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Evaluation of creel survey methodology for steelhead fisheries on the Quillayute and Hoh rivers


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by Kale Bentley

Washington Department of FISH and WILDLIFE

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Executive Summary

The Hoh and Quillayute river systems provide two of the most popular steelhead fisheries in Washington State with the majority of fish caught being wild steelhead. Beginning in the mid-1970s in the Quillayute River and the 2000s in the Hoh River, the Washington Department of Fish and Wildlife (WDFW) has conducted on-site steelhead creel surveys (i.e., 'coastal creels') in order to estimate fishing pressure and catch of winter steelhead. In both rivers, fishery regulations for steelhead have changed over time as have the specific goals of the coastal creel surveys and methods used to generate estimates of catch. The purpose of this report is to summarize the present day goals and methods of the coastal creel surveys, evaluate whether these goals are being met based on current methodology, and propose recommendations for future surveys.

The primary goal of the coastal creel surveys is to generate unbiased estimates of total end-of-season recreational steelhead catch, where catch is a combination of harvest and catch and release (C&R). During an on-site creel survey, fishing pressure (angler effort) and angler success (catch per unit effort – CPUE) data are collected via anger counts and interviews, respectively. These data are subsequently used to make expanded estimates of effort and catch. For unbiased estimates to be generated, creel survey data must be collected in a spatially and temporally representative manner. This assumption may not be met with the current methodology resulting in an underestimate of catch. I make several recommendations to improve the spatial (e.g., effort expansion surveys) and temporal (e.g., randomized sample schedule, use of day length in effort calculation) coverage.

A secondary goal of the coastal creel surveys is to produce catch estimates with a precision of ± 20% at the 95% confidence level, which corresponds to a coefficient of variation (CV) of 10%. A method for calculating precision is provided based on previously derived equations outlined in Pollock et al. (1994) and Hahn et al. (2000). Catch and precision estimates were generated for each pairwise combination of fish origin (wild, hatchery) and fate (harvested, released) in the Upper and Lower river-sections of the Hoh River during the 2014-15 creel survey season. The resulting CVs ranged from 11% to 25%, which are all greater than the specified goal of 10% but relatively precise based on standards for other estimates such as monitoring of ESA-listed species (Crawford and Rumsey 2011). Before additional time and funds are invested in lowering the precision of the creel estimate, the current precision goal should be examined with regards to how the resulting data will be used for management and decision making.

Background

The Hoh and Quillayute river systems provide two of the most popular steelhead fisheries in Washington State. Each year, recreational anglers cumulatively spend tens of thousands of hours fishing for winter steelhead resulting in the catch of thousands of fish – the vast majority of which are wild-origin. Prior to the mid-1980s, recreational steelhead fisheries in the Hoh and Quillayute river systems were largely focused on harvest (i.e., retention). During this time period, hatchery steelhead were not mass marked and thus the origin of individual fish could not reliably be distinguished by anglers. However, over the following two decades, mass marking of hatchery steelhead with an adipose fin clip allowed hatchery and wild catch to be visually distinguished in the field. In addition, the focus of steelhead management shifted towards fishing regulations that primarily provided catch and release (C&R) opportunities for wild fish and harvest of hatchery fish. Through these years and changes in steelhead management, the Washington Department of Fish and Wildlife (WDFW) has conducted angler surveys in order to quantify the actual number of anglers utilizing these rivers (angler effort) and the quantity and composition (hatchery, wild) of steelhead catch.

Angler surveys are an established method used to estimate catch and fishing pressure in recreational fisheries (Malvestuto et al. 1978, Pollock et al. 1994, Jones and Pollock 2012). These surveys generally fall into two categories: (1) "on-site" surveys, such as roving creels and (2) "off-site" surveys, such as phone interviews or catch cards. Since the 1960s, WDFW has used the off-site Catch Record Card (CRC) reporting method to monitor catch of salmon and steelhead throughout the state (Kraig and Smith 2010). Here, WDFW issues a "catch card" to each individual angler that purchases a fishing license and anglers are required to record their catch of certain species before returning the card annually. From these CRCs, WDFW generates estimates of total catch by species and location of catch. Although the CRC reporting method generates estimates of total catch, the current program has only been designed to collect and calculate catch from harvested fish and does not provide a way to report fish that are released. Therefore, an alternative survey method is necessary to generate estimates of C&R catch.

One specific type of angler survey that is used to estimate catch, whether it be for harvested or C&R fish, is the creel survey (Pollock et al. 1994). Creel surveys (hereafter referred to as "creels") are on-site angler surveys aimed at collecting data on fishing pressure and angler success, via angler counts and interviews, that are subsequently used to make expanded estimates of catch. In the mid-1970s, WDFW (formally Washington State Game Department) began implementing on-site steelhead creels in Western Washington rivers following the 1974 Federal District Court Order (United States vs. Washington, Civil Case No. 9213), referred to as the Boldt Decision. The purpose of these creels was to ground-truth catch estimates derived from CRCs and provide accurate and precise in-season estimates of sport harvest that were calculated and reported every two weeks to all groups involved in litigation and/or steelhead harvest and management activities. Over the following decades, WDFW has continued to use on-site creels for a variety of purposes, including the generation of in-season catch reports and end-of-season estimates of catch. On Washington's north coast, on-site steelhead creels have been conducted annually on Quillayute River since the winter of 1976-77 and the Hoh River since the winter of 2003-04 (hereafter referred to as the "coastal creels"). Over the years, the specific goals of creels on these northcoast rivers and methods used to generate estimates of catch have changed. The purpose of this report is to summarize the present day goals and methods, evaluate whether these goals are being met based on current methodology, and propose recommendations for future creels.

Current Goals and Methodology for Coastal Creels

Goals of the Coastal Creels

The primary goal of the present day creels on the Quillayute and Hoh rivers is to generate unbiased estimates of total end-of-season recreational steelhead catch (catch = harvest + C&R). A secondary goal is to produce catch estimates with a precision of ± 20% at the 95% confidence level (*Randy Cooper, WDFW, personal communication*). A precision of ± 20% at the 95% confidence level is equivalent to a coefficient of variation (CV) of 0.10 (or 10%). This specific precision goal can be traced back to original WDFW creel reports (e.g., Washington State Game Department 1978), but the justification for this specific target is unknown. While the objective of the creels is to estimate catch for both hatchery and wild steelhead, emphasis has been placed on wild C&R estimates given that these cannot be generated from the CRC method. Unlike historical surveys, in-season catch estimates are not generated but raw catch data are summarized weekly and reported on the WDFW website for public viewing (http://wdfw.wa.gov/fishing/creel/steelhead/). A tertiary goal of the coastal creels is to understand patterns in the sport fishery. Specifically, angler effort data (i.e., time anglers spend fishing) is used to evaluate the distribution of effort across the primary angler-types (i.e., plunkers, drifters, private boats, and guided boats), responses to regulation changes, and general patterns among years.

Collection of Creel Data

The present day coastal creel field surveys use a stratified random survey design to conduct roving-roving creel surveys. These methods are largely based on a WDFW creel methods manual published by Hahn et al. (2000) and historical Washington State creel methodologies developed by Burns and Brown (1976). These survey methods are similar to those published by the American Fisheries Society (Pollock et al. 1994, Jones and Pollock 2012), which have been widely implemented across a range of recreational fisheries (e.g., Bernard and Clark 1995, Brouwer and Buxton 2002, Hansen et al. 2000).

Prior to conducting on-site creels, a survey schedule is developed for the period of interest using a stratified sample design. For the Hoh and Quillayute rivers, the annual creel survey focuses on the winter steelhead fishery, which typically occurs from mid- to late-November through mid- to late-April. First, the survey is stratified by day-type (weekday or weekend) and five sample days are selected per week consisting of three randomly selected weekdays and both weekend days. Second, a start time is selected for each sample date. An individual sample date typically consisted of an eight-hour work day (including drive time) that occurs sometime between sunrise and sunset. During early winter months (December and January) day length (sunrise to sunset) is similar to the shift length and thus start times are fairly close to sunrise and almost all daylight hours are sampled. However, as the day length gets longer in late-winter and early-spring (February – April), start times are shifted and only a fraction (~0.5 to 0.75) of the total daylight hours are sampled each day.

Once the set of randomized creel sample days have been selected, each survey day is sampled and data collection involves two main activities: effort counts and angler interviews. Effort counts are designed to estimate angler pressure (i.e., number of anglers fishing) and angler interviews are designed to estimate angler success (i.e., number of steelhead caught for a given amount of time). Prior to the first sample date, a predefined set of index sites are selected for the effort counts. Within each survey date, one to two effort counts are conducted, including one in the morning and one in the afternoon. During an effort count, creel technicians visit the complete set of index sites. Effort is counted as the total number of bank anglers (plunkers and drifters) and the number of boat/raft trailers at each site. A current list of the coastal creel index effort sites is outlined in the "North Coast Winter Steelhead Creel Sampling Guidelines" (for a copy contact R. Cooper at *Randy.Cooper@dfw.wa.gov*). Before and after effort counts, bank and boat anglers are interviewed by creel technicians. Information gathered during interviews includes: angler-type (plunker, drifter, private boater, guided boater), number of anglers in the group, angling start time, interview time, whether the trip was incomplete or complete (i.e., trip status), fishing location, and number of fish caught. For anglers who report catch, the species, origin (hatchery or wild), fate (harvested or released), and other biological information for each individual fish are recorded. At the end of each survey date, individual interview and effort count data are tallied and recorded on a daily summary creel form.

During the creel season, high flows can lead to high turbidity and low clarity, which subsequently results in "poor" fishing conditions and decreased fishing pressure. On the Hoh River, guides generally do not fish when flows are above ~3,000 cfs (*Randy Cooper, WDFW, personal communication*). However, plunkers, drifters, and private boats sometimes fish at higher flow levels. Similar patterns are seen on the Quillayute River system with limited guide pressure when flows are above ~4,000 cfs on the Sol Duc and ~2,500 on the Calawah (*John McMillan, Trout Unlimited, personal communication*). Therefore, when flows are high creel technicians still conduct the morning angler index counts and interview anglers. After qualitatively assessing the fishing conditions and angler effort, creel technicians may determine that the river is unfishable and will classify the river as "out". After the river is classified as out, the creel survey for the date is typically cancelled, catch is assumed to be zero, and the survey is moved to a subsequent day with improved fishing conditions if the schedule allows.

Analysis of Creel Data

Following the creel season, data from the daily summarized creel forms are entered in an Excel spreadsheet and analyzed to generate estimates of total steelhead catch. Below is a brief description of the analytical methods used to derive catch.

First, average daily estimates of catch are generated in a three-step process:

$$\widehat{Mean}(Daily\ effort) = \frac{Index\ count\ 1 + Index\ count\ 2}{2} \times Day\ Length/Trip\ Time \quad (1)$$

$$\widehat{Mean}(Daily\ catch\ rate) = \frac{Total\ Number\ of\ Fish\ Caught}{Total\ Number\ of\ Hours\ Fished} \quad (2)$$

$$\widehat{Mean}(Daily\ catch) = \widehat{Mean}(Daily\ effort) \times \widehat{Mean}(Daily\ catch\ rate) \quad (3)$$

where average effort, catch rate (i.e., CPUE), and catch are calculated for each individual survey date and for each individual pairwise combination of angler-type (e.g., plunkers), river section (e.g., Lower Hoh), and fish-type (harvested hatchery steelhead). The daily catch rate is calculated using the "ratio-of-the-means" estimator where the total number of fish caught and total number of hours fished for all interviewed anglers are combined for a single daily estimate. Currently, daily effort is calculated for plunkers, drifters, and private boaters by multiplying the average of the daily index counts by the total day length (i.e., hours of day from sunrise to sunset). However, daily effort is calculated for guided boat anglers by multiplying the average of the daily index counts by the average trip time for guided boaters (typically eight hours). See "Future Recommendations" section for further discussion.

Second, the average daily catch estimates are then expanded to generate weekly estimates (stratified by "day-type" - weekends and weekdays) using:

$$\widehat{Mean}(Weekly\ catch) = \frac{\sum_{i=1}^{n} \widehat{Mean}(Daily\ catch)}{n} \times N \quad (4)$$

where n is the number of days sampled (creeled) and N is the total number of days in a given week (i.e., sampled and non-sampled) for each individual day-type.

Lastly, monthly and annual catch estimates are generated by summing all weekly estimates for each pairwise combination of angler-type, river section, and fish-type:

$$\widehat{Mean}(Total\ catch) = \sum_{j=1}^{n} \widehat{Mean}(Weekly\ catch) \quad (5)$$

Angler-types are defined as either plunkers, drifters, private boaters, or guided boaters based on previous knowledge that catch rates vary among these four-groups. Because trailers are enumerated in index effort sections (opposed to boats), the trailers counts are expanded to boats under the assumption that one trailer equal one boat. Boats are then partitioned into either guided or private based on either (1) the creel technicians best judgement using the characteristics of each individual vehicle/trailer (e.g., guide vehicles typically have lots of sponsors stickers) or (2) ratio of these two angler-types from angler interviews. The number of boats is then expanded to number of anglers by multiplying the number of boats by the average number of anglers per boat. Rivers are sub-divided into "Upper" and "Lower" sections for each of the major rivers within the Quillayute (Sol Duc, Bogachiel, Calawah) and Hoh (mainstem Hoh) based on geographic break-points listed in WDFW's fishing regulations (Table 1). Steelhead are sub-divided into four main fish-type categories based on origin (hatchery, wild) and fate (harvested, released).

Table 1. Description of the Lower and Upper section delineations by river for the recreational steelhead creel surveys conducted in the Quillayute and Hoh rivers. Within each river, fishing regulations differ between the Upper and Lower sections and therefore catch is reported as two separate areas on catch record cards (CRC).

Basin	River	Section	Miles of River	Downstream	Upstream
Quillayute	Bogachiel	Lower	15.2	Mouth of Bogachiel River at Leyendecker's, including Richwine Bar	US. Hwy 101 Bridge
		Upper	7.2	US. Hwy 101 Bridge	Olympic National Park Boundary
	Sol Duc	Lower	24.7	Mouth of Sol Duc at Leyendecker's	Sol Duc Hatchery concrete pump station
		Upper	14.7	Sol Duc Hatchery concrete pump station	U.S. hwy 101 Bridge upstream of Klahowya Campground
	Calawah	Lower	6.9	Mouth of Calawah at Bogachiel Confluence (near Forks Hole)	US. Hwy 101 Bridge @ river-mile (RM) 6.9
		Upper	9.3[¥]	US. Hwy 101 Bridge	Olympic National Park Boundary (only to Hyas Creek)
Hoh	Hoh	Lower	13.9	Olympic National Park Boundary near river mouth	Dept. of Natural Resources' Oxbow Campground boat launch
		Upper	15.6	Dept. of Natural Resources' Oxbow Campground boat launch	Olympic National Park Boundary below SF Hoh (DNR Campground)

[¥]The SF Calawah River is closed to fishing upstream of the confluence with the NF Calawah (RM 10.6) after the last day in February, which effectively limits the Upper Calawah to ~3.7 miles.

Evaluation of the Current Coastal Creel Goals and Methodology

In order for the primary goal of the coastal creels (i.e., generate unbiased catch estimates) to be met, three assumptions of the data analysis must be true of the current methodology: (1) angler effort enumerated in the index areas is a census of all fishing locations for each river-section, (2) creel technicians are representatively sampling angler-types when conducting interviews, and (3) anglers are truthful when responding to creel interview questions. While it is important that all three of these assumptions are met, the first assumption (i.e., index effort counts = total effort counts) is currently in most need of assessment. With regard to the secondary goal, estimates of precision are currently not being generated and thus this goal is not being met. Therefore, the following sub-sections address two specific areas of concern with the current methodology. First, I assess the assumption that effort counts are accounting for all possible angler effort; second, I demonstrate how to calculate precision for the catch estimates.

Evaluation of Angler Effort Data Collection Methods

The goal of an effort count is to provide a “snap-shot” of fishing effort (i.e., the number of anglers) on a given day and time, which is subsequently used to generate temporally expanded estimates of effort (i.e., numbers of hours fished). Therefore, the counts are designed to be instantaneous as possible, meaning that the area covered can be surveyed in approximately one hour. However, it is often impractical and/or impossible to census all possible fishing locations for an entire fishery in an hour. For example, the Hoh and Quillayute watersheds consist of approximately 80 and 145 miles of fishable river miles, respectively, and much of these areas are not easily accessible. Thus, it is often necessary to select a sub-portion of the river to serve as an index of effort. These selected index areas should consist of a mixture of the different angler-types anticipated to utilize the fishery and contain the highest proportion of all anglers as possible.

Depending on fishing access and the geographic extent of a particular fishery, the proportion of all anglers that are surveyable in the selected index areas will vary. For instance, when fishing access is limited and/or the total fishable area is relatively small, it is possible that a small number of fishing sites may contain most or all of the fishing pressure. Additionally, if all boat anglers launch and land from a limited number of public boat ramps then these angler-types can essentially be censused by enumerating boat trailers even if the anglers themselves are not visible to surveyors. Conversely, if a specific fishery contains a large number of access and fishing sites over expansive areas then the index reaches will almost always represent only a fraction of all angling effort. In this latter case (i.e., when the index counts are not census counts), additional surveys are needed to develop a relationship between angler effort in the standardized index reaches and angler effort throughout the entire river that is open to fishing. One method to develop this relationship is to conduct periodic “tie-in” surveys where both index reaches and the entire fishery are surveyed simultaneously. Tie-in surveys are typically conducted via a motorized (truck, boat, plane, helicopter) or non-motorized vehicle (boat) depending on the size of the fishery and access/visibility.

Currently, the coastal creels are not implementing any sort of tie-in survey to expand index counts. Thus, the effort estimates being generated assume that angler effort in the standardized index count areas represent 100% of all angling effort. Although the standardized index areas do comprise the most popular fishing areas within the Hoh and Quillayute sub-basins, these index sections do not consist of all possible fishing locations and two independent sources of data suggest that effort, and thus catch, is currently being underestimated.

The first line of evidence that angler effort is currently underestimated comes from historical steelhead creel data from the Quillayute River. The current coastal creel study design is still largely based on the methods that were developed for the historical steelhead creels on the Quillayute River. Historical creels were designed using an "index-expansion" model that relied on tie-in surveys to develop angler effort expansion factors (i.e., regression coefficients). Tie-in surveys involved one to four aerial flights each month over the length of the fishing season. Regression coefficients that expanded index counts to a total angler effort were calculated for individual river-sections, angler-types, and, when possible, by month. These aerial tie-in flights were routinely conducted each year on the Quillayute River from the mid-1970s through the late 1990s and the results of these surveys can be found in old WDFW reports (e.g., Washington State Game Department 1977, 1979, 1980) and various PDF files (obtained from Robert Leland, WDFW, *Robert.Leland@dfw.wa.gov*). Although a formal analysis of all available historical reports was not completed, the previously calculated expansion factors on the Quillayute River commonly range from 1.0 to 3.5, but sometimes were greater than 10.0. An example of expansion factors derived for the Bogachiel and Calawah rivers in the 1992-93 creel season is shown in Table 2. Because catch estimates are directly proportional to estimated effort (equation 3), catch estimates will always be underestimated if angler effort is underestimated (i.e., true expansion factor is greater than one). For instance, calculated catch by boat-anglers on the Bogachiel River in December 1992 would have been underestimated by almost a third had the expanded effort data not been incorporated. It is possible that these historical effort expansion factors have changed relative to present day due to changes in effort count index reaches, fishing boundaries, fishing regulations, and angler demographics. However, the consistent pattern of expansion factor results (i.e., expansion >1) across multiple decades suggests that the index counts rarely represent 100% of angling effort.

The second line of evidence that angler effort is currently underestimated by the coastal creel surveys comes from a comparison of estimated steelhead catch generated via creel surveys with the catch estimate derived from the catch record card (CRC) expansion method. CRC estimates are generally thought to be unbiased as the methodology uses a stratified random sample design and incorporates an estimate of reporting bias (Kraig and Smith 2010). Additionally, a recent analysis from the South Fork Toutle and Washougal rivers in the lower Columbia River found that estimates of steelhead catch derived with the CRC method were similar to those derived with creel analytical methods (Bentley et al. 2015). Therefore to evaluate the importance of tie-in counts, I compared CRC and creel derived estimates of catch for harvested steelhead in years when tie-in counts were conducted (and thus presumably incorporated into the creel catch estimates) and in years when tie-in counts were not conducted. The purpose was not to conduct a formal regression analysis, but rather to compare catch estimates between the two methods in years when the creel surveys did and did not use tie-in surveys to expand angler counts.

Table 2. Example of historical "expanded effort" results from Bogachiel and Calawah rivers during 1992-93. Expanded effort is the regression coefficient between number of anglers counted during census aerial flights relative to the number of anglers counted in index sections. A coefficient >1 means the index counts do not represent census counts while a coefficient of 1 means all angling effort occurred in the index reach. Values <1 are grayed out because in theory these should not occur and suggests there was an issue with the surveys (e.g., observer efficiency of flights <100% for drifters and plunkers). Data obtained from Robert Leland, WDFW, *Robert.Leland@dfw.wa.gov*.

River	Angler-Type	Month	Expanded Effort	River	Angler-Type	Month	Expanded Effort
Bogachiel	Boat	Dec	2.95	Calawah	Boat	Dec	2.50
		Jan	2.34			Jan	2.88
		Feb	2.69			Feb	2.50
		Mar	2.15			Mar	1.00
	Drifter	Dec	1.94		Drifter	Dec	0.73
		Jan	3.73			Jan	1.25
		Feb	6.21			Feb	1.13
		Mar	0.33			Mar	0.27
	Plunker	Dec	0.00		Plunker	Dec	1.00
		Jan	0.53			Jan	1.00
		Feb	0.19			Feb	1.00
		Mar	9.00			Mar	1.00

Three datasets were needed to conduct this analysis (and were provided by): (1) CRC data (Eric Kraig, WDFW, *Eric.Kraig@dfw.wa.gov*), (2) “index-expansion” creel data, which are historical creel estimates (prior to 2001) for when tie-in surveys were conducted (Robert Leland), and (3) “index-census” creel data, which are more recent creel estimates (after 2001) when tie-in surveys were not conducted (Randy Cooper). The index-expansion creel dataset consisted of nine total annual estimates of steelhead catch from 1976-77 to 1985-86 and nine total monthly estimates (December to February) from 1994-95 to 1996-97 collected from the Quillayute River. The index-census creel data set consisted of 12 total (annual) catch estimates for the Hoh River (2002-03 to 2014-15) and two for the Quillayute River system (2013-14 to 2014-15).

For the “index-expansion” dataset, the creel and CRC estimates are relatively similar among the 18 paired datasets and, with the exception of a few data points, most fall along the 1:1

relationship line (Figure 1). Conversely, for the “index-census” creel data, most paired data points fall below the 1:1 relationship line (Figure 2) meaning that the creel estimates used in this second comparison were consistently less than CRC estimates. Interestingly, in the analysis of “index-census” creel data, the estimates of wild fish harvest were more similar to CRC estimates while all but one hatchery creel estimate was less than the CRC estimate. This pattern may result from one of many drivers (e.g., under reporting of wild catch on CRCs) or may be an artifact of low catch and uncertainty in the estimates. Regardless, creel estimates were more similar to CRC estimates in years when tie-in expansion data were incorporated into harvest estimates.

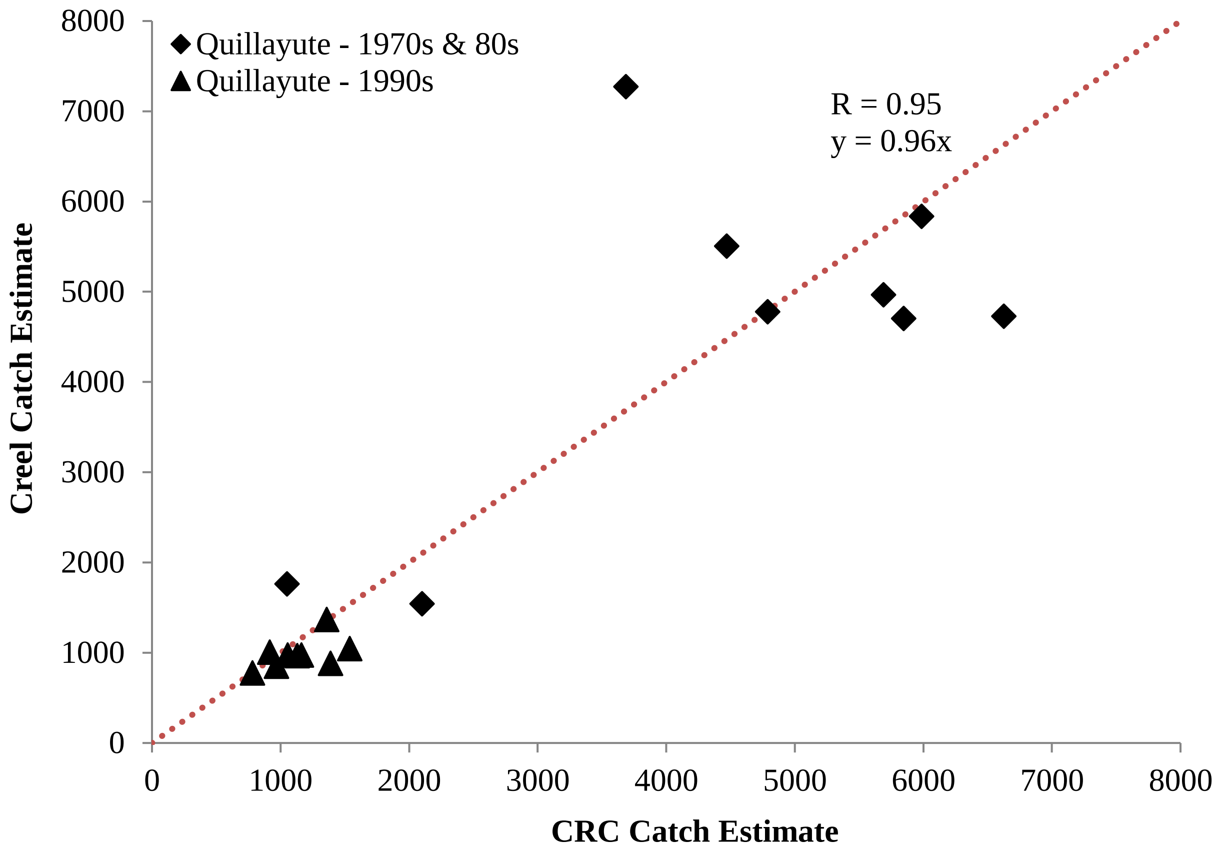


Figure 1. Comparison of catch record card (CRC) and creel generated estimates of steelhead catch (i.e., harvest) from years when tie-in flights were conducted. Data were collected from the Quillayute River during 1976-77 to 1985-86 (nine total <u>annual</u> estimates) and during 1994-95 to 1996-97 (nine total <u>monthly</u> estimates, December – February). A 1:1 relationship is shown by the red dashed line. Prior to mid-1980s, steelhead were not mass marked and thus harvest estimates were a combination of hatchery and wild fish. The data source for the 1990s data did not specify whether data were hatchery or combination of hatchery and wild. No formal regression analysis was conducted but the correlation coefficient (R) and best-fit linear regression equation (combined datasets) are shown for reference.

Taken together, there is fairly substantial evidence that recent coastal creel catch estimates (i.e., since 2002-03) have underestimated the true total catch given that (1) tie-in counts are no longer conducted and thus any angling effort occurring outside of index effort count reaches has not been incorporated into catch estimates, (2) historical tie-in counts demonstrated that a substantial portion of angler effort can occur outside of the index reaches, and (3) recent creel-generated estimates of harvested steelhead (no tie-in counts) are generally less than those generated via CRCs while historical creel estimates (tie-in counts) typically matched CRC estimates. Another explanation for these findings is that present day index effort count sections encompasses a larger portion of angler effort relative to historical surveys and that CRCs overestimate harvest in the Hoh and Quillayute river systems. However, given the evidence and the potential that the current creel method is underestimating catch, I strongly recommend a re-evaluation of the angler effort count methods. Specifically, in order to ensure that the primary goal of the coastal creels is being met, tie-in surveys need to be conducted in future years to assess angler effort (see "Recommendations").

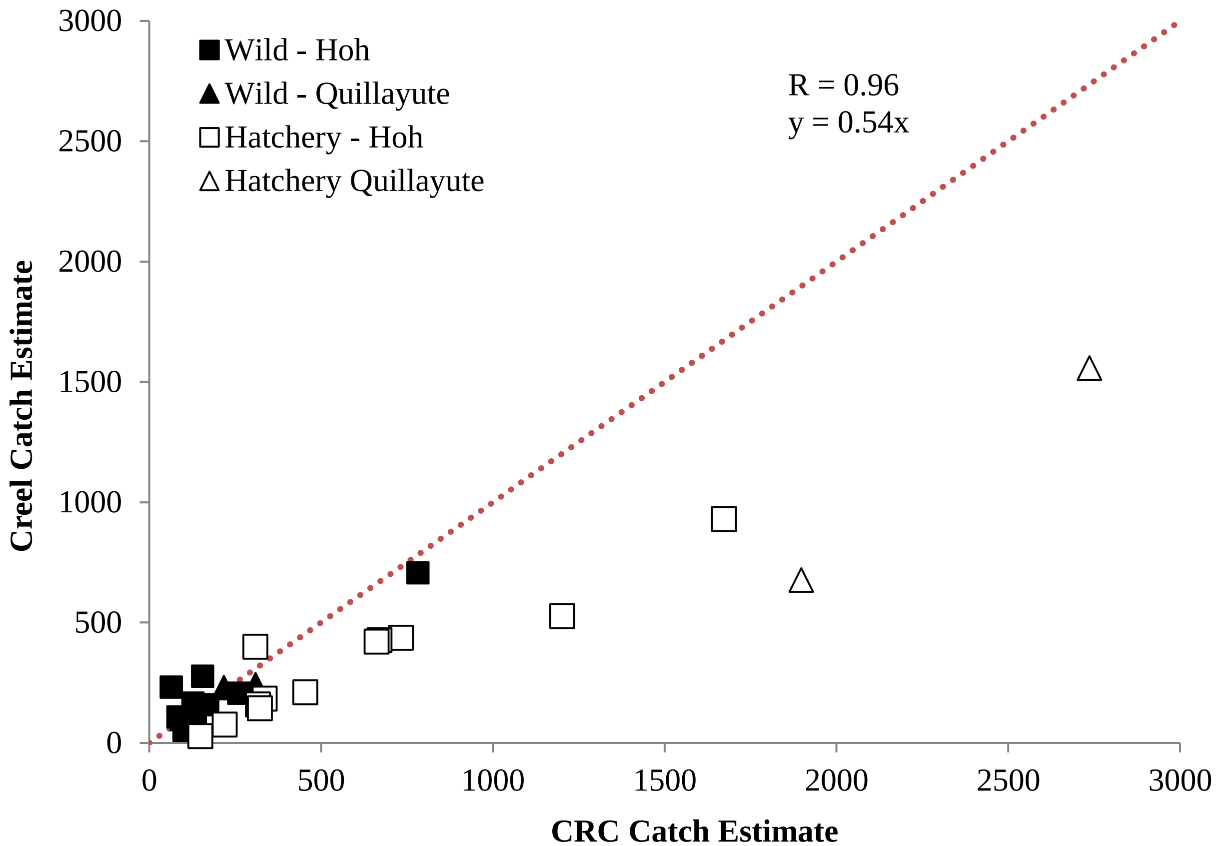


Figure 2. Comparison of catch record card (CRC) and creel generated estimates of catch (i.e., harvest) in years since tie-flights were discontinued. Each data point represents a total annual harvest estimate for hatchery (white) and wild (black) steelhead. Data were collected in the Hoh River system (square) from 2002-03 to 2014-2015 and in the Quillayute River system (triangle) from 2013-14 to 2014-15. A 1:1 relationship is shown by the red dashed line. No formal regression analysis was conducted but the correlation coefficient (R) and best-fit linear regression equation (combined datasets) are shown for reference.

Estimation of Catch Precision

While the primary goal of the coastal creels is to produce unbiased (i.e., accurate) estimates of catch, it is important that an estimate is precise enough to be informative. Therefore, the secondary goal of the coastal creels is to generate catch estimates that have a precision of ± 20% at the 95% confidence level. Another way to express this same statement would be that catch estimates need to have a coefficient of variation (CV) of 0.10. CV is calculated as the standard deviation (SD) of the estimate divided by the mean (i.e., point estimate). As an example, a catch estimate of 1,000 with a CV of 0.10 would have a SD of 100 and a 95% confidence interval that ranges approximately from 800 to 1,200 assuming normal distribution. Currently, the precision of catch estimates from the coastal creel surveys are not being calculated. However, precision can be calculated using previously derived equations that have been outlined in both Pollock et al. (1994) and Hahn et al. (2000). Below, I outline the steps to calculate the precision of a catch estimate and then calculate the precision of steelhead catch estimates from the Hoh River in 2014-15. It should be noted the equations below pertain to the estimate of precision for any type of estimate. Therefore, precision can and should be calculated for estimates of angler effort and CPUE.

To calculate precision, first calculate the mean daily variance of catch using:

$$\widehat{Var}(Daily\ Catch) = \frac{\sum_{i=1}^{n}(Daily\ Catch - Avg.Daily\ Catch)^2}{n-1} \quad (6)$$

where the daily catch is calculated using equation 3, n is the number of sampled (creeled) days for a given week, and the average daily catch is calculated as the average of all daily estimates for a given week and day-type (weekends and weekdays).

Second, calculate the variance for each week (e.g.,) using:

$$\widehat{Var}(Weekly\ Catch) = \frac{\sum_{i=1}^{n}\widehat{Var}(Daily\ Catch)}{n} \cdot N^2 \quad (7)$$

where N is the total number of days within a given week and day-type. The weekly specific variance equation in Hahn et al. (2000) includes a "finite-population correction factor" (FPCF) if the sample size is at least 5% of the total population (i.e., total days in a given week) resulting in an equation of:

$$\widehat{Var}(Weekly\ Catch) = \frac{\sum_{i=1}^{n}\widehat{Var}(Daily\ Catch)}{n} \cdot N^2 \cdot \left(\frac{N-n}{N}\right) \quad (8)$$

The FPCF ultimately reduces the calculated variance relative to the proportion of creel days that are sampled for a particular week. Thus, it assumes that if you sample every weekend day in a particular week then the resulting variance is zero. However, this will almost never be true given that there is unaccounted for variance within the daily estimates (i.e., all anglers are not interviewed and effort is not censused). Therefore, I recommend using equation 7 to calculate strata specific variance without the FPCF as it provides a more realistic and conservative estimate.

Third, calculate the total variance for a particular period of interest (e.g., month or year) by summing all weekly estimates:

$$\widehat{Var}(Total\ Catch) = \sum_{i=1}^{n} \widehat{Var}(Weekly\ Catch) \quad (9)$$

Fourth, calculate the standard deviation (SD) and coefficient of variance (CV) using:

$$\widehat{SD}(Total\ Catch) = \sqrt{\widehat{Var}(Total\ Catch)} \quad (10)$$

$$\widehat{CV}(Total\ Catch) = \frac{\widehat{SD}(Total\ Catch)}{\widehat{Mean}(Total\ Catch)} \quad (11)$$

where the $\widehat{Mean}(Total\ Catch)$ is calculated using equation 5.

Using equations 1 – 11, I calculated the total catch of steelhead, and its associated levels of precision, from the 2014-15 Hoh River creel survey season using the program R (R Development Core Team 2011). Specifically, catch and precision estimates were generated for the each pairwise combination of fish origin (NOR = wild, HOR = hatchery) and fate (harvested, released) in the Upper and Lower river-sections of the Hoh River during the 2014-15 creel survey season resulting in a total of eight catch estimates (Table 3). Note that these estimates do not include tie-in surveys and thus are likely underestimates of catch and variance. Regardless, the resulting CVs for all eight estimates range from 0.11 to 0.25, which are all greater than the specified goal of 0.10. However, I would argue that these estimates of catch are relatively precise based on standards for other estimates. For example, the ESA monitoring guideline for precision of abundance is a coefficient of variation of 0.15 for salmon species and 0.30 for steelhead (Crawford and Rumsey 2011). Thus, before additional time and funds are invested in lowering the precision of the creel estimate, the current precision goal should be examined with regards to how the resulting data will be used for management and decision making. Given that estimates of precision have not been reported for over a decade, a first step would be to make these calculations for the all catch estimates from previous years and moving forward.

Table 3. Estimated total catch of steelhead and the associated levels of precision for pairwise combinations of fish origin (wild, hatchery) and fate (harvested, released) in the Upper and Lower river-sections of the Hoh River from Dec. 1, 2014 through Apr. 15, 2015.

River Section	Origin	Fate	Catch	Variance	SD	CV
Lower	Wild	Harvested	251	2,948	54	0.22
		Released	2,977	116,092	341	0.11
	Hatchery	Harvested	89	239	15	0.17
		Released	206	790	28	0.14
Upper	Wild	Harvested	31[¥]	61	8	0.25
		Released	1,603	40,424	201	0.13
	Hatchery	Harvested	-	-	-	-
		Released	120	198	14	0.12

[¥] Illegal harvest

Recommendations for Future Coastal Creels

Based on this review of the current coastal creel goals and methodologies, I recommend the following changes to both field and analytical methods. The list is prioritized in the order that items should be addressed to improve the accuracy and precision of steelhead catch estimates in the Hoh and Quillayute rivers.

1) **Implement effort expansion surveys**. Over the past decade, estimates of steelhead catch derived from coastal creel surveys have, in effect, assumed that all of the fishing pressure (i.e., angler effort) in the Hoh and Quillayute watersheds occurs in the index effort count reaches. Based on the evaluation provided in sub-section "Evaluation of the Current Coastal Creel Goals and Methodology", this assumption is likely not being met and is resulting in an underestimate (i.e., bias) of the total catch. To correct this issue, effort expansion (i.e., tie-in) surveys are needed to calculate the proportion of angling effort that is occurring in and out of the standardized index survey reaches. Based on the expansive area these fisheries encompass and need for the tie-in surveys to be completed "instantaneously," the only viable option for tie-in surveys is flights. Deciding how many flights are necessary will depend on many factors, including (1) budget/cost, (2) variability in tie-in results among surveys, and (3) desired precision of catch estimates. Historically, tie-in flights were conducted as part of the coastal creel survey methods and generally 1-4 flights were completed each month. Regardless of the total number, flights should be distributed among the fishing season and weekday types. Specifically here, flights need to occur both early and late in the season as well as on both weekends and weekdays to capture spatial and temporal differences in fish and angler distributions. If cost ultimately limits the total number of flights to a relatively small number (<5), flight days should be chosen that are likely to have the highest fishing pressure across the season (e.g., President's Day weekend and mid-March) – flights with larger counts will result in higher precision and are less likely to be biased due to small sample sizes. In the future, alternative effort expansion methods (e.g., drones, automated counters, floats) should be explored once more information on the current expansion ratios is known.
2) **Improve creel survey data storage.** Currently, individual angler interview and effort count survey data are summarized on a daily basis and the summary data are then entered into an Excel spreadsheet. Although daily and strata specific estimates of effort, catch per unit effort (CPUE), and catch can still be calculated under the current data storage format, there are many advantages to entering the individual data rather than the daily summarized data into a standardized database:
    - First, location specific index effort count data can be analyzed to improve the efficiency of creel surveys, resulting in a potential savings of time and ultimately cost. Currently, two to five creel technicians survey the Hoh and Quillayute river sub-basins each survey day and during the bi-daily effort counts visit 20-30 index sites. Although anglers are enumerated and data are recorded for each individual index site, these data are summarized and entered as a single count. However, if these raw individual index data were entered and analyzed, it is possible that not all index sites are needed and thus the coastal creel surveys could be conducted with fewer creel technicians. Index effort count sites are, as their name implies, only intended to be indices. Therefore, there only needs to be enough index sites surveyed to provide a robust and representative sample. This process of selecting index sites also requires there to be tie-in surveys conducted to extrapolate the index counts to the entire fishery.

If data were stored as individual interviews, a Monte Carlo simulation could be conducted to evaluate the number and specific location of index sites needed for a robust sample. Specifically, total (extrapolated) effort would be calculated by sub-sampling a different number of index sites and the sensitivity of the results to changes in sample size and specific sample locations could be evaluated. Because creel technicians conduct interviews in addition to effort counts, and these data are used to calculate CPUE, this same simulation would need to incorporate individual interview data (i.e., fewer technicians would mean fewer anglers could be interviewed in addition to fewer index sites surveyed). Depending on the results of this analysis, fewer technicians may be needed to conduct the creel surveys among the coastal creel sub-basins. If fewer technicians are needed, the cost savings could go towards paying for tie-in survey flights, which are critically needed to generate unbiased estimates of steelhead catch. Note: once the final set of index sites are selected, regardless of number, it is important that all sites are surveyed during every effort count (i.e., never sub-sample the index sites).

- Second, individually entered data will allow for data screening and additional estimates to be derived. Examples of estimates and changes to methods that cannot be made until individual data are available for analysis include:
    1. *Calculation of CPUE*: Currently, average daily catch per unit effort (CPUE) is calculated using the "ratio-of-the-means" estimator (i.e., all catch divided by all effort). However, a better estimate would be the "mean-of-ratios" CPUE (i.e., average CPUE per group divided by number of groups interviewed), which alleviates the potential for a "length-of-stay" bias caused by the inclusion of both complete and incomplete trip data in the estimate (Pollock et al. 1994). Length of stay bias occurs when anglers who fish longer are more likely to be interviewed and their resulting information is unequally weighted when calculating CPUE.
    2. *Removal of short-incomplete trips:* Previous analysis suggest "incomplete" trips that are less than 30 minutes should be removed from the analysis to decrease bias in the CPUE estimate (Pollock et al. 1997, Hoenig et al. 1997). "Trip status" (i.e., is the angler's fishing trip "complete" or "incomplete" at the time of the interview) data are currently collected in the field, but lost upon summarization.
    3. *Calculation of Number of Anglers*: Angler effort is calculated as the total number of "angler-hours," but can be converted to number of anglers with information on average trip time per angler (i.e., number of anglers = angler hours / avg. trip time). However, average trip time should only be calculated from angler-group interviews with completed trips. Without a calculation of number of anglers, it is impossible to calculate the proportion of all anglers that were subsequently interviewed (and thus part of the creel survey).
- Third, storage of creel data in a standardized database will improve the efficiency of data analysis and the reliability of collected data through QA/QC protocols. For example, in a couple of days I analyzed one year of Hoh River steelhead creel data by adapting R code that I had previously written to analyze steelhead creel survey data collected from lower Columbia River tributaries. Most of the expended time was spent reformatting the Excel spreadsheet data, and this reformatting would not be necessary if the data were entered into a standardized database. From the resulting R code, I was not only able to produce

estimates of catch, and their associated levels of precision, but I also created summary figures that could be made publicly available on an annual basis through final reports (see "Appendix A – Results of Hoh River 2014-15 Creel Survey").

- o Therefore, individual daily creel data need to be entered into a standardized creel database. A database developed by WDFW for lower Columbia River tributary creels could potentially be adapted for use with the coastal creels.

3) **Ensure creel survey sample schedules are randomized.** The current coastal creel methods used to calculate effort, CPUE, and catch are based on peer-reviewed analytical approaches (Pollock et al. 1994). However, in order to truly implement this approach, the field data (i.e., angler counts and interviews) must be collected in a representative manner that reflects the assumptions of the calculations used. Typically, roving creel surveys are implemented using a stratified random survey design similar to methods used for the coastal creels. Specifically, the creel survey sample schedule is generated by: first, selecting a specified number of weekend and weekday samples per week; second, selecting randomized start times for each day; and third, selecting randomized effort count times. The calculation for expanded weekly catch that is currently used assumes that within a given week the sample schedule provides a uniform distribution of effort count times (note: there are other methods available if this is not the case; e.g., Malvestuto et al. 1978). Based on the data collected and conversations with the lead biologists, this general format appears to be followed, and it is critical that the lead biologists continue to ensure the schedule generation process follows this strict logic. For example, if effort count start times are not randomized and not uniformly distributed, it is possible that the resulting samples will not be representative and estimates will biased. Randomized selection of effort count times will result in surveys that occur during times of the day when angling pressure is both high and low.

4) **Expand standardized set of creel interview questions.** Although the primary goal of the coastal creels is to estimate the catch of wild and hatchery steelhead, the resulting data can be used to calculate encounter rates (i.e., number of fish caught divided by run size), the hooking mortality of C&R fish (i.e., catch multiplied by a C&R mortality rate), and total impact rates (i.e., hooking mortalities divided by run size). Current estimates of hooking mortality are calculated by applying a single C&R mortality rate of 10%. However, there is increasing evidence that C&R mortality rates are influenced by angling techniques, environmental conditions, fish handling, and terminal gear (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005, Arlinghaus et al. 2007, and Cooke et al. 2013). An analysis by Rawding and Bentley (*in prep*) found that hooking location (e.g., jaw, gills, eye, stomach) and water temperature were the most influential factors affecting the mortality of steelhead and developed a model to predict the C&R mortality rate based on these factors. Therefore, the current set of creel interview questions should be expanded to at least include hooking location and potentially match the entire list of interview questions that are being used on lower Columbia River tributaries (see "Appendix B – Creel Survey Datasheets").

5) **Calculate expanded daily effort using average day length.** Currently, daily catch is calculated two ways depending on angler-type. For plunkers, drifters, and private boats, daily catch is calculated by multiplying the average of the index effort counts for an individual day by the total day length (sunrise to sunset). For guided boats, daily catch is calculated by multiplying the average index count for an individual day by the average trip time for guided boats, which is assumed to be eight hours on most days. However, the current calculation used for guided boats will always result in an underestimate of angler effort for this angler type. Therefore, averaged index effort counts should only be expanded using the day length regardless of angler-type

assuming data are collected using a stratified random survey design resulting in a uniform sample distribution (see recommendation #3).

To demonstrate why the day length expansion should be used, as opposed to average trip time, I created a simple two-part simulation. First, I simulated the distribution of angler-effort for a given day based on a set number of anglers and an average trip time (Figure 3). Second, I created a randomized creel schedule with two effort count times, which sampled the simulated angler distribution (here I assumed the effort counts were censuses of angling effort during the time period sampled). The creel schedule was created two ways: (1) Simple random sample: the day was evenly divided into two periods ("morning" and "afternoon") and a count time was randomly selected from both periods; (2) Systematic sample: the first effort count time was randomly selected during the morning period and the second count sample occurred a specified amount of time later (e.g., four hours following the first sample). Third, I calculated the expanded daily effort by averaging the two effort counts and expanding by either day length (12 hours) or average trip time (8 hours). Steps 1 – 3 were repeated 500 times and the results from each simulation were saved. Using the results from each simulation, the overall average daily effort was calculated, along with the associated CV, and compared to the true angler effort.

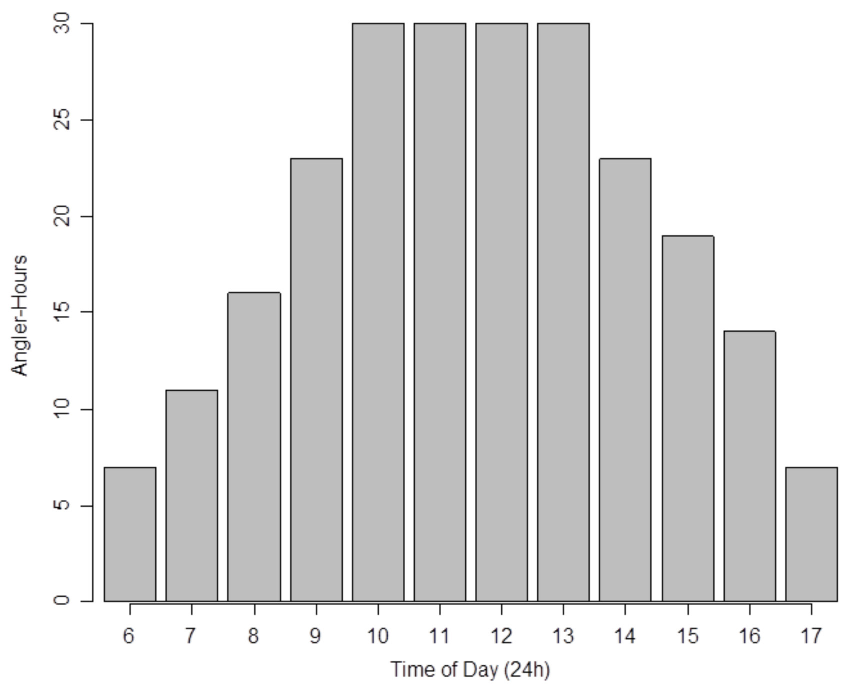


Figure 3. Example of the distribution of angler effort (angler-hours) by time of day (24hr) used in the effort count expansion simulation. In each simulation, there was a total 240 hours of angler-effort per day (30 anglers and each fished for eight hours), but each angler had varying start and end times and therefore the shape of the distribution changed.

The results from the simulation demonstrate that regardless of the sample scheme (i.e., systematic or simple random), estimated angler effort will always be underestimated (i.e., biased) using the "average trip time" expansion method (Figure 4C, Figure 4D) while estimates of angler effort using the "day length" expansion method were centered around the true mean (Figure 4A, Figure 4B). Interestingly, the systematic sample method resulted in a much more precise estimate relative to the simple random method (i.e., lower CV). Put another way, although catch estimates from the simple random sample method were unbiased over the total number of simulations, individual estimates of effort (i.e., a single simulation) were much more likely to be biased relative to the systematic sample method (again, for the "day length" expansion method).

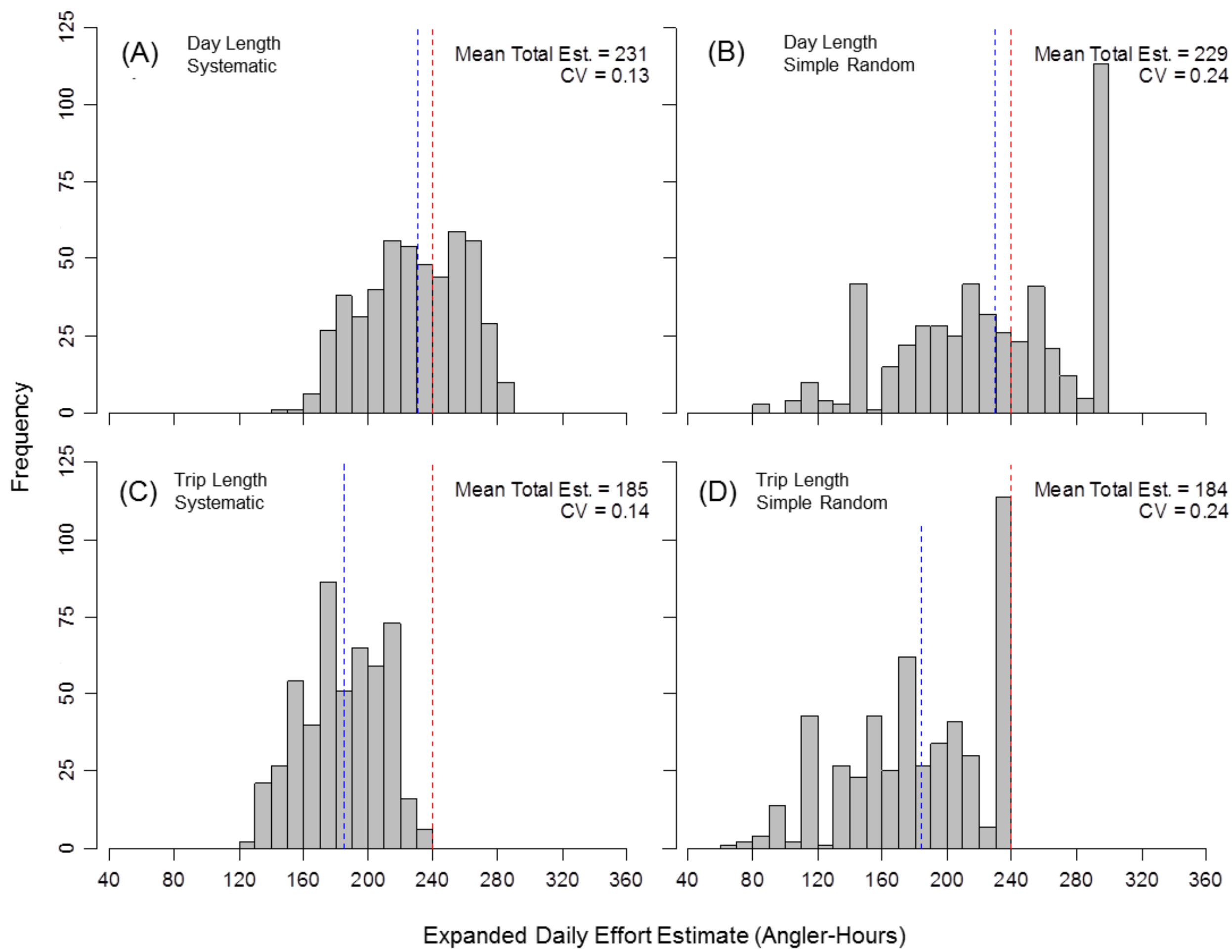


Figure 4. Effort count simulation results. Distribution of daily effort estimates as a function of the expansion method (day length vs. trip length) and effort count start time method (systematic vs. random). The mean estimate of angler effort across all simulations (n = 500) is shown with the blue vertical dashed line while the true mean is shown with the red vertical dashed line.

Based on the results of these simulations, the "day length" expansion should be used for all estimates of daily effort using a systematic random sample design to schedule the creel survey effort count start times. Because coastal creel catch estimates in previous years have used the "average trip length" expansion method for guided boaters, estimates of catch in these years will have been underestimated. For example, when I re-ran the catch calculations for the Lower Hoh River in 2014-15 using the day length method, estimates of total C&R wild steelhead catch for guided anglers differed by over 1,000 fish (previous estimate = 942, updated estimate = 2,099). Thus, all prior year steelhead catch estimates may need to be re-analyzed.

6) **Expand the classification of angler-types.** The current coastal creel survey methods classify anglers into four groups: plunkers, drifters, private boaters, and guided boaters. During effort counts, plunkers and drifters are directly enumerated while boat trailers are used as a surrogate for boaters and expanded to anglers during analysis assuming a 1:1 relationship between trailers and boats. Although this method provides a creative way of enumerating trailers over expansive areas, boaters without trailers (i.e., single-craft boats such as pontoons and kayaks) will never be counted leading to an underestimate of angler effort. Therefore, effort count categories and angler interview questions need to be modified to ensure all angler-types are properly accounted for.
    - For index effort counts, technicians should count four categories of "angler- types":
        - Trailers
        - Single-craft boats (i.e., 1 boat = 1 angler)
        - Drifters
        - Plunkers
    - For interviews, questions for anglers will be:
        - *Trip Type*: private or guided
        - *Angler-Type*: drifter, plunker, or boater (boater = single or multi-craft)
        - *Trailer (Y/N)*: If boater, does boat have an associated trailer (ask angler if trailer exists if one not present at interview)
        - *Fish from boat (Y/N):* If boater, did angler(s) primarily fish from the boat or primarily use it for transportation

    These slight modifications to the data collection protocols will now allow boaters to be properly enumerated and incorporated into the estimates. For example, the relationship between trailers and boats could be actually calculated, instead of assuming 1:1. Alternatively, given that anglers rarely fish from single-craft boats (that are unlikely to be associated with a trailer), these boaters would effectively be enumerated as drifters during effort and tie-in counts, but could then be apportioned out based on interview data using the same logic as to how private and guided boats are divided.

7) **Expand duration of creel survey to encompass entire winter steelhead run.** The coastal creel surveys typically begin in early December and continue through late April to match the directed winter steelhead recreational fisheries. However, winter steelhead can potentially still be caught after April in spring Chinook salmon fisheries (e.g., Sol Duc River) as steelhead spawning can extend in June (*Randy Cooper, WDFW, personal communication*). Although the large majority of winter steelhead catch in May and June will likely be kelts, creel surveys need to extend past April if the goal of the creel surveys is to truly enumerate the total number of steelhead caught in recreational fisheries, whether they are caught in the directed fisheries or a result of bycatch.

8) **Assess how trailer counts are partitioned into guided and private boats.** As previously mentioned, trailer counts are expanded to boats assuming one trailer per boat and boats are partitioned into either guided or private based on either (1) the creel technicians best judgement using the characteristics or familiarity of each individual vehicle/trailer (e.g., presence of sponsors stickers on guide vehicles) or (2) ratio of these two angler-types from angler interviews. In order to obtain unbiased estimates of boat counts, both methods require certain assumptions to be met. For the first method, creel technicians must be able to consistently and accurately assign trailers to an angler-type. For second method, creel technicians must interview private and guided boats in exact proportion as they are abundant throughout the entire fishery. For example, if there are 25 total boats throughout the entire Lower Hoh River of which 10 are guided and 15 are private then 40% of the interviews would need to be guided boaters and 60% private regardless of the total

number conducted. In theory, by "randomly" interviewing anglers, the proportion interviewed will represent the true proportion. However, if angler interviews are not entirely random due to unequal sampling probability (e.g., technicians inadvertently targeting one angler-type or anglers are not equally available to be interviewed) then the sampled ratio will not match the true ratio. Although hypothetically possible, the assumptions with both of these methods would be difficult to test. Therefore, it is important to assess how sensitive total catch estimates are to the chosen expansion method by calculating daily effort for private and guided boaters both ways. Ultimately, the method used to expand trailer counts should be the one that is most likely to lead to accurate estimates (i.e., meets the inherent assumption(s) of the method).

9) **Collect "River Out" classifications on all dates.** Qualitative assessments are used by coastal creel technicians to classify daily fishing conditions of each river. When high flow leads to poor fishing conditions, the river can be classified as "out" and the creel surveys are subsequently cancelled based on the assumption that angling effort and/or catch is effectively zero. As long as the assumption that angling effort/catch is truly zero and river out days are consistently classified, utilizing this information can lead to more precise estimates of catch because a higher proportion of "fishable" days are then sampled. However, in order for this approach to work, river out information needs to be collected on all dates throughout the fishing season and not just on schedule sample dates. If river out data is collected on all dates, these dates can essentially be removed when expanding daily estimates to strata (i.e., weekly or monthly) estimates resulting in estimates only being generated for fishable days (on both sampled and non-sampled dates). If river out classifications are only made on sample dates then this information is not as informative and the day should be creeled even if no anglers are present. If river out classifications are only made on sample dates but creel surveys are cancelled and moved to alternative dates, expanded catch may potentially be overestimated as days with low to zero catch are not part of the sample but can still occur on non-sampled dates. In summary, river out classifications need to be defined and implemented in a clear and consistent fashion. By collecting this information on all dates, catch estimates can be improved.

10) **Distribute interview "effort" proportion to angler-type and locations.** Similar to recommendation #8, creel technicians need to conduct angler interviews in proportion to the distribution of angler-types and in proportion to how anglers are using different fishing locations. This will ensure representative catch rate data are being collected, which is important because (1) the larger the number of anglers there are for a particular angler-type the higher likelihood that their catch rates will differ and (2) catch rates can differ throughout different areas of the river. During the creel season, this "requirement" can be difficult to assess and therefore it is best to instruct creel technicians to think about the distribution of angler-types among all fishing locations that they are actively seeing and attempt to distribute their interviews in a similar proportion (opposed to focusing on a particular angler-type or location that is easier to sample). During data analysis, the distribution of angler interviews relative to angling effort can be assessed. For example, we can evaluate the correlation between the total number of angler interviews and the expanded estimates of effort by angler-type and month. During the 2014-15 Hoh River creel season, there is strong evidence that creel technicians did a good job distributing their interviews in proportion to the overall abundance of each angler-type (Figure 5). Specifically here, we see that the data points generally fall along the red-dashed line, which represents a slope of 0.10, for almost all months and angler-types. The only exception is that in the highest angler effort months, proportionally fewer boat anglers were interviewed. However, this was likely a result of work load

capacity of technicians (i.e., an individual technician can only interview so many anglers in a given day) opposed to an inappropriate distribution of angler interviews.

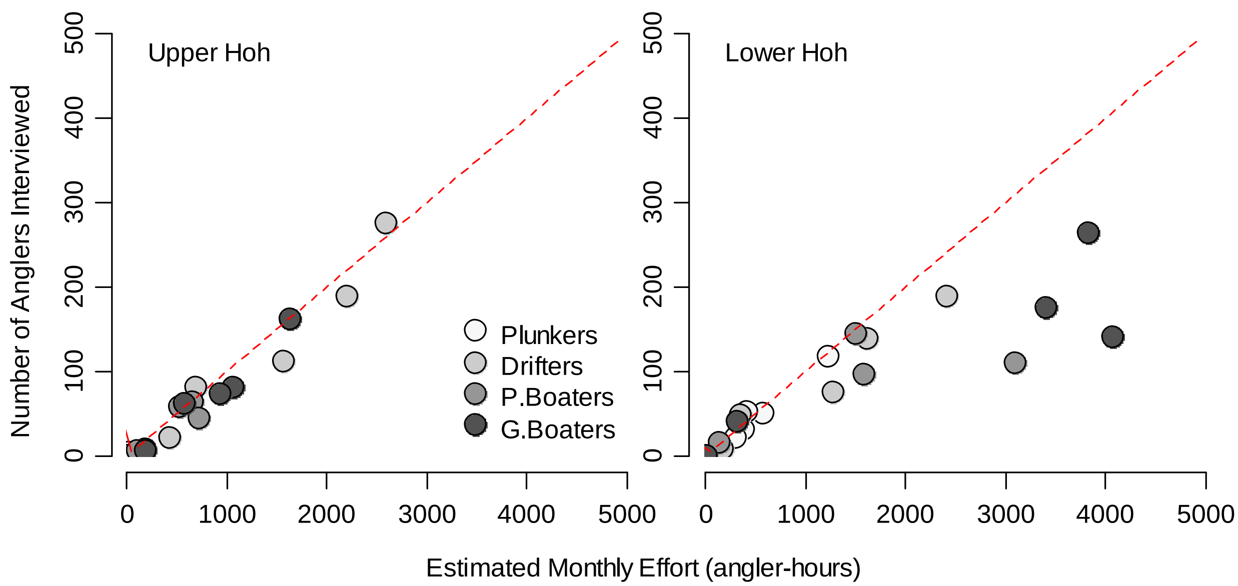


Figure 5. Correlation between the number of anglers interviewed and the estimated (expanded) angler effort by river-section (Upper and Lower) month and angler-type (plunker, drifter, private boater, and guided boater) on the Hoh River, 2014-15. Each individual data point represents a monthly estimate. The red-dashed line represents a slope of 0.10 and is only shown for reference (i.e., if all data points fell exactly along the line then anglers were interviewed in equal proportion to their relative effort among angler-types and months).

11) **Consider the effect of time strata length on catch estimates.** Estimates of catch can be derived at many different time scales (i.e., strata length; daily, weekly, bi-weekly, monthly, annually). Choosing the appropriate strata length may depend on management needs. For example, historical coastal creel estimates of steelhead catch were derived bi-weekly during the recreational fishery to provide "real time" information for fisheries managers. However, if in-season estimates are not needed one should consider how a particular strata length affects the accuracy of the catch estimate. For instance, data that are divided into smaller strata (e.g., daily or weekly) will more closely represent the specific fishing conditions during that period and estimates will be able to capture the heterogeneity in angler effort and catch among these smaller strata. However, smaller strata will also have fewer samples (effort counts and angler interviews), which can potentially lead to inaccurate and/or imprecise estimates. Over the past few years, steelhead catch estimates for the Hoh and Quillayute rivers have been calculated upon completion of the entire creel season and total (i.e., annual) catch estimates have been calculated by stratifying catch estimates by day-type within each week. However, end-of-season estimate can be derived with almost any strata length (e.g., day-type with a month). Thus, it is important to consider the trade-offs of choosing a particular strata length to ensure an unbiased catch estimate is obtained.

To help assess the effects of strata length, I created a simulation that calculates angler effort by stratifying estimates by both week and month. Similar to the simulation outlined previously in section #5, I first simulated the distribution of angler-effort for each day throughout an entire month (n = 31 days) by randomizing the number of anglers fishing (5 to 100), the length of time each angler spent fishing (mean = 5 hrs, sd =1.5), and the time of day each angler began fishing. Second, I created a stratified random creel schedule. Here, two weekend days and three weekdays were sampled each week and on each individual day two effort counts were conducted using effort count starts times derived from a systematic sample. Third, I calculated the daily estimate of effort for each creeled date using the day length expansion method (equation 1). Fourth, daily estimates of effort were then expanded to monthly estimates by stratifying the daily estimates by either individual weeks or the entire month. Steps 1 – 4 were repeated 500 times and the calculated angler effort estimate from each simulation was saved. Finally, the two derived estimates were compared by calculating (1) the percent difference between the modeled estimate and the true angler effort, and (2) the root-mean-square-error (RMSE) for each set of modeled estimates, which basically is a relative measure of accuracy.

The results of the simulation demonstrate that monthly derived estimates produce more accurate results relative to weekly derived estimates (Figure 6). Specifically, 98% of the monthly derived estimates were within ±20% of the true estimates while 92% of the weekly derived estimates were within ±20%. While this is not a substantial difference and both nearly met the current coastal creel precision goals, it is important to remember these are only simulated data whose results reflect the supplied variability in angler effort within and among days. Therefore, the main take away from this exercise is not to say weekly derived estimate are inferior to monthly estimates, but rather to explain that additional thought is required regarding the strata lengths used in the calculations. For the north coast rivers, I would recommend switching to monthly estimates knowing how variable fishing conditions can be among days within a week. However, it may be worth calculating catch estimates with both weekly and monthly strata see how sensitive the total catch estimates are to the choice of strata length.

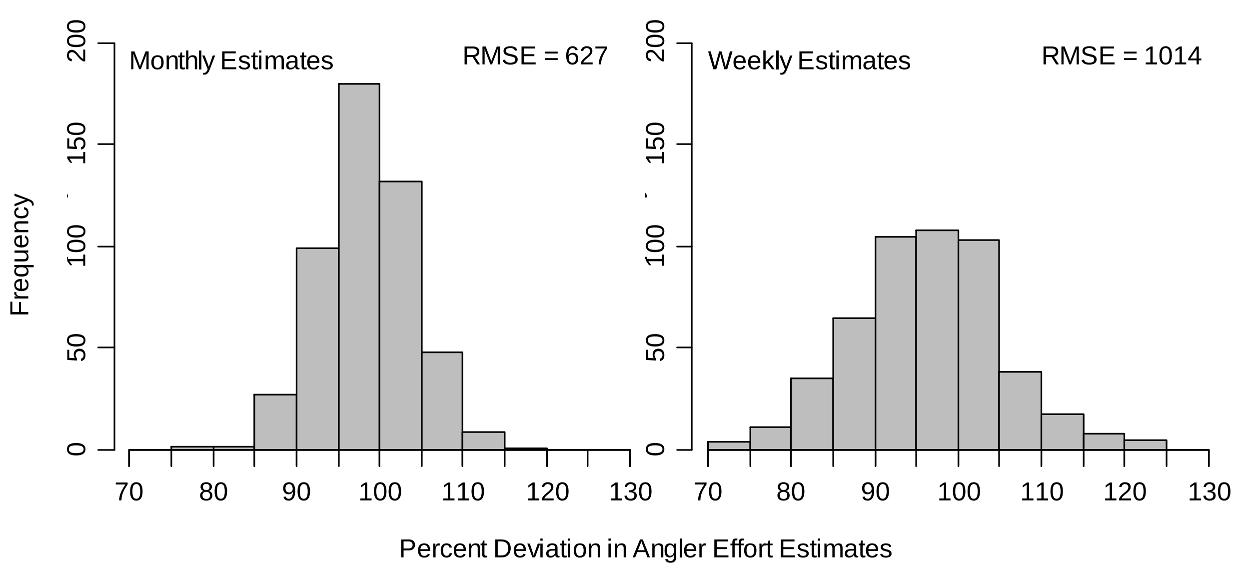


Figure 6. Percent deviation in estimated angler effort relative to the observed (i.e., true) effort for monthly (left) and weekly (right) stratified estimates (i.e., values >100 were biased high and values <100 were biased low). The root-mean-square-error (RMSE) is reported for reference with smaller values representing a more accurate estimate.

12) **Assess the accuracy of angler reported catch rates.** One major assumption of the coastal creel methodology, or really any catch estimator that is based on angler interviews, is that anglers are accurately reporting their catch rates of hatchery and wild fish. If anglers misreport their catch rates (e.g., fail to report caught fish or exaggerate their catch of released fish) then catch rates estimates, and thus catch estimates, will be biased. Unfortunately, there is no simple method to evaluate whether anglers are accurately reporting their catch especially for non-harvested fish. However, there are two general methods that could potentially be employed that involve the comparison of observed versus reported catch from a subset of anglers. First, individual anglers could be unknowingly observed while fishing and their catch recorded. Later in the day, the same set of anglers could be interviewed and the resulting catch rates compared. While in theory this method works, it may be difficult to implement and would likely result in backlash from anglers over the use of "undercover" surveillance. Therefore, a second method involves having a set of reliable volunteers record their catch rates and compare these rates with those reported from creel surveys. Because catch rates can be quite variable among days and anglers, it may be best to compare the relative catch rate ratio of wild released to hatchery harvested fish. Using these data, angler reported catch rates could be adjusted for reporting biases, similar to methods employed for CRC catch estimation (Kraig and Smith 2010).

13) **Assess variability of angler effort within individual days.** Currently, two angler index effort counts are typically conducted during each individual creel survey day, which is the minimum number needed to calculate a daily average. Determining how many angler effort counts are "needed" each day will ultimately depend on the within day variation in angler abundance, the variation in catch rates among anglers, and the desired precision of the catch estimate. Simply put, the more variable angler pressure is throughout the day the more effort counts are needed. However, without increasing the level of technician staffing, the number of effort counts conducted each day is inversely related to the number of interviews (i.e., as the number of effort counts increases there is less time available to conduct interviews). Therefore, there may be a trade-off to increasing the number of effort counts depending on the variability in catch rates among anglers. In order to determine the most parsimonious distribution of creel technician time (i.e., time spent conducting effort counts vs. interviews), additional data are needed. Specifically, we would need to know how variable catch rates and angler abundance are within individual days. The variability in catch rates could be assessed with the current methodology if individual interview data were entered into a database (see recommendation #2). The variability in angler abundance could be assessed many ways (e.g., focused effort counts every hour, remote cameras at popular fishing sites) so long as the resulting data represented angler abundance by time (see Figure 3). Once these data were collected, a simulation model could be run to evaluate the most appropriate number of angler counts per day.

14) **Implement above changes and re-evaluate.** Based on the findings from this evaluation, the current creel methods used to estimate angler effort, catch rates, and catch of steelhead generally follow accepted methodologies, but are in need of some refinement. Therefore, the recommendations listed above should be implemented and the subsequent results (e.g., catch estimates) re-evaluated to ensure that unbiased estimates of catch are being derived with adequate levels of precision. If this cannot be achieved even after implementing the recommended improvements, additional changes (e.g., increased staffing levels and tie-in surveys) may need to be employed.

References

Arlinghaus, R., S. J. Cooke, J. Lyman, D. Policansky, A. Shwab, C. Suski, S. G. Sutton, and E. B. Thorstad. 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. Reviews in Fisheries Science 15:75–167.

Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129-154.

Bentley, K., B. Glaser, T. Buehrens, J. Byrne, and S. Kelsey. 2015. Evaluation of recreational steelhead catch in the South Fork Toutle and Washougal rivers, 2011-14. Washington Department of Fish and Wildlife. FPT 15-06.

Bernard, D.R., and J.E. Clark. 1995. Estimating salmon harvest with coded-wire tags. Canadian Journal of Fisheries and Aquatic Sciences 53: 2323-2332.

Brouwer, S.L., and C.D. Buxton. 2002. Catch and effort of the shore and skiboat linefisheries along the South African Eastern Cape Coast. South African Journal of Marine Science 24: 341-354.

Burns, D. and L. Brown. 1976. The development of in-season sport catch estimates for the Green River steelhead fishery; Addendum I to Progress Report, Sept. – Dec. 1975. Washington State Department of Game, Olympia, WA. Unpublished manuscript.

Cooke, S.J., G. D. Raby, M. R. Donaldson, S. G. Hinch, C. M. O'Connor, R. Arlinghaus, A. J. Danylchuck, K. C. Hanson, T. D. Clark, and D. A. Patterson. 2013. The physiological consequences of catch and release angling: perspectives on experimental design, interpretation, and relevance to stakeholders. Fisheries Management and Ecology 20:268-287.

Crawford, B.A., and S.M. Rumsey. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act. National Marine Fisheries Service, NW Region.

Hahn, P., S. Zeylmaker, and S. Boner. 2000. WDFW methods manual - Creel information from sport fisheries. Washington Department of Fish and Wildlife, Fish Program Division, Olympia, Washington. Technical report #93-18.

Hansen, M.J., T.D. Beard, Jr., and S.W. Hewett. 2000. Catch rates and catchability of walleyes in angling and spearing fisheries in northern Wisconsin lakes. North American Journal of Fisheries Management 20:109-118.

Hoenig, J. M., C. M. Jones, K. H. Pollock, D. S. Robson, and D. L. Wade. 1997. Calculation of catch rate and total catch in roving surveys of anglers. Biometrics 53:306–317.

Jones, C. M., and K. H. Pollock. 2012. Recreational angler survey methods: Estimation of effort, harvest, and released catch. American Fisheries Society Symposium:1–38.

Kraig, E., and S. Smith. 2010. Washington state sport catch report 2003. Washington Department of Fish and Wildlife, Fish Program Science Division, Olympia, WA.

Malvestuto, S. P., W. D. Davies, and W. L. Shelton. 1978. An evaluation of the roving creel survey with nonuniform probability sampling. Transactions of the American Fisheries Society 107:255–262.

Muoneke, M. I., and W.M. Childress. 1994. Hooking mortality: a review for recreational fisheries. Reviews in Fisheries Science 2:123–156.

Pollock, K. H., J. M. Hoenig, C. M. Jones, D. S. Robson, and C. J. Greene. 1997. Catch rate estimation for roving and access point surveys. North American Journal of Fisheries Management 17:11–19.

Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society special publication No. 25. American Fisheries Society, Bethesda, Maryland.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing Vienna, Austria. (http://www.r-project.org).

Rawding, D., and K.T. Bentley. *In prep.* Development of a catch and release mortality model for recreational steelhead fisheries. Washington Department of Fish and Wildlife.

Washington State Game Department. 1977. Progress Report – June 30, 1977 – Cooperative Agreement #14-16-0001-5776 FS, Cooperative Agreement #14-16-0001-6345 IFC between the United States Fish and Wildlife Service and the Washington State Game Department. Washington State Library A60003 578022.

Washington State Game Department. 1978. Progress Report – June 30, 1978 –Cooperative Agreement #14-16-0001-6345 IFC between the United States Fish and Wildlife Service and the Washington State Game Department. Washington State Library A60003 578276.

Washington State Game Department. 1979. Steelhead Program Progress Report – June 30, 1979 – Cooperative Agreement #14-16-0001-5776 FS, Cooperative Agreement #14-16-0001-6345 IFC between the United States Fish and Wildlife Service and the Washington State Game Department. Washington State Library A60003 334151.

Washington State Game Department. 1980. Steelhead Program Progress Report – June 30, 1980 – Cooperative Agreement #14-16-0001-5776 FS, Cooperative Agreement #14-16-0001-6345 IFC between the United States Fish and Wildlife Service and the Washington State Game Department. Washington State Library A60003 334274.

Appendix A – Results of Hoh River 2014-15 Creel Survey

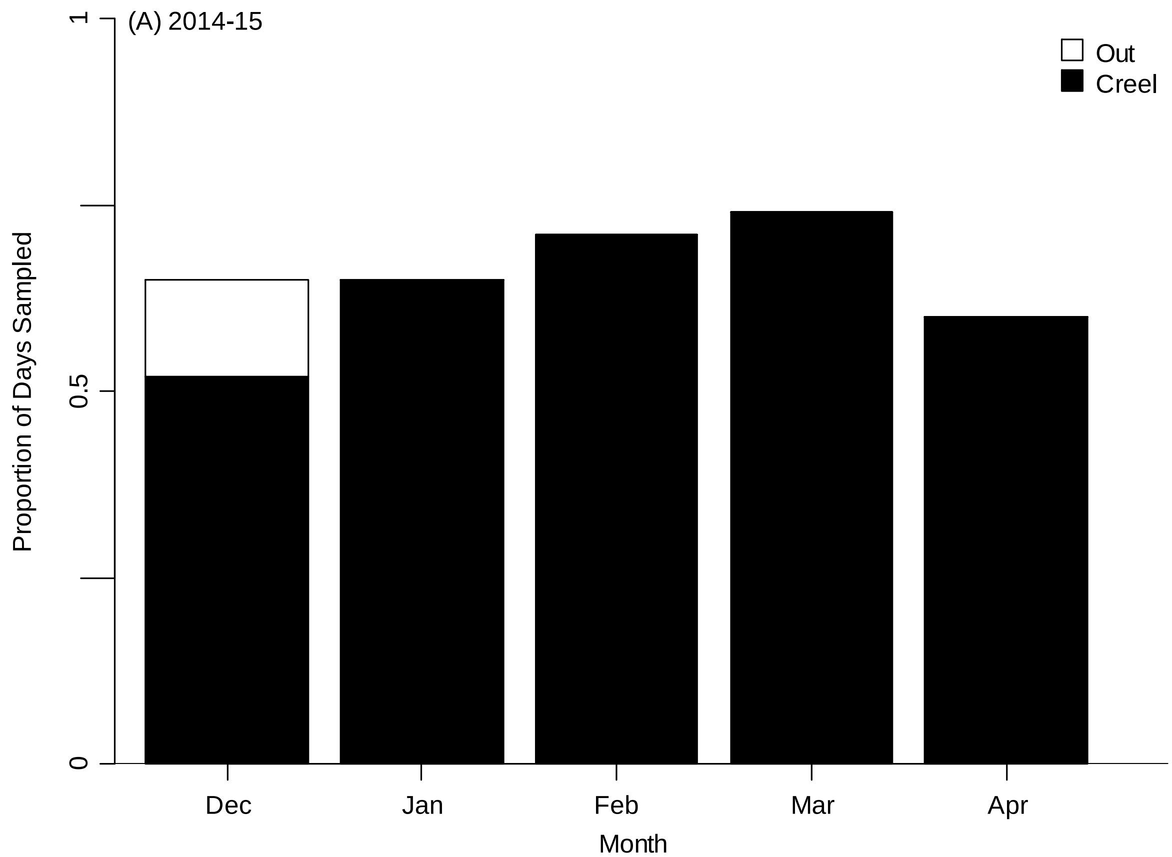


Figure A1. Proportion of all days per month a roving creel survey was conducted on the Hoh River during the 2014-15 recreational steelhead fishery. Surveys were conducted from December 1st, 2014 through April 15th, 2015. Black bars denote the proportion of days that were actually creeled while white bars denoted days where the river was classified as "out" and not surveyed. Although "out" days were not surveyed, fishing conditions on these days are poor likely leading to low levels of angler effort and catch.

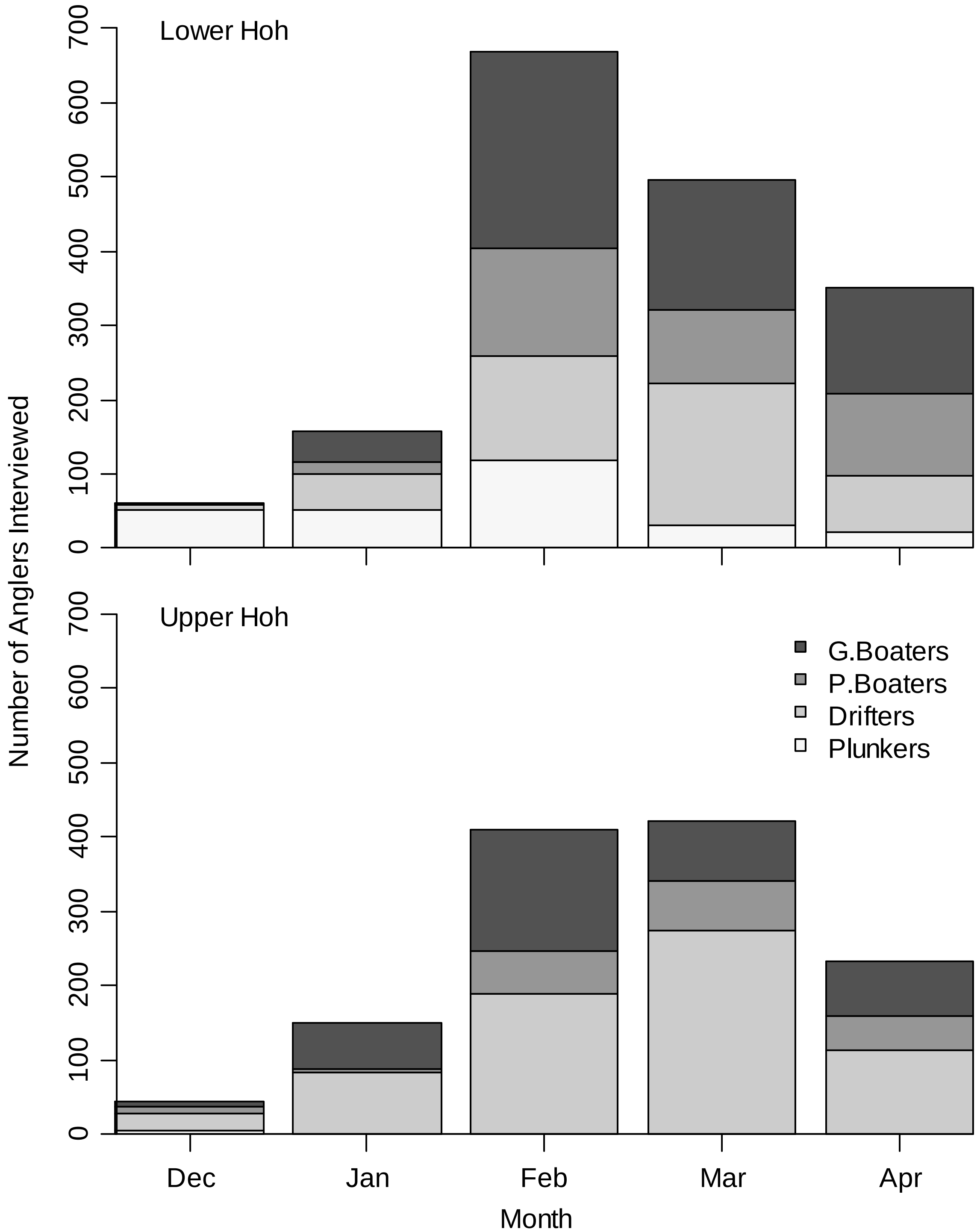


Figure A2. Number of anglers interviewed in the Lower (top) and Upper (bottom) Hoh River by month and angler-type during the 2014-15 recreational steelhead fishery.

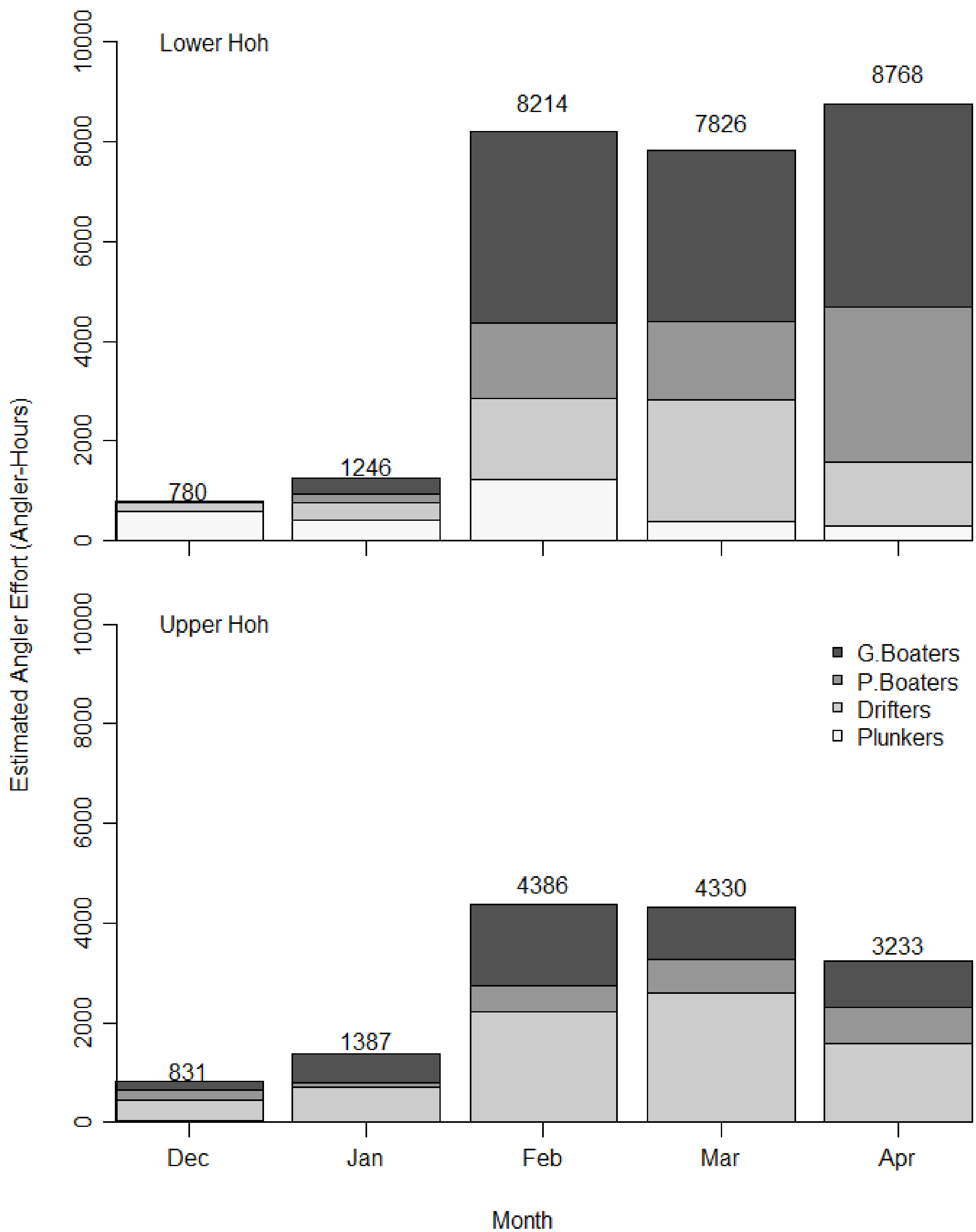


Figure A3. Estimated (expanded) angler effort in the Lower (bottom) and Upper (top) Hoh River by month and angler-type during the 2014-15 recreational steelhead fishery. Angler effort is reported in angler-hours.

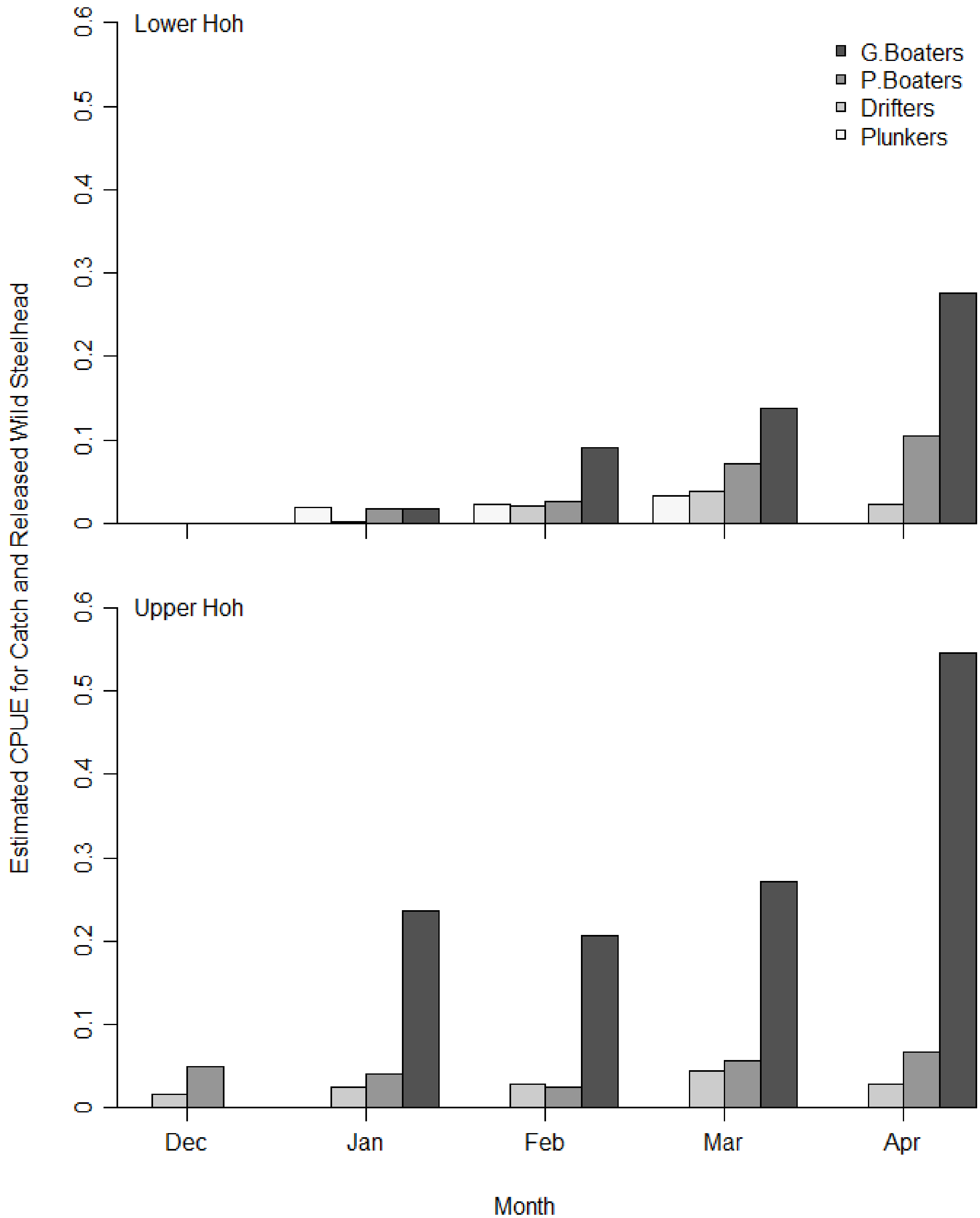


Figure A4. Estimated catch per unit effort (fish/hour) of non-harvested (released) wild steelhead in the Lower (top) and Upper (bottom) Hoh River by month and angler-type during the 2014-15 recreational steelhead fishery.

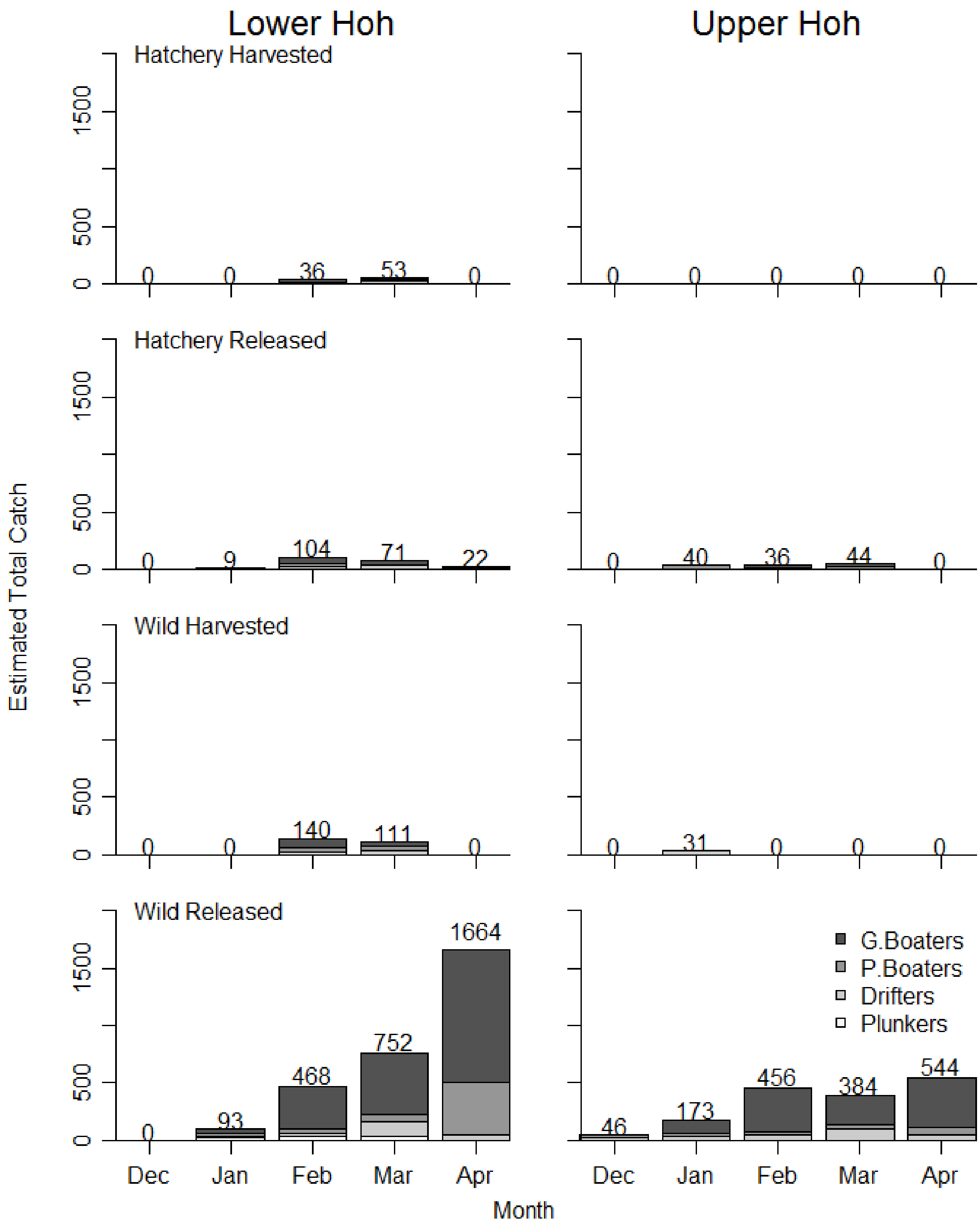


Figure A5. Estimated total catch of steelhead by recreational anglers in the Lower (left) and Upper (right) Hoh River by month, angler-type, and catch group during the 2014-15 recreational steelhead fishery. Steelhead catch were group into four categories using pairwise combinations of origin (wild, hatchery) and fate (released, harvested).

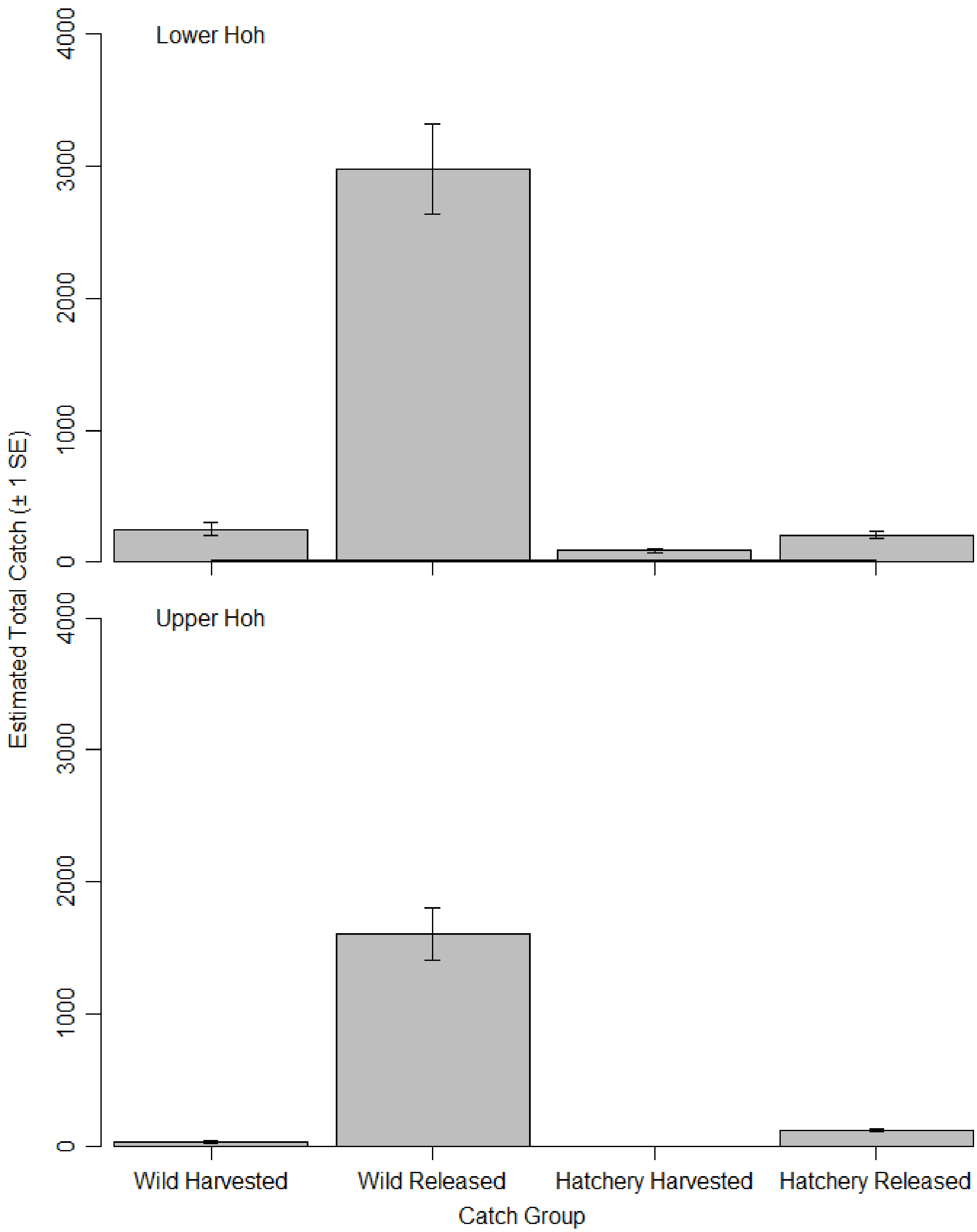
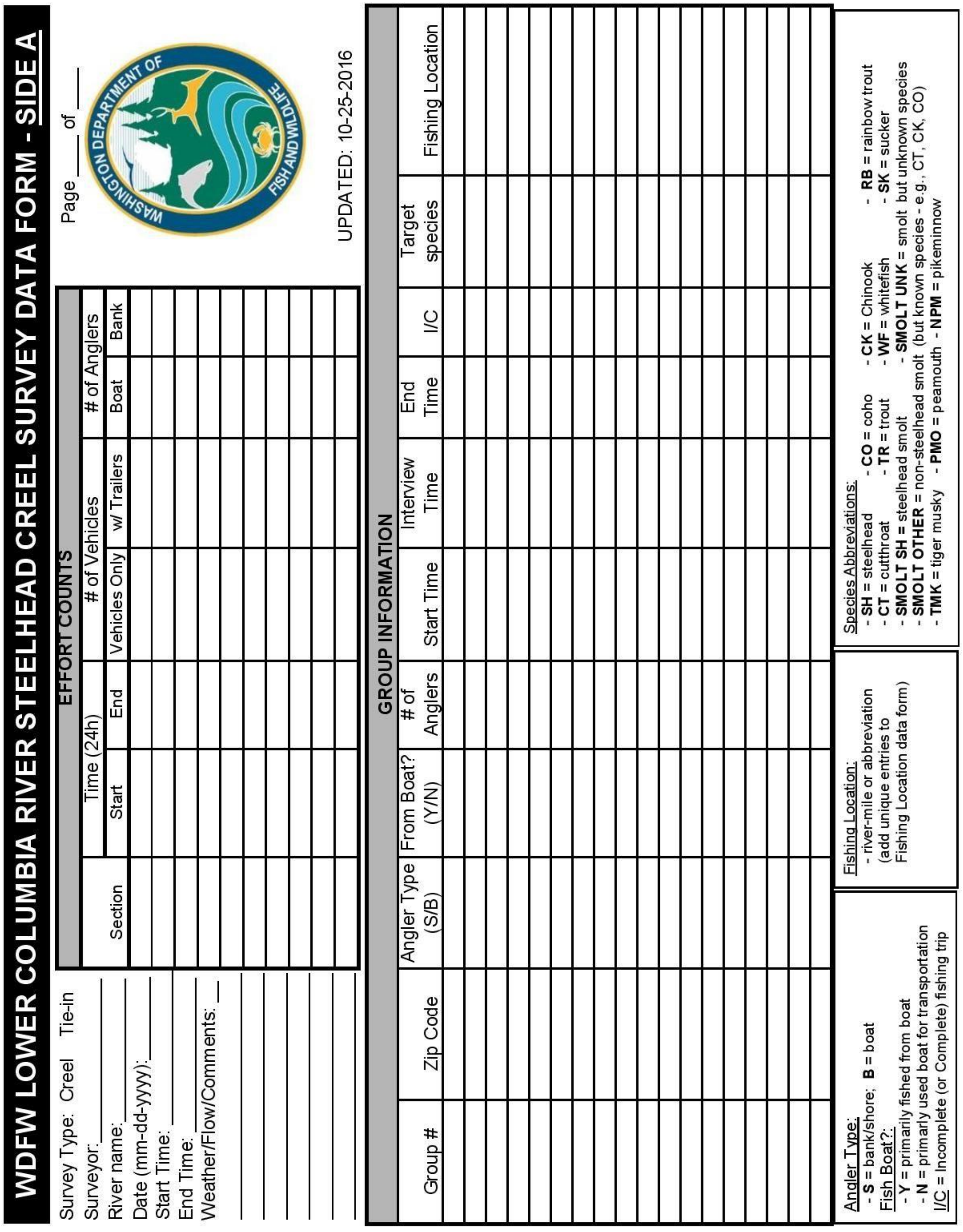


Figure A6. Estimated total catch of steelhead by recreational anglers in the Lower (top) and Upper (bottom) Hoh River during the 2014-15 recreational steelhead fishery. Steelhead were grouped into four categories using pairwise combinations of origin (wild, hatchery) and fate (released, harvested).

Appendix B – Lower Columbia River Steelhead Creel Survey Datasheets



WDFW LOWER COLUMBIA RIVER STEELHEAD CREEL SURVEY DATA FORM - SIDE A

Survey Type: Creel Tie-in

Surveyor: ______

River name: ______

Date (mm-dd-yyyy): ______

Start Time: ______

End Time: ______

Weather/Flow/Comments: ______

Page ___ of ___

UPDATED: 10-25-2016

EFFORT COUNTS

Section	Time (24h) Start	End	# of Vehicles Vehicles Only	w/ Trailers	# of Anglers Boat	Bank

GROUP INFORMATION

Group #	Zip Code	Angler Type (S/B)	From Boat? (Y/N)	# of Anglers	Start Time	Interview Time	End Time	I/C	Target species	Fishing Location

Angler Type:
- **S** = bank/shore; **B** = boat

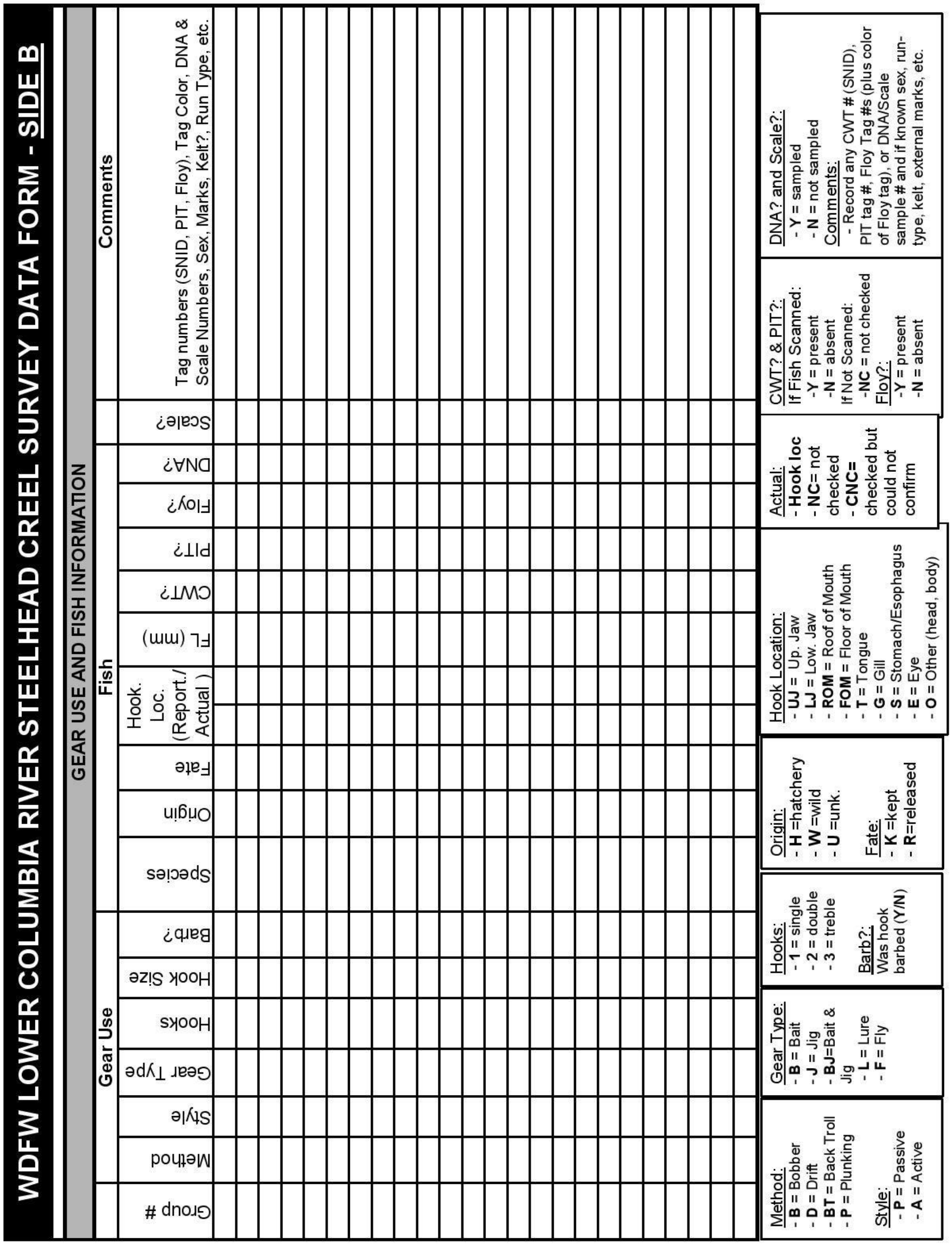
Fish Boat?:
- **Y** = primarily fished from boat
- **N** = primarily used boat for transportation

I/C = Incomplete (or Complete) fishing trip

Fishing Location:
- river-mile or abbreviation (add unique entries to Fishing Location data form)

Species Abbreviations:
- **SH** = steelhead - **CO** = coho - **CK** = Chinook - **RB** = rainbow trout
- **CT** = cutthroat - **TR** = trout - **WF** = whitefish - **SK** = sucker
- **SMOLT SH** = steelhead smolt - **SMOLT UNK** = smolt but unknown species
- **SMOLT OTHER** = non-steelhead smolt (but known species - e.g., CT, CK, CO)
- **TMK** = tiger musky - **PMO** = peamouth - **NPM** = pikeminnow

Figure B1. Side A of the WDFW Lower Columbia River tributary creel survey data sheet.



WDFW LOWER COLUMBIA RIVER STEELHEAD CREEL SURVEY DATA FORM - SIDE B

GEAR USE AND FISH INFORMATION

	Gear Use					Fish										Comments
Group #	Method	Style	Gear Type	Hooks	Hook Size	Barb?	Species	Origin	Fate	Hook. Loc. (Report./ Actual)	FL (mm)	CWT?	PIT?	Floy?	DNA?	Scale?	Tag numbers (SNID, PIT, Floy), Tag Color, DNA & Scale Numbers, Sex, Marks, Kelt?, Run Type, etc.

Method:
- **B** = Bobber
- **D** = Drift
- **BT** = Back Troll
- **P** = Plunking

Style:
- **P** = Passive
- **A** = Active

Gear Type:
- **B** = Bait
- **J** = Jig
- **BJ**=Bait & Jig
- **L** = Lure
- **F** = Fly

Hooks:
- **1** = single
- **2** = double
- **3** = treble

Barb?: Was hook barbed (Y/N)

Origin:
- **H** =hatchery
- **W** =wild
- **U** =unk.

Fate:
- **K** =kept
- **R**=released

Hook Location:
- **UJ** = Up. Jaw
- **LJ** = Low. Jaw
- **ROM** = Roof of Mouth
- **FOM** = Floor of Mouth
- **T** = Tongue
- **G** = Gill
- **S** = Stomach/Esophagus
- **E** = Eye
- **O** = Other (head, body)

Actual:
- **Hook loc**
- **NC**= not checked
- **CNC**= checked but could not confirm

CWT? & PIT?:
If Fish Scanned:
- **Y** = present
- **N** = absent

If Not Scanned:
- **NC** = not checked

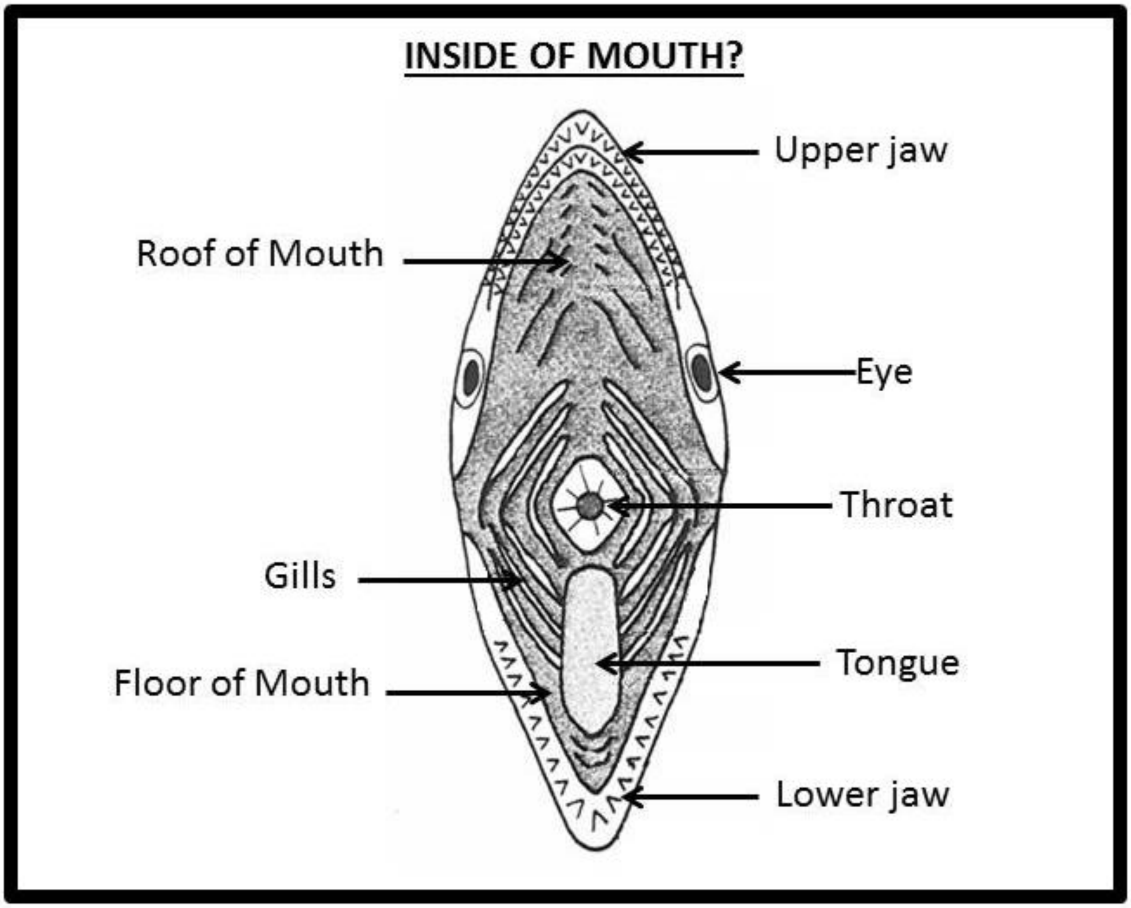
Floy?:
- **Y** = present
- **N** = absent

DNA? and Scale?:
- **Y** = sampled
- **N** = not sampled

Comments:
- Record any CWT # (SNID), PIT tag #, Floy Tag #s (plus color of Floy tag), or DNA/Scale sample # and if known sex, run-type, kelt, external marks, etc.

Figure B2. Side B of the WDFW Lower Columbia River tributary creel survey data sheet.

HOOKING LOCATION



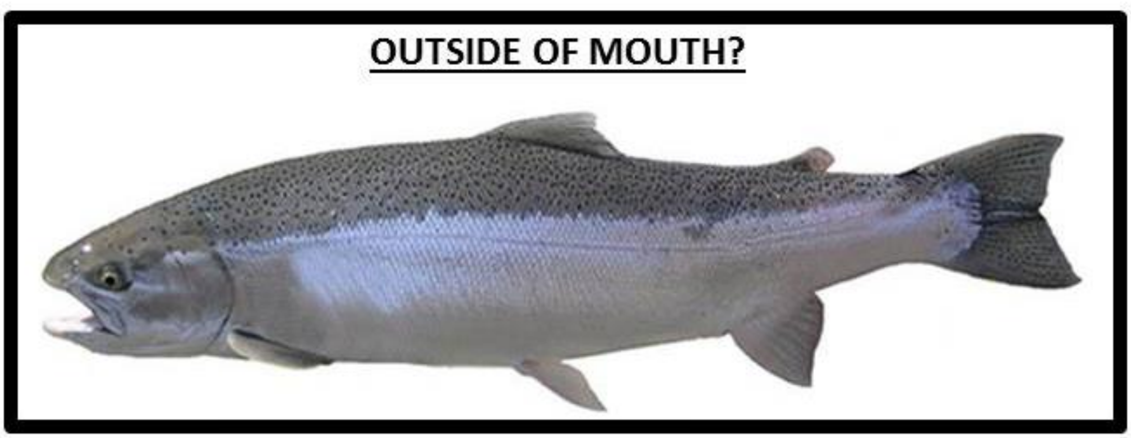


Figure B3. Diagram used to collect hooking location data from interviewed ang