Estimating outmigrant and overwinter survival of juvenile spring Chinook salmon in the Tucannon River

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**Introduction**

The Tucannon River spring Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and bull trout (*Salvelinus confluentus*) populations are listed for protection under the Endangered Species Act (ESA). Despite extensive aquatic and riparian habitat restoration and decades of hatchery supplementation, including a captive broodstock program, population-scale monitoring has not shown increased abundance or productivity associated with these efforts. The existing monitoring program within the Tucannon River basin results in run escapement, spawning escapement, spawning distribution, and smolt production estimates for spring Chinook salmon. The Tucannon salmonid monitoring program includes one smolt trap, four instream Passive Integrated Transponder tag detection sites (IPTDS) that are intended for evaluating spawning distribution, but are also critical to the evaluation of survival and movement of the Passive Integrated Transponder (PIT) tagged juveniles in this study. The impetus for this project in the Tucannon arose from an obvious lack of information about location- and life-stage-specific juvenile survival and mortality within the subbasin. By elucidating the patterns of survival and habitat utilization within the Tucannon River watershed across life stages, the appropriate reaches and life stages can be targeted for habitat restoration efforts that will maximize recovery for at-risk salmonid populations.

The specific objectives of this study were to:

1. Estimate survival of yearling spring Chinook salmon smolts to Lower Monumental Dam,
2. Estimate survival of parr to the lower Tucannon River from various overwintering areas.
3. Describe the spatial distribution of overwintering juvenile spring Chinook salmon within the Tucannon River.

**Methods**

*Study area*

This study was implemented throughout the Tucannon River basin with additional fish interrogation sites outside of the sub-basin (Figure 1). The study area includes 10 previously identified geomorphic reaches that were identified for habitat restoration purposes (Anchor 2011). The locations of the IPTDSs were Lower Tucannon River (LTR) at rkm 2.7, Middle Tucannon River (MTR) at rkm 17.8, Upper Tucannon River (UTR) at rkm 44.4, and Tucannon Fish Hatchery at rkm 59.2. We also utilized the Tucannon River smolt trap (SMT) at rkm 3. Outside of the Tucannon River basin, PIT tag detection sites included Lower Monumental (LMN), Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams, along with detections from the estuary trawl.



Figure 1. Study area and important features for spring Chinook salmon survival evaluation in the Tucannon River basin, Washington. The four Passive integrated transponder (PIT) detection sites are labeled (TFH, UTR, MTR, and LTR), geomorphic river reaches 1-10 are shown, and the area where parr tagging occurred as part of this study is represented by the shaded portion of the upper Tucannon River. PIT tags were also detected at mainstem dams throughout emigration and used to estimate survival to Lower Monumental Dam (LMN, inset map).

*Fish capture and tagging*

Electrofishing was used capture juvenile spring Chinook salmon parr during fall of 2013, approximately proportional to their 2012 spawning distribution based on redd locations (Table 1). Captured fish were anesthetized, measured for fork length, and fish greater than 70mm were implanted with a 12.5 mm 134.2 kHz full duplex PIT tag in the peritoneal cavity using standard Columbia River protocols (CBFWA 1999). After tagging, fish were allowed to recover fully in fresh water (approximately 30 minutes) before being released near the area of capture. A second group of fish was captured and tagged during their smolt outmigration at the smolt trap in the lower Tucannon River. Although juvenile Chinook salmon emigrate from the system throughout the year, we truncated the smolt-trap tagged dataset only to include yearling smolts tagged after February 28. Outmigrating smolts were sampled using the above methods and assumed to be representative of the smolt population. Following release, this study relied on the detection of PIT-tagged juveniles throughout the remainder of their rearing and emigration in freshwater using IPTDSs and the Tucannon River smolt trap.

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| Table 1. Spring Chinook salmon redd distribution in 2012 among reaches identified in figure 1. The parr tagging target for each geomorphic reach was based on a total 1,500 tagged fish. | | |
| Geomorphic reach | 2012 redds (%) | Parr tagging target by reach |
| 1 | 0 | 0 |
| 2 | 0 | 0 |
| 3 | 0 | 0 |
| 4 | 0 | 0 |
| 5 | 0 | 0 |
| 6 | 0 | 0 |
| 7 | 6 | 90 |
| 8 | 45 | 675 |
| 9 | 13 | 195 |
| 10 | 36 | 540 |

Water temperature data was collected by the Washington Department of Ecology (WDOE) near Marengo at rkm 41, which is approximately 3 km downstream of the UTR IPTDS. The DOE water temperature data are available at: <https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?wria=35#block4> . Flow data was collected by the United States Geological Survey (USGS) near Starbuck at rkm 9.5, which is approximately 6.8 km upstream of the LTR IPTDS. The USGS flow data are available at: <http://nwis.waterdata.usgs.gov/wa/nwis/uv/?site_no=13344500&agency_cd=USGS> .

*Statistical Analysis*

The Cormack-Jolly-Seber (CJS) model was used to estimate reach-scale and parr-to-smolt survival (i.e., survival from release to next downstream IPTDS) of juveniles tagged in the Tucannon River (Cormack 1964, Jolly, 1965, Seber 1965). The CJS model is an open population capture-mark-recapture (CMR) model that is used to estimate the probability of capture and survival of tagged animals between multiple sampling events (Burnham et al. 1987). The sampling design for the CJS model consists of a random sample of animals from the first event that are individually tagged and immediately returned to the population. This sampling is repeated at multiple times and/or locations depending on the study objectives and is commonly used to estimate animal survival within a season or annually (Williams et al. 2002). In the Columbia River, the CJS model is most often used to estimate reach-scale survival of juvenile salmonids tagged with PIT tags (Prentice et al. 1990a) associated with dam infrastructure and hydrosystem operations (Burnham et al. 1987, Skalski et al. 1998, Muir et al. 2001, Smith et al. 2002). King at al. (2010) indicated the likelihood for the CJS model is:

(1)

where *S* is the number of sites, *m* is the *m*-array, ρ is the probability of capture, ϕ is the probability of survival, and χ is the probability that an animal is released at site *i* is not observed in the study, *m*i,*S*is the corresponding number of individuals. The χ term is calculated by:

. (2)

We developed a single CJS model for fish released from the smolt trap to estimate survival to LMN. A total of five CJS models were developed for parr: 1) tagged in reach 8 in July, 2) parr tagged in section 8 in the fall, 3) parr tagged in the fall above TFH (reaches 9 and 10 combined), 4) parr tagged in the fall between TFH and UTR (reaches 7 and 8), and 5) all parr tagged in the fall (reaches 7-10). Since sample size was small we pooled all recoveries downstream from LMN into one site to assist in model selection and testing, as well as developing average detection probabilities at IPTDSs. Pooling should have negligible impact in the results (Schwarz et al. 1993). One advantage of CJS model for salmonid life cycle modeling is life stage estimates can be directly estimated and survival estimates for successive reaches are the product of the survival estimates for those reaches (Rawding et al. in prep).

(3)

where ϕ*j*is the reach scale survival from equation 1 and 2 and Cumϕ*j* is the cumulative survival through reach *j*. Since survival estimates are multiplicative, estimated the parr outmigration survival to the smolt trap was estimated by multiplying the reach scale survival estimates to the smolt trap.

The use of a paired release study design is the preferred when estimating survival because the control group accounts for common mortality experienced by control and treatment groups including tagging and handling effects along with natural mortality (Burnham et al. 1987, Giorgi et al. 2010). Thus, we estimated overwintering survival by comparing the relative survival of parr-tagged fish to smolt-trap-tagged fish to LMN. The overwinter survival of parr release groups was estimated by:

(4)

where *OW\_ϕg* is the estimate of overwinter survival to LMN, *LMNp\_ϕg* is the cumulative parr survival to LMN by release location from equation 3, and *LMNs\_ϕ* is survival of smolts from the Tucannon smolt trap to LMN based on equation 3.

We used a Bayesian framework to develop these CJS models (Brooks et al. 2000). In the last two decades Bayesian methods have increasing been used to estimate survival (King et al. 2009, Link and Barker 2010). The Bayesian framework allows the use of previous data to be updated with new data via the likelihood function. Bayes theorem states the posterior distribution or posterior [p(θ|*y*)] is proportional to the prior distribution or prior [p(θ)] times likelihood of parameter θ given the observed data [p(y|θ)] (Gelman et al. 2004). Bayesian estimates of survival are becoming more common, in part due to the ability to formally incorporate prior information into the estimation process and to estimate survival from highly parameterized models (McCarthy 2007, Kery and Schaub 2012). The Bayesian analysis was conducted using Markov Chain Monte Carlo (MCMC) methods to sample the posterior probability density function (Gilks et al.1996) using the WinBUGS software, version 1.43 (Spiegelhalter et al. 2003, Lunn et al. 2000). This software is commonly used in survival analysis (Brooks et al. 2000, Gimenez et al. 2009). We called WinBUGS from the statistical package R using R2WinBUGS (Sturtz et al. 2005). All of the modeling results described in this paper have been assessed for chain convergence and the uncertainty in the parameter estimates due Markov Chain variability (Plummer et al. 2006). We used multiple chains starting at divergent initial values and monitored the chains until they reached equilibrium. Convergence was assessed by visually inspecting the MCMC chains and using the Brooks-Gelman-Rubin (BGR) statistic (Lunn et al. 2013). BGR values less than 1.1 are considered to have converged (Gelman et al. 2004). After discarding the burn-in iterations before convergence, we monitored the Monte Carlo standard error until it was less than 5% of the standard deviation to obtain accurate parameter estimates (Lunn et al. 2013). Based on this approach, we assume that our reported distributions are accurate and represent the underlying stationary distributions of the estimated parameters.

The conclusions from any analysis are dependent on the appropriateness of the model given the data collected from the sampling design. Our analysis includes the definition of the basic model, development and assessment of alternative models, and testing model assumptions (Gelman et al. 2013). For model selection, we used the Deviance Information Criteria (DIC), which is a Bayesian analog of AIC that assesses model fit and complexity (Spiegelhalter et al. 2002, Burnham and Anderson 2002). For the Bayesian framework Brooks et al. (2000) suggested using CJS posterior predictive model checks to compare of the posterior predictive distribution of replicated data from the model with the data analyzed by the model for a goodness of fit (GOF) test (Gelman et al. 1995). This is an omnibus test for model assessment that tests the capture and survival assumptions (Cooch and White 2014). The posterior predictive distribution is defined as the expected observations after replicating the study, having observed the data, and assuming the model is true. When using MCMC simulations, a measure of discrepancy is computed for the actual and replicated datasets for all iterations. The Bayesian *p*-value is the proportion of the iterations that the discrepancy measure of the replicated data is more extreme than the observed data (Gelman et al. 1996). If there is a good fit of the model to the data, we would expect the observed data to be similar to the replicated data resulting in a Bayesian *p*-value of 0.50; values near 0 or 1 indicate that the model does not fit the data. To assess the GOF for the CJS model we used the Freeman-Tukey statistic since our count data consisted of many zero counts and this test statistic allows zeroes and does not require the pooling of cells to meet a minimum value (Brooks et al. 2000, King et al. 2010).

In the Bayesian models, there is extrinsic non-identifiablity which is due to the data (Kery and Schaub 2011). This occurs when the posterior distribution is dominated by the prior due to sparse data. In these cases the parameter estimates are sensitive to the prior. One method of testing for extrinsic non-identifiabilty in survival model is a sensitivity analysis based on different priors (Brooks et al. 2000). Since it can be time consuming to re-run models with different priors, Gimenez et al. (2009) proposed to test for extrinsic non-identifiability in capture-recapture models by comparing the overlap between a flat prior and the resulting posterior distribution. They proposed that parameters are considered weakly identifiable, thus sensitive to the prior, if the overlap between the prior and posterior is greater than 35%, which was the standard we used in our analysis.

**Results**

*Smolt survival to Lower Monumental Dam*

A total of 775 spring Chinook salmon outmigrants were captured and PIT tagged from October 2013 through June 2014, but the release group was truncated to 607 to include only yearling smolts captured from March to June, a similar emigration window as the parr-tagged fish. For the CJS smolt model the Bayesian p-values for the omnibus GOF test was 0.14, which indicate no lack of fit. The estimated median survival from the smolt trap (rkm 3.0) to LTR was 95.5%, from LTR to LMN was 92.6%, and the cumulative survival from the smolt trap to LMN was 87.2% (95% CI = 76.6% - 96.6%, Table 2). There was no weak identifiability (>35%) in the probability of survival and capture estimates for the CJS smolt model, which indicates prior distribution had little influence on posterior distributions/survival estimates.

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| Table 2. Spring Chinook salmon smolt survival estimates within the lower Tucannon River and from the smolt trap (SMT) and lowest IPTSD (LTR) (rkm 3) to Lower Monumental Dam (LMN). | | | |
| Section | Median | 2.50% | 97.50% |
| SMT-LTR | 95.5% | 85.8% | 99.8% |
| LTR-LMN | 92.6% | 80.3% | 99.6% |
| SMT-LMN | 87.2% | 76.6% | 96.6% |

*Parr Survival*

Capture and tagging efforts began in late July, but approximately half of the spring Chinook salmon were not large enough to PIT tag per our ESA permits. Field activities were reinitiated on September 30, a date we assumed to precede any major redistribution into downstream overwintering areas, and thus still reflect the summer rearing distribution. A total of 1,531 juvenile spring Chinook salmon were tagged in the upper Tucannon River watershed, which included a total of 785 funded by the McNary Project. A total of 216 were tagged in reach eight in July with a total of 1,315 tagged in late September and October, approximately proportionate their spawning distribution in 2012. The fall tags were allocated throughout geomorphic reaches seven (n = 102), eight (n = 463), nine (n = 210), and ten (n = 540). All fish tagged in reach seven were above UTR. The mean length was 80.5 mm (SD = 6.5mm) for fish tagged from September 30 to October 10. A total of 124 mortalities were observed as a result of electrofishing and 2 mortalities occurred during post-tagging recovery, which represents an 8.2% handling and tagging mortality rate. Three PIT-tagged parr were detected in September 2014 in the upper Tucannon River having never emigrated; these fish were removed from the study and not used in the analysis.

*CJS Estimates of Parr Survival*

We tested the survival difference between the July 30 release group (n=216) and the October release group in section 8 (n=462) in order to determine the appropriateness of pooling the two groups in subsequent survival analyses. July-tagged fish survived at approximately 82% as well as fish tagged in October to LMN. Thus, we only used fall-tagged fish in subsequent survival estimates.

For the three parr CJS models (all reaches (7-10), reaches 7-8, and reaches 9-10) the Bayesian *p*-values for the omnibus GOF tests were 0.32, 0.02, and 0.52, respectively. These indicate no lack of fit for the all-reaches and reach 9/10 models, but some lack of fit for the reach 7/8 model. Using DIC for model selection, the most parsimonious CJS model was pooled (reaches 7-10) model (DIC = Δ125), which indicates no support for the separate reach models. Despite the lack of support for the reach models, we continued to provide information regarding that model as it may be useful for comparison. For PIT tagged parr in the all-reaches CJS model there was no weak identifiability (>35%) in the probability of capture estimates past LMN, or the survival probabilities through the upper two Tucannon IPTDSs, but some weak identifiability at the MTR and smolt trap sites (41% and 51%, respectively). Due to the low number of recaptures, the localized models had weak identifiability in all survival estimates except to the first downstream IPTDS. Since we used a uniform prior (0 – 1) this had the effect of pulling the survival and captures estimates toward 50%. Thus our estimates of survival using the pooled model would be considered slightly conservative (a slight underestimate of survival).

The pooled CJS model estimated parr-to-outmigrant survival to SMT was 15.7% (95% CI = 0.113 – 0.227, Table 3). Parr-to-smolt survival to LMN was 10.2% (95% CI = 0.078 - 0.134, Table 4) and overwinter survival to LMN based on equation 4 was 11.7% (95% CI = 0.087 – 0.157, Table 5). The pooled model survival estimates were always lower than the non-pooled, reach 9/10 or reach 7/8, estimates which were not supported by the model selection process. The result of higher survival for the non-pooled models appears counter intuitive and is a result of smaller samples size in these models and the uniform prior, which had a slight effect of pulling the median survival estimates closer to 50%. Due to the large sample size in the pooled model, these estimates were more robust to be influenced by this prior.

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| Table 3. Survival estimates for Tucannon River spring Chinook salmon from fall tagging until smolt emigration measured at the lower Tucannon River smolt trap. | | | |
| Section | Median | 2.50% | 97.50% |
| All | 15.7% | 11.3% | 22.7% |
| 9-10 | 16.8% | 11.6% | 24.4% |
| 7-8 | 26.6% | 18.2% | 40.6% |

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| Table 4. Survival estimates for Tucannon River spring Chinook salmon from fall tagging in 2013 until smolt emigration in 2014 measured at Lower Monumental Dam. | | | |
| Section | Median | 2.50% | 97.50% |
| All | 10.2% | 7.8% | 13.4% |
| 9-10 | 11.0% | 8.0% | 14.9% |
| 7-8 | 16.3% | 11.6% | 23.3% |

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| Table 5. Overwintering survival estimates for Tucannon River juvenile spring Chinook salmon from fall tagging in 2013 through smolt emigration in 2014 to Lower Monumental Dam. | | | |
| Section | Median | 2.50% | 97.50% |
| All | 11.7% | 8.7% | 15.7% |
| 9-10 | 12.6% | 9.0% | 17.6% |
| 7-8 | 18.8% | 13.2% | 27.3% |

*Spatial and Temporal Migration Patterns*

A total of 750 juveniles were tagged upstream from TFH, 565 were tagged between UTR and TFH, and no fish were tagged downstream from UTR, which is similar to our target tagging rates (Table 1). Detection probabilities were higher for the two most upstream IPTDSs (TFH ~25% and UTR ~40%, Figure 3). The detection efficiency at TFH is biased low due to missed days of operation in October and November. Detection efficiency for MTR, SMT, and LTR were approximately 10%, 3%, and 15%, respectively.

Figure 3. Estimates of capture probability for PIT-tagged juvenile spring Chinook salmon from tagging in fall 2013 through outmigration in 2014 by location in the Tucannon River. The groups are All (reaches 7-10), 9/10 (reaches 9-10), and 7/8 (reaches 7-8).

We examined the individual detections of all PIT-tagged fish released above TFH between TFH and UTR (Figure 4). No fish tagged above the TFH were detected at TFH until mid-November due to equipment malfunction, but fish were detected from mid-November through late February. The fish tagged between TFH and UTR exhibited a bimodal pattern of passage timing at UTR; fish were detected shortly after release through mid-November, not detected in January and most of February, and frequently detected beginning in March, which coincides with the spring smolt outmigration. At MTR detections from both groups occurred intermittently from early December through May (Figure 4), although few fish were detected at the site. Downstream detections at LTR of fish moving into the Snake River occurred primarily during the spring outmigration period, although several individuals from the lower tagging area emigrated during fall and winter.

Figure 4. Histogram of individual spring Chinook salmon juvenile PIT tag detections at the TFH (upper panel), UTR (second panel), MTR (third panel), and LTR (lower panel). The histogram displays PIT tagged fish released in October in reaches 9/10 above TFH (black) and in reaches 7/8, which are between FTH to UTR (grey). Superimposed are the mean gauge height in feet as a measure of daily flow (solid grey line) and the daily mean water temperature (dotted grey line).

In addition to the overwinter survival estimate that described survival at the riverscape scale (Table 5), we also examined reach-scale overwinter survival (Figure 5). Survival for those fish that were tagged and remained in the upper most section was 54% (above TFH). Fish that were tagged and remained between TFH and UTR survived at 51%, compared to 50% survival of all tagged fish (i.e., fish tagged between TFH and UTR along with fish tagged above TFH that moved down) that completed their rearing in this section. We estimated higher survival in downstream reaches that were infrequently used for overwintering, based on the migration and habitat utilization described in Figure 4.

Figure 5. Estimates of reach scale overwinter survival for PIT-tagged juvenile spring Chinook salmon by rearing location in the Tucannon River from tagging in fall 2013 through outmigration in 2013 and 2014. The groups are all (All -reaches 7-10), 9/10 (reaches 9-10), and 7/8 (reaches 7-8).

**Discussion**

*CJS Assumptions*

The survival estimates in this report are only valid if the study is implemented to meet the assumptions in this survival model. The following assumptions are needed for the CJS model (e.g. Williams et al. 2002): 1) every marked animal present in the population at sampling period i has the same probability of being recaptured or detected; 2) every marked animal present in the population immediately following sampling period i has the same probability of survival until the next sampling period i +1; 3) marks are neither lost nor overlooked, and are recorded correctly; 4) sampling periods are instantaneous and recaptured animals are immediately released; and 5) the fate of each animal with respect to capture and survival probability is independent of the fate of any other animal.

Assumptions 1 and 2 were assessed using the GOF test based on the posterior predictive distribution described above. Results of these tests for the smolt, all reaches parr, and reaches 9/10 parr CJS models did not suggest lack for fit which would result from a violation of these assumptions but lack of fit was noted for the 7/8 model. To meet the marking assumption, we used standard Columbia Basin protocols for PIT tagging parr and smolts, used experience and trained taggers, tagged fish above 70mm, held fish 30 minutes after tagging, and only released fish that were in good condition. Using these standardized protocols resulted in released fish with high survival and tag retention and this is the standard protocol for PIT tagging Columbia River juvenile salmonids (CBFWA 1999). Prentice et al. (1990b) found that PIT tags could be inserted in salmonids as small as 55 mm fork length (FL) with no apparent effects on growth or survival. Petersen et al. (1994) reached the same conclusion for coho salmon greater than 65mm. Juvenile PIT tag loss is often low for overwintering salmonids (< 3%) when using the standardized tagging protocols (Prentice et al. 1990a, Brakensiek and Hankin 2007, and Knudsen et al. 2009). Although the early PIT tag studies conducted by Prentice et al. (1990) indicated minimal tagging effect more recent work by Brakensiek and Hankin (2007) indicated survival was positively correlated with the size at the time of PIT tagging and there is a tagging effect on survival (Knudsen et al. 2009). To extent these last two studies apply to our study our estimates of survival may be slightly negatively biased but overwintering survival is likely to be less biased due to the paired control/treatment design.

To meet the instantaneous sampling assumption all fish were released immediately after recovery from tagging and recapture, and detection. Since our model is a spatial model, the instantaneous assumption may be considered as being met because tagging and detection occurs over a negligible distance relative to the reach lengths (Buchanan and Skalski 2007). The survival estimates are unbiased if the independent fates assumption is met but variance may be underestimated due to lack of fit, which is usually caused by overdispersion (Williams et al. 2002). In this spatial CJS model our estimate of survival is based on the assumption that juveniles emigrate to be detected at IPTDSs. Since this may not always occur our estimates are more correctly termed ‘apparent survival’ (Thomson et al. 2009). In our study apparent would equal true survival if all tagged juveniles emigrate from the Tucannon River to LMN. Most wild spring Chinook parr emigrate to the Columbia River but some male parr may remain and mature in their natal stream (Mullen et al. 1992, Johnson et al. 2012). We monitored upstream migration of PIT tagged juveniles to spawning areas in the summer and fall of 2014 via the IPTDS and found only four individual detections from three separate fish during September 2014. This equates to 0.03% of the parr tagged which were removed from our study. Although our detection efficiencies were above 25% at the upper two IPTDS and not all resident parr have to migrate past an IPTDS, we believe parr residency is not a significant factor affecting our survival estimates.

*Survival Estimates*

This study represents one year of results, but it offers valuable insight into the potential survival bottlenecks facing an ESA-listed population of spring Chinook salmon. Continuing the study over multiple years is important as variable environmental conditions and spawning escapement levels may affect survival and movement (Copeland et al. 2014). Indeed, research by Walter et al. (2014) and Brakensiek and Hankin (2007) showed that overwintering survival varies annually. This study contributes to a small, but growing body of research describing survival and movement patterns within lotic environments using PIT technology. Walter et al. (2014) found overwinter survival of spring Chinook salmon in the Wenatchee and Methow Rivers ranged from 18% to 41% depending on whether individuals reared in tributaries or mainstem river habitats.

Brakensiek and Hankin (2007) estimated that overwintering survival of coho salmon in a headwater stream was 36%, which was within the middle of the range for the coho salmon overwintering survival of the six studies they examined. The lowest overwintering survival for coho salmon was found in degraded habitat on the Oregon coast (~12%) and was increased to approximately 38% after habitat restoration (Solazzi et al. 2000). In this study, we estimated Tucannon spring Chinook parr-to-outmigrant survival was 15.7% and overwintering survival was 11.7%, which is lower than those observed in the upper Columbia River and more consistent with the survival of salmonids in degraded habitat (Solazzi et al. 2000).

Gallinat and Ross (2012) indicated the average egg-to-smolt survival for Tucannon River spring Chinook salmon was 5.6% for the 1985 to 2009 brood years. By dividing their estimated mean egg-to-smolt survival (5.6%) by the outmigrant survival found in this study (15.7%), we approximate egg-to-parr (in the fall) survival at 35.7% (95% CI = 0.25 – 0.50). By providing separate estimates of egg-to-parr and parr-to-outmigrant survival within the Tucannon River, recovery planning processes may develop habitat restoration strategies appropriately.

In addition to habitat considerations, the relatively low survivals that we documented may be attributed to, at least in part, reduced reproductive success of naturally spawning hatchery-origin spring Chinook salmon (Christie et al. 2014). As such, recovery of ESA-listed salmonids throughout their range will depend on evaluating and addressing multiple threats in addition to habitat restoration.

*Life History Summary*

This study was the first to use PIT-tagged juvenile Spring Chinook salmon to identify complex life history patterns in the Tucannon River. In 2012, the majority of spawning occurred above TFH and between TFH and UTR, with negligible spawning below UTR. Emergence occurs in the late winter and spring and there is some downstream movement of fry into suitable summer rearing habitats (Healy 1992, Bjorn 1971); however that movement may not be far as the proximity of spawning locations to juvenile rearing is important (Clark et al. 2014). Most summer rearing is believed to occur above UTR due to summer water temperatures that frequently exceed 20°C downstream of UTR and the concentration of spawning activity in the upper river. During the fall and winter we observed downstream emigration of parr from the area above TFH that was completed by mid-February. Fall downstream movements of spring Chinook salmon parr have been observed for other Snake River populations (Bjornn 1971, Copeland et al. 2014). Our analysis of detections at UTR showed little juvenile movement from mid-November until the onset of smoltification in March. This suggests that the area between TFH and UTR is an important reach for over wintering. Detections at MTR were sparse, which makes it difficult to determine the importance of the UTR to MTR reach for overwinter rearing. We hypothesize the high survivals in the below UTR are likely due to these reaches being mainly migration corridors. The survival estimate for the upper bound for the lowest two reaches includes 100%, which also supports our hypothesis that these are primarily migration reaches. Detections at LTR occurred mostly during the spring, which suggests that most juveniles reared in their natal system, however we documented some fish rearing downstream from LTR and potentially in the Snake River. Indeed, smolt trap operations during the same period showed a somewhat bimodal distribution with approximately 20% of emigrants leaving the Tucannon in the fall (WDFW unpublished).

*Restoration Opportunities*

Any interpretation of our findings that is used for restoration planning should consider that it is only a one-year study at this point. However, if the patterns of habitat use, survival, and movement that we observed remain consistent across years, which we intend to continue evaluating, there are some implications for restoration actions. The reach above TFH should be restored with a focus on survival in the incubation, fry, and summer/fall parr rearing life stages. The area between TFH and UTR was critical to all life stages, but overwintering capacity limitations may be paramount as fish from above TFH moved downstream, which likely increased competition. Indeed, overwinter survival estimates were slightly higher for the reach above TFH compared to the reach above UTR, although fewer fish overwintered above TFH. These movement and survival findings suggest that restoration targeting overwinter habitat in the reach above the UTR is likely to benefit juveniles that emigrate to this reach from above and those that occupy the reach in summer and winter. This restoration could include the creation of pools with cover, including but not limited to, large woody debris and interstitial spaces amid the substrate (Hillman et al. 1987, Van Dyke et al. 2009). We also observed a fall downstream movement of parr into areas below UTR, which suggests some rearing in the reach between UTR and MTR but we are less certain about the importance of this area, or the distribution of fish within the area, due to the low detection efficiency at MTR. We hypothesize that the middle and lower Tucannon River (downstream from UTR) is not utilized for summer rearing by Chinook salmon due to water temperatures, but may be important for overwintering and restoration activities should be focused accordingly. We hypothesize that the reaches below MTR are primarily a migration corridor and may not be extensively used for overwintering due to behavioral patterns or habitat limitations, but more research will be needed to understand fish distribution and habitat utilization upstream and downstream from MTR.

*Recommendations*

Our estimated outmigrant survival to the SMT site (rkm 3) was 16%, 17%, and 27% for Chinook salmon tagged in all reaches, reaches 9/10, and reaches 7/8, respectively. The higher survival in reach 7/8 relative to the other sections was also observed in survival to LWM and overwintering survival. A pattern of higher survival for downstream-rearing juveniles has been observed elsewhere, although not always consistently across years (Walter et al. 2014). The importance of that life history strategy has also been linked to higher smolt-to-adult productivity (Copeland et al. 2014). Future work should continue to examine reach-scale differences in survival and habitat utilization.

The precision of the survival estimate is influenced by the number of tags released and detected. The detection efficiencies of TFH, UTR, MTR, and LTR were approximately 25%, 40%, 10%, and 15%, respectively. We recommend upgrades to MTR that would improve capture probability at that site that would reduce the coefficient of variation of 14% in our survival estimate. This improved precision may also be realized by releasing more PIT-tagged fish. Due to the minimum size restrictions on our ESA permit, most fish captured in July were too small to be PIT tagged. This required us to delay capture and tagging of fish until October, when most fish exceeded the 70mm threshold. We recommend future studies target a sample size of 3,000 PIT tagged fish to improve the precision of the survival estimates. We also think the potential benefits of this research to recovery planning and restoration outweigh the concerns that led to a 70mm minimum size for tagging and initiating tagging during summer would provide valuable insight into summer movement and mortality.

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