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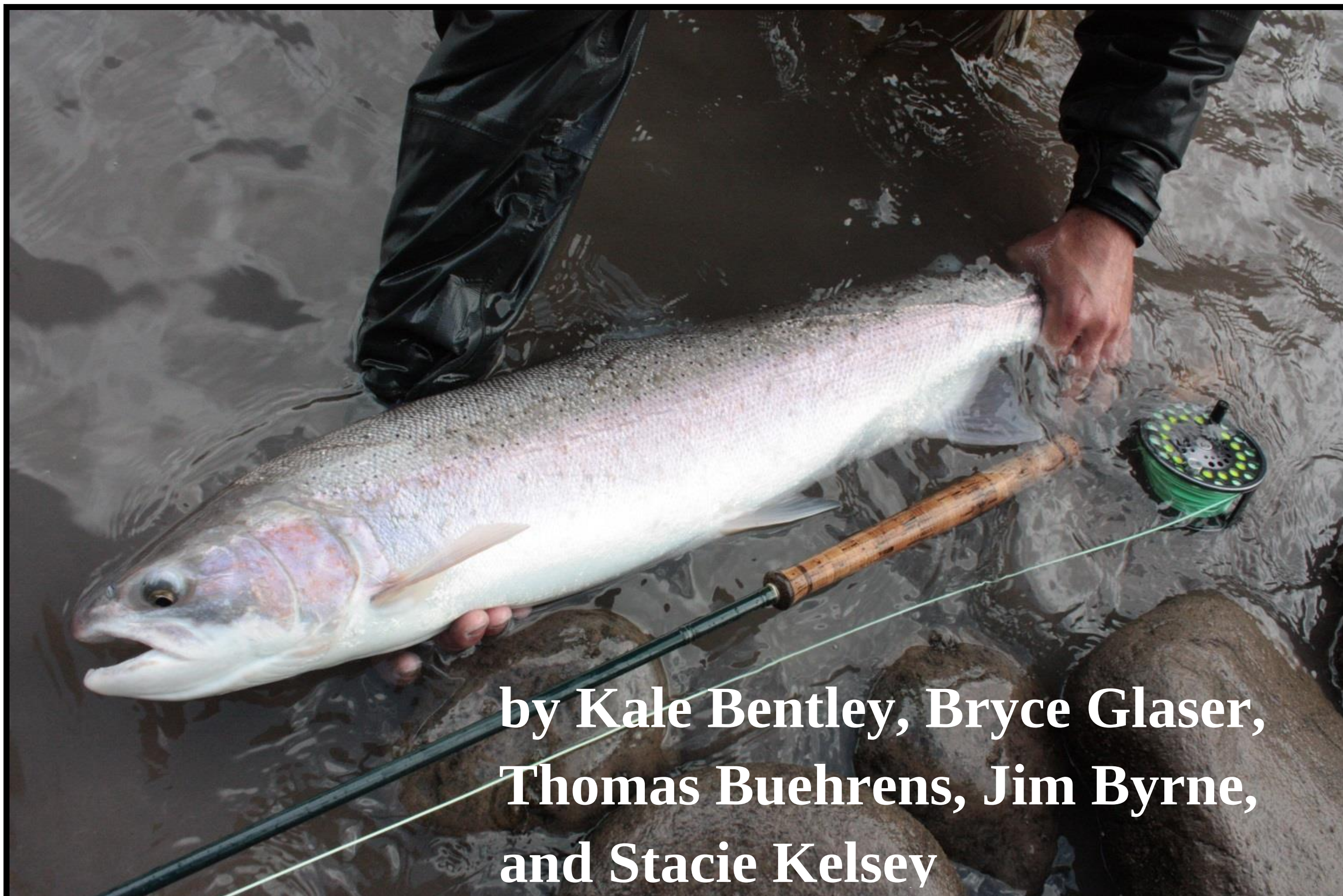
Evaluation of recreational steelhead catch in the South Fork Toutle and Washougal rivers, 2011-2014



by Kale Bentley, Bryce Glaser, Thomas Buehrens, Jim Byrne, and Stacie Kelsey

Washington Department of FISH and WILDLIFE

FPT 15-06

Evaluation of recreational steelhead catch in the South Fork Toutle and Washougal rivers, 2011-2014: creel survey analysis, catch record card expansion, and impacts to wild populations

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Executive Summary

The mission of the Washington Department of Fish and Wildlife (WDFW) is to preserve, protect and perpetuate fish, wildlife, and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities. In the lower Columbia River (LCR), WDFW's goal is to recover populations of steelhead (*Oncorhynchus mykiss*), which are listed as threatened under the Endangered Species Act (ESA) in the LCR distinct population segment (DPS), while simultaneously managing rivers for recreational fishing opportunities through harvest of hatchery fish and some catch and release (i.e., non-retention) of wild fish. To meet these goals, WDFW must maintain the impacts these fisheries have on wild stocks of steelhead within levels authorized by the LCR Fisheries Management and Evaluation Plan (FMEP). Currently, the only annually occurring method WDFW uses in the LCR to monitor the impacts of recreational steelhead fisheries is through Catch Record Cards (CRC). However, the CRC system is not designed to capture catch information from non-retention fisheries. Therefore, in 2011, WDFW began steelhead creel surveys in LCR tributaries and has developed a plan for continued implementation on a three-year rotating basis. To date, WDFW has completed three years of steelhead creel surveys on the South Fork Toutle and Washougal rivers. This report provides the first comprehensive analysis of the creel data and had three main objectives.

Our first objective was to estimate monthly, seasonal (summer and winter), and yearly patterns of angler effort and catch for hatchery and wild steelhead. A programmed creel survey was conducted on the South Fork Toutle River from May 2011 through March 2014 and on the Washougal River from April 2011 through March 2014; however, surveys were not performed on the Washougal River from mid-June through October in two of the three years. Over the three years, an estimated 7,991 anglers spent 24,346 hours fishing the South Fork Toutle, caught an average of one steelhead per 7.8 hours fished, and landed a total of 3,395 steelhead. Of the landed fish, 60% were of wild origin and released, 35% were of hatchery origin and harvested, and 5% were either hatchery-run or unidentified-origin and released. In the Washougal River, an estimated 28,640 anglers spent 74,351 hours fishing, caught an average of one steelhead per 17.8 hours fished, and landed a total of 6,366 steelhead. Of the landed fish, 44% were of wild origin and released, 43% were of hatchery origin and harvested, and 13% were either hatchery-run or unidentified-origin and released. Among years, the monthly and seasonal pattern in catch and effort was relatively similar. However, the absolute number of hours fished and steelhead caught varied among years, river-systems, and stocks of steelhead (i.e., summer/winter, hatchery/wild).

Our second objective was to evaluate the feasibility of using CRC estimates of hatchery catch to estimate wild catch based on relative handle rates in the South Fork Toutle and Washougal River fisheries. The performance of this ratio in estimating wild fish catch was of interest because it presents a possible method for estimating wild fish catch during periods when creel surveys do not occur. First, we derived the relationship between the two catch estimates by fitting normal and non-normal probability distribution function regression models to the data and

found that a zero-inflated Poisson (ZIP) Bayesian mixture model was most appropriate. Relative to creel methods, the CRC method under-estimated monthly catch when catch was less than 200 fish (observed range of monthly catch = 0 – 407 steelhead). However, the two methods provided similar estimates when monthly catch was approximately >200 fish. Therefore, CRC estimates of hatchery catch needed to be adjusted for their negative bias at low ranges of catch prior to their use in estimating wild fish catch based on relative handle rates. Second, we calculated the ratio of wild fish released to hatchery steelhead harvested from creel surveys (i.e., the expansion factor). During the surveyed time period, there was little temporal overlap in catch of hatchery and wild steelhead in the South Fork Toutle River. Thus, few ratios could be calculated and expansion of CRC for wild fish was not feasible. In contrast, the Washougal River did have high temporal overlap in hatchery and wild catch. Therefore, we estimated the "expanded" monthly catch of wild steelhead by multiplying the adjusted CRC catch estimates by the expansion factor, and compared these estimates of wild catch to creel derived estimates. We found a statistically significant, positive linear relationship in wild steelhead monthly catch as estimated by creel and expanded CRC methods. Although the relationship was relatively weak ($r = 0.60$), the two estimates of wild catch followed a similar monthly pattern with absolute differences in catch ranging from 1 to 201 steelhead. Overall, expanded estimates of wild catch from CRC was possible in river-systems that had high overlapping catch of wild and hatchery steelhead.

Our final objective was to estimate wild population impact rates resulting from non-retention sport fisheries (i.e., hooking mortality) as well as determining the relationship between gear-type and hooking location for use in studies of non-retention mortality. First, we estimated the total number of hooking mortalities by multiplying our estimated seasonal catch per population by the LCR FMEP defined hooking mortalities of 5% for winter steelhead and 8% for summer steelhead. Second, we estimated total impact rates by dividing the total number of mortalities by the total run size, where run size was equal to escapement plus mortalities. From 2012 – 2014, impact rates on wild winter-run steelhead ranged from 2.4 – 6.9% in the South Fork Toutle and from 5.2 – 10.7% in the Washougal River. These estimated impact rates were less than the expected exploitation rate of ≤10% as outlined in the LCR FMEP in all years and populations except one (Washougal River in 2012). Although absolute total catch was relatively similar among years and populations, the encounter rate of winter-run steelhead in the Washougal River in 2012 was nearly twice that of other years due to the low run size estimate. This high encounter rate led to the relatively high impact rate. However, impact rates can be influenced by bias in escapement estimates if the assumptions made to calculate escapement are not met. For example, WDFW spawner estimates for steelhead based on redds are not currently adjusted for inter-annual variability in survey conditions (i.e., observer efficiencies, females per redd). Finally, we found that >97% of steelhead caught on jigs, lures, and flies were hooked in either the jaw or tongue, which have very high survival rates. Of all fish caught with bait, which accounted for 25 – 45% of catch depending on season, 92% were caught in the jaw or tongue. Therefore, based on the results of these three years of creel surveys, the steelhead sport fisheries in these tributaries appear to be consistent with the expectations described in the LCR FMEP.

Introduction

The Washington Department of Fish and Wildlife (WDFW) manages multiple steelhead (*Oncorhynchus mykiss*) fisheries in tributaries throughout the lower Columbia River (LCR). Many of these fisheries occur in areas where wild steelhead populations are listed as threatened under the Endangered Species Act (ESA). The majority of these fisheries provide opportunity to harvest hatchery steelhead, but some also offer specific catch and release opportunities of wild fish. Although all wild steelhead caught in these fisheries must be released, wild steelhead are still susceptible to post-release mortality and sub-lethal impacts resulting from recreational angling-related injuries. Therefore, WDFW's goal is to actively monitor LCR recreational steelhead fisheries in order to provide scientific information needed to assess risk to wild steelhead populations posed by their handle in both indirect fisheries targeting hatchery steelhead and directed (catch and release) fisheries targeting wild steelhead.

Monitoring impacts of non-retention fisheries on wild stocks is a critical component of fishery management and a requirement of conducting fisheries under the ESA, as described in WDFW's LCR Fisheries Management and Evaluation Plan (FMEP; WDFW 2003) and Hatchery and Genetic Management Plans (HGMP). With increasing selective fisheries, it is imperative that the reported fishing impacts on wild fish in FMEP's and HGMP's be accurate and within acceptable levels. By achieving this, the rebuilding of wild stocks can progress and fishing opportunity can be maximized. Thus, the first-step to estimating the impacts of recreational fisheries on wild populations, as well as impacts of hatchery programs on wild stocks, was to estimate total catch through the use of angler surveys.

As recreational angling has increased in popularity over time, angler surveys have become an established method to estimate fishing pressure and catch (Malvestuto et al. 1978, Pollock et al. 1994, Jones and Pollock 2012). Angler 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. The advantages of estimating catch through on-site creel surveys is that the data collection is almost instantaneous and does not suffer from the vagaries of anglers' memory and knowledge relative to off-site methods. Additionally, creel surveys can provide information on angler effort, catch rates, fishing location, gear-type, hooking location, and other biological information from harvested fish. A disadvantage of creel surveys is that they are more expensive to conduct than off-site collection methods.

Currently, WDFW uses the off-site Catch Record Card (CRC) reporting method (Kraig and Smith 2010) to monitor recreational steelhead fisheries. However, this program is not designed to capture catch information from non-retention fisheries. Therefore, WDFW has begun conducting creel surveys to monitor the impacts recreational fisheries have on river specific wild populations in the LCR. Because of the cost involved in conducting creel surveys, WDFW has proposed a three-year rotating cycle for creel surveys among LCR systems with

ESA listed populations of steelhead. In order to make estimates of total catch and impact rates in years lacking creel surveys, we wanted to explore if CRC estimates of hatchery catch could be used to estimate wild catch based on relative handle rates in co-mingled fisheries. For this to be feasible, we needed to know the relationship between catch estimates from creel surveys and the CRC method and to calculate the monthly ratio (index) of hatchery versus wild catch.

In 2011, WDFW began implementing steelhead creel surveys in LCR tributaries and has developed a plan for continued implementation on a three-year rotating basis. To date, WDFW has completed three years of steelhead creel surveys on the South Fork Toutle and Washougal rivers. With these data, the specific objectives of this study were to: (1) Quantify monthly, seasonal (summer and winter), and yearly patterns of effort and catch for hatchery and wild steelhead using creel surveys; (2) Compare CRC and creel estimates of hatchery catch and determine the feasibility of using CRC estimates of hatchery catch to estimate wild catch based on relative handle rates in co-mingled fisheries; and (3) Estimate wild population impact rates resulting from non-retention sport fisheries (i.e., hooking mortality) as well as determining the relationship between gear-type and hooking location for use in studies of non-retention mortality.

Methods

Study sites

SOUTH FORK TOUTLE RIVER

The South Fork Toutle River (SF Toutle) is located in southwestern Washington and is a tributary of the Toutle River. The SF Toutle River is a major tributary of the Cowlitz River, which ultimately flows into the Columbia River 68 miles upstream of the Pacific Ocean (Figure 1). The headwaters begin on the western slope of Mount Saint Helens and flow approximately 30 miles downstream where the south fork meets the mainstem Toutle River 12 miles east of Castle Rock, Washington. The river runs alongside a Weyerhaeuser Company (WeyCo) logging road and the lower 13 – 14 miles are easily accessed by anglers. Motor vehicle traffic is prohibited above a WeyCo gate, located at approximate river-mile 13, but walk-in or bike-in angling was possible. The SF Toutle River supports an endemic, ESA listed stock of wild winter-run steelhead and is planted with hatchery summer-run (Skamania) steelhead. The fishery is focused on providing harvest opportunities for hatchery steelhead, but also provides some catch and release opportunities for wild steelhead.

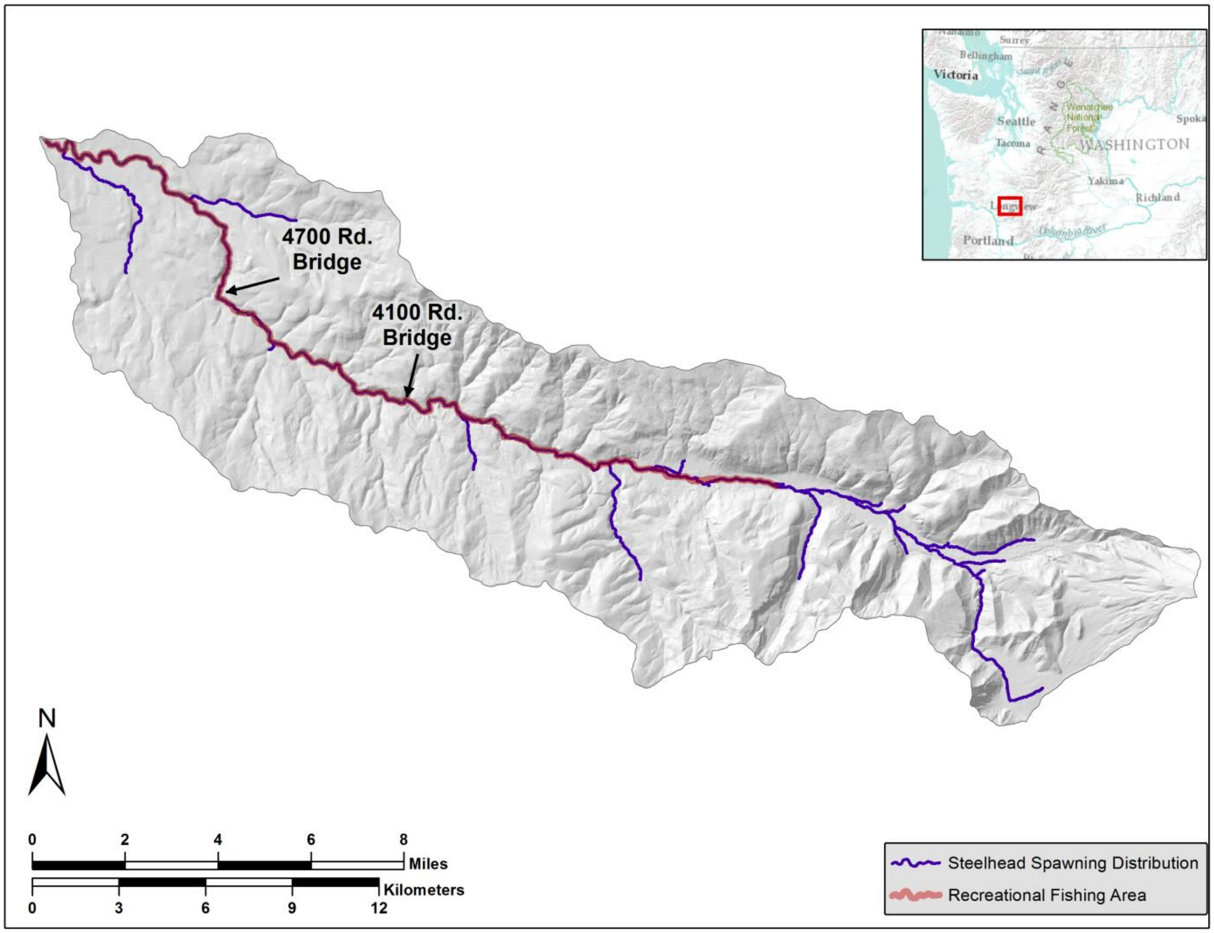

Figure 1. Map of the South Fork Toutle River watershed showing the modeled spawning distribution of steelhead (blue) and the fishing extent of surveyed recreational steelhead anglers (red).

There are many fishing regulations designed to protect wild spawning steelhead adults and smolts. Though the specific dates have changed over time, in recent years the fishery has generally been closed annually from mid- to late-March through mid- to late-May. When the fishery is open, wild steelhead release regulations apply. These regulations allow the retention of two hatchery steelhead, but all wild steelhead must be released. During the fishery season, there are additional spatial and temporal regulations. From mid- to late-May through the first Saturday in June, selective gear rules apply and fishing is only allowed from the mouth of the SF Toutle to the 4700 Rd. Bridge (river-mile 7.25). Selective gear regulations require anglers to only use unscented artificial flies or lures (i.e., no bait) with one single-point, barbless hook. From the first Saturday in June through November 30th, fishing is allowed throughout the entire main-stem river, under statewide freshwater rules (bait permitted), but tributaries are closed. From December 1st through mid-March, the river is open from the mouth to the 4100 Rd. Bridge (river-mile 12.7), but selective gear regulations apply and internal combustion motors are prohibited.

WASHOUGAL RIVER

The Washougal River is a tributary of the Columbia River, located approximately 50 miles upstream of the Cowlitz River (Figure 2 – Map). The headwaters of the Washougal River begin in Gifford Pinchot National Forest and the river flows approximately 33 miles downstream to the confluence with the Columbia River near the town of Washougal, Washington. Washougal River Road runs alongside the river providing potential access to anglers. However, much of the river's banks are on private property. The Washougal River fishery is focused on providing harvest opportunities for segregated hatchery early winter-run (Chambers Creek stock) steelhead and segregated hatchery summer-run (Skamania stock) steelhead (Crawford 1979), but also provides some catch and release opportunities for ESA listed wild summer- and winter-run steelhead.

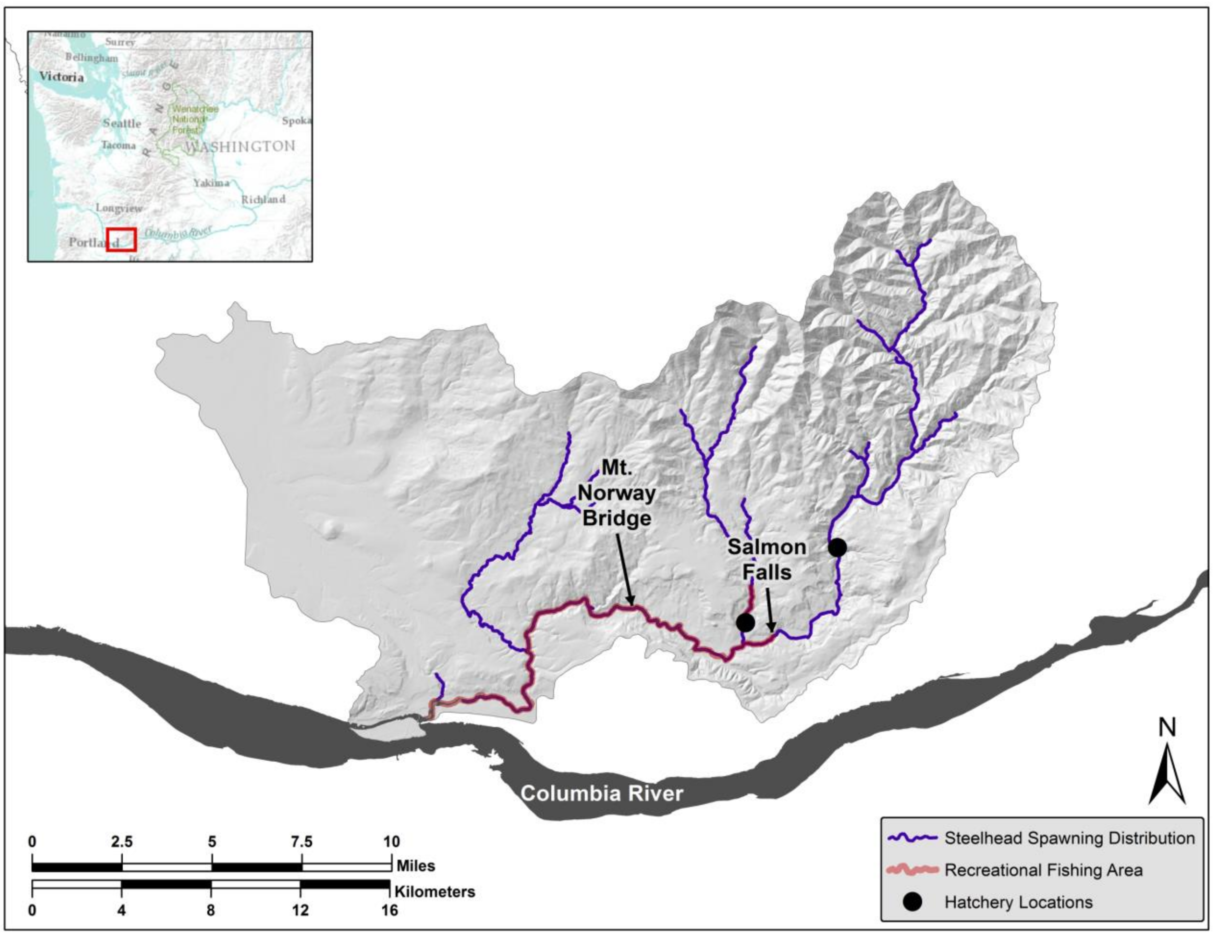

Figure 2. Map of the Washougal River watershed showing the modeled spawning distribution of steelhead (blue), the fishing extent of surveyed recreational steelhead anglers (red), and the location of WDFW hatcheries.

Similar to the SF Toutle, regulations on the Washougal River have changed over time, but the steelhead fishery has generally been closed from mid-March through early-June to protect spawning adults and out-migrating smolts. When the fishery is open, wild steelhead release regulations and statewide freshwater rules apply. In recent years, a selective gear fishery was created from April 16th to the Friday before the first Saturday in June from the mouth of the Washougal River up to the Mt. Norway Bridge at Vernon Road. From the first Saturday in June through March 15th fishing is allowed from the mouth of the Washougal River up the bridge at Salmon Falls. Fishing is prohibited year round upstream of Salmon Falls including all tributaries. Beginning on May 1, 2013, barbless hooks were required in the Washougal and SF Toutle rivers, as well as other Columbia River tributaries open to angling for salmon and steelhead.

Creel survey data collection

Creel surveys on the Washougal and SF Toutle rivers were initiated in April and May of 2011, respectively, and continued through March 15th, 2014. Outside of the spring fishery closure period, the SF Toutle creel survey was conducted continuously across these three fishing seasons. The Washougal River creel survey was initially commenced to survey the selective gear fishing period in April and May and the winter fishery from November through March. Therefore, creel surveys were not conducted on the Washougal River from June 15th – October 31st in 2011 and 2012. However, in 2013 the creel survey was continued past mid-June and the summery fishery was surveyed.

We used a stratified random survey design to conduct roving-roving creel surveys on the SF Toutle and Washougal rivers, following the methods outlined in Malvestuto et al. (1978), Pollock et al. (1994) and Hahn et al. (2000). First, the survey was stratified by day-type (weekday or weekend) and four sample days were randomly selected consisting of two to three weekdays and two weekend days per week. Second, the survey was stratified within each sample date by shift (AM or PM) and a random survey start time was selected within that shift. The length of a fishing day was defined from dawn to dusk, or rather as ½ hour before sunrise to ½ hour after sunset, (Appendix; Table A1) while surveys typically consisted of eight hour days (approximately 7 hours of creel surveys and 1 hour of commute).

Each creel survey day consisted of effort counts and angler interviews by the creel clerk. Within each survey, typically two effort counts were conducted and the start times were randomly selected. Angler counts were designed to be “instantaneous”, meaning that the entire survey section of the river was covered in less than one hour. During each effort count, the clerk drove the river and recorded the number of bank and boat anglers along with the number of vehicles with trailers. Only people who appeared to be actively fishing at the time of observation were counted as anglers. On the SF Toutle River, the entire surveyed section included the area from the mouth of the river up to the 4100 Rd. Bridge (Figure 1). Due to relative location of the WeyCo road to river and open canopy around the SF Toutle, bank and boat anglers were easy to see. Therefore, we assumed our effort counts were a true (i.e., 100%) representation of angling effort. On the Washougal River, the survey section included the area from the mouth of the river up to Salmon Falls (Figure 2). Although the Washougal River Road is relatively close to the river, there are long sub-sections of the river that cannot be seen from the road or are only accessible through private property. Therefore, we assumed that our effort counts were not a 100% representation of angling effort (see "Creel analysis" below for spatial expansion). In between effort counts, bank and boat anglers were interviewed by the roving creel clerk. Information gathered included angler-type (boat or bank), number of anglers in the group, angling start time, interview time, whether the trip was incomplete or complete, fishing location(s), number of fish caught, and zip code of residency. If an angler had caught a fish, we recorded the species, origin (hatchery or wild), whether it was harvested or released, fishing method, gear-type, and hooking location. General comments on the fish's sex, condition, run-type, etc. were also collected if available.

Stock categorization

Prior to data analysis, steelhead catch was apportioned by stock based on two criteria. First, individual fish were classified as either wild or hatchery origin. Anglers and creel clerks classified fish using the presence or absence of the small, fleshy adipose fin that is naturally found on the back of wild fish between the dorsal and caudal fin, but is removed from hatchery fish prior to release as juveniles. Second, steelhead were categorized as either summer- or winter-run type based on the month an individual fish was caught in the recreational fishery (Figure 3). Although some anglers provided summer/winter classifications during interviews, this information was not available for all wild catch. Therefore, we assigned run type to the catch based on a regional index of run timing from data collected at the Kalama Falls fish trap on the Kalama River.

In general, summer-run steelhead first enter the river in late May and peak during July and August. By late November, more than 95% of individuals have returned, regardless of hatchery or wild origin. In comparison, winter-run steelhead first enter the river in late November and peak in either January (hatchery) or April (wild) the following year. By mid-May more than 90-95% have returned (Kalama Falls; Lamperth et al. 2013). Based on the available classification of fish condition by anglers in the Washougal River, winter-run steelhead comprised the majority of catch through the end of April while steelhead caught after May 1st were primarily summer-run steelhead. Of the fish caught during the last two weeks of April, 80% were classified as kelts (i.e., post-spawned adults that have not emigrated). Therefore, individual fish in the Washougal River were categorized as summer-run if they were caught from

May through November, winter-run if caught from December through March, and kelts if caught in April (Figure 3).

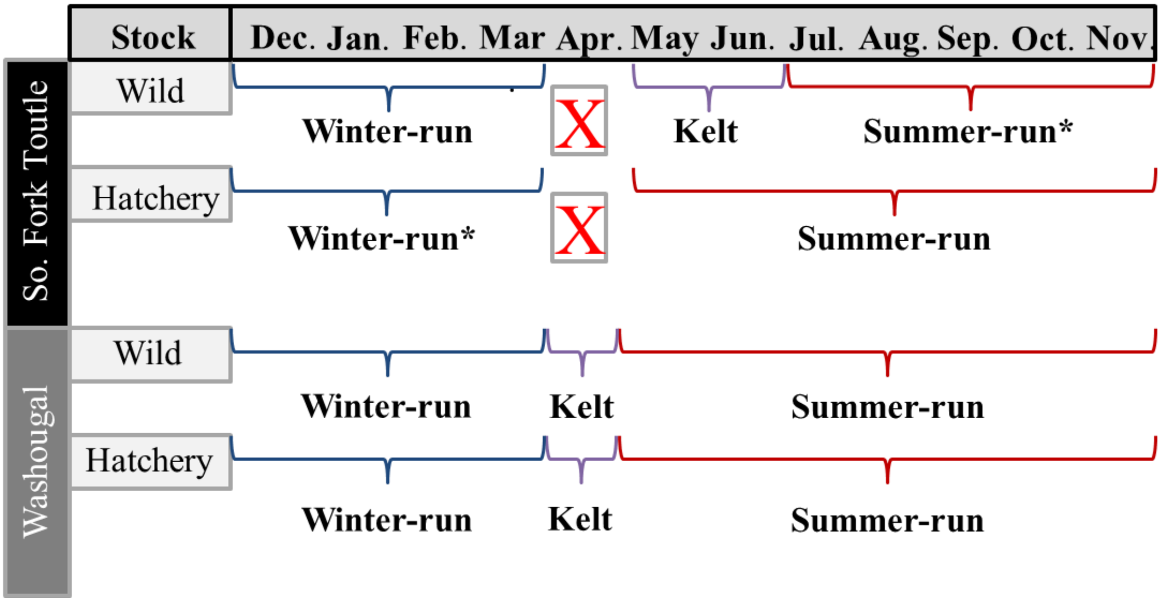

Figure 3. Summary of stock categorization for steelhead in the SF Toutle and Washougal rivers based on the month individual fish were caught in the recreational fishery. Note: no fish were caught during April in the SF Toutle due to fishery closures and this is denoted by the red "X". Asterisks denote populations that have some uncertainty in classification (see methods).

The Toutle River basin does not have any releases of hatchery winter-run steelhead. Therefore, all hatchery catch were likely summer (Skamania) run, with potentially some portion of catch in December and January being comprised of stray hatchery winter-run steelhead from other basins (e.g., Cowlitz River). There is no "recognized" (i.e., known) wild summer-run population in the SF Toutle River, nor was there historically thought to be one. Therefore, all wild steelhead caught during May or June were considered "kelts". Any "wild" steelhead caught from July through November were omitted from our wild impact rate (see below), but were included in our analysis of catch. However, some of these fish could have been from an unknown wild summer population (e.g., feral descendants of hatchery spawners) or early wild winter-run steelhead from the next run year.

Creel analysis

Effort, catch rate, and catch data were analyzed using methods similar to those found in Pollock et al. (1994, 1997). Here, we outline the method of moments calculations used to derive daily and monthly estimates. For variance calculation equations see Appendix B.

First, daily estimates of effort were calculated using:

$$Effort_{i,j,k,l,m} = \frac{Count1_{i,j,l,k,m} + Count2_{i,j,k,l,m}}{2} \times Day\ Length_k$$

where effort is an estimate of total angler-hours fished on day_i, $day\text{-}type_j$, $month_k$, and $year_l$ by $angler\text{-}type_m$. Total effort estimates by $month_k$ in $year_l$ were calculated by multiplying the average daily effort by the total number of days in $month_k$ for $day\text{-}type_j$ and summing the two totals. Estimates were then summarized by year-group and season. A year-group ran from May through the following April, consistent with WDFW sport fishing regulations. For example, year-group 2011-12 ran from May 2011 through April 2012. Within each year group we defined two seasons: summer (May – November) and winter (December – April).

As mentioned in the "Creel survey data collection" methods above, effort estimates in the SF Toutle River were assumed to be a true representation of total effort as a result of "ideal" survey conditions while the Washougal River estimates were assumed to be a partial representation. We verified our lack of spatial coverage in the Washougal River two ways: (1) calculating the total length of the survey section that was deemed "unsurveyable" from qualitative estimates by our creel clerk, and (2) calculating the ratio of boat angler counts versus expanded trailer counts. Expanded trailer counts were calculated by multiplying the number of trailers seen during an angler effort count by the average number of anglers per boat. For a full explanation of methods see Appendix C. Both methods suggested that we were missing a substantial portion of the overall effort in the Washougal River. Ultimately, we calculated boat effort in the Washougal River by using expanded trailer counts and bank effort by multiplying our derived bank effort estimate (prior to expansion) by the average trailer to boat effort ratio estimation (expansion factor), which was 2.4.

Second, daily estimates of catch per unit effort (CPUE) were calculated using the "mean of ratios" estimator:

$$CPUE_{h,i,j,k,l,m} = \frac{\sum_{i=1}^{n} \frac{Catch_{h,i,j,k,l,m}}{Effort_{h,i,j,k,l,m}}}{n}$$

where catch rate is an estimate of the total number of $fish\text{-}type_h$ caught per hour on day_i, $day\text{-}type_j$, $month_k$, and $year_l$ by $angler\text{-}type_m$ and n is the number of days sampled in $month_k$. Because complete trip interviews are inherently difficult to obtain in a roving-roving creel survey, we chose to use both complete and incomplete interviews when calculating catch rates. However, we did exclude incomplete interviews that had a total trip time less than 30 minutes to decrease bias, as suggested by Pollock et al. (1997) and Hoenig et al. (1997) unless there were no surveys more than 30 minutes on a specific date. Monthly estimates in $year_l$ were made by averaging daily catch rate estimates. If there was an estimated effort for a specific angler-type on $day_{i,j,k,l}$ but no corresponding interview, we used the CPUE from the other angler-type. Estimates were then summarized by year-group and season.

Third, daily estimates of catch were calculated using:

$$Catch_{h,i,j,k,l,m} = Effort_{i,j,k,l,m} \times CPUE_{h,i,j,k,l,m}$$

where catch is an estimate of the total number of $fish\text{-}type_h$ caught on day_i, $day\text{-}type_j$, $month_k$, and $year_l$ by $angler\text{-}type_m$. Total catch estimates by $month_k$ in $year_l$ were calculated by multiplying the average daily catch by the total number of days in $month_k$ for $day\text{-}type_j$ and summing the two totals. If a particular date had interview data, but no effort counts, the data were dropped from the catch calculation but still used in calculating catch rates. Estimates were then summarized by year-group and season.

Fourth, we calculated the number of steelhead anglers (angler-trips) per month using:

$$Number\ of\ Anglers_{k,l,m} = \frac{Effort_{k,l,m}}{Average\ Trip\ Time_{k,l,m}}$$

where the number of anglers is an estimate of the total number of unique anglers-trips in $month_k$ and $year_l$ for $angler\text{-}type_m$. The average trip time was calculated using only completed trips. Standard error and confidence intervals were calculated using Fieller's theorem (Appendix B). Estimates were then summarized by year-group and season. We then evaluated the relationship between number of anglers interviewed and the estimated number of angler-trips per month by angler-type using ordinary least squares linear regression. These relationships allowed us to calculate an overall proportion of anglers interviewed throughout the survey. Lastly, we estimated the proportion of all steelhead anglers interviewed per month by dividing the total number of interviews by the estimated number of anglers. All creel data were analyzed using Program R (R Development Core Team 2011).

Catch record cards (CRC)

Catch record cards (CRC) are a self-reporting method used by WDFW to collect catch information for harvested fish of certain species. Detailed information on the program can be found in agency technical reports (e.g., Kraig and Smith 2010). Briefly, a uniquely numbered CRC is issued to all anglers who purchase a fishing license and indicate their intent to fish for salmon or the other catch card species (steelhead, sturgeon, and halibut). Anglers are legally required to record the species, date, location, and origin of all fish that they harvest and return their CRC by the end of April each year.

Prior to the license year, WDFW CRC unit randomly selects 25% of the issued CRC to be in the "in-sample" group. In-sample group CRCs that are returned are used to generate catch estimates, while out-of-sample CRCs that are returned are used in addition to the in-sample group to apportion catch among months for steelhead. If in-sample CRCs are not returned voluntarily, multiple reminders are sent out to increase the return rate. Total harvest is estimated by multiplying reported catch by the sample proportion expansion factor (i.e., proportion of returned CRCs) and a non-response bias correction factor. Each year, approximately half of the in-sample CRCs are returned. The non-response bias is 1.02 for steelhead anglers (*E. Kraig, WDFW, personal communication*).

WDFW has estimated steelhead catch based on CRC data for the SF Toutle and Washougal rivers since 1962 (Figure 4). Prior to 1986, hatchery steelhead were not mass marked (with an adipose fin clip) and therefore harvest estimates were a composite of both hatchery and wild origins. Since 1986, CRCs have only collected catch data for harvested hatchery steelhead, and thus, catch estimates do not include any released fish (wild or hatchery). To evaluate the feasibility of using CRC harvest estimates of hatchery steelhead to estimate wild steelhead catch (see below), we used monthly CRC hatchery harvest estimates from April 2011 through March 2014 from the SF Toutle and Washougal rivers. Catch estimates through March 2013 have been finalized while estimates from April 2013 through March 2014 are currently in review.

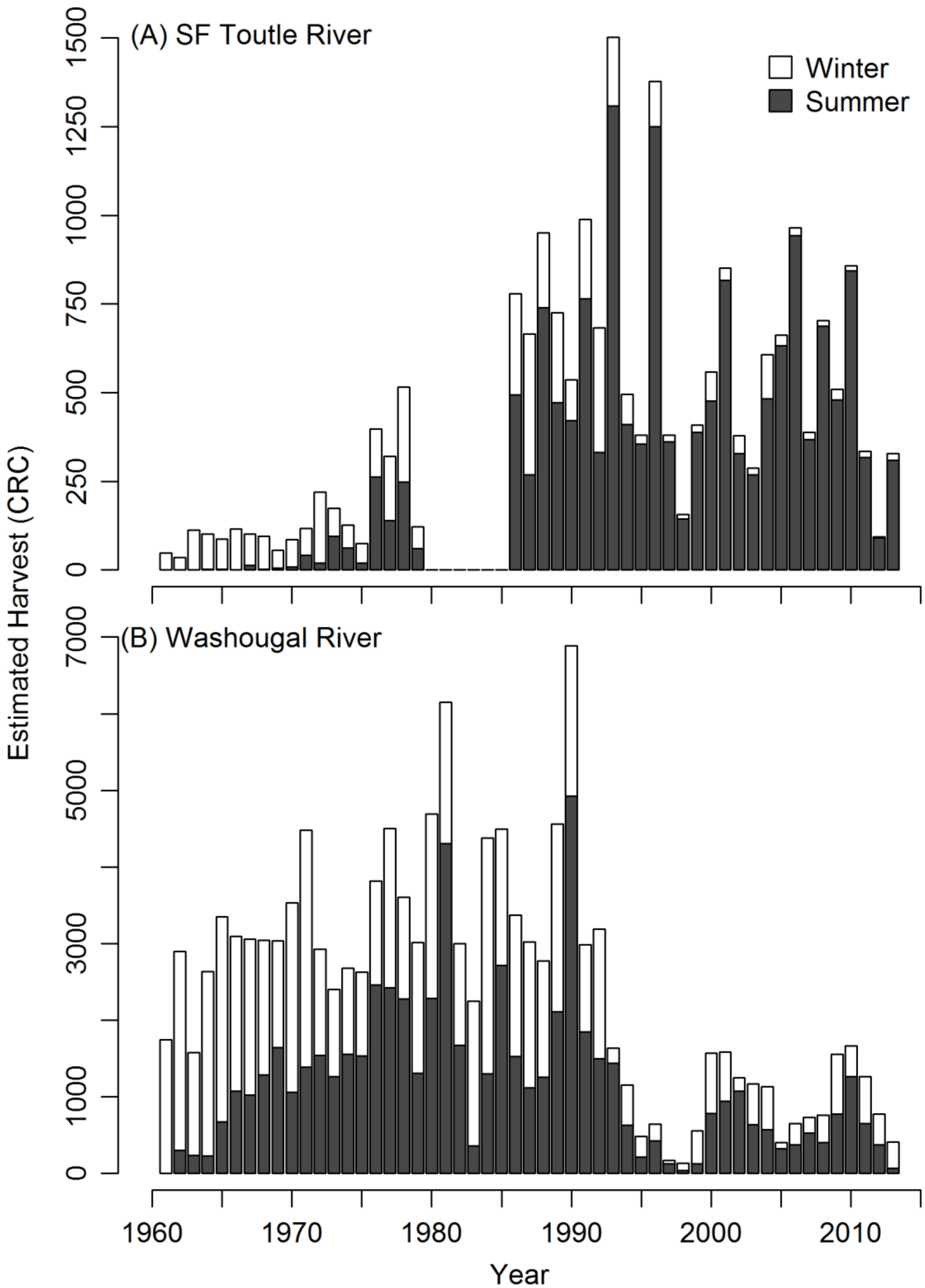

Figure 4. Estimated harvest of steelhead during the summer (May – November) and winter (December – April) in the (A) SF Toutle River and (B) Washougal River from January 1962 – March 2014 from catch record cards (CRC). Years are grouped from May through the following April (e.g., 2000 = May 2000 – March 2001). Note: Estimates from 1986 to 2013 are hatchery fish only. Prior to 1986, hatchery and wild steelhead were not differentiated on CRCs and harvest estimates include both origins.

Evaluation of CRC catch expansion

The relationship between CRCs and creel surveys catch estimates was evaluated to determine the feasibility of "expanding" CRC harvest estimates of hatchery steelhead to estimate catch of wild steelhead based on their relative handle rates reported in creel surveys. We first examined the correlation of the two methods to determine if they provide similar estimates of catch or whether one method consistently over- or under-estimated catch relative to the other. CRC and creel data collected from April 2011 through March 2014 were used in this first analysis.

The total catch of steelhead is the estimated count of all individual fish caught within a particular sub-stratum (e.g., area and time). Count data are typically non-normally distributed because the data are discrete (i.e., not continuous), limited to non-negative values, and right-skewed as many observations in a data set are equal to zero. The standard distribution for modeling count data is the Poisson distribution. If the data are over-dispersed (i.e., variance > mean) the negative binomial distribution may be more appropriate. However, these distributions assume that the processes that lead to observations of zero catch are the same as those that lead to non-zero catch. If this assumption is not met, these models tend to under predict the occurrence of zero counts relative to the observed dataset with a large number of zeroes. Theory suggests that the excess zeros are generated by a separate process from the count values and that these two "processes" can be modeled independently using a zero-inflated distribution (Maunder and Punt 2004, Zuur et al. 2009).

Therefore, we first evaluated the distribution of our data and determined that a non-normal probability distribution family was more appropriate (see results). Next, we fit Poisson and negative binomial models with an identity link. Models were evaluated for over-dispersion using a chi-squared likelihood ratio test. Both models were over-dispersed, suggesting a zero-inflated mixture model was needed. Once we had our best-fit model distribution, we evaluated the fitted relationship between river-systems (i.e., SF Toutle and Washougal rivers) by adding a river-specific coefficient to the model. Model results were validated by visually examining residuals and evaluated amongst one another using Deviance Information Criteria (DIC). DIC is a hierarchical modeling generalization of the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), where lower DIC models should be preferred and model DIC differences >10 (ΔDIC) generally rule out support for the model with the higher DIC. Model parameters and 95% credible intervals were estimated from the Bayesian posterior probability distributions of MCMC simulations implemented using JAGS (Plummer 2003) in Program R. Simulations included four chains and 1×10^6 iterations, of which the first 8×10^5 were discarded to "burn-in" the model. Chains were visually assessed for convergence and confirmed using the Gelman-Rubin diagnostic (Rhat < 1.1). Autocorrelation among chains was assessed through the calculation of the number of effective iterations.

After we derived the relationship between creel and CRC catch estimates, we estimated the catch of wild steelhead in each river system using a three-step "CRC expansion method". First, monthly CRC estimates of hatchery steelhead were "adjusted" using the derived numeric relationship between creel and CRC estimates (from our zero-inflated Poisson regression model). Second, we calculated the ratio of wild to hatchery catch by month and year from our derived creel survey estimates. In order to calculate an expansion, catch of hatchery steelhead must be more than 0 during months when catch of wild steelhead was more than 0. We calculated the mean of these ratios to get a single wild:hatchery catch "expansion" estimate per month. Third, we multiplied the adjusted CRC hatchery catch estimate by the average monthly wild:hatchery ratio to get an "expanded" estimate of monthly catch for wild caught steelhead. Comparisons of wild steelhead catch were then made between those derived from expanded CRC estimates and those derived from creel surveys.

Impacts to wild populations

We defined impacts on wild adult steelhead as the hooking mortality rate caused by non-retention recreational fishing (a.k.a., post-release mortality or indirect harvest). Recreational fishing hooking mortality is a function of the number of fish caught and released (i.e., encounters) and the mortality of those released fish. Based on previous research (Hooton 1987, Lirette 1989), the LCR FMEP identified hooking mortality rates of 5% for released winter steelhead and 8% for summer steelhead. We applied these hooking mortalities and estimated total mortalities using:

$$Mortalities_{i,j} = Hooking\ Mortality_k \times Catch_{i,j}$$

where total mortalities was a function of the catch in $year_i$ for steelhead $stock_j$ multiplied by the hooking $mortality_k$. In the Washougal River, the total catch of kelts for a given year consisted of an unknown proportion of summer and winter steelhead. We apportioned the catch of kelts among the two run-types by the relative size of the two runs. For example, in 2012, 155 steelhead were defined as kelts in the Washougal River. The total run-size was 842 and 338 for summer- and winter-run fish, respectively. Therefore, 111 kelts were assigned as summer-run fish and 44 were assigned as winter-run fish. To be conservative, kelt catch was assigned an 8% hooking mortality regardless of their stock designation.

The relative impact these mortalities have on a specific stock of steelhead is a function of run size, which was calculated using:

$$Run\ Size_{i,j} = Mortalities_{i,j} + Escapement_{i,j}$$

where run size in $year_i$ was a function of $mortalities_{i,j}$ and $escapement_i$. Escapement is the total number of steelhead spawners as estimated by WDFW. This approach assumed that hooking mortalities occurred prior to spawning. Therefore, mortalities of kelts were not included in the run size estimation. When we were unable to calculate total mortalities for a given stock and year (e.g., 2013 summer-run steelhead), we used escapement as a surrogate for run-size.

Encounter rates were calculated using:

$$Encounter\ Rate_{i,j} = \frac{Total\ Catch_{i,j}}{Run\ Size_{i,j}} \times 100$$

where the encounter rate in $year_i$ for steelhead $stock_j$ was a function of total $catch_{j,j}$ and run $size_i$.

The hooking mortality rate (i.e., impacts to wild steelhead) was calculated using:

$$Impact\ Rate_{i,j} = \frac{Mortaliies_{i,j}}{Run\ Size_{i,j}} \times 100$$

where impacts in $year_i$ for steelhead $stock_j$ were a function of $mortalities_{i,j}$ and run $size_i$.

Lastly, we evaluated the relationship between the angling techniques and the catch of steelhead in the SF Toutle and Washougal rivers. Specifically, we assessed the proportion of all steelhead caught as a function of (1) angling method (back troll, bobber, drift, or plunking) by fishing season and angler type, (2) gear type (fly, jig, lure, or bait) by fishing season and angler type, (3) fishing method by gear type, (4) anatomical hooking location (jaw, tongue, eye, gill, stomach, head, or body) by gear type, and (5) the use of barbed and barbless hooks by fishing season and year. Catch data were separated by river system for the first, second, and fifth comparisons, but were combined for the third and fourth comparison based on the similarity in patterns. Steelhead were not differentiated by origin (wild vs. hatchery) or run type (winter vs. summer) as these variables were coupled with season.

Results

Creel survey analysis: SF Toutle River

Over the study period, a roving creel survey was conducted on the SF Toutle River on 460 out of the 905 (51%) days that the fishery was open. Although there was some variation in the proportion of days sampled among months, 22 (67%) of the 33 months had more than 50% of its days sampled and only 4 (12%) months had fewer than 20% of the days sampled (Figure 4). No surveys were conducted during November 2011 despite the fishery being open. Therefore, total effort and catch estimates during the summer period of year group 2011-12 were likely underestimates of the true values.

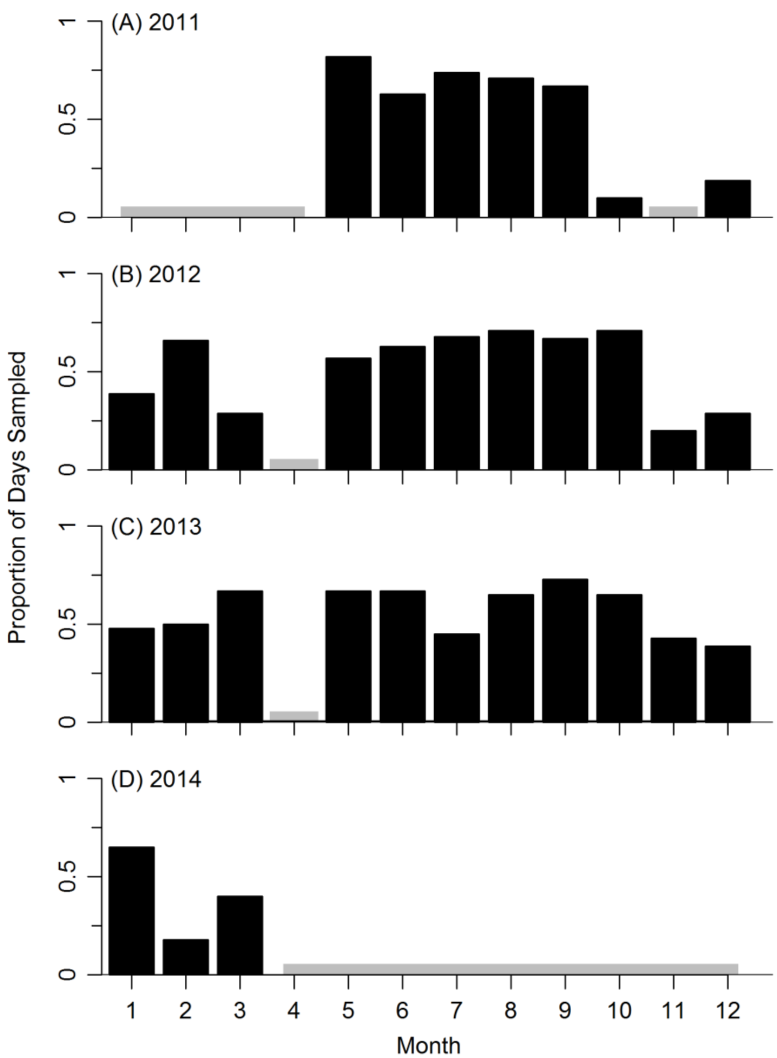

Figure 4. Proportion of all days per month a roving creel survey was conducted in (A) 2011, (B) 2012, (C) 2013 and (D) 2014 on the SF Toutle River. Surveys were conducted from May 21, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted. Note: fishery was closed from mid- to late-March through late-May each year.

During the 460 days that were creel surveyed, clerks interviewed 1,309 anglers groups, for a total of 1,968 individual anglers, that had either completed their angling trip (723; 37%) or been fishing for more than 30 minutes (1,245; 63%). No boat anglers were interviewed, as boat anglers comprised less than1% of the total angling effort (see "Effort results" below). The total number of bank anglers interviewed varied greatly among months and ranged from 7 anglers in November 2012 to 203 anglers in June 2011 (Figure 5). The among-month variation in number of interviews was largely reflective of angling effort (see "Effort results" below).

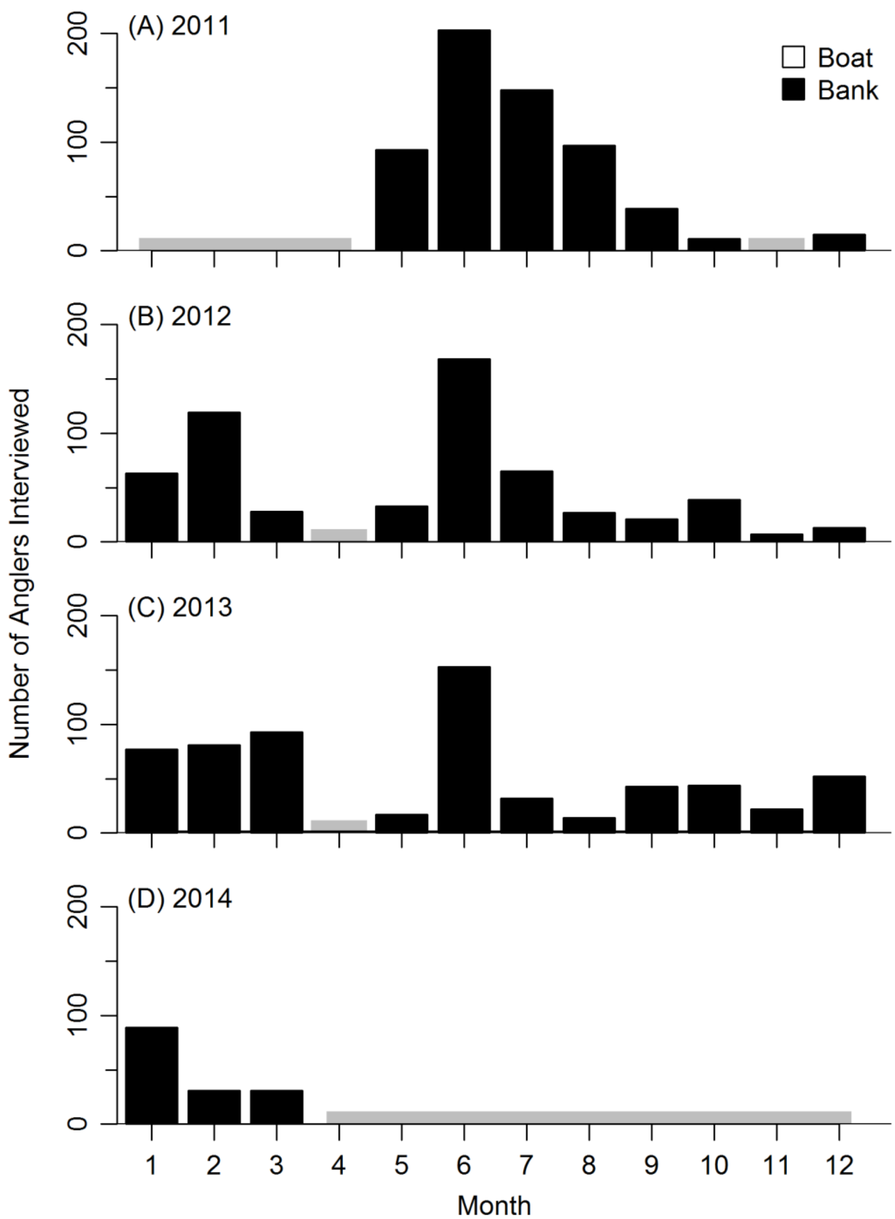

Figure 5. Number of bank (black) and boat (white) anglers interviewed per month on the SF Toutle River in (A) 2011, (B) 2012, (C) 2013 and (D) 2014. Surveys were conducted from May 21, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted. Note: no boat anglers were interviewed.

Anglers came from four different states to fish for steelhead in the SF Toutle River including: California, Colorado, Oregon, and Washington. Of the individual trips, 94.4% of all anglers were from Washington State and 5.3% were from Oregon State. Within the group of anglers from Washington State, 53.5% of anglers resided in Cowlitz County, 13.8% were from Thurston County, 11.0% were from Lewis County, 8.1% were from Pierce County and 13.6% were from 15 other counties (Figure 6). Within the group of anglers from Oregon State, 90.3% resided in Multnomah.

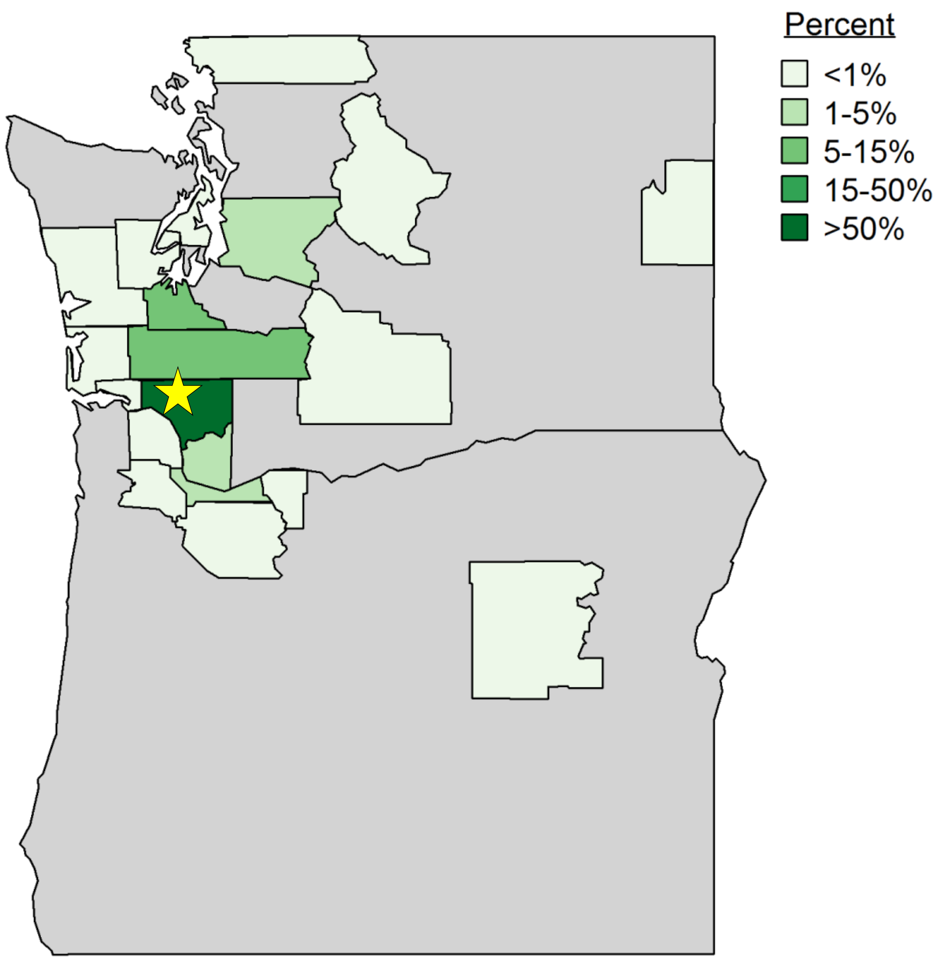

Figure 6. County of residence for steelhead anglers that fished the SF Toutle River from May 21, 2011, to March 15, 2014. Shading reflects the percentage of anglers from each county. Star denotes approximate location of the SF Toutle River.

Anglers fished for an estimated total of 24,346 (SE = 1,126) hours from May 21, 2011 to March 15, 2014 (Table 1). Total effort was approximately 80% higher in 2011-12 (11,542 anglers-hours) relative to 2012-13 (6,367 angler-hours) and 2013-14 (6,437 anglers-hours; Table 1). Although overall total effort was higher in 2011-12, the overall pattern among months was similar across year groups (Figure 7). Among all three year groups, June and July comprised 35-40% of all annual angling effort while January, February, and March comprised an additional 25-40% of the annual angling effort (Appendix D; Table C1). Across years and months, 99.4% of all effort was by bank anglers and 42% of the bank angler effort occurred on weekend days.

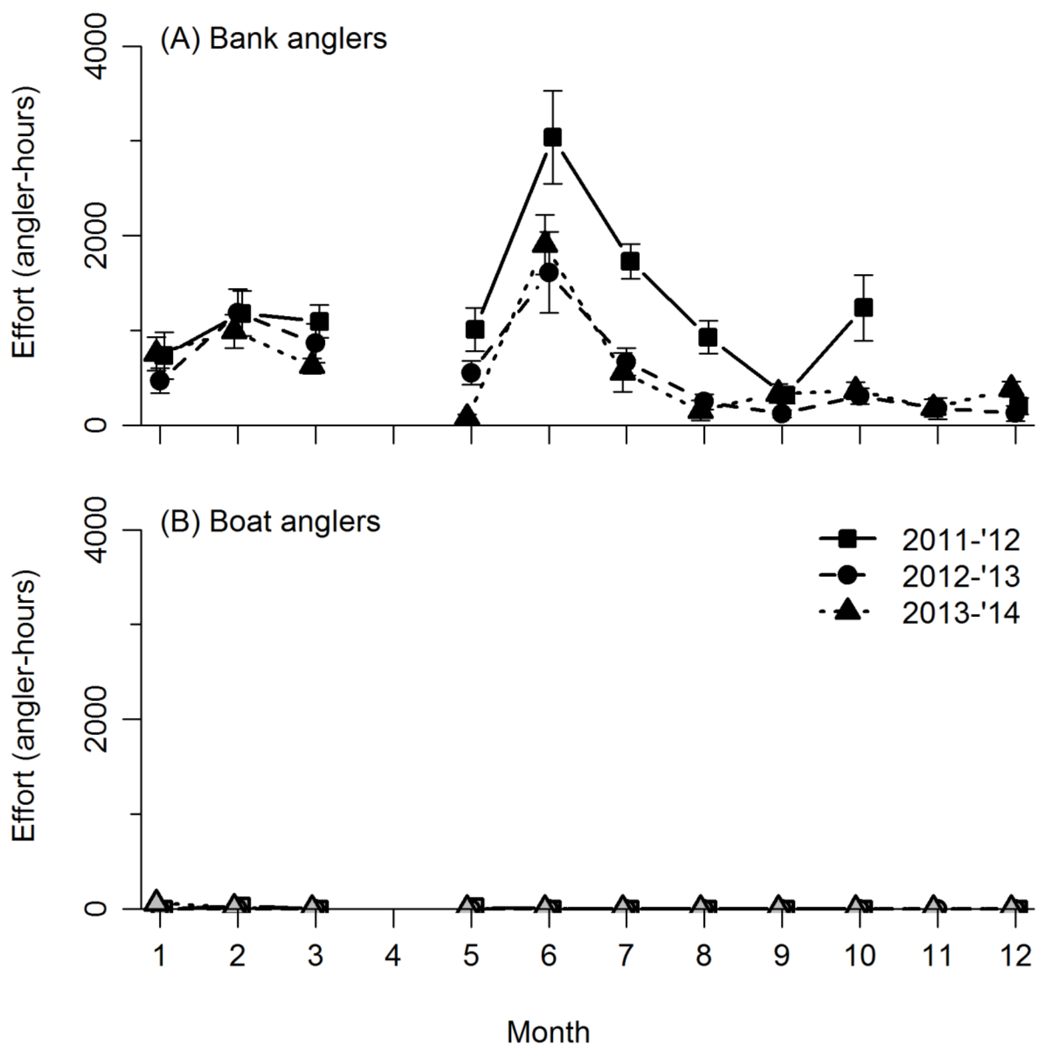

Figure 7. Mean (± SE) monthly fishing effort (angler-hours) by (A) bank and (B) boat steelhead anglers by year-group on the SF Toutle River from May 21, 2011 to March 15, 2014. Consistent with fishing regulations, years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012).

Table 1. Estimated (SE) total effort (angler-hours), anglers (angler-days), catch per unit effort (fish per hour), and catch for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead during the summer (May - November) and winter (December - April) on the South Fork Toutle River collected May 21, 2011, to March 15, 2014.

		Summer					
Category	Stock-origin	2011 - '12		2012 - '13		2013 - '14	
Effort	-	8292	(683)	3704	(497)	3596	(424)
Anglers	-	2381	(232)	1398	(212)	1410	(188)
CPUE	Hatchery Harvested	0.057	(0.188)	0.024	(0.1)	0.103	(0.298)
	Hatchery Released	0.008	(0.05)	0	(0)	0.002	(0.011)
	Wild Released	0.037	(0.133)	0.004	(0.0164)	0.03	(0.13)
	Unknown Released	0	(0)	0.001	(0.001)	0	(0)
Catch	Hatchery Harvested	551	(99)	171	(37)	385	(101)
	Hatchery Released	71	(36)	0	(0)	8	(5)
	Wild Released	466	(84)	53	(12)	106	(32)
	Unknown Released	0	(-)	23	(6)	0	(-)
		Winter					
Category	Stock-origin	2011 - '12		2012 - '13		2013 - '14	
Effort	-	3250	(394)	2663	(359)	2841	(275)
Anglers	-	1021	(143)	852	(134)	929	(123)
CPUE	Hatchery Harvested	0.0122	(0.111)	0.01	(0.06)	0.003	(0.014)
	Hatchery Released	0.004	(0.023)	0.006	(0.033)	0.006	(0.036)
	Wild Released	0.079	(0.165)	0.26	(0.616)	0.168	(0.517)
	Unknown Released	0	(0)	0	(0)	0	(0)
Catch	Hatchery Harvested	21	(9)	23	(7)	32	(8)
	Hatchery Released	35	(21)	31	(12)	9	(7)
	Wild Released	527	(61)	442	(93)	441	(117)
	Unknown Released	0	(-)	0	(-)	0	(-)

Using the month specific mean trip time, we estimated the total number of unique bank-angler trips per month. Despite there being clear temporal trends in angler effort, there was relatively little variation in mean trip time among anglers across months (Figure 8). The overall mean trip time by bank anglers was 2.8 hours (SE = 0.12). Therefore, the estimated number of anglers per month (Figure 9) followed a similar pattern to the estimated monthly effort (Figure 7). Over the three years, there was a total of 7,991 unique angler-trips, with approximately 50% more angler-trips in 2011-12 (3,402 angler-trips), relative to 2012-12 (2,250 angler-trips) and

2013-14 (2,339 angler-trips), and 50-130% more angler-trips in the summer relative to winter (Table 1).

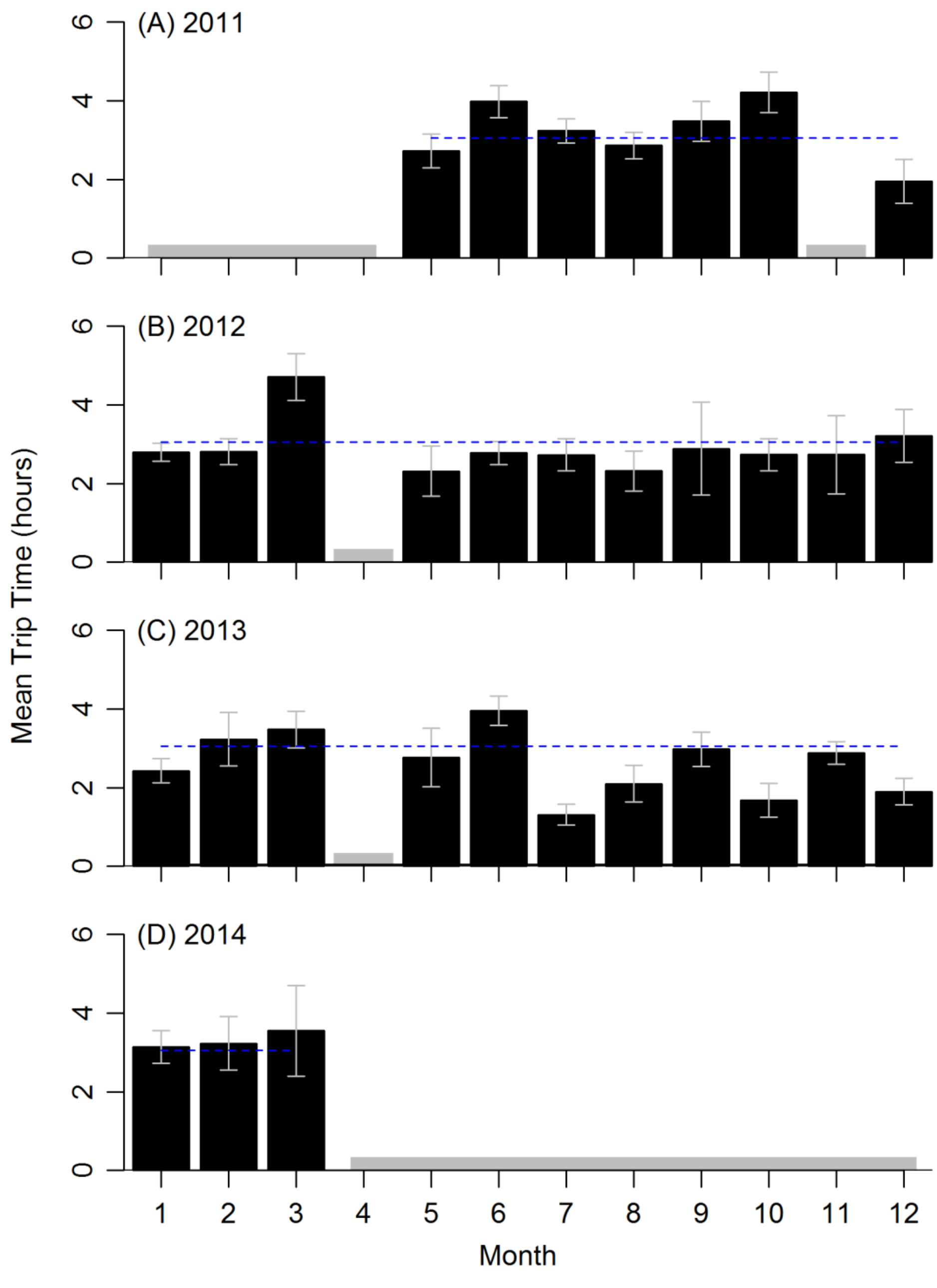

Figure 8. Mean monthly trip time (± SE) by steelhead bank anglers on the SF Toutle River during (A) 2011, (B) 2012, (C) 2013, and (D) 2014. Surveys were conducted from May 21, 2011 to March 15, 2014. Dashed blue lines correspond to the mean trip time across all months for bank anglers. Gray bars denote full months when creel surveys were not conducted. Note: No boat anglers were interviewed as they comprised less than 1% of all effort.

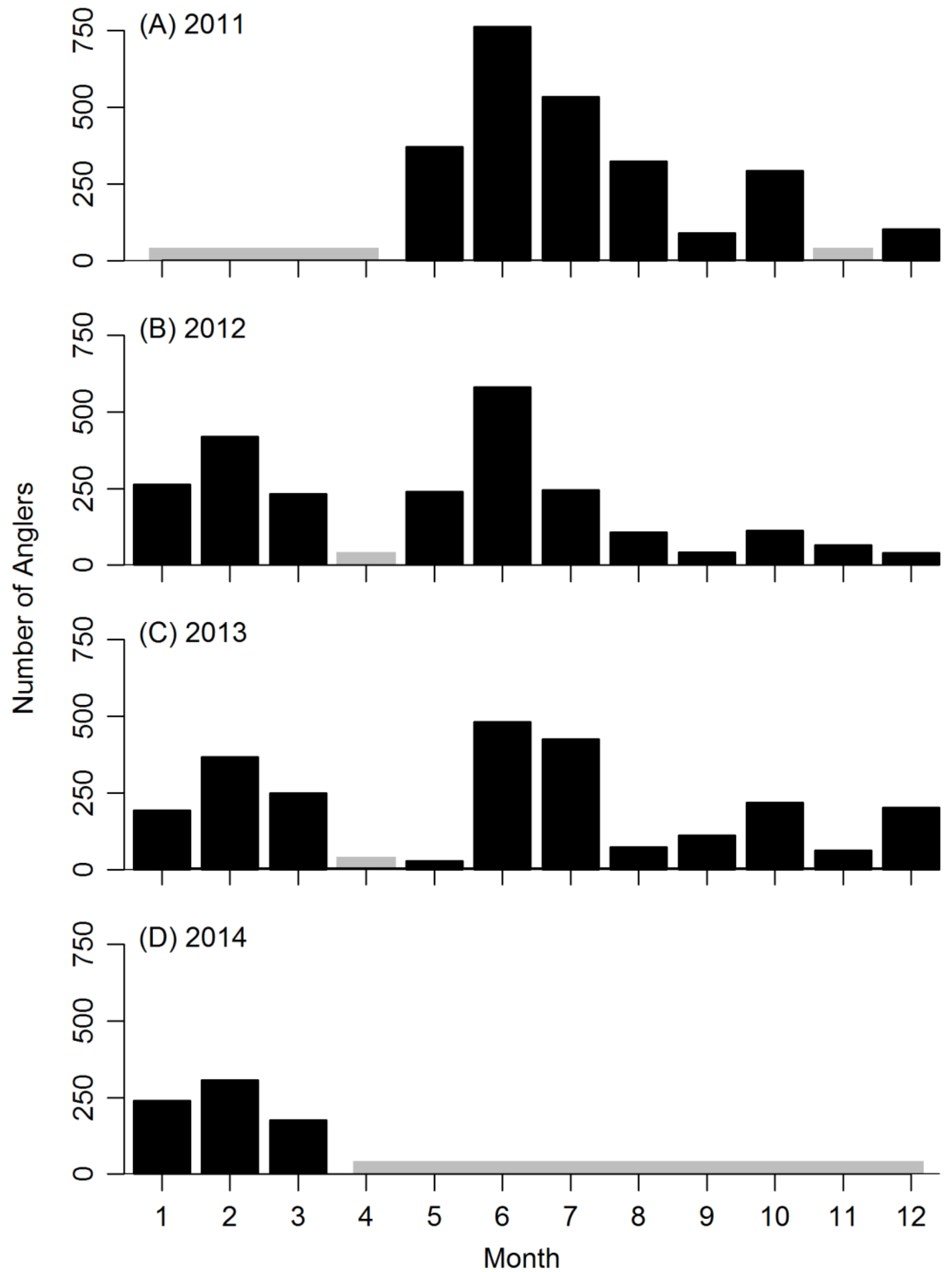

Figure 9. Estimated number of bank anglers per month on the SF Toutle River during (A) 2011, (B) 2012, (C) 2013 and (D) 2014. Surveys were conducted from May 21, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

The number of anglers that were interviewed per month was directly related to the estimated number of anglers fishing for steelhead ($p<0.001$, $R = 0.95$; Figure 10) and the best-fit linear model was parameterized as y(Number of Bank Anglers) = 3.64(Bank Angler Interviews). Therefore, we interviewed approximately 27% of all individual anglers across all months and years. The proportion of anglers (i.e., angler-trips) that were interviewed by a clerk varied among months (Figure 11) because our sampling effort was relatively uniform among months and years (Figure 4) but angling effort was not (Figure 7).

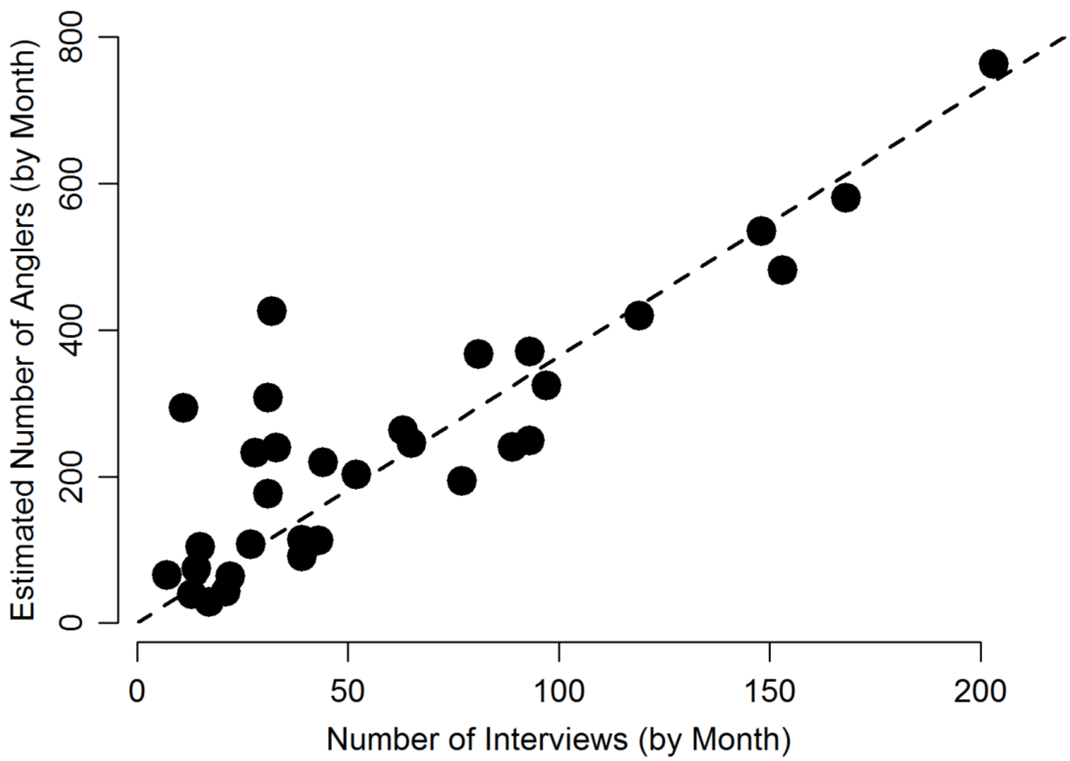

Figure 10. Correlation between number of bank angler interviews per month and the estimated number of monthly anglers on the SF Toutle River from May 21, 2011 to March 15, 2014.

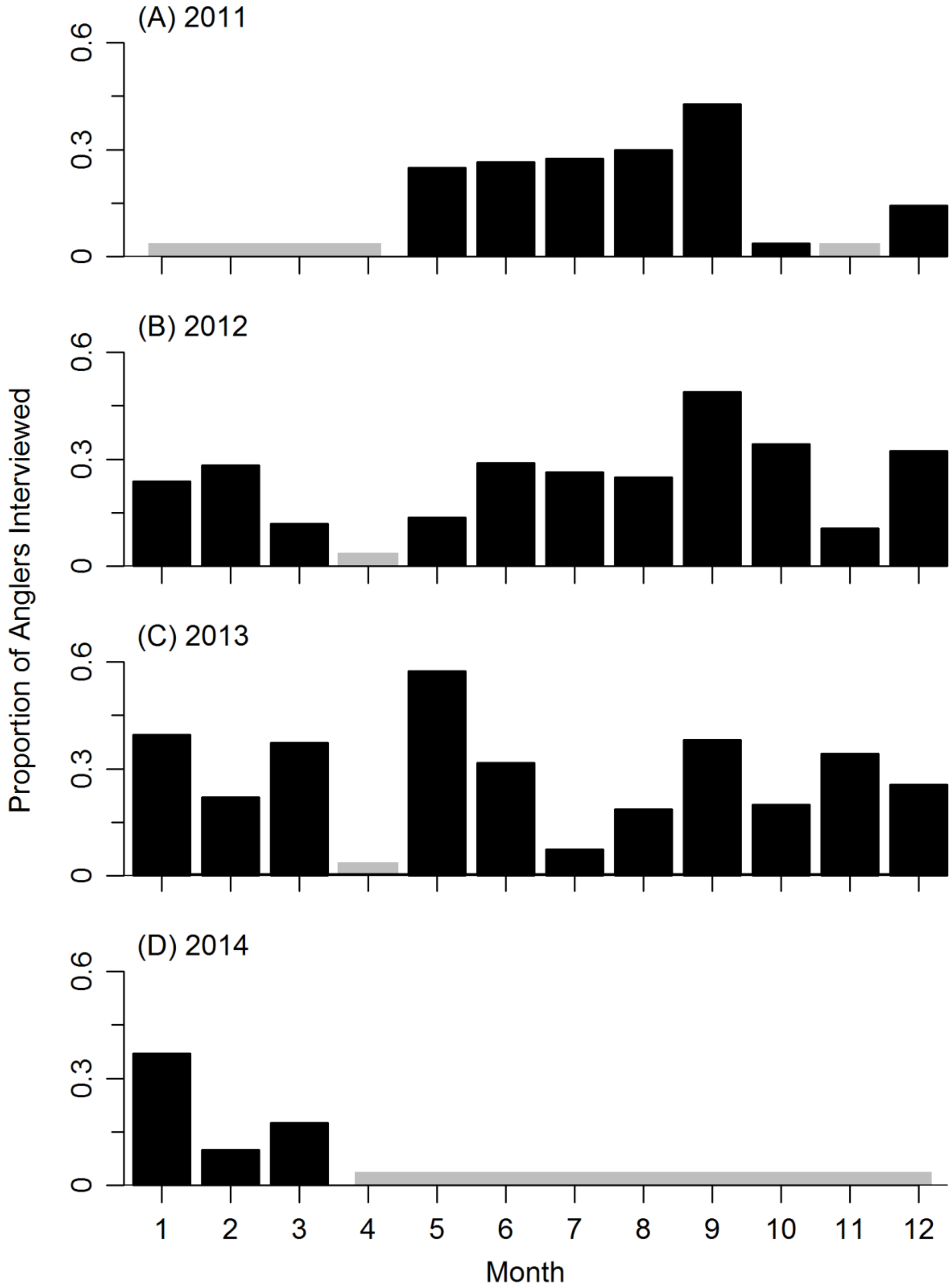

Figure 11. Estimated proportion of all steelhead anglers that were interviewed each month on the SF Toutle River during (A) 2011, (B) 2012, (C) 2013 and (D) 2014. Surveys were conducted from May 21, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

The overall catch per unit effort (CPUE) for steelhead by bank anglers in the SF Toutle River was 0.13 (SE = 0.012) fish per hour (7.8 hours of fishing per steelhead) averaged across all years, seasons, and stocks. However, there was a wide range of variation in CPUE among anglers, seasons, and years (Table 1; Figure 12). Among the 1,309 angler-groups interviewed, 78% (1025 groups) reported no catch (CPUE of zero). Among the anglers with a catch of one or more steelhead during an individual trip, the average CPUE was 0.59 (SE = 0.03; 1.7 hours of fishing per steelhead). Variation in catch among individual anglers led to relatively large estimates of standard error when calculating CPUE among year-groups, seasons, and months (Figure 12).

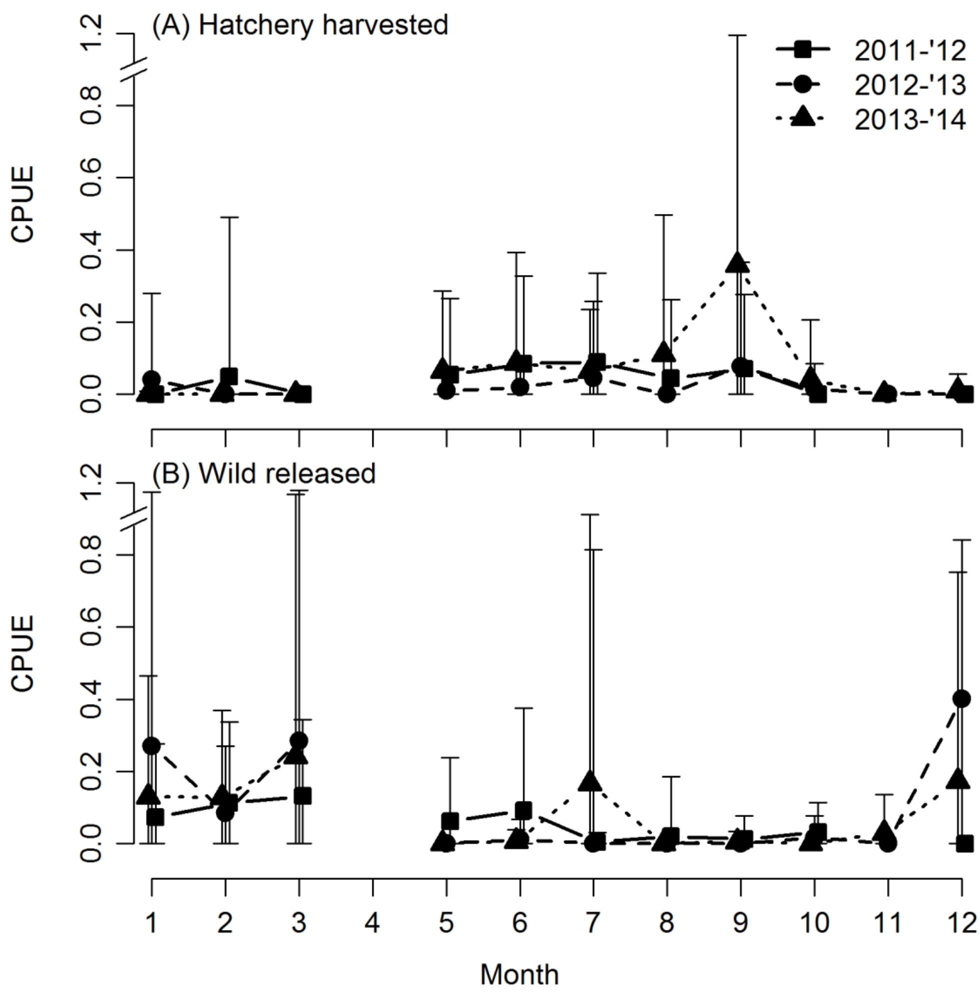

Figure 12. Mean (± SE) monthly catch per unit effort (fish/hour) by bank anglers for (A) hatchery harvested and (B) wild released steelhead by year group on the SF Toutle River from May 21, 2011 to March 15, 2014. Years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012). No boat anglers were interviewed and therefore CPUE could not be calculated.

Catch rates for hatchery fish were higher during summer months (May – November) while catch rates for wild fish were higher during winter months (December – March). Within the peak months of run-timing for each stock, catch rates were generally higher for wild steelhead. Catch rates of wild steelhead were more than 0.10 fish per hour in 9 (75%) out of the 12 winter months (across three years) while catch rates for hatchery steelhead were more than 0.10 fish per hour in only 2 (10%) out of the 20 summer months. Among the three year-groups, catch rates for harvested hatchery steelhead were substantially lower during the summer of 2012-13 (average ± SE: 0.024 ± 0.10) relative to 2011-12 (0.057 ± 0.19) and 2013-14 (0.103 ± 0.30). Catch rates were highest for wild steelhead during the winter of 2012-13 (0.260 ± 0.61) followed by 2013-14 (0.168 ± 0.52) and 2011-12 (0.079 ± 0.17).

CATCH: SOUTH FORK TOUTLE RIVER

An estimated total of 3,395 steelhead were caught in the SF Toutle River from May 2011 – March 2014 (Table 1). Overall, more than 99% of all fish caught were identified as either hatchery or wild origin, and the total catch of "unknown" origin steelhead was extremely low. Of the steelhead identified by origin, more than 88% of the hatchery fish were harvested while 100% of the wild were reported to be released. Across all seasons and years, boat anglers constituted less than 0.05% of the estimated total catch.

Among years, variation in catch of harvested hatchery steelhead was greater among years than variation in catch of wild steelhead. Across all summer months, a total of 551, 171, and 385 hatchery steelhead were harvested during 2011-12, 2012-13, and 2013-14, respectively, resulting in an inter-annual coefficient of variation (CV) of 0.51. Across all winter months, a total of 527, 442, and 441, wild steelhead were caught, respectively, resulting in an interannual coefficient of variation (CV) of 0.11.

The total number of steelhead caught within a particular season was generally influenced by the origin of the fish. Across the three fishing seasons, 96, 88, and 92% of hatchery steelhead were harvested during summer months while 53, 89, and 81% of wild fish were caught and released during winter months for 2011-12, 2012-13, and 2013-14 respectively. In general, harvest of hatchery fish peaked in June and July, was low in August, had a small peak in September, and was relatively low from October through March (Figure 13). Although there were small numbers of wild steelhead reported to be caught in the summer months, wild steelhead catch generally did not pick up until December and January and peaked in February and March. An exception to these general patterns occurred in 2011-12, when an abnormally high number of wild steelhead were caught in May and June relative to the other two year groups (Figure 13) leading to the lower percentage of wild fish caught during the winter of that year (Table 1; Appendix E: Table E1).

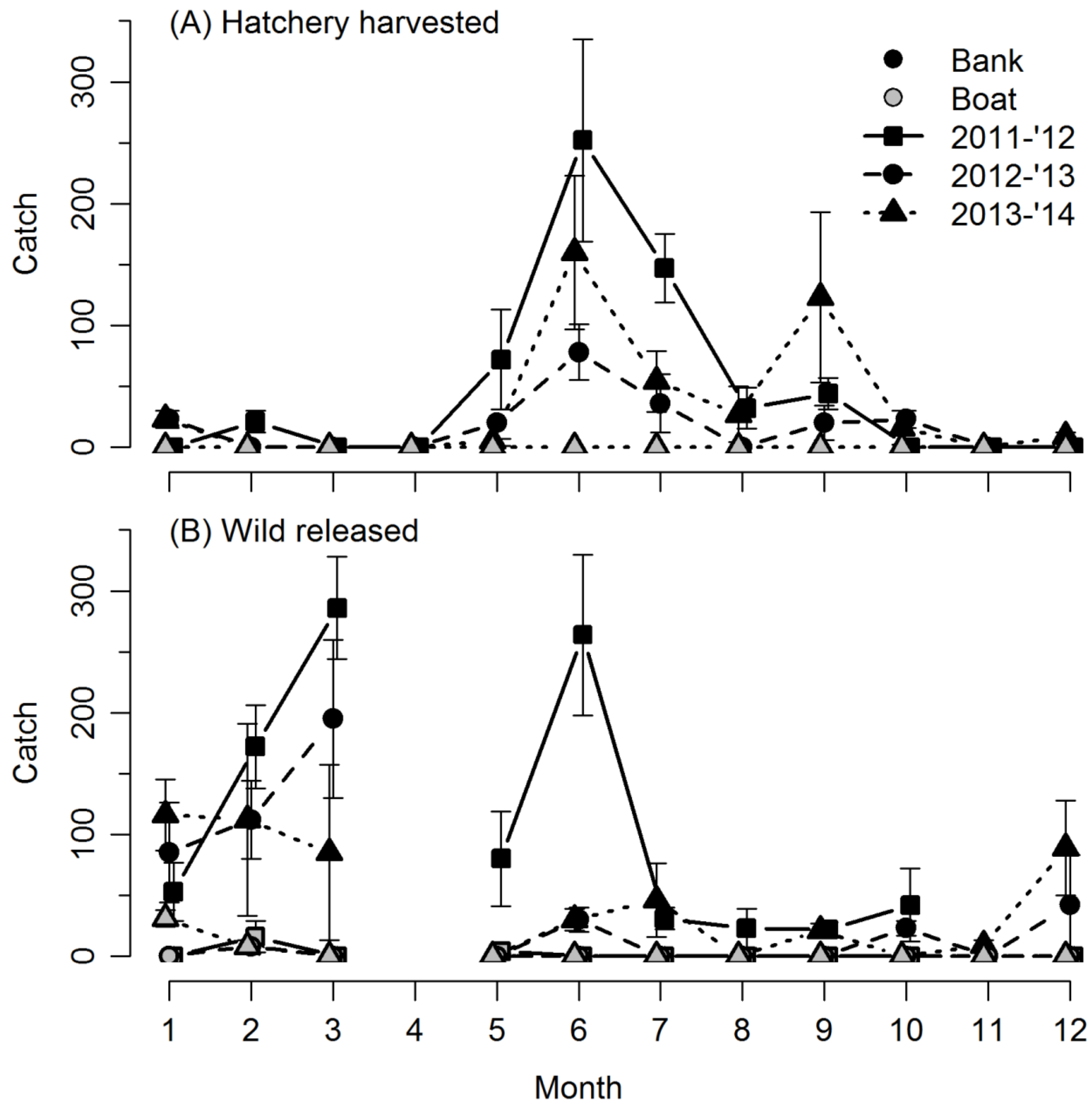

Figure 13. Mean (± SE) monthly catch by bank (black) and boat (gray) anglers for (A) hatchery harvested and (B) wild released steelhead by year-group on the SF Toutle River from May 21, 2011 to March 15, 2014. Years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012).

Creel survey analysis: Washougal River

Over the study period, a roving creel survey on the Washougal River was conducted on 435 out of the 950 (46%) days that the fishery was open. Overall, 25 (93%) of the 27 months that were sampled had more than 50% of its total days sampled and only 1 (4%) month had fewer than 20% of the days sampled (Figure 14). Due to the initial study design (see methods) and staffing limitation, no surveys were conducted from June 15th – October 31st in 2011 and 2012 nor in September 2013 despite the fishery being open. Therefore, total effort and catch estimates during the summer season of all year-groups were under-estimates of the true values.

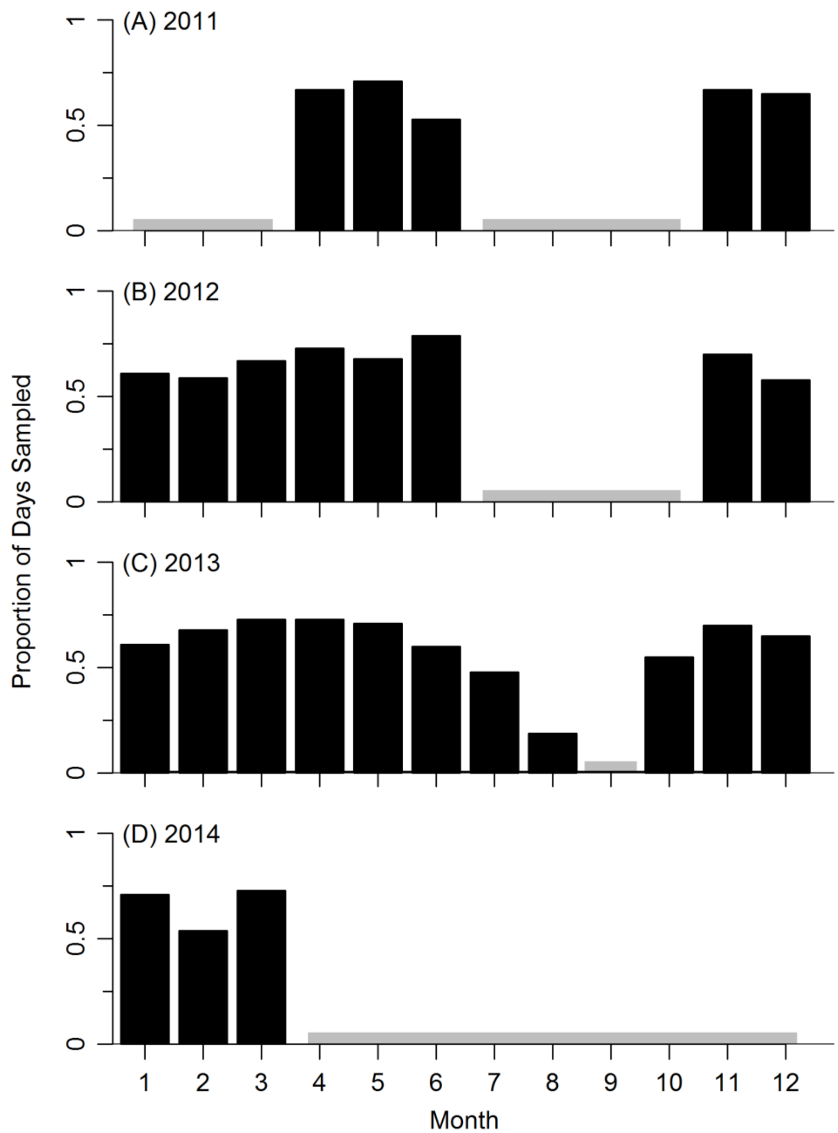

Figure 14. Proportion of all days per month a roving creel survey was conducted in (A) 2011, (B) 2012, (C) 2013 and (D) 2014 on the Washougal River. Surveys were conducted from April 16, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted. Note: fishery was closed from mid-March to mid-April each year.

During the 435 days that were creel surveyed, clerks interviewed 2,927 bank and 755 boat angler groups for a total of 3,543 individual bank- and 1,609 boat-anglers that had either completed their angling trip (20% of bank-anglers; 99% of boat-anglers) or been fishing for more than 30 minutes (80% of bank-anglers; 1% of boat-anglers). The total number of bank and boat anglers interviewed varied greatly among months, ranging from fewer than 10 up to more than 300 (Figure 15). The among-month variation in number of interviews was largely reflective of angling effort (see “Effort results” below).

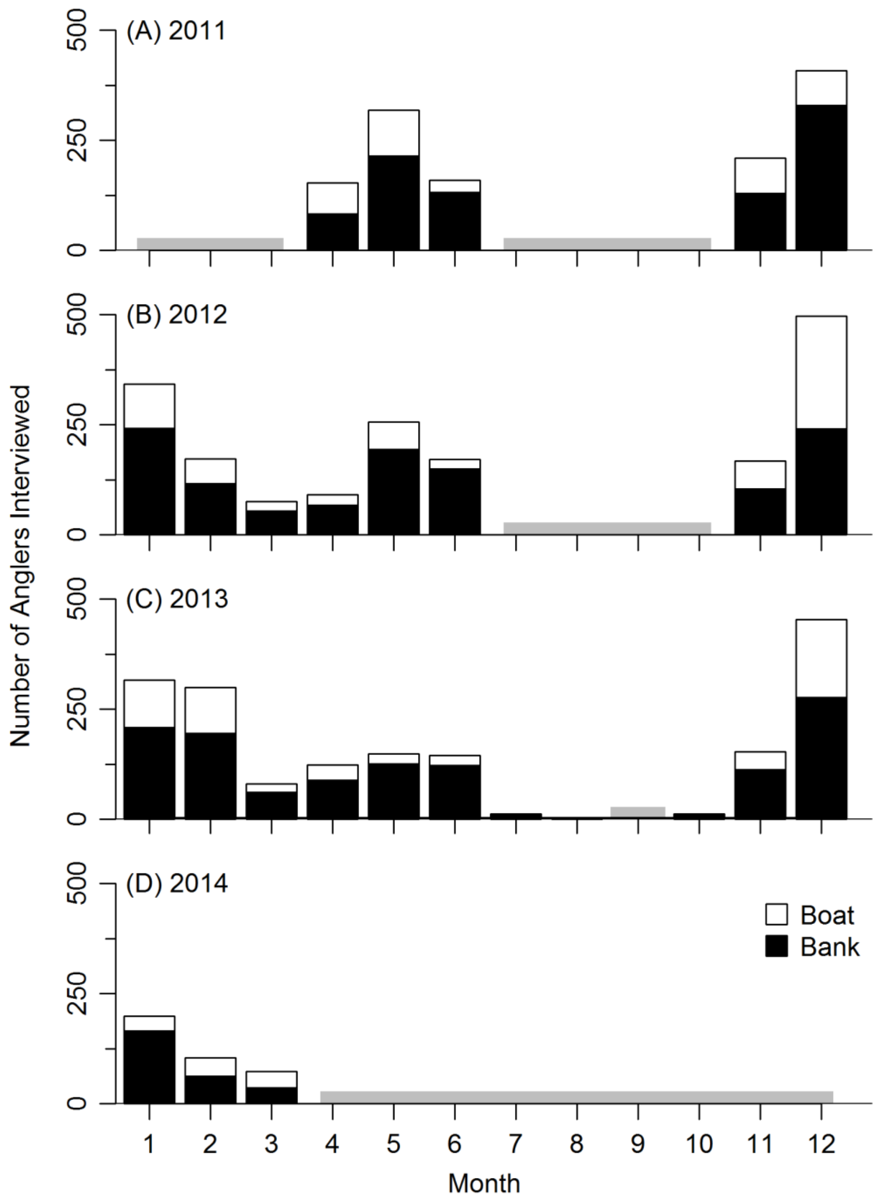

Figure 15. Number of bank (black) and boat (white) anglers interviewed per month on the Washougal River in (A) 2011, (B) 2012, (C) 2013 and (D) 2014 from April 16, 2011, to March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

Anglers came from nine different states to fish for steelhead in the Washougal River including: Alaska, California, Florida, Idaho, Montana, New Mexico, Oregon, Pennsylvania, and Washington. Of the individual trips, 96.1% of all anglers were from Washington State and 3.6% were from Oregon State. Within the group of anglers from Washington State, 92.5% of anglers resided in Clark County, 3.6% were from Skamania County, and 3.9% were from seven other counties (Figure 16). Within the group of anglers from Oregon State, 91.4% resided in Multnomah County.

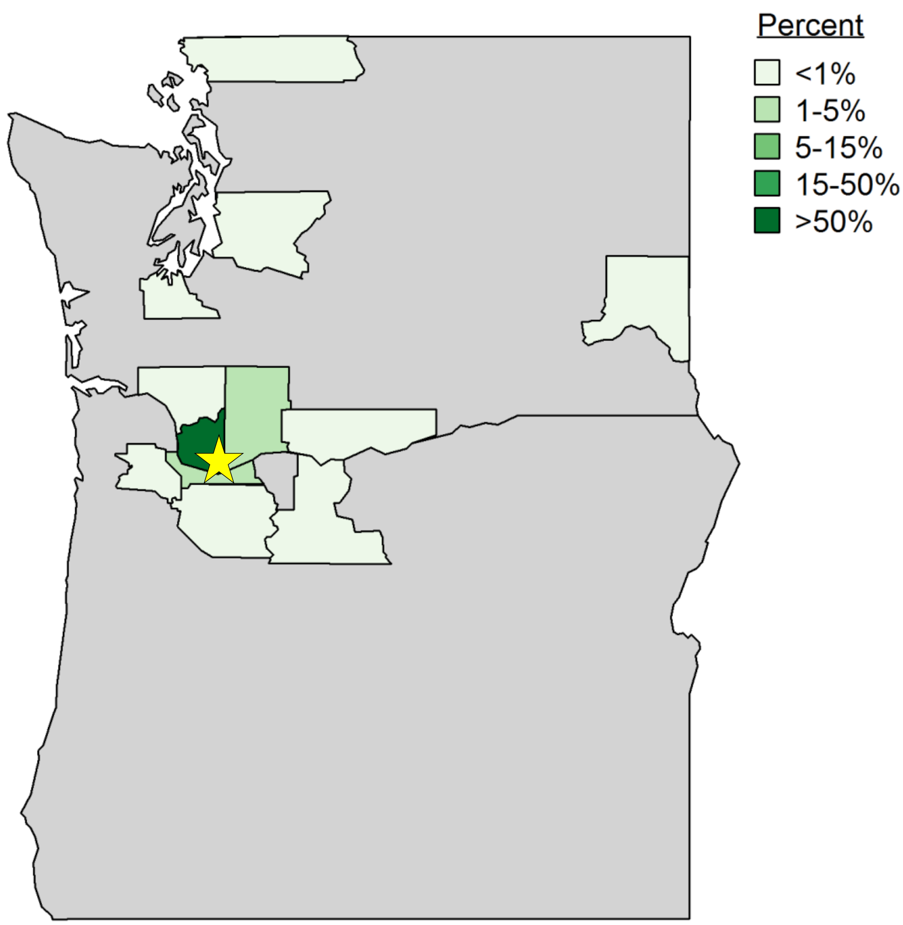

Figure 16. County of residence for steelhead anglers that fished the Washougal River from April 16, 2011, to March 15, 2014. Shading reflects the percentage of anglers from each county. Star denotes approximate location of the Washougal River.

Anglers fished for an estimated total of 74,351 hours (SE = 2,279) on the Washougal River from April 16, 2011 to March 15, 2014. Total annual effort was highest in 2012-13 (27,570 angler-hours, SE = 1,452) followed by 2011-12 (24,474, SE = 1,250) and 2013-14 (19,929, SE = 1,146). Among the three years groups, angling effort was 23 – 62% higher during the winter season relative to the summer (Table 2). However, 4.5 (mid-June – October) of the 7 summer months were not sampled in two out of the three years. The overall pattern in effort among months was similar across the three year groups (Figure 17). Among all three year groups, December had the highest angler effort, comprising 21-30% of the annual total, followed by June, May, and January (Appendix D; Table D2). On average, 39% of all effort occurred on weekend days. Across years and months, bank anglers comprised 72% of the total angler-hours (53,492, SE = 1820), but varied from as low as 42% in March 2013 up to 100% in July and October 2013.

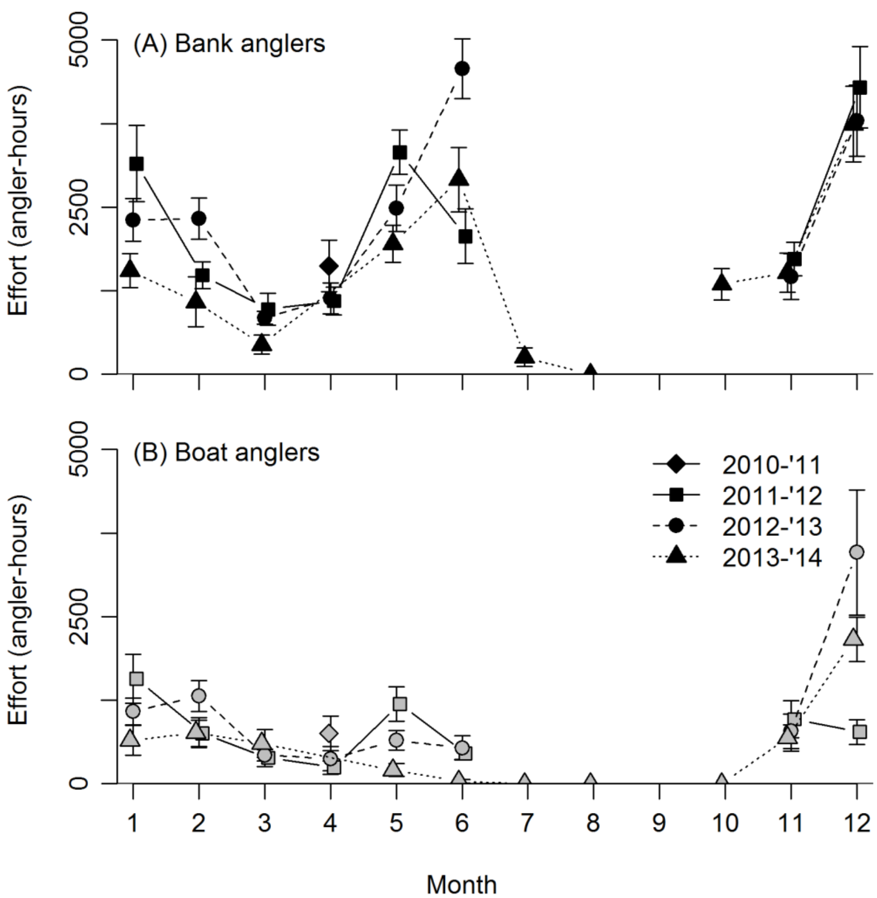

Figure 17. Mean (± SE) monthly fishing effort (angler-hours) by (A) bank and (B) boat steelhead anglers by year-group on the Washougal River from April 16, 2011, to March 15, 2014. Years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012). Note: year group 2010-11 only includes April.

Table 2. Estimated (SE) total effort (angler-hours), anglers (angler-days), catch per unit effort (fish per hour), and catch for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead during the summer (May - November) and winter (December - April) on the Washougal River collected April 16, 2011, to March 15, 2014.

		Summer					
Category	Stock-origin	2011 - '12		2012 - '13		2013 - '14	
Effort	-	9737	(701)	10494	(747)	8926	(720)
Anglers	-	3551	(416)	4169	(516)	3714	(574)
CPUE	Hatchery Harvested	0.018	(0.08)	0.015	(0.055)	0.017	(0.058)
	Hatchery Released	0.002	(0.013)	0.007	(0.038)	0	(0)
	Wild Released	0.014	(0.059)	0.009	(0.049)	0.003	(0.021)
	Unknown Released	0	(-)	0.004	(0)	0	(-)
Catch	Hatchery Harvested	265	(60)	506	(195)	234	(87)
	Hatchery Released	27	(10)	144	(35)	0	(-)
	Wild Released	246	(50)	344	(136)	122	(39)
	Unknown Released	0	(-)	23	(6)	0	(-)

		Winter					
Category	Stock-origin	2011 - '12		2012 - '13		2013 - '14	
Effort	-	14737	(1034)	17076	(1245)	11003	(891)
Anglers	-	5721	(595)	6572	(792)	3982	(560)
CPUE	Hatchery Harvested	0.036	(0.123)	0.018	(0.089)	0.029	(0.107)
	Hatchery Released	0.01	(0.023)	0.007	(0.028)	0.019	(0.076)
	Wild Released	0.054	(0.147)	0.048	(0.167)	0.063	(0.149)
	Unknown Released	0	(-)	0.001	(0.006)	0	(-)
Catch	Hatchery Harvested	744	(115)	366	(61)	556	(138)
	Hatchery Released	195	(28)	170	(24)	225	(47)
	Wild Released	795	(109)	787	(107)	446	(87)
	Unknown Released	0	(-)	11	(10)	0	(-)

Using the month specific mean trip time, we estimated the total number of bank and boat anglers per month. Although there were clear differences in the mean trip time among bank (2.04 hours, SE = 0.10) and boat anglers (4.98 hours, SE = 0.09), there was relatively little variation across months for each angler type (Figure 18). Therefore, the estimated number of unique angler-trips per month (Figure 19) followed a similar pattern to the estimated monthly effort measured in angler-hours (Figure 17). The comparison between boat and bank anglers differed when effort was represented as angler-hours versus angler-trips. Because boat-angler trips typically lasted 2-3 times as long as bank-angler trips, there was more bank angler effort per month relative to boat angler effort when measured in angler-trips rather than angler-hours. Over the three years, there were a total of 28,640 unique angler-trips, 85% of which were by bank anglers.

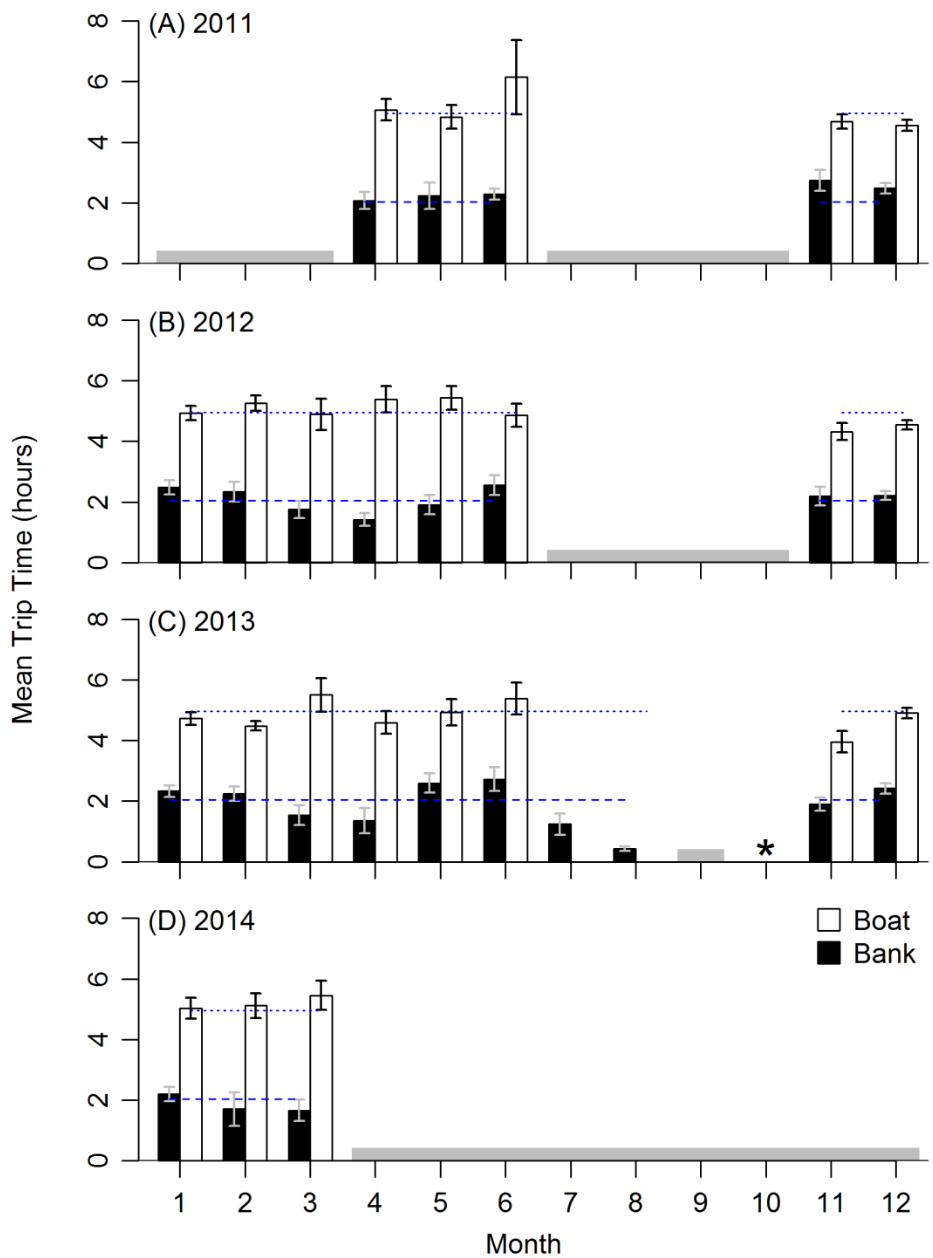

Figure 18. Mean monthly trip time (± SE) by steelhead anglers on the Washougal River during (A) 2011, (B) 2012, (C) 2013, and (D) 2014. Surveys were conducted from April 16, 2011 to March 15, 2014. Dashed and dotted blue lines correspond to the mean trip time across all months for bank and boat anglers, respectively. The asterisk denotes a month when the fishery was open but no completed trip creel surveys were conducted. Gray bars denote full months when creel surveys were not conducted.

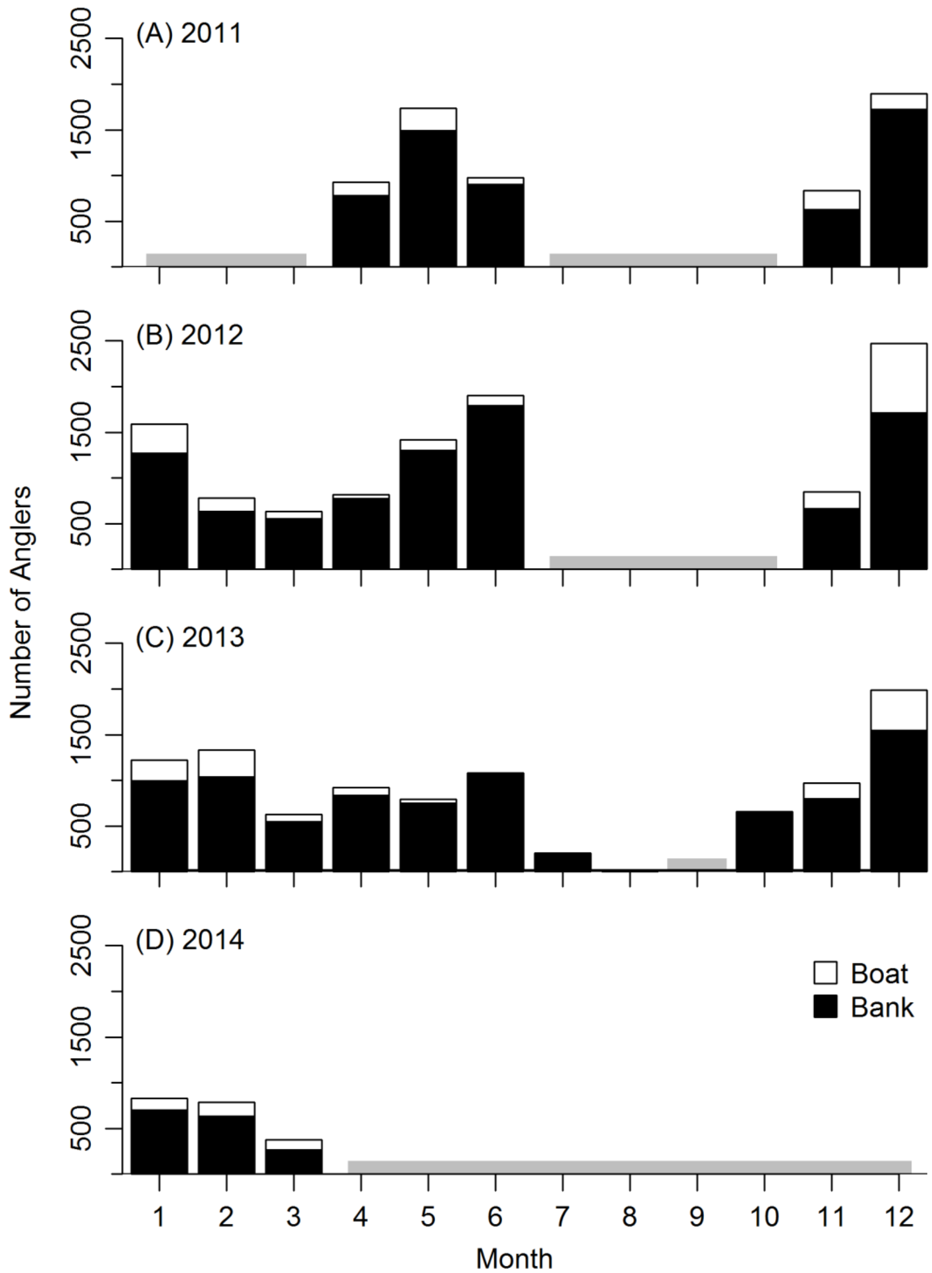

Figure 19. Estimated number of bank (black) and boat (white) anglers per month on the Washougal River during (A) 2011, (B) 2012, (C) 2013 and (D) 2014 from April 16, 2011, through March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

The number of anglers that were interviewed per month was strongly related to the estimated number of anglers fishing for steelhead (Figure 20; Bank: $p<0.001$, $R = 0.96$; Boat: $p<0.001$, $R = 0.99$). The best-fit linear model between number of anglers interviewed and the estimated number of anglers per month was parameterized as y(Number of Bank Anglers) = 6.24(Bank Angler Interviews) and y(Number of Boat Anglers) = 2.71(Boat Angler Interviews). Therefore, approximately 16 and 37% of all individual bank and boat anglers were interviewed, respectively, across all months and years. The proportion of all individual anglers (i.e., angler-trips for bank and boat anglers combined) that were interviewed by a clerk varied among months (Figure 21) between 0.02 in October 2013 and 0.24 in January 2013. This variation occurred because our sampling effort was relatively uniform among months and years (Figure 14) but angling effort was not (Figure 17).

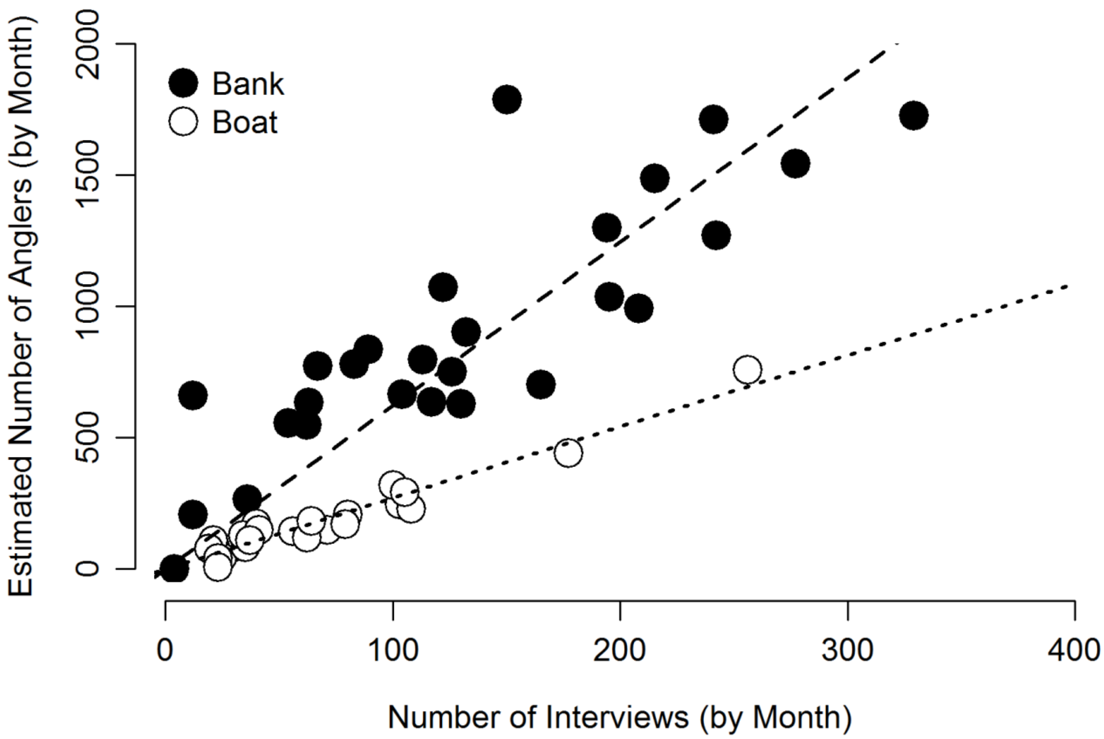

Figure 20. Correlation between number of bank (black) and boat (white) angler interviews per month and the estimated number of monthly anglers on the Washougal River from April 16, 2011 to March 15, 2014.

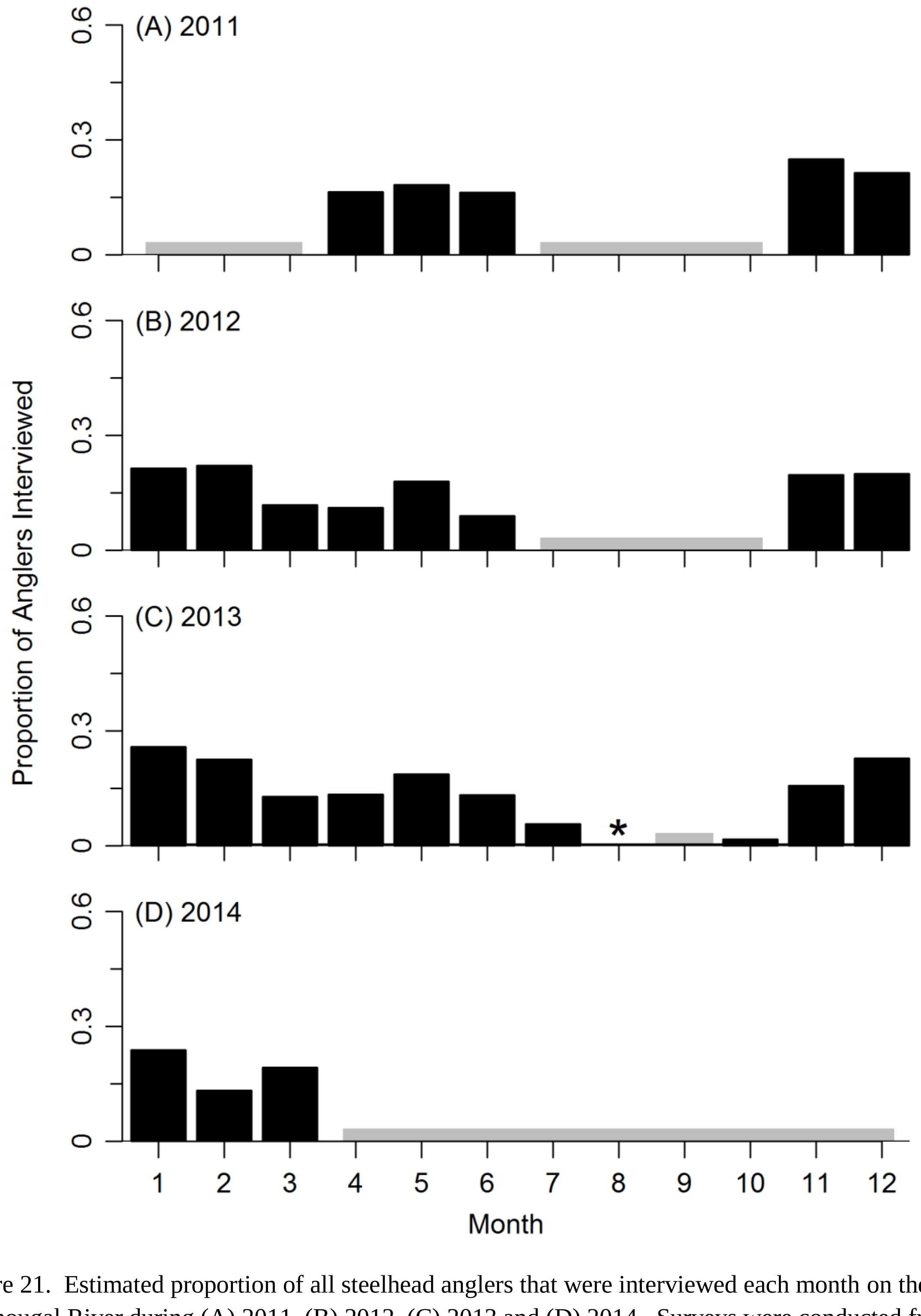

Figure 21. Estimated proportion of all steelhead anglers that were interviewed each month on the Washougal River during (A) 2011, (B) 2012, (C) 2013 and (D) 2014. Surveys were conducted from April 16, 2011 to March 15, 2014. The asterisk denotes a month when the estimated number of anglers was zero. Gray bars denote full months when creel surveys were not conducted.

CATCH RATES: WASHOUGAL RIVER

The overall catch per unit effort (CPUE) for steelhead in the Washougal River was 0.056 fish per hour for bank anglers (SE = 0.001; 17.8 hours of fishing per steelhead) and 0.066 for boat anglers (SE = 0.001; 15.1 hours of fishing per steelhead) averaged across all years, seasons, and stocks. However, there was a wide range of variation in CPUE among individual anglers. Among the 2,916 bank and 752 boat angler-groups interviewed, 91% (2,668 groups) of bank and 63% (473 groups) of boat angler-groups reported a catch of no fish (CPUE of zero). Of the anglers reporting a catch of one or more steelhead during an individual trip, bank anglers had an average CPUE of 0.66 (SE = 0.016; 1.5 hours of fishing per steelhead) while boat angler had an average CPUE of 0.18 (SE = 0.007; 5.6 hours of fishing per steelhead). This large variation in catch among individual anglers led to relatively large estimates of standard error when calculating CPUE among year-groups, seasons, months, and angler-types (Figure 22).

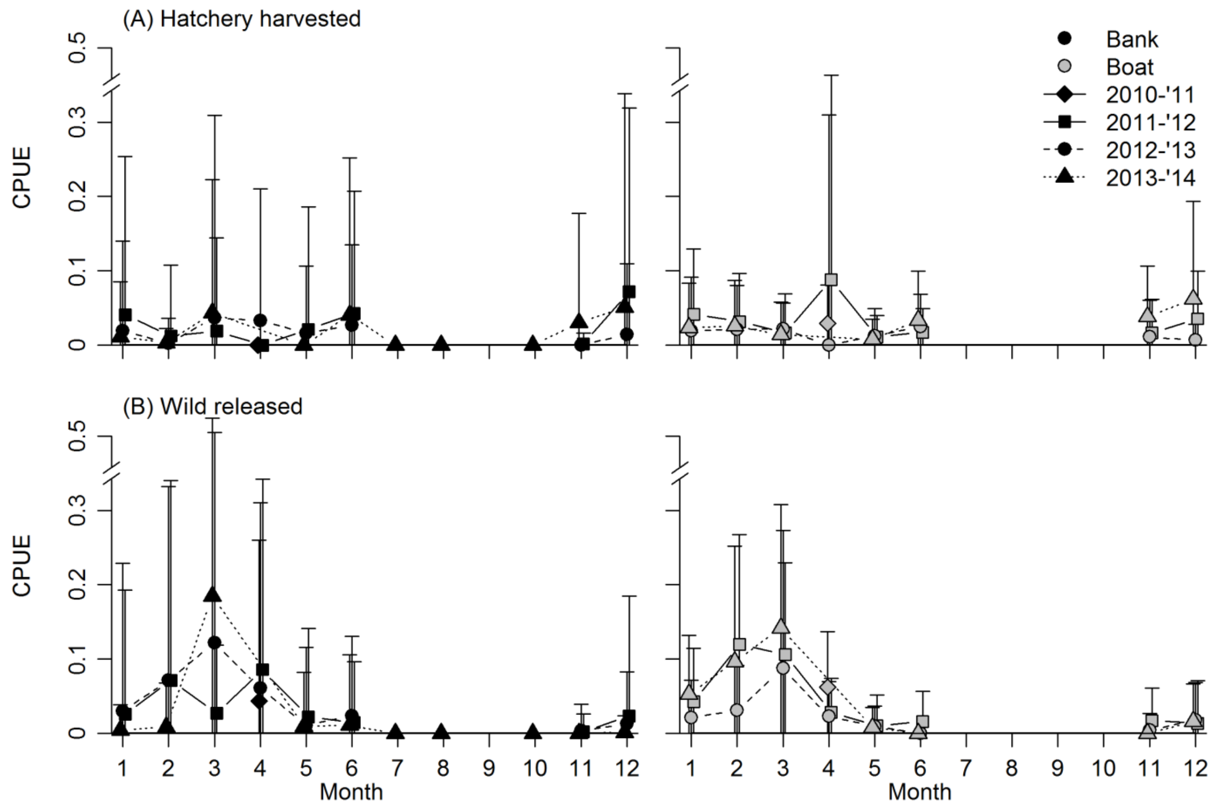

Figure 22. Mean (± SE) monthly catch per unit effort (fish/hour) by bank (left) and boat (right) anglers for (A) hatchery kept and (B) wild released steelhead by year-group on the Washougal River from April 16, 2011, to March 15, 2014. Years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012). Note: year group 2010-11 only includes April.

Catch rates were relatively similar among months, years, and steelhead stocks (Table 2; Figure 22) and this was particularly true for hatchery steelhead. Overall, catch rates for wild steelhead were greater than catch rates for hatchery steelhead in 93% of winter months and 57% of summer months. Across all individual survey months and seasons, catch rates for hatchery steelhead never exceeded the overall average CPUE (i.e., for all stocks and seasons) for either bank or boat anglers, and ranged between 0.0 and 0.047. In comparison, wild steelhead CPUE ranged from 0.0 to 0.185 among seasons. Catch rates for wild steelhead were greater than the overall average in 37% of the winter months, but always below the average CPUE in the summer months.

CATCH: WASHOUGAL RIVER

An estimated total of 6,366 (SE = 382) steelhead were caught in the Washougal River (Table 2) from April 16, 2011 – March 15, 2014. Overall, more than 99% of all fish caught were identified as either hatchery or wild, and the total catch of "unknown" origin steelhead was extremely low. Of all steelhead identified by origin, 78% of the hatchery fish were harvested while 100% of the wild were reportedly released. Across all years, seasons, and stocks, boat anglers constituted 37% of the overall catch.

Among years, total catch was almost the same for harvested hatchery (2,671 fish) and released wild (2,740 fish) steelhead. However, there was relatively substantial variation in the total catch among years and stocks. For example, anglers caught a total of 795 and 787 wild winter-run steelhead in 2011-12 and 2012-13, respectively, but only 446 in 2013-14. This inter-annual variation in catch for wild winter-run steelhead resulted in a CV of 0.30, which was still lower than that calculated for winter-run harvested hatchery (0.34), summer-run harvested hatchery (0.44), and summer-run released wild (0.47) steelhead.

The total number of steelhead caught varied by month, year, and stock-type (Figure 23; Appendix E: Table E2). In general, catch was greater for hatchery and wild winter-run stocks, than for hatchery and wild summer-run stocks. The one exception occurred during 2012-13, when the total number of winter hatchery fish caught in December was 79 – 80% lower relative to 2011-12 and 2013-14, but in June the number of summer hatchery fish caught was 204% and 145% higher than these years, respectively. Overall, 69% of the total catch occurred during winter months with the caveat that 4.5 of the 7 summer months were not sampled in two of the three year-groups making the interpretation of temporal trends difficult for summer-run catch. From mid-April through mid-June, catch for hatchery steelhead was highest during June while catch of wild steelhead was variable among months and years. For winter-run stocks, catch was generally highest during December for hatchery steelhead and January – March for wild steelhead.

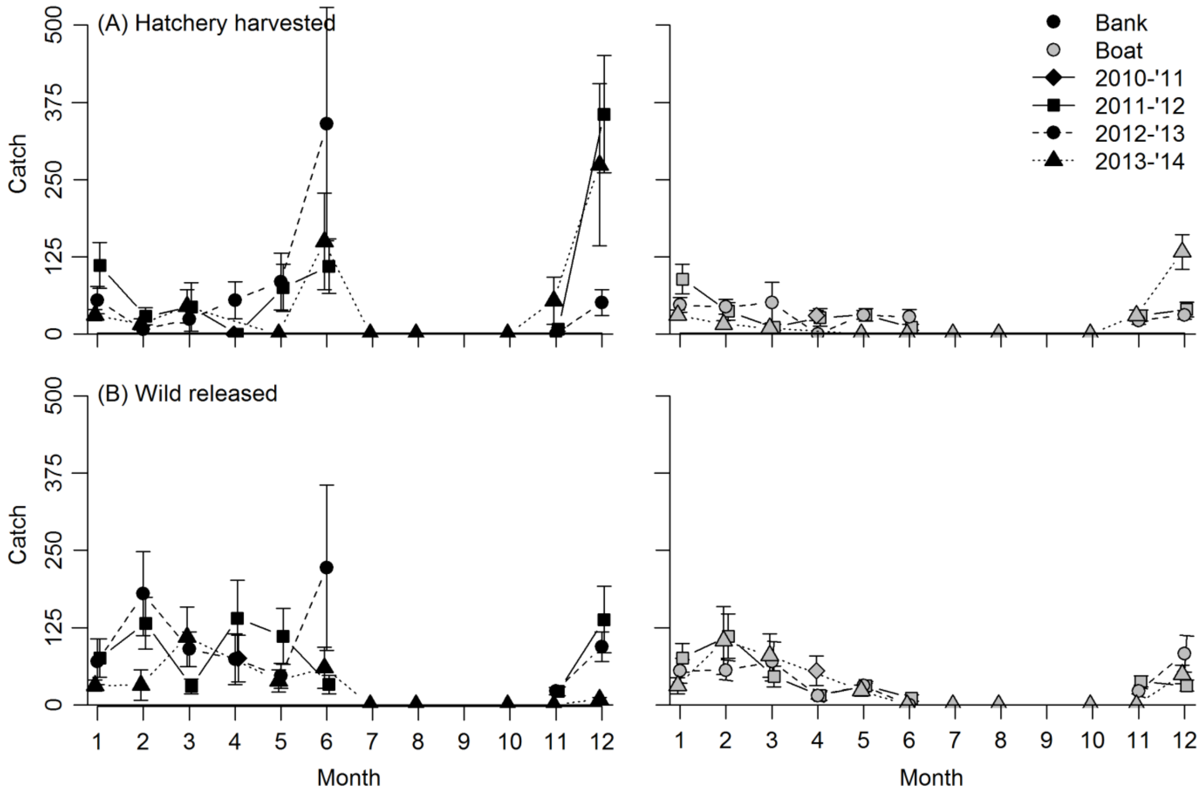

Figure 23. Mean (± SE) monthly catch by bank (left) and boat (right) anglers for (A) hatchery kept and (B) wild released steelhead by year-group on the Washougal River from April 16, 2011 to March 15, 2014. Years are grouped from May through the following April (e.g., 2011-12 = May 2011 – April 2012). Note: year group 2010-11 only includes April.

Evaluation of CRC catch expansion

STEP 1: EVALUATE RELATIONSHIP OF CATCH BETWEEN CREEL AND CRC SURVEYS

The distribution of our derived monthly estimates of steelhead catch from creel surveys and catch record cards (CRC) did not fit a normal distribution (Shapiro-Wilks: creel surveys $W=0.68$, $p<0.0001$; CRC $W=0.61$, $p<0.0001$). A linear model fit to log-transformed datasets resulted in heteroscedastic residuals. Therefore, ordinary least-squared linear models provided poor fits and a regression model with a non-normal probability distribution function was required. A Poisson and negative binomial regression model were fit to the catch dataset, but the model output revealed that data were over-dispersed using both Poisson (residual deviance = 1437.5, df = 55, $p<0.0001$) and negative binomial distributions (residual deviance = 1437.7, df = 55, $p<0.0001$). However, the over-dispersion was not due to the count data as the Poisson and negative binomial models provided almost the same goodness-of-fit. Thus, we fit a zero-inflated Poisson (ZIP) Bayesian mixture model.

The ZIP model was greatly improved (ΔDIC = 52) by adding "river-specific" coefficient (i.e., modeling two river datasets separately). This suggested that the relationship between hatchery steelhead catch estimated from creel surveys and from CRCs was different for the SF Toutle and Washougal rivers (Figure 25). While the ZIP model predicted a higher estimate of harvest using creel survey data for both streams when total catch was low (i.e., less than 100), once catch increased to more than 200-300 steelhead per month in the Washougal River, creel and CRC catch estimates were similar (slope $\approx$ 1). CRC estimates of hatchery steelhead catch from SF Toutle River never exceeded 110 steelhead, and thus, we could not evaluate the prediction of catch over the same range as the Washougal River. Over the entire range of catch, the 95% credible interval encompassed the 1:1 relationship for both rivers.

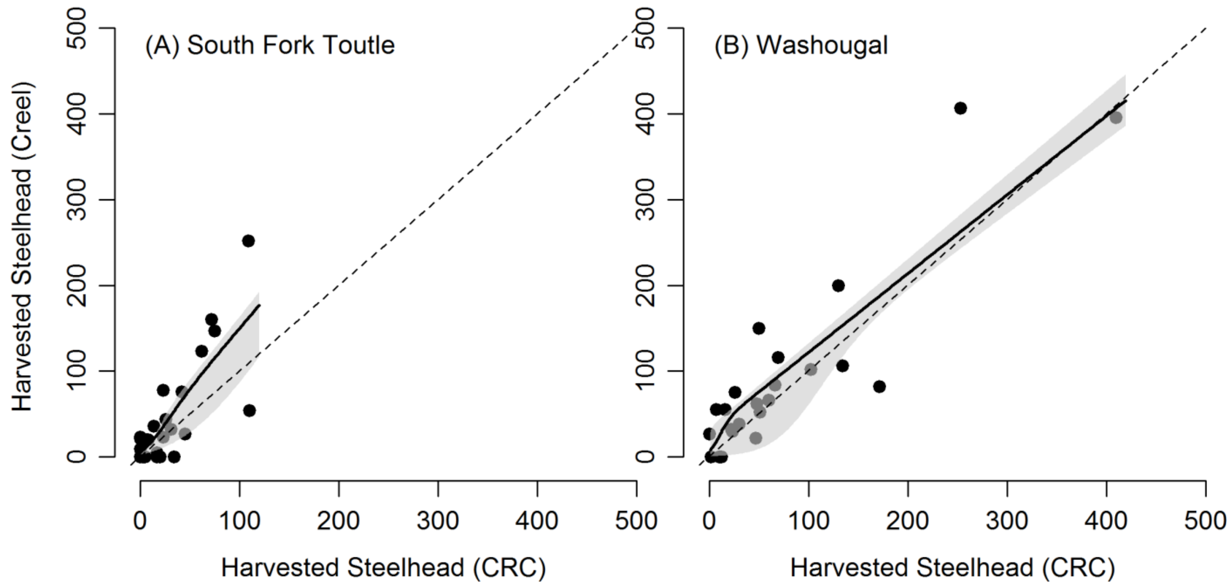

Figure 25. Mean monthly harvest of hatchery steelhead estimated from catch record cards (CRC) and roving creel surveys for the (A) SF Toutle and (B) Washougal rivers. Black lines with gray polygons represent the best-fit (± 95% credible intervals), stream specific zero-inflated Poisson model of creel catch and CRC catch. The dashed-line represents a 1:1 relationship.

STEP 2: CALCULATE WILD:HATCHERY CATCH "EXPANSION" FACTOR

Second, we calculated the ratio of catch between wild released and hatchery harvested steelhead from creel surveys. In the SF Toutle River, there was little temporal overlap in catch of hatchery and wild steelhead. Of the 23 months when catch of wild steelhead was more than zero, catch of hatchery steelhead was more than zero in only 14 of the 23 (61%) months, and only 3 (27%) of the 11 winter months (Figure 26). Due to the lack of overlap in catch of hatchery and wild steelhead, we did not continue with the expansion analysis for the SF Toutle River dataset. In the Washougal River, of the 23 months when catch of wild steelhead was more than zero, catch of hatchery steelhead was more than zero in 22 of the 23 (96%) months (Figure 27). Therefore, we calculated the monthly expansion factor across all months for the Washougal catch data and averaged the "expansion" by month across the three years of catch data (Figure 28).

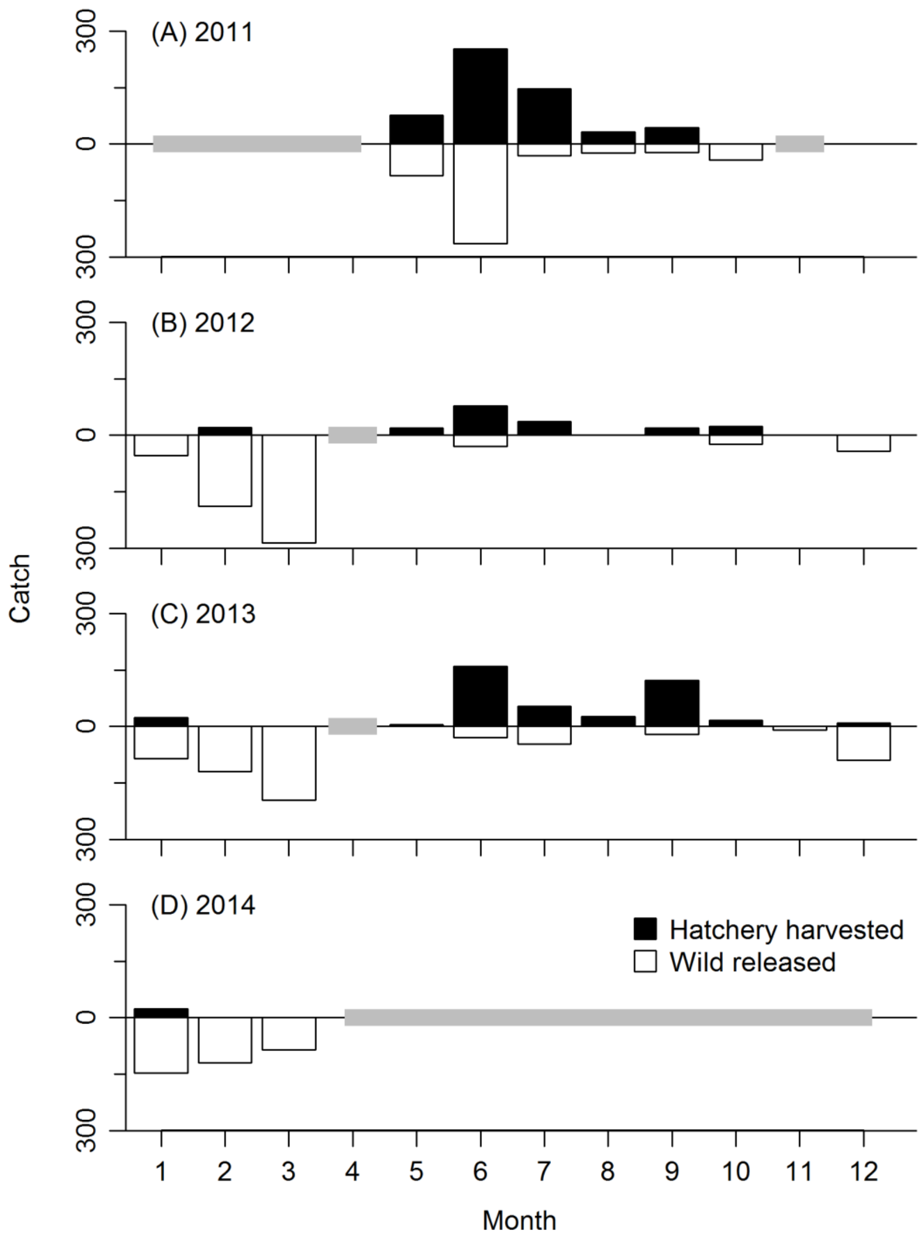

Figure 26. Mean monthly catch of hatchery kept (black) and wild released (white) steelhead estimated from creel surveys in the SF Toutle River during (A) 2011, (B) 2012, (C) 2013, and (D) 2014. Survey period was from May 21, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

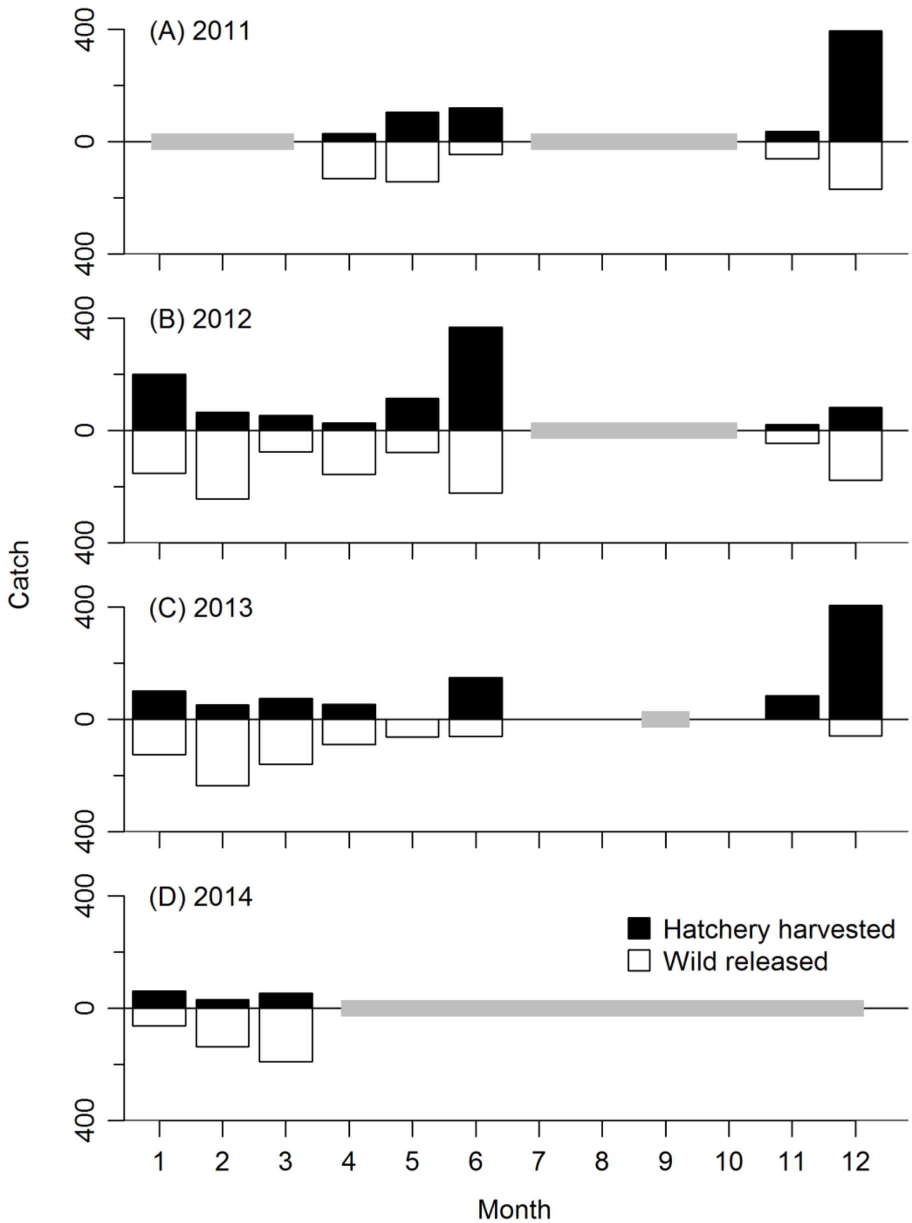

Figure 27. Mean monthly catch of hatchery kept (black) and wild released (white) steelhead estimated from creel surveys in the Washougal River during (A) 2011, (B) 2012, (C) 2013, and (D) 2014. Survey period was from April 16, 2011 to March 15, 2014. Gray bars denote full months when creel surveys were not conducted.

In the Washougal River, the expansion factor ranged from 0 in November of 2013 to 5.7 in April of 2012. Averaged by month across all years, the wild:hatchery expansion was lowest, and less than one (i.e., more hatchery fish caught than wild), in June (0.46) and December (0.91) and highest in April (3.9) and February (4.2). However, the calculated expansion factor for a given month varied among years. For example, the three expansion factors calculated for February were 3.7, 4.3, and 4.5 (CV = 0.10) while the three expansion factors for April were 1.6, 4.3, and 5.7 (CV = 0.53). Additionally, the expansion factor for some individual months was more than one in one year but less than one in another. For example, catch of hatchery steelhead in December was substantially greater than wild catch in 2011 (0.43) and 2013 (0.14), but substantially less than wild catch in 2012 (2.2; CV = 1.2).

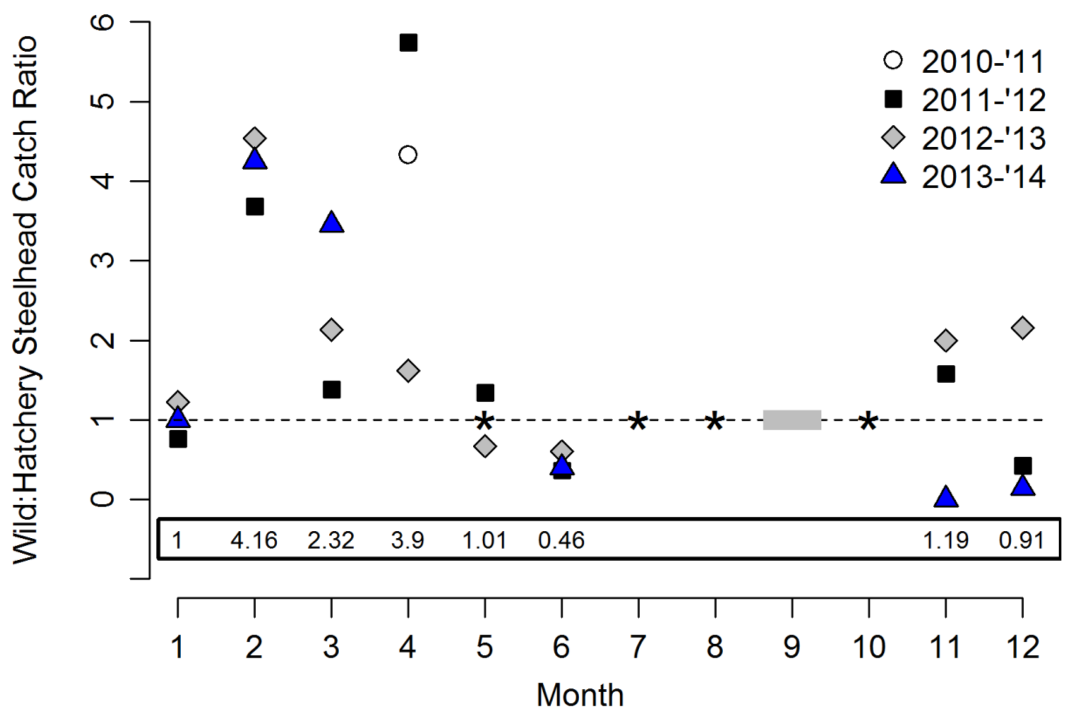

Figure 28. Ratio of wild steelhead released to hatchery steelhead harvested by month and year-group in the Washougal River from April 16, 2011 to March 15, 2014. Averaged monthly ratios are reported in the box. Asterisks denote months when catch of hatchery steelhead, or both hatchery and wild steelhead were zero, and thus, no ratio could be calculated. Gray bar denotes a month when no creel surveys were conducted. Note year group 2010-11 only includes April.

STEP 3: ESTIMATE "EXPANDED" WILD CATCH

We calculated the "expanded" monthly catch of wild steelhead from CRC information in the Washougal River in two steps. First, we calculated an "adjusted" CRC harvest estimate of hatchery steelhead in each month using the ZIP model. To do this, we predicted hatchery catch from the creel versus CRC catch regression. Second, we multiplied the adjusted CRC hatchery harvest estimates by the average expansion factor for each month to get wild catch. Across the three years, monthly estimates of wild steelhead catch from creel and expanded CRC displayed a similar pattern (Figure 29) and there was an overall positive, but somewhat weak (R = 0.60), linear relationship of y(CRC expand) = 0.83(Creel) + 38.1 (F=13.7, p=0.001). Summarized by season and year-group, the absolute (and percent) difference between the expanded and creel catch ranged from 23 (10%) steelhead during the summer of 2013-14 to 155 (28%) during the winter of 2013-14 for hatchery catch and from 16 (2%) during the winter of 2012-13 to 189 (24%) during the winter of 2011-12 (Table 3).

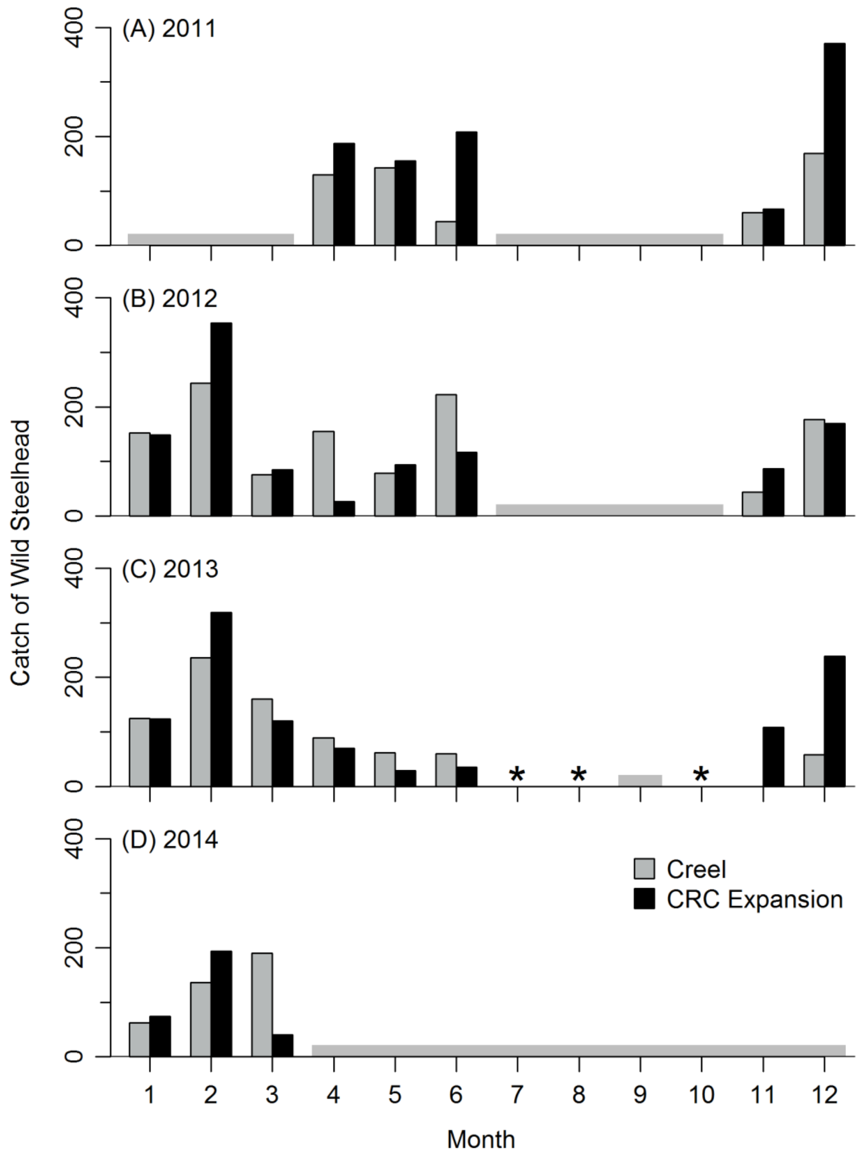

Figure 29. Estimated catch of wild steelhead using roving creel surveys (gray) and expanded catch record cards (see methods) by month in the Washougal River from April 16, 2011 to March 15, 2014. Horizontal gray bars denote full months when creel surveys were not conducted. Asterisks denote months when creel catch of hatchery and wild fish was estimated as zero and thus no CRC expansion could be made.

Table 3. Total estimated (SE) catch of hatchery and wild steelhead by season and year group from the Washougal River derived from roving creel surveys and catch record card (CRC) expansions (see methods) and the absolute and percent difference between the two estimates. Note: Creel derived catch totals for the summer season differ from Table 2 for 2011-12 and 2012-13 year groups because June catch was excluded in this analysis due to partial survey coverage.

			Hatchery Catch				
Year Group	Season	No. Months	Creel Survey		CRC Expanded	Absolute Difference	Percent Difference
2011-2012	Summer	2	144	(40)	209	-65	-45
	Winter	5	744	(115)	684	60	8
2012-2013	Summer	2	138	(47)	166	-28	-20
	Winter	5	366	(61)	457	-91	-25
2013-2014	Summer	6	234	(87)	257	-23	-10
	Winter	4	556	(138)	401	155	28

			Wild Catch				
Year Group	Season	No. Months	Creel Survey		CRC Expanded	Absolute Difference	Percent Difference
2011-2012	Summer	2	202	(47)	222	-20	-10
	Winter	5	795	(109)	984	-189	-24
2012-2013	Summer	2	122	(23)	181	-59	-48
	Winter	5	787	(107)	803	-16	-2
2013-2014	Summer	6	122	(39)	171	-49	-41
	Winter	4	446	(87)	548	-102	-23

Impacts to wild populations

ENCOUNTER RATES, MORTALITIES, AND IMPACT RATES

We estimated the encounter rates, total mortalities, and impact rates to wild populations of steelhead from the recreational fishery in the SF Toutle (Table 4) and Washougal rivers (Table 5) from April and May 2011 through March 2014. The total catch of wild winter-run steelhead among years ranged from 442 – 527 in the SF Toutle River and 446 – 698 in the Washougal River while total catch of kelts ranged from 29 – 111 among years and rivers. Despite relatively similar levels of total catch among years, total encounter rates of winter-run steelhead (pooling maiden and kelts) ranged from 48 – 138% in the SF Toutle River and 102 – 202% in the Washougal due to differences in total run size. Among years and rivers, the estimated encounter rate of winter-run steelhead was greater than the anticipated encounter rate of 38 – 40% outlined in the LCR FMEP. In both rivers, encounter rates of winter-run steelhead were nearly twice as high in spawning year 2012 relative to 2013 and 2014.

By applying a hooking mortality of 5% to winter-run catch and 8% to kelts, the total number of winter-run steelhead mortalities among years ranged from 22 - 26 in the SF Toutle River and 22 - 35 in the Washougal River while mortalities of kelts ranged from 2 – 9 among years and rivers. Although the total number of mortalities varied by less than 13 steelhead among years, total impact rates of winter-run steelhead (pooling maiden and kelts) ranged from 2.4 – 6.9% in the SF Toutle River and 5.2 – 10.7% in the Washougal River. Total impact rates on these two tributaries were less than the expected maximum rate of 10%, as outlined in the LCR FMEP, in all years and streams except for winter-run steelhead in the Washougal River during 2011-12. Similar to the among year pattern in encounter rates, impact rates were nearly 2 – 3 times higher in 2012 relative to 2013 and 2014, as a result of the low run size. In 2014, 122 summer-run steelhead were caught in the Washougal River, resulting in an encounter rate of 22%, an estimated 10 hooking mortalities, and an impact rate of 1.8%. Due to partial creel survey coverage and resulting "incomplete" catch estimates, we were unable to calculate encounter rates, hooking mortalities, and impact rates for summer-run steelhead and kelts in spawning year 2012 and 2013.

Table 4. Estimated total angler catch, mortalities, escapement, run size, encounter rate, and impact rate for wild steelhead by spawning year group and run-type in the South Fork Toutle River. Hooking mortalities were estimated by applying the LCR FMEP hooking mortality (5% for winter-run and 8% for kelts). Note: nd = no data (i.e., no creel surveys conducted).

Spawning Year	Catch Year Group	Run type	Spawning Condition	Total Catch	Hooking Mortalities	Escape-ment	Run Size	Encounter Rate	Impact Rate
2012	2011-12	Winter	Maiden	527	26	378	404	130.4%	6.4%
	2012-13		Kelt	30	2	378	404	7.4%	0.5%
			Total	557	28	378	404	137.9%	6.9%
2013	2012-13	Winter	Maiden	442	22	972	994	44.5%	2.2%
	2013-14		Kelt	30	2	972	994	3.0%	0.2%
			Total	472	24	972	994	47.5%	2.4%
2014	2013-14	Winter	Maiden	450	23	708	731	61.6%	3.1%
	2014-15		Kelt	*nd*	-	708	731	-	-
			Total	-	23	708	731	-	-

Table 5. Estimated total angler catch, mortalities, escapement, run size, encounter rate, and impact rate for wild steelhead by spawning year group and run-type in the Washougal River. Hooking mortalities were estimated by applying the LCR FMEP hooking mortality (5% for winter-run and 8% for summer-run and kelts). Note: nd = no data (i.e., no creel surveys conducted).

Spawning Year	Catch Year Group	Run type	Spawning Condition	Total Catch	Hooking Mortalities	Escape-ment	Run Size	Encounter Rate	Impact Rate
2012	2011-12	Summer	Maiden	*nd*	-	842	-	-	-
	2012-13		Kelt	111	9	-	-	-	-
			Total	-	-	842	-	-	-
	2011-12	Winter	Maiden	640	32	306	338	*189.3%	9.5%
	2012-13		Kelt	44	4	306	338	*13.0%	1.2%
			Total	684	36	306	338	*202.4%	10.7%
2013	2012-13	Summer	Maiden	*nd*	-	1464	-	-	-
	2013-14		Kelt	60	5	-	-	-	-
			Total	-	-	1464	-	-	-
	2012-13	Winter	Maiden	698	35	678	713	97.9%	4.9%
	2013-14		Kelt	29	2	678	713	4.1%	0.3%
			Total	727	37	678	713	102.0%	5.2%
2014	2013-14	**Summer	Maiden	122	10	544	554	22.0%	1.8%
	2014-15		Kelt	*nd*	-	-	-	-	-
			Total	-	10	544	554	-	-
	2013-14	Winter	Maiden	446	22	388	410	108.8%	5.4%
	2014-15		Kelt	*nd*	-	388	410	-	-
			Total	-	22	388	410	-	-

* Encounter rate likely over-estimated leading to an over-estimation of the impact rate (see discussion).

** Total catch does not include September catch, and therefore, neither do encounter and impact rates.

FISHING METHOD, GEAR, AND HOOKING LOCATION

Across all years, the majority of steelhead caught by bank anglers were captured with either bobber (gear suspended under float) or drift fishing (drifting/swinging gear without suspension) methods while boat anglers primarily back trolled (e.g., using plugs or bait-divers), regardless of season (Figure 30). Less than 1% of all steelhead were caught by plunking (e.g., bait or lures fished suspended above a stationary weight).

Similarly, the proportion of steelhead caught with different gear types was relatively similar among seasons for a given angler-type (Figure 31). Outside of the winter fishery (December 1st – mid-March) on the SF Toutle River, where the use of bait was not permitted in all years for the entire season, 40% (range: 24 – 45%) of all steelhead were caught using bait across all seasons and angler-types, followed by 30% on jigs, 28% on lures, and 2% on flies. However, note that bait was not permitted during the early summer fishing periods in all years, when selective gear regulations were in place, and likely influenced the catch patterns we observed.

Among all steelhead caught across seasons, angler types, and rivers, there were differences in gear use by fishing method. Of the steelhead caught by bobber fisherman, over 80% were caught using jigs. Of steelhead caught by anglers that were drift fishing or back trolling, more than 90% were caught using bait and lures (Figure 32).

Across all steelhead caught on jigs, lures, and flies, more than 97% were caught in either the jaw (93 – 96%) or the tongue (3 – 7%; Figure 33). Of all fish caught with bait, 87% were caught in the jaw, 7% in the stomach, 5% in the tongue, and <1% in the eye, gill, head, or body (defined as “other” on plot).

Prior to 2013, when regulations allowed the use of barbed hooks, 79 – 95% of steelhead were caught by anglers using barbed hooks (Figure 34). During seasons with full (e.g., SF Toutle River winter fishery – December through March) or partial (Washougal River selective gear fishery - April through May) barbless hook regulation coverage, a higher proportion of steelhead were caught without barbed hooks. After 2013, 100% of steelhead were reported to be caught with barbless hooks.

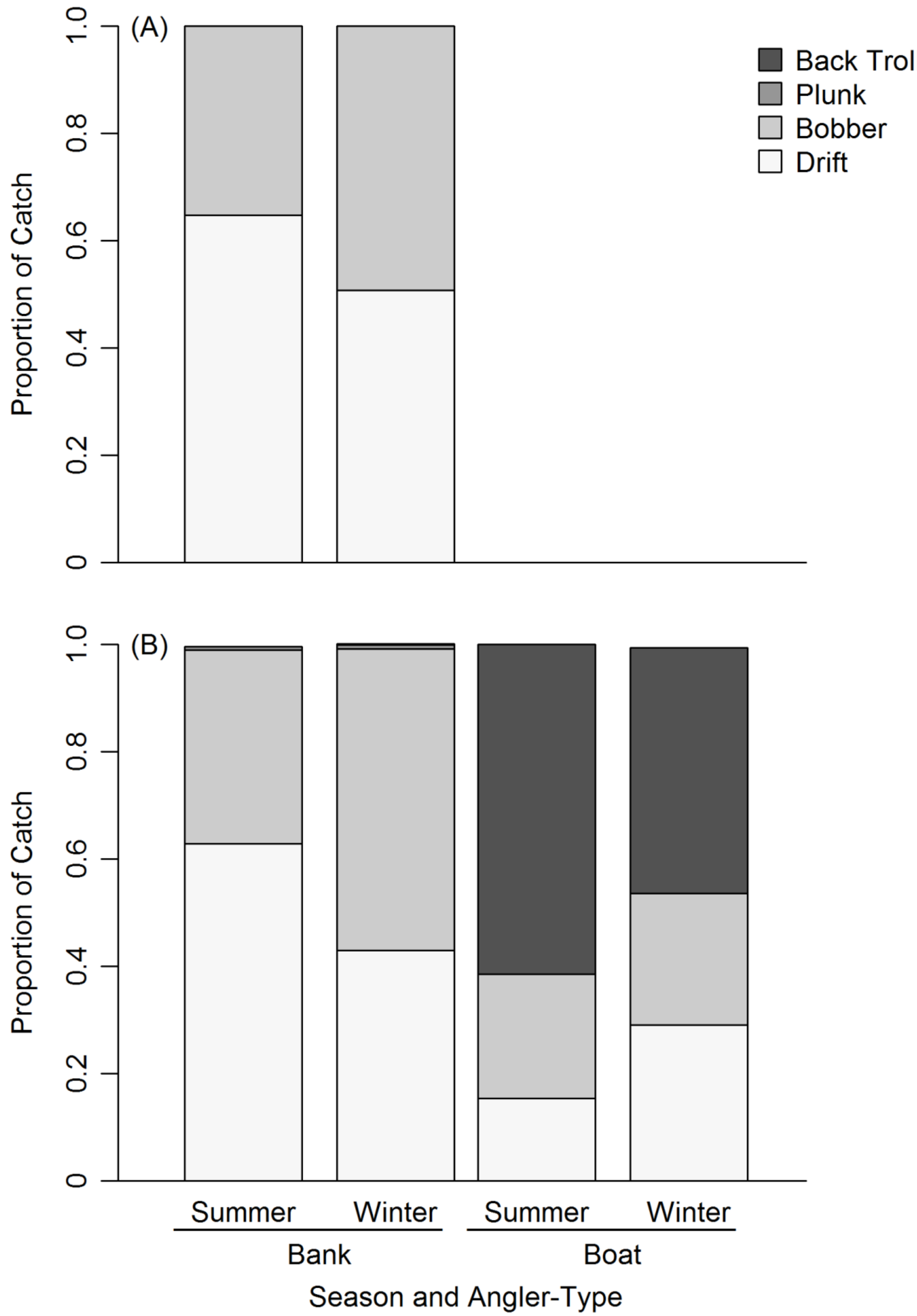

Figure 30. Proportion of steelhead caught by season and angler type as a function of fishing method in the (A) SF Toutle and (B) Washougal rivers from April 16, 2011 to March 15, 2014.

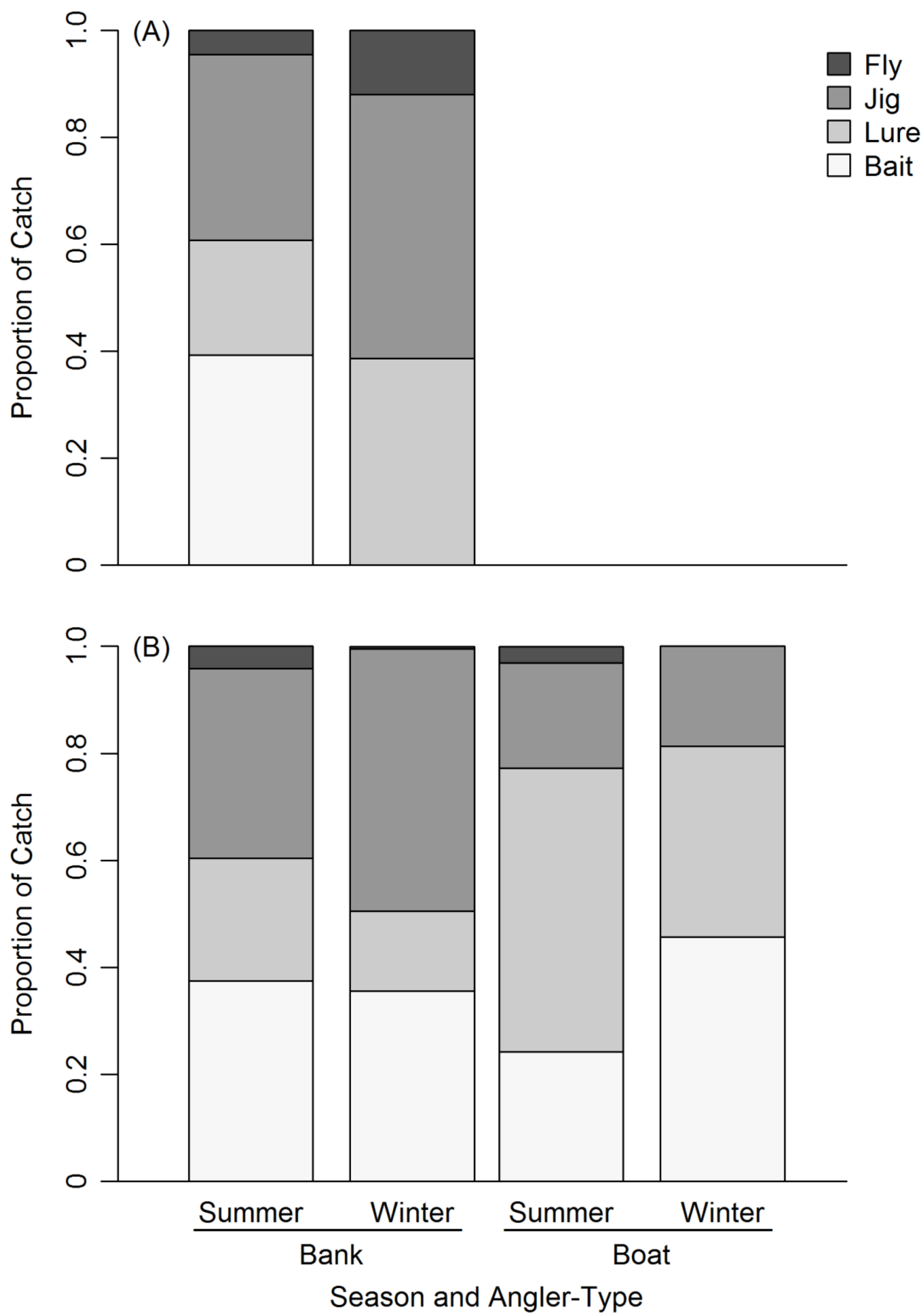

Figure 31. Proportion of steelhead caught by season and angler type as a function of gear type in the (A) SF Toutle and (B) Washougal rivers from April 16, 2011 to March 15, 2014.

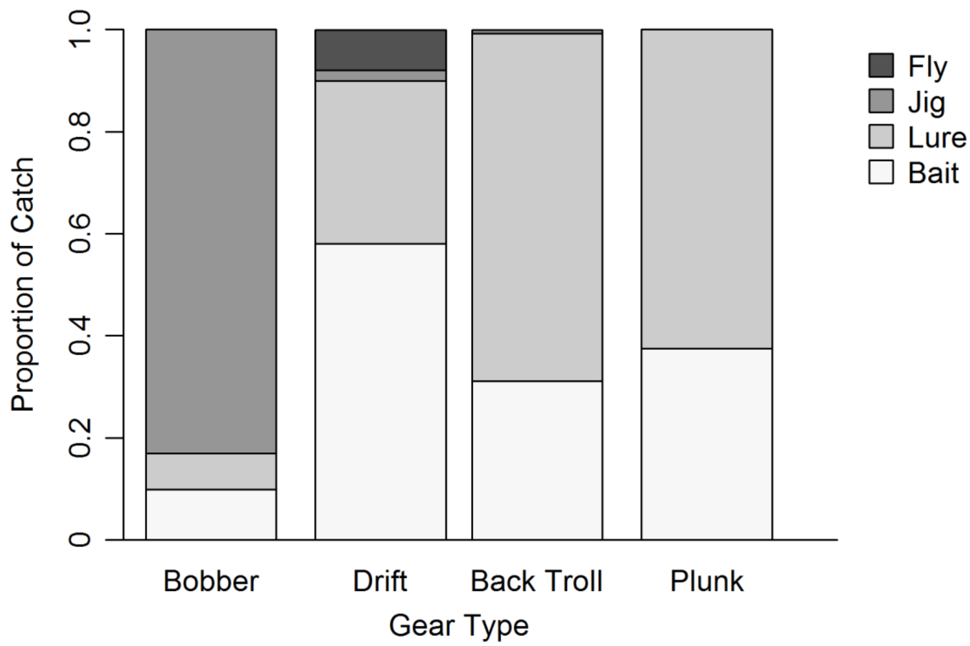

Figure 32. Proportion of steelhead caught by fishing method as a function of gear type in the SF Toutle and Washougal rivers (combined) from April 16, 2011 to March 15, 2014.

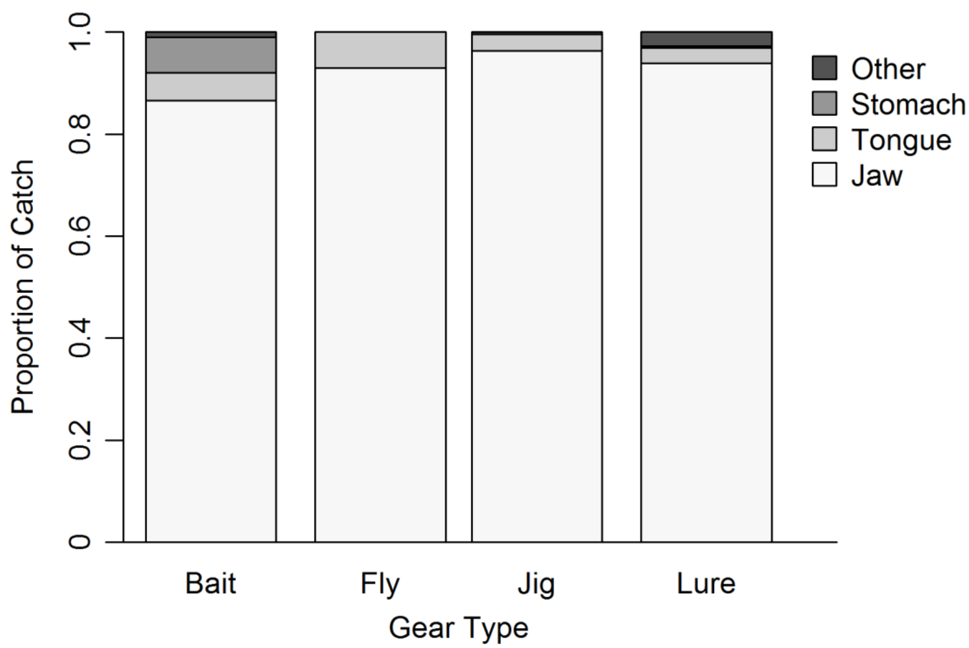

Figure 33. Proportion of steelhead caught by gear type as a function of hooking location in the SF Toutle and Washougal rivers (combined) from April 16, 2011 to March 15, 2014.

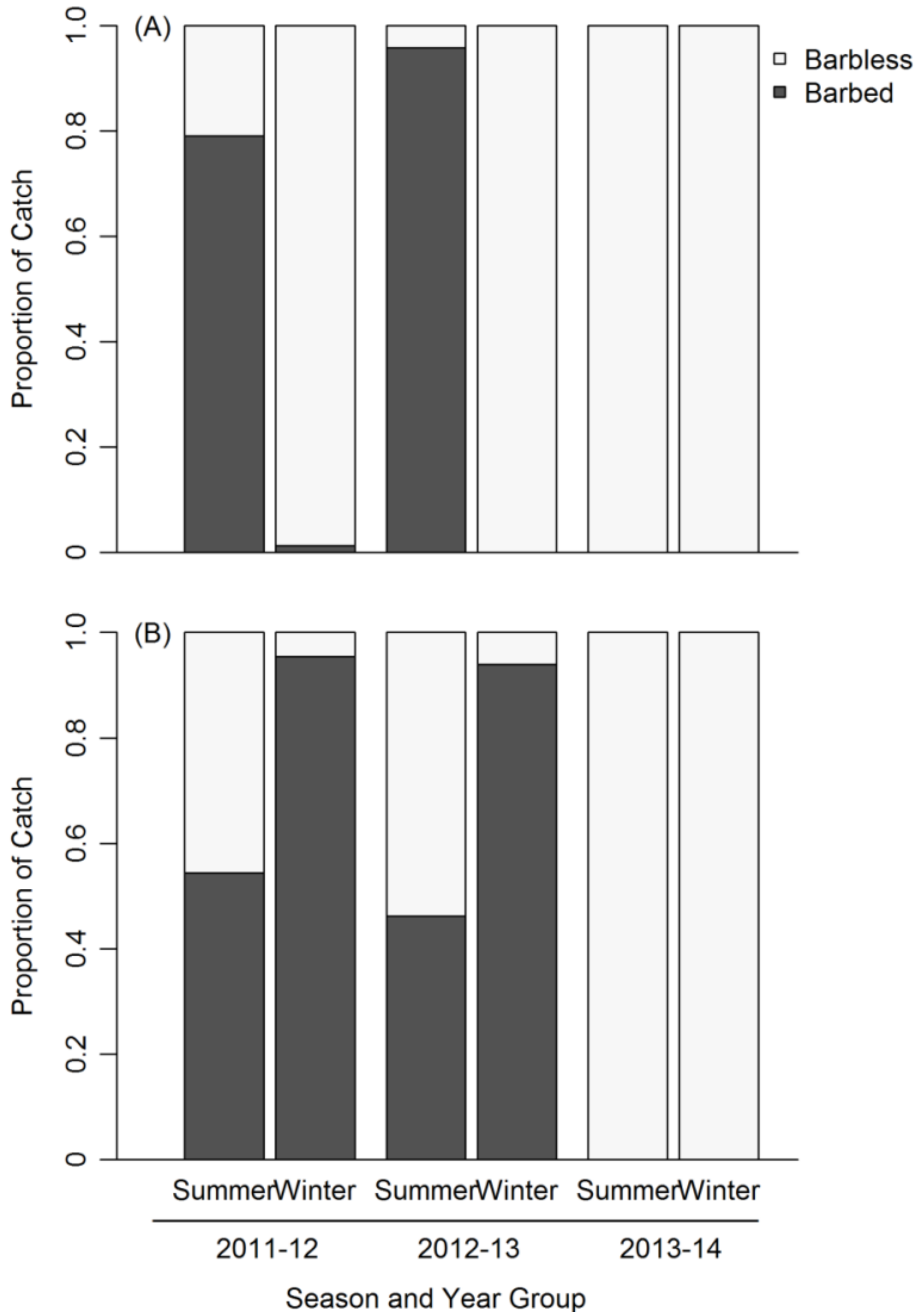

Figure 34. Proportion of steelhead caught using barbed or barbless hooks by season and year group in the (A) SF Toutle, and (B) Washougal rivers from April 16, 2011 to March 15, 2014. Note that prior to the lower Columbia River basin-wide ban of barbed hooks in 2013, barbed hooks were not allowed during the SF Toutle River winter fishery and the Washougal River selective gear fishery from mid-April through late-May (summer).

Discussion

Catch and Effort Estimates

From April 2011 through March 2014, steelhead creel surveys were conducted on the SF Toutle and Washougal rivers. Using the data collected, we successfully quantified monthly, seasonal (summer and winter), and yearly estimates of angling effort, catch per unit effort (CPUE), and total catch for hatchery and wild origin steelhead. Overall, CPUE for both hatchery and wild steelhead was generally higher in the SF Toutle River than the Washougal River. However, across all three year groups, the Washougal River had approximately three times the total angling effort and two times the total catch of steelhead relative to the SF Toutle River (Table 1 and 2). This cumulative difference in effort, CPUE, and catch between the two river-systems could be a function of many factors, including, but not limited to, angler demographics, proximity of the river to urban areas, physical and biological conditions, and fishing regulations. One of the most plausible reasons may be the result of the overall difference in abundance of steelhead among the two rivers.

Each year, WDFW estimates the abundance of wild steelhead adults, hatchery steelhead adults, and hatchery steelhead smolts, by conducting spawning ground surveys, enumerating returns to the hatchery, and enumerating the number of released smolts, respectively (WDFW *unpublished data*). From 2012-2014, the escapement of winter-run wild steelhead to the SF Toutle River was, on average, slightly higher than on the Washougal River. However, the Washougal River also has wild summer-run and a hatchery winter-run steelhead, two stocks that the SF Toutle River lacks. Additionally, WDFW has stocked approximately four times as many hatchery summer-run smolts in the Washougal River relative to the SF Toutle River over the past decade. The difference in overall abundance of adult steelhead was shown clearly by the difference in total effort and catch among the two river systems during the month of December, which coincides with the peak in run timing for winter-run hatchery steelhead. In the Washougal River, 20 – 30% of all annual effort and up to 50% of all hatchery steelhead were caught during December while in the SF Toutle River only 2-6% of total annual effort and up to 16% of catch was caught during the same time period.

Across the three years of our study, a relatively similar proportion of all days were sampled on the SF Toutle (0.51) and Washougal (0.46) rivers but the relative coverage across all months was not equal. Out of the 33 months that the SF Toutle River steelhead fishery was open, creel surveys were conducted during all months except one. Lacking surveys during November 2011 meant we could not estimate total angling effort and catch for this month, and therefore, we likely under estimated the true effort and catch for the summer 2011-12 season. However, our estimates were likely not affected too much by these missing November surveys as this month comprised less than 3% of total annual effort and less than 2% of the total annual catch, for both hatchery and wild steelhead combined, in 2012 and 2013.

Creel surveys were not conducted on the Washougal River during the majority of summer months (mid-June through October) in two of the three surveyed years even though the fishery was open. These summer months were not surveyed as the creel survey was initially focused on the winter fishery. In 2013-14, creel surveys were continued past mid-June and about 8% of the total annual effort came from July, August, and October (September was not surveyed), but there was no recorded catch of either hatchery or wild steelhead in any of these months. While catch during late-summer months may be a small fraction of the total catch in the Washougal River, catch record card (CRC) data indicate the catch during these months is not zero. Across all summer months (May – November) in the Washougal River during 2011-12 and 2012-13, CRC indicate that 49-55% of summer-run hatchery steelhead were caught during June while 25-28% were caught from July to October. In 2013-14, CRCs estimated 20% of summer-run hatchery steelhead were caught from July to September, but this only equated to 32 harvested steelhead and happened to be the lowest number of summer hatchery steelhead harvested from the Washougal River in the previous 15 years. Therefore, our estimates of effort and total summer-run hatchery steelhead catch were certainly under-estimated due to missing survey months. Future creel surveys will be conducted year round.

Total abundance of hatchery and wild steelhead will likely influence the annual patterns of catch and effort. Therefore, abundance estimates should be considered when interpreting creel survey derived estimates. Our results from both rivers showed a fairly consistent monthly pattern of effort and catch among years (Figure 7, 13, 17, 23). However, annual estimates of total catch and effort varied quite substantially among some years. For example, total effort and catch of hatchery summer-run steelhead in the SF Toutle River was more than two times higher in 2011-12 relative to our two other survey years. What could have led to this dramatic change? One explanation is a decrease in hatchery smolt production. Indeed, WDFW intentionally cut the production of summer steelhead smolts by nearly 30% in the SF Toutle River beginning with the 2009 ocean entry year. However, given that more than 90% of the segregated summer-run (Skamania stock) hatchery steelhead spend two years in the ocean prior to returning (WDFW *unpublished data*), this decrease in smolt production would have begun to affect the number of returning adults in 2011. Thus, the total number of returning hatchery summer-run steelhead adults among survey years would have been produced from approximately the same level of smolt production. Interestingly, there is evidence that predation by otters on steelhead being held in acclimation ponds may have substantially reduced the total number of smolts released in 2010 (*A. Danielson*, WDFW, *personal communication*). The severity of this smolt predation was not measured, but could have certainly influenced the abundance of returning adults. Another explanation for the observed changes in catch among years was inter-annual changes in ocean productivity. Annual and decadal changes in ocean productivity are known to influence the survival of salmon and steelhead, and thus, the total abundance of returning adults (Smith and Ward 2000, Ward 2000). This is clearly shown in the Washougal River where hatchery production of Skamania summer-run steelhead smolts decreased by 5% from 2000-08 to 2009-12, but the average catch (from CRC) of returning adults between the two periods decreased by

45% (Figure 4), suggesting factors in addition to smolt plants affected adult returns. Additionally, returns of summer-run hatchery steelhead to hatcheries throughout the lower Columbia River displayed similar patterns, with 2011 through 2013 marking low abundances relative to 2008 through 2010 (WDFW *unpublished data*).

For our analysis, steelhead catch was apportioned by stock based on origin (hatchery vs. wild) and race (summer- vs. winter-run). Although we did not evaluate the ability of angler's to identify the origin of steelhead, we assumed fish were classified correctly as less than 1% of released fish were identified as "unknown" and no wild steelhead were (reportedly) harvested illegally. On the other hand, visually classifying the race of a steelhead can be much more challenging and was rarely reported by anglers to creel clerks. We, therefore, classified the race of steelhead based on the month an individual fish was caught in the recreational fishery using a regional index of run timing from data collected at the Kalama Falls fish trap on the Kalama River. Based on this index, steelhead caught from May through November should have primarily been summer-run fish and steelhead caught from December through April should have primarily been winter-run fish. However, analyzing the catch data from the SF Toutle River demonstrates some of the uncertainly involved in this process.

The SF Toutle River has two "recognized" runs of steelhead – hatchery summer-run and wild winter-run. As a result, stock classification should theoretically be easy in this river. However, across the three fishing seasons in SF Toutle River, 47, 11, and 18% of steelhead identified as wild by anglers were caught and released during summer months in 2011-12, 2012-13, and 2013-14, respectively. Given the SF Toutle River does not have a recognized run of wild summer-run steelhead, what could have led to this observed pattern? The most parsimonious explanation is that these wild steelhead, which were caught during the early summer, were kelts of wild winter-run steelhead. Spring 2011, which was the year with 47% of the annual wild fish caught during summer months in the SF Toutle River, was a relatively cold spring with high river flows. These conditions could have extended the typical spawning period, leading to relatively more wild winter-run steelhead in the river and caught during late-May and June in 2011-12. As a result, the early-summer wild steelhead were classified as kelts for the purpose of estimating wild population impacts.

The relatively small number of reportedly wild steelhead caught during late summer (July – November) in the SF Toutle River were included in our catch results, but were not included in estimates of impacts to the wild winter steelhead population. Although we are uncertain of the true origin of these late summer wild steelhead, we provide four potential explanations. First, hatchery steelhead that were caught and released could have been hatchery fish misidentified as wild. Although this might explain some of the variation in timing of wild-run catch, this explanation is unlikely to account for much of the catch due to the relative ease of recognizing the presence of an adipose fin. Second, wild steelhead caught in the summer months could be early returning winter-run steelhead. Although this explanation was more likely for steelhead that were caught in the fall, 55 – 80% of the wild steelhead caught during summer months were caught in the months between May and July. Third, wild steelhead caught in the summer months could have been volunteer fish (i.e., dip-ins or strays from other populations). However, there are no nearby known populations of wild summer-run steelhead to provide an obvious source of wild fish strays. Fourth, wild steelhead caught during summer months could have been a feral population of summer-run steelhead established from spawning hatchery fish. Although this naturalized population of summer-run steelhead in the SF Toutle River has not been formally investigated, there have been several reports of chrome steelhead caught during late summer with adipose fins.

The Washougal River has four recognized stocks of steelhead. Given the above uncertainties in assigning catch based solely on when steelhead were caught, there were certainly some uncertainty when classifying steelhead catch by stock in the Washougal River. Similar to the SF Toutle River, the largest amount of uncertainty occurred from late-April through mid-June where wild fish could have been late arriving winters, early arriving summers, or kelts from either race. Therefore, some caution should be taken when interpreting hooking mortalities and impact rates on a specific stock (see below). But regardless of how catch is allocated among specific stocks, it is important to also evaluate the reliability and assumptions that were made in order to estimate angler-effort and CPUE, which make up the two pieces of the catch calculation.

Traditionally, "tie-in" counts are used to calculate the efficacy of roving creel survey effort counts. These counts are conducted simultaneously with the normal effort count using a transportation method that is quicker (e.g., plane or boat vs. car or walking) and provides 100% spatial coverage of the fishing area. The ratio of the normal and tie-in effort count provides an estimate of the proportion of effort that is typically captured during daily effort counts. If the ratio is less than 1 (i.e., the daily effort count is not a census), the ratio can be used as an "expansion factor" to adjust the effort estimates. Unfortunately, "tie-in" effort counts were not conducted on the either of our two river-systems. Although we were unable to quantitatively verify, we assumed that our effort counts on the SF Toutle River were true representations of total instantaneous effort. Given the visual coverage and ease of access to the river, we feel confident in our assumption of 100% spatial coverage for our effort count. However, we had qualitative and quantitative evidence that this was not the case on the Washougal River, and ultimately, we expanded our estimates of both bank and boat angler-effort using the ratio of boat angler counts to expanded trailer counts. As discussed in the methods (Appendix C), this expansion required two assumptions: (1) boat angler-effort derived from expanded trailer counts were accurate, and (2) the average ratio of boat counts to expanded trailer counts represented the average spatial coverage of our daily effort count, and thus, could be used as an expansion factor for bank anglers. While both assumptions may have not been met for every single effort count that was conducted over the three years on the Washougal River, our expanded effort counts are most likely closer to the true values than the unexpanded counts, which we know were an under estimate. For future creel survey, tie-in counts will be conducted, which will allow us to analyze the reliability of the effort expansion factor we used here.

Catch per unit effort was calculated using both complete and incomplete trip interviews of steelhead anglers. While both interview types provide an estimate of CPUE, there are two potential issues with using incomplete trip interview data. First, there is a potential "length-of-stay" bias because anglers that fished longer were more likely to be interviewed. However, this issue was alleviated by using the mean-of-ratios estimator (opposed to the ratio-of-means; see Pollock et al. 1994). Here each estimate of CPUE was given equal weight regardless of the time spent fishing. Second, an assumption of our estimator was that each angler had a specific catch rate parameter that was constant over time and did not depend on the duration of the angler's fishing trip. Previous studies have compared the CPUE from paired incomplete and completed trip data and some have found no difference (Malvestuto et al. 1978, Dent and Wagner 1991, Rasmussen et al. 1998) while others have found that the CPUE estimate from incomplete trips are higher relative to completed trips (Mackenzie 1991, Keefe et al. 2009).

Ultimately, we chose to use incomplete trip interviews as 60 – 70% of all surveys were from incomplete trips and by dropping them approximately 40% of the sampled dates would not have any interviews. Although our estimates of CPUE could have potentially been biased high, this would make our estimates of catch conservative (i.e., over-estimated). Alternatively, we could have dropped the incomplete trip interviews and aggregated all interviews within a stratum (e.g., month) to calculate a single CPUE. While this would have allowed us to use only completed trip interviews, this estimator ignores daily fluctuations in fishing activity and success, and thus, may be subject to bias caused by disproportional sampling of angler trips (Su and Clapp 2013). Overall, our average estimates of CPUE fell within the ranges seen in other steelhead producing watersheds. For example, the CPUE of Washougal River bank (18 hour of fishing per steelhead) and boat (15 hours/steelhead) anglers were similar to catch rates by bank (19 hours/steelhead) and unguided boat (24 hours/steelhead) anglers in the lower Hoh River during the winter of 2013-14 (WDFW *unpublished data*). But again, catch rates were so variable among individual anglers in the SF Toutle and Washougal rivers that the average estimates of CPUE had high amounts of uncertainly. Previous research has found that the precision of catch rate estimates (along with estimates of total effort and catch) can be improved using a two-part generalized linear model (Taylor et al. 2011). Although these models are similar to those used in our "CRC vs. creel catch estimate" evaluation, we did not employ these methods due to time and budget restrictions, but recommend future creel survey analyses explore these methods if possible.

CRC vs. Creel Catch Estimates

The first step to evaluating the potential use of CRC catch estimates for estimating wild steelhead catch was to determine the relationship between CRC and creel estimates of hatchery harvest. We found that the relationship most appropriately described by a zero-inflated Poisson model. This model provided the most appropriate fit because both catch data sets were over-dispersed (excess number of zeros) and it allowed the process causing the zeros vs. non-zeros (logit) and the process explaining the non-zero counts (Poisson) to be modeled separately. On average, catch estimates derived from CRCs were less than those derived from creel surveys when catch was less than 100 – 200 steelhead. However, data from the Washougal River suggested that when catch was more than 200 fish, the relationship between the two catch estimates did not differ from 1:1. Although we do not know which catch estimate method produced values that were closer to the truth, we assumed that estimates from the creel surveys were closer to the true values and chose to adjust CRC catch estimates prior multiplying by the wild:hatchery expansion factor.

We assumed that creel surveys likely sampled a higher proportion of the catch and effort relative to CRC making the creel estimates more accurate, especially when catch was low. For example, in 2013-14, we interviewed 45 angler-groups (65 anglers) on the SF Toutle River and 125 angler-groups (233 anglers) in the Washougal River that had caught ≥1 steelhead, while CRC derived catch estimates were calculated with 26 and 50 returned cards with catch (for both "in-" and "out-of-sample"), respectively (*E. Kraig, WDFW, personal communication*). While we cannot calculate the number of unique angler-trips from CRC, each angler would have had to of made at least 3 – 4 trips each to equal the sampled proportion from creel surveys. Interestingly though, across the entire range of catch for both streams, the 95% credible interval for the predicted relationship between creel and CRC catch encompassed the 1:1 relationship. Therefore, the two methods appear to provide similar average estimates of catch (Figure 25).

The second step in determining the feasibility of CRC expansion for wild impact rate estimation was to calculate the ratio of catch between wild released to hatchery harvested steelhead from creel surveys. We were able to calculate a CRC expansion factor (ratio) for the Washougal River from November through June as each of these months had both wild and hatchery steelhead catch recorded in the creel surveys. We were unable to calculate similar ratios from July through October as there was no recorded catch of either origin of steelhead during these months. If continuous creel surveys were conducted during all three summer months, we would have been able to compute ratios for these missing months, as well. Therefore, the CRC expansion may be a feasible method for estimating wild catch for rivers like the Washougal River that have overlapping catch of wild and hatchery origin fish. However, we found that the CRC expansion would not be possible for the SF Toutle River, or similar rivers, that had limited overlap in run timing, and thus catch, of hatchery and wild steelhead.

The benefit of using expanded CRC catch is that creel surveys do not have to be conducted annually to estimate impact rates on wild populations. Overall, we found a significantly positive linear relationship between the expanded CRC and creel survey catch estimates of wild winter-run steelhead in the Washougal River. Statistically speaking, the strength of the relationship was relatively weak ($r = 0.60$), and thus, caution should be taken when estimating wild catch from expanded CRC estimates. The variation in the two estimates was likely borne out of two processes. First, catch estimates from CRC and creel surveys were derived independently and the relationship between the two was not exactly 1:1 (Figure 25). Therefore, we would expect *a priori* that the catch estimates for wild steelhead would be slightly different from expanded CRC and creel surveys. Second, expanded CRC estimates rely on an average monthly ratio of hatchery to wild catch. While we found that this ratio was fairly consistent among years for a few months (January and February), we also observed high amounts of among year variability in others (April, November, and December). Although hatchery and wild steelhead likely do overlap during ocean residency, we would expect some differences in population dynamics among years, due to genetic differences, which would lead to variation in their abundance ratios. Additionally, we would expect some changes in the hatchery to wild catch ratio when hatchery smolt production is changed. Regardless, the estimates of wild winter-run catch from expanded CRC did follow a similar pattern to creel estimates. Among the three survey years, expanded CRC estimates of wild winter-run steelhead total catch were 2 – 24% higher than creel derived estimates, resulting in absolute differences of 16 – 189 caught steelhead. Depending on the required accuracy of the catch estimates and impact rates, the derived relationship we found supports the accuracy of CRC estimates when creel data are not available.

Impacts to Wild Steelhead

Although all wild steelhead caught in lower Columbia River (LCR) tributaries must be released upon capture, catch and release angling can still have deleterious effects on these threatened populations by compounding physiological stress, which may reduce survival to spawning or post-spawning survival. Overall, the total number of post-release mortalities may be relatively small in magnitude, but can still contribute to the decline of populations when the productivity and abundance of particular stocks are severely depressed. Therefore, the total impact non-retention recreational fisheries had on adult wild steelhead in the SF Toutle and Washougal rivers was not only a function of the total number of steelhead caught within a given year, but also the estimated run size and the hooking mortality. When deriving estimates of impacts, we made several assumptions regarding our estimates of run size and hooking mortality.

The annual run size for a specific race of wild steelhead was estimated by summing the river-specific escapement (i.e., number of returning spawners) and total number of indirect mortalities (i.e., catch × hooking mortality). This calculation of run size assumed that all post-release mortalities occurred prior to the enumeration of wild steelhead population abundance. For summer-run steelhead in the Washougal River, escapement estimates were conducted during early fall (i.e., prior to spawning), but surveys occurred upstream of the Washougal Hatchery (i.e., after fish have passed the fishery area several miles downstream). On the SF Toutle River, spawning ground surveys for winter-run steelhead were typically conducted from late-February through early June. Therefore, a large majority of hooking mortality likely occurred prior to enumeration of escapement. However, if a small proportion of fish survived to be counted as part of the escapement before perishing from hooking mortality, then including these individuals in the escapement estimate and as a hooking mortality will have resulted in a negatively biased (i.e., under-estimated) harvest rate estimates. Conversely, our estimated impact rate could have been positively biased depending on what proportion of non-retention mortality occurred on maiden steelhead (i.e., pre-spawned adults) versus kelts (post-spawned adults). Although steelhead are iteroparous, on average only 5 – 10% survive and return to spawn multiple times. Therefore, if hooking mortality occurred after spawning then the impacts on population productivity may be somewhat alleviated. We chose to differentiate estimates of impact rates on maiden steelhead versus those that were likely kelts, but we did not "discount" the estimated impacts of hooking mortality on a particular steelhead population based on the lower survival of kelts. In the future, the discounting kelts could be explored (e.g., multiplying the estimated impact rate by the average repeat spawner rate). Regardless, the overall impact non-retention fisheries have on populations of wild steelhead in the LCR depends highly on the assumed hooking mortality.

In this study we used an average hooking mortality of 5% for winter-run steelhead and 8% for summer-run steelhead and kelts, which are reported in the WDFW LCR FMEP. While these hooking mortalities are supported by previous research (Hooton 1987, Lirette 1989, Nelson et al. 2005), these studies did not account for additional factors which have been shown to influence hooking mortalities. For example, bait has been shown to inflict mortality rates 2 – 3 times higher than fish caught on artificial flies and lures (Muoneke and Childress 1994, Hooton 2001). While 75 – 100% of the steelhead were caught by anglers using bait in the Hooton (1987) and Nelson et al. (2005) studies, we found only 40% of steelhead were caught by anglers using bait when averaged across all seasons, rivers, and fishing methods.

In addition to gear type, anatomical hooking location has been shown to influence post-release hooking mortality of salmonids. A recent study on adult Chinook salmon in the lower Willamette River found that mortality rates were highly influenced by anatomical hooking location (Lindsay et al. 2004). Specifically, they found that Chinook hooked in the jaw had an average post-release mortality of 2.4% while Chinook hooked in the gills and esophagus-stomach had an average post-release mortality of 81.6% and 67.3%, respectively. Interestingly, they also found a post-release mortality of 17.7% for Chinook hooked in the tongue. However, this estimate was based on a low sample size (n = 14) and, similar to jaw-hooked fish, the mortality rate was not significantly different from zero. Across all years, we found that more than 97% of steelhead in the SF Toutle and Washougal rivers were caught in the either the jaw (93 – 96%) or the tongue (3 – 7%; Figure 33) when anglers used jigs, lures, or flies. Of all fish caught with bait, 87% were caught in the jaw, 7% in the stomach, 5% in the tongue, and <1% in the eye, gill, head, or body. Therefore, the average mortality rates used in our analysis may have over-estimated the total number of hooking mortalities for steelhead in the SF Toutle and Washougal rivers. There is no analogous Lindsay et al. (2004) study published for steelhead, but WDFW is currently conducting a hooking mortality study for summer steelhead in the Wind

River. Preliminary data analysis from the first three years of the study has generated an estimate of hooking mortality, but is still ongoing to improve estimates and their uncertainty. In the future, we hope to apply the steelhead anatomical hooking mortalities and the creel survey encounter rates to more accurately calculate recreational steelhead impact rates.

One limitation of our study was that gear type and angling method were not recorded for anglers who did not catch fish. Therefore we were not able to calculate estimates of CPUE specific to gear types or methods. Gear type or method-specific estimates of CPUE are informative for management of fisheries constrained by total catch limits. For example, if CPUE varies among gear types or angling methods, gear type or angling method restrictions may be a viable alternative to season or area closures in order to reduce impacts in fisheries likely to exceed their impact targets. We therefore recommend that gear type and angling method be recorded for all anglers in future creel surveys.

One assumption we made when calculating mortality estimates was that hooking mortality was independent among capture events (i.e., non-cumulative/multiplicative). During a two year study on winter-run British Columbia steelhead, Nelson et al. (2005) reported a maximum initial capture mortality of 1.4 and 5.8% and found that seventy-two tagged fish (out of 226) were recaptured and released in the sport fishery up to three times without any mortality before spawning. We found that the number of maiden winter-run steelhead that were caught (and released) was almost equal to the estimated run size during 2012-13 in the Washougal and was 20 – 105% greater during 2011-12 in both river-systems. Therefore, a decent proportion of steelhead had to have been caught, released, and survived one or more times prior to spawning. Interestingly, while these data may help support our assumption of non-cumulative hooking mortality, high capture to run size ratios also led to relatively high estimates of encounter and impact rates, particularly in 2011-12. However, underlying our encounter and impact rate estimates was the assumption that steelhead escapement estimates were accurate.

Escapement estimates for winter-run steelhead were derived from bi-weekly spawning ground counts of redds. Annual surveys were conducted from late February through mid-June to encompass the majority of spawning timing in the SF Toutle and Washougal rivers. This designated period also coincides with some of the highest flows and associated turbidity in tributaries throughout the LCR. These high flow conditions make redd surveys difficult, resulting in unobserved redds and negatively biased escapement estimates. An evaluation of observer efficiency for steelhead redd surveys in the Wenatchee and Methow watersheds (Washington state) found that, on average, only 25 – 75% of the true total number of redds were counted (*A. Murdoch, WDFW, personal communication*). To date, no formal study has been conducted to assess redd survey observer efficiency across a range of streamflow in the SF Toutle and Washougal rivers, but survey conditions are generally considered: "great" when streamflow is less than 500 cubic feet per second (cfs), "good" with streamflow of 500 – 1,000 cfs, "okay" with streamflow of 1,000 – 1,500 cfs, and "poor" with streamflow more than 1,500 cfs (*S. Gray, WDFW, personal communication*). Although redd surveys were certainly done under the best possible day-to-day conditions, streamflow, and thus survey conditions, can vary greatly among years (Appendix F). Additionally, extremely high flow events can mobilize spawning substrates, making redds indistinguishable. WDFW redd-based escapement estimates are not adjusted for inter-annual variability in survey conditions (i.e., observer efficiencies) and therefore may be negatively biased, particularly in high flow years.

WDFW has received the authority to operate recreational fisheries in the LCR from National Marine Fisheries Service based on information provided in the LCR FMEP. The LCR FMEP estimates tributary exploitation rates for recreational fisheries will be less than or equal to 10% for wild summer- and winter-run steelhead. We found that total impact rates (i.e., maiden and kelts combined) ranged between 2.4 – 6.9% across all years and rivers except for one. The impact rate for winter-run steelhead in the Washougal River during 2011-12 was estimated at 10.7%. While it is possible that the impact rate to winter-run steelhead in this particular year was 0.7% above compliance, we have reason to believe that this estimate may be biased high. During the 2012 spawner survey period (February through June), 45% of all days had an average daily streamflow greater than or equal to 1,500 cfs (i.e., poor survey conditions) compared to 24 and 33% in 2013 and 2014, respectively. As mentioned above, these high flows can affect survey conditions, which can negatively bias estimates of spawner abundance and over-estimate estimates of encounter and impact rates. Although impact rates did not exceed 10% in the SF Toutle among years, a similar pattern in flow, encounter, and impact rates was observed. Specifically, during the spring of 2012 in the SF Toutle River, flows were relatively high compared to 2013 (no data in 2014) and encounter and impact rates were approximately 2 – 3 times higher despite similar estimates of total catch. Thus, the assumptions that are made to calculate escapement, in addition to catch and hooking mortality, should be critically evaluated when drawing conclusion for the impacts of non-retention steelhead fisheries in the LCR.

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Supplemental Material

Appendix A – Monthly Day Length Averages

Table A1. Monthly timing of dawn and dusk and the corresponding day length (hours) used in the SF Toutle and Washougal River creel analysis.

Month	Dawn	Dusk	Day Length
January	7:11	17:28	9.18
February	6:41	18:07	10.40
March	6:35	19:32	11.95
April	5:53	20:28	13.55
May	5:05	21:10	14.92
June	4:44	21:37	15.62
July	5:02	21:30	15.25
August	5:40	20:47	14.03
September	6:19	19:50	12.50
October	6:58	18:53	10.92
November	6:40	17:15	9.50
December	7:09	17:03	8.77

Appendix B – Variance Estimations

We calculated the mean daily variance for angler effort, catch per unit effort (CPUE), and catch using:

$$\widehat{Var}(\bar{x}_i) = \left(\frac{N_i - n_i}{N_i}\right) \cdot \frac{s_i^2}{n_i}$$

where N_i is the total number of days in sub-stratum$_i$, n_i is the total number of sampled days in sub-stratum$_i$, and s_i^2 is the standard deviation of daily effort, CPUE, or catch in sub-stratum$_i$.

The total variance for angler effort, CPUE, and catch for a particular sub-stratum was calculated using:

$$Var(\hat{X}_i) = \widehat{Var}(\bar{x}_i) \cdot N_i^2$$

Fieller's theorem allows confidence intervals to be calculated for the ratio of two means and we used it to estimate the standard error of the average number of anglers (Q) using the following equation:

$$\widehat{SE}(\bar{Q}_i) = \frac{Effort_i}{Trip\ Time_i} \cdot \sqrt{\frac{SE^2_{Effort_i}}{Effort_i^2} + \frac{SE^2_{Trip\ Time_i}}{Trip\ Time_i^2}}$$

where *Effort* is the sum of all angler-hours, *Trip Time* is the average length of an angler trips, and *SE* is the standard error in sub-stratum *i*.

Appendix C – Effort Expansion for the Washougal River

Prior to analyzing the Washougal River effort count data, there was anecdotal evidence that our counts surveys were not capturing 100% of all bank and boat anglers throughout the survey reach. Sections of private property and the Washougal River road parting from the river make instantaneous effort counts difficult. During preliminary data analysis, we also discovered additional evidence that our angler-effort count were likely under-estimates of the true values. First, if we assumed that the creel clerk was able to count 100% of fisherman during the effort counts, we estimated that >80% of all boat anglers were interviewed in 22 (91%) out of 24 months (with any boat anglers). Although this was technically possible, it was highly unlikely given that we only sampled ~50% of all days each month and the sample period rarely encompassed the entire day length. Second, using the same set of assumptions, our calculations found that we interviewed more boat anglers than we estimated were fishing during the entire month in 7 (29%) of the 24 months. This is not possible and clearly demonstrated that our effort counts were not capturing 100% of the anglers, and thus, were biased low. Since we did not conduct any "tie-in" counts to expand the calculated effort estimates, we explored two options: (1) calculating the total length of the survey section that was deemed "unsurveyable" from qualitative estimates by our creel clerk, and (2) calculating the ratio of boat angler counts versus expanded trailer counts.

First, we had our creel clerk, who conducted all creel surveys over the three seasons, estimate individual sections of the stream that were "unsurveyable" from the road on a map. These maps were digitized in ArcGIS and spatially referenced. We then calculated the total length of the stream from the sections of the river that were identified as unsurveyable relative to the entire length of the river (from the mouth up to Salmon Falls). In total, 8.8 of the 15.2 (58%) miles of river were identified as unsurveyable, which lead to a spatial expansion factor estimate of 2.4. An inherent assumption of this method and expansion factor was that total effort in the areas that were surveyable was proportional to the effort throughout the entire 15.2 miles of survey area.

Second, we compared boat angler counts with expanded boat angler counts using trailer counts. We expanded trailer counts to get boat angler effort by first enumerating the number of trailers parked along the entire length of the river. Then we multiplied the average daily trailer count by the average number of anglers per boat for each individual survey date. If a particular date had a non-zero effort count of trailers, but no boat anglers were interviewed, then the trailer count was multiplied by the overall average of anglers per boat across all dates. Here, we assumed each trailer had one boat, all trailed boats were fishing, and there were no trailer-less boats. The first two assumptions were likely true as most boats were drift boats and recreational boating is almost non-existent on the Washougal River. The small portion of recreational boating on the Washougal River was kayaking or pontoon rafting, which do not require a "standard" boat trailer. Our third assumption may have been violated if a trailer was parked on private property and not visible, or if the boat did not require a trailer (e.g., single-occupant boat or launch from shore of private property). We know that this assumption was not always met and would lower our effort estimate. However, our violation was partially offset since single occupant boats were still interviewed, and thus, contributed to the average number of anglers per boat calculation.

We found that expanded trailer counts were: greater than boat counts 78% of the time, equal to boats 12% of the time, and less than boats 9% of the time (Appendix B: Figure B1) when both trailer and boat angler counts were not zero (both zero 388 out of 855 individuals counts). Additionally, we found that there were approximately twice as many days (44 vs. 23) where at least one boat angler was interviewed, but no boat anglers were enumerated in either effort count using boat angler counts relative to expanded trailer counts. Therefore, expanded trailer counts were a better representation of boat angler effort relative to boat angler counts. Across all surveyed months, the percent difference in estimated angler-hours using expanded trailer count versus boat counts varied from -20 to 520%, resulting in effort expansion ranging from 0.8 to 6.2 (Appendix B: Table B1). In order to account for our likely under-estimated effort estimation for bank anglers, we averaged the ratio of expanded trailer to boat angler count effort estimates and derived an effort expansion factor of 2.4. We used this average ratio to expand bank angler effort estimates. The assumption of using this expansion factor was that bank and boat anglers were equally detected and distributed longitudinally throughout the stream.

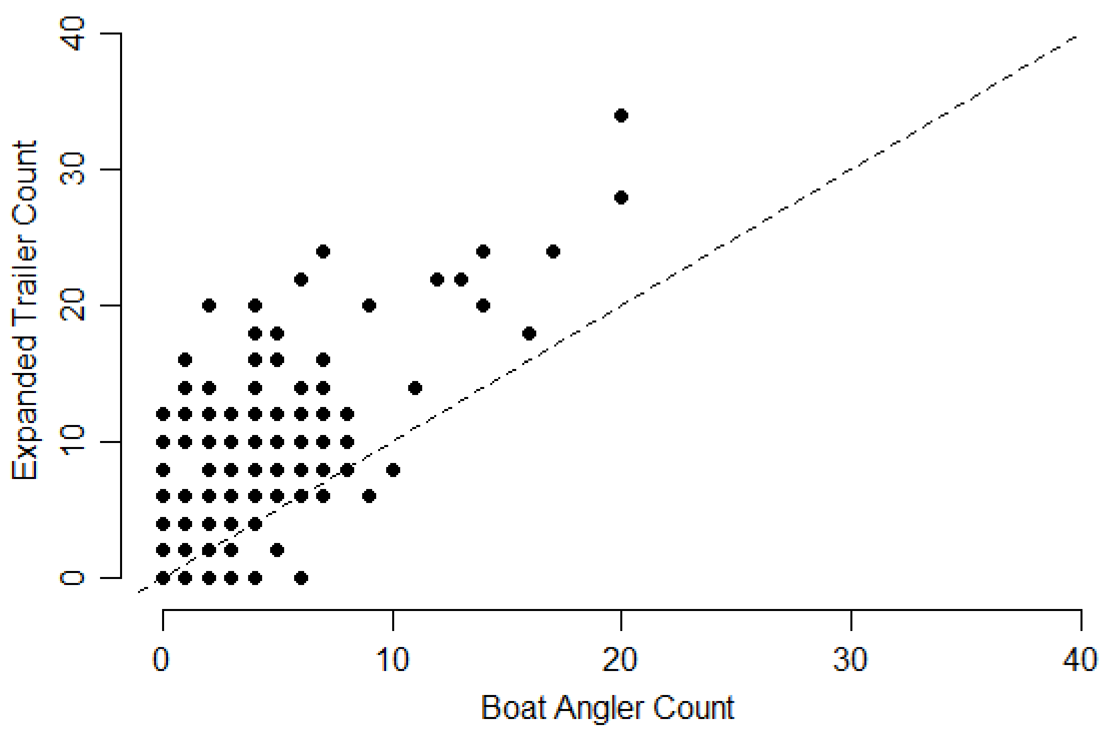

Figure C1. Effort counts of boat anglers using expanded trailer and boat angler counts on the Washougal River from April 16, 2011, to March 15, 2015 (N = 855). The dashed line represents the 1:1 relationship.

Appendix D – Estimated total monthly fishing effort (angler-hours)

Table D1. Estimated total angling effort (angler-hours) for hatchery and wild steelhead by month and year group (May - March), and the distribution of effort by day-type (weekend, weekday) and angler-type (% Bank vs. Boat) per month, and by month in a given year group on the SF Toutle River from May 21, 2011, to March 14, 2014.

Year Group	Month	Effort	SE	% Weekend Effort by Month	% Bank Effort by Month	% Monthly Effort by Year Group
2011-2012	May	1034	229	55.5	97.9	9.0
	Jun	3039	489	44	100.0	26.3
	Jul	1731	185	37.2	100.0	15.0
	Aug	930	172	39.2	100.0	8.1
	Sep	318	84	13.5	100.0	2.8
	Oct	1240	344	35.2	100.0	10.7
	Dec	204	86	28.9	100.0	1.8
	Jan	735	248	47.8	100.0	6.4
	Feb	1214	237	57.6	97.3	10.5
	Mar	1097	175	49	100.0	9.5
2012-2013	May	555	126	48.5	100.0	8.7
	Jun	1612	427	52.9	100.0	25.3
	Jul	671	143	37.6	100.0	10.5
	Aug	251	80	8.4	100.0	3.9
	Sep	124	37	50	100.0	1.9
	Oct	311	85	19.3	100.0	4.9
	Nov	180	113	42.2	100.0	2.8
	Dec	129	80	0	100.0	2.0
	Jan	473	132	26.4	100.0	7.4
	Feb	1194	249	32.8	99.5	18.8
	Mar	867	206	40.5	100.0	13.6
2013-2014	May	82	37	54.9	100.0	1.3
	Jun	1907	315	43.3	100.0	29.6
	Jul	560	203	21.8	100.0	8.7
	Aug	157	105	75.2	100.0	2.4
	Sep	336	99	42.9	100.0	5.2
	Oct	369	90	42.3	100.0	5.7
	Nov	185	92	34.6	100.0	2.9
	Dec	386	80	50	100.0	6.0
	Jan	818	177	25.8	92.4	12.7
	Feb	1009	177	53.6	98.6	15.7
	Mar	628	82	49.2	100.0	9.8

Table D2. Estimated total angling effort (angler-hours) for hatchery and wild steelhead by month and year group (May - March), and the distribution of effort by day-type (weekend, weekday) and angler-type (% Bank vs. Boat) per month, and by month in a given year group on the Washougal River from April 16, 2011, to March 15, 2014.

Year Group	Month	Effort	SE	% Weekend Effort by Month	% Bank Effort by Month	% Monthly Effort by Year Group
2010-2011	Apr	2378	461	47.4	68.2	100
2011-2012	May	4518	420	38.5	73.6	18.5
	Jun	2526	419	22	81.9	10.3
	Nov	2693	375	49.6	64.1	11.0
	Dec	5069	635	35.3	84.7	20.7
	Jan	4724	679	42.9	66.7	19.3
	Feb	2238	277	43.2	66.3	9.1
	Mar	1363	273	36.1	71.5	5.6
	Apr	1343	232	25.5	81.8	5.5
2012-2013	May	3135	379	32.2	79.3	11.4
	Jun	5111	481	29.2	89.5	18.5
	Nov	2248	429	25.3	65	8.2
	Dec	7256	1075	34.6	52.3	26.3
	Jan	3391	379	43.8	68.1	12.3
	Feb	3642	384	47.4	63.9	13.2
	Mar	1274	126	45.1	66.4	4.6
	Apr	1513	295	43.8	75.1	5.5
2013-2014	May	2159	294	43.9	90.4	10.8
	Jun	2953	482	35.5	98.7	14.8
	Jul	258	136	21.7	100	1.3
	Aug	0	0	-	-	0.0
	Oct	1349	237	38.2	100	6.8
	Nov	2207	353	35.4	68.8	11.1
	Dec	5902	654	33	63.4	29.6
	Jan	2203	338	37.7	70.5	11.1
	Feb	1849	434	50.4	58.6	9.3
	Mar	1049	254	63.6	42.4	5.3

Appendix E – Estimated total monthly catch

Table E1. Estimated total mean monthly catch, and the proportion of catch by month in a given year group (May - March), for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead on the SF Toutle River from May 21, 2011, to March 14, 2014.

			Hatchery Harvested			Wild Released			Hatchery Released			Unknown Released		
Year Group	Year	Month	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group
2011-2012	2011	May	76	41	0.13	84	39	0.08	61	36	0.58	0	0	-
	2011	Jun	252	83	0.44	264	66	0.27	0	0	0.00	0	0	-
	2011	Jul	147	28	0.26	31	9	0.03	10	3	0.09	0	0	-
	2011	Aug	32	17	0.06	23	16	0.02	0	0	0.00	0	0	-
	2011	Sep	44	13	0.08	22	6	0.02	0	0	0.00	0	0	-
	2011	Oct	0	0	0.00	42	30	0.04	0	0	0.00	0	0	-
	2011	Nov	-	-	-	-	-	-	-	-	-	-	-	-
	2011	Dec	0	0	0.00	0	0	0.00	0	0	0.00	0	0	-
	2012	Jan	0	0	0.00	53	24	0.05	27	20	0.25	0	0	-
	2012	Feb	21	9	0.04	188	37	0.19	8	4	0.08	0	0	-
	2012	Mar	0	0	0.00	286	42	0.29	0	0	0.00	0	0	-
2012-2013	2012	May	20	0	0.10	0	0	0.00	0	0	0.00	0	0	0
	2012	Jun	78	23	0.39	30	10	0.06	0	0	0.00	0	0	0
	2012	Jul	36	24	0.18	0	0	0.00	0	0	0.00	0	0	0
	2012	Aug	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0
	2012	Sep	20	14	0.10	0	0	0.00	0	0	0.00	0	0	0
	2012	Oct	23	7	0.12	23	6	0.05	0	0	0.00	23	6	1
	2012	Nov	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0
	2012	Dec	0	0	0.00	42	41	0.08	0	0	0.00	0	0	0
	2013	Jan	23	7	0.12	85	41	0.17	23	10	0.74	0	0	0
	2013	Feb	0	0	0.00	120	32	0.24	8	5	0.26	0	0	0
	2013	Mar	0	0	0.00	195	65	0.39	0	0	0.00	0	0	0
	2013	May	5	0	0.01	0	0	0.00	0	0	0.00	0	0	-

Table E1 *continued*. Estimated total mean monthly catch, and the proportion of catch by month in a given year group (May - March), for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead on the SF Toutle River from May 21, 2011, to March 14, 2014.

			Hatchery Harvested			Wild Released			Hatchery Released			Unknown Released		
Year Group	Year	Month	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group
2013-2014	2013	May	5	0	0.01	0	0	0.00	0	0	0.00	0	0	-
	2013	Jun	160	63	0.38	30	9	0.05	0	0	0.00	0	0	-
	2013	Jul	54	25	0.13	46	30	0.08	0	0	0.00	0	0	-
	2013	Aug	27	23	0.06	0	0	0.00	0	0	0.00	0	0	-
	2013	Sep	123	70	0.29	21	6	0.04	0	0	0.00	0	0	-
	2013	Oct	16	14	0.04	0	0	0.00	8	5	0.47	0	0	-
	2013	Nov	0	0	0.00	9	4	0.02	0	0	0.00	0	0	-
	2013	Dec	9	3	0.02	89	39	0.16	9	7	0.53	0	0	-
	2014	Jan	23	7	0.06	147	30	0.27	0	0	0.00	0	0	-
	2014	Feb	0	0	0.00	120	79	0.22	0	0	0.00	0	0	-
	2014	Mar	0	0	0.00	85	72	0.16	0	0	0.00	0	0	-

Table E2. Estimated total mean monthly catch, and the proportion of catch by month in a given year group (May - March), for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead on the Washougal River from April 16, 2011, to March 14, 2014.

			Hatchery Harvested			Wild Released			Hatchery Released			Unknown Released		
Year Group	Year	Month	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group
2010-2011	2011	Apr	30	8		130	45		0	0		0	0	
2011-2012	2011	May	106	39	0.11	142	46	0.16	0	0	0.00	0	0	-
	2011	Jun	121	44	0.12	44	16	0.05	11	4	0.05	0	0	-
	2011	Jul	-	-	-	-	-	-	-	-	-	-	-	-
	2011	Aug	-	-	-	-	-	-	-	-	-	-	-	-
	2011	Sep	-	-	-	-	-	-	-	-	-	-	-	-
	2011	Oct	-	-	-	-	-	-	-	-	-	-	-	-
	2011	Nov	38	9	-	60	11	-	16	9	-	0	0	-
	2011	Dec	396	96	0.40	169	55	0.19	53	14	0.24	0	0	-
	2012	Jan	200	44	0.20	152	39	0.17	80	18	0.36	0	0	-
	2012	Feb	66	20	0.07	243	56	0.27	58	16	0.26	0	0	-
	2012	Mar	55	39	0.06	76	21	0.09	4	2	0.02	0	0	-
	2012	Apr	27	14		155	63		0	0		0	0	
2012-2013	2012	May	116	46	0.14	78	21	0.07	46	10	0.15	23	6	1
	2012	Jun	368	189	0.45	222	134	0.21	10	4	0.03	0	0	0
	2012	Jul	-	-	- -	-	-	- -	-	-	- -	-	-	-
	2012	Aug	-	-	- -	-	-	- -	-	-	- -	-	-	-
	2012	Sep	-	-	- -	-	-	- -	-	-	- -	-	-	-
	2012	Oct	-	-	- -	-	-	- -	-	-	- -	-	-	-
	2012	Nov	22	6	0.03	44	9	0.04	88	33	0.28	0	0	0
	2012	Dec	82	23	0.10	177	37	0.17	72	15	0.23	0	0	0
	2013	Jan	102	25	0.12	125	42	0.12	47	12	0.15	0	0	0
	2013	Feb	52	13	0.06	236	70	0.23	36	13	0.11	0	0	0
	2013	Mar	75	40	0.09	160	42	0.15	15	5	0.05	0	0	0
	2013	Apr	55	30		89	42		0	0		11	10	

Table E2 *continued*. Estimated total mean monthly catch, and the proportion of catch by month in a given year group (May - March), for harvested (hatchery origin) and released (wild, hatchery, and unknown origin) steelhead on the Washougal River from April 16, 2011, to March 14, 2014.

			Hatchery Harvested			Wild Released			Hatchery Released			Unknown Released		
Year Group	Year	Month	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group	Catch	SE	Proportion by Year Group
2013-2014	2013	May	0	0	0.00	62	20	0.11	0	0	0.00	0	0	-
	2013	Jun	150	78	0.19	60	33	0.11	0	0	0.00	0	0	-
	2013	Jul	0	0	0.00	0	0	0.00	0	0	0.00	0	0	-
	2013	Aug	0	0	0.00	0	0	0.00	0	0	0.00	0	0	-
	2013	Sep	-	-	-	-	-	-	-	-	-	-	-	-
	2013	Oct	0	0	0.00	0	0	0.00	0	0	0.00	0	0	-
	2013	Nov	84	39	0.11	0	0	0.00	0	0	0.00	0	0	-
	2013	Dec	407	134	0.52	58	15	0.10	53	14	0.24	0	0	-
	2014	Jan	62	13	0.08	62	15	0.11	46	15	0.20	0	0	-
	2014	Feb	32	11	0.04	136	60	0.24	96	36	0.43	0	0	-
	2014	Mar	55	28	0.07	190	60	0.33	30	21	0.13	0	0	-

Appendix F– Daily streamflow

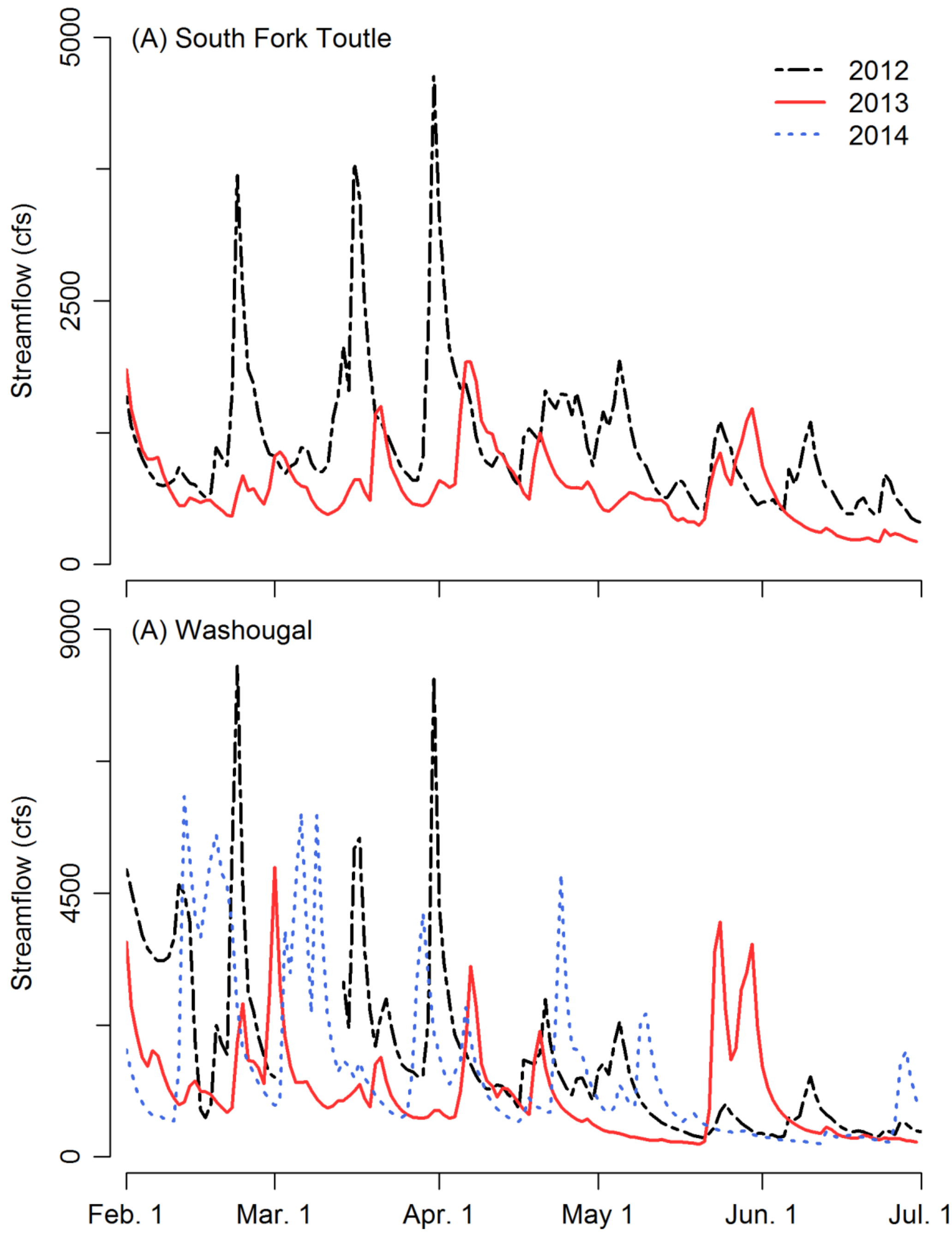

Figure F1. Mean daily streamflow (cubic feet per second) in the (A) SF Toutle and (B) Washougal Rivers from February 1st through June 30th during 2011 (black-dashed), 2012 (red-solid), and 2013 (blue-dotted). These data were from USGS stream gauge 14241500 (SF Toutle – discontinued September 2013) and Washington Department of Ecology stream gauge 28B080 (Washougal River).