Review of the Central Valley Angler Survey

By

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INTRODUCTION

Inland sport harvest of Chinook salmon in California's Central Valley (CV) streams comprises a significant proportion of the total escapement. The CV angler harvest survey, reinitiated in 2007, is a long-term monitoring program designed to develop annual estimates of total angler effort and in-river harvest of sport fish from the Sacramento River and major tributaries. In addition to Chinook salmon, the survey includes a number of other species considered to have recreational value. As described in Titus et al. (2009), the key objectives of the CV angler survey specific to Chinook salmon are:

1. Analysis and reporting of angler effort and harvest,
2. Estimating the contribution of hatchery Chinook in the CV sport harvest, and
3. Estimating the age structure of Chinook salmon and steelhead in the CV sport harvest.

Estimates of Chinook salmon harvest in the recreational fishery are used by the Pacific Fishery Management Council to help determine ocean harvest quotas off the coasts of California, Oregon and Washington (Titus et al. 2009).

This document reviews the existing angler survey design and analysis techniques used in the CV for estimating Chinook salmon angler effort and harvest (Titus et al. 2009). After describing the current angler survey protocol, we provide recommendations for future surveys and analyses of those survey data. The recommended methods will allow for estimation of precision (e.g., confidence interval [CI]), and are expected to reduce bias and improve precision of estimates of Chinook salmon angler effort and harvest in the CV.

CURRENT METHODS

Survey Design

The CV angler survey is based on a stratified sampling design developed for the Sacramento River Sport Fish Inventory (Wixom et al. 1995) and the Upper Sacramento River Sport Fishery (Smith 1950). Physical strata (river sections) have been identified, and a stratified allocation of effort is used to survey river sections each month. A total of 21 river sections ranging from 1 to 56 miles in length were surveyed in 2008 – 2009 (Titus et al. 2009). We assume that stratification of river sections is based on a combination of physical/geographic features, angler and surveyor access to the river, and unique features of the fishery (e.g., estimated historic harvest levels). In 2008 – 2009, each section was surveyed on eight randomly selected days per month: four weekdays and four weekend days. Relatively more effort was given to weekend days since angling effort during these times is typically greater.

Surveys are conducted using a method similar to what is called a 'roving-roving' survey, in combination with access point interviews. Roving-roving surveys involve a survey team traveling the entire river section at least once to count the number of anglers, and then traveling the river section again to interview anglers. Given two or more random roving (or progressive) count surveys, angler effort and total harvest can be calculated for that day, along with estimates of precision (Pollock et al. 1994). Estimates of harvest are calculated by multiplying an estimate of the amount of angler effort (e.g., number of angler-hours) by an estimate of total harvest-per-unit-effort (*hpue*; e.g., how many fish were caught by the average angler, per hour).

Only one roving count is conducted for each section, each survey, which precludes estimation of precision. This single count is combined with data from an effort distribution model (EDM) to estimate the number of angler-hours. The EDM represents an estimate of the proportion of a day's total angler-hours that occur over any period of time. For example, the EDM may identify that 12% of all angler-hours occur between 6 and 7 am on weekend days during August on a particular river section. If a roving count conducted during the same period resulted in a total count of 10 anglers, we would estimate that 83 anglers $(10 / 0.12 = 83.3)$ fished that section of river that day.

The first EDMs for the CV were developed using access interviews (Wixom et al. 1995). Access interviews occur at a representative sample of river access locations and target anglers that have completed their fishing experience for that day. Although access interviews were conducted in 2008 – 2009, development of EDMs for 2008 – 2009 based on those interviews was incomplete. Thus, the historical EDMs developed by Wixom et al. (1995) were used by Titus et al. (2009). Although historical EDMs have been compared to more recent data (Rob Titus, personal communication), no statistical comparisons were presented in Titus et al. (2009).

Roving counts and access interviews provide information regarding the number of anglers present and the total number of angler-hours during a day. While access interviews allow collection of completed trip information at access sites, roving interviews intercept anglers while they are still fishing. Angler success and the number of fish harvested are estimated from access point interviews and roving interviews. If time permits, every angler in the section during the roving survey is interviewed. Otherwise, every N^{th} angler is interviewed, where N is determined by field personnel and based on the time of day, number of anglers present, and field logistics.
Surveys of river sections begin at sample start times and launch locations. For each section, a survey start time is determined by randomly selecting the beginning, middle, or final 1/3 of the sample day. Actual start times within a selected period (early, middle or late) vary according to length of the survey and logistics. If a river section can be surveyed using a motorboat, a launch location (upstream or downstream) is randomly sampled for each survey. Surveys along river sections traveled by kayak or drift boat, due to available boat access and/or water depth, always begin upstream.

Estimation of Angler Effort and Harvest of Chinook Salmon
The procedures used to estimate total angler effort and harvest of Chinook salmon follow those described in Wixom et al. (1995). Three survey parameters are estimated for each river section on each survey day: (1) total effort in angler-hours (E), (2) harvest per unit of effort ($hpue$) measured as the number of Chinook salmon harvested per angler per hour, and (3) total Chinook harvest (H). Daily estimates are then expanded to provide monthly estimates. Months were chosen as the time interval for survey periods because historical CV angler surveys (e.g., Wixom et al. 1995, Murphy et al. 1999) focused on monthly estimates of angler effort and harvest.

To describe the estimators used for each parameter, the following definitions are needed:

Let b = time required to conduct a roving (roving) count pass through the section;
E = total angling hours for all species;
$E_{Chinook}$ = total angling hours for Chinook salmon;
e = length (hours) of a fishing experience for an interviewed angler;

H = total harvest in numbers of Chinook salmon kept (or released) by anglers;
h = total numbers of fish kept (or released) during a fishing trip by an interviewed angler;
P = proportion of anglers present during a given period of day (based on EDM);
$P_{Chinook}$ = proportion of angler-hours targeting Chinook salmon (based on interviews);

Estimates of total angler effort for all species for a particular day is calculated by dividing the roving angler count (n) by the estimated average proportion of individual anglers present in the section for the period during which the count was made:

$$\hat{E} = \frac{n}{P}, \qquad [1]$$

where P is based on the EDM and time period when the roving count was conducted.

Estimates of angler effort specific to fishing for Chinook salmon are calculated for each sampled day, using

$$\hat{E}_{Chinook} = \hat{E} \times P_{Chinook}. \qquad [2]$$

The average daily *hpue* is estimated by dividing a sample day's average number of Chinook salmon harvested by the average number of hours fished for Chinook by the anglers interviewed (i.e., a ratio of means):

$$\overline{hpue} = \frac{\bar{h}}{\bar{e}}. \qquad [3]$$

Harvest is estimated sample day in the CV angler survey by multiplying an estimate of $\overline{hpue}$ (equation [3]) by an independent estimate of effort for that sample day:

$$\hat{H} = \hat{E}_{Chinook} \times \overline{hpue}. \qquad [4]$$

Separate estimates are made for kept and released fish, and total harvest is calculated as the sum of harvests over days, months and or river sections of the survey. No variance estimates or confidence intervals are available for estimates of angler effort (equations [1] and [2]) or total harvest (equation [4]), since only one roving count is conducted for each river section, each survey.

RECOMMENDATIONS

Separate EDMs have been developed for various river sections in the CV (Wixom et al. 1995), but not for all 21 river sections surveyed in 2008 – 2009 (Titus et al. 2009). In addition, the EDM method used for estimating angler effort assumes that the distribution of hourly effort throughout each day is constant for all days regardless of the date or year (and possibly section) of the survey. We believe this tenuous assumption is not met in many situations (e.g., holidays, inclement weather). In addition, as mentioned above, using only one roving count per survey day precludes estimation of precision for both angler effort and total harvest, which is critical for trend monitoring and effective management of the fishery. Thus, we recommend that the current angler survey be continued, but with some modification.

We recommend roving-roving surveys include two or more roving counts of anglers at random times during the day, with a randomized direction of travel (when practical). These counts can then be used for calculation of total angler-hours for a sampled day. This approach follows several angler survey designs described in the literature (e.g., Wade et al. 1991, Pollock et al. 1994, Bernard et al. 1998), and if implemented correctly, can be expected to produce accurate estimates of harvest and effort (Hoenig 1993). We describe one possible method of implementing the multiple roving count approach below. In addition, formulas for estimating total harvest based on access interviews or a combination of roving and access interviews are provided in the Appendix.

Implementing Two or More Roving Counts

There are many ways in which two or more roving counts can be conducted, but all methods assume that a random start time, and possibly a random direction of travel (upstream or downstream) can be selected for each count. We envision the simplest approach, which is to conduct only two roving counts for a river section within a survey day, with one occurring either before or after a roving interview survey, and the other occurring during the roving interview.

If a roving count is expected to take *b* hours, then divide the fishing day into *B* blocks of length *b*, and randomly select one of the blocks for the roving count. For example, if the fishing day is 14 hours long, and a roving count would require *b*=1 hour, the survey day would be divided into *B*=14 blocks of time. A random sample of the 14 blocks would determine when the roving count was conducted, and a coin-flip would determine whether the roving interview was conducted prior to, or following the roving count. If a sampled block is near the beginning (end) of the day and a roving interview cannot be conducted (before) after the roving count, the roving interview can be conducted after (before), as long as the randomly selected start time for the roving count is maintained. It is important to randomly select the starting time for the first roving count each sampled day for each river section.

If *b* hours were required to complete a roving count, an unbiased estimate of the fishing effort in any particular *b* block of time is calculated as

$$\hat{E}_b = x \times b, \qquad [5]$$

where *x* is the number of anglers counted. When a roving count of anglers is conducted using a random start time and direction of travel, the count can be considered an unbiased estimate of the mean number of anglers fishing during any block of time of that duration (Hoenig et al. 1993, Robson 1961). Thus, if the fishing day contains *B* *b*-hour blocks, an unbiased estimate of the total fishing effort in angler-hours for the day is estimated using (Hoenig et al. 1993)

$$\hat{E} = x \times b \times B\,. \qquad [6]$$

The second roving count during a survey can either take place at a random time (same methods described above), or during the roving interview. Since a count of anglers during the interview process may result in a substantial underestimate of fishing effort due to length-of-stay bias (Wade et al. 1991, Pollock et al. 1994:244, Bernard et al. 1998), we recommend including adjustments in the survey protocol involving scheduled checkpoint locations (Wade et al. 1991). Length-of-stay bias exists when the amount of time an angler spends on the river depends on his or her fishing success.

The checkpoint method insures that anglers are counted evenly along the entire survey section through the sampling period. A time schedule is followed so the survey team reaches specific checkpoints at designated times along the survey. Although fewer angler interviews may be conducted using the checkpoint method because some anglers may need to be skipped in order for the survey to stay on schedule, the resulting estimate of effort is expected to be accurate. Total angler-hours using the checkpoint method can be calculated using equation [6].

Using two roving counts to obtain two estimates of angler effort (equation [6]), the average angler effort for the survey day should then be used as the final estimate of total angler-hours:

$$\hat{E} = \frac{\hat{E}_1 + \hat{E}_2}{2} . \qquad [7]$$

Anglers are usually classified by harvest type, i.e. whether they will (are) going to keep or release any Chinook caught. The proportion of anglers determined to be targeting Chinook is multiplied by the roving total count of anglers to obtain the number of Chinook anglers. The number of sample day hours determined to belong to each harvest category (kept or released) is the product of the number of hours in the day and the proportion of total hours fished by harvest type. This allows for partitioning of estimates of Chinook angler effort and harvest by harvest type.

We recommend that information on angler-trips of less than 0.5 hours not be used in $\overline{hpue}$ calculations based on the roving-roving survey due to the fact that the angler(s) was likely interviewed prior to completion of their ‘angling trip’. This tends to stabilize the variance of the estimates of angler effort and harvest, while not contributing appreciable bias (Pollock et al. 1997).

Estimation of $\overline{hpue}$ and total harvest using the roving-roving survey design with at least two roving counts follows equations [3] and [4], with details in the Appendix. Variance estimates for angler effort and harvest for a survey day are also presented in the Appendix. In addition, we present formulas for estimating angler effort and harvest using a combination of roving and access point interviews.

CONCLUSIONS

The CV Angler Survey uses a stratified random roving-roving design in which access interview data is also sometimes used in combination with roving interviews to estimate angler effort and harvest of Chinook salmon. However, a historical EDM is used in place of two or more random roving counts. Use of the historical EDM requires tenuous assumptions, and precludes estimation of CIs for total harvest. A modification of the current approach would improve estimates (reduce bias and improve precision), and allow for calculation of CIs. This modification involves conducting multiple (two or more) roving counts of the number of anglers each survey day, where one of the counts can be conducted simultaneously with the roving interview survey.

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APPENDIX

Harvest-per-unit-effort Using a Roving-Roving Survey

Angler effort and $\overline{hpue}$ are estimated separately for each river section, survey day and harvest type. Subscripts in the formula presented below only represent an individual harvest type, though they are not specific to kept or released fish.

Since interviewed anglers in a roving-roving survey have not completed their fishing trips, the mean of ratios of harvest to effort for individual interviewed anglers is the least biased estimate of $\overline{hpue}$ (Jones et al. 1995, Hoenig et al. 1997, Pollock et al. 1994). An estimate of the $\overline{hpue}$ for sample day i is calculated using a mean of ratios:

$$\overline{hpue}_i = \frac{1}{m_i} \sum_{k=1}^{m_i} \frac{h_{ik}}{e_{ik}} \quad , \qquad [8]$$

with an estimated variance of

$$v\left(\overline{hpue}_i\right) = \frac{\sum_{k=1}^{m_i} \left(hpue_{ik} - \overline{hpue}_i\right)^2}{m_i\left(m_i - 1\right)} \quad , \qquad [9]$$

where m_i is the number of anglers interviewed, h_{ik} is the harvest of the k^{th} angler, e_{ik} is the effort (in hours) up to the time of interview for the k^{th} angler, and $hpue_{ik}$ is the harvest-per-hour for the k^{th} angler.

If m_i anglers are interviewed systematically (every N^{th} angler) the following variance formula should be used (Wolter 2007, pg 300):

$$v\left(\overline{hpue}_i\right) = \frac{\sum_{k=2}^{m_i} \left(hpue_{ik} - hpue_{i(k-1)}\right)^2}{m_i(2)\left(m_i - 1\right)} \quad . \qquad [10]$$

Angler Effort

An estimate of monthly effort for a given river section and day-type is calculated using equation [7] and

$$\hat{E} = \frac{D}{d} \sum_{i=1}^{d} \hat{E}_i \quad , \qquad [11]$$

where D is the number of days of that day-type (weekday or weekend day) in a given month, and d is the number of sampled days (currently 4) of a given day-type within the month.

Using two or more roving counts of x anglers based on random start times for the surveys, variance for a sample day is calculated as (Pollock et al. 1994, pg 248)

$$v\left(\hat{E}_i\right) = T^2 \frac{\sum_{t=1}^{r}\left(x_{it} - \bar{x}_i\right)^2}{r(r-1)}, \quad [12]$$

where T is the number of hours in the fishing day, x_{it} is the number of anglers counted during the t^{th} daily roving count, and $\bar{x}_i$ is the mean of the r roving counts. The variance for angler effort for a given day-type within a month is estimated using

$$v\left(\hat{E}\right) = \frac{D(D-d)}{d} \frac{\sum_{i=1}^{d}\left(\hat{E}_i - \bar{\hat{E}}\right)^2}{d-1} + \frac{D}{d}\sum_{i=1}^{d} v\left(\hat{E}_i\right). \quad [13]$$

Estimating Total Harvest

Estimated harvest for sample day i on a river section is calculated as

$$\hat{H}_i = \hat{E}_i \overline{hpue_i}. \quad [14]$$

The daily estimated harvest is then expanded over all available days (weekdays or weekend days) to estimate the total number of fish harvested ($\hat{H}$) for a specific month and river section by day-type:

$$\hat{H} = D \frac{\sum_{i=1}^{d} \hat{H}_i}{d}, \quad [15]$$

and D is the number of weekdays (or weekend days) in the month, and d is the number of days sampled (4).

An approximate variance formula for estimated total harvest in a sample day was derived by Goodman (1960) as,

$$v\left(\hat{H}_i\right) = \hat{E}_i^2 v\left(\overline{hpue}_i\right) + \overline{hpue}_i^{\,2} v\left(\hat{E}_i\right) - v(\overline{hpue}_i) v\left(\hat{E}_i\right). \quad [16]$$

However, a bootstrap procedure (Manly 2004) may provide a better method for estimating variance in harvest when coefficients of variation (CV) are large (say ≥ 0.25).

Variance for a harvest estimate for a particular stratum (e.g., month, river section, type of day) is consistent with a stratified random sampling design (Thompson 1992, pgs 119 and 134):

$$v\left(\hat{H}\right) = D(D-d)\frac{s_1^2}{d} + \frac{D}{d}\sum_{i=1}^{d} v\left(\hat{H}_i\right), \quad [17]$$

$$s_1^2 = \frac{\sum_{i=1}^{d}\left(\hat{H}_i - \overline{\hat{H}}\right)^2}{d-1}, \quad [18]$$

and $\overline{\hat{H}} = \left(\sum_{i=1}^{d} \hat{H}_i\right)/d$. If sample days are chosen systematically to obtain a more even distribution of harvest and effort over the available days in the month (Pollock et al. 1994), an approximation of s_1^2 (Wolter 2007, pg 300) is

$$s_1^2 = \frac{\sum_{i=2}^{d}\left(\hat{H}_i - \hat{H}_{i-1}\right)^2}{2(d-1)}. \quad [19]$$

The systematic method may be preferred over random sampling when it is known that there is a temporal trend in harvest, as may be the case with migratory salmon fisheries.

Angler Effort and Harvest Using a Roving-access Survey

The roving-access survey method interviews anglers as they exit the fishery having completed their fishing trips (Hayne 1991). For some sample days the angler survey may involve both roving interviews and access point interviews so that the survey becomes a combination of roving-roving and roving-access survey types. For the roving-access method, the total angler count is obtained by roving counts. An advantage to the roving-access survey is the elimination of "length-of-stay" bias, where an angler's harvest influences the length of his or her fishing trip (Pollock et al. 1994, pg 179). Another advantage is the assumption that each angler experiences a constant harvest rate throughout the day is not necessary. This condition is a necessary assumption for minimal bias in estimates of $\overline{hpue}$ using roving interviews (Pollock et al. 1997, pg 13). However, access points to a river section may be too numerous, too sparse or too inaccessible to allow enough anglers to be interviewed to achieve acceptable estimates of $\overline{hpue}$ given limited personnel (Pollock et al. 1994, pg 160).

When a moderately large number of interviews can be obtained, the roving-access survey is preferred since bias in harvest per unit of efforts will in general be lower than those estimated from roving interviews (Bernard et al. 1998). Access sites must be chosen in a probabilistic manner. If the section has multiple access sites, one or more sites should be selected at random from a list of available access sites. Precision can be maximized if access sites are chosen randomly with weights in proportion to the fishing effort occurring at those sites (Pollock et al. 1994, pg 142). If access point interviews are used, the best method for estimating mean sample day $\overline{hpue}$ is the ratio of means (Jones et al. 1995, pg 921; Hoenig et al. 1997):

$$\overline{hpue}_i = \frac{\sum_{k=1}^{m_i} h_{ik}}{\sum_{k=1}^{m_i} e_{ik}}. \quad [20]$$

The variance can be calculated using (Thompson 1992, pg 60)

$$v\left(\overline{hpue}_i\right)=\frac{\sum_{k=1}^{m_i}\left(h_{ik}-e_{ik}\,\overline{hpue}_i\right)^2}{\bar{e}_i m_i\left(m_i-1\right)},\qquad [22]$$

where $\bar{e}_i=\frac{1}{m_i}\sum_{k=1}^{m_i}e_{ik}$, and m_i is the number of anglers interviewed during sample day *i*.

Using A Combination of Roving and Access Interviews

When both roving interviews and access interviews are used to estimate $\overline{hpue}$ for a river section, the following weighted average should be used:

$$\overline{hpue}_{wi}=\frac{\overline{hpue}_{Ai}m_{Ai}+\overline{hpue}_{Ri}m_{Ri}}{m_{Ai}+m_{Ri}}\ ,\qquad [23]$$

with a variance estimated as

$$v\left(\overline{hpue}_{wi}\right)=\frac{v\left(\overline{hpue}_{Ai}\right)+v\left(\overline{hpue}_{Ri}\right)}{\left(m_{Ai}+m_{Ri}\right)^2}\ ,\qquad [24]$$

where m_{Ai} is the number of access interviews, m_{Ri} is the number of roving interviews, $\overline{hpue}_{Ai}$ is the estimated harvest rate based on the access interviews (equation [21]), $\overline{hpue}_{Ri}$ is the estimated harvest rate based on roving interviews (equation [10]), $v\left(\overline{hpue}_{Ai}\right)$ is the estimated variance for the access interviews (equation [22]), and $v\left(\overline{hpue}_{Ri}\right)$ is the estimated variance for the roving interviews (equations [11] or [12]).

Cumulative Estimates for Season and Strata

When strata are established according to time and location of anglers, all anglers within such stratum belong by definition to that stratum. Thus sample sizes for basic units are fixed (Thompson 1992: 109). Unbiased estimates of harvest, effort and their sample variances are then independent for each stratum. Since days are scheduled independently across time-space strata, adding stratified estimates of harvest and their sample variances across any combination of such strata will produce unbiased, cumulative estimates (Thompson 1992:102, Bernard et al. 1998).

For example a total season estimate of harvest which would include both kept and released fish with its estimated variance would be calculated as

$$\hat{H}_{season}=\sum_{i=1}^{I}\sum_{j=1}^{21}\sum_{k=1}^{2}\sum_{l=1}^{2}\hat{H}_{ijkl},\qquad [25]$$

$$v\left(\hat{H}_{season}\right)=\sum_{i=1}^{I}\sum_{j=1}^{21}\sum_{k=1}^{2}\sum_{l=1}^{2}v\left(\hat{H}_{ijkl}\right),\qquad [26]$$

where i indexes sampled months of the survey season, j indexes river section (e.g., 21 sections in current survey), k indexes type of day (weekday or weekend day) and l indexes harvest type (kept or released). Stratum estimates and their variances follow equations [14] and [16], respectively.

An approximate asymptotic 90% confidence interval for total seasonal harvest can be calculated as

$$\hat{H}_{season} \pm Z_{0.05}\sqrt{v\left(\hat{H}_{season}\right)}, \qquad [27]$$

where $Z_{0.05}$ is the upper 0.95 tail value of the standard normal distribution.