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Juvenile Salmonid Mark-Recapture Sampling within the Entiat River Intensively Monitored Watershed Study, 2015.

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***On the cover**: Considering winter sampling conditions in the upper Entiat River.*

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Abstract — During 2015, the Mid-Columbia River Fishery Resource Office completed winter period mark-recapture sampling in the main stem Entiat and Mad rivers as part of the Integrated Status and Effectiveness Monitoring Program's Entiat River Intensively Monitored Watershed study. A total of 3,061 juvenile fishes were collected at 20 locations along the main stem Entiat and Mad rivers and a total of 2,733 salmonids were marked. Juvenile spring Chinook and summer steelhead made up for 13.72% and 85.10% of the total catch respectively. Average fork lengths (±SD) of spring Chinook and steelhead were 88.34 (±11.87) mm and 107.82 (±36.77) mm, respectively. Winter period mark-recapture sampling produced a total of 3 valid point estimates for spring Chinook and 6 for steelhead of the 8 possible for each species. Point estimates of abundance (95% C.I.) for wild Chinook and steelhead ranged from 13 - 399 (13 - 682) and 25 - 915 (25 - 1,055), respectively. A total of 139 spring Chinook salmon and steelhead recaptures were used to generate estimates of specific growth rate for winter, summer, and annual periods. Estimates of specific growth rate for steelhead varied between growth period and river location with the summer period exhibiting greater growth for both Entiat and Mad river sample populations. Juvenile steelhead from the Mad River exhibited lower growth rates than those from the Entiat River. Watershed scale averages of apparent survival for juvenile steelhead were 0.53 and 0.73 for the winter and 0.63 and 0.59 for the summer periods in the Entiat and Mad rivers. Models for spring Chinook failed to estimate apparent survival for the summer period; however, estimates of overwinter survival indicate a positive relationship with upstream rearing location.

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Table of Contents

Introduction 1
Study Area 1
Methods 2
Sample periods and site selection 2
Fish collection 3
Fish handling 4
Growth per day estimates 6
Seasonal estimates of apparent survival 6
Results 7
Winter fish capture summary 7
Site level point estimates 8
Growth per day estimates 9
Seasonal estimates of apparent survival 9
Data dissemination 12
Discussion 13
Fish sampling 13
Site level point estimates 13
Growth per day estimates 14
Seasonal estimates of apparent survival 14
References 16
Appendix 18

List of Figures

Figure 1. Map of the Entiat River depicting fish capture locations during the winter period of 2015. 2

Figure 2. Entiat River average daily flow (m^3/s) (USGS gaging station 12452990) during the winter fish capture period, 2015..... 7

Figure 3. Sub basin scale apparent over winter survival and 95% confidence intervals for juvenile spring Chinook salmon within the Entiat sub basin, 2010-2015. 10

Figure 4. Valley segment scale apparent over winter survival and 95% confidence intervals for juvenile spring Chinook salmon within the Entiat sub basin, 2010-2015. MAD not estimable in 2011 and 2015 due to low sample size. 10

Figure 5. Sub basin scale apparent over winter and over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. 11

Figure 6. Watershed scale apparent over winter and over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. 11

Figure 7. Valley segment scale apparent over winter survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. VS2 not estimable in 2014 and VS3 not estimable in 2011 and 2014 due to low sample size. 12

Figure 8. Valley segment scale apparent over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. VS2 not estimable in 2012 due to low sample size. 12

List of Tables

Table 1. Site code, river kilometer (RKM) and sampling type for Entiat River IMW sampling sites, 2015. 3

Table 2. Number of fish captured, PIT tagged, and associated mortality from the winter fish capture period, 2015. 7

Table 3. Mean fork-length (mm), weight (g), and body condition factor (K) for spring Chinook salmon and steelhead captured in the winter fish capture period, 2015. 8

Table 4. Point estimates of abundance and 95% confidence intervals for juvenile spring Chinook salmon and steelhead at mark-recapture sites sampled during the winter period, 2015. Estimates were considered invalid (INV) if failing validity testing. Estimates were considered not applicable (N/A) if no captures of that species occurred within the site. 8

Table 5. Estimated specific growth rates (mm/day) and SD for juvenile Chinook salmon and steelhead captured during mark-recapture sampling per residence river and growth period, 2015..... 9

List of Appendices

Appendix Table 1. Estimated specific growth rates (mm/day) and SD for juvenile Chinook salmon and steelhead captured during mark-recapture sampling per river and growth period, 2011-2015. 18

Appendix Table 2. Model selection results for estimating sub basin scale juvenile spring Chinook apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.71)..... 20

Appendix Table 3. Model selection results for estimating sub basin scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.64). 21

Appendix Table 4. Model selection results for estimating watershed scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.35). 22

Appendix Table 5. Model selection results for estimating valley segment scale juvenile spring Chinook apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.13)..... 23

Appendix Table 6. Model selection results for estimating valley segment scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.29)..... 24

Introduction

This report provides the results for juvenile salmonid capture efforts performed by the Mid-Columbia River Fishery Resource Office (MCRFRO) within the Entiat River Intensively Monitored Watershed (IMW) study in 2015. The intent of this report is to disseminate relevant information while providing annual documentation of methodologies and any deviations from these protocols and procedures.

The MCRFRO has been involved with the Entiat River IMW study since it was implemented through the Integrated Status and Effectiveness Monitoring Program (ISEMP; BPA project #2003-0017) in 2010 and was tasked with facilitating fish sampling efforts under the IMW design. Prior to the IMW study, the MCRFRO was funded through ISEMP to perform fish capture throughout the Entiat and Mad rivers for the purpose of marking fish with Passive Integrated Transponder (PIT) tags and collecting biological information from a subset of the standing-crop juvenile Chinook salmon and steelhead population.

This report represents the sixth and final year of MCRFRO involvement with fish capture efforts under the Entiat River IMW study and is limited to the winter capture period of 2015. All subsequent reporting of fish capture activities performed within the IMW, including the summer capture period of 2015, will be provided by TerrAqua Inc.

Study Area

The Entiat River watershed originates from 11 glaciers and snowfields in the Cascade Mountains and flows southeast approximately 69 km to join the Columbia River at river kilometer (rkm) 778 (CCCD 2004, Mullan et al. 1992). The Entiat watershed is bordered by the Entiat Mountains to the southwest and the Chelan Mountains to the northeast and drains approximately 1,085 km^2. The topography is steep with unstable erodible soils and vegetation types varying from semi-arid shrub steppe near the confluence with the Columbia River to temperate forests and alpine meadows in the headwaters.

Past glacial activity has shaped the Entiat River valley by creating a U-shaped valley upstream of terminal moraine at rkm 26.1 and V shaped valley downstream (Mullan et al. 1992). The present upstream limit to anadromy is at Entiat Falls (rkm 54.4) (Figure 1).

The Entiat River watershed supports eight salmonid species including spring and summer Chinook salmon *Oncorhynchus tshawytscha*, steelhead and resident rainbow trout *O. mykiss gairdneri*, sockeye salmon *O. nerka*, westslope cutthroat trout *O. clarki lewisi*, coho salmon *O. kisutch*, mountain whitefish *Prosopium williamsoni*, bull trout *Salvelinus confluentus*, and introduced eastern brook trout *S. fontinalis*. Other fish species include, chiselmouth *Acrocheilus alutaceus*, northern pikeminnow *Ptychocheilus oregonensis*, largescale sucker *Catostomus macrocheilus*, bridgelip sucker *C. columbianus*, speckled dace *Rhinichthys osculus*, longnose dace *R. cataractae*, redside shiner *Richardsonius balteatus*, sculpin *Cottus spp*., three-spined

stickleback *Gasterosteus aculeatus* and Pacific lamprey *Entosphenus tridentatus*. (Mullan et al 1992, CCCD 2004,).

Methods

Sample periods and site selection

Fish sampling within the IMW study has been designed around a framework of a rotating panel of sites within defined geomorphic reaches of the Entiat River. Fish sampling occurs twice annually in the winter and summer. Winter fish sampling generally begins in late February or early March as river surface ice recedes allowing crews access to river margins.

Winter period sample sites remained unaltered from the summer 2014 selection. A total of 20 sites were sampled using mark-recapture or single-pass methods during the winter. Eight sites were identified as mark-recapture sites and 12 were sampled as single-pass sites. Sample site locations for the winter sampling period of 2015 are presented in Figure 1 and Table 1, respectively.

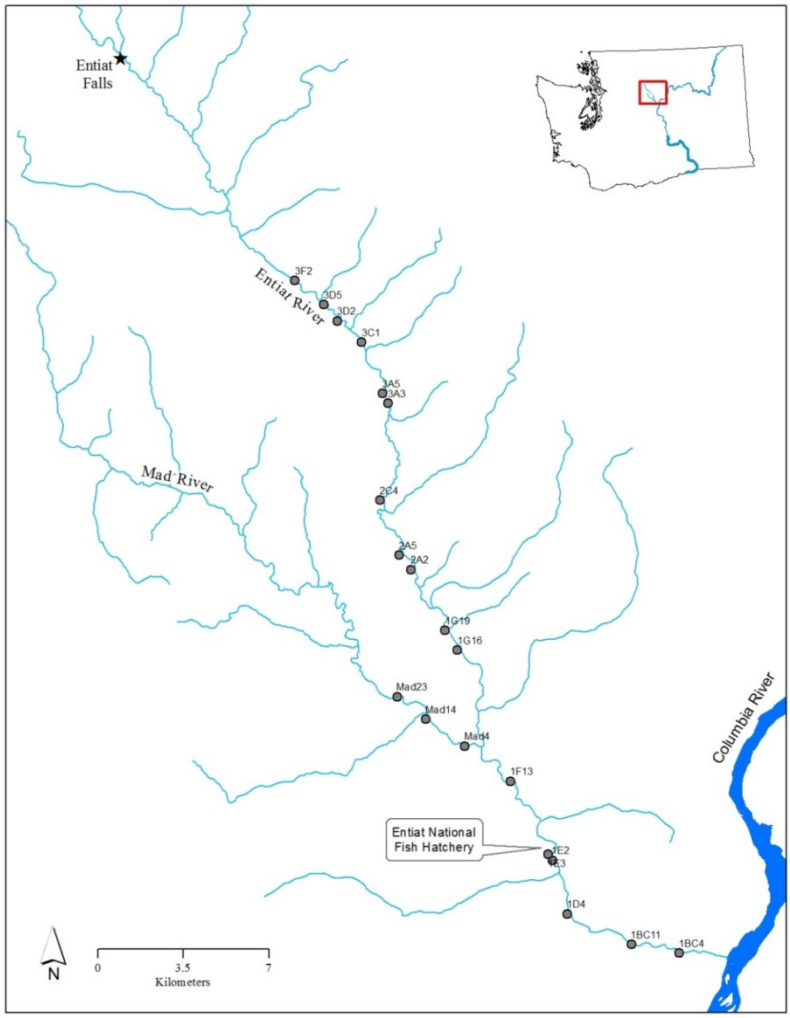

Figure 1. Map of the Entiat River depicting fish capture locations during the winter period of 2015.

Table 1. Site code, river kilometer (RKM) and sampling type for Entiat River IMW sampling sites, 2015.

Site	RKM	Sampling Type
1BC4	1.9	Single-pass
1BC11	4.2	Mark-recapture
1D4	7.4	Single-pass
1E2	9.9	Single-pass
1E3	10.3	Mark-recapture
1F13	14.7	Mark-recapture
1G16	22.5	Single-pass
1G19	23.4	Single-pass
2A2	27.1	Single-pass
2A5	28.1	Single-pass
2C4	31.6	Mark-recapture
3A3	36.7	Mark-recapture
3A5	37.4	Single-pass
3C1	40.2	Single-pass
3D2	41.8	Single-pass
3D5	42.7	Single-pass
3F2	44.6	Single-pass
M04	0.7	Single-pass
M14	2.9	Mark-recapture
M23	4.8	Mark-recapture

Fish collection

Mark-recapture methods were used to estimate capture probability and population size for Chinook salmon and steelhead at discrete sites within the Entiat subbasin. As MCRFRO staff involvement was limited to winter period fish capture in 2015, fish were captured using snorkel-herding and hand-netting methods. Capture methods relied on the assumption that a population within a site can be treated as effectively closed and that immigration, emigration, or mortality during the sampling period was zero or negligible.

Sampling was conducted at each mark-recapture site over a period of two consecutive days while single-pass sites required only one day. During the winter period all sites were sampled following sunset to maximize fish capture numbers. One to three capture crews, each consisting of a minimum of six personnel, sampled sites independently of one another. Within each crew, four personnel were assigned to fish capture and the remaining two to fish handling and PIT tagging. All sampling was conducted in an upstream direction with crews beginning at the lowermost point and methodically working upstream until the site was completely sampled. In some cases the site or specific habitat was sampled a second time if deemed necessary to increase total capture/marking numbers.

Fish handling

Fish were transported within 5 gallon aerated buckets from the point of capture to 25 gallon plastic live boxes located on the river margins throughout the site. Water temperatures and fish condition were closely monitored during transportation and holding. All individuals that exhibited signs of injury or excessive stress were scanned for a pre-existing PIT tag and released. Fish were periodically transported from live boxes to a stationary fish handling and tagging station.

Collected species were anesthetized in a water bath with a measured amount of tricaine (MS-222) buffered with sodium bicarbonate. Small groups of fish were anesthetized at any one time during daily handling to reduce the chance of incidental mortality from anesthetic overdose. Fish were identified to species with the exception of sculpin, dace and suckers. All Chinook salmon encountered during the winter sampling period were classified as spring run. . All salmonids were ascribed to a life history stage as either fry (<60 mm), parr (>60mm and distinctive parr marks), transitional (>60 mm silver sheen, faint parr marks, and deciduous scales) or smolt (>60 mm silver sheen, absent parr marks, deciduous scales, and with possible black tipped caudal fins).

All spring Chinook salmon, steelhead, coho salmon, sockeye salmon, bull trout, and cutthroat trout were measured to the nearest millimeter of fork length and weighed to the nearest tenth of a gram. Fulton-type condition factor was calculated for all Chinook and steelhead as described by Anderson and Gutreuter (1983) using the following calculation:

$$K = \frac{W}{L^3}$$

where K is the Fulton-type condition factor, W is the individual fish weight and L is the individual fish length.

Throughout the summer sampling period genetic samples were taken from a subset of PIT tagged Chinook salmon at a ratio of 1:10. Tissue was obtained from a small portion of the ventral fin, preserved in alcohol, and sent to the Region 1 USFWS genetics lab for storage. Scale samples were collected from a subset of juvenile steelhead at a ratio of 1:10 and archived for future age analysis.

Non-target species were either measured or counted and released within the site dependent upon time restrictions. All individuals were allowed full recovery prior to release. Non-marked individuals were released within the site in close proximity to their point of capture.

Marking of fish was performed using PIT tags. PIT tagging of juvenile fish followed the procedures and file submission requirements outlined by Pacific State Marine Fisheries Commission PIT Tag Information System (PTAGIS). Fish were tagged using a disinfected hollow needle to insert the PIT tag into the abdominal cavity. Individuals measuring between 50 and 60 mm in fork length were tagged with a 9 mm PIT tag (ISO tag model TX148511B operating at 134.2 kHz and weighing 0.065 g) and individuals greater than 60 mm were tagged with a 12.5 mm PIT tag (ISO tag model TX1411SST operating at 134.2 kHz and weighing 0.102 g). Any injuries or abnormalities were noted and juveniles were not PIT tagged if determined to

have had a recent or substantial injury that could be aggravated by tagging. Marked juveniles were held for a minimum of one hour to ensure full recovery prior to being released in close proximity to their capture origin.

All fish data were entered into the P3 program from PTAGIS (http://www.ptagis.org/). P3 is a data entry application used to collect and submit information about marked or recovered PIT tagged fish in the Columbia River basin. MCRFRO used this program to enter all fish information whether or not the fish was marked with a PIT tag. Data files generated from P3 were parsed into a custom Microsoft Access™ database constructed by MCRFRO staff for the purpose of preparing data for analytical use and various reports. The original P3 file was left intact and subsequently uploaded to PTAGIS where it is available to researchers throughout the Columbia River basin.

Throughout the winter sampling period genetic samples were taken from a subset of PIT tagged spring Chinook salmon. Tissue was obtained from a small portion of the ventral fin, preserved in alcohol and sent to the Region 1 USFWS genetics lab for storage. Scale samples were taken from a subset of juvenile steelhead and archived for future age analysis.

Site level point estimates

Point estimates of abundance and 95% confidence intervals were generated for wild Chinook salmon and steelhead at each of the mark-recapture sampling locations. Estimates were generated using the Chapman modification of the Peterson equation as presented in Van Den Avyle and Hayward (1999). All estimates were further tested and considered valid when the data met the validity test conditions proposed by Robson and Regier (1964). The Chapman modification of the Peterson equation is as follows:

$$N = \frac{(M+1)(C+1)}{R+1} - 1$$

with variance:

$$V(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2\,(R+2)}$$

where *N* is the population estimate; *M* is the number of fish captured, marked, and released in the first sample; *C* is the total number of fish caught in the second sample including recaptures; and *R* is the number of recaptures caught in the second sampling event.

The Robson and Regier equation to test the amount of bias present within the estimate is as follows:

$$\text{Negligible bias if } N \times C \ < N \times 4$$

Growth per day estimates

Estimates of specific growth rate (SGR) were obtained through the recapture of PIT tagged spring Chinook salmon and steelhead for winter (August to March), summer (March to August), and annual (August to August or March to March) periods. SGR was calculated by determining the temporal change in mean fork-length between mark-recapture sampling periods (Fausch and White 1986). Total growth rate was determined for each recaptured fish and was then applied to the date intermediate between sampling periods to achieve SGR in growth per day. Estimates were limited to recaptures of fish occurring within the sample site they were originally tagged in.

Seasonal estimates of apparent survival

Apparent survival was estimated for spring Chinook salmon and steelhead for the winter and summer periods at the sub basin, watershed and valley segment scales. Apparent survival estimates were generated using the Barker model (Barker 1997; Barker and White 1999) available through Program MARK (White and Burnham 1999). The Barker model was chosen due to its' ability to include data from resights and recoveries outside of the study area (Barker 1997; Barker and White 1999; Conner et al. 2015). Due to the inclusion of these additional data, estimates of apparent survival generated using the Barker model result in higher precision and lower or equal bias than the more traditional Cormack-Jolly-Seber models (Conner et al. 2015). A total of seven parameters including survival are estimated within the Barker model: the probability of survival from $time_i$ to $time_i + 1$ (S); the probability of recapture given alive at $time_i$ (p); the probability of recovery if dead from $time_i$ to $time_i$ (r); the resight probability if alive from $time_i$ to $time_i$ (R); the resight probability if dead from $time_i$ to $time_i$ (R'); the probability of fidelity to the capture area between $time_i$ and $time_i + 1$ (F); and the probability of temporary emigration from the capture area between $time_i$ and $time_i + 1$ (F'). Given that survival was our *a priori* parameter of interest, the relevance of the remaining six parameters was limited to their ability to adequately fit the data.

Goodness-of-fit testing was performed within Program MARK to calculate $\hat{c}$ using 500 iterations of parametric bootstrapping (White and Burnham 1999). Next a fully time dependent, saturated model was constructed for comparison to reduced models. A two-step approach similar to that outlined in Slattery and Alisauskas (2002) was used to reduce Barker parameters (F', F, R', R, r and p) from the saturated starting model. Each parameter was fit to reflect a constant (.), time (t) or group (g) dependency. As appropriate, models considering the additive (g+t) or multiplicative (g*t) effects of group and time were assessed.

Model selection was based on an information-theoretic approach with the Akaike information criterion (AIC_c) within Program MARK adjusted for low sample sizes (Burnham and Anderson 1998). Models were ranked among one another by comparing the AIC_c rank of a candidate model to the lowest AIC_c (ΔAIC_c). In general, ΔAIC_c values less than 3 indicated that a model had support similar to the top ranking model while values between 4 and 7 indicated lessened support and values greater than 7 indicated very little support for the candidate model as related to the top model. Normalized Akaike weights ($wAIC_c$) were used to compare the relative strength of one model over another. Models with comparative wAICc values of 10 or less were considered plausible alternatives to the top model (Burnham and Anderson 2002).

Results

Winter fish capture summary

Fish sampling began on March 4, 2015 when river surface ice had receded allowing safe access to sample sites. All sampling activities were completed by March 14. Average daily flow (ft^3/s) during the sampling period is summarized in Figure 2.

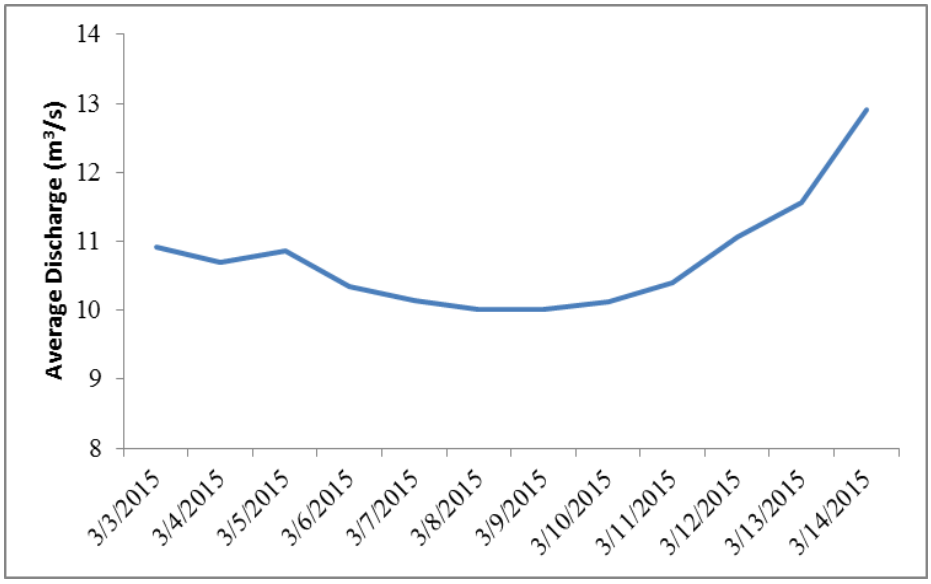

Figure 2. Entiat River average daily flow (m^3/s) (USGS gaging station 12452990) during the winter fish capture period, 2015.

A total of 3,061 fish were captured at 20 sites throughout the Entiat and Mad rivers during the winter sampling period (Table 2). Species composition included 420 wild spring Chinook salmon (13.72%), 2,602 wild steelhead (85.10%), and 17 bull trout (0.55%). Of the salmonids caught, a total of 2,733 (89.28%) were implanted with PIT tags. Mean fork length (SD) of juvenile spring Chinook salmon and steelhead was 88.34 (±11.87) mm and 107.82 (±36.77) mm, respectively (Table 3). During the 2015 winter sample period, capture related mortality was attributed to a total of two spring Chinook salmon and one wild steelhead.

Table 2. Number of fish captured, PIT tagged, and associated mortality from the winter fish capture period, 2015.

Species	Total Number of Fish Captured	Total PIT Tagged	Mortality
Spring Chinook salmon	420	379	2
Steelhead	2,602	2,332	1
Bull trout	17	17	0

Table 3. Mean fork-length (mm), weight (g), and body condition factor (K) for spring Chinook salmon and steelhead captured in the winter fish capture period, 2015.

	Spring Chinook			Steelhead		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**
Fork-length	88.34	11.87	420	107.82	36.77	2,602
Weight	7.38	2.94	418	16.42	17.53	2,594
K	1.01	0.09	418	0.97	0.11	2,594

Site level point estimates

Point estimates of abundance and 95% confidence intervals were generated for spring Chinook salmon and steelhead at each of the sample sites where mark-recapture sampling was performed during the winter period (Table 4). Winter mark-recapture sampling produced a total of 3 valid point estimates for spring Chinook salmon and 6 for steelhead of the 8 possible for each species.

Table 4. Point estimates of abundance and 95% confidence intervals for juvenile spring Chinook salmon and steelhead at mark-recapture sites sampled during the winter period, 2015. Estimates were considered invalid (INV) if failing validity testing. Estimates were considered not applicable (N/A) if no captures of that species occurred within the site.

Site	Sample Type	Species	Est. Pop. Size (N)	Lower 95% C.I.	Upper 95% C.I.
1BC11	M-R	Spring Chinook	N/A	-	-
		Steelhead	478	426	530
1E3	M-R	Spring Chinook	INV	-	-
		Steelhead	652	582	721
1F13	M-R	Spring Chinook	INV	-	-
		Steelhead	915	774	1,055
2C4	M-R	Spring Chinook	179	107	251
		Steelhead	INV	-	-
3A3	M-R	Spring Chinook	399	115	682
		Steelhead	INV	-	-
3F2	M-R	Spring Chinook	13	13	13
		Steelhead	25	25	25
M14	M-R	Spring Chinook	N/A	-	-
		Steelhead	175	153	197
M23	M-R	Spring Chinook	N/A	-	-
		Steelhead	220	150	290

Growth per day estimates

A total of 139 recaptures were used to generate SGR estimates for the period of August, 2014 to March, 2015 (winter) and March, 2015 to September, 2015 (summer). These recaptures consisted of 20 Chinook salmon (14.38%) and 119 steelhead (85.61%). Estimates of SGR for steelhead varied between growth period with the summer period exhibiting greater SGR for both Entiat and Mad rivers during 2015. Steelhead from the Mad River exhibited lower growth rates than fish from the Entiat River (Table 5). A comparison of SGR estimates between Entiat and Mad rivers for Chinook salmon was not possible in 2015 due to the lack of recaptures within the Mad River. Estimates SGR for the period of 2011- 2015 are presented as Appendix Table 1.

Table 5. Estimated specific growth rates (mm/day) and SD for juvenile Chinook salmon and steelhead captured during mark-recapture sampling per residence river and growth period, 2015.

				Total Growth (mm)		**Days to Recapture**		**Specific Growth Rate (mm/day)**	
River	**Species**	**Growth Period**	**n**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Entiat	Steelhead	Winter	52	15.02	11.23	200.75	5.56	0.07	0.05
Mad	Steelhead	Winter	27	10.03	11.68	190.3	8.85	0.05	0.06
Entiat	Chinook	Winter	20	20.15	6.40	204	3.44	0.10	0.31
Entiat	Steelhead	Summer	29	57.24	11.28	171.79	6.78	0.33	0.06
Mad	Steelhead	Summer	11	47.36	13.14	182.36	1.03	0.25	0.07
Entiat	Steelhead	Annual	35	69.38	19.66	354.61	3.81	0.19	0.05
Mad	Steelhead	Annual	23	47.14	11.14	354.17	4.71	0.13	0.03

Seasonal estimates of apparent survival

Candidate models for juvenile steelhead performed well at each scale attempted (Sub basin, watershed, and valley segment). Models for spring Chinook salmon, however, failed to estimate apparent survival for the summer period at each scale. All data fit to the various scales indicated a slight level of over-dispersion with estimates of $\hat{c}$ ranging between 1.13 and 1.71. Specific model results for each scale are presented as Appendix Tables 2 through 5.

For the period of 2010 through 2015, juvenile spring Chinook winter period apparent survival averaged 0.21 at the sub basin scale (Figure 3). During the same time interval, VS1 averaged 0.12, 0.17 for VS2, 0.31 for VS3 and 0.35 for the Mad River (Figure 4). Juvenile steelhead averaged 0.57 for the winter and 0.56 for the summer periods at the sub basin scale (Figure 5). Watershed scale averages of apparent survival for juvenile steelhead were 0.53 and 0.73 for winter and 0.63 and 0.59 for the summer periods in the Entiat and Mad rivers (Figure 6). Winter period apparent survival for juvenile steelhead at the valley segment scale was 0.45, 0.66, 0.72 and 0.73 for VS1, VS2, VS3 and the Mad River, respectively (Figure 7). Valley segment scale estimates averaged 0.72, 0.56, 0.50 and 0.47 for VS1, VS2, VS3 and the Mad River during the summer periods (Figure 8).

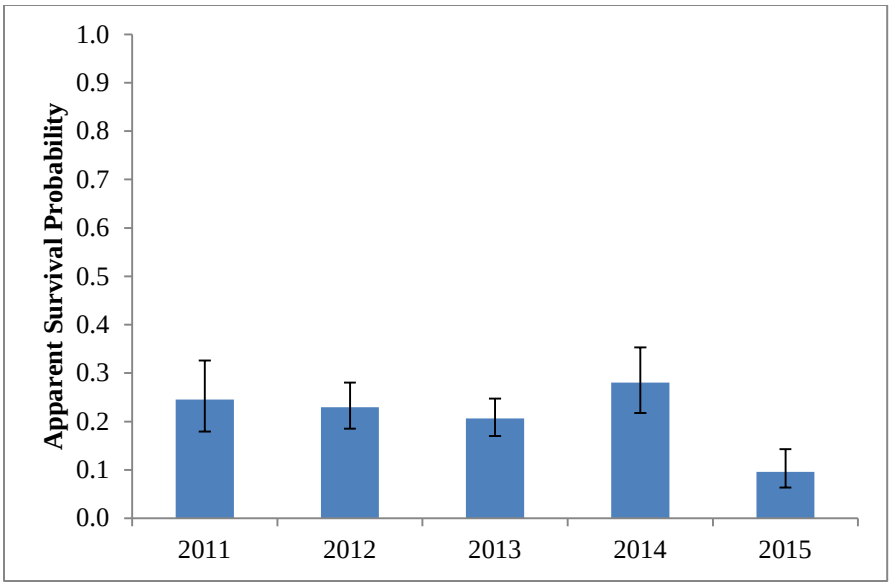

Figure 3. Sub basin scale apparent over winter survival and 95% confidence intervals for juvenile spring Chinook salmon within the Entiat sub basin, 2010-2015.

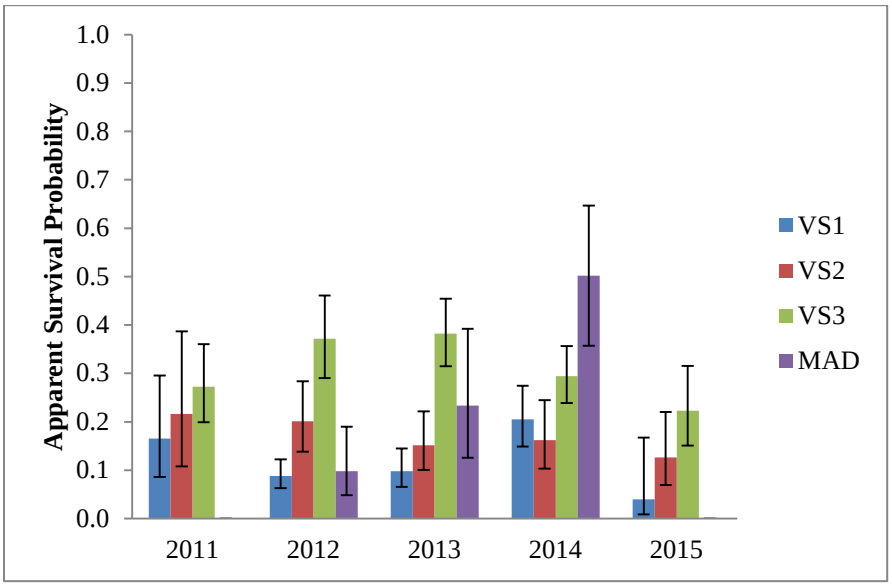

Figure 4. Valley segment scale apparent over winter survival and 95% confidence intervals for juvenile spring Chinook salmon within the Entiat sub basin, 2010-2015. MAD not estimable in 2011 and 2015 due to low sample size.

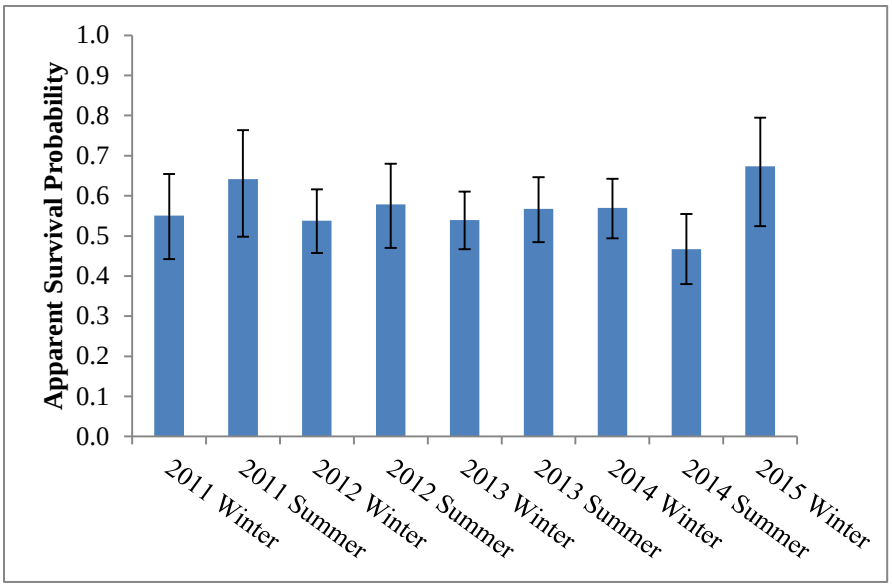

Figure 5. Sub basin scale apparent over winter and over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015.

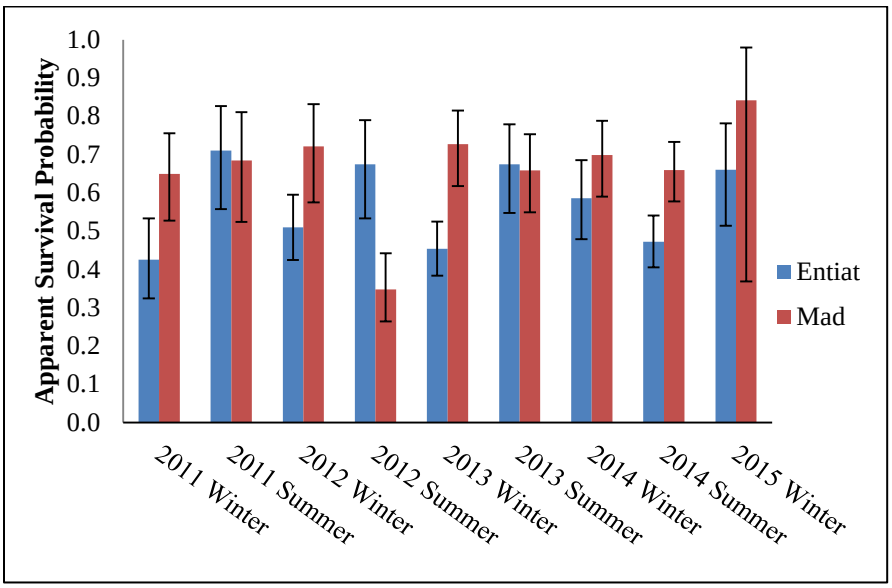

Figure 6. Watershed scale apparent over winter and over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015.

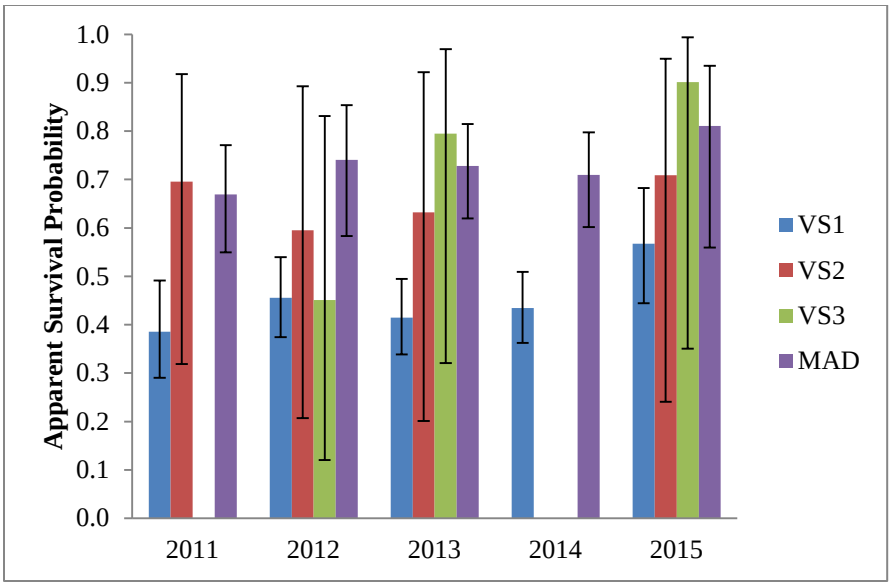

Figure 7. Valley segment scale apparent over winter survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. VS2 not estimable in 2014 and VS3 not estimable in 2011 and 2014 due to low sample size.

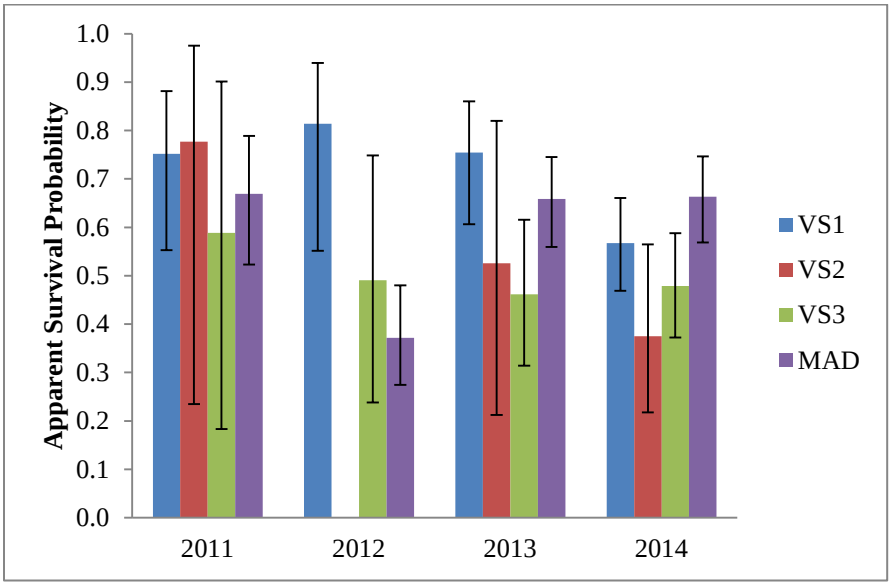

Figure 8. Valley segment scale apparent over summer survival and 95% confidence intervals for juvenile steelhead within the Entiat sub basin, 2010-2015. VS2 not estimable in 2012 due to low sample size.

Data dissemination

Data obtained during the winter sampling period was entered into the P3 program from PTAGIS. Once data quality checks were complete, this data was then uploaded to PTAGIS and the MCRFRO database. Data was also transferred to the Upper Columbia ISEMP coordinator on December 30, 2015.

Discussion

Fish sampling

Untypically high river flow was observed during winter period sampling of 2015. Sampling was delayed until flows fell to a level consistent with established protocols. Fish capture activities were performed as planned with exception to the recapture event at site 3F2 when rising flows prevented the completion the recapture sampling event.

Few spring Chinook were observed during the winter fish capture period relative to past years sampling efforts and fish were most notably absent from valley segment 1. Rotary-screw trap captures of spring Chinook out-migrants during 2015 confirmed that fewer fish were present within the Entiat sub basin than in previous years.

Site level point estimates

Estimates of site level abundance were calculated for all sample sites using the Chapman modification of the Petersen estimate where mark-recapture methods were used. Several assumptions were made concerning the validity of these estimates: 1) the sample population remained closed to immigration and emigration during the study or rates were negligible; 2) marked and unmarked fish had the same mortality rates; 3) marked and unmarked fish were equally available for capture; 4) all marks were retained during the sample period and all marks on recaptured fish were recognized; 5) marked fish randomly mixed with the unmarked population following release. We are confident that our current study design accounts for these assumptions with exception to ensuring a closed sample population.

Due to the high discharge and width of the Entiat and Mad rivers, block netting is not feasible. By leaving the sample populations physically open to immigration and emigration during the study period, we were not able to meet the assumption of a closed population. The MCRFRO tested the assumption of population closure at a subset of mark-recapture sites using portable antennas. Analyses of these data show a violation of population closure and indicate that current estimates of abundance likely overestimate the actual populations. Furthermore, evaluations of movements of PIT tagged juveniles within the Entiat sub basin following marking events indicate that newly tagged fish are highly mobile, especially following marking events. Further investigation will be required to determine if these movements are ‘natural’ and expected of these populations or if they are the result of capture and tagging activities.

Theoretical bias within the Petersen estimator of population abundance has been well documented (Baily, 1951; Chapman, 1948). According to Robson and Regier (1964), bias in abundance estimates produced by the Chapman modification of the Petersen estimate are negligible (less than 2%) when the product of marked fish (M) and the total number of fish examined for marks (C) exceeds the population size (N) by a factor of 4 ($M \times C > N \times 4$). Of the 14 abundance estimates generated, all but 4 were determined to be valid estimates. The bias within these estimates is most likely attributed to low fish densities leading to insufficient numbers of marked fish available for recapture.

Growth per day estimates

A comparison of specific growth rates between Entiat and the Mad River steelhead was possible in 2015 and a higher growth rate within the Entiat River was observed. This trend is consistent with previous years as shown in Appendix Table 1. This difference may be attributed to a number of factors such as temperature and habitat functions (Brett et al. 1969; Nielsen 1992). In order to adequately address this difference, future analysis incorporating these variables is needed. Steelhead growth varied between periods with the summer period exhibiting greater SGR for both Entiat and Mad rivers. Observed differences in seasonal growth rates have been wildely published, many focusing on the winter period, were growth has been shown to be slower (Campbell and MacCrimmon 1970; Pitcher and Macdonald 1973). Increased water temperatures as well as an increase in potential forage are among the drivers that promote increased growth during the summer months (Quinn and Peterson 1996).

Seasonal estimates of apparent survival

Model selection criteria was adequate and in most cases the model selected to represent estimates of apparent survival had a $wAIC_c$ comparison of greater than 10 to the next best candidate model. Comparison of the top and second best candidate models for juvenile spring Chinook salmon at the sub basin scale indicated a $wAIC_c$ comparison of 5.17. Although the $wAIC_c$ indicates the second best model is a plausible alternative to the top model, the ΔAIC score for the second best model was 3.29, and although weak, this was sufficient support to accept the top model based on model selection criteria.

A similar lack of support arose with model selection for watershed scale juvenile steelhead. In this case, four models all shared similar support. The top selected model and three subsequent candidate models lacked sufficient support in both $wAIC_c$ (all comparative values less than 10) and ΔAIC (all values less than 3). A visual comparison of apparent survival estimates from each model indicated that all models produced similar estimates. Despite violating model selection criteria the top model was chosen to represent watershed estimates of apparent survival for juvenile steelhead. Additional analysis will be required to distinguish the top model in terms of support from other candidate models but due to the lengthy computation time requirements for these analyses they are not included at this time.

In some cases, estimates of apparent survival were impacted by the limited availability of fish marked within a specified spatial scale. Small sample sizes limited the ability to estimate for steelhead in some years in valley segments 2 and 3 while spring Chinook salmon were limited in the Mad River. In these cases the failure to produce estimates of apparent survival were directly related to the scarcity of fish within these areas. Estimates of summer period apparent survival for spring Chinook were limited by the species absence during this time period due to their life-history. A portion of juvenile spring Chinook marked in the summer months will over winter within the Entiat sub basin and emigrate the following spring. Since the fish encountered in the winter sampling period emigrate prior to the summer sampling period, it is not possible to estimate apparent survival during the over summer period.

Juvenile spring Chinook and steelhead survival during the winter period has recently come into question as a potential ‘bottle-neck’ in terms of limiting smolt production and subsequent adult returns from the Entiat subbasin as well as other basins within the Upper Columbia River.

Although notably low during the winter period, estimates for juvenile spring Chinook lack comparison to an alternative season to indicate if a true ‘bottle-neck’ exists. Despite this, it is apparent that habitat restoration actions targeting increases to survival during the winter period would hold the greatest benefit within valley segment 1 which currently exhibits the lowest survival for winter rearing spring Chinook.

Estimates of juvenile spring Chinook apparent survival between valley segments within the Entiat River indicate a positive relationship to upstream winter rearing location. Prior exploration has also indicated a similar positive relationship between survival and fork-length. Additionally, a substantial amount of habitat data has been collected through the Columbia Habitat Monitoring Program (CHaMP). Exploratory analysis has recently been completed for the purpose of assessing the ability to utilize Program MARK for the purpose of relating the Barker survival parameter to specific biological and habitat covariates. Given the positive outcomes of this exploration, in 2016 we will begin a formal analysis that will seek to directly identify specific relationships between juvenile spring Chinook apparent over winter survival and many of the available habitat metrics.

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Appendix

Appendix Table 1. Estimated specific growth rates (mm/day) and SD for juvenile Chinook salmon and steelhead captured during mark-recapture sampling per river and growth period, 2011-2015.

					Total Growth (mm)		Days to Recapture		Specific Growth Rate (mm/day)	
Year	**River**	**Species**	**Growth Period**	**n**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
2015	Entiat	Steelhead	Winter	52	15.02	11.23	200.75	5.56	0.07	0.05
	Entiat	Chinook	Winter	20	20.15	6.40	204	3.44	0.10	0.03
	Mad	Steelhead	Winter	27	10.03	11.68	190.3	8.85	0.05	0.06
	Entiat	Steelhead	Summer	29	57.24	11.28	171.79	6.78	0.33	0.06
	Mad	Steelhead	Summer	11	47.36	13.14	182.36	1.03	0.25	0.07
	Entiat	Steelhead	Annual	35	69.38	19.66	354.61	3.81	0.19	0.05
	Mad	Steelhead	Annual	23	47.14	11.14	354.17	4.71	0.13	0.03
2014	Entiat	Steelhead	Winter	90	17.68	9.06	207.49	4.97	0.08	0.04
	Entiat	Chinook	Winter	47	18.17	6.51	217.00	5.64	0.08	0.02
	Mad	Steelhead	Winter	62	10.00	6.01	214.77	6.61	0.04	0.02
	Entiat	Steelhead	Summer	24	67.71	15.79	160.46	7.51	0.42	0.08
	Mad	Steelhead	Summer	17	41.14	8.17	157.88	9.61	0.26	0.05
	Entiat	Steelhead	Annual	12	85.19	17.69	364.25	2.45	0.23	0.04
	Mad	Steelhead	Annual	16	43.21	19.12	365.57	10.06	0.13	0.02
2013	Entiat	Steelhead	Winter	84	15.46	10.44	200.02	5.14	0.08	0.05
	Entiat	Chinook	Winter	46	16.8	6.0	194.5	5.0	0.09	0.03
	Mad	Steelhead	Winter	70	3.81	8.04	202.19	6.49	0.02	0.04
	Mad	Chinook	Winter	2	-	-	-	-	-	-
	Entiat	Steelhead	Summer	41	60.54	11.87	156.41	5.64	0.39	0.07
	Mad	Steelhead	Summer	64	37.56	10.55	158.11	4.15	0.24	0.06
	Entiat	Steelhead	Annual	30	74.53	13.45	359.57	4.88	0.21	0.04
	Mad	Steelhead	Annual	30	48.57	10.89	361.43	2.56	0.13	0.03
2012	Entiat	Steelhead	Winter	99	13.5	8.3	192.8	7.9	0.07	0.04
	Entiat	Chinook	Winter	17	24.06	4.29	203.35	6.09	0.12	0.02
	Mad	Steelhead	Winter	68	9.9	4.6	202.0	4.9	0.05	0.02
	Mad	Chinook	Winter	4	17.5	2.5	204.8	5.2	0.08	0.01
	Entiat	Steelhead	Summer	5	57.4	5.98	160.6	0.55	0.36	0.04
	Mad	Steelhead	Summer	22	41.0	10.2	160.2	4.5	0.25	0.06
	Entiat	Steelhead	Annual	11	76.9	16.0	363.5	15.0	0.21	0.04
	Mad	Steelhead	Annual	31	49.2	11.5	366.0	3.7	0.13	0.03

Appendix Table 1. continued

Year	River	Species	Growth Period	n	Total Growth (mm)		Days to Recapture		Specific Growth Rate (mm/day)	
					Mean	SD	Mean	SD	Mean	SD
2011	Entiat	Steelhead	Winter	41	24.29	13.77	199.27	3.83	0.12	0.07
	Mad	Steelhead	Winter	27	15.81	9.42	206.81	11.68	0.07	0.05
	Entiat	Steelhead	Summer	6	69.17	12.19	175.17	1.17	0.40	0.07
	Mad	Steelhead	Summer	10	43.10	10.84	171.80	2.44	0.25	0.06
	Entiat	Steelhead	Annual	2	--	--	--	--	--	--
	Mad	Steelhead	Annual	21	55.81	14.84	381.38	7.24	0.15	0.04

Appendix Table 2. Model selection results for estimating sub basin scale juvenile spring Chinook apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.71).

Model	**Parameters**	**ΔAIC_c**	**$wAIC_c$**
S(t) p(t) r(.) R(.) R'(t) F(.) F'(.)	28	0	0.75286
S(t) p(t) r(t) R(.) R'(t) F(.) F'(.)	35	3.2867	0.14555
S(t) p(t) r(t) R(t) R'(t) F(.) F'(.	40	5.1995	0.05593
S(t) p(.) r(.) R(.) R'(t) F(.) F'(.)	23	5.9633	0.03818
S(t) p(t) r(t) R(t) R'(t) F(t) F'(.)	42	9.223	0.00748
S(t) p(t) r(t) R(t) R'(.) F(.) F'(.)	39	168.8578	0
S(t) p(t) r(t) R(t) R'(t) F(t) F'(t)	47	203.8141	0

Appendix Table 3. Model selection results for estimating sub basin scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.64).

Model	**Parameters**	**ΔAIC_c**	**$wAIC_c$**
S(t) p(t) r(.) R(t) R'(t) F(t) F'(t)	55	0	0.95169
S(t) p(.) r(.) R(t) R'(t) F(t) F'(t)	48	5.9612	0.04831
S(t) p(t) r(t) R(t) R'(t) F(t) F'(t)	63	52.5875	0
S(t) p(t) r(t) R(t) R'(t) F(.) F'(t)	56	52.9481	0
S(t) p(t) r(t) R(t) R'(t) F(t) F'(.)	55	80.5908	0
S(t) p(t) r(t) R(.) R'(t) F(t) F'(t)	50	137.2891	0
S(t) p(t) r(t) R(t) R'(.) F(t) F'(t)	54	16..2143	0

Appendix Table 4. Model selection results for estimating watershed scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.35).

Model	**Parameters**	**ΔAIC_c**	**$wAIC_c$**
S(g*t) p(g+t) r(.) R(g*t) R'(t) F(g*t) F'(t)	87	0	0.38468
S(g*t) p(g*t) r(.) R(g*t) R'(t) F(g*t) F'(t)	95	0.4789	0.30276
S(g*t) p(g*t) r(g) R(g*t) R'(t) F(g*t) F'(t)	96	1.6236	0.17082
S(g*t) p(g) r(.) R(g*t) R'(t) F(g*t) F'(t)	79	1.9987	0.14161
S(g*t) p(t) r(.) R(g*t) R'(t) F(g*t) F'(t)	86	16.0094	0.00013
S(g*t) p(.) r(.) R(g*t) R'(t) F(g*t) F'(t)	78	22.4472	0.00001
S(g*t) p(g*t) r(g*t) R(g*t) R'(t) F(g*t) F'(t)	114	38.0875	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g+t) F(g*t) F'(t)	115	38.7258	0
S(g*t) p(g*t) r(g*t) R(g+t) R'(t) F(g*t) F'(t)	105	42.7112	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(t)	123	50.7605	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g+t)	124	52.6285	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g+t)	124	52.6596	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(.)	117	57.6085	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g+t) F'(t)	116	58.9986	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g) F(g*t) F'(t)	106	73.051	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g) F'(t)	108	85.8299	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g*t)	132	86.2295	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(.) F'(t)	107	108.7585	0
S(g*t) p(g*t) r(t) R(g*t) R'(t) F(g*t) F'(t)	104	113.9702	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g)	118	117.2484	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(t) F'(t)	115	173.677	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(.) F(g*t) F'(t)	105	232.6705	0
S(g*t) p(g*t) r(g*t) R(g) R'(t) F(g*t) F'(t)	96	263.5821	0
S(g*t) p(g*t) r(g*t) R(t) R'(t) F(g*t) F'(t)	104	282.345	0
S(g*t) p(g*t) r(g*t) R(.) R'(t) F(g*t) F'(t)	95	287.85	0

Appendix Table 5. Model selection results for estimating valley segment scale juvenile spring Chinook apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.13).

Model	**Parameters**	**ΔAIC_c**	**$wAIC_c$**
S(g*t) p(g+t) r(g) R(g+t) R'(g+t) F(.) F'(.)	84	0	0.9989
S(g*t) p(g) r(g) R(g+t) R'(g+t) F(.) F'(.)	76	14.3256	0.00077
S(g*t) p(.) r(g) R(g+t) R'(g+t) F(.) F'(.)	73	17.2994	0.00017
S(g*t) p(t) r(g) R(g+t) R'(g+t) F(.) F'(.)	81	17.6197	0.00015
S(g*t) p(g*t) r(g) R(g+t) R'(g+t) F(.) F'(.)	108	44.9406	0
S(g*t) p(g*t) r(.) R(g+t) R'(g+t) F(.) F'(.)	105	64.0038	0
S(g*t) p(g*t) r(t) R(g+t) R'(g+t) F(.) F'(.)	114	64.4216	0
S(g*t) p(g*t) r(g+t) R(g+t) R'(g+t) F(.) F'(.)	117	68.8534	0
S(g*t) p(g*t) r(g*t) R(g+t) R'(g+t) F(.) F'(.)	144	75.0215	0
S(g*t) p(g*t) r(g*t) R(t) R'(g+t) F(.) F'(.)	141	102.2408	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g+t) F(.) F'(.)	171	104.0223	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(t) F(.) F'(.)	168	106.7414	0
S(g*t) p(g*t) r(g*t) R(g) R'(g+t) F(.) F'(.)	135	119.8482	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g) F(.) F'(.)	162	121.0615	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(.) F(.) F'(.)	159	133.3475	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(.) F'(.)	198	141.921	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(t) F'(.)	206	158.145	0
S(g*t) p(g*t) r(g*t) R(.) R'(g+t) F(.) F'(.)	132	169.7254	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g) F'(.)	201	189.7263	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(.)	233	213.9629	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g)	236	220.179	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(t)	240	228.4716	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g+t)	243	235.1943	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g*t)	264	278.3332	0

Appendix Table 6. Model selection results for estimating valley segment scale juvenile steelhead apparent survival in the Entiat River sub basin, 2010-2015 ($\hat{c}$ = 1.29).

Model	**Parameters**	**ΔAIC_c**	**$wAIC_c$**
S(g*t) p(g*t) r(.) R(g*t) R'(t) F(g*t) F'(.)	164	0	0.95538
S(g*t) p(g*t) r(g) R(g*t) R'(t) F(g*t) F'(.)	167	6.1304	0.04456
S(g*t) p(g*t) r(t) R(g*t) R'(t) F(g*t) F'(.)	173	19.5936	0.00005
S(g*t) p(t) r(.) R(g*t) R'(t) F(g*t) F'(.)	137	31.9016	0
S(g*t) p(g) r(.) R(g*t) R'(t) F(g*t) F'(.)	132	35.6865	0
S(g*t) p(.) r(.) R(g*t) R'(t) F(g*t) F'(.)	129	50.0588	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(t) F(g*t) F'(.)	203	79.8887	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g+t) F'(.)	209	88.6594	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g+t) F(g*t) F'(.)	206	100.4058	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(t) F'(.)	206	122.2019	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(.)	233	123.9911	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(.) F(g*t) F'(.)	194	126.9386	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g)	236	137.7181	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g) F'(.)	178	178.1626	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(g*t)	264	181.0324	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g) F(g*t) F'(.)	197	194.0431	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(.) F'(.)	198	200.5045	0
S(g*t) p(g*t) r(g*t) R(t) R'(t) F(g*t) F'(.)	173	219.3696	0
S(g*t) p(g*t) r(g*t) R(g*t) R'(g*t) F(g*t) F'(t)	240	227.3411	0
S(g*t) p(g*t) r(g*t) R(g) R'(t) F(g*t) F'(.)	167	346.8646	0
S(g*t) p(g*t) r(g*t) R(.) R'(t) F(g*t) F'(.)	164	397.4675	0