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Operation and Maintenance of PIT Tag Interrogation Sites within the Entiat River Basin, 2015

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On the cover*: The lower Entiat River PIT tag interrogation site (PTAGIS site code ENL).*

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OPERATION AND MAINTENANCE OF PIT TAG INTERROGATION SITES WITHIN THE ENTIAT RIVER BASIN, 2015.

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Abstract— During 2015, Mid-Columbia Fishery Resource Office operation and maintenance of PIT tag interrogation sites within the Entiat and Mad rivers resulted in a maximum of only 26 monitoring days lost of the 365 day monitoring period (7%). A combined total of 2,223 unique PIT tag detections were recorded between all sites, of which juvenile fish accounted for 82.7% and adult fish 16.8% of those detections. Juvenile detections were predominantly Entiat River sub basin natural origin (99.5%). Hatchery origin fish were primarily composed of Entiat National Fish Hatchery produced summer Chinook salmon juveniles and returning adults. Detections of returning adults straying into the Entiat sub basin were documented and primarily composed of 12 hatchery origin spring Chinook salmon and 13 hatchery origin summer steelhead.

Detection efficiencies were calculated for each antenna site over the course of the monitoring period for both juvenile and adult salmonids. Juvenile detection efficiency averaged 76.7% (range 59.3-97.1%) for all Entiat and Mad river locations while adult efficiency averaged 97.5% (range 91.8-100%).

Movement patterns derived from antenna detections of juvenile Chinook salmon and steelhead produced similar life-history trajectories when compared to the temporal distribution of out-migrant abundance estimated from the operation of a rotary-screw trap in the lower Entiat River. Juvenile natural origin Chinook and steelhead exhibited a bimodal distribution in movements with peaks in the spring and fall, while hatchery origin Chinook quickly out-migrate from the Entiat River shortly after release from the Entiat National Fish Hatchery. Adult spawning migration into the Entiat and Mad rivers began in the late spring and early summer for Chinook and in the spring for steelhead.

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Introduction

The use of Passive Integrated Transponder (PIT) tags have become a staple for monitoring salmonid populations within the Columbia River Basin. Prior to the widespread use of PIT tags, fisheries researchers relied upon capture-mark-recapture (CMR) methodologies to estimate population level movement, survival, and abundance. The use of PIT tag technology is particularly well suited for assessing movement since a large number of fish may be individually marked and subsequent detections may be passive and require substantially less effort than traditional recapture methods. Furthermore, the ability to directly estimate movement has lessened the confounding effects of emigration when estimating survival in CMR studies (Barker et al. 2004).

Early use of stationary PIT tag antenna systems to passively decode migrating salmonids within the Columbia River basin primarily served to estimate survival through hydroelectric facilities (Achord et al. 1996; Slakski et al. 1998; Muir et al. 2001; Zabel and Achord 2004). As PIT tag technology advanced, stationary antennas were deployed in small stream systems to assess tributary level movements (Zydlewski et al. 2006) and in more recent years this application has expanded to include larger river systems. Currently, there are over 300 stationary PIT tag antenna systems identified within the Pacific Northwest, most of which are concentrated within the Columbia and Snake River basins (PTAGIS, http://www.ptagis.org).

Although intended to provide consistent, passive monitoring, in-stream PIT tag Interrogation Sites (PTIS) are imperfect. PTIS's utilize Radio Frequency Identification (RFID) technology to detect and decode PIT tags passing through the antenna field and are subject to external radio frequency (RF) signals ("noise"), which diminish PIT tag detection efficiency by interfering with the ability of the system to detect and decode a PIT tag (Zydlewski et al. 2006; Horton et al. 2007). Other factors impacting PTIS detection efficiency may include the presence of multiple tags in the detection field at the same time (Greenberg and Giller 2000), changes to stream flow conditions (velocity and depth), water temperature, conductivity, and air temperature (Connolly et al. 2008). Given the dynamic conditions PTIS's are exposed to it can be expected that detection efficiency may fluctuate seasonally or even at more discrete time intervals (Horton et al. 2007) and calculating detection efficiencies may be required to fully assess system performance.

This report provides the results for the eighth year of operation and maintenance of PTIS's as performed by the Mid-Columbia River Fishery Resource Office (MCRFRO) in the Entiat River subbasin in central Washington. The goal of PTIS monitoring is to increase the amount of quantifiable data on PIT tagged adult and juvenile fish species within the Entiat River sub basin. This is facilitated through remote detections, or resightings of PIT tagged fish at seven independent locations. PTIS monitoring addresses many of the study objectives outlined within the Entiat River Intensively Monitored Watershed (IMW) study but also compliments a multitude of other projects occurring within the Upper Columbia basin as resighting data generated from the Entiat River sub basin are made available to resource managers and researcher through a regional database. PTIS data collected within the Entiat River sub basin directly bolster estimates of juvenile apparent survival, adult escapement, within basin movements, and serves to document a multitude of life-history strategies for multiple aquatic species.

Study Area

The Entiat River watershed originates from 11 glaciers and snowfields in the Cascade Mountains and flows southeast approximately 69 kilometers (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).

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,).

PTIS locations

MCRFRO operated seven PIT tag interrogation sites within the Entiat subbasin 2015, five in the Entiat River and two in tributaries to the Entiat River (Figure 1). The lower Entiat River site (ENL) has been operational since 2007 and is located downstream of the rotary-screw trap at rkm 2. The site near the town of Ardenvoir (ENA) was installed in May of 2011 and is located at rkm 17.1. The middle Entiat River site (ENM) has been operational since 2008 and is located below the McKenzie diversion dam at rkm 26. The site near Stormy Creek (ENS) was installed in April of 2011 and is located at rkm 35.7. The Entiat River Forest Service boundary (ENF) site became operational in 2010 and is located at rkm 40.6. The Mad River (MAD) site has been operational since 2008 and is located on the Mad River at rkm 1. The Roaring Creek temporary site (RCT) was first operational in 2011 and is located on Roaring Creek at rkm 0.3.

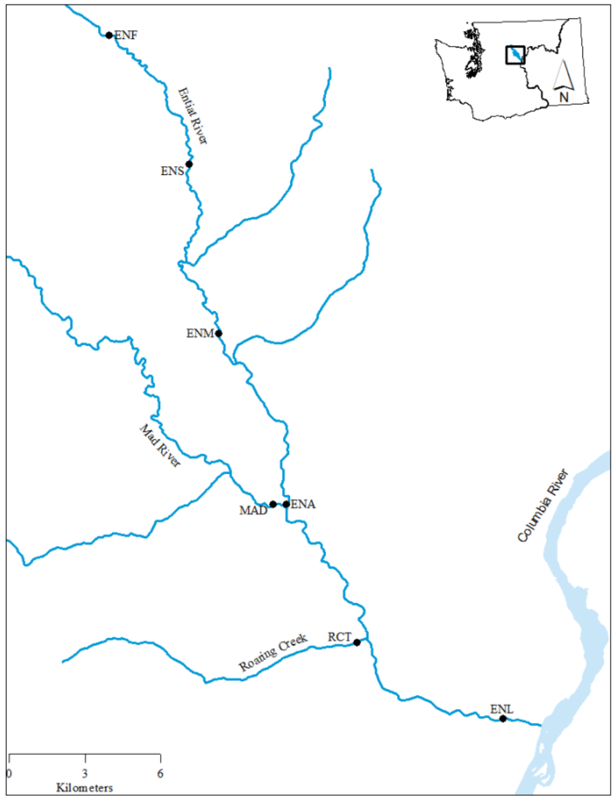

Figure 1. Map of the Entiat River basin and PIT tag interrogation site locations.

Methods

PTIS operations

All sites, excluding the Roaring Creek site (RCT), were equipped with a multiplexing transceiver (Destron-Fearing Digital Angel model # FS1001M) capable of reading full duplex PIT tags (134.2 kHz). Six antennas, each ranging from 3.0 to 6.1 m, spanned the width of the river at each site. Antenna power and communication was provided by a coax cable connected to the transceiver. External AC power was used to charge DC batteries in a weatherproof housing.

Antenna size was dependent upon the width of the river and thus varied between individual sites. Antennas were configured within the river in rows to determine the direction of fish movement and increase site efficiency through redundancy. At Entiat River PTIS locations (ENL, ENA, ENM, ENS and ENF) antennas were configured in two rows of three (2x3, Figure 2) while at the Mad River site (MAD) three rows of two antennas (3x2, Figure 3) were used. All Entiat and Mad river locations utilized a 'pass-over' configuration in which each antenna was anchored flat upon the substrate in order to better avoid entanglement with woody debris during periods of high river flow.

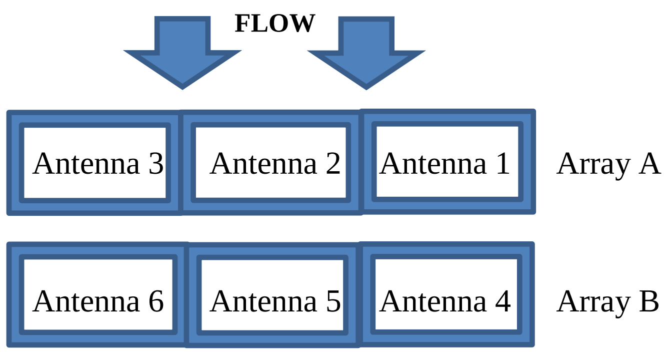

Figure 2. Depiction of an antenna system in a 2x3 configuration

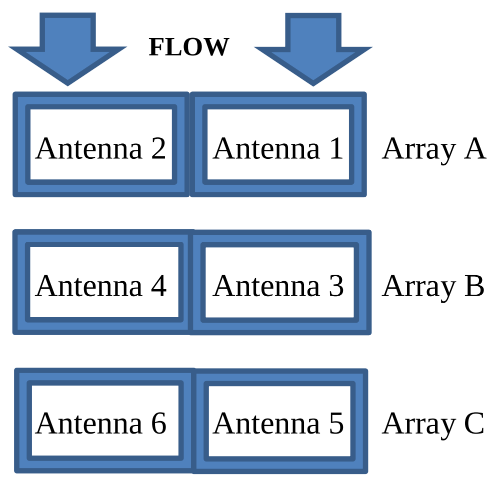

Figure 3. Depiction of an antenna system in a 3x2 configuration.

Unlike other locations, the RCT site was equipped with one 3 m channel spanning antenna installed in a ‘pass-through’ or ‘up-right’ configuration with an Allflex (Biomark model # RM310) transceiver. Data was stored on an Acumen Data Bridge serial data logger (Acumen Instruments Corporation model # SDR2-OEM-CF) with tag data stored on a removable 2 GB flash card. The site was powered by two 6 volt batteries stored in a waterproof, locking worksite storage box.

All Entiat and Mad river PTIS’s were operated continuously throughout the year with exception to brief periods of equipment failure while the operation of RCT focused on March through June. Records of operational status were taken during each site visit. Transceiver data files were either transmitted via a cellular or satellite modem located at the site or by manually downloading the file onto a laptop computer. Site operational status and data files were uploaded to the PTAGIS website on a weekly basis.

PTIS maintenance

Routine maintenance was conducted by MCRFRO and included cable reconnection, replacement of anchor straps, debris removal, antenna replacement, battery replacement, antenna tuning, updating software, responding to alarms and notifications generated from Quantitative Consultants Inc. (QCI) servers, and other troubleshooting measures. For repairs in the event of equipment failure that were beyond the contractual scope of work for MCRFRO, the Upper Columbia ISEMP coordinator was contacted to help facilitate repairs.

Detection summary

Proportions of Entiat River sub basin origin, stray, and unknown origin fish were calculated using PTAGIS based web queries of all PTIS detections. Unique detections were determined by pooling detections from all sites during the monitoring period and removing any duplicate values. Juvenile versus adult classification was based on a combination of comments made by tagging agencies at time of marking or recapture, the time period between the initial tagging date and last detection date, detection location, and direction of travel. A classification of 'orphan' was assigned to PIT tag codes that were not present in the PTAGIS database.

PTIS detection efficiency

Detection efficiencies were calculated on all interrogation sites excluding RCT, where there were not multiple antennas to determine an estimate of detection efficiency. Detection efficiencies were estimated for juvenile and adult salmonids over the course of the entire monitoring period (January 1st through December 31st, 2015) using an indirect method that accounted for both the detection efficiency of the individual arrays (row) and the entire interrogation system based on a method developed by Connolly et al. (2008). Estimates of juvenile and adult salmonid detection efficiency for the MAD PTIS were derived directly from the method outlined by Connolly et al. (2008) for detection systems consisting of three arrays (rows) of two antennas (3x2) each. While the detection efficiencies of ENL, ENA, ENM, ENS and ENF, calculations were adjusted to account for a system configuration of 2x3.

Detection efficiency for the MAD PTIS location was calculated in two parts. First, the detection efficiency of each individual array was calculated based on one of seven potential detection histories that relate the probability of detection from one array to another. Next, the individual array detection efficiencies were combined to estimate the detection efficiency of the entire system.

Individual detections were summed to one of seven detection histories:

$\sum a$ = fish detected only on array A,

$\sum ab$ = fish detected on both array A and array B but not array C,

$\sum ac$ = fish detected on both array A and array C but not array B,

$\sum abc$ = fish detected on array A, array B, and array C,

$\sum b$ = fish detected only on array B,

$\sum c$ = fish detected only on array C,

$\sum bc$ = fish detected on both array B and array C but not array A.

The resulting detection histories were then used to calculate four values necessary for determining individual array detection efficiency. For array A, these values were as follows:

NA = fish detected on array A ($\sum$a + $\sum$ab + $\sum$ac + $\sum$abc),

NABC = fish detected on array A and at least one other array ($\sum$ab + $\sum$ac + $\sum$abc),

NBC = fish detected on arrays other than array A ($\sum$b + $\sum$c + $\sum$bc),

UA = fish undetected by array A, estimated as (NA × NBC) / NABC.

The resulting four values were then used to calculate the detection efficiency of array A (*PA*) using the following equation:

$$PA = NA/(NA + UA)$$

Detection efficiencies were calculated in the same manner for arrays B and C and the detection efficiency for the entire site (*P)* was calculated as follows:

$$P = 1 – [(1\text{-}PA) \times (1 – BA) \times (1 – PC)]$$

To calculate the detection efficiencies of ENL, ENA, ENM, ENS and ENF, the detection histories and calculations were adjusted to remove Array C to account for a system configuration of 2x3. To calculate the detection efficiency, variance, and standard error, we used a likelihood model available in the Lady et al.'s (2003) USER program.

Juvenile and adult movement

Movement was derived from PTAGIS queries of detections at each PTIS. The resulting detection histories for 2015 were then reduced to include only the first occurring unique detection of a fish at each PTIS. Juvenile and adult salmonids were then differentiated from one another based on a combination of interrogation history, the time difference between mark and detection date, the location of initial marking, and comments made at the time of marking. Juvenile out-migrants receiving a PIT tag as part of the operation of a rotary-screw trap in the lower Entiat River were excluded from movement data as not to bias juvenile detections at the ENL location.

Water temperature and flow

Water temperature was logged at all PTIS locations with exception to RCT at 10 minute intervals with on-site temperature sensors. Measurements of water depth were periodically recorded using on-site pressure transducers. For RCT, hourly water temperature data was collected using HOBO U22 Water Temp Pro (version 2) data loggers (Onset Computer Corporation, Bourne, Massachusetts) and depth measurements were not taken. Flow was monitored by USGS station number 12452990, located at rkm 2.3

Results

Site operation and maintenance

Seven PTIS's were operated and maintained in 2015. PTIS's were considered fully operational if all antennas were functioning properly and the site was logging data as expected. During the 365 day monitoring period, the ENL site operated for 364 days (99%), ENA operated 365 days (100%), ENM operated for 363 days (99%), ENS operated for 339 days (93%), ENF operated for 365 days (100%), MAD operated for 362 days (99%), and RCT operated for 155 days out of the 162 days that it was installed (96%). Additional details pertaining to site activity, maintenance, and periods of inoperability are outlined in Appendices 1 through 7.

Detection summary

In 2015, a total of 2,223 unique PIT tag detections were recorded between all sites (Table 1). Juvenile fish accounted for a total of 1,839 (82.7%) of all unique detections, adult detections accounted for 373 (16.8%) and orphan tags accounted for 11 (0.5%). Of the juvenile detections, a total of 1,829 (99.5%) were determined to be of Entiat River origin and 10 (0.5%) were strays (Table 2). A total of 157 (42.1%) adults were of Entiat River origin, 47 (12.6%) were strays, and 169 (45.3%) were of unknown origin (Table 3). In general, adults of unknown origin were tagged as adults at collection facilities within the Columbia River hydro-system.

Table 1. Combined unique detections from all interrogation sites within the Entiat River sub basin, 2015. PTAGIS naming convention used to indicate species, run and rear type.

Species (indicating rear and run type)	**Juvenile**	**Adult**	**Total Detected**
Hatchery spring Chinook salmon	1	12	13
Wild spring Chinook salmon	156	29	185
Hatchery summer Chinook salmon	285	62	347
Wild summer Chinook salmon	104	3	107
Hatchery fall Chinook salmon	0	4	4
Chinook salmon (unknown run and rear type)	0	8	8
Hatchery Chinook salmon (unknown run)	0	1	1
Wild Chinook salmon (unknown run)	450	4	454
Hatchery coho salmon	2	5	7
Wild coho salmon	10	0	10
Hatchery summer steelhead	5	13	18
Summer steelhead (unknown rear type)	0	9	9
Steelhead (unknown run and rear type)	0	2	2
Wild Steelhead (unknown run)	16	0	16
Wild summer steelhead	796	186	982
Hatchery summer sockeye salmon	0	3	3
Wild sockeye salmon (unknown run)	1	0	1
Sockeye salmon (unknown run and rear type)	0	4	4
Bull trout	10	22	32
Wild resident cutthroat trout	3	6	9
Orphan	N/A	N/A	11
Grand Totals	1,839	373	2,223

Table 2. Origin of juvenile fish detected at interrogation sites within the Entiat River sub basin, 2015. PTAGIS naming convention used to indicate species, run and rear type.

Species (indicating rear and run type)	Entiat Origin	Stray	Total
Hatchery spring Chinook salmon	0	1	1
Wild spring Chinook salmon	156	0	156
Hatchery summer Chinook salmon	285	0	285
Wild summer Chinook salmon	104	0	104
Wild Chinook salmon (unknown run)	450	0	450
Hatchery coho salmon	0	2	2
Wild coho salmon	10	0	10
Hatchery summer steelhead	0	5	5
Wild summer steelhead	794	2	796
Wild steelhead (unknown run)	16	0	16
Wild sockeye salmon (unknown run)	1	0	1
Bull trout	10	0	10
Wild resident cutthroat trout	3	0	3
Grand Totals	1,829	10	1,839

Table 3. Origin of adult fish detected at interrogation sites within the Entiat River sub basin, 2015. PTAGIS naming convention used to indicate species, run and rear type.

Species (indicating rear and run type)	Entiat Origin	Stray	Unknown Origin	Total
Hatchery spring Chinook salmon	0	12	0	12
Wild spring Chinook salmon	27	1	1	29
Hatchery summer Chinook salmon	54	3	5	62
Wild summer Chinook salmon	2	0	1	3
Hatchery fall Chinook salmon	0	4	0	4
Chinook salmon (unknown run and rear type)	0	0	8	8
Hatchery Chinook Salmon (unknown run)	0	0	1	1
Wild Chinook salmon (unknown run)	4	0	0	4
Hatchery coho salmon	0	5	0	5
Hatchery summer steelhead	0	13	0	13
Summer steelhead (unknown rear type)	0	0	9	9
Steelhead (unknown run and rear type)	0	0	2	2
Wild summer steelhead	47	1	138	186
Hatchery summer sockeye salmon	0	3	0	3
Sockeye salmon (unknown run and rear type)	0	0	4	4
Bull trout	17	5	0	22
Wild resident cutthroat trout	6	0	0	6
Grand Totals	157	47	169	373

PTIS detection efficiency

Detection efficiencies were successfully calculated for each PTIS location in 2015 with exception to RCT. PTIS detection efficiencies ranged from 59.3% to 97.1% site for juvenile salmonids (Table 4) and 91.8% to 100% for adults (Table 5). Detection efficiencies for both juvenile and adult salmonids were lowest at ENF and highest at MAD. The overall detection efficiency of the entire interrogation system was greater than the efficiency of the individual arrays for juveniles and adults (Table 4 and 5). Measurements of individual array detection efficiency were lowest for the downstream array at ENF with efficiencies of 23.4% and 47.4% for juvenile and adult salmonids, respectively.

Table 4. Estimates of PTIS detection efficiency for juvenile salmonids in the Entiat River sub basin, 2015.

PTIS	**Unique Detections**	**Upstream Array**	**95% C.I. (+/-)**	**Middle Array**	**95% C.I. (+/-)**	**Downstream Array**	**95% C.I. (+/-)**	**Entire System**	**95% C.I. (+/-)**
ENL	908	0.386	0.036	-	-	0.548	0.044	0.723	0.038
ENA	251	0.542	0.082	-	-	0.414	0.071	0.732	0.070
ENM	147	0.506	0.104	-	-	0.437	0.096	0.722	0.093
ENS	257	0.479	0.066	-	-	0.734	0.072	0.862	0.047
ENF	81	0.469	0.173	-	-	0.234	0.104	0.593	0.173
MAD	368	0.620	0.050	0.676	0.049	0.765	0.045	0.971	0.009

Table 5. Estimates of PTIS detection efficiency for adult in the Entiat River sub basin, 2015.

PTIS	**Unique Detections**	**Upstream Array**	**95% C.I. (+/-)**	**Middle Array**	**95% C.I. (+/-)**	**Downstream Array**	**95% C.I. (+/-)**	**Entire System**	**95% C.I. (+/-)**
ENL	320	0.975	0.020	-	-	0.742	0.048	0.993	0.005
ENA	155	0.930	0.047	-	-	0.721	0.072	0.980	0.015
ENM	91	0.803	0.089	-	-	0.803	0.089	0.961	0.027
ENS	101	0.980	0.028	-	-	0.980	0.028	1.000	0.001
ENF	62	0.844	0.126	-	-	0.474	0.130	0.918	0.075
MAD	84	0.988	0.023	0.964	0.040	0.976	0.033	1.000	0.000

Juvenile and adult movement

Detections of juvenile Chinook salmon during the 2015 monitoring period revealed three modes of movement within the Entiat sub basin occurring primarily in March (11.5%), September (20.8%), and again in November (21.9%)(Table 6). Detections were lowest for juvenile Chinook salmon during the month of February with only 0.6% of the total unique detections occurring at all of PTIS locations. Detections of ENFH origin juvenile summer Chinook salmon were limited to ENL, and all of the first detections occurred within 10 days following their release on April 13th (Figure 4). Juvenile steelhead detections demonstrated a bimodal distribution of movement with peaks occurring in both April (14.4%) and November (14.6%), while detections were at a minimum in February with 1.6% of total unique detections recorded at each PTIS location (Table 7). The one exception to this was RCT site, which only had a one peak in April.

Adult Chinook salmon were not detected within the Entiat River until May and movement peaked in June at 36.9 % of total unique detections recorded at each PTIS location (Table 8). Adult Chinook salmon detections declined in general from the peak until no further detections were recorded in the month of December. Hatchery Chinook salmon primarily composed of hatchery summer-run Chinook based on PTAGIS naming convention were generally detected later than wild Chinook salmon which were primarily composed of spring-run Chinook salmon (Figure 5). The average first detection date for wild Chinook salmon was June 13th, while hatchery Chinook salmon was August 15th at ENL. Detections of adult steelhead within the Entiat sub basin indicate a single peak in movement occurring in March and April with 76.0% of all unique detections recorded at each PTIS location. When considering just detections at the ENL site, a bimodal distribution in movement is evident with the first peak occurring in March and April (61.3%) and the second occurring in October (11.0%; Table 9).

Bull trout detections in 2015 were sparse between January and May with only 8.9% of total unique detections recorded at each PTIS location. Detections peaked in June at 40.4% of the total detections and generally decreased until no detections were recorded during the month of December (Figure 5; Table 10).

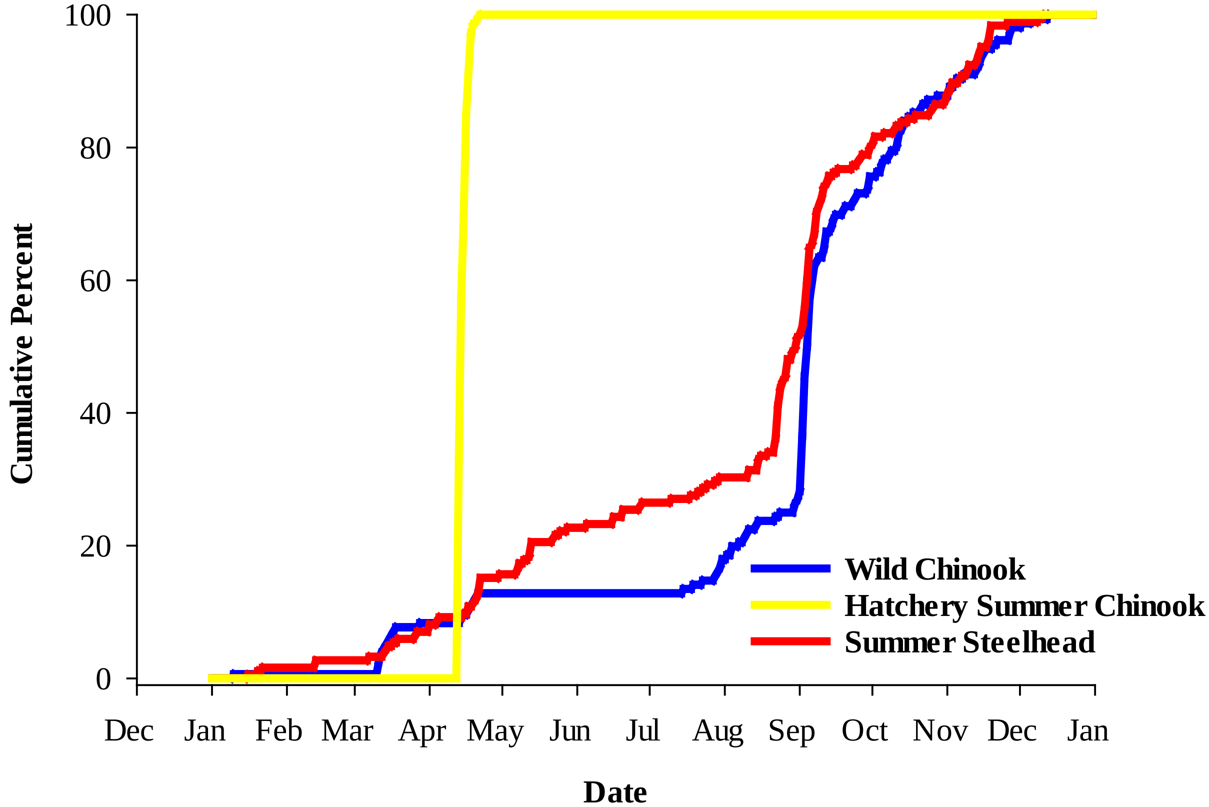

Figure 4. Cumulative percent of when the first detection of juvenile steelhead, wild Chinook salmon, and hatchery summer Chinook salmon not tagged at the rotary-screw trap occurred at the lower Entiat River interrogation site (ENL), 2015

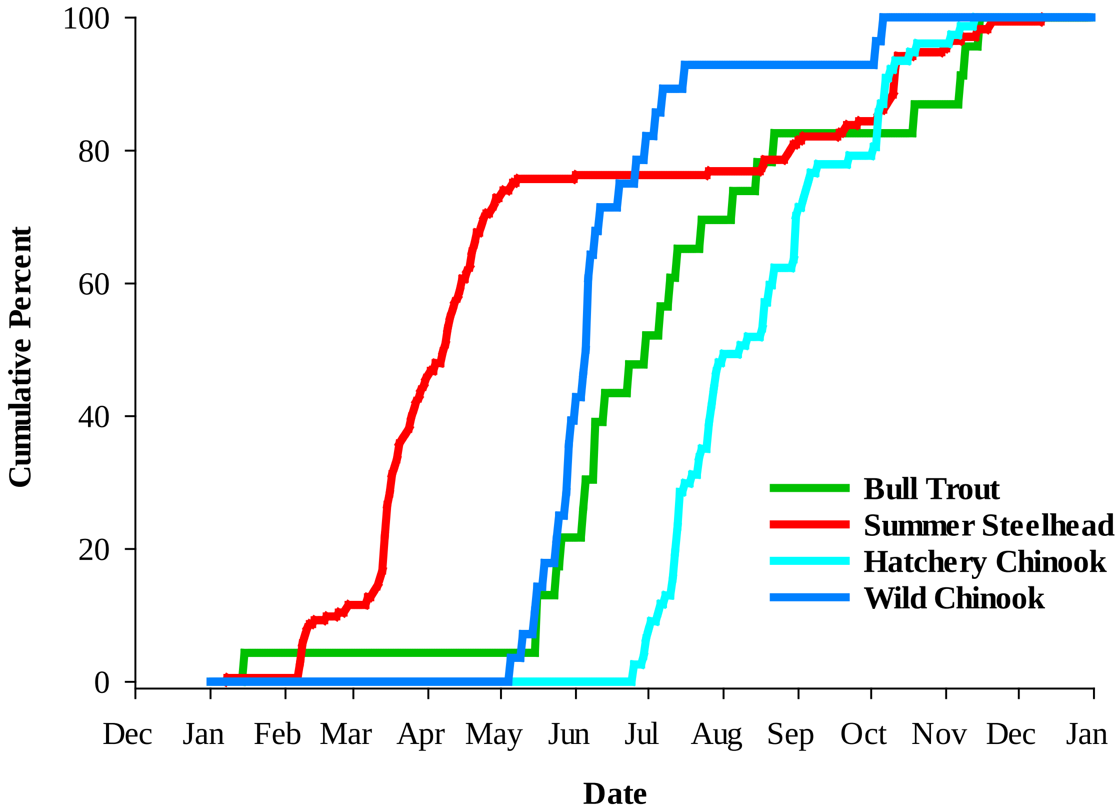

Figure 5. Cumulative percent of when the first detection of adult steelhead, adult hatchery and wild Chinook salmon, and bull trout occurred at the lower Entiat River interrogation site (ENL), 2015

Table 6. Percent of first detections that occurred at each interrogation site for juvenile Chinook in 2015 by month.

Month	**Interrogation Site**							**Weighted Average**
	ENL	**ENA**	**ENM**	**ENS**	**ENF**	**MAD**	**RCT**	
January	0.6%	1.3%	5.0%	3.1%	0.0%	5.0%	-	2.2%
February	0.0%	0.0%	0.0%	1.9%	2.5%	0.0%	-	0.6%
March	7.7%	22.2%	8.0%	10.6%	0.0%	5.0%	-	11.5%
April	4.5%	8.2%	5.0%	2.5%	2.5%	0.0%	-	4.7%
May	0.0%	0.6%	3.0%	0.0%	2.5%	0.0%	-	0.8%
June	0.0%	0.6%	0.0%	1.9%	2.5%	0.0%	-	0.8%
July	5.1%	0.6%	4.0%	8.8%	12.5%	0.0%	-	5.0%
August	9.0%	3.2%	17.0%	23.1%	52.5%	5.0%	-	15.0%
September	48.7%	15.2%	11.0%	9.4%	5.0%	20.0%	-	20.8%
October	12.2%	12.0%	11.0%	12.5%	5.0%	20.0%	-	11.8%
November	10.3%	31.6%	31.0%	20.0%	15.0%	20.0%	-	21.9%
December	1.9%	4.4%	5.0%	6.3%	0.0%	25.0%	-	4.7%
Total Detections	156	158	100	160	40	20	0	--

Table 7. Percent of first detections that occurred at each interrogation site for juvenile steelhead in 2015 by month.

Month	**Interrogation Site**							**Weighted Average**
	ENL	**ENA**	**ENM**	**ENS**	**ENF**	**MAD**	**RCT**	
January	1.6%	1.1%	2.2%	2.2%	2.6%	4.0%	0.0%	2.7%
February	1.1%	1.1%	0.0%	3.3%	0.0%	1.7%	5.0%	1.6%
March	4.3%	2.2%	2.2%	8.8%	5.3%	17.9%	30.0%	10.9%
April	8.6%	17.8%	6.7%	8.8%	13.2%	17.1%	50.0%	14.4%
May	7.0%	11.1%	2.2%	9.9%	13.2%	13.0%	15.0%	10.6%
June	3.8%	13.3%	4.4%	7.7%	0.0%	2.3%	0.0%	4.4%
July	3.8%	8.9%	13.3%	6.6%	10.5%	2.3%	0.0%	4.7%
August	21.1%	8.9%	22.2%	9.9%	18.4%	0.9%	0.0%	9.3%
September	28.6%	8.9%	4.4%	1.1%	7.9%	11.8%	0.0%	13.3%
October	7.0%	1.1%	15.6%	11.0%	0.0%	12.7%	0.0%	9.2%
November	11.9%	20.0%	24.4%	27.5%	21.1%	10.1%	0.0%	14.6%
December	1.1%	5.6%	2.2%	3.3%	7.9%	6.1%	0.0%	4.3%
Total Detections	185	90	45	91	38	346	20	--

Table 8. Percent of first detections that occurred at each interrogation site for adult Chinook in 2015 by month.

Month	**Interrogation Site**							**Weighted Average**
	ENL	**ENA**	**ENM**	**ENS**	**ENF**	**MAD**	**RCT**	
January	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
February	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
March	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
April	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
May	9.7%	20.5%	12.9%	0.0%	4.2%	0.0%	-	9.8%
June	17.7%	47.7%	48.4%	69.2%	41.7%	25.0%	-	36.9%
July	34.5%	20.5%	25.8%	17.9%	20.8%	0.0%	-	26.7%
August	15.0%	0.0%	0.0%	5.1%	16.7%	0.0%	-	9.0%
September	6.2%	6.8%	6.5%	5.1%	16.7%	50.0%	-	7.8%
October	14.2%	4.5%	6.5%	2.6%	0.0%	25.0%	-	8.6%
November	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	-	1.2%
December	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
Total Detections	113	44	31	39	24	4	0	--

Table 9. Percent of first detections that occurred at each interrogation site for adult steelhead in 2015 by month.

Month	**Interrogation Site**							**Weighted Average**
	ENL	**ENA**	**ENM**	**ENS**	**ENF**	**MAD**	**RCT**	
January	0.6%	3.3%	2.3%	0.0%	0.0%	0.0%	0.0%	1.1%
February	11.0%	5.4%	9.1%	0.0%	0.0%	1.3%	0.0%	6.3%
March	34.1%	42.4%	25.0%	34.9%	29.2%	32.0%	87.5%	35.3%
April	27.2%	38.0%	54.5%	58.1%	62.5%	53.3%	12.5%	40.7%
May	2.9%	5.4%	9.1%	7.0%	8.3%	12.0%	0.0%	6.1%
June	0.6%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
July	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
August	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
September	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%
October	11.0%	4.3%	0.0%	0.0%	0.0%	1.3%	0.0%	5.2%
November	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
December	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Total Detections	173	92	44	43	24	75	8	--

Table 10. Percent of first detections that occurred at each interrogation site for bull trout in 2015 by month.

Month	**Interrogation Site**							**Weighted Average**
	ENL	**ENA**	**ENM**	**ENS**	**ENF**	**MAD**	**RCT**	
January	4.3%	0.0%	0.0%	0.0%	0.0%	20.0%	-	2.2%
February	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
March	0.0%	0.0%	0.0%	5.3%	0.0%	0.0%	-	1.1%
April	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
May	17.4%	0.0%	0.0%	0.0%	0.0%	20.0%	-	5.6%
June	30.4%	35.7%	30.8%	47.4%	60.0%	40.0%	-	40.4%
July	17.4%	14.3%	15.4%	15.8%	6.7%	20.0%	-	14.6%
August	13.0%	7.1%	7.7%	5.3%	13.3%	0.0%	-	9.0%
September	0.0%	7.1%	23.1%	10.5%	6.7%	0.0%	-	7.9%
October	4.3%	28.6%	15.4%	15.8%	13.3%	0.0%	-	13.5%
November	13.0%	7.1%	7.7%	0.0%	0.0%	0.0%	-	5.6%
December	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%
Total Detections	23	14	13	19	15	5	0	--

Water Temperature and flow

Average peak water temperature for Entiat and Mad River PTIS locations was 22.6 ˚C during the 2015 monitoring period. The highest water temperature was recorded at ENL on July 20th at 25.1˚C. For RCT, water temperature averaged 7.9.˚C through the limited operational period (Figure 6). River flow reached its peak on May 25th at 43.3 m^3/s and quickly declined through the summer until increasing to a lesser extent in October (Figure 7).

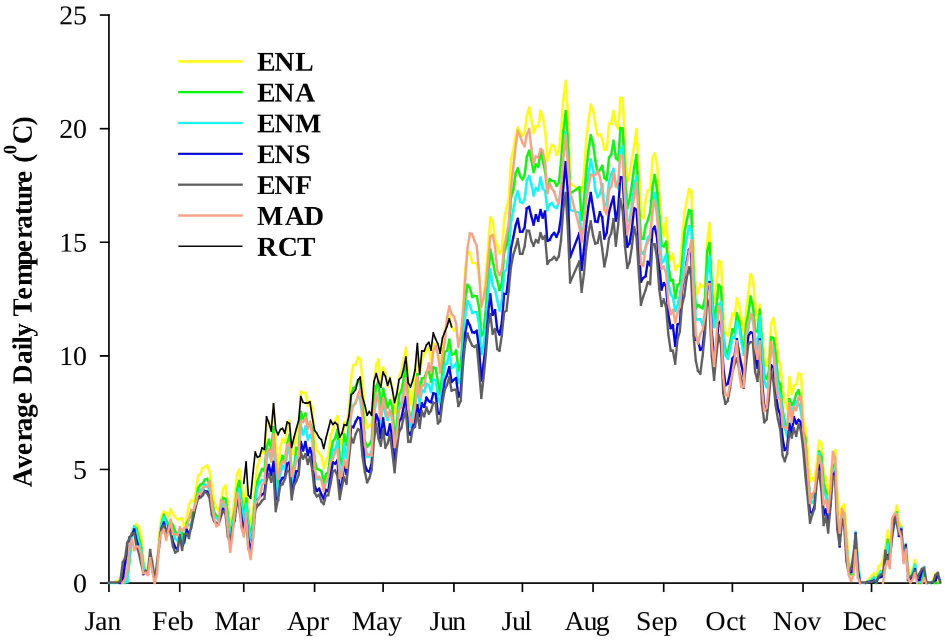

Figure 6. Average daily water temperature (^{0}C) measurements from Entiat sub basin PTIS locations, 2015

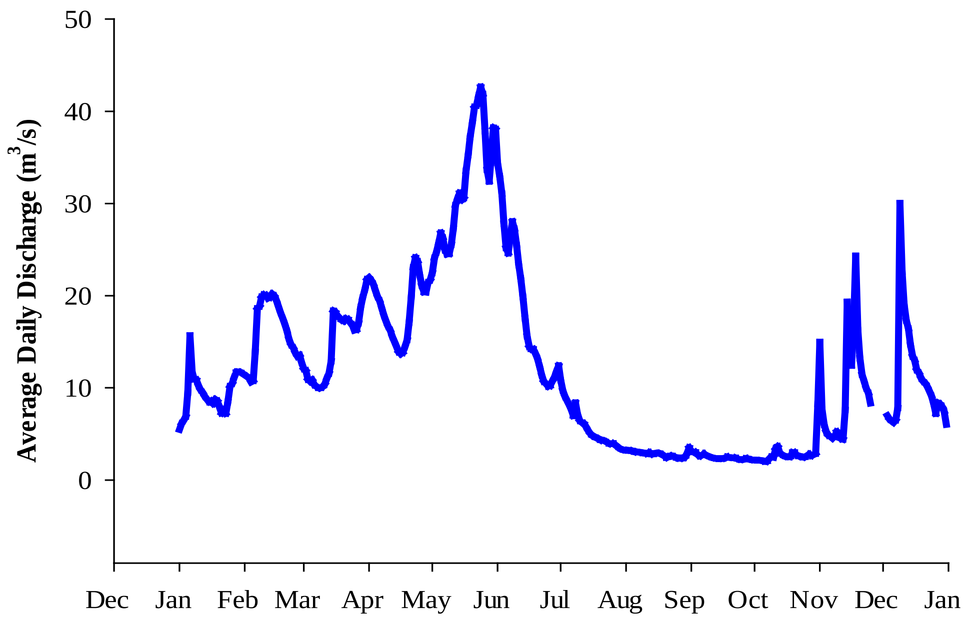

Figure 7. Average daily discharge (m3/s) of the Entiat River at the USGS station (12452990), located at rkm 2.3, 2015.

Discussion

PTIS operation and maintenance

In-stream PTIS's are often subjected to a multitude of harsh conditions that can result in equipment loss or damage. These conditions typically occur during high water events, therefore there are periods of time in which they cannot be safely accessed for repair. In 2015, only minor repairs were required following peak spring river flow and were limited to the replacement of two antennas; one due to damage and the other due to poor performance. Overall, PTIS's were functioning properly and logging data as expected for the majority of the year.

During the 2015 operational year, there were some issues that were beyond the contractual scope of work outlined for MCRFRO. At the ENF site, electronic malfunction and out-of-date software issues arose between January and March that resulted in detections of PIT tags containing a 3DD prefix not being uploaded to the QCI server and subsequently the PTAGIS database. Additionally, another out-of-date software issue resulted in data loss for PIT tags containing a newly available 3DA prefix. While this was an issue for all of the Entiat and Mad river sites, data loss was likely limited to ENL as use of PIT tags containing the 3DA prefix in the Entiat River were limited to hatchery summer Chinook released from the ENFH on April 13th.

PTIS detection efficiency

Documenting annual PTIS detection efficiencies provides a means to gauge the comparative performance of each individual monitoring location over time and aids in the determination of when and where additional efforts to increase performance are appropriate. In addition, detections efficiencies are becoming increasingly more important in regional efforts to create predictive models capable of estimating adult escapement to specific watersheds within the Upper Columbia River basin.

The overall detection efficiency of the entire interrogation site was greater than the detection efficiency of the individual arrays at each site. This was expected because the overall estimate of detection efficiency for an entire interrogation system is considerable influenced by having multiply arrays in the system which can increase the site detection efficiency through redundancy. Therefore, this is likely why the efficiency for the MAD interrogation site with three arrays was greater than the other interrogation systems with two arrays. For the two array interrogation systems, detection efficiency was the lowest at the ENF site for both juvenile and adult salmonids, which could be the result of site based factors such as depth, ambient noise, or antenna performance issues. However, assessment of the individual array efficiencies indicates that the downstream array detection efficiency is substantially lower than should be expected and increasing the performance of this array could result in an overall increase to system efficiency of 10-15%.

The ability to detect a PIT tag can be influenced by a number of factors, which can result in tag detection efficiencies likely being less than 100%. One example is that the electrical properties of the interrogation system can change with changes in environmental conditions like water level and temperature, which can compromise a system's ability and consistency to detect tags (Connolly et al. 2008). Another is that changes in stream conditions can provide passage opportunities for fish to pass interrogation sites without being detected. This can occur during times of high water where the water depth or stream width is greater than the read range or length of the antennas. We likely observed lower detection efficiencies for juvenile salmonids than adult salmonids due to juvenile salmonids generally out-migrating quickly with flows and using the entire water column, while adults tend to linger in areas for extended periods of time when migrating and often orient themselves on the bottom or at greater depths closer to where interrogation systems are located (Gerking 1958; Healey 1983; Gregory 1993; Emmett et al. 2004; Johnson et al. 2005).

Juvenile and adult movement

Defining life-stage specific movement patterns through the use of PTIS detections requires substantial effort to PIT tag enough individuals to adequately represent the population at each life-stage. For juvenile salmonids within the Entiat sub basin, this is facilitated through CMR surveys conducted as part of the Entiat River IMW study. Similarly, detections of adult salmonids predominantly rely upon the return of fish marked during CMR surveys along with those PIT tagged as out-migrants at the Entiat River rotary-screw trap. In recent years, PIT tagging of returning adult salmonid at hydroelectric facilities has increased and resulted in greater numbers of adult detections at PTIS locations.

In attributing PTIS detections of juvenile and adult salmonids to movement within the Entiat sub basin, we are making a number of assumptions concerning this data. First, we assume that unique detections represent movements of significant proportion and are not localized or limited in nature; we assume that individual detection represents a live fish and not a bare tag set adrift; finally, we assume that spatial and temporal patterns of detections adequately represent the life-history trajectories of the respective population.

Environmental conditions like flow and water temperature, along with life-history characteristics of the individual species can greatly influence the movement and migration of salmonids. Based on the 2015 PTIS detections, we observed three peaks in movement which aligned with the expected life-history characteristics of the two different run-types of juvenile Chinook salmon present within the Entiat River. We first observed one smaller peak in the spring, which coincides with age-1 spring Chinook salmon emigration from the 2013 broodyear, and two larger peaks and the majoring of our out-migration detections in the late-summer and early fall which coincide with age-0 summer and spring Chinook salmon emigration from the 2014 broodyear, respectively. Observing more unique out-migration detections in the late-summer and early fall in comparison to those in the spring was expected based on the life-history characteristics of both run-types of Chinook salmon. This is likely due to a proportion of sub-yearlings from both run-types utilizing this late-summer and early fall period for out-migration while in the spring generally only yearling spring Chinook which overwintered and survived in the Entiat River are emigrating. In addition, differences in detection efficiencies could have biased the number of unique detections towards those periods of lower flows which occur during the late-summer and fall when age-0 Chinook are emigrating. During this period of time, the read range of the PTIS's likely covers the majority of the water column opposed to the higher flow periods in the spring when the age-1 spring Chinook emigrating and the water depth is greater than the read range of the PTIS's. To examine this further, we informally tested the suitability of PTIS derived movement at ENL by comparing them to out-migrant abundance estimates generated from the operation of a rotary-screw trap at the mouth of the Entiat River. In comparing juvenile out-migrant abundance estimates to PTIS derived movement for Chinook salmon from the ENL site, we have found that they follow a similar trend, but PTIS derived movements appear to be biased low during the late-spring to early-fall period (Appendix 9). Past efforts to produce PTIS detection efficiency have shown that a negative relationship exists between detection efficiency and flow, and it is entirely likely that by not accounting for this period of diminished detection efficiency movement during the spring period has been underestimated. Furthermore, we are likely seeing PTIS derived movements biased low extend to the fall due to a lack of PIT tagged age-0 juvenile Chinook salmon from the 2014 broodyear due to tagging limitations based on size of the fish.

Similar to juvenile Chinook salmon, we observed a large proportion of juvenile steelhead being first detected in the spring and fall. In the MAD and RCT, we saw a larger proportion of juvenile steelhead being detected in the spring than other mainstem sites. For the Roaring Creek, all of the juvenile steelhead detections occurred in the spring partly due to the operation dates of the array, but also because Roaring Creek is a non-perennial creek that is dry part of the year, which prohibits emigration. In comparing our PTIS derived movement from ENL detections to our out-migrant juvenile steelhead abundance estimates from the rotary-screw trap, we observed that our juvenile steelhead detections appear to also be biased low during the spring and summer period, but less so than juvenile Chinook salmon (Appendix 9). In addition, we also observed that PTIS derived movements based on ENL detections in the fall was higher than rotary-screw trap abundance, which could be a result of trap avoidance by old age classes of juvenile steelhead seen in another study (Tattam et al. 2013).

Similar to juveniles, adult movement is greatly influenced by environmental conditions and life-history characteristics of the individual species. In general, we saw the majority of PTIS based movement of adult Chinook salmon into the Entiat River in June and July with also marginal movement in the fall at the lower PTIS's prior to peak spawning for spring and summer Chinook salmon (August/September and October, respectively; Fraser and Hamstreet 2016). After entering the Entiat River, adult Chinook salmon were detected moving upstream quickly and presumably occupying holding areas prior to spawning. For adult steelhead, the majority of the first detections at the interrogation sites occurred between March and May. Detections were the highest in March at ENL, RCT, and ENA, while detections at the upstream PTIS locations (ENM, ENS, and ENF) and the MAD location peaked in April. The majority of PTIS based movement for adult steelhead appeared to occur just prior and during periods of peak spawning (April/May; Potter et al. 2014), which suggests that the steelhead are utilizing the lower elevations of the watershed for a short period of time, prior to moving to upstream spawning locations. While the majority of adult steelhead are entering the Entiat River in the spring just prior to spawning, we also observed a second peak in immigration in the fall at the lower interrogation sites. These fish likely represent the next return year of summer steelhead and are either holding over in the lower Entiat River until the following spring, dropping back out into the Columbia River or other tributary to over-winter, or are temporarily holding in the Entiat River during the fall before continuing their migration to other tributaries in the Columbia River.

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Appendix

Appendix 1. Site operational summary for the lower Entiat River interrogation site (ENL) during the 2015 monitoring period.

Date	Operational Comments
2/26	Site visited. Site fully operational.
3/30	Low Current Alarm Antenna #1
4/20	Low Current Alarm Antenna #1
4/24	Low Current Alarm Antenna #1
4/27	Low Current Alarm Antenna #1
5/20	Low Current Alarm Antenna #1
5/20	Biomark 8.01 installed on the CR1000. Buffer was downloaded to look for tags with a 3DA prefix, but they had already been removed from the buffer.
5/21-7/22	Low Current Alarm Antenna #6. Current is below 200. Tuning was attempted, but antenna will need to be replaced when flows allow. Site is still fully operational.
6/7	Low Current Alarm Antenna #1. Current briefly dropped below 200 on all antennas. Site is still fully operational.
6/13	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/14	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/18	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/19	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/20	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/22	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
6/27	Site visited. Biomark 9.01 installed. Site is still fully operational.
7/3	Low Current Alarm Antenna #1. Current briefly dropped below 200 on all antennas. Site is still fully operational.
7/21	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
7/22	Site visited. Antenna #6 was replaced due to a reoccurring low current alarm. Antennas were also re-tuned. Site is still fully operational.
7/23	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
7/26	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
7/27	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
7/28	Tag download alert occurred as a result of the QCI servers migrating to a new network. All sites are still fully operational and no data was lost during this event.
7/28-8/3	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
8/7-8/11	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
8/11	Site visited. Debris cleaned off the antennas. Modified settings on the MUX. Changed unique mode from off to delayed. Site is still fully operational.
8/13-8/21	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
8/25	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
8/25	Site visited. Antennas restrapped. Site is fully operational.
8/26	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
8/27	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
9/25	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.

Appendix 1. continued

Date	Operational Comments
9/26	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
10/9	Low current alarm on antennas #3, 4, 5, and 6. Site still fully operational.
11/1	Noise alarm antenna #3. Noise greater than 90%. Site still fully operational.
11/10	Noise alarm antenna #2. Noise greater than 90%. Site still fully operational.
11/13	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/30	Site visited. Debris cleaned off the antennas. Site is fully operational.
12/17	Site visited. Debris cleaned off the antennas. Site is fully operational.

Appendix 2. Site operational summary for the Entiat River interrogation site at Ardenvoir (ENA) during the 2015 monitoring period.

Date	Operational Comments
2/26	Site visited. Site fully operational.
6/27	Site visited. Biomark 9.01 installed. Site is still fully operational.
8/11	Site visited. Debris cleaned off the antennas. Modified settings on the MUX. Changed the unique mode delay from 1 to 30 minutes, report delay was changed from 240 to 10, changed noise delay from 0 to 14, and changed noise alarm from 50 to 30. Site is still fully operational.
8/27	Site visited. Antennas restrapped. Site is fully operational.
9/25	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/26	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
10/17	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/13	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/30	Site visited. Debris cleaned off the antennas. Site is fully operational.

Appendix 3. Site operational summary for the middle Entiat River interrogation site (ENM) during the 2015 monitoring period.

Date	Operational Comments
5/4	Site visited. Antenna #1 was plugged back in. Site is fully operational.
5/12	Noise Alarm Antenna #5
5/15	DRS Tag download alert.
5/15	Tag download alert.
6/3	Low current alarm for antenna #1. Antenna #1 is currently unplugged and will be plugged back in when flows allow.
6/4	Low current alarm for antenna #1. Antenna #1 is currently unplugged and will be plugged back in when flows allow.
6/4	Site visited. Antenna #1 was plugged back in. Site is fully operational.
6/20	Site visited. Biomark 9.01 installed. Site is still fully operational.
6/20	Low Current Alarm Antenna #1. Current briefly dropped below 200 on all antennas. Site is still fully operational.
7/28	Tag download alert occurred as a result of the QCI servers migrating to a new network. All sites are still fully operational and no data was lost during this event.
8/10	Site visited. Settings on MUX were checked. Site is still fully operational.
8/11	Site visited. Debris cleaned off the antennas. Modified settings on the MUX. Test tag was turned on, test tag delay was changed from 180 to 60, report delay was changed from 240 to 10, and changed noise delay from 0 to 14. Site is still fully operational.
8/14	Site visited. Antennas restrapped. Site is fully operational.
8/31	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
9/1	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
9/2	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
9/3	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
9/7	DRS and Tag Download Alerts. Site still fully operational.
9/12	Low Current Alarm Antenna #1. Current briefly dropped below 200 on all antennas. Site is still fully operational.
9/25	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/26	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
10/17	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/1	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
11/2	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
11/12	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/13	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.

Appendix 3. continued

Date	Operational Comments
11/14	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
11/15	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
11/16	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
12/1	Site visited. Debris cleaned off the antennas. Site is fully operational.
12/12	DRS and Tag Data Download Alerts. Site still fully operational.
12/14	Noise alarm antenna #2. Noise greater than 90%. Site still fully operational.
12/22	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
12/23	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.
12/25	Noise alarm antenna #6. Noise greater than 90%. Site still fully operational.

Appendix 4. Site operational summary for the Entiat River interrogation site near Stormy Creek (ENS) during the 2015 monitoring period.

Date	Operational Comments
1/12	Site down. Antenna #3 has no current. Antenna is currently broken and needs to be replaced.
1/23	Site visited. Some antennas were restrapped with NRS straps.
1/27	Site up. Antenna #3 plugged back in with modified cord. Antenna used to replace the old one is 10ft instead of the 15ft antenna that was there before. Site fully operational.
2/24	Site visited. Site fully operational.
2/26	Site visited. Site fully operational.
6/27	Site visited. Biomark 9.01 installed. Antennas tuned. Site is still fully operational.
7/28	Tag download alert occurred as a result of the QCI servers migrating to a new network. All sites are still fully operational and no data was lost during this event.
8/11	Site visited. Debris cleaned off the antennas. Changed the unique delay on the MUX from 1 minute to 30 minutes. Site is still fully operational.
8/14	Site visited. Antennas restrapped. Site is fully operational.
8/28	Noise alarm antenna #1. Noise greater than 90%. Site still fully operational.
8/29	Noise alarm antenna #1. Noise greater than 90%. Site still fully operational.
9/6	Noise alarm antenna #1. Noise greater than 90%. Site still fully operational.
9/25	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/26	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
10/9	Noise alarm antenna #5. Noise greater than 90%. Site still fully operational.
10/17	Site visited. Debris cleaned off the antennas. Site is fully operational.
10/31	Low current alarm on antennas #1 and 2. Site still fully operational.
11/12	Site visited. Debris cleaned off the antennas. Site is fully operational.
12/1	Site visited. Debris cleaned off the antennas. Site is fully operational.
12/26	Noise alarm antenna #3. Noise greater than 90%. Site still fully operational.

Appendix 5. Site operational summary for the Entiat River Forest Service boundary interrogation site (ENF) during the 2015 monitoring period.

Date	Operational Comments
1/30	Site visited. Data downloaded. Shed tag appears to be on antenna #2.
2/4	Site visited. Antennas restrapped.
2/9	Data from the buffer was downloaded. Buffer was then erased.
2/11	Data from the buffer was downloaded. Buffer was then erased. Biomark 8.0 was installed on the CR1000
2/16	Tag download alert.
2/23	Site visited. MUX replaced.
2/24	Tag Download Alert
2/24	Failure processing interrogation file. File has since been submitted.
2/24	Site visited. Antenna sequence changed.
2/25	Tag Download Alert
2/25	Failure processing interrogation file ENF15065.F0A
2/26	Tag Download Alert
2/26	Site visited. Site fully operational.
2/28	Tag Download Alert
3/1	Tag Download Alert
3/2	Tag Download Alert
3/2	Site visited. Antenna sequence changed to 123456123456
3/3	Failure processing interrogation file ENF15062.F0A
3/3	Site visited. Antenna sequence changed to 123456000000 due to issues with uploading the file.
3/4	Failure processing interrogation file ENF15063.80A. File will be corrected later and uploaded.
6/20	Site visited. Biomark 9.01 installed. Site is still fully operational.
7/28	Tag download alert occurred as a result of the QCI servers migrating to a new network. All sites are still fully operational and no data was lost during this event.
8/10	Site visited. Settings on MUX were checked. Site is still fully operational.
8/11	Site visited. Debris cleaned off the antennas. Site is still fully operational.
9/25	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/26	DRS and Tag Data Download Alert.
9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
10/17	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/12	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/30	Site visited. Debris cleaned off the antennas. Site is fully operational.

Appendix 6. Site operational summary for the Mad River interrogation site during the 2015 monitoring period.

Date	Operational Comments
1/7	Site down. Antenna #1 was unplugged due to ice flow.
1/8	Site up. Antenna #1 was plugged back in. Site is fully operational.
1/17	Site down. Antenna #1 was unplugged due to ice flow.
2/13	Noise Alarm. Noise greater than 90%. Site still fully operational.
2/18	Low voltage alarm. Voltage dropped momentarily, but is quickly restored automatically. Site fully operational.
2/20	Noise Alarm. Noise greater than 90%. Site still fully operational.
2/22	Low voltage alarm. Voltage dropped momentarily, but is quickly restored automatically. Site fully operational.
2/24	Site visited.
2/26	Site visited. Site fully operational.
2/26-2/27	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/4	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/6	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/8	Low Voltage Alarm
3/8-3/13	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/10	Low Voltage Alarm
3/17	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/19	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/27	Noise Alarm. Noise greater than 90%. Site still fully operational.
3/30-4/2	Noise Alarm. Noise greater than 90%. Site still fully operational.
4/13-4/14	Noise Alarm. Noise greater than 90%. Site still fully operational.
4/28-4/29	Noise Alarm. Noise greater than 90%. Site still fully operational.
5/3-5/6	Noise Alarm. Noise greater than 90%. Site still fully operational.
5/6	Site visited. Debris removed from antennas.
5/8	Noise Alarm. Noise greater than 90%. Site still fully operational.
5/11-5/12	Noise Alarm. Noise greater than 90%. Site still fully operational.
5/15-5/17	Noise Alarm. Noise greater than 90%. Site still fully operational.
5/19	Noise Alarm. Noise greater than 90%. Site still fully operational.
6/5	Noise Alarm. Noise greater than 90%. Site still fully operational.
6/16	Noise Alarm. Noise greater than 90%. Site still fully operational.
6/18-6/19	Noise Alarm. Noise greater than 90%. Site still fully operational.
6/20	Site visited. Biomark 9.01 installed. Site is still fully operational.
6/26	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/2	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/7	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/10	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/10	Tag Download Alert
7/11	Tag Download Alert
7/11-7/14	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/16-7/19	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/23	Noise Alarm. Noise greater than 90%. Site still fully operational.
7/24	Site visited. Debris cleaned off the antennas. Site is still fully operational.

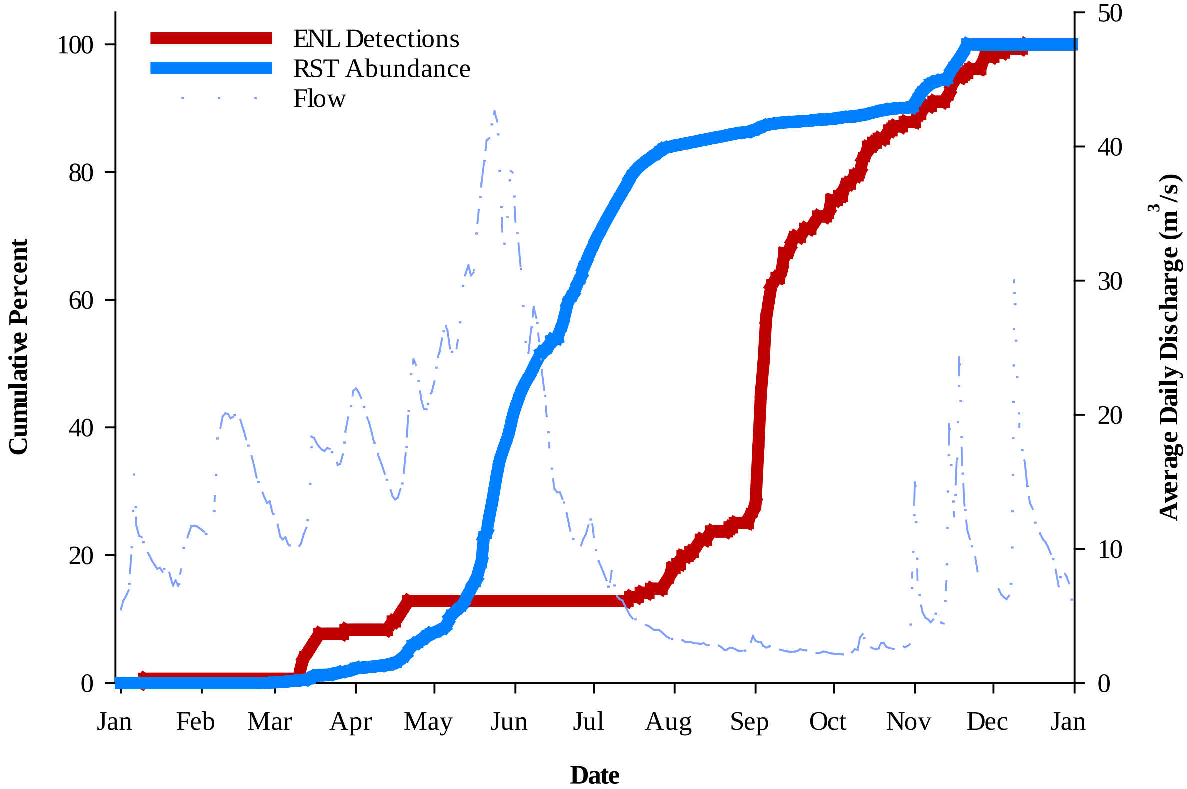
Appendix 6. continued

Date	Operational Comments
7/28	Tag download alert occurred as a result of the QCI servers migrating to a new network. All sites are still fully operational and no data was lost during this event.
7/29-7/30	Noise Alarm. Noise greater than 90%. Site still fully operational.
8/2-8/3	Noise Alarm. Noise greater than 90%. Site still fully operational.
8/5-8/26	Noise Alarm. Noise greater than 90%. Site still fully operational.
8/10	Site visited. Debris cleaned off the antennas. Also, antennas were tuned . Site is still fully operational.
8/11	Site visited. Debris cleaned off the antennas. Modified settings on the MUX. Turned test tag on, changed test tag delay from 180 to 60 minutes, report delay was changed from 14 to 10, and changed noise delay from 0 to 14. Site is still fully operational.
8/27	Site visited. Antennas restrapped. Site is fully operational.
8/28-8/30	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/1	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/4	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/11	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/13	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/15-9/19	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/21-9/24	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/24-9/27	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/28	Noise Alarm. Noise greater than 90%. Site still fully operational.
9/29	DRS and Tag Data Download Alert. Alerts occurred starting on 9/25/2015 as a result of an outage of dial-up powers lines supplying connectivity to satellite and dial-up modem based CR1000 sites. Issue was resolved on 9/29/2015. No data was lost. Site is still fully operational.
9/30-10/4	Noise Alarm. Noise greater than 90%. Site still fully operational.
10/7	Noise Alarm. Noise greater than 90%. Site still fully operational.
10/17	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/6	Noise Alarm. Noise greater than 90%. Site still fully operational.
11/13	Site visited. Debris cleaned off the antennas. Site is fully operational.
11/27-11/28	Noise Alarm. Noise greater than 90%. Site still fully operational.
11/29	Low voltage alarm. Site still fully operational.
11/30	Site visited. Stream and arrays completely iced over. Site is fully operational.
12/7	Site visited. Low voltage on antenna #1 due to a loose connection. Connection was tightened and site is fully operational again.
12/13-12/15	Noise Alarm. Noise greater than 90%. Site still fully operational.
12/18	Noise Alarm. Noise greater than 90%. Site still fully operational.

Appendix 7. Site operational summary for the Roaring Creek interrogation site (RCT) during the 2015 monitoring period.

Date	Operational Comments
2/26	Site set up near the mouth of Roaring Creek. Site is set up in the pass-through orientation with one antenna and is battery powered. Site fully operational.
3/7	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
3/19	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
4/4	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
4/26	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
5/12	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
6/2	Site down. Site went down due to a loss of power. Power was restored on 6/8.
6/8	Site up. Site visited and was down on arrival due to a loss of power. Data was downloaded, batteries swapped, and the tuning checked. Site fully operational.
6/28	Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational.
7/21	Site visited. Data downloaded and tuning checked. Stream is dry. Site fully operational.
8/6	Site down. Data downloaded and tuning checked. Equipment was removed because the stream is dry. Site will be installed again when water returns to the stream bed.

Appendix 8. Comparison of out-migrant abundance and ENL detection based movements for juvenile Chinook in the Entiat sub basin, 2015.



Appendix 9. Comparison of out-migrant abundance and ENL detection based movements for juvenile steelhead in the Entiat sub basin, 2015.