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# Operation and Maintenance of PIT Tag Interrogation Sites within the Entiat River Basin, 2017

Nicholas Albrecht and Tom Desgroseillier

U.S. Fish and Wildlife Service
Mid-Columbia Fish and Wildlife Conservation Office
Leavenworth, WA 98826

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

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*Authored by*

Nicholas C. Albrecht
Tom Desgroseillier

U.S. Fish and Wildlife Service
Mid-Columbia Fish and Wildlife Conservation Office
7501 Icicle Rd.
Leavenworth, WA 98826

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# OPERATION AND MAINTENANCE OF PIT TAG INTERROGATION SITES WITHIN THE ENTIAT RIVER BASIN, 2017

Nicholas Albrecht
Tom Desgroseillier

*U.S. Fish and Wildlife Service*
*Mid-Columbia River Fishery Resource Office*
*7501 Icicle Rd.*
*Leavenworth, WA 98826*

*Abstract*— During 365 day monitoring period in 2017, Mid-Columbia Fish and Wildlife Conservation Office staff operated and maintained 7 PIT tag interrogation sites within the Entiat and Mad rivers. A combined total of 1,819 unique PIT tag detections were recorded between all sites, of which juvenile fish accounted for 87% and adult fish 12.5% of those detections. Juvenile detections were predominantly Entiat River natural origin (99.5%). Adult detections were primarily composed of Entiat National Fish Hatchery produced summer Chinook salmon. Detections of adults straying into the Entiat sub basin were documented and primarily composed of 9 hatchery origin Chinook salmon and 15 hatchery origin summer steelhead. Juvenile detection efficiency averaged 78.8% (range 47.6-100%) for all Entiat and Mad river locations while adult efficiency averaged 94.3% (range 86.1-100%). Juvenile natural origin Chinook and steelhead exhibited a bimodal distribution in movements with peaks in the spring and fall. 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 has 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.

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 survival, adult escapement, within basin movements, and serves to document a multitude of life-history strategies for marked species. This report provides the results for the $10^{th}$ and final year of operation and maintenance of PTIS's as performed by the Mid-Columbia Fish and Wildlife Conservation Office (MCFWCO) in the Entiat River sub basin and all subsequent reporting will be provided by the Washington Department of Fish and Wildlife.

## 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*

The MCFWCO operated seven PTISs within the Entiat River sub basin in 2017: five in the Entiat River and one each in the Mad River and Roaring Creek (Figure 1). The lower Entiat River PTIS (ENL) has been operational since 2007 and is located downstream of the rotary-screw trap at rkm 2. The PTIS near the town of Ardenvoir (ENA) was installed in May of 2011 and is located at rkm 17.1. The middle Entiat River PTIS (ENM) has been operational since 2008 and is located below the McKenzie diversion dam at rkm 26. The PTIS near Stormy Creek (ENS) was installed in April of 2011 and is located at rkm 35.7. The Entiat River Forest Service boundary (ENF) PTIS became operational in 2010 and is located at rkm 40.6. The Mad River (MAD) PTIS has been operational since 2008 and is located on the Mad River at rkm 1. The Roaring Creek temporary PTIS (RCT) was first operational in 2011 and is located on Roaring Creek at rkm 0.3.

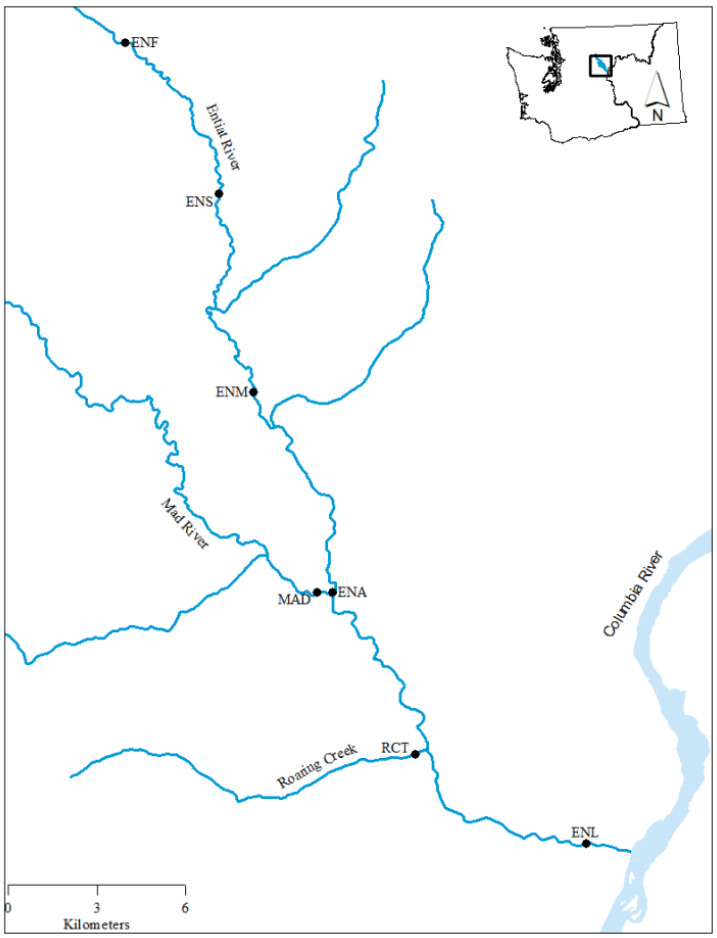


Figure 1. Map of the Entiat River basin and PIT tag interrogation site locations.

## Methods

*PTIS operations*

All sites, excluding 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 detection 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.

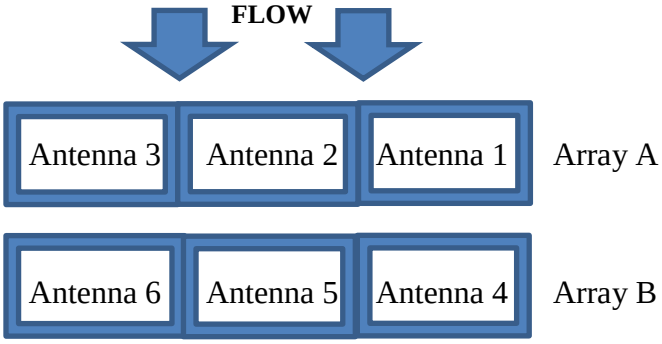


Figure 2. Depiction of an antenna system in a 2x3 configuration

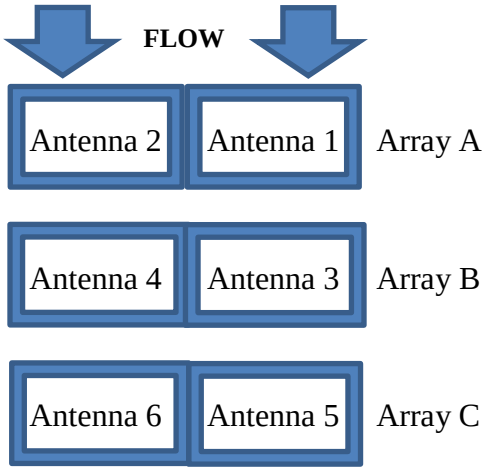


Figure 3. Depiction of an antenna system in a 3x2 configuration.

Unlike other locations, the RCT site was equipped with a single 3 m channel spanning antenna installed in a 'pass-through' or 'up-right' configuration. The site was operated with a single antenna from January 1st through April 3rd, 2017. On April 4th, an additional antenna was installed and operated for the remainder of the monitoring period. Prior to the addition of a second antenna, data was collected with an Allflex (Biomark model # RM310) transceiver and data was stored on an Acumen Data Bridge serial data logger (Acumen Instruments Corporation model # SDR2-OEM-CF). Following the installation of the second antenna, data was collected with two synchronized IS1001 transceivers and powered by two 12V batteries being charged by solar power.

All Entiat and Mad river PTIS's were operated continuously throughout the year with exception to 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 the MCFWCO and included cable reconnection, replacement of anchor straps, debris removal, antenna replacement, battery replacement, cable replacement, antenna tuning, updating software, responding to alarms and notifications generated from Quantitative Consultants Inc. (QCI)/Biomark servers, and other troubleshooting measures. For repairs in the event of equipment failure that were beyond the contractual scope of work for MCFWCO, the Upper Columbia ISEMP coordinator was contacted to help facilitate repairs.

*Detection summary*

PTAGIS based web queries for all PTIS detections were used to develop detection summaries. Detections at each PTIS location were examined using a combination of interrogation histories, time period between initial tagging date and the last detection date, detection location, direction of travel, number of detections, and time of detection to determine whether detections were from live fish or likely bare tags that resulted from mortality or shedding of the PIT tag. Unique detections were determined by pooling detections from all sites during the monitoring period and removing any duplicate values. Juvenile versus adult classification along with proportions of Entiat River sub basin origin, stray, and unknown origin fish 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, direction of travel, and interrogation histories. A classification of 'orphan' was assigned to PIT tag codes that were not present in the PTAGIS database.

*PTIS detection efficiency*

Detection efficiencies were estimated for all interrogation sites. Detection efficiencies were calculated for juvenile and adult salmonids over the course of the entire monitoring period (January 1$^{st}$ through December 31$^{st}$, 2017) 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, ENF, and RCT, 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, ENF, and RCT, 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 2017 were then reduced to the first 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*

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 257 days (70%), ENA operated 197 days (54%), ENM operated for 223 days (61%), ENS operated for 254 days (70%), ENF operated for 182 days (50%), MAD operated for 317 days (87%), and RCT operated for 365 days (100%). Additional details pertaining to site activity, maintenance, and periods of inoperability are outlined in Appendices 1 through 7.

*Detection summary*

In 2017, a total of 1,819 unique PIT tag detections were recorded between all sites (Table 1). Juvenile fish accounted for a total of 1,582 (87.0%) of all unique detections, adult detections accounted for 228 (12.5%) and orphan tags accounted for 9 (0.5%). Of the juvenile detections, a total of 1,574 (99.5%) were determined to be of Entiat River origin and 8 (0.5%) were strays (Table 2). A total of 81 (35.5%) adults were of Entiat River origin, 33 (14.5%) were strays, and 114 (50.0%) 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, 2017. 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 | 0 | 4 | 4 |
| Wild spring Chinook salmon | 367 | 8 | 375 |
| Hatchery summer Chinook salmon | 140 | 41 | 181 |
| Wild summer Chinook salmon | 59 | 9 | 68 |
| Hatchery fall Chinook salmon | 0 | 0 | 0 |
| Chinook salmon (unknown run and rear type) | 0 | 27 | 27 |
| Hatchery Chinook salmon (unknown run) | 0 | 4 | 4 |
| Wild Chinook salmon (unknown run) | 428 | 1 | 429 |
| Hatchery coho salmon | 0 | 6 | 6 |
| Wild coho salmon | 0 | 1 | 1 |
| Hatchery summer steelhead | 7 | 15 | 22 |
| Summer steelhead (unknown rear type) | 0 | 3 | 3 |
| Steelhead (unknown run and rear type) | 0 | 0 | 0 |
| Wild Steelhead (unknown run) | 0 | 0 | 0 |
| Wild summer steelhead | 578 | 75 | 653 |
| Hatchery summer sockeye salmon | 0 | 0 | 0 |
| Wild sockeye salmon (unknown run) | 0 | 0 | 0 |
| Sockeye salmon (unknown run and rear type) | 0 | 4 | 4 |
| Bull trout | 2 | 6 | 8 |
| Wild resident cutthroat trout | 1 | 3 | 4 |
| Pacific lamprey | 0 | 21 | 21 |
| Orphan | N/A | N/A | 9 |
| **Grand Totals** | 1,582 | 228 | 1,819 |

Table 2. Origin of juvenile fish detected at interrogation sites within the Entiat River sub basin, 2017. 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 | 0 | 0 |
| Wild spring Chinook salmon | 367 | 0 | 367 |
| Hatchery summer Chinook salmon | 140 | 0 | 140 |
| Wild summer Chinook salmon | 59 | 0 | 59 |
| Wild Chinook salmon (unknown run) | 428 | 0 | 428 |
| Hatchery coho salmon | 0 | 0 | 0 |
| Wild coho salmon | 0 | 0 | 0 |
| Hatchery summer steelhead | 0 | 7 | 7 |
| Wild summer steelhead | 578 | 0 | 578 |
| Wild steelhead (unknown run) | 0 | 0 | 0 |
| Wild sockeye salmon (unknown run) | 0 | 0 | 0 |
| Bull trout | 1 | 1 | 2 |
| Wild resident cutthroat trout | 1 | 0 | 1 |
| **Grand Totals** | 1,574 | 8 | 1,582 |

Table 3. Origin of adult fish detected at interrogation sites within the Entiat River sub basin, 2017. 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 | 3 | 1 | 4 |
| Wild spring Chinook salmon | 7 | 0 | 1 | 8 |
| Hatchery summer Chinook salmon | 35 | 6 | 0 | 41 |
| Wild summer Chinook salmon | 5 | 0 | 4 | 9 |
| Hatchery fall Chinook salmon | 0 | 0 | 0 | 0 |
| Chinook salmon (unknown run and rear type) | 0 | 0 | 27 | 27 |
| Hatchery Chinook Salmon (unknown run) | 0 | 0 | 4 | 4 |
| Wild Chinook salmon (unknown run) | 1 | 0 | 0 | 1 |
| Hatchery coho salmon | 0 | 6 | 0 | 6 |
| Wild coho salmon | 1 | 0 | 0 | 1 |
| Hatchery summer steelhead | 0 | 15 | 0 | 15 |
| Summer steelhead (unknown rear type) | 0 | 0 | 3 | 3 |
| Steelhead (unknown run and rear type) | 0 | 0 | 0 | 0 |
| Wild summer steelhead | 23 | 2 | 50 | 75 |
| Hatchery summer sockeye salmon | 0 | 0 | 0 | 0 |
| Sockeye salmon (unknown run and rear type) | 0 | 0 | 4 | 4 |
| Bull trout | 6 | 0 | 0 | 6 |
| Wild resident cutthroat trout | 3 | 0 | 0 | 3 |
| Pacific lamprey | 0 | 1 | 20 | 21 |
| **Grand Totals** | 81 | 33 | 114 | 228 |

*PTIS detection efficiency*

Detection efficiencies were successfully calculated for each PTIS location in 2017 including RCT after April 4th when a second antenna was added to the interrogation site. PTIS detection efficiencies ranged from 0.476 to 1.000 for juvenile salmonids (Table 4) and 0.861 to 1.000 for adults (Table 5). Detection efficiencies were the lowest at ENL for juvenile salmonids and at ENA for adult salmonids. 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 upstream array at ENL for juveniles (0.267) and the downstream array at ENF for adult salmonids (0.310).

Table 4. Estimates of PTIS detection efficiency for juvenile salmonids in the Entiat River sub basin, 2017.

| PTIS | Unique Detections | Upstream Array | 95% C.I. (+/-) | Middle Array | 95% C.I. (+/-) | Downstream Array | 95% C.I. (+/-) | Entire System | 95% C.I. (+/-) |
|---|---|---|---|---|---|---|---|---|---|
| ENL | 713 | 0.267 | 0.042 | - | - | 0.285 | 0.044 | 0.476 | 0.058 |
| ENA | 177 | 0.429 | 0.106 | - | - | 0.279 | 0.077 | 0.588 | 0.110 |
| ENM | 137 | 0.467 | 0.113 | - | - | 0.361 | 0.096 | 0.659 | 0.110 |
| ENS | 202 | 0.724 | 0.073 | - | - | 0.648 | 0.074 | 0.903 | 0.037 |
| ENF | 46 | 0.800 | 0.143 | - | - | 0.600 | 0.152 | 0.920 | 0.072 |
| MAD | 428 | 0.593 | 0.047 | 0.697 | 0.045 | 0.772 | 0.042 | 0.972 | 0.008 |
| RCT | 30 | 1.000 | - | - | - | 0.767 | 0.151 | 1.000 | - |

Table 5. Estimates of PTIS detection efficiency for adult in the Entiat River sub basin, 2017.

| PTIS | Unique Detections | Upstream Array | 95% C.I. (+/-) | Middle Array | 95% C.I. (+/-) | Downstream Array | 95% C.I. (+/-) | Entire System | 95% C.I. (+/-) |
|---|---|---|---|---|---|---|---|---|---|
| ENL | 179 | 0.761 | 0.087 | - | - | 0.446 | 0.078 | 0.867 | 0.058 |
| ENA | 62 | 0.750 | 0.150 | - | - | 0.444 | 0.132 | 0.861 | 0.101 |
| ENM | 25 | 0.632 | 0.217 | - | - | 0.667 | 0.218 | 0.877 | 0.125 |
| ENS | 34 | 0.970 | 0.058 | - | - | 0.970 | 0.058 | 0.999 | 0.003 |
| ENF | 29 | 1.000 | - | - | - | 0.310 | 0.168 | 1.000 | - |
| MAD | 27 | 1.000 | - | 0.963 | - | 0.963 | - | 1.000 | - |
| RCT | 5 | 1.000 | - | - | - | 1.000 | - | 1.000 | - |

*Juvenile and adult movement*

Detections of juvenile Chinook salmon during the 2017 monitoring period revealed two periods of movement based on first detections within the Entiat sub basin with the majority occurring between February and April (44.6%) and September through November (35.6%) (Figure 4; Table 6). Detections were lowest for juvenile Chinook salmon during the month of June and July with only 0.3% of the total unique detections occurring at all of PTIS locations. Detections of ENFH origin juvenile summer Chinook salmon were limited to ENL and 95.7% of the first detections occurred within 6 days following their release on April 13$^{th}$ (Figure 4). Juvenile steelhead detections revealed a bimodal distribution of movement similar to Chinook salmon with the majority of first detections occurring between March and May (57.6.7%) and August through November (27.8%), while detections were at a minimum in December with 1.8% of total unique detections recorded at each PTIS location (Table 7).

Adult Chinook salmon were not detected within the Entiat River until June and peaked in July (Figure 5; Table 8). Adult Chinook salmon detections declined from the peak until no further detections were recorded in the month of December. In addition, there was more than 3 times as many adult Chinook detected at ENL (79) than any other PTIS location and the number of unique detections decreased the further upstream the PTIS site was located. The majority of adult Chinook detected at ENL were hatchery summer Chinook salmon (51.9%) and Chinook salmon with an unknown run and rear (34.2%) based on PTAGIS naming convention. Furthermore, no wild spring Chinook salmon were detected at ENL. Detections of adult steelhead within the Entiat sub basin indicate a single peak in movement with 86.0% of all first unique detections recorded at each PTIS location occurring in March and April (Table 9). Adult steelhead detections declined from the peak until no further detections were recorded in the month of June, excluding ENL and MAD where adult steelhead were also detected later in the year (September through December). The largest number of adult steelhead unique detections occurred at ENL (84) and the number of unique detections declined the further upstream in the Entiat River the PTIS site was located. The MAD and RCT PTIS recorded 26 and 7 unique adult steelhead detections, respectively. In addition to adult Chinook and steelhead, 21 adult Pacific lamprey were detected in the Entiat River starting in April at ENL and were detected at all of the mainstem Entiat River PTIS locations.

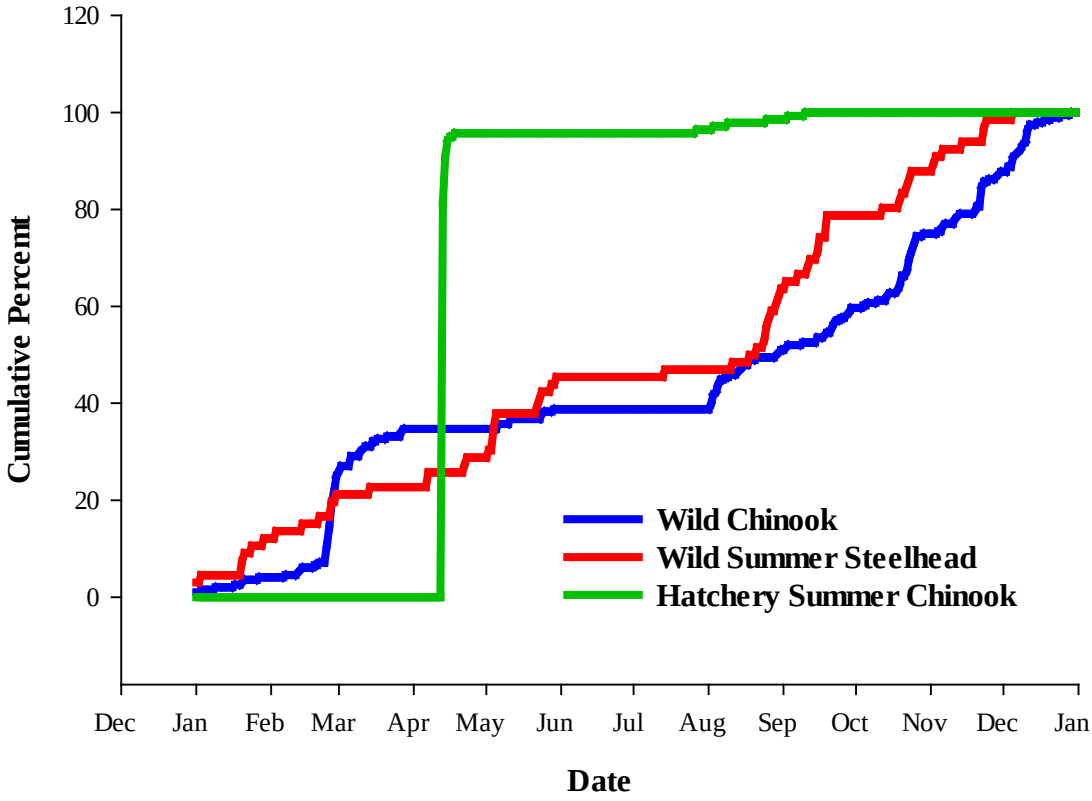


Figure 4. Cumulative percent of first detections for juvenile wild summer steelhead, wild Chinook salmon, and hatchery summer Chinook salmon not tagged as part of the rotary-screw trap operations that occurred at the lower Entiat River interrogation site (ENL), 2017

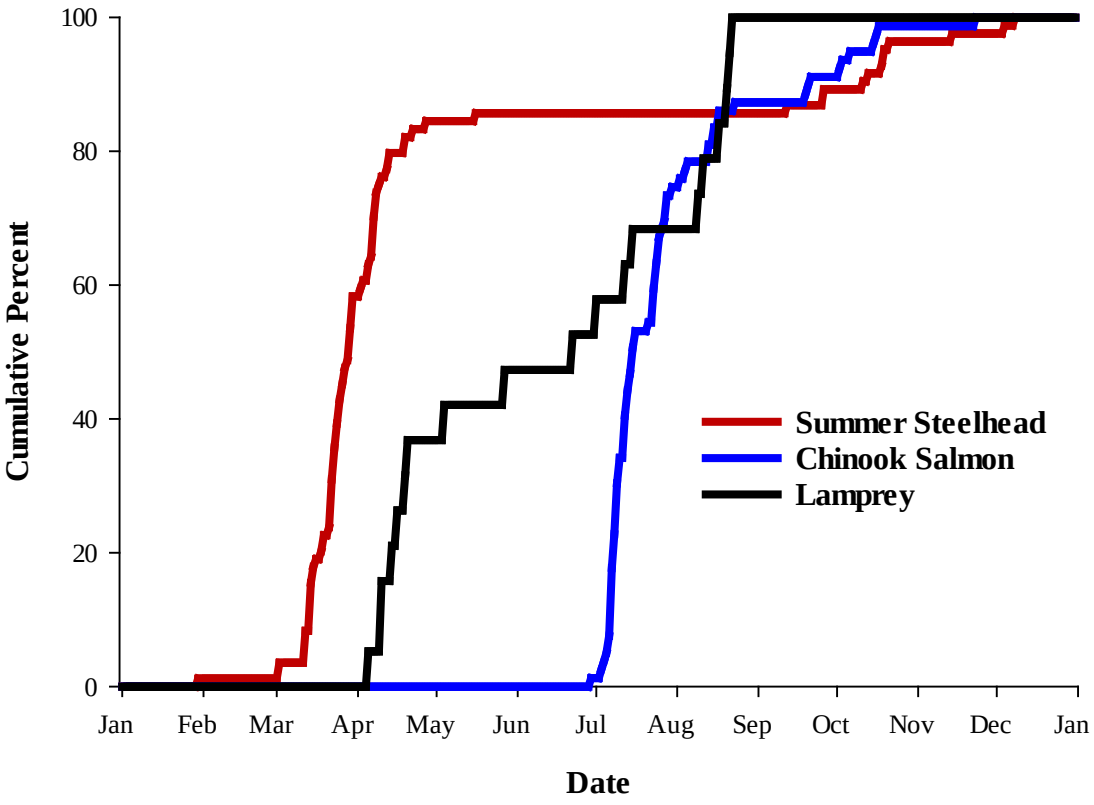


Figure 5. Cumulative percent of first detections for adult steelhead, Chinook salmon, and lamprey that occurred at the lower Entiat River interrogation site (ENL), 2017

Table 6. Percent of first detections occurring at each PTIS location for juvenile Chinook in 2017 by month.

| Month | Interrogation Site | | | | | | | Weighted Average |
|---|---|---|---|---|---|---|---|---|
| | ENL | ENA | ENM | ENS | ENF | MAD | RCT | |
| January | 2.4% | 5.2% | 3.7% | 0.0% | 4.2% | 6.7% | 0.0% | 3.0% |
| February | 12.2% | 9.6% | 4.6% | 4.3% | 4.2% | 3.4% | 0.0% | 8.2% |
| March | 5.7% | 37.0% | 32.1% | 29.6% | 12.5% | 7.9% | 0.0% | 18.9% |
| April | 39.9% | 9.6% | 0.0% | 0.6% | 0.0% | 2.2% | 0.0% | 17.5% |
| May | 2.4% | 0.7% | 0.0% | 0.6% | 0.0% | 3.4% | 0.0% | 1.5% |
| June | 0.0% | 0.0% | 0.0% | 0.6% | 0.0% | 0.0% | 0.0% | 0.1% |
| July | 0.3% | 0.0% | 0.0% | 0.0% | 4.2% | 0.0% | 0.0% | 0.2% |
| August | 8.0% | 0.7% | 6.4% | 8.6% | 37.5% | 0.0% | 0.0% | 6.8% |
| September | 5.7% | 6.7% | 14.7% | 17.3% | 25.0% | 16.9% | 0.0% | 10.9% |
| October | 8.9% | 12.6% | 11.0% | 13.0% | 8.3% | 40.4% | 0.0% | 13.8% |
| November | 7.4% | 11.9% | 16.5% | 14.8% | 4.2% | 10.1% | 0.0% | 10.9% |
| December | 7.1% | 5.9% | 11.0% | 10.5% | 0.0% | 9.0% | 0.0% | 8.1% |
| **Unique Detections** | 336 | 135 | 109 | 162 | 24 | 89 | 0 | -- |

Table 7. Percent of first detections occurring at each PTIS location for juvenile steelhead in 2017 by month.

| Month | Interrogation Site | | | | | | | Weighted Average |
|---|---|---|---|---|---|---|---|---|
| | ENL | ENA | ENM | ENS | ENF | MAD | RCT | |
| January | 11.0% | 9.8% | 3.6% | 0.0% | 0.0% | 1.5% | 5.4% | 3.5% |
| February | 8.2% | 2.4% | 0.0% | 0.0% | 0.0% | 1.8% | 3.6% | 2.5% |
| March | 1.4% | 7.3% | 17.9% | 20.5% | 4.8% | 16.5% | 35.7% | 15.7% |
| April | 5.5% | 17.1% | 0.0% | 10.3% | 19.0% | 25.1% | 17.9% | 19.1% |
| May | 16.4% | 24.4% | 21.4% | 28.2% | 28.6% | 23.0% | 23.2% | 22.8% |
| June | 0.0% | 0.0% | 0.0% | 2.6% | 9.5% | 4.1% | 8.9% | 3.7% |
| July | 2.7% | 14.6% | 3.6% | 7.7% | 9.5% | 1.2% | 0.0% | 3.0% |
| August | 16.4% | 2.4% | 14.3% | 2.6% | 9.5% | 2.9% | 0.0% | 5.0% |
| September | 15.1% | 9.8% | 17.9% | 12.8% | 9.5% | 2.7% | 3.6% | 6.4% |
| October | 12.3% | 9.8% | 17.9% | 10.3% | 4.8% | 13.0% | 0.0% | 11.2% |
| November | 9.6% | 2.4% | 3.6% | 0.0% | 4.8% | 6.2% | 0.0% | 5.2% |
| December | 1.4% | 0.0% | 0.0% | 5.1% | 0.0% | 2.1% | 1.8% | 1.8% |
| **Unique Detections** | 73 | 41 | 28 | 39 | 21 | 339 | 56 | -- |

Table 8. Percent of first detections occurring at each PTIS location for adult Chinook in 2017 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% | 0.0% |
| February | 0.0% | 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% | 0.0% |
| April | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| May | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| June | 1.3% | 14.3% | 0.0% | 12.5% | 0.0% | 0.0% | 0.0% | 3.8% |
| July | 73.4% | 61.9% | 9.1% | 50.0% | 50.0% | 0.0% | 0.0% | 62.3% |
| August | 12.7% | 9.5% | 27.3% | 25.0% | 40.0% | 0.0% | 0.0% | 16.2% |
| September | 3.8% | 9.5% | 45.5% | 12.5% | 10.0% | 0.0% | 0.0% | 9.2% |
| October | 7.6% | 4.8% | 18.2% | 0.0% | 0.0% | 100% | 0.0% | 7.7% |
| November | 1.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% |
| December | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| **Unique Detections** | 79 | 21 | 11 | 8 | 10 | 1 | 0 | -- |

Table 9. Percent of first detections occurring at each PTIS location for adult steelhead in 2017 by month.

| Month | Interrogation Site | | | | | | | Weighted Average |
|---|---|---|---|---|---|---|---|---|
| | ENL | ENA | ENM | ENS | ENF | MAD | RCT | |
| January | 1.2% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.5% |
| February | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| March | 57.1% | 42.1% | 58.3% | 4.5% | 8.3% | 3.8% | 28.6% | 37.8% |
| April | 26.2% | 57.9% | 25.0% | 81.8% | 66.7% | 76.9% | 71.4% | 48.8% |
| May | 1.2% | 0.0% | 16.7% | 13.6% | 25.0% | 15.4% | 0.0% | 6.5% |
| June | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| July | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| August | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| September | 3.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.5% |
| October | 7.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.0% |
| November | 1.2% | 0.0% | 0.0% | 0.0% | 0.0% | 3.8% | 0.0% | 1.0% |
| December | 2.4% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.0% |
| **Unique Detections** | 84 | 38 | 12 | 22 | 12 | 26 | 7 | -- |

*Water Temperature and flow*

Average peak water temperature for Entiat and Mad river PTIS locations occurred in late August and early September during the 2017 monitoring period with the highest water temperature being recorded on August 23rd at 20.9 ˚C. For RCT, water temperature peaked at 15.2 ˚C on July 23rd (Figure 6). Entiat discharge reached its peak on May 31st at 131.7 $m^3$/s and quickly declined through the summer until late November where there was a small peak in flow (Figure 7).

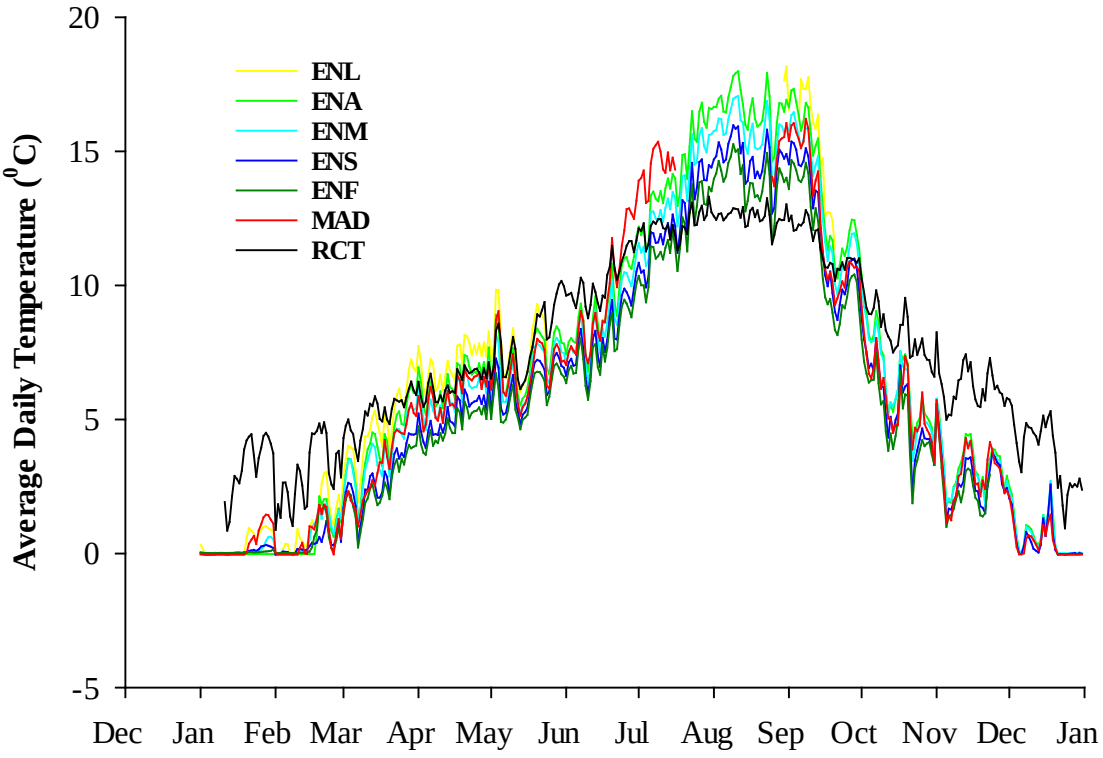


Figure 6. Average daily water temperature ($^0$C) measurements from Entiat sub basin PTIS locations, 2017

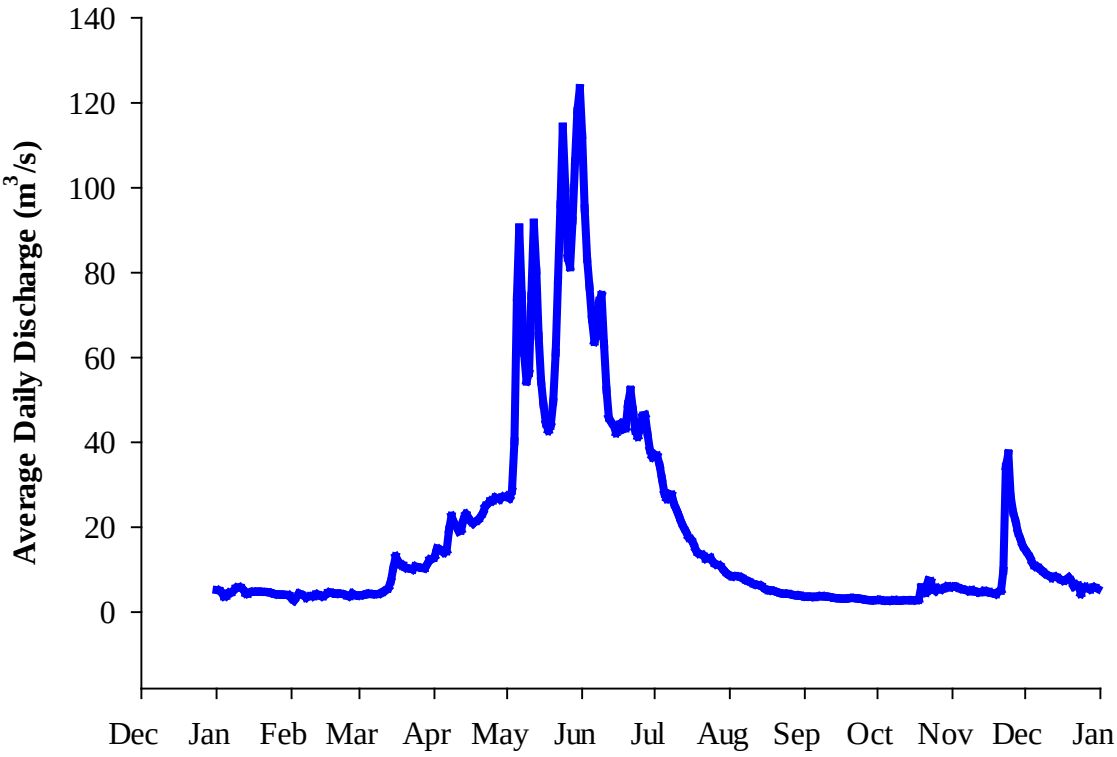


Figure 7. Average daily discharge (m3/s) of the Entiat River at the USGS station (12452990), located at rkm 2.3, 2017.

## 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 when they cannot be safely accessed for repair. In 2017, fourteen antennas had to be replaced or repaired following peak spring river flow due to damage. Another three were repaired as a result of poor performance and four more need to be replaced or repaired as a result of ice flows in the winter.

During the 2017 operational year, there was an issue that was beyond the contractual scope of work outlined for MCFWCO. At all of the PTIS locations excluding RCT, software issue could have resulted in data loss for PIT tags containing the 3DA prefix. While this was an issue for all

of the Entiat and Mad river sites, data loss was likely minimal as use the 3DA prefix was limited ENFH produced summer Chinook salmon. This issue was resolved prior to the ENFH release in 2017 which limited further data loss.

*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 generally greater than the other interrogation systems with two arrays, excluding RCT and ENF where the size of the creek and number of detections likely influenced detection efficiency, respectively. For the two array interrogation systems, detection efficiency was the lowest at the ENL site for juvenile salmonids and ENA for adult salmonids. In assessing the individual array efficiencies, upstream and downstream arrays generally had similar detection efficiencies for juveniles. However for adult salmonids, the downstream array detection efficiencies for ENL, ENA, and ENF are noticeably lower than the upstream arrays, which could be the result of site based factors such as depth, ambient noise, and antenna performance issues. However, the lower detection of all three was likely also the result of functionality of the antennas because each site had at least two broken downstream antennas during the time period that both adult Chinook and steelhead migrating into the Entiat River.

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 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 the tendency of juveniles to out-migrate quickly at elevated flows while utilizing the entire water column, whereas adults tend to linger in areas for extended periods of time when migrating and often orient themselves lower in the water column 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 using 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 2017 PTIS detections, there were two major periods of juvenile Chinook salmon movement which aligned with the expected life-history characteristics of the two different run-types present within the Entiat River. The first period was observed in the spring, which coincides with age-1 spring Chinook salmon emigration from the 2015 brood year, and second period of out-migration detections occurred in the late-summer and early fall which coincide with age-0 summer and spring Chinook salmon emigration from the 2016 brood year. Similar to juvenile Chinook salmon, we observed a large proportion of juvenile steelhead first detected in the spring and fall.

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 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 2017). Hatchery Chinook salmon were primarily composed of ENFH origin summer-run Chinook. Of the 41 hatchery summer-run Chinook salmon detected at ENL, only four were detected at PTIS locations above the hatchery, while 8 of the 9 wild summer-run Chinook salmon were detected above the hatchery. In 2017, we did not detect any wild spring-run Chinook salmon at ENL. However, 8 were detected at sites above ENL with the first one being detected on the 24$^{th}$ of June at ENA, which was before the date that the first hatchery summer-run Chinook salmon was detected at ENL. For adult steelhead, the majority of first detections occurred in March and April. Detections were the highest in March at ENL and ENM, while detections at the more upstream PTIS locations (ENS and ENF) and the MAD and RCT locations peaked in April. The majority of PTIS based movement for adult steelhead appeared to occur prior and during periods of peak spawning (June; Inc et al. 2017), which suggests that the steelhead are utilizing the lower elevations of the watershed for a short period time of before moving to upstream spawning locations. While the majority of adult steelhead enter the Entiat River in the spring prior to spawning, we also observed immigration during the fall at lower river PTIS locations. These fish represent adults that are utilizing the lower Entiat River as overwinter holding habitat before

spawning the following spring. Our past observations indicate that these individuals may not remain to spawn in the Entiat River based on subsequent detections within other basins during spawning period.

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# Appendix

Appendix 1. Site operational summary for the lower Entiat River interrogation site (ENL) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/3 | Site visited. |
| 1/9 | Site visited. |
| 1/19 | Site visited. |
| 1/25 | Site visited. Site fully operational. |
| 1/25 | Noise alarm antenna #5. Noise greater than 90%. Site still fully operational. |
| 2/1 | Site visited. |
| 2/8 | Site visited. |
| 2/13 | Site visited. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 2/27 | Site visited. |
| 3/6 | Site visited. |
| 3/14 | Site visited. |
| 3/16 - 3/20 | Frequent noise alarms on antenna #3. Noise greater than 90%. Site still fully operational. |
| 3/22 | Site visited. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/5 - 4/30 | Frequent noise alarms on antenna #3. Noise greater than 90%. Site still fully operational. |
| 4/14 | Site visited. |
| 4/28 | Site visited. Site is fully operational. |
| 5/3 - 5/31 | Frequent noise alarms on antenna #3. Noise greater than 90%. Site still fully operational. |
| 5/6 | Antenna #6 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/9 | Site visited. |
| 5/12 | Antenna #5 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/18 | Site visited. |
| 5/20 | Antenna #1 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/24 | Water level and temperature probe quit working. Issues will be repaired when conditions allow. |
| 5/31 | Antenna #3 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/31 | Site visited. |
| 6/9 | Site visited. |
| 6/15 | Site visited. |
| 6/24 | Site visited. |
| 7/2 | Site visited. |
| 7/7 | Current is getting low and antenna #4. Antenna will need to be replaced in the near future. |
| 7/13 | Site visited. |
| 7/22 | Site visited. |
| 7/28 | Site visited. Replaced antenna #3. Antenna #3 is now fully operational. |
| 7/28 | Site visited. Replaced antenna #1. Antenna #1 is now fully operational, but cable needs to be replaced in order to increase the current. |
| 7/31 | Site visited. Replaced antenna #5. Antenna #5 is now fully operational. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/16 | Site visited. Unplugged antenna #1 to replace cable. Cable will be replaced in the near future. |

Appendix 1. continued

| Date | Operational Comments |
|---|---|
| 8/17 | Site visited. Replaced cable to antenna #1. Antenna #1 is now fully functional. |
| 8/20 | Site visited. Replaced antenna #6. |
| 8/22 | Noise alarm antenna #1. Noise greater than 90%. |
| 8/27 | Site visited. Replaced antenna #4 because the current was getting low. Site is fully operational. |
| 8/29 | Site visited. Repaired temperature and water level probe. |
| 8/30 - 8/31 | Frequent noise alarms on antenna #3 due to fluctuating current on the antenna. Noise greater than 90%. |
| 9/2 | Site visited. |
| 9/4 - 9/15 | Noise alarms on antennas #3, #5, and #6. Noise great than 90%. |
| 9/15 | Site visited. Replaced antenna #3 cable to reduce noise. |
| 9/17 | Site visited. Debris cleaned off antennas. |
| 9/25 | Site visited. Replaced antenna #5 and #6 cables to reduce noise. |
| 9/26 | Site visited. |
| 9/28 - 9/30 | Frequent noise alarms on antenna #4. Noise greater than 90%. |
| 10/7 | Site visited. |
| 10/15 | Noise alarms on antenna #1. Noise is greater than 90%. |
| 10/20 | Noise alarms on antenna #5. Noise is greater than 90%. |
| 10/25 | Site down. Site went down due to it being left in standby mode. Site was down for about 1 hour. |
| 10/25 | Site visited. |
| 10/25 | Site up. Site visited. MUX was reset and put back into scan mode. Site is fully operational. |
| 10/28 - 10/29 | Noise alarms on antenna #5. Noise is greater than 90%. |
| 10/30 | Site visited. Site was visited to correct issues that were causing files not to upload as a result of reader ID being accidentally changed from 20 to 10. Changed reader ID back to 20. Site is still fully operational. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/27 | Site visited. |
| 12/8 | Site visited. |
| 12/18 | Site visited. |

Appendix 2. Site operational summary for the Entiat River interrogation site at Ardenvoir (ENA) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/4 | Site visited. Antenna #3 is down due to ice flow. Antenna will be repaired when conditions allow. |
| 1/9 | Site visited. Antenna #3 is down due to ice flow. Antenna will be repaired when conditions allow. |
| 1/19 | Site visited. |
| 1/25 | Site visited. |
| 2/1 | Site visited. |
| 2/8 | Site visited. |
| 2/13 | Site visited. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 3/6 | Site visited. |
| 3/8 | Replaced antenna #3. Site is now fully operational. |
| 3/14 | Site visited. |
| 3/22 | Site visited. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/14 | Site visited. |
| 4/15 | Noise alarm antenna #1. Noise greater than 90%. Site still fully operational. |
| 4/28 | Site visited. Site is fully operational. |
| 5/2 - 5/3 | Noise alarm antenna #5. Noise greater than 90%. |
| 5/4 | Site visited. |
| 5/6 | Noise alarm antenna #5. Noise greater than 90%. |
| 5/9 | Site visited. |
| 5/18 | Noise alarm antenna #5. Noise greater than 90%. |
| 5/18 | Site visited. |
| 5/21 | Antenna #6 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/24 | Antenna #4 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/31 | Antenna #5 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/31 | Site visited. |
| 6/9 | Site visited. |
| 6/11 | Current on antenna #2 is getting low. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 6/24 | Site visited. |
| 6/26 | Current on antenna #6 increased from 0 amps, but it is still low and fluctuating. Antenna will be repaired when conditions allow. |
| 7/2 | Site visited. |
| 7/13 | Site visited. |
| 7/22 | Site visited. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/21 | Site visited. Replaced antenna #4 and #5 |
| 8/25 | Site visited. Replaced antenna #6 cable and moved temperature logger. |
| 8/27 | Site visited. Antenna #2 was unplugged and removed for repair. Antenna will be fixed and re-installed in the near future. |
| 8/27 | Low Current Alarm #4. Antenna #4 was unplugged. It will be plugged back in the near future. |
| 8/28 | Site visited. Antenna #4 was plugged back in. |
| 8/29 | Site visited. Antenna #2 was repaired and re-installed. Site is now fully operational. |
| 9/2 | Site visited. |
| 9/10 - 9/11 | Frequent noise alarms on antenna #4. Noise is greater than 90%. |

Appendix 2. continued

| Date | Operational Comments |
|---|---|
| 9/12 - 9/19 | Frequent noise alarms on antennas #4 and #5. Noise is greater than 90%. |
| 9/17 | Site visited. Debris cleaned off antennas. Site is fully operational. |
| 9/20 | Frequent noise alarms on antenna #4. Noise greater than 90%. |
| 9/23 | Frequent noise alarms on antenna #4. Noise greater than 90%. |
| 9/28 | Site visited. |
| 10/4 | Current on antenna #5 is getting low and fluctuating. Antenna and cable need to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 10/7 | Site visited. |
| 10/9 | Frequent noise alarms on antenna #5. Noise greater than 90%. |
| 10/12 - 10/13 | Frequent noise alarms on antenna #5. Noise greater than 90%. |
| 10/17 - 10/19 | Frequent noise alarms on antenna #5. Noise greater than 90%. |
| 10/22 - 10/24 | Frequent noise alarms on antenna #5. Noise greater than 90%. |
| 10/25 | Site visited. |
| 10/29 | Site visited. Replaced cable to antenna #5 to correct low and fluctuating current levels. Site is fully operational. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/27 | Site visited. |
| 12/8 | Site visited. |
| 12/18 | Site visited. |

Appendix 3. Site operational summary for the middle Entiat River interrogation site (ENM) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/4 | Site visited. |
| 1/9 | Site visited. |
| 1/19 | Site visited. |
| 1/23 | Antenna #5 went down due to ice flow. Antenna will be repaired when conditions allow. |
| 1/25 | Site visited. |
| 1/26 | Site visited. |
| 2/1 | Site visited. |
| 2/7 | Site visited. |
| 2/8 | Site visited. |
| 2/18 | Noise alarm antenna #2. Site still fully operational. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 3/2 | Replaced antenna #5. Site is now fully operational. |
| 3/6 | Site visited. |
| 3/9 - 3/15 | Noise alarm antenna #5. Noise greater than 90%. Site still fully operational. |
| 3/14 | Site visited. |
| 3/22 | Site visited. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/14 | Site visited. |
| 4/28 | Site visited. Site is fully operational. |
| 5/4 | Site visited. |
| 5/6 | Antenna #1 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/6 | Antenna #5 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/9 | Site visited. |
| 5/11 | Antenna #4 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/18 | Site visited. |
| 5/28 | Frequent noise alarms on antenna #6. Noise greater than 90%. |
| 5/30 | Frequent noise alarms on antenna #6. Noise greater than 90%. |
| 5/31 | Site visited. |
| 5/31 | Antenna #2 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 6/1 - 7/5 | Frequent noise alarms on antenna #6. Noise greater than 90%. |
| 6/9 | Site visited. |
| 6/15 | Site visited. |
| 6/24 | Site visited. |
| 7/2 | Site visited. |
| 7/5 | Site visited. Plugged antenna #4 back in. Antenna is now fully operational. |
| 7/11 | Site visited. Plugged antenna #1 back in. Antenna #1 is now fully operational. |
| 7/13 | Site visited. |
| 7/19 | MUX turned on standby mode accidently. |
| 7/22 | Site visited. |
| 7/27 | MUX turned on to scan mode. MUX and site are now operating. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/16 | Site visited. Replaced antenna #2. |
| 8/16 | Site visited. Replaced cable to antenna #5. Site is now fully operational. |
| 8/18 - 8/25 | Frequent noise alarms on antenna #6. Noise greater than 90%. |

Appendix 3. continued

| Date | Operational Comments |
|---|---|
| 8/19 | Noise alarm antenna #5. Noise greater than 90%. |
| 8/23 - 8/24 | Frequent noise alarms on antenna #2 due to fluctuating current on the antenna. Noise greater than 90%. |
| 8/28 | Site visited. |
| 9/2 | Site visited. |
| 9/5 - 9/24 | Frequent noise alarms on antenna #6. Noise greater than 90%. |
| 9/5 | Noise alarm antenna #5. Noise greater than 90%. |
| 9/17 | Site visited. Debris cleaned off antennas. Site is fully operational. |
| 9/24 | Site visited. Replaced antenna #6 cable to reduce noise. |
| 9/24 | Noise alarm on antenna #4. Noise greater than 90%. |
| 9/28 | Site visited. |
| 10/7 | Site visited. |
| 10/25 | Site visited. |
| 11/1 | Site visited. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/27 | Site visited. |
| 12/8 | Site visited. |
| 12/18 | Site visited. |

Appendix 4. Site operational summary for the Entiat River interrogation site near Stormy Creek (ENS) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/4 | Site visited. |
| 1/9 | Site visited. |
| 1/19 | Site visited. |
| 1/25 | Site visited. Site fully operational. |
| 2/1 | Site visited. |
| 2/8 | Site visited. |
| 2/13 | Site visited. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 3/6 | Site visited. |
| 3/12 | Noise alarm antenna #5. Noise greater than 90%. Site still fully operational. |
| 3/14 | Site visited. |
| 3/22 | Site visited. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/14 | Site visited. |
| 4/28 | Site visited. Site is fully operational. |
| 5/5 | Antenna #5 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/9 | Noise alarm antenna #6. Noise greater than 90%. |
| 5/9 | Antenna #2 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/9 | Site visited. |
| 5/17 | Noise alarm antenna #6. Noise greater than 90%. |
| 5/18 | Site visited. |
| 5/23 - 7/30 | Frequent noise alarms on antenna #3 due to fluctuating current on the antenna.. Noise greater than 90%. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 5/24 | Noise alarm antenna #6. Noise greater than 90%. |
| 5/28 | Noise alarm antenna #6. Noise greater than 90%. |
| 5/31 | Site visited. |
| 6/1 | Current on antenna #6 is getting low. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 6/9 | Site visited. |
| 6/15 | Site visited. |
| 6/16 - 6/21 | Frequent noise alarms on antenna #6 due to fluctuating current on the antenna. Noise greater than 90%. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 6/24 | Site visited. |
| 7/2 | Site visited. |
| 7/13 | Site visited. |
| 7/22 | Site visited. |
| 7/31 | Site visited. Replaced antenna #3 because current was getting low. Antenna #3 is now fully operational. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/12 | Noise alarm antenna #3. Noise greater than 90%. |
| 8/22 | Site visited. Replaced antennas #5 and #6 |
| 8/22 - 8/23 | Frequent noise alarms on antenna #6 due to fluctuating current on the antenna. Noise greater than 90%. |
| 8/23 | Site visited. Replaced antenna #2. |

Appendix 4. continued

| Date | Operational Comments |
|---|---|
| 8/23 - 9/12 | Frequent noise alarms on antenna #3 due to fluctuating current on the antenna. Noise greater than 90%. |
| 9/2 | Site visited. |
| 9/9 | Swapped out antenna #3 with a new one to try and reduce noise issues. |
| 9/17 | Site visited. Debris cleaned off antennas. Site is fully operational. |
| 9/18 | Noise alarms on antenna #6. Noise is greater than 90%. |
| 9/28 | Site visited. |
| 10/7 | Site visited. |
| 10/18 | Noise alarms on antenna #6. Noise is greater than 90%. |
| 10/20 | Noise alarms on antenna #6. Noise is greater than 90%. |
| 10/22 | Noise alarms on antenna #3. Noise is greater than 90%. |
| 10/25 | Site visited. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/27 | Site visited. |
| 12/8 | Site visited. |
| 12/18 | Site visited. |

Appendix 5. Site operational summary for the Entiat River Forest Service boundary interrogation site (ENF) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/4 | Site visited. |
| 1/9 | Site visited. Antenna #4 is down due to ice flow. Antenna will be repaired when conditions allow. |
| 1/19 | Site visited. |
| 1/25 | Site visited. |
| 1/25 | Noise alarm antenna #2. Noise greater than 90%. Site still fully operational. |
| 1/27 | Antenna #6 went down due to ice flow. Antenna will be repaired when conditions allow. |
| 2/1 | Site visited. |
| 2/8 | Site visited. |
| 2/13 | Site visited. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 2/28 | Noise alarm antenna #2. Noise greater than 90%. |
| 3/3 | Noise alarm antennas #2, #3, and #5. Noise greater than 90%. |
| 3/6 | Noise alarm antenna #3. Noise greater than 90%. |
| 3/6 | Site visited. |
| 3/8 | Replaced antenna #4. |
| 3/13 | Site visited. |
| 3/14 | Site visited. |
| 3/20 - 3/21 | Noise alarm antennas #3 and #5. Noise greater than 90%. Site still fully operational. |
| 3/22 | Site visited. |
| 3/24 | Site visited. Plugged antenna #6 back in. Site is now fully operational. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/9 | Noise alarm antenna #6. Noise greater than 90%. Site still fully operational. |
| 4/14 | Site visited. |
| 4/28 | Site visited. Site is fully operational. |
| 5/3 | Antenna #4 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/7 - 5/12 | Noise alarm antenna #6. Noise greater than 90%. |
| 5/9 | Site visited. |
| 5/12 | Antenna #6 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/18 | Site visited. |
| 5/23 | Antenna #3 went down due to high flows and debris. Antenna will be repaired when conditions allow. |
| 5/31 | Site visited. |
| 5/31 | Noise alarm on antenna #1. Noise greater than 90%. |
| 6/1 | Site visited. Raised job box up to prevent water damage. |
| 6/9 | Site visited. |
| 6/15 | Site visited. |
| 6/24 | Site visited. |
| 7/2 | Site visited. |
| 7/11 | Site visited. Plugged antenna #3 and #6 back in. Antennas are now fully operational. |
| 7/13 | Site visited. |
| 7/22 | Site visited. |
| 7/23 - 7/24 | Noise alarm on antenna #3. Noise greater than 90%. |
| 7/27 | Noise alarm on antenna #3. Noise greater than 90%. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/11 | Site visited. Fixed cable to antenna #4. Antenna #4 and the entire site are now fully operational. |

Appendix 5. continued

| Date | Operational Comments |
|---|---|
| 8/28 | Site visited. |
| 9/2 | Site visited. |
| 9/15 - 9/18 | Frequent noise alarms on antenna #3. Noise is greater than 90%. |
| 9/17 | Site visited. Debris cleaned off antennas. Site is fully operational. |
| 9/28 | Site visited. |
| 10/7 | Site visited. |
| 10/25 | Site visited. |
| 10/30 | Low current alarm antenna #4. Antenna #4 was unplugged from 10/30 till 10/31 due to debris. |
| 10/31 | Site visited. Plugged antenna #4 back in and cleaned debris off cables and antennas. Site is fully operational. |
| 10/31 | Noise alarms on antenna #3. Noise is greater than 90%. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/23 | Water temperature and level probe quit working. Issue will be fixed when a new probe arrives. |
| 11/27 | Site visited. |
| 12/5 | Antenna #4 was unplugged due to flows. It will be plugged back in as soon as possible. |
| 12/6 | Antenna #4 was plugged back in. Site is fully operational again. |
| 12/8 | Site visited. |
| 12/10 | Site down. Site went down due to voltage issues caused by a malfunction battery charger. |
| 12/11 | Site visited. Reset battery charger. |
| 12/12 | Site up. Site is back up after reset the battery charger and MUX. Site is now fully operational again. |
| 12/12 | Site visited. Reset MUX. |
| 12/18 | Site visited. |
| 12/21 | Current on antenna #4 is low due to a damage cord. Cord will be replaced in the near future when conditions allow. |

Appendix 6. Site operational summary for the Mad River interrogation site during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/3 – 1/7 | Low voltage alarm. Voltage dropped and site was likely down intermittently due to low voltage issues. |
| 1/4 | Site visited. |
| 1/9 | Site visited. |
| 1/12 | Low voltage alarm. Voltage dropped and site was likely down intermittently due to low voltage issues. |
| 1/19 | Site visited. |
| 1/24 | Low voltage alarm. Voltage dropped and site was likely down intermittently due to low voltage issues. |
| 1/25 | Site visited. |
| 1/31 - 2/9 | Noise alarm antenna #4. Noise greater than 90%. Site still fully operational. |
| 2/1 | Site visited. |
| 2/8 | Site visited. |
| 2/13 | Site visited. |
| 2/14 | Noise alarm antenna #4. Noise greater than 90%. Site still fully operational. |
| 2/16 | Noise alarm antenna #4. Noise greater than 90%. Site still fully operational. |
| 2/20 | Noise alarm antenna #1. Site still fully operational. |
| 2/21 | Site visited. |
| 2/23 | Site visited. Installed corrected biomark 9.01 software on CR1000 to fix issues with certain PIT tag prefixes. Site is fully operational. |
| 2/25 | Noise alarm antenna #4. Noise greater than 90%. Site still fully operational. |
| 3/6 | Site visited. |
| 3/6 – 3/8 | Low voltage alarm. Voltage dropped and site was likely down intermittently due to low voltage issues. |
| 3/8 | Noise alarms. Site still fully operational. |
| 3/10 | Noise alarm. Site still fully operational. |
| 3/10 – 3/12 | Low voltage alarm. Voltage dropped and site was likely down intermittently due to low voltage issues. |
| 3/13 | Noise alarm antenna #4. Site still fully operational. |
| 3/13 | Site visited. |
| 3/14 | Site visited. |
| 3/21 - 3/22 | Noise alarm on all antennas. Noise greater than 90%. Site still fully operational. |
| 3/22 | Site visited. |
| 3/30 | Site visited. |
| 4/5 | Site visited. |
| 4/14 | Site visited. |
| 4/19 | Site visited. Cleaned off antennas. |
| 4/28 | Site visited. Site is fully operational. |
| 5/9 | Site visited. |
| 5/13 | Noise alarm on antennas #1 and #3. Noise greater than 90%. Site still fully operational. |
| 5/18 | Site visited. |
| 5/24 - 6/2 | Frequent noise alarms on antenna #1. Noise greater than 90%. |
| 5/24 | Noise alarm on antenna #6. Noise greater than 90%. |
| 5/30 | Noise alarm on antenna #5. Noise greater than 90%. |
| 5/30 - 6/2 | Frequent noise alarms on antenna #6. Noise greater than 90%. |
| 5/31 | Noise alarm on antenna #2. Noise greater than 90%. |
| 5/31 | Noise alarm on antenna #5. Noise greater than 90%. |
| 5/31 | Site visited. |
| 5/31 | Low voltage alarm antenna #1. Voltage dropped on antenna #1 and was down from 12:21 to 14:21 on 5/31. |
| 6/3 | Current on antenna #1 is fluctuating and is low at times. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 6/3 | Frequent noise alarms on antenna #6. Noise greater than 90%. |

Appendix 6. continued

| Date | Operational Comments |
|---|---|
| 6/4 | Frequent noise alarms on antenna #1. Noise greater than 90%. |
| 6/5 - 6/15 | Frequent noise alarms on antenna #1 due to fluctuating current on the antenna.. Noise greater than 90%. Antenna needs to be replaced or repaired. Issue will be resolved in the near future when conditions allow. |
| 6/9 | Site visited. |
| 6/15 | Site visited. Cleaned off antennas. Issue will frequent noise alarms and low current on antenna #1 was resolved by plugging the antenna fully in after the high flows had partially unplugged it. Site is fully operational. |
| 6/16 | Antenna #3 went down due debris falling into the river. Antenna will be repaired when conditions allow. |
| 6/20 | Low Current Alarm #1. Antenna #1 was unplugged due to flows and debris. It will be plugged back in the near future. The rest of the site is still fully operational. |
| 6/21 | Site visited. Antenna#1 was plugged back in. |
| 6/24 | Site visited. |
| 7/2 | Site visited. |
| 7/13 | Site visited. |
| 7/17 | Site visited. Replaced antenna #3. Antenna #3 is now fully operational. Antenna that was used to replace the old one is 10ft opposed to 15ft. A 15ft will be installed in the near future. |
| 7/22 | Site visited. |
| 8/3 | Site visited. |
| 8/8 | Site visited. |
| 8/19 | Site visited. Replaced antenna #3. Antenna that was used was 10ft and was replaced with a 15ft antenna. Site is still fully operational. |
| 8/25 | Site visited. Battery for PS100 and fuse were replaced. Site is not uploading data correctly. |
| 9/2 | Site visited. |
| 9/12 | Low voltage alarm. Voltage dropped and site was likely down from 9/12 at 9:40 till 12:40 due to a blown fuse. |
| 9/17 | Site visited. Debris cleaned off antennas. |
| 9/18 | Low voltage alarm. Voltage dropped and site was likely down from 9/18 at 10:40 till 12:40. |
| 9/26 | Site visited. |
| 9/27 | Likely shed on antenna #5 (3DD.007737E37E). Shed will be removed in the near future. |
| 9/30 | Noise alarm on antenna #5. Noise greater than 90%. |
| 10/7 | Site visited. |
| 10/25 | Site visited. |
| 10/30 | Site visited. |
| 10/31 | Noise alarms on antenna #3. Noise is greater than 90%. |
| 11/1 | Site visited. Removed shed tag (3DD.007737E37E) from near antenna #5. |
| 11/2 | Site visited. |
| 11/15 | Site visited. |
| 11/27 | Site visited. |
| 12/8 | Site visited. |
| 12/18 | Site visited. |

Appendix 7. Site operational summary for the Roaring Creek interrogation site (RCT) during the 2017 monitoring period.

| Date | Operational Comments |
|---|---|
| 1/11 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 1/25 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 2/8 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 2/21 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 3/6 | Site visited. Data downloaded, batteries swapped, and tuning checked. Site fully operational. |
| 3/22 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 3/31 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |
| 4/4 | Additional antenna was added to the site. In addition to the allflex antenna an IS1001 antenna was added that is being powered by solar. Site is fully operational. |
| 4/12 | Site visited. Allflex set up was removed. Site now consists of 2 synchronized IS1001s separated by 30 feet powered by solar. Site is fully operational. |
| 4/18 | Site visited. Data downloaded and tuning checked. Site fully operational. |
| 4/19 | Site visited. Data downloaded and tuning checked. Install antenna braces. Site fully operational. |
| 4/22 | Site visited. Data downloaded and tuning checked. Site fully operational. |
| 4/28 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 5/4 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 5/9 | Site visited. |
| 5/15 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 5/19 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 5/24 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 5/30 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 6/9 | Site visited. Data downloaded and voltage checked. Batteries were replaced due to low voltage, which was preventing both antennas from operating effectively at the same time. Site is still fully operational. |
| 6/15 | Site visited. Data downloaded and voltage checked. Unique detection delay mode was enabled with a 30 second delay due to one fish continuously being detected. Site is fully operational. |
| 6/22 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 6/24 | Antenna #2 is out of tune. Issue will be resolved in the near future. |
| 6/29 | Site visited. Data downloaded and voltage checked. Antenna #2 was out of tune on arrival. Capacitors need to be replaced in order to read tags. Issue will be resolved in the near future. |
| 7/10 | Site visited. Data downloaded and voltage checked. Antenna #2 was manually tuned to deal with issues with it being out of tune. Site is fully operational. |
| 7/27 | Site visited. Data downloaded and voltage checked. Antenna #2 was out of tune on arrival. Capacitors need to be replaced in order to read tags. Issue will be resolved in the near future. |
| 8/14 | Site visited. |
| 8/28 | Site visited. Data downloaded and voltage checked. Antenna #2 repaired. Site is fully operational. |
| 9/2 | Site visited. |
| 9/6 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 9/19 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 10/3 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 10/16 | Site visited. Data downloaded and voltage checked. Site is fully operational. |
| 10/29 | Site visited. Data downloaded and swapped batteries. Site is fully operational. |
| 11/13 | Site visited. Data downloaded. Site is fully operational. |
| 11/15 | Site visited. Swapped batteries. |
| 11/29 | Site visited. Swapped batteries. |
| 12/1 | Site visited. Data downloaded. Site is fully operational. |
| 12/8 | Site visited. Swapped batteries. |
| 12/21 | Site visited. Data downloaded. Site is fully operational. |
| 12/28 | Site visited. Data downloaded. Site is fully operational. |
| 1/11 | Site visited. Data downloaded, batteries replaced, and tuning checked. Site fully operational. |