + \hat{R}^2_{2k}\hat{V}(\hat{E}_k) - \hat{V}(\hat{R}_{2k})\hat{V}(\hat{E}_k), \quad (17)$$

where the variance of effort and catch rate are estimated using equations (3) and (12), respectively. Estimated catch and variance among strata can then be summed to estimate season catch ($\hat{C}_2$) and season variance ($\hat{V}[\hat{C}_2]$). A CI ($CI_{\hat{C}_2}$) can be estimated as

$$CI_{\hat{C}_2} = \hat{C}_2 \pm Z_{\alpha/2}\sqrt{\hat{V}(\hat{C}_2)}. \quad (18)$$

Equation (18) can be solved for n, the number of days to sample when estimating effort using a stratified design. However, it cannot be solved for j (i.e., the number of anglers to interview when estimating the catch rate) because the total number of anglers is not known. Thus, we used iterative methods when conducting the sample size analysis when estimating catch using the multi-day catch rate estimator. For this exercise, the product of the two previous bootstrapping exercises described above were used to estimate catch, except that catch rate was estimated separately for each stratum (i.e., weekday and weekend day). Example R code to do so can be found in Supplement C.

Application to Idaho and Oregon Creel Survey Data

Existing creel surveys from inland recreational fisheries in the Pacific Northwest (Idaho and Oregon) were used to investigate sample size requirements to achieve varying levels of precision. The existing creel surveys included harvest-oriented warmwater fisheries, hatchery trout fisheries, trophy wild trout fisheries, and a sturgeon fishery. The diversity in creel survey data allowed us to evaluate the impact that sample size had on estimates of effort, catch rate, and catch across a variety of fishery types (Tables 1–3).

TABLE 1. Estimates of weekday and weekend angling effort (h), weekday and weekend sample variance (s^2), number of days surveyed (n days), number of angler counts per day (n counts), total number of interviews (n int), and number of days in the fishing season (N) for nine fisheries in Idaho and Oregon. Data from these fisheries were used to parameterize sample size analyses to estimate angling effort and catch in roving creel surveys.

							Weekday		Weekend	
Fishery	Species	Year	N	n days	n counts	n int	Effort	s^2	Effort	s^2
Chetco River, Oregon	Steelhead *Oncorhynchus mykiss*	2011–2012	132	70	3	1,833	42,682	189,714	21,734	184,486
Coeur d'Alene Lake, Idaho	Kokanee *O. nerka*	2009	242	69	2	1,617	43,115	76,226	38,206	243,199
Crooked River, Oregon	Rainbow Trout *O. mykiss*	2013	223	119	3	1,097	34,232	13,956	16,882	18,017
Diamond Lake, Oregon	Rainbow Trout	2013	152	39	4	389	39,281	53,664	29,615	97,954
Henry's Lake, Idaho	Cutthroat Trout *O. clarkii*	2005	153	36	2	372	72,504	206,158	25,469	174,710
Odell Lake, Oregon	Kokanee	2013	124	32	4	395	14,821	17,883	7,911	31,224
Phillips Reservoir, Oregon	Yellow Perch *Perca flavescens*	2013	154	98	8	500	3,829	814	3,902	4,213
Priest Lake, Idaho	Lake Trout *Salvelinus namaycush*	2014–2015	364	104	1	551	41,163	47,596	19,645	43,392
Snake River, Idaho	White Sturgeon *Acipenser transmontanus*	2007–2008	360	96	3	1,152	19,927	7,242	16,405	18,524

TABLE 2. Estimates of weekend and weekday catch rate (fish/h) and sample variance (s^2) using the daily and multi-day estimators for nine fisheries in Idaho and Oregon.

	Daily estimator		Multi-day estimator			
	Weekday	Weekend	Weekday		Weekend	
Fishery	Catch rate	Catch rate	Catch rate	s^2	Catch rate	s^2
Chetco River	0.089	0.093	0.109	1.353	0.101	1.248
Coeur d'Alene Lake	0.353	0.259	0.391	25.420	0.208	18.581
Crooked River	1.530	1.146	1.599	46.378	1.088	27.566
Diamond Lake	0.408	0.268	0.338	13.517	0.316	25.150
Henry's Lake	0.951	0.833	0.614	30.333	0.647	28.093
Odell Lake	1.087	1.075	1.079	104.693	1.106	174.880
Phillips Reservoir	0.897	0.671	0.633	91.424	0.692	120.482
Priest Lake	0.548	0.588	0.727	40.801	0.769	37.595
Snake River	0.074	0.065	0.069	1.974	0.044	1.000

All creel surveys included instantaneous counts. Roving interviews with primarily incomplete-trip data were conducted on the Chetco and Crooked rivers and on Henry's and Priest lakes. A mix of roving- and access-based interviews (i.e., incomplete and complete trips) were conducted at Coeur d'Alene Lake and the Snake River, and access-based interviews with primarily completed trips were conducted on the remaining fisheries. For several creel surveys, anglers caught a number of fish species, but for simplicity we present results only for the most targeted species in each survey. Targeted species included the Rainbow Trout, steelhead (anadromous Rainbow Trout), Cutthroat Trout, kokanee (lacustrine Sockeye Salmon *O. nerka*), Lake Trout, White Sturgeon, and Yellow Perch.

Desired precision in sample size analyses was expressed as the relative size of the 95% CI, calculated as the size of the CI divided by the estimate for the metric of interest (i.e., total effort, mean catch rate, or total catch) times 100. Sample sizes were evaluated over a range of desired CIs that were 15–100% of the estimate. Lester et al. (1991) summarized estimated sample sizes for roving creel surveys given one desired level of precision: a CV of 0.2. Although precision was not expressed in the form of CVs in the current study, a relative CI of 40% is approximate to a CV of 0.2 and can be used for comparison to the results of Lester et al. (1991).

RESULTS

Creel Survey Results

Effort, catch rate, and catch varied widely among fisheries (Tables 1–3). On average, 37% of the days during a fishing season were surveyed by creel clerks, but the percentage of days surveyed varied from 24% to 64% (Table 1). Estimated catch rates varied from 0.04 to 1.60 fish/h (Table 2). For the daily estimator, average catch rates were higher during the week than on weekends, with a mean difference between

TABLE 3. Estimates of weekend and weekday catch and sample variance (s^2) using the daily and multi-day estimators for nine fisheries in Idaho and Oregon.

	Daily estimator				Multi-day estimator	
	Weekday		Weekend		Weekday	Weekend
Fishery	Catch	s^2	Catch	s^2	Catch	Catch
Chetco River	3,786	3,413	2,027	2,037	4,640	2,206
Coeur d'Alene Lake	15,223	17,056	9,891	88,429	16,858	7,955
Crooked River	52,387	99,210	19,352	72,703	54,721	18,373
Diamond Lake	16,034	14,564	7,934	14,696	13,284	9,345
Henry's Lake	68,963	1,625,591	21,212	234,787	44,549	16,471
Odell Lake	16,117	56,392	8,505	42,550	15,985	8,749
Phillips Reservoir	3,434	3,691	2,619	5,949	2,422	2,699
Priest Lake	22,538	23,105	11,555	30,382	29,905	15,103
Snake River	1,467	79	1,066	444	1,380	717

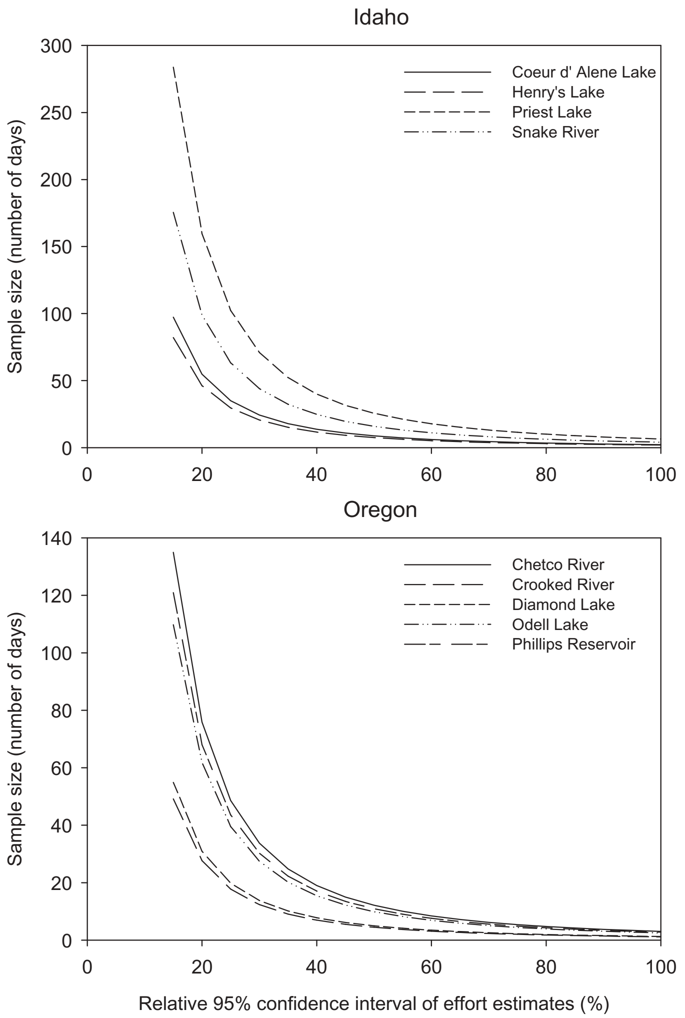

FIGURE 2. Required sample size to estimate angling effort for nine fisheries in Idaho and Oregon given desired 95% confidence intervals expressed as the percentage of estimated effort.

weekdays and weekends of 0.10 fish/h among fisheries. For the multi-day estimator, catch rates were more similar, with a mean difference of 0.06 fish/h among fisheries. Total catch varied by nearly two orders of magnitude among fisheries (Table 3).

Effort Estimates

Estimated sample sizes (in survey days) required to estimate effort was variable among fisheries (Figure 2). Required sample size was a function of total estimated effort, the desired CI, and weekend and weekday variance. The Lake Trout fishery at Priest Lake required the largest sample size, with 40 survey days (out of the 364-d season) needed to estimate effort with a relative 95% CI of 40% (Table 4). The Crooked River fishery required the smallest sample size to achieve a CI of 40% at 7 d (out of the 223-d season). On average, 16 survey days were needed to achieve estimates of effort with a 95% CI of 40% among all fisheries. There were marginal decreases in required sample size as desired relative CIs increased beyond 40% of the estimate.

Daily Estimator

Similar to estimates of effort, Priest Lake required the largest sample size to achieve desired levels of precision for estimates of mean catch rate, with 95 survey days needed to estimate catch rates with a relative 95% CI of 40% (Figure 3; Table 4). Odell Lake required the smallest sample size to achieve the same level of precision at 8 d (out of the 124-d season). Among the nine fisheries examined, on average, approximately 43 sample days would be required to achieve 95% CIs that were 40% of estimated mean catch rate.

For estimates of total catch, the Snake River White Sturgeon fishery required the largest sample size to achieve a relative 95% CI of 40% at 89 d, whereas Diamond Lake required the smallest sample size at 14 d over the duration

TABLE 4. Number of days surveyed (n) and number of days in the fishing season (N) for nine fisheries in Idaho and Oregon as well as the sample size (d) required to estimate effort, catch rate, or total catch with a 95% confidence interval (CI) within 40% of the estimate.

				Sample days needed for 95% CIs within 40% of the estimates				
					Daily estimator		Multi-day estimator	
Fishery	Species	N	n	Effort	Catch rate	Total catch	Catch rate	Total catch
Chetco River	Steelhead	132	70	19	18	37	4	30
Coeur d'Alene Lake	Kokanee	242	69	14	50	83	12	140
Crooked River	Rainbow Trout	223	119	7	16	21	5	19
Diamond Lake	Rainbow Trout	152	39	8	16	14	6	19
Henry's Lake	Cutthroat Trout	153	36	12	55	84	7	40
Odell Lake	Kokanee	124	32	15	8	32	3	25
Phillips Reservoir	Yellow Perch	154	98	17	70	67	18	90
Priest Lake	Lake Trout	364	104	40	95	69	17	95
Snake River	White Sturgeon	360	96	15	60	89	30	55
All	Mean	212	74	16	43	55	11	57

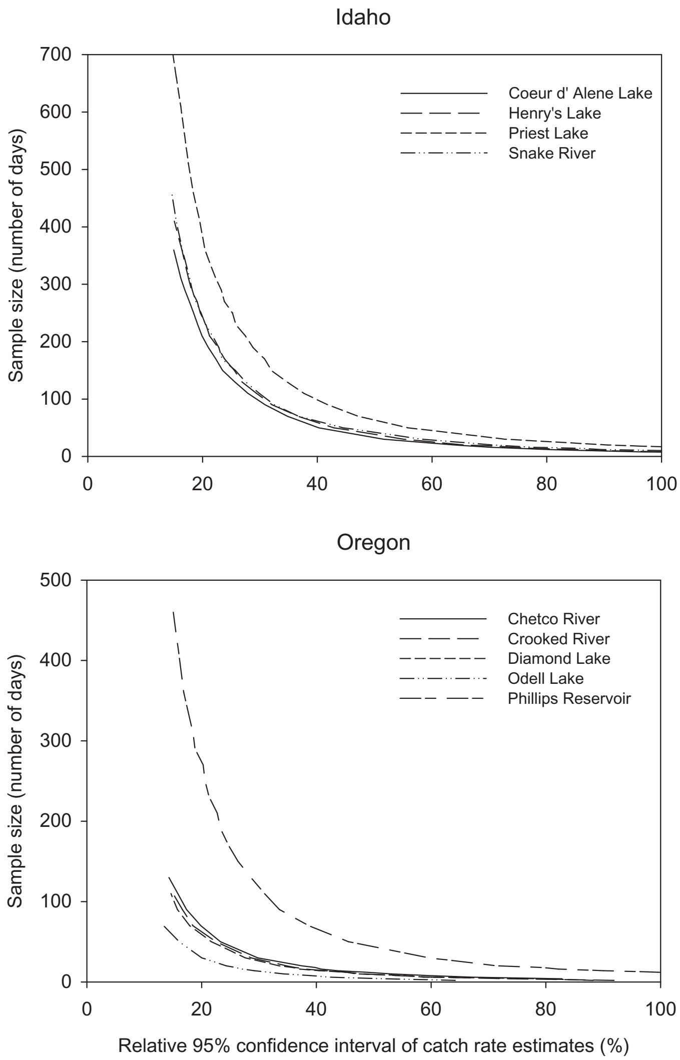

FIGURE 3. Required sample size to estimate angler catch rate (fish/h) using the daily estimator for nine fisheries in Idaho and Oregon given desired 95% confidence intervals expressed as the percentage of estimated mean catch rate.

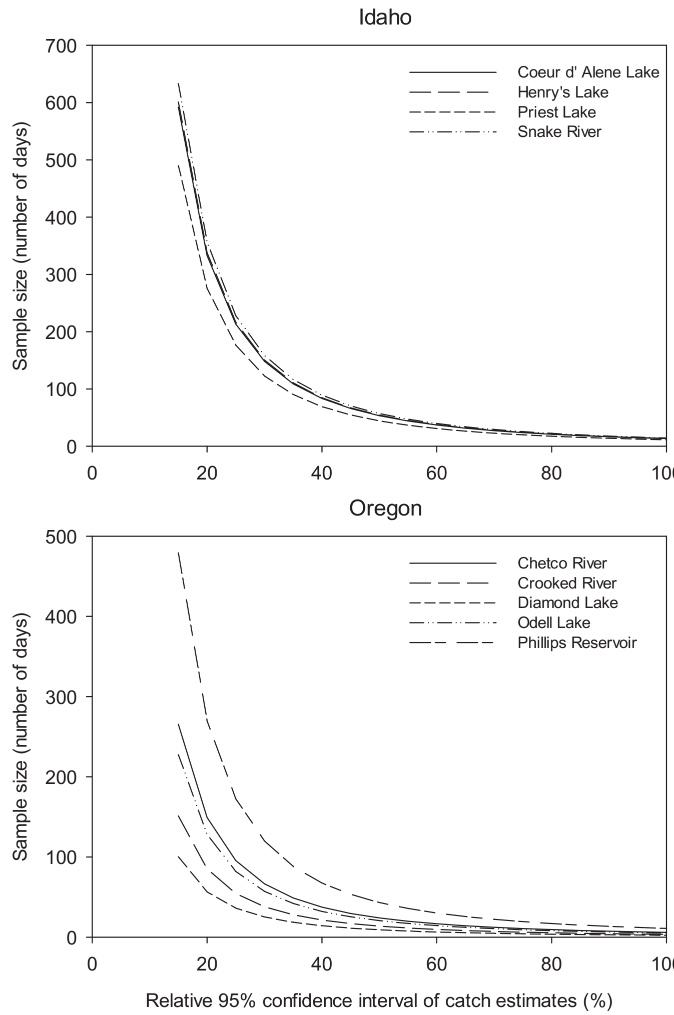

FIGURE 4. Required sample size to estimate catch using the daily estimator for nine fisheries in Idaho and Oregon given desired 95% confidence intervals expressed as the percentage of estimated catch.

of the season (Figure 4; Table 4). Among all nine fisheries, on average, sampling on 55 d over the duration of the fishing season would be expected to result in 95% CIs that were 40% of estimated total catch.

Multi-Day Estimator

Unlike the other estimators evaluated, the units for sample sizes for the multi-day catch rate estimator are in number of anglers to interview rather than number of days to sample. However, the number of days to sample can be estimated by dividing the sample size of anglers by the average number of anglers that are expected to be interviewed each day. The largest sample size of anglers required to reach desired levels of precision was observed in the Snake River White Sturgeon fishery, where 182 angler interviews (or 30 d) would be required to estimate mean catch rate with a relative 95% CI of 40% (Figure 5; Table 4). The smallest sample size was required at Odell Lake, where just 39 angler interviews (or 3 d) were expected to achieve the same level of precision. Among all fisheries, 90 interviews (or 11 d) were required on average to achieve CIs that were 40% of estimated mean catch rate.

Although the Snake River White Sturgeon fishery required the largest sample size to estimate catch when using the daily estimator, Coeur d'Alene Lake required the largest sample size to estimate catch when using the multi-day estimator (Figure 6; Table 4). Approximately 140 survey days' effort would be required to estimate total catch with a 95% CI that was 40% of estimated total catch. Crooked River and Diamond Lake required the smallest sample sizes when estimating catch using the multi-day estimator, with approximately 19 sample days needed to achieve the same level of precision. On average, sampling approximately 57 d would be

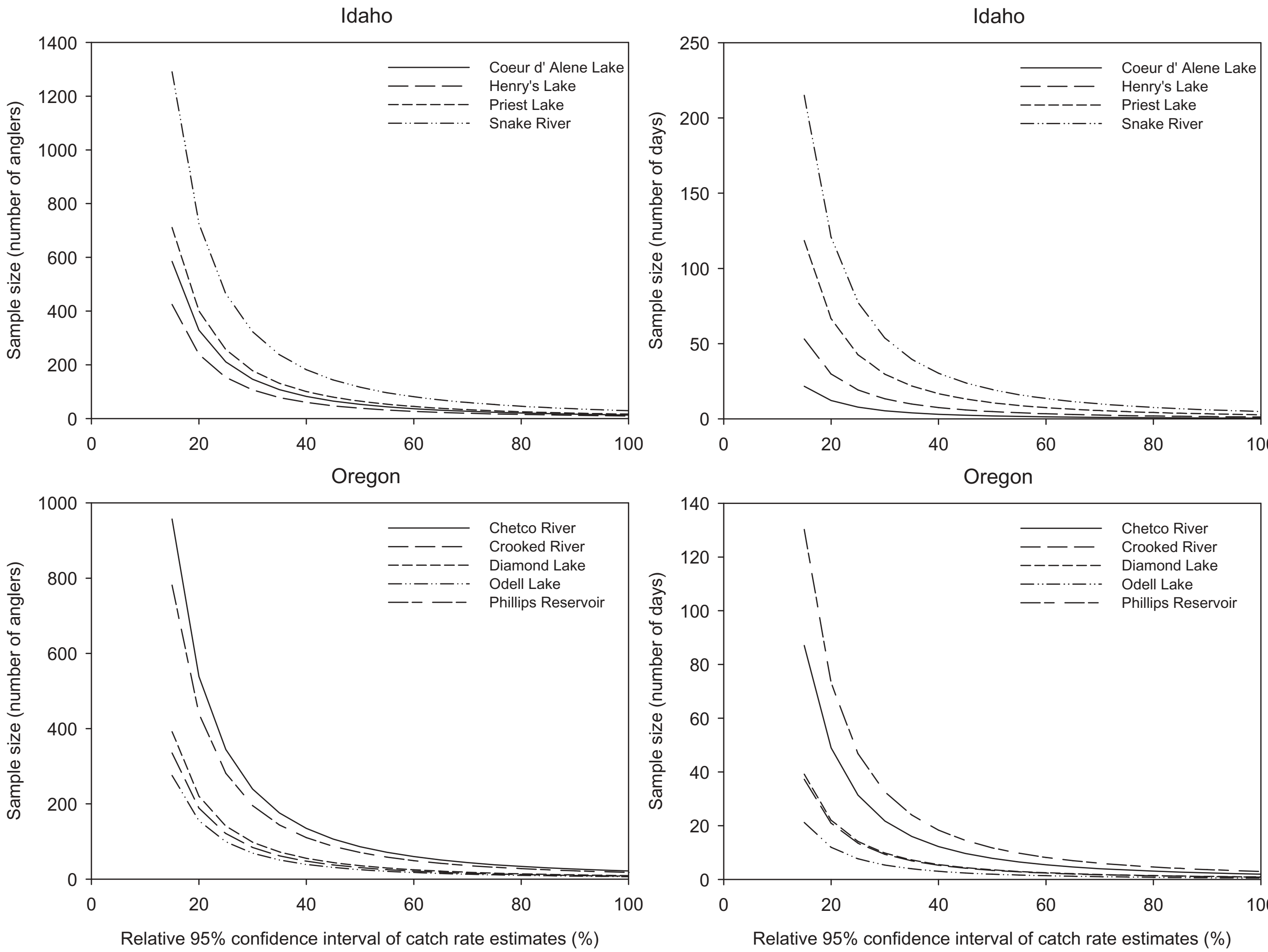

FIGURE 5. Required sample size in number of angler interviews to conduct (left panels) and number of days to sample (right panels) to estimate angler catch rate (fish/h) using the multi-day estimator for nine fisheries in Idaho and Oregon given desired 95% confidence intervals expressed as the percentage of estimated mean catch rate.

expected to result in 95% CIs that were 40% of estimated total catch among all nine fisheries. Sample sizes to estimate catch were greater than the sample sizes needed to estimate effort or catch rate given the same level of precision using both the daily and multi-day catch rate estimators.

DISCUSSION

The variance and sample size estimators presented here can generally be applied to both access- and roving-based on-site creel surveys. The generality of the sample size estimators is a consequence of not accounting for within-day variation due to the lack of replication of secondary sampling units. Although within-day variance is not accounted for, the approximate variance estimators used in this study and resulting sample size estimates are conservative approximations (i.e., overestimates; Su and Clapp 2013). Additionally, the finite population corrections are ignored in all of the variance estimators. If the number of units sampled is greater than 5–10% of the sampling frame, which is common when estimating effort or catch using on-site creel surveys, then the actual variance is likely proportionally smaller than what is estimated using the approximate variance formulas (Cochran 1977). Consequently, the estimated sample sizes using the formulas presented in this study are also likely too large when at least 5–10% of the sampling frame is sampled, and the degree to which they are too large increases nonlinearly as the proportion of the total units sampled increases. Including the finite population correction in the variance and sample size formulas would likely underestimate variance and required sample size. For instance, if all days were sampled, the estimated variance would be zero. However, variance would still be present due to the subsampling of days (i.e., within-day variance). Using the approximate variance formulas is necessary for most creel surveys due to the

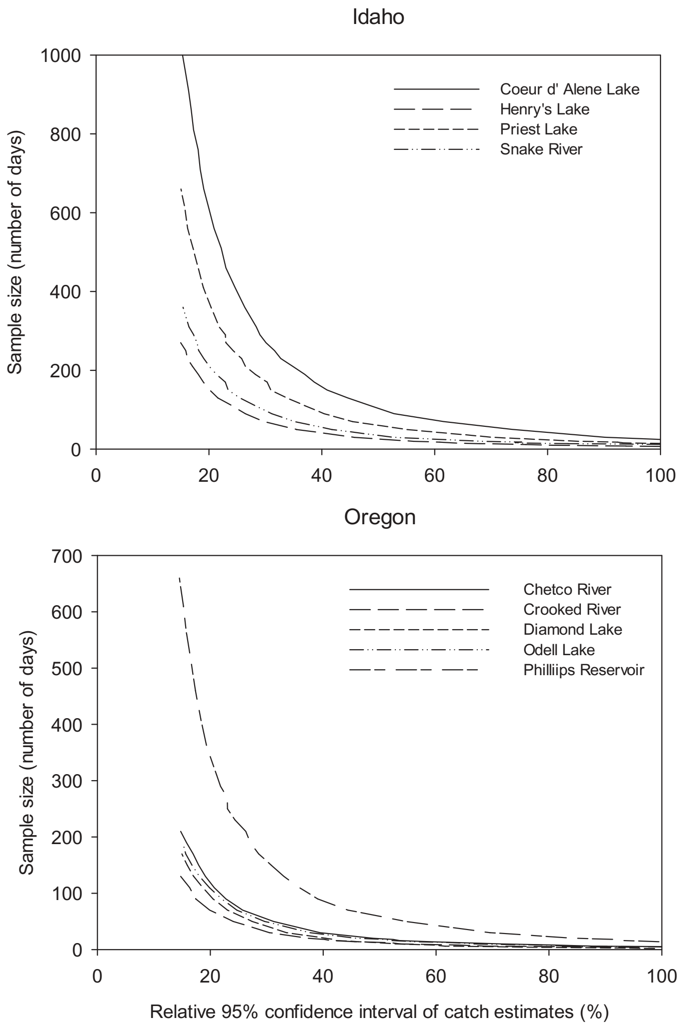

FIGURE 6. Required sample size to estimate catch using the multi-day estimator for nine fisheries in Idaho and Oregon given desired 95% confidence intervals expressed as the percentage of estimated catch.

lack of replication of secondary sampling units. Additional research is needed to evaluate the accuracy of the approximate variance formulas and their effect on sample size requirements.

Sample sizes required to meet a given level of precision for estimates of effort, catch rate, and catch in this study were highly variable among fisheries. This emphasizes the importance of using pilot or historical data to plan creel surveys. However, pilot data may be expensive to collect, and any single estimate of sample variance is itself a random variable that has a sampling distribution. Although results from individual fisheries in this study may not generalize (e.g., the sample size requirement of 14 d to achieve a CI of 40% of the estimate of catch in Diamond Lake may not produce the same CI in all fisheries for Rainbow Trout in lakes), the general nonlinear relationship between sample size and expected CIs can be useful in planning surveys that lack pilot data. For instance, decreasing the CI from 55% of the estimate of catch to 50% would require increasing the sample size by only 6 d on average. In comparison, decreasing the CI from 25% to 20% would require an increase in sample size of 80 d. The relative increase in required sample size is always inversely related to the desired precision; diminishing gains in precision were observed starting at 30 d of surveying for fisheries in this study (also observed by Lester et al. 1991). Although this study was limited to nine fisheries, effort and catch were highly variable among fisheries (effort varied from approximately 8,000 to 98,000 h; catch varied from approximately 2,000 to 90,000 fish); however, this general trend was apparent for all fisheries. This suggests that although the absolute precision will vary among fisheries, 30 d may serve as a reasonable minimum starting point for planning creel surveys when no prior information is available on expected sample variance.

The sample size estimators in this study assumed that samples were allocated proportionally to day-type strata, which generally requires larger sample sizes than other allocation methods. For instance, using Neyman or optimal allocation will often reduce the variance compared to proportional allocation and will result in smaller sample sizes (Cochran 1977; Thompson 2012). Additionally, seasonal (e.g., Lester et al. 1991) or within-day (e.g., Kozfkay and Dillon 2010) stratification with optimal or Neyman allocation or using nonuniform probability designs (Cochran 1977; Pollock et al. 1994; Thompson 2012) can also reduce variance and sample sizes beyond what was observed in this study.

Creel survey sample size requirements can vary greatly depending on the statistic of interest. Because total catch is the product of estimated effort and catch rate (i.e., two random variables), the sample size requirements are larger to estimate catch with the same level of precision as effort and catch rate independently. Consequently, the objectives of the creel survey should be considered before implementation and sample size analyses are conducted. For instance, in an inland recreational fishery, estimating catch rate and effort may be more informative for fisheries management than their product. Thus, goals for precision can be set for those metrics and will result in less sampling effort to meet those goals than would be needed to estimate total catch with the same precision.

In many instances, the required sample size when estimating catch rate in this study using the multi-day estimator was relatively small. For example, on average, only 90 interviews were expected to result in a 95% CI of mean catch of 40%, and only 39 interviews were required to meet the target precision at Odell Lake. Although these sample sizes should meet the desired precision, Jones et al. (1995) noted that CI coverage did not meet target levels with relatively small sample sizes of angler interviews (e.g., less than 95% of CIs of mean catch rate encompassed the simulated mean catch rate). For instance, the sample sizes estimated in this study should meet needs for the size of the 95% CI, but the CIs may not have 95% coverage in all scenarios. The lack of coverage observed by Jones et al. (1995) was due to the highly skewed distribution of catch rate among anglers. Consequently, Jones et al. (1995) recommended a minimum sample size of 100 interviews to ensure that 95% CIs will be near target levels.

Although the sample size estimators presented in this study provide a starting point for planning creel surveys, more advanced analyses could be conducted to further refine creel survey planning. For instance, when conducting a sample size analysis for estimating effort, equation (6) is somewhat unsatisfying because it only informs how many days to sample, not how many counts within a day need to be sampled. The methods in this study were presented in this manner because often there is no within-day replication of counts or shifts; thus, no estimate of within-day variance exists, which is influenced by the number of counts. If the same number of counts will be conducted in the future creel survey (i.e., the one for which the sample size analyses is being conducted) as in the pilot survey or historical surveys, then equation (6) is all that is needed. However, if there is interest in evaluating how the number of counts within a day affects the precision of effort estimates, alternative methods (e.g., iterative techniques) are recommended (Rasmussen et al. 1998). Additionally, Lester et al. (1991) provided alternative sample size estimation equations that incorporated relative within- and among-day variance that are appropriate under certain designs. Moreover, there is a tradeoff in precision of catch estimates by conducting more counts and less interviews or surveying more days with shorter shifts (or vice versa) that could be further investigated. Conducting analyses to evaluate such tradeoffs can be difficult due to the complexity of creel survey designs. However, we anticipate that increased training and access to powerful open-source computing software (e.g., R software) can lead to more advanced empirical evaluations by fisheries scientists that will improve the efficiency of creel surveys for individual fisheries in the future.

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