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# Acoustic Tracking of Redband Rainbow Trout (Oncorhynchus myskiss gairdneri) in Lake Roosevelt (2015-2016), Evaluation of an Acoustic Receiver Array, and Low-Voltage Electroanesthesia for Tag Implantation.

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**Acoustic Tracking of Redband Rainbow Trout (*Oncorhynchus myskiss gairdneri*) in Lake Roosevelt (2015-2016), Evaluation of an Acoustic Receiver Array, and Low-Voltage Electroanesthesia for Tag Implantation.**

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**MASTER'S THESIS**

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# Executive Summary

Fisheries managers are often concerned with fish movements. Gathering information on how far they move, and when/where they move is important to understand fish life history and how they react to their environment (Thorstad et al. 2013). Examples of movements include, migration for reproductive events (Reishel and Bjorn 2003) and movements in response to environmental perturbations (Cooke et al. 2004). Also when/where and how far they move determines the home area they occupy which is a useful parameter for understanding population dynamics (Mulfeld and Marotz 2005).

Telemetry (a method of remotely measuring movements of organisms) allows us to track fish movements. Equipment used in telemetry includes transmitters (tags) and receivers. Tags emit unique signals that are recorded by receivers.  Tags and receivers can be either acoustic or radio. Acoustic telemetry tags emit an acoustic (or sonic signal) that travels through the water and is decoded by a submersible receiver. Radio telemetry tags emit a radio signal that exits the water and is decoded by a receiver on land (Thorstad et al. 2013). Often, multiple receivers are placed in a study area forming an array to passively detect tagged fish. The data collected from receivers is used to show timing of movements, distances fish moved, and areas of use by tagged fish.

The components of this thesis are related to evaluating methodologies associated with understanding fish movements. Specific chapters are as follows: 1) tag implantation, 2) evaluation of an acoustic receiver array and 3) acoustic telemetry investigations of Redband Rainbow Trout (*Oncorhynchus mykiss gairdneri*), hereafter referred to as

Redband Trout in Lake Roosevelt, Washington. Each component of this thesis has its own associated chapter.

Minor surgical procedures requiring anesthesia are used to implant acoustic and radio tags. Anesthesia is often achieved with chemicals. Chemical anesthetics have been extensively studied but there are restrictions (such as mandatory holding times of 21 days for release of fish anesthetized with the chemical Tricaine Methanesulfonate) on their use and time for fish to recover from anesthesia is variable, usually taking several minutes. (Hudson et al. 2011). An alternative to chemical anesthetics is the use of non-pulsed direct current known as Low-Voltage Electro Anesthesia (LVEA). This method offers no restrictions and the fish recover quickly, usually within a matter of seconds or instantaneously as soon as the current is turned off (Hudson et al. 2011). However, this method has not been extensively studied on commonly tagged fish species (Rous et al. 2015).

In Chapter 1 I describe the methods used to collect various species of fish and expose them to LVEA and factors that influence voltage gradient required for anesthesia. I compared voltage gradients (voltage applied/spacing between electrodes) necessary to anesthetize fish by size among 11 species collected, within species and by scale type (ctenoid or comb shaped scales and cycloid or round scales). In addition, I compared water conductivity (a measure of water's ability to carry an electric charge in µSiemens/cm) when different scaled fish were collected.

Multiple regression indicated that scale type, fish size, species, and water conductivity explained 62% of the variation in the voltage gradient to anesthetize fish. Comparison between ctenoid and cycloid scaled fish indicated ctenoid scaled fish had higher (Kruskal

Wallis chi square = 118, df = 1, $p < 0.0001$) mean voltage gradient (0.41 V/ cm) than cycloid scaled fish (0.19 V/cm). Water conductivity did vary between the locations where cycloid scaled fish were collected (average conductivity 136 µS/cm) and when ctenoid scaled fish were collected (average conductivity 249 µS/cm). There appeared to be interactions between water conductivity, fish species, and scale type that determined voltage gradient necessary to anesthetize fish. With these findings, I propose that agencies utilizing LVEA make data available in a repository to further refine a standard operating procedure on this method. I also recommend those that use this technique use the minimum voltage to anesthetize fish rather than starting with a fixed voltage. For this study I successfully anesthetized 280 fish by gradually increasing the voltage from zero until the fish rolled over. With this the fish did not dart quickly to one side of the apparatus as was seen by starting with a fixed voltage (Walston 2015).

Evaluation of receiver limitations is required for passive acoustic telemetry studies. This is important to determine the effectiveness of an acoustic receiver array in a study area. Receivers are typically limited to only detecting the presence of tagged fish and the distance the fish is from the receiver is unknown (Thorstad et al. 2013). It is necessary to determine receiver detection range by range testing (Kessel et al. 2014). Understanding detection range allows for refined interpretation of tag detections and can be used to arrange an array of receivers to better cover the study area (Kessel et al. 2014).

Chapter 2 is on an evaluation of the acoustic receiver array in Lake Roosevelt and Rufus Woods Reservoirs. The array consists of 52 acoustic receivers in the United States portion of the Columbia River from 13 km downstream of Grand Coulee Dam in Rufus Woods's Reservoir and upstream over the length of Lake Roosevelt to the Canadian

Border. The receivers in the United States are attached to an anchored buoy via a 3 m cable. In addition to these receivers there are 23 receivers in the Canadian portion of the Columbia River between the international border and the next hydroelectric dam. This array was used for tracking Redband Trout, which is described in detail in Chapter 3. This chapter details procedures to evaluate array receivers in the United States which were 1) stationary range testing, 2) tracks past receivers from tagged Redband Trout, and 3) float range testing.

The first procedure used to evaluate the array was stationary range testing. This procedure was accomplished by placing a tag at three known distances from the receiver in four cardinal directions (N, E, S, and W) and at different depths (5m above the bottom, middle water column, and 5 m below the surface). Maximum distance away from the receiver was 500 m from previous range testing that demonstrated a sharp drop off in detection at distances greater than 500 m (Stroud et al. 2011). Tags were placed at three distances (in one third of 500 m increments) in each direction around receivers to understand how detection ability of receivers decreases with distance. The exception to this was directions where distance between the shoreline and receiver that was less than 500 m. In these directions, I divided the distance between receiver and shore by three. Tags were held at each depth in each direction around the receiver. Tags were at each of these depths long enough for the tag to transmit 20 times. The number of detections on the receiver divided by tag transmissions was the detection frequency. Detection frequency was incorporated into a general linear mixed model (GLMM) with distance, direction, and depth to produce detection range maps. Maximum detection range was the distance that five percent of transmissions were detected (or one out of 20 transmissions).

Comparisons of detection frequency were made between 10 receivers in three regions (lower, middle and upper) of the reservoir and depth class. These comparisons were made due to previous studies that noted detection issues of fish tagged in the upper reservoir. Comparisons between regions were further subdivided into distance groups (<165m, 165-330m, and 330 – 500m from receivers). The next comparisons were made by depth within each region by distance group. These comparisons were made since comparisons by depth and region among all distances was highly variable and not statistically different.

Detection ability was variable across receivers in the array and by region. The effects plot from the GLMM indicated detection frequency was 75% at 100 m, 50 % at 300 m, and 25 % at 500 m from receivers across the entire array. Comparisons among regions in each of the distance groups showed the upper reservoir had lower detection than the lower reservoir at distances of 165-330 m from receivers (Kruskal Wallis Chi square = 6.53, df= 2, $p = 0.03$). Depth only impacted detection in the middle reservoir (Kruskal Wallis chi square = 12.24, df = 2, $p < 0.01$). Of 43 receivers, eight had a maximum detection range across the reservoir where they were situated.

The second procedure used was an evaluation of receivers with telemetry data from tagged Redband Trout. This was accomplished by determining tracks of tagged fish. A track was a movement that went by at least three receivers. Receivers along a track were tallied for detections and misses. Receivers were ranked by percent of tracks they detected. In addition the proportion of fish detected by receivers was compared to distance from the edge of the maximum detection range to the opposite shore for receivers.

Receivers in the array appeared to effectively detect fish despite large spaces outside of detection range. Most receivers (26 of 43) detected more than 70% of the tracks that went by them. Distance from edge of detection range to opposite shoreline for receivers ranged from 30 to 2,000 m. Tagged fish tracks showed no pattern between distance outside detection range of receivers and percent of fish detected indicating fish preferentially move along one shoreline in some locations where receivers are placed. For example, there was 780 m between the edge of the maximum detection range and shoreline for a receiver in the lower reservoir. This receiver detected 94% (78 of 83) tracks that went past it. This would indicate that few fish traveled past this receiver in the area outside its detection range.

The last procedure was float range testing to evaluate a gate (receivers located across from each other to overlap in detection range) located in swift water downstream of Grand Coulee Dam in Rufus Woods Reservoir. Stationary range testing could not be performed here due to the difficulty of staying in place at this location. This gate consisted of two receivers across from each other downstream of Grand Coulee Dam. The receivers were placed here to detect entrainment out of Lake Roosevelt and were placed here after float testing conducted by Stroud et al. (2011) on a receiver upstream of the current gate. Stroud et al. (2011) float tested this receiver by drifting a random delay 1-3 minute random delay tag from 250 m upstream of receiver and 250 m downstream for a total of 75 drifts on 9 April 2011. The receiver detected this tag on 27 of 75 drifts (36%).

Rufus Woods gate receivers were evaluated by drifting a tag between them and between receivers and the opposite bank. In 2015 I used a tag with a 10 second time interval between transmissions to determine where tags can be detected in relation to the receivers. In 2016 a 1-3 minute random delay tag which was the same as tags implanted into Redband Trout in Chapter 3 was used to determine how well a tagged fish moving past these receivers could be detected.

Orientation of the receivers in the gate in Rufus Woods Reservoir likely played a role in the results obtained in 2015 and 2016. In 2015, the tag was detected on one of nine drifts on both receivers. In 2016 the tag was detected on both receivers on all 20 drifts. Receiver orientation in 2015 had both receivers 150 m apart and across from each other. In 2016 current pushed receiver buoys to different locations with one positioned downstream of the other. During both tests the majority of detections occurred downstream of the receivers (22 of 33 in 2015, and 65 of 114 in 2016). This is likely due to the current that pushes on these receivers causing them to point downstream from the buoys they are attached to.

Results from 2016 starkly differed from Stroud et al. (2011). In 2016 we conducted a total of 20 floats. These floats were initiated 400 m upstream of receivers and ended 400 m downstream. The tag was detected on both receivers on every drift. This receiver gate appears to be effectively acting as a gate. However, tests conducted by Stroud et al. (2011) on the single receiver upstream were done in April during times of high flow. The 2016 test was conducted during a time of low flow in late summer. It would be beneficial to test the receiver gate in Rufus Woods during times of high flow to better evaluate its effectiveness as a gate.

Chapter three describes an acoustic telemetry study of Redband Trout in Lake Roosevelt. This was the final year of a study that commenced in 2013. A native population of

Redband Trout currently reside in Lake Roosevelt and uses tributary streams of the reservoir to spawn. Here I implanted 81 acoustic tags into adult Redband Trout from eight tributary streams in 2015 and monitored their movements using the acoustic array I range tested in Chapter 2 into 2016. Redband Trout were tagged in the Sanpoil River, Blue and Spring Creeks (tributaries of the Spokane River Arm of the reservoir), Wilmont, Alder, and Hunters Creeks (tributaries of the Middle Reservoir), and Onion and Big Sheep Creeks (tributaries of the Upper Reservoir). The goals of this study were to 1) determine how Redband Trout from different tributaries utilize the reservoir, 2) if Redband Trout return to their tagging stream the following year (homing), and 3) the frequency of entrainment through Grand Coulee Dam.

Fish were grouped by region of the reservoir (Sanpoil, Spokane River, Middle Reservoir, and Upper Reservoir). Acoustic detections from these fish were incorporated into a dynamic Brownian bridge movement model to estimate utilization of the reservoir by these groups of fish. The estimated utilization by each group over the course of the year was compared with a Mantel's test (Spearman's correlation) to distinguish which groups had similar utilization and which did not.

Redband trout appeared to exhibit distinctive use of the reservoir. Fish from the Sanpoil, Spokane and Middle reservoir tributaries all made extensive use of the lower and middle reservoir and lower Spokane River with few fish moving up the reservoir above Gifford Washington. In contrast most of the fish from Upper Reservoir tributaries remained in the upper reservoir above Gifford. Comparisons of utilization by region showed Sanpoil and the Upper Reservoir were the most distinctive in utilization ($r = 0.051$, $q = 0.025$).

Results from comparisons of utilization distribution show similarities to genetic studies conducted on Lake Roosevelt Redband Trout. Previously, Small et al. (2014) analyzed tissue samples from Redband Trout across the reservoir. Small et al. (2014) found that fish from the Sanpoil River, Spokane Arm, and Middle Reservoir tributaries were most similar to each other with these groups being distinct from the Upper Reservoir. Comparisons of utilization showed a similar pattern in utilization with the exception of only the Sanpoil River fish being distinct from the upper reservoir tributaries. The other groups and the upper reservoir fish likely intermingle in the reservoir throughout the year and return to their spawning streams as evidenced by homing observed in this study.

Homing was confirmed with the use of PIT Tags and entrainment with the use of acoustic receivers. Streams with PIT tag arrays were the Sanpoil River, Blue Creek, Alder, Onion and Big Sheep Creeks. Additional streams without PIT tag arrays were periodically monitored with the use of a hydrophone attached to a receiver.

In total ten Redband Trout exhibited homing the following year. No fish were detected in tributaries other than the ones in which they were tagged in. This is similar to previous years and cumulatively 26 fish were confirmed to home with no instance of PIT tags being detected in streams other than ones they were tagged in.

At the current time there is no evidence from PIT tag arrays that these Redband Trout stray (return to a stream other than the one they were originally from). However, PIT tag arrays are not present in all tributary streams of Lake Roosevelt. Therefore, it is possible some Redband Trout tagged between 2013-2015 fish strayed. Some (minimal) straying likely occurs to explain the results obtained by Small et al. (2014) that indicated the Sanpoil, Spokane, and Middle Reservoir tributary Redband Trout are similar to each other (i.e., although each tributary has its own distinctive frequency of alleles they are all genetically similar to each other so they all appear on the same branch of a dendogram).

Entrainment was confirmed if fish were detected on receivers downstream of Grand Coulee Dam. No entrainment into Rufus Woods Reservoir was confirmed for Redband Trout tagged in 2015. However, four fish were last detected on receivers just upstream of Grand Coulee Dam. Three of these had the majority of detections on the north receiver. These fish may have continued along the north shore and entrained through the third powerhouse of Grand Coulee Dam. This powerhouse is located on the north side of the dam and is the route in which the majority of fish were confirmed to have entrained during a previous study (LeCaire 1998). If these fish did entrain possibilities to explain why they were not detected on the receiver downstream of the dam include: 1) Fish were killed as they passed over or through the dam, mortality for fish passing through or over dams averages 15% (all dams large and small); 2) The tag inside the fish was damaged as fish passing over or through Grand Coulee experience a 100 m elevation change; 3) Fish that passed through the dam were damaged and susceptible to predators, and 4) The nearest receivers to Grand Coulee Dam are 13 km downstream and fish that did entrain may have resided in the river upstream of these receivers.

The fourth fish had the majority of detections on the south receiver. It is possible this fish may have continued along the south shore and was pumped into Banks Lake (a storage reservoir for the Columbia Basin Irrigation Project) through intake pipes located at the southern part of Grand Coulee Dam. Here entrainment has been documented by Stober et al. (1976) who collected 13 species of fish in gill nets set in the feeder canal between Grand Coulee Dam and Banks Lake. Fish collected included Rainbow Trout, Kokanee

Salmon (*O. nerka*), Lake Whitefish (*Coregonus clupeaformis*), and Burbot (*Lota lota*). It would be beneficial for future telemetry studies to place a receiver in Banks Lake near the outflow of the feeder canal of Banks Lake to address the possibility of entrainment into Banks Lake.

Entrainment was documented for Redband Trout tagged in 2013 and 2014. Between 2013 and 2014 five Redband Trout entrained and between 2014 and 2015 three entrained over Grand Coulee Dam as they were detected in Rufus Woods Reservoir. Noticeable differences in reservoir operation were seen between these years. For example, between 2015 and 2016 when no entrainment was observed, the lowest Lake Roosevelt was drawn down was 13 m below full pool. Between 2014 and 2015 the reservoir was also drawn down 21 m below full pool. Such drawdowns reduce the water retention time (time it takes water to move through the reservoir). During the month of lowest reservoir elevation the average water retention time was 28 days in 2015, 21 days in 2014-2015, and 24 days in 2013-2014. Low reservoir level and short water retention time has been shown to correlate with entrainment of hatchery rainbow trout below Grand Coulee dam (McLellan et al. 2008).

We chose to tag post spawn Redband Trout to monitor their movements after leaving what was presumed to be their spawning stream. Of the 81 tagged in 2015 18 were detected into 2016, 22 of 60 tagged in 2014 were detected into 2015, and 15 of 51 tagged in 2013 were detected into 2014. Total number detected into the following year was 55 of 192, indicating there was approximately 28.6% survival of kelts (for this study a kelt is defined as a post spawn Redband Trout) from one spawning season to the next spawning season. Kelt survival from one spawning season to the next of steelhead (ocean going

Rainbow Trout) is typically low. Little literature is available on the mortality of post spawn freshwater rainbow trout, but studies on steelhead indicate survival to the next spawning season in the Upper Columbia is 3-5% and upwards of 17% in Coastal streams (Trammell et al. 2016). Natural mortality in post spawn Rainbow Trout is typically high and may explain the disappearance of tagged Redband Trout.

Angling mortality could also explain the disappearance of Redband Trout tagged from 2013-2015. It is unlikely mortality due to fish predators is responsible for the disappearance of these fish as these were adult Redband Trout (average length 415 mm). Over the course of the three years 5 transmitters from tagged Redband Trout were returned by anglers. Previously, harvest rules on Lake Roosevelt did not distinguish between Redband Trout (with an adipose fin) and hatchery triploids (lacking an adipose fin) stocked in the reservoir to provide angling opportunities. From creel surveys, McLellan (2015) estimated 3,735 Redband Trout were harvested across Lake Roosevelt between 2014 and 2015. The estimated population of adult Redband Trout spawners from all tributaries of Lake Roosevelt was near 5,000 (McLellan 2015). With the harvest potentially taking a large proportion of potential spawners, harvest rules have been changed since the conclusion of this study and currently harvest is only allowed on hatchery rainbow trout.

I recommend future acoustic telemetry studies on Lake Roosevelt include placement of additional receivers to understand fish movement in this system. Currently there is no receiver in place to detect entrainment into Banks Lake. Based on range testing I suggest moving a receiver in Lake Roosevelt that is performing poorly at its current location (e.g.

the Spring Canyon Boat Launch receiver that detected 35% of tracks) to the north end of Banks Lake.

I plan to assist in preparing a publication encompassing all three years of data for submission to a peer reviewed journal. The method used to analyze this data is unique in that it has only been used for telemetry data on terrestrial animals. Walston et al. (2015) was able modify this method for telemetry data gathered on animals that have a defined barrier, such as the confines of a water body for fish.  The method Walston et al. (2015) developed is applicable to similar data collected from other fish telemetry studies and is likely of interest to the fisheries community.

Maintaining this population of Redband Trout is essential for the survival of this species, and for the return of anadromous fish above Grand Coulee Dam. Redband Trout have diverse life history strategies and appear to retain anadromy even after their environment is altered. McLellan et al. (2015) PIT tagged Redband Trout in the Sanpoil River with some individuals appearing in the Columbia downstream of Rock Island Dam. These fish may be exhibiting the potential anadromy and if so, Lake Roosevelt Redband Trout could be a potential source for reestablishing the anadromous form Redband Trout above Grand Coulee Dam if passage is restored.

**Literature Cited**

Cooke, S. J. C. M. Bunt, and J. F. Schreer. 2004. Understanding fish behavior, distribution and survival in thermal effluent using fixed telemetry arrays: a case study Smallmouth bass in a discharge canal during winter. Environmental Management 33: 140-150.

Hudson, J. M., J. R. Johnson, and B. Kynard. 2011. A portable electronarcosis system for anesthetizing salmonids and other fish. North American Journal of Fisheries Management 31: 335-339.

Kessel, S. T., S. J. Cooke, M. R. Heupel, N. E. Hussey, C. A. Simpfendorfer, S. Vagle, and A.T. Fisk. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. Reviews in Fish Biology and Fisheries. 24: 199-218.

LeCaire, R. 1998. Chief Joseph Kokanee enhancement project: 1996 - 1997 annual report. United States Department of Energy, Bonneville Power Administration, Portland,Oregon. Document ID # 113: 92 pp.

McLellan, H. J., S. G. Hayes, and A. T. Scholz. 2008. Effects of reservoir operation on hatchery coastal rainbow trout in Lake Roosevelt, Washington. North American Journal of Fisheries Management 28: 1201-1213.

McLellan H. J. 2015.Lake Roosevelt rainbow trout harvest regulation change request draft. Presented to Redband Trout Technical/Coordination Group, Spokane, Washington. 9 July 2015: 21pp.

McLellan, H. J., B. W. Jones, and E. A. Simonsen. 2015. Colville Confederated Tribes resident fish research, monitoring, and evaluation. 2012 annual report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon.Project No. 2008-109-00. 30 pp.

Muhlfeld, C. C., and B. Marotz. 2005. Seasonal movement and habitat use by subadult Bull trout in the upper Flathead River System, Montana. North American Journal Of Fisheries Management 25: 797-810.

Reischel T. S., and T. C. Bjorn. 2003. Influence of fishway placement on fallback of Adult salmon at the Bonneville Dam on the Columbia River. North American Journal of Fisheries Management 23:1215-24.

Small, M. P., C. Lee, H. McLellan, C. Flanagan, and V. Smilansky. 2014. Lake Roosevelt wild Rainbow Trout genetic study, draft report. Combined report for greater Lake Roosevelt Redband genetic assessment, WDFW Molecular Genetics Lab. 36 pp.

Stober, Q.J. R.W. Tyler, G.L. Thomas, L. Jensen, J.A. Knutzen, D.L. Smith, and R.E. Nakatani.1976. Operation effects of irrigation and pumped/storage on the ecology of Banks Lake, Washington. Third Annual Progress Report June 1, 1975 to May 31, 1976. Contract Number 14-06-100-7794. United States Bureau of Reclamation, Boise, Idaho: 313 pp.

Stroud, D. H. P., A. O. Blake, H. J. McLellan, and A. T. Scholz. 2011. Annual Assessment of hatchery kokanee and sonic tracking of wild and hatchery kokanee In lake Roosevelt. 2011 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 297 pp.

Thorstad, E. B., A. H. Rikardsen, A. Alp, and F. Okland. 2013. The use of electronic tags in fish research- an overview of fish telemetry methods. Turkish Journal of Fisheries and Aquatic Sciences 13:881-896.

Trammell, J. L., D. E. Fast, D. R. Hatch, W. J. Bosch, R. Branstetter, A. L. Pierce. 2016 Evaluating steelhead kelt treatments to increase iteroparous spawners in the Yakima River Basin. North American Journal of Fisheries Management. 36: 876-887.

Walston, J.A. 2015. Effects of anesthetics on rainbow trout swimming ability and statistical comparison of the movements of acoustically tagged redband trout in Lake Roosevelt. MS Thesis, Department of Biology, Eastern Washington University, Cheney, Washington: 171 pp.

# Chapter 1

## Low-Voltage Electroanethesia for Tag Implantation


### Abstract

Telemetry methods are able to acquire knowledge of fish movements which are used for a variety of management decisions. Implanting tags for telemetry requires minor surgery and anesthesia. Anesthesia for tag implantation is typically achieved with chemicals. However, chemicals are inherently variable and have restrictions on their use. This has led to the use of alternative methods for achieving anesthesia such as low voltage electroanesthesia (LVEA). LVEA subjects fish to a continuous non- pulsed direct current to achieve anesthesia appropriate for tag implantation. Unlike chemicals fish are quickly anesthetized and recover from anesthesia instantaneously. My objectives were to subject several species of fish to LVEA and determine if it can bring these species to anesthesia appropriate for tag implantation and if the voltage gradient (volts applied/ distance between electrodes) varies by fish based on size, scale type, species and conductivity of the water. LVEA successfully anesthetized 280 individuals which comprised of 11 species. Ctenoid scaled fish required a significantly higher voltage gradient than cycloid scale fish (Kruskal Wallis chi square = 118, $p<0.001$). Water conductivity was greater where ctenoid scaled fish where collected than cycloid scaled fish ($p<0.0001$). Multiple regression indicated that an interaction of fish length, scale type, water conductivity, and species explained 62% of variation in voltage gradient to anesthetize fish. I suggest agencies that use LVEA record information while using this method and make the information freely available to help form a standard procedure.

## Introduction

Gathering information on fish life history and behavior is a crucial component of fisheries management. Some aspects of life history and behavior are related to movement (Baras 1998). These can be migration (for feeding or reproduction) or the way a fish reacts to its environment, which can be responses to natural or anthropogenic disturbances (Reishel and Bjorn 2003; Welch et al. 2009). Understanding fish movements provides managers with a framework on which to base management decisions (Baras 1998; Hayden et al. 2014).

Acquiring information on fish movements can be accomplished by telemetry studies. These studies involve the implantation of tags that transmit a unique signal, coupled with equipment that can record tag signals as a tagged fish passes by (Heupel et al. 2006). There are three types of tags that are often used to describe fish movement patterns. Passive Integrated Transponder (PIT) tags emit an individual code when exposed to a frequency from an underwater antenna or a hand held detector (Smyth and Nebel 2013). PIT tags are small (less than 25 mm) and cheap allowing for researchers to tag large numbers of fish (Smyth and Nebel 2013). Underwater antennas can be used to determine timing of return to streams. Tags detected on handheld detectors from fish captured during surveys can be searched in databases to determine where the fish was originally tagged, and when to gather information on movement.

For studies in which an investigator would like to locate fish in open water, two options are available. Radio tags actively emit a radio signal that encodes a set of numbers unique to the tag which can be detected and decoded by receivers placed both in and out of the water (Thorstad et al. 2013). Acoustic tags also emit a signal encoded with information unique to the tag. Unlike radio tags the signal is only detected by receivers placed in the water (Thorstad et al. 2013). Both radio and acoustic tags emit signals at specific intervals and have predetermined battery life. Radio tags have the advantage of being able to track fish into small spawning streams (Paluch 2011; Thorstad et al. 2013), whereas acoustic tags can track fish in water deeper than radio tags are able to (Thorstad et al. 2013). Radio tags can be detected to maximum depth of 10 m due to how a radio signal moves exits the water at an angle, whereas acoustic tags can be detected at nearly any depth (Thorstad et al. 2013).

Valuable information can be gathered from telemetry studies. For example, Reishel and Bjorn (2003) used radio tags to determine the movement of adult Chinook Salmon (*Oncoryhnchus tshawytscha*) through fish passage facilities at Bonneville Dam on their upstream migration to spawn. All fish were tagged at the downstream end of the dam, released, tracked through the fish passage facility and a short distance upstream of the dam. Of these 21% (26 of 122) were subsequently detected downstream of the dam. Reishel and Bjornn (2003) determined this behavior from radio telemetry receivers placed up and downstream of the dam. In addition, they also followed individual fish as they exited fish passage facilities to move upstream. One fish ladder exit was along an island upstream of the dam and 90% of tagged fish followed the shoreline of this island. This particular shoreline led near the spillway of the dam where a variety of factors such as visibility, current and temperature, may have led some fish to move downstream and back over the dam. Reishel and Bjorn (2003) noted salmon fallback over this dam could lead to an overestimate of population size since fish can be counted more than once as they ascend the dam again. Reishel and Bjorn (2003) suggested the exit of the fish ladder be extended to the opposite shoreline from the island to potentially reduce the fallback behavior of salmon at this particular dam.

Fish telemetry studies can also be used to collect data on fish movements over the entire lifespan of the animals in question. Currently extensive arrays of receivers used to track tagged fish exist in ocean environments, major lakes, reservoirs and rivers (Heuppel et al. 2006; Welch et al. 2009; Welsh 2012). Welch et al. (2009) implanted 876 Sockeye Salmon (*Oncorhynchus. nerka*) smolts from 2004-2007 with acoustic tags in the Fraser River drainage of British Columbia. These tagged fish were detected on an array of stationary receivers in the Fraser River as well as the Pacific Ocean surrounding Vancouver Island. Welsh et al. (2009) used detections of these tagged fish at sea to infer migration patterns of smolts. Of the 876 tags used by Welsh et al. (2009), 280 of them had a preprogrammed sleep period, meaning tags would transmit for a predetermined period of time, go dormant and reactivate at a later date when the fish were on their adult migration back to the Fraser River. Unfortunately for Welsh et al. (2009) none of the fish tagged with “sleeper tags” appear to have survived their time at sea. However, the technology exists to track individuals over their lifetime.

Implantation of radio and acoustic tags involves minor surgery and requires anesthesia for the procedure to occur safely. The anesthesia is typically achieved with chemical anesthetics. Fish are placed in a chemical bath to achieve anesthesia. Fish have achieved the level of anesthesia required to implant tags when they lose equilibrium (are unable to remain upright), do not respond to external stimuli, and their opercula (gill covering) continue to move. The amount of time it takes the fish to reach this level of anesthesia is the induction time. Once fish are anesthetized they can be placed on a moist surface (typically a sponge with a v notch) with the ventral side of the fish up for tag implantation. During the time a fish is on this surface for implantation water with the chemical anesthetic flows over its gills from a tube attached to a bucket. An incision is made into the body cavity on the ventral side offset from the midline of the body, tag is inserted, and the incision is closed with sutures. After the incision is closed the fish is placed into water without any chemical anesthetic to come out of anesthesia. The fish is ready to be released when it is upright and responsive to external stimuli. The amount of time it takes the fish to come out of anesthesia and be releasable is the recovery time.

Two commonly used anesthetics for tag implantation are Tricaine Methanesulfonate commonly known as MS-222 (Hudson et al. 2011) and clove oil derivatives such as AQUI-S 20E. MS-222 is a highly soluble white crystalline powder that forms a colorless acid when placed in water (Marking 1967). It is absorbed across the fish's gills and suppresses action potentials in the central nervous system (Spath and Schweikert 1977). MS-222 is carcinogenic in its powdered form and is currently approved for use on fish that may be potentially consumed as long as they are held for at least 21 days before release, or on fish that cannot be harvested, such as threatened and endangered species (Hudson et al. 2011). Another anesthetic, AQUI-S 20E allows for immediate release of fish but requires the researcher to obtain a $700 investigational permit (Keep et al. 2015). The compound's active ingredient is eugenol. It works similar to MS-222 by being absorbed through the gills and inhibiting the central nervous system (Bowker et al. 2015).

Chemical anesthetics are useful but there are drawbacks to their use. Dosage for MS-222 has been extensively studied for multiple species and there are well established operating procedures of its use (Marking 1967; Murphy and Willis 1996). Induction times for chemical anesthetics can vary between 2 to 5 minutes and recovery times can vary between 15 and 45 minutes (Hudson et al. 2011). Variable times for induction and recovery coupled with lengthy holding periods prior to release have lead fisheries biologist to look for alternative means of fish sedation (Hudson et al. 2011; Trushenski and Bowker 2012).

Low-Voltage Electroanesthesia (LVEA) is an alternative form of fish sedation that is becoming increasingly popular for tag implantation (Balazik et al. 2013; Keep et al. 2015). LVEA is the process of subjecting a fish to continuous (nonpulsed) direct current to immobilize it. Fish are placed in a mesh cradle between two electrodes situated in a cooler that are attached to a power source. Voltage is gradually increased until the fish is unable to remain upright. Fish remain in the water with the current during the entire time a tag is implanted. Direct nonpulsed electric current interferes with medullary motor paths which in turn inhibit spinal reflexes causing a loss of equilibrium (Henyey et al. 2002). However, gill movement is still maintained while the fish is in the electrical field (Henyey et al. 2002). This is important as fish are still able to respire while in the electrical field. Amperages are typically less than 100 milliamps and depending on fish size voltage is less than 50 volts (Hudson et al. 2011). Unlike chemical anesthetics, induction and recovery times are nearly instantaneous, as fish immediately become upright after current is turned off (Hudson et al. 2011). Additional benefits are fish subjected to this method can be released immediately and no investigational permit is required. Finally, some species of fish such as catfish are fairly resistant to chemical anesthetics (Waterstrat 1999), using low voltage current for sedation may prove useful for these species.

LVEA offers some form of anesthesia during tag implantation surgeries. For example, Balazik et al. (2013) analyzed blood cortisol (hormone typically associated with stress) concentrations of Atlantic Sturgeon (*Acipenser oxyrinchus*) subjected to incisions and sutures associated with tag implantation. Cortisol concentration in fish anesthetized with MS-222 and LVEA were comparable to each other, and both were much lower than fish subjected to incisions and sutures without any anesthetic mechanism (Balazik et al. 2013). This indicated that fish exposed to LVEA had reduced stress than those that were subjected incisions and sutures without an anesthetic.

Concerns about LVEA include survival of both fish and eggs after exposure. Previously, most work on the effects of electricity on fish has been concerned with electrofishing (Dalby and MacMahon 1994). Typically pulsed direct current is used for electrofishing, with high frequency (Hz) being the most detrimental to fish wellbeing (Dalby and MacMahon 1994). Hudson et al. (2011) used LVEA to radio tag Bull Trout (*Salvelinus confluentus*) and did not see any evidence of mortality during the time tags were active. The Colville Confederated Tribes acoustically tagged Rainbow Trout in 2015 and there was no evidence of mortality fish after tagging (Witte and Scholz 2017). There are concerns that as the electric current passes through fish it may cause gametes to become unviable. Studies on Steelhead Trout (*Oncorhynchus mykiss*) and Coho Salmon (*O. kisutch*) have indicated that eggs remain viable after fish are exposed to LVEA (Keep et al. 2015). It appears that the electrical waveform used for LVEA does not damage fish and is safe for use in implanting tags.

Despite increasing popularity, information on use of LVEA to implant tags in commonly tagged North American species is somewhat lacking. Previous studies have exposed several sturgeon species (*Acipenser* spp.), Rainbow Trout, Bluegill (*Lepomis macrochirus*), and Gulf coastal fishes to LVEA (Henyey et al. 2002; Balazik et al. 2013; Trushenski and Bowker 2012; Rous et al. 2015). The voltage gradient which is the voltage divided by the spacing between the electrodes necessary to achieve anesthesia has been reported to range from 0.25 – 0.54 V/cm (Curray and Kynard 1978; Hudson et al. 2011). However, this voltage gradient can vary with water conductivity and between species of fish (Hudson et al. 2011). Water conductivity can influence the amount of electricity that goes into a fish compared to the electricity that dissipates in the water around it (Hudson et al. 2011). Size of fish and scale thickness can influence fish's susceptibility to electrofishing (Emery 1984). Current literature suggests the need for further studies of this method of fish sedation on more species (Hudson et al. 2011; Trushenski and Bowker 2012; Rous et al. 2015).

**Objectives**

My objectives were to determine if LVEA is effective at bringing the fish species I tested to the level of anesthesia required for tag implantation and compare necessary voltage required for anesthesia for several species by, size, scale type, and water conductivity.

## Methods

I used an apparatus similar to the one described by Hudson et al. (2011). This consisted of a cooler with two metal electrodes attached to a BK Precision model 9110 60V/5A power supply (Figure 1-1). This power supply was connected to a 12 volt battery via an inverter to allow for use in field locations. A mesh cradle was placed between the electrodes that were situated in the cooler.

Several species present in the Pacific Northwest that I exposed to LVEA were chosen due to their documented use in telemetry work (Table 1-1). Methods of fish collection were angling and boat electrofishing. Electrofishing was conducted in accordance with guidelines set by the American Fisheries Society and with IACUC approval (IACUC 2016-06-01). Settings on the electrofisher were at the minimum and increased until the minimum current to catch fish was produced (Reynolds 1996). Settings were 30 Hz 20% frequency 300 volts DC at 2-3 amps. All fish were measured in total length to the nearest millimeter, and weighed on a portable electronic scale to the nearest gram prior to being placed in the LVEA apparatus.

Once placed in the LVEA apparatus all fish were subjected to the same procedure. The fish was oriented head toward the positive electrode, since this orientation results in the quickest induction and recovery time (Rous et al. 2015). The voltage was slowly increased until the fish lost equilibrium. The voltage remained at this point for 30 seconds to ensure that the fish was not responding to external stimuli. After that time the voltage was recorded, the power source was turned off and fish resumed its normal state.


Figure 1-1. Portable LVEA Apparatus as described in text. Consists of cooler, electrodes (A), power supply (B), inverter (C), and battery (D).

Table 1-1. Fish species chosen to be exposed to LVEA with scale type and reference to tagging study.* All white sturgeon were from Eastern Washington University aquatics facilities.

| **Scale Type** | **Species** | **Reference to Tagging** |
|---|---|---|
| Ganoid | *White Strugeon (*Acipenser transmontanus*) | Robichaud et al. (2017) |
| Cycloid | Northern Pikeminnow (*Ptychocheilus oregenesis*) | Weitkamp et al. (2003) |
| Cycloid | Tench (*Tinca tinca*) | Donnelly et al. 1998 |
| Cycloid | Largescale Sucker (*Catostomus macrocheilus*) | Baxter (2003) |
| Cycloid | Longnose Sucker (Catostomus catostomus) | Sweet (2007) |
| Cycloid | Lake Trout (*Salvelinus namaycush*) | Flavelle et al. (2002) |
| Cycloid | Bull Trout (*Salvelinus confluentus*) | Muhlfeld and Marotz (2005) |
| Ctenoid | Largemouth Bass (*Micropterus salmoides*) | Hanson et al. (2007) |
| Ctenoid | Smallmouth Bass (*Micropterus dolomeiu*) | Cooke et al. (2004) |
| Ctenoid | Black Crappie (*Pomoxis nigromaculatus*) | Petering and Johnson (1990) |
| Ctenoid | Walleye (*Sander vitreus*) | Hayden et al. (2014) |

All fish were returned to location of capture after testing. Voltage applied between the electrodes was divided by the space between electrodes in cm to obtain the voltage gradient.

### *Data Analysis*

The relationship between voltage gradient and fish length, scale type, conductivity, and species were analyzed by multiple regression for all fish and by species. Comparisons of voltage gradient between fish of different scale types and water conductivity where different scaled fish were collected were made using a Kruskal-Wallis Test. Significance were determined with alpha = 0.05. Relationships between voltage gradient and size of fish by species were analyzed by linear regression.

## Results

Eleven species comprised of 280 individuals were exposed to LVEA during this study (Table 1-2). LVEA successfully brought all individuals to a level of anesthesia appropriate for tag implantation. Multiple regression indicated that length and species were the most important variables to explain the variation in voltage gradient among all species (Table 1-3). There appeared to be a distinct difference in the voltage gradient to anesthetize cycloid and ctenoid scaled fish. Mean voltage gradient for cycloid fish was 0.41 v/cm (range 0.13 -0.79) which was significantly higher (Kruskal Wallis chi square = 118 $p<0.0001$) than mean gradient to sedate cycloid scaled fish (mean 0.19 v/cm range 0.06 - 0.40). However, water conductivity differed when these fish were collected (Figure 1-2). Mean water conductivity was 136 µS/cm (range from 35 to 330 µS/cm) for cycloid scaled fish and 249 µS/cm (range 96 to 330 µS/cm) for ctenoid scaled fish. Mean water conductivity was significantly greater for ctenoid scaled fish than cycloid scaled fish ($p<0.001$). I collected Largemouth Bass a ctenoid scaled fish on Silver Lake (n = 25) and Tench a cycloid scaled fish (n = 4) on April 28, 2017. The voltage gradient range for Tench (0.20 – 0.24 v/cm) was within the range for Largemouth Bass (0.16 – 0.24 v/cm) on this day (conductivity = 330 µS/cm). This indicates that scale type may not influence voltage gradients to sedate fish, rather conductivity may be more important.

Range of voltage gradients somewhat differed between species but there appeared to be little relationship between voltage gradient and size of fish for individual species of cycloid fish (Figure 1-3) and individual species of ctenoid scaled fish (Figure 1-4) with the exception of Black Crappie and Lake Trout.

Table 1-2. Species collected for study by number, length, weight, and voltage gradient to achieve sedation. LKT = Lake Trout, BLT = Bull Trout, NPM= Northern Pikeminnow, LSS = Largescale Sucker, LNS = Longnose Sucker, TNC = Tench, BLC = Black Crappie, LMB = Largemouth Bass, SMB = Smallmouth Bass, WAL = Walleye, and WHS = White Sturgeon.

| Species | Median Length (Range) | Median Weight (Range) | Median Voltage Gradient (Range) |
|---|---|---|---|
| LKT (n = 120) | 425 (325 – 611) | 641 (349 – 1620) | 0.19 (0.06 – 0.40) |
| BLT (n = 20) | 349 (265 – 854) | 408 (150 – 6500) | 0.10 (0.07 - 0.27) |
| NPM (n = 4) | 288 (285- 423) | 193 (188 – 582) | 0.27 (0.22 – 0.31) |
| LSS (n = 22) | 473 (425- 549) | 1309 (728 – 1900) | 0.29 (0.21 – 0.36) |
| LNS (n = 3) | 433 (407 – 501) | 886 (790- 1720) | 0.29 (0.29 – 0.35) |
| TNC (n = 5) | 205 (143-359) | 85 (49 – 421) | 0.22 (0.20 – 0.24) |
| BLC (n = 20) | 200 (168 – 224) | 121 (16 – 174) | 0.32 (0.19 – 0.48) |
| LMB (n = 25) | 393 (256 – 494) | 607 (280 – 2009) | 0.24 (0.16 – 0.24) |
| SMB (n = 28) | 265 (150 – 400) | 213 (128 – 864) | 0.54 (0.13 – 0.79) |
| WAL (n = 14) | 407 (230 - 525) | 551 (87 – 1099) | 0.32 (0.15 - 0.38) |
| WHS (n = 19) | 615 (510 – 792) | NA | 0.24 (0.13 – 0.31) |

Table 1-3. Comparison of linear models for predicating voltage gradient (V.cm in table) across all fish sampled.

| **Model** | **p - value** | **$R^2$** |
|---|---|---|
| V.cm ~ Fish Length | < 0.0001 | 0.24 |
| V.cm ~ Fish Length + Scale Type | < 0.0001 | 0.32 |
| V.cm ~ Fish Length + Scale Type + Conductivity | < 0.0001 | 0.40 |
| V.cm ~ Fish Length + Scale Type + Conductivity + Species | < 0.0001 | 0.62 |

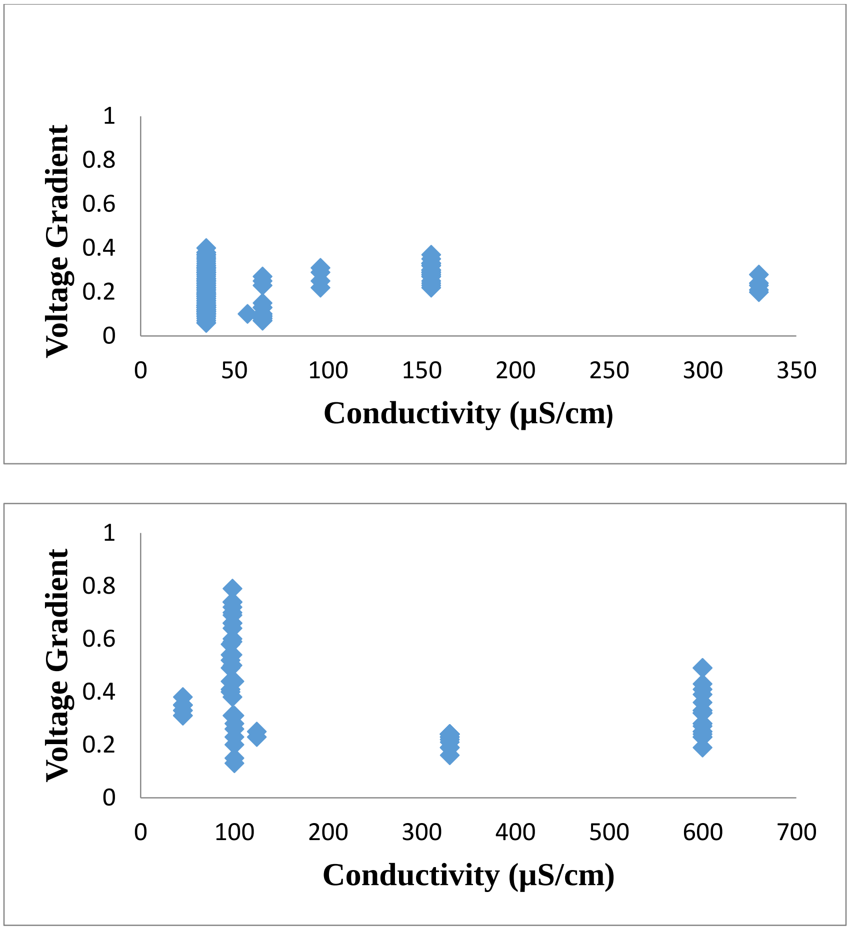


Figure 1-2. Voltage gradients for cycloid scale fish (top) and ctenoid scaled fish (bottom) compared to water conductivity. Conductivity was greater where ctenoid scaled fish were captured compared to cycloid ($p<0.001$).

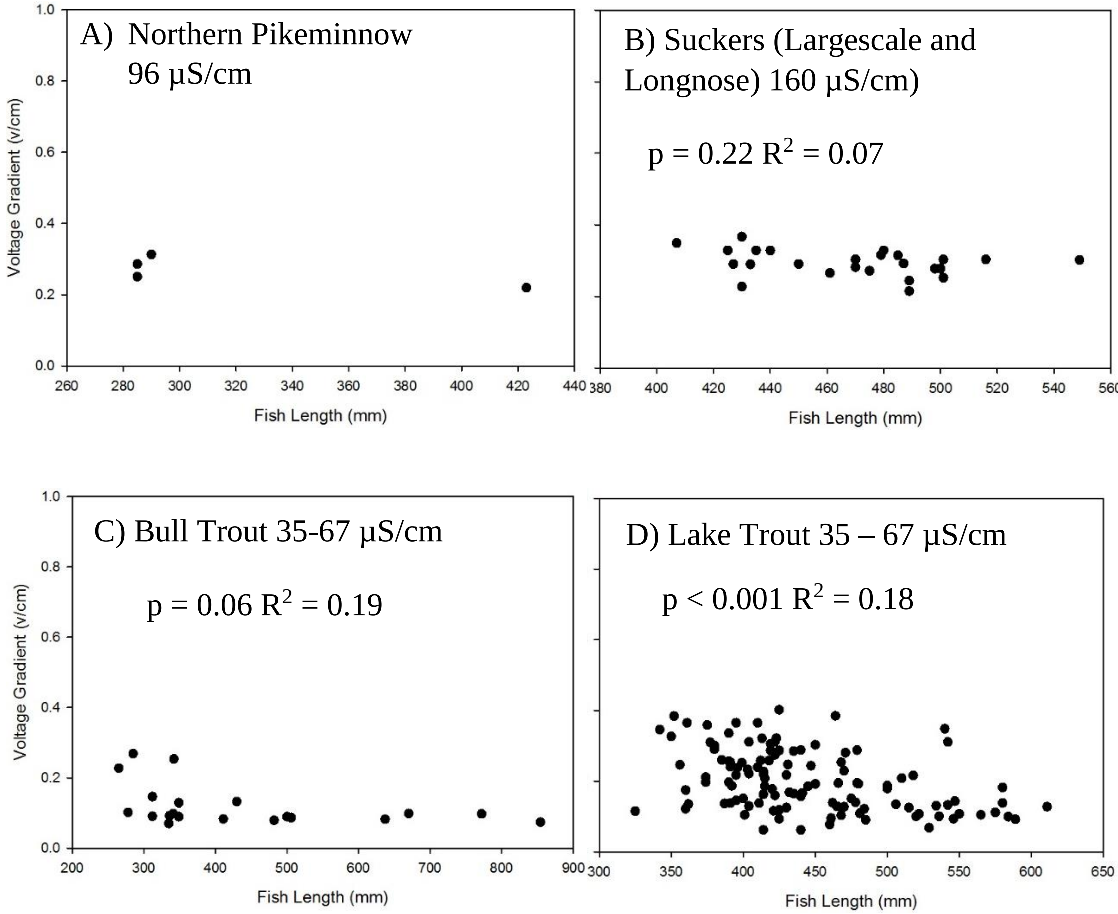


Figure 1-3. Scatterplots of voltage gradient by length of fish for four species of cycloid scaled fish. A) Northern Pikeminnow, B) Suckers (Large Scale and Longnose), C) Bull Trout, and D) Lake Trout. Given with each plot are range of conductivity encountered along with p-value for relationship between voltage gradient and fish length with $R^2$.

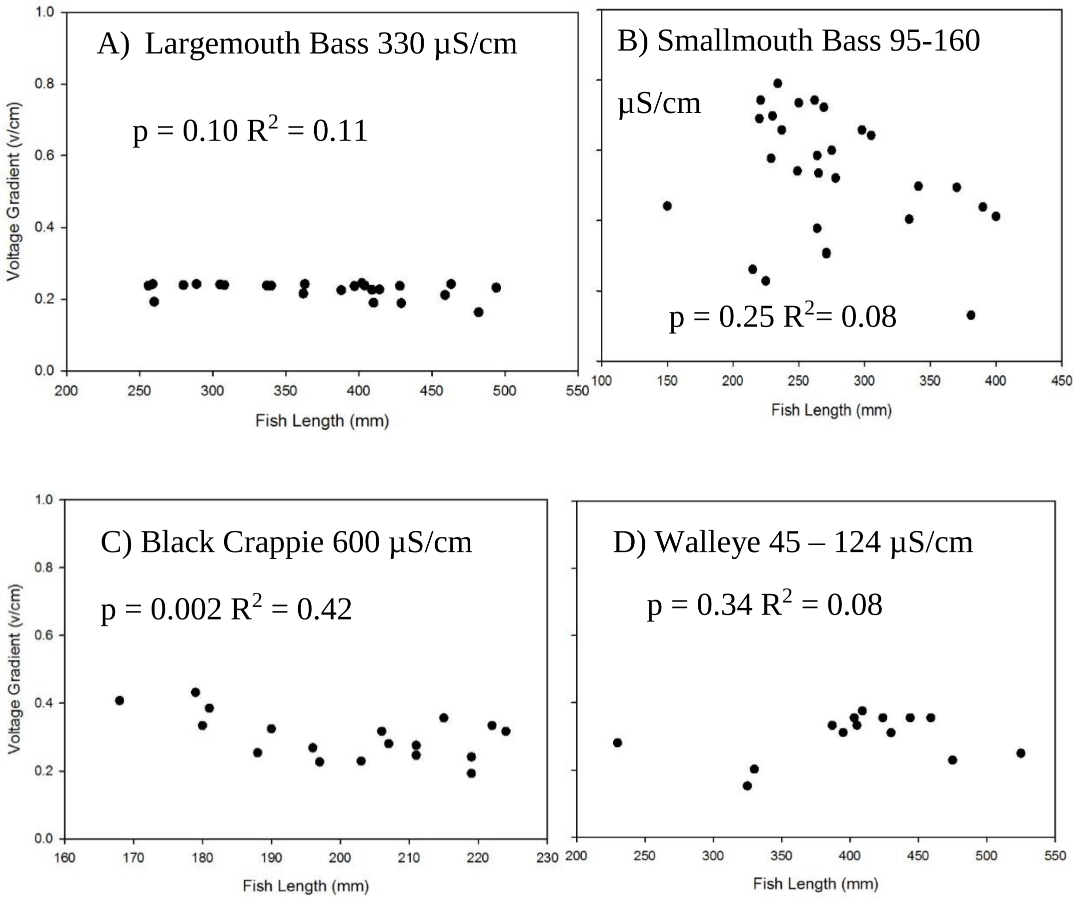


Figure 1-4. Scatterplots of voltage gradients by fish length for four species of ctenoid scaled fish. A) Largemouth Bass, B) Smallmouth Bass, C) Black Crappie, and D) Walleye. Shown on each plot are range of conductivity encountered along with p –value for relationship between voltage gradient and size of fish and $R^2$.

## Discussion

LVEA is an appropriate alternative to other anesthetics for tag implantation. Fish immediately come out of anesthesia as soon as the power is turned off. This method successfully sedated all 280 fish during this study. To my knowledge this is the first study to subject Northern Pikeminnow, Largescale Sucker, Lake Trout, Black Crappie, and Smallmouth bass to LVEA. Previous studies have shown a range of voltage gradients to sedate fish but these can be influenced by water conductivity and fish species.

Water conductivity is a confounding factor to explain the difference in voltage gradient applied between ctenoid and cycloid scaled fish as water conductivity was significantly higher for ctenoid scaled fish than cycloid scaled fish. When cycloid and ctenoid scaled fish were sampled from the same water body they had similar voltage gradients to be sedated. With the multiple regression water conductivity explained 8% of the variance in voltage gradient whereas species explained 22% of the variance in voltage gradient. All together an interaction of fish size, scale, water conductivity, and species explained 62% of the variation in voltage gradient. This indicates that voltage gradient is specific to the type of fish tagged and conditions when tagging.

Within each species there was little relationship between size of the fish and voltage gradient to sedate the fish. Previous studies on electrofishing indicate that larger fish are more effectively captured with less electricity than smaller fish (Dalby and McMahon 1996). The waveform used for electrofishing is pulsed DC and voltage required to sedate fish with LVEA that uses non-pulsed DC may not necessarily translate between these two waveforms. There was an exception with relationship between voltage gradient and fish length. Black crappie had a significant negative relationship between voltage gradient and length of fish. A potential explanation for this may be related to the surface area of the fish because Black Crappies are saucer shaped as their length increases so does the surface area to absorb electricity.

When first working with this method at Eastern Washington University in 2014, Walston (2015) placed fish in the LVEA apparatus and sedated them by turning on the power set at a specific voltage. This worked to sedate the fish although during some trials fish would respond by jolting to the sides of the cooler as soon as voltage was applied. The method used by this study is a fined tuned approach to sedate fish by individuals as the voltage is incrementally increased from zero. Fish do not jolt to the sides of the cooler; rather they stay in the field and eventually roll over when the voltage gradient has reached a threshold to anesthetize them.

Future use of this methodology for tag implantation should incorporate a standard operating procedure. Data collected for this standard operating procedure can be obtained during tagging studies. Currently, The Washington State Department of Fish and Wildlife, Colville Confederated Tribes, and Kalispel Tribe all utilize LVEA for tagging of fish. I propose that during tagging studies researchers' record several parameters while tagging each fish and make them available. This would be similar to the investigational permit used for studying AQUI-S 20E but would be free to those that are uploading data to it.  Data collected from these investigations would encompass several fish species and varying water conditions. With this data a standard operating procedure would be produced to make the use of LVEA a standard and effective anesthetic option.

# Literature Cited


Balazik, M. T., B. C. Langford, G. C. Garman, M. L. Fine, J. K. Stewart, R. J. Latour and S. P. Mclnich. 2013. Comparison of MS-222 and electronarcosis as anesthetics on cortisol levels in juvenile Atlantic Sturgeon. Transactions of the American Fisheries Society, 142: 1640-1643.

Baras, E. 1998. Selection of optimal positioning intervals in fish tracking: an experimental study on *Barbus barbus*. Hydrobiologia 371: 19-28.

Baxter, J. S., G. J. Birch, and W. R. Olmsted. 2003. Assessment of a constructed fish migration barrier using radio telemetry and floy tagging. North American Journal of Fisheries Management 23: 1030-1035.

Bowker, J. D., J. T. Trushenski, D. C. Glover, D. G. Carty, and N. Wandelear. 2015. Sedative options for fish research: a brief review with new data on sedation of coldwater fishes and recommendations for the drug approval process. Reviews in Fish Biology and Fisheries. 25: 147-163.

Cooke, S. J. C. M. Bunt, and J. F. Schreer. 2004. Understanding fish behavior, distribution and survival in thermal effluent using fixed telemetry arrays: a case study Smallmouth bass in a discharge canal during winter. Environmental Management 33: 140-150.

Curry, K. D. and B. Kynard. 1978. Effect of extended galvanonarcosis on behavior of rainbow trout, *Salmo gairdneri*, and channel catfish, *Ictalurus punctatus*. Journal of Fisheries Research Board of Canada 35: 1297-1302.

Donnelly, R. E., J. M. Caffrey, and D. M. Tierney. 1998. Movements of bream (*Abramis brama* (L.)), rudd x bream hybrid, tench (*Tinca tinca* (L.)) and pike (*Esox lucius* (L.)) in an Irish canal habitat. Hydrobiologia: 305-308.

Emery, L. 1984. The physiological effects of electrofishing. California-Nevada Wildlife Transactions 1984: 59-72.

Flavelle, L. S., M. S. Ridgeway, T. A. Middel, and R. S. McKinley. 2002. Integration of acoustic telemetry and GIS to identify potential spawning areas for lake trout *(Salvelinus namaycush*). Hydrobiologia 483: 137-146.

Hanson, K. C., S. J. Cook, C. D. Suski, G. Niezgoda, F. J. S., Phelan, R. Tinline, D. P. Philipp. 2007. Assessment of largemouth bass (*Micropterus salmoides*) behavior and activity at multiple spatial and temporal scales utilizing a whole lake telemetry array. Hydrobiologia 582: 243- 256.

Hayden, T. A., C. M. Holbrook, D. G. Fielder, C. S. Vandergoot, R. A. Bergstedt, J. M. Dettmers, C. C. Krueger, and S. J. Cooke. 2014. Acoustic telemetry reveals large-scale migration patterns of walleye in Lake Huron. PLOS One 9: e114833. Doi: 10.1371/journal.pone.0 114833.

Henyey, E., B. Kynard, and P. Zhuang. 2002. Use of electronarcosis to immobilize Juvenile Lake shortnose sturgeons for handling and the effects on their behavior. Journal of Applied Ichthyology 18: 502-504.

Heupel, M. R., J. M. Semmens, and A. J. Hobday. 2006. Automated acoustic tracking of aquatic animals: scales, design, and deployment of listening station arrays. Marine and Freshwater Research 57: 1-13.

Hudson, J. M., J. R. Johnson, and B. Kynard. 2011. A portable electronarcosis system for anesthetizing salmonids and other fish. North American Journal of Fisheries Management 31: 335-339.

Keep, S. G, M. B.Aleen, and S. Zendt. 2015. Comparison of electronarcosis and carbon dioxide sedation effects on travel time in adult chinook and coho salmon. North American Journal of Fisherie Management 35: 906-912.

Marking, L. F. 1967. Toxicity of ms-222 to selected fishes. In: Investigations in Fish Control 13 (Shoettger R. A., and A. M. Julian eds.) United States Fish and Service, La Crosse, Wisconsin pp. 3-10.

Muhlfeld, C. C., and B. Marotz. 2005. Seasonal movement and habitat use by subadult Bull trout in the upper Flathead River System, Montana. North American Journal Of Fisheries Management 25: 797-810.

Murphy, B. R. and D. W. Willis, editors. 1996. Fisheries Techniques, 2nd Edition. American Fisheries Society, Bethesda, MD. 732 pp.

Paluch, M. 2011. The movements of bull trout (*Salvelinus confluentus*) above and below Albeni Falls Dam. MS Thesis. Department of Biology, Eastern Washington University, Cheney, Washington: 150 pp.

Petering, R. W., and D. L. Johnson. 1990. Notes: suitability of a cyanoacrylate adhesive To close incisions in black crappies used in telemetry studies. Transactions of the American Fisheries Society 4: 535-537.

Reischel T. S., and T. C. Bjorn. 2003. Influence of fishway placement on fallback of Adult salmon at the Bonneville Dam on the Columbia River. North American Journal of Fisheries Management 23:1215-24.

Reynolds, J. B. 1996. 1996. Electrofishing. In: Fisheries Techniques (Murphy, B. R. and D. W. Willis eds.) American Fisheries Society, Bethesda, Maryland pp. 513-529.

Robichaud, D., K. K. English, and T. C. Nelson. 2017. Annual movments of acoustic Tagged white sturgeon in the lower reaches of the Fraser River and its Tributaries. Transaction of the American Fisheries Society 146: 611-625.

Rous, A. M., A. Forrest, E. H. McKittrick, G. Letterio, J. Roszell, T.Wright, and S. J. Cooke. 2015. Orientation and position of fish affects recovery time from electrosedation. Transactions of the American Fisheries Society 144: 820-828.

Smyth, B. and S. Nebel. 2013. Passive integrated transponder (PIT) tags in the study of animal movement. Nature Education Knowledge 4(3): 3.

Spath, M. and W. Scweikert. 1977. The effect of metacaine (ms-222) on the activity of The efferent and afferent nerves in the teleost lateral-line system. Naunyn-Schmiedberg's Achieves of Pharmacology 297: 9-16.

Sweet, D. E. 2007. Movement patterns and habitat associations of native and introduced Catostomids in a tributary system of the Colorado River. MS Thesis, Department of Zoology, University Wyoming, Laramie Wyoming: 202 pp.

Thorstad, E. B., A. H. Rikardsen, A. Alp, and F. Okland. 2013. The use of electronic tags in fish research- an overview of fish telemetry methods. Turkish Journal of Fisheries and Aquatic Sciences 13:881-896.

Trushenski, J. T, and J. D. Bowker. 2012. Effects of voltage and exposure time on fish response to Electrosedation. Journal of Fish and Wildlife Management 3:276-287.

Walston, J. A., K. Magori, and A.T. Scholz. 2015. A comparison of the movements of Columbia River Redband Rainbow Trout (*Oncorhynchus mykiss* var. *gairdneri*) tagged with acoustic transmitters in different tributaries of Lake Roosevelt: A A synopsis of 2013 and 2014 data. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 71 pp.

Welch, D. W., M. C. Melnychuk, E. R.Rechisky, A. D.Proter, M. C.Jacobs, A. Ladoucer, R. S. McKinley, and G.D. Jackson. 2009. Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Canadian Journal of Fisheries 66:736-750.

Welsh, J. Q., R. J. Fox, D. M. Webber, and D. R. Bellwood. 2012 Performance of remote acoustic receivers within a coral reef habitat: implications for array design. Coral Reefs 31: 693-702.

Weitkamp, D. E., R. D. Sullivan, T. Swant, and J. DosSantos. 2003. Behavior of resident fish relative to total dissolved gas supersaturation in the Lower Clark Fork River. Transactions of the American Fisheries Society 132: 856-864.

# Chapter 2

## Results from Range Testing Acoustic Receivers on Lake Roosevelt and Rufus Woods Reservoirs


### Abstract

An array of acoustic receivers is in place on Lake Roosevelt and Rufus Woods Reservoirs to study the movements of important fish species. The receivers in this array cannot determine how far away an acoustically tagged fish is from the receiver when an acoustic signal is detected on a receiver. Therefore, it is important to test the range at which these receivers can detect tags to understand where detections are likely coming from and to potentially improve the array by suggesting where to put additional receivers. I evaluated the receiver array with three methods: 1) stationary range testing which was done with a known delay tag at known distances from the receiver in 4 cardinal directions and at three depths at each location, 2) with telemetry data from tagged Redband Trout, and 3) float range testing conducted in the swift water downstream of Grand Coulee Dam. In total 43 receivers were stationary range tested. Generalized linear model indicated that detection frequency declined to 75% 100 m from receivers, 50% 300 m from receive and 25% 500 m from receiver. Tracks of tagged fish indicated 26 of 44 receivers detected greater than 70% of the fish that pass by them Float Range testing indicated the receivers below Grand Coulee Dam are functioning well as a gate..

## Introduction

Passive acoustic telemetry is a method widely used to determine movements of aquatic organisms (Heupple et al. 2006; Welsh et al. 2012; Kessel et al. 2014). Passive acoustic telemetry systems employ battery powered transmitters (tags) and receivers. A signal encoding information specific to a tag is sent from the tag through the water and is decoded by a receiver. This allows for individually tagged fish to be identified. (Welsh et al. 2012). Multiple receivers can be put in place throughout the study area forming an array to monitor movements of tagged fish (Selby et al. 2016). Researchers can use data from these acoustic receiver arrays to infer timing of movement and area of use by the species in question (Heuppel et al. 2006; Selby et al. 2016).

Receivers are limited in the distance at which they can detect signals from tagged fish. The strength of an acoustic signal naturally decreases with distance (Kessel et al. 2014). Water quality, bottom topography, and turbulence can impact how quickly the strength of a signal from an acoustic tag diminishes (Heuppel et al. 2006). When a receiver detects a signal from a tag, it is usually unable to determine where the tag is in relation to a receiver (with some exceptions, e.g., HTI 3D positioning system, and Lotek MAP systems). All that can be determined from detections is the tag was within the detection range of the receiver.

Detection range for receivers do not have an agreed upon definition in the literature (Kessel et al. 2014). One definition of detection range is the maximum distance that a receiver can detect a tag, others define it as the distance in which a certain proportion of transmissions are detected (Selby et al. 2016). Another definition of detection range is “the relationship between detection probability and the distance between the receiver and tag” which can be shown graphically as a descending curve (Kessel et al. 2014).

The probability of detecting a fish moving past a receiver can be influenced by the physical limitations of the receiver (detection range) or behavior of fish migrating in a path outside the detection range. This information can be used to understand and improve an array of receivers (Heupple et al. 2006; Welsh et al. 2012; Kepple et al. 2014). Understanding the detection ranges of receivers is crucial information that can be used to place receivers in a manner that allows for adequate coverage for the study question. Acquiring information on the detection range of receivers is accomplished by range testing.

Range testing can be accomplished in different ways. One way is with stationary range testing where a tag with a known ping rate (emits signals at known time intervals) is positioned at varying distances from a receiver and at known times for each distance (Welsh et al. 2012). The information is downloaded and analyzed, typically as number of detections divided by number of transmissions from the tag over the period of time it was at that distance from the receiver. Another way is by drift or float testing. This is similar to stationary range testing but the tag drifts with wind or current past or away from the receiver (Kessel et al. 2014). Other authors have used detections from tagged organisms across a receiver array to determine their movements and noting which receivers along a fish’s path detects the tag and which receivers do not. This later method does not attempt to determine a detection range for receivers but can offer insight into where they may be apparent gaps in a receiver array (Kessel et al. 2014).

An acoustic receiver array is in place on Lake Roosevelt, a 240 km long reservoir of the Columbia River in Eastern Washington. Lake Roosevelt has had a history of acoustic telemetry to monitor fish movements. Movements of White Sturgeon (*Acipenser transmontanus)* (Howell and McLellan 2007), both hatchery and wild Kokanee Salmon (*Oncoryhychus nerka*) (McLellan et al. 2009, 2010; Scholz et al. 2011; Stroud et al. 2012, 2013; Parsons 2014), and wild Columbia River Redband Trout (*O. mykiss gairdneri*) (Stroud et al. 2014; Walston et al. 2015; Stroud 2015; Walston 2015; Witte and Scholz 2017). The receiver array consists of 52 VEMCO VR2W receivers deployed from 13 km downstream of Grand Coulee Dam River Kilometer (RKM 953.6) to the Canadian Border (RKM 1,190.0). Receivers in this array typically hang three to four meters below the surface on a cable attached to an anchored buoy.

In three locations receivers are arranged as a “gate” with two receivers across from each other to be able to detect any tags that go by the area of the gate. Two of these gates are within Lake Roosevelt, with one just upstream of Grand Coulee Dam at Spring Canyon (RKM 962.4) and the other at Hunters (RKM 1,070.0). The third is downstream of Grand Coulee Dam in Rufus Woods Reservoir near the mouth of the Nespelem River (RKM 940). This later gate was set in place to detect entrainment over Grand Coulee Dam. The gates in Lake Roosevelt have never been range tested. The one below Grand Coulee Dam provides a challenge to range test with the stationary method due to current. Previously a receiver upstream of this gate was evaluated by float testing (Stroud et al. 2011).

Previous range testing and analysis of fish tracks has been conducted on Lake Roosevelt (Stroud et al. 2012, 2013; Walston et al. 2015). These previous range tests were carried out in two directions (to either bank) from a receiver and in 250 meter intervals. Tags were not detected beyond 500 meters from receivers. These tests provided up to four points around a receiver with detections at known distances which is somewhat inadequate to determine the relationship between detection probability and distance from the receiver as defined by Kessel et al. (2014). Since the time of these range tests new receivers have been added to the receiver array. We tested 45 of 52 receivers in the array with more points around each receiver and in different directions to better ascertain the detection ranges of the receivers in this array. Walston et al. (2015) determined the upper portion of the array was not as effective as lower portion at detecting tagged fish, stating the quick flowing or shallow water may limit the detection range of the upper array receivers. With this information we planned to determine if the detection ability of receivers differs between regions of the reservoir.

**Objectives**

My objectives were 1) determine the detection range of receivers in the array by stationary range testing; 2) identify any apparent gaps in the receiver array by analyzing the tracks of tagged Columbia River Redband Trout in Lake Roosevelt, and 3) determine the performance of the receiver gate below Grand Coulee Dam by float range testing.

## Methods

Receivers, their location by river km, coordinate, and method(s) by which they were evaluated are listed in Table 2-1. Locations of receivers in the array are shown in Figure 2-1.

### *Stationary Range Testing Methods*

The first method used to evaluate receiver effectiveness was stationary range testing. A receiver was approached, brought on board, battery checked and coordinates recorded. Tests were conducted at three distances in four directions (N, E, S, and W) around each receiver (Figure 2-2). These distances were determined by dividing the length between the receiver and shoreline by three if this length was less than 500 meters. If this length was greater than 500 meters than the distances were 500 divided by three. For directions that did not go towards the shore each distance was also 500 meters divided by three. Distances were determined with a hand held GPS. Once the boat was at a distance an anchor was set to hold the boat in place at that distance.

Once the anchor was secure a range testing tag was deployed. This tag (VEMCO V-7 with a seven second delay) specifically made for range testing was placed on a rope five meters above a 10 kg anchor. This rope was lowered to the bottom and the tag was at three depths (five meters above the bottom, middle water column, and five meters below the surface) for 200 seconds at each depth. The amount of time at each depth was chosen since we had previously determined the seven second delay tag should be detected every 10 seconds (due to the slight delay it takes the receiver to decode a signal) and 200 seconds would yield 20 transmissions. After the test at one distance the anchor was pulled, and the boat was moved to the next distance. This process was repeated 12 times around each receiver (Figure 2-2). At the conclusion of the test the receiver was downloaded and data stored for future analysis. We were unable to complete tests in all four directions around receivers in the Upper Reservoir. These receivers were Kettle Falls, North Gorge, Flat Creek, China Bend, Little Dalles and North Gorge. For these receivers we tested across to the shoreline from the receivers.

***Tagged Fish Trajectory Methods***

From 2015-2016 Redband Rainbow Trout implanted with acoustic tags in Lake Roosevelt were passively monitored on the receiver array. The detection histories are stored at Eastern Washington University in a database. Receivers are arranged by reservoir kilometer in the database so I compared the receivers that detected a fish along its track to a list of receivers in the reservoir to determine if any receivers along a fish's track did not detect it (Figure 2-3). Receivers at end points of the array in Lake Roosevelt (the first receiver above Grand Coulee Dam or the receiver the furthest up the Spokane River) were not evaluated with tagged fish detections because I cannot determine if fish went past these points.

Detection ranges of receivers from stationary range testing were used in conjunction with tagged fish trajectory methods. The distance between the outer edges of the detection range to nearest shoreline was measured to the nearest 10 m in ARCMAP. The percent of fish detected on a receiver and distance outside of the detection range of the receiver were used to determine where fish are likely moving in relation to the shoreline. For example, if the distance to the shore from the outside of the detection range of a receiver is long and the proportion of fish detected on that receiver is high then it is likely fish are passing by the side of the reservoir near the receiver. If the percent of fish detected on a receiver is low then it is likely the fish are passing by the side of the reservoir well outside of the detection range of the receiver.

***Float Range Testing Methods***

On two occasions the receiver gate below Grand Coulee Dam was float tested (Figure 2-4). The first occasion was with a known delay transmitter (with a seven second delay to ascertain the detection range of the receivers) in 2015 and on the other occasion with a random 180-300 second delay transmitter (to mimic the transmitter used to tag fish) in 2016. Tags were placed in a similar manner to those used for the stationary range testing and the tag was placed 5 meters below the surface. The boat was positioned 400 meters upstream of the receiver gate and drifted 400 meters below the gate for each drift of the float test. During each drift coordinates were recorded every 5 minutes to ascertain the path the boat was drifting. The test in 2015 was done with nine drifts (3 between shoreline and each receiver and between receivers) and in 2016 20 drifts were conducted with 10 between receivers and 10 between the north receiver and bank on account of the shift in receiver positions. Tests in 2016 with the random delay transmitter also used a VEMCO VR 100 hydrophone to record the number of transmissions from this tag. This was done to determine detection frequency on these receivers with this random delay transmitter.

***Data Analysis***

All data from the three above categories were analyzed with the free statistical program R (www.r-project.org). Detection probability (number of detections on the receiver/number of transmissions by the tag) is plotted against distance from the receiver and analyzed by a generalized linear mixed model (GLMM) with individual receivers as the random effects. Outputs of this model were overlaid onto a map of the reservoir per receiver with ARCGIS 10.4. The farthest from receivers these outputs went was 500 m as that was the farthest we tested.

Receivers that were tested in all direction in the main reservoir body subdivided into regions of the reservoir (Lower = receiver five to 13 and SP1) Middle = receiver 14 to 25; Upper = 26 to 35). Comparisons of detection frequency were made with a Kruskal Wallis Test between the regions in three distance groups (<165 m, 165-330m, and 330-500m). If significance was found a Dunn's test was used to determine specific differences (Dunn 1964). In addition comparisons of detection frequency were made between depth classes (bottom, middle and surface) at the aforementioned distance groups in each region. Again these comparisons were made with a Kruskal Wallis Test.

Float test detection data were plotted onto a map with ARCGIS to examine tag locations by drift when detections occurred on receivers. Detection Frequency between the two receivers for the 2016 test was compared with a Kruskal Wallis Test.

Receivers were ranked with tag fish data by proportion detected. Proportion detected and distance between edge of detection range and shoreline where examined to determine correlation.

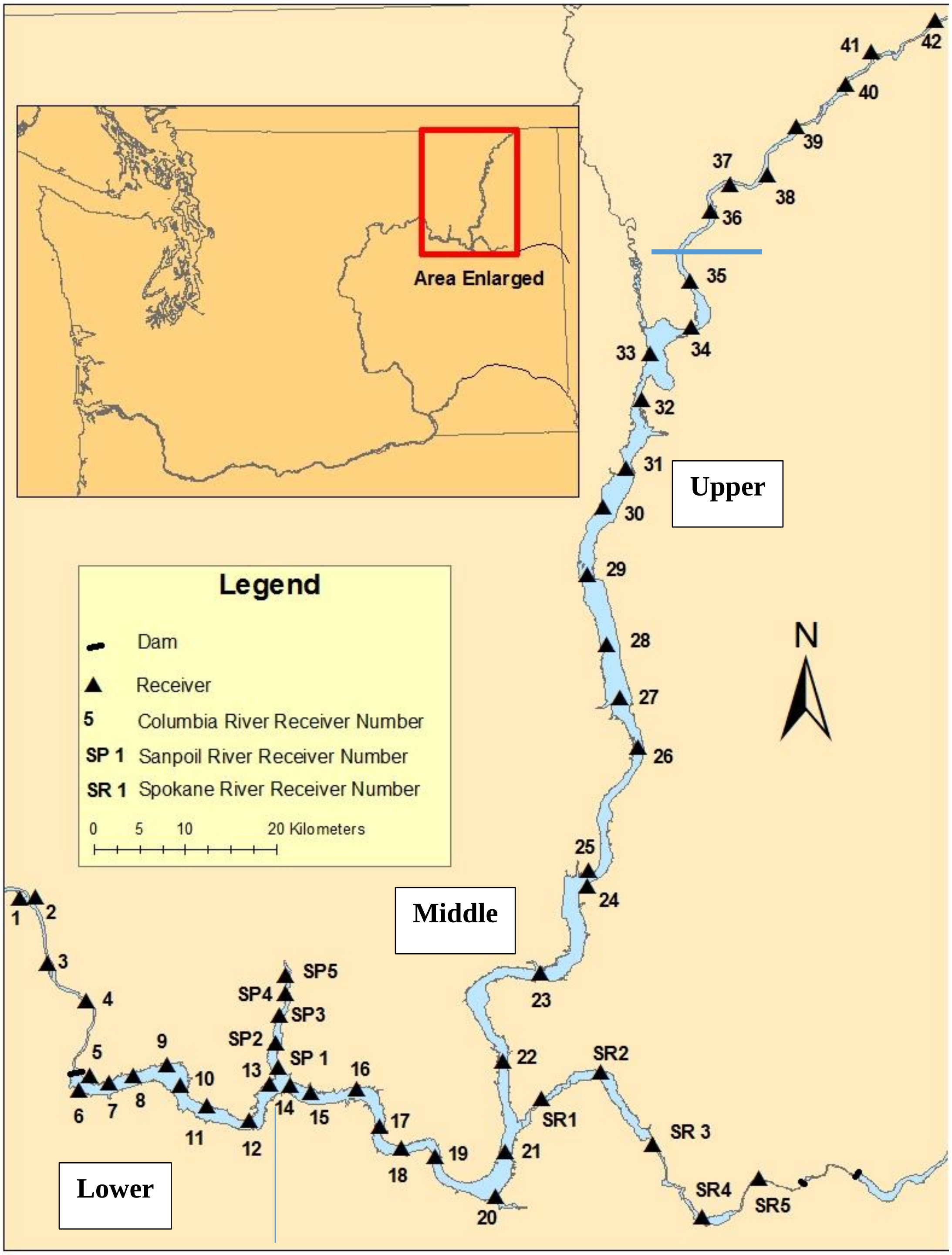


Figure 2-1. Map of receiver locations with region of the main reservoir

Table 2-1. Receivers evaluated in this study with latitude, longitude, river kilometer and method employed for each receiver (SP= Sanpoil River, SR= Spokane River, 1= stationary range testing, 2=float testing, and 3 = tagged fish trajectory, NE=Not Evaluated). Page 1 of 2.

| No. | River Km | Receiver | Latitude | Longitude | Method |
|---|---|---|---|---|---|
| 1 | 940.0 | Nespelem North | 48.12717 | -119.04401 | 2 |
| 2 | 940.0 | Nespelem South | 48.12614 | -119.04644 | 2 |
| 3 | 944.6 | Buckley Bar | 48.06529 | -119.01654 | 1 |
| 4 | 948.8 | Seaton's Grove | 48.03682 | -118.97552 | NE |
| 5 | 962.4 | Spring Canyon North | 47.94323 | -118.95462 | 1 |
| 6 | 962.4 | Spring Canyon South | 47.93779 | -118.95581 | 1 |
| 7 | 965.5 | Spring Canyon | 47.94493 | -118.92883 | 1,3 |
| 8 | 968.0 | Spring Canyon Camp | 47.94944 | -118.89706 | 1,3 |
| 9 | 971.3 | Plum Point West | 47.95865 | -118.85766 | 1,3 |
| 10 | 975.3 | Plum Point East | 47.93467 | -118.82943 | 1,3 |
| 11 | 979.3 | Camel Rocks West | 47.91978 | -118.78762 | 1,3 |
| 12 | 984.9 | Camel Rocks East | 47.90214 | -118.71642 | 1,3 |
| 13 | 989.7 | Keller Ferry West | 47.93152 | -118.70901 | 1,3 |
| SP1 | 991.0 | Sanpoil Buoy A | 47.94882 | -118.68600 | 1,3 |
| SP2 | SP 1.6 | Sanpoil Mouth | 47.96188 | -118.69256 | 3 |
| SP3 | SP 6.9 | Sanpoil Middle | 47.99245 | -118.68353 | 3 |
| SP4 | SP 8.7 | Sanpoil Arm Buoy B | 48.01203 | -118.67242 | 3 |
| SP5 | SP 10.9 | Sanpoil Camp | 48.027 | -118.669 | NE |
| 14 | 989.7 | Keller Ferry East | 47.93843 | -118.66530 | 1,3 |
| 15 | 992.2 | Hanson Harbor | 47.92767 | -118.61789 | 1,3 |
| 16 | 995.4 | Whitestone Creek | 47.93303 | -118.56144 | 1,3 |
| 17 | 999.4 | Whitestone Rock | 47.90028 | -118.53391 | 1,3 |
| 18 | 1,003.4 | Halverson Canyon | 47.87510 | -118.51991 | 1,3 |
| 19 | 1,007.4 | Burbot Creek | 47.86485 | -118.45594 | 1,3 |
| 20 | 1,013.1 | Hawk Creek | 47.82549 | -118.37244 | 1,3 |
| 21 | 1,020.3 | Seven Bays | 47.86465 | -118.35300 | 1,3 |
| SR1 | SR 4.8 | Fort Spokane | 47.91607 | -118.30206 | 1,3 |
| SR2 | SR 11.1 | McCoy's Marina | 47.94482 | -118.22707 | 1,3 |
| SR3 | SR 22.5 | Upper Spokane River | 47.87255 | -118.13604 | 1,3 |
| SR4 | SR 32.2 | Harker Canyon | 47.80176 | -118.07917 | 1,3 |
| SR5 | SR 41.8 | Spokane Tribal BL | 47.83430 | -117.98350 | 1 |
| 22 | 1,035.6 | Castle Rock | 47.96057 | -118.35055 | 1,3 |
| 23 | 1,053.0 | Wilmont Cove | 48.04183 | -118.31779 | 1,3 |

Table 2-1 Continued. Receivers evaluated in this study with latitude, longitude, river kilometer and method employed for each receiver (SP= Sanpoil River, SR= Spokane River, 1= stationary range testing, 2=float testing, and 3 = tagged fish trajectory, NE=Not Evaluated). Page 2 of 2.

| No. | River Km | Receiver | Latitude | Longitude | Method |
|---|---|---|---|---|---|
| 24 | 1,070.0 | Hunters South | 48.13592 | -118.21472 | 1,3 |
| 25 | 1,070.0 | Hunters North | 48.13953 | -118.21772 | 1,3 |
| 26 | 1,080.0 | Bissell Island | 48.26492 | -118.14310 | 1,3 |
| 27 | 1,084.3 | Gifford | 48.28700 | -118.15438 | 1,3 |
| 28 | 1,091.9 | Mission Point | 48.36045 | -118.18363 | 1,3 |
| 29 | 1,105.6 | Chalk Grade | 48.43502 | -118.20287 | 1,3 |
| 30 | 1,112.9 | French Rocks | 48.50033 | -118.18298 | 1,3 |
| 31 | 1,120.9 | Rickey Point | 48.54604 | -118.14476 | 1,3 |
| 32 | 1,128.2 | Kettle Falls Marina | 48.59976 | -118.12479 | 1,3 |
| 33 | 1,133.6 | Nancy Creek | 48.65200 | -118.10700 | 1,3 |
| 34 | 1,135.3 | Milepost 110 | 48.67728 | -118.03718 | 1,3 |
| 35 | 1,149.1 | Snag Cove | 48.73621 | -118.05446 | 1,3 |
| 36 | 1,155.3 | North Gorge | 48.78020 | -118.00815 | 1,3 |
| 37 | 1,161.8 | Flat Creek Eddy | 48.81647 | -117.97498 | 1,3 |
| 38 | 1,169.9 | China Bend | 48.81942 | -117.92492 | 1,3 |
| 39 | 1,172.4 | Little Dalles Eddy | 48.86600 | -117.87892 | 1,3 |
| 40 | 1,179.6 | Northport | 48.90539 | -117.80548 | 1,3 |
| 41 | 1,185.9 | Big Sheep Creek | 48.93655 | -117.76200 | 3 |
| 42 | 1,191.5 | Black Sand Dock | 48.97353 | -117.64686 | 3 |

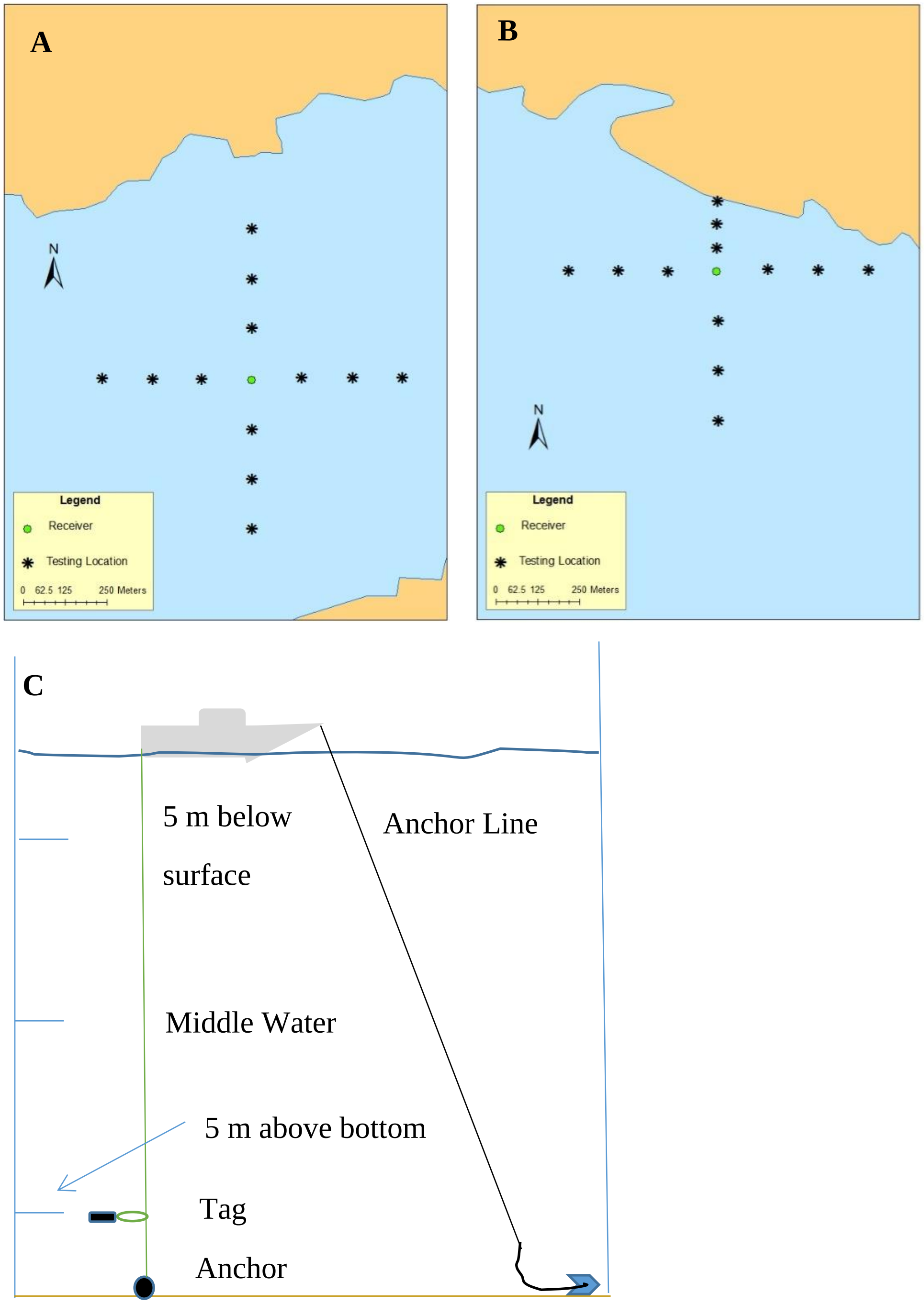


Figure 2-2. Arrangement of testing locations around receivers. A) Maximum distance in each direction is 500 m. B) Distance to one shoreline is less than 500 m. C) Diagram of range testing procedure with depths tested at each location.

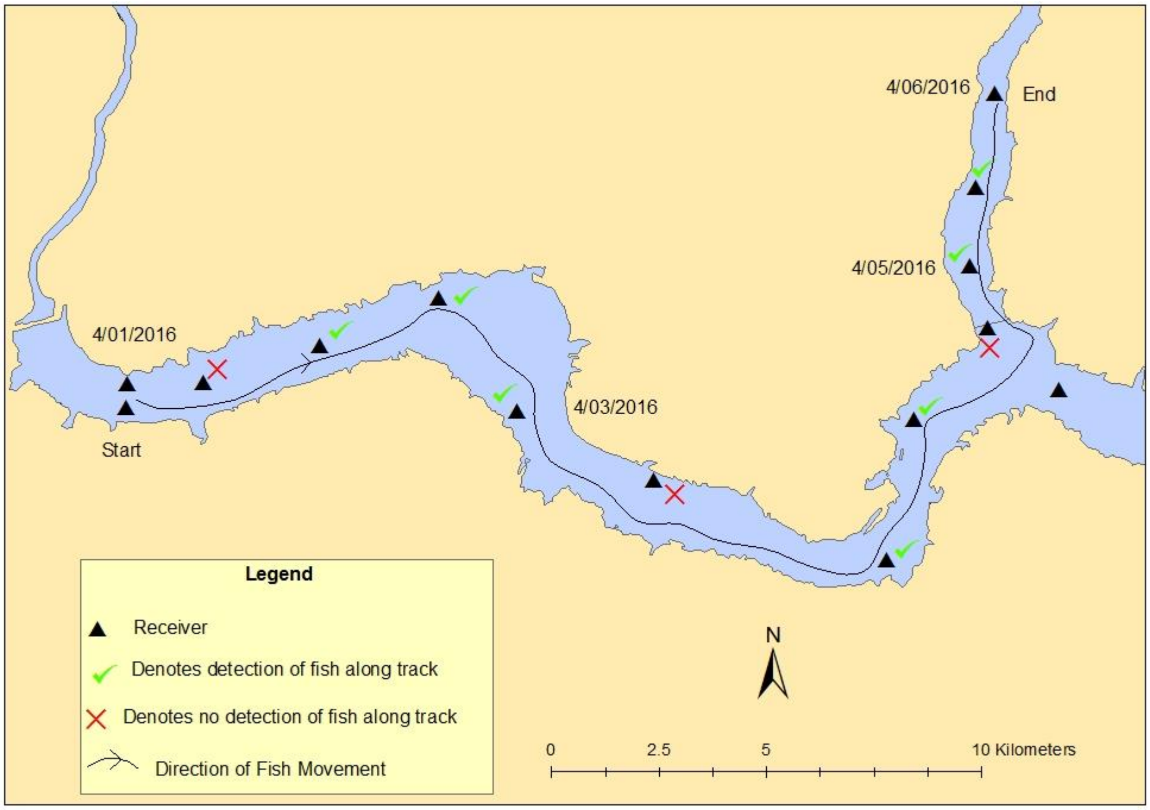


Figure 2-3. An example fish track that started on 4/01/2016 and ended on 4/06/2016. Dates indicate when detections occurred. Red X's next to receiver denote no detection, and green checks next to receiver indicate detection. This example track starts at 4/01/2016 and passed by 10 receivers. Of these receivers, seven detected the tag and three did not.

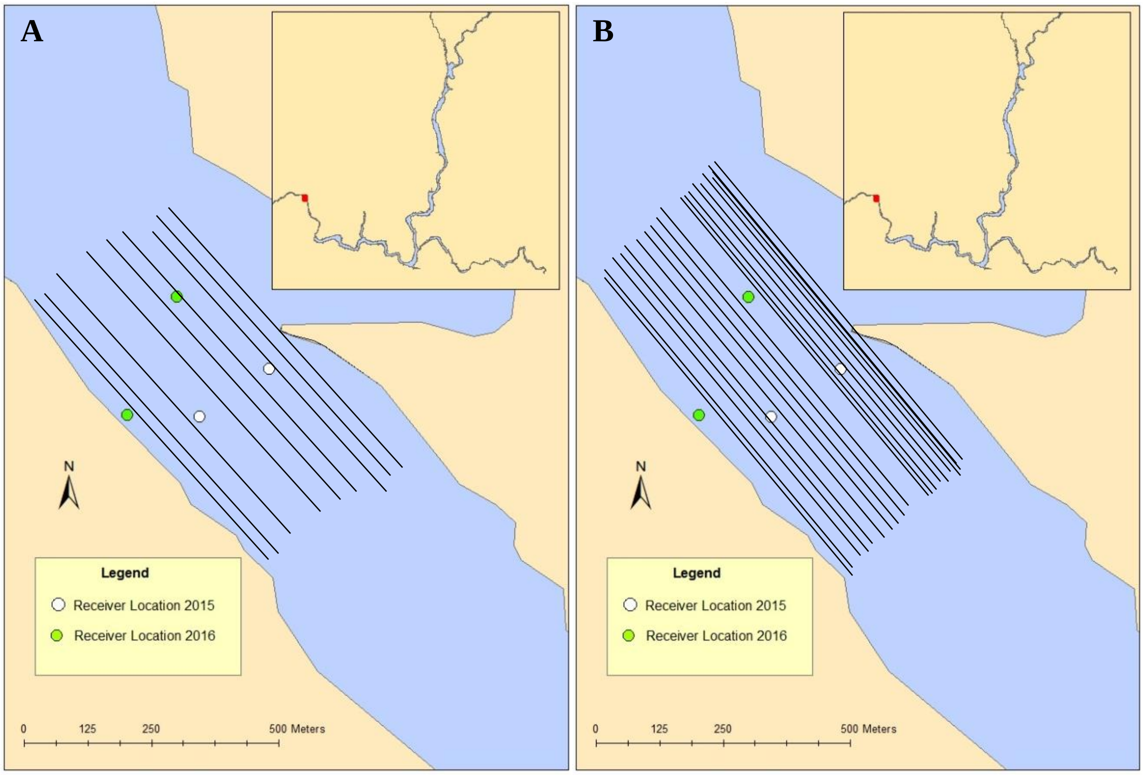


Figure 2-4. Layout of receivers and Nespelem Float Tests. White dots are receiver locations in 2015 and green dots are receiver locations in 2016. A) Planned drifts for 2015 were three between each receiver and adjacent shoreline, and three between receivers. B) Planned drifts for 2016 which were 10 between receivers and 10 between North receiver and adjacent shoreline.

## Results

### *Stationary Range Testing*

Forty three receivers were stationary range tested (10 in 2015, and 33 in 2016). Across the array predicted detection probability decreased to 75% 100 m from receiver 50% at 300 m, and 25% 480 m from the receivers as shown by the distance effect plot from the GLMM (Figure 2-5.) In total there were 1,202 observations of detection frequency across the receivers tested. Outputs of the GLMM were used to inform detection ranges, and detection probability by direction summarized in Table 2-2.

Distance from the edge of the detection range to the shoreline (right bank, and or left bank) was determined as was relative probability in direction around receivers. Right or left bank is relative to an observer facing downstream. Probability of detection with distance from receiver was organized into three categories based on parallel or perpendicular to shore. These categories were 1) probability of detection decreased the same with distance in parallel and perpendicular directions; 2) Probability of detection decreased less with distance parallel to shore and 3) probability of detection decreased less with distance perpendicular to shore.

Across the array, receivers differed in their detection probability with direction. Detection probability was similar at different distances in all directions (n = 7 receivers), generally greater parallel to shore (n = 11 receivers) and generally greater perpendicular to shore (n = 16 receivers) for all receivers that were tested in all directions. Distance between edge of detection range and shoreline ranged from 30 to 2,000 meters. Of the 43 receivers, eight had detection ranges that extend across the reservoir where they were situated at (Table 2-2.).

Figure 2-6 shows detection probabilities around four receivers. These are color coded around the receiver with darker shades of red showing higher detection probability. There are four shades of red each progressively darker with the first shade that represents 5-24% detection probability, the next shade is 25-49%, the third shade is 50-74%, and the last shade is 75-100% detection probability. These same maps were made for 43 receivers and can be found in Appendix 1.

Detection frequencies were compared among regions of the reservoir, by depth and direction within regions of the reservoir and within distance groups. Region of the reservoir had significant impact on detection frequency within distances of 165-330 meters (Kruskal Wallis chi square = 6.53, df = 2, p = 0.03) The lower reservoir had significantly higher detection frequency than the upper reservoir at these distances (Dunn Test, z= 2.48, p=0.04, Figure 2-7).

Comparisons of detection frequency from different depth class showed no difference by depth class in the lower reservoir and upper in distance categories (Table 2-3). Depth class did have an effect on detection frequency in the Middle Reservoir (Table 2-3). Detection frequency was greater five meters above the bottom than five meters below the surface (Dunn Test, z=2.47, p=0.04) and the middle water column had greater detection frequency than the surface (Dunn Test, z= 2.31, p=0.03) 165 meters from the receiver in the Middle Reservoir (Figure 2-8). Detection frequency was greater five meters above the bottom than five meters below the surface (Dunn Test, z=2.47, p=0.04) 165-330 m from receivers in the Middle Reservoir (Figure 2-9). Detection Frequency was greater 5 m above the bottom (Dunn Test, z=3.41, p>0.01) than the surface 330-500 m from receivers in the Middle Reservoir (Figure 2-10).

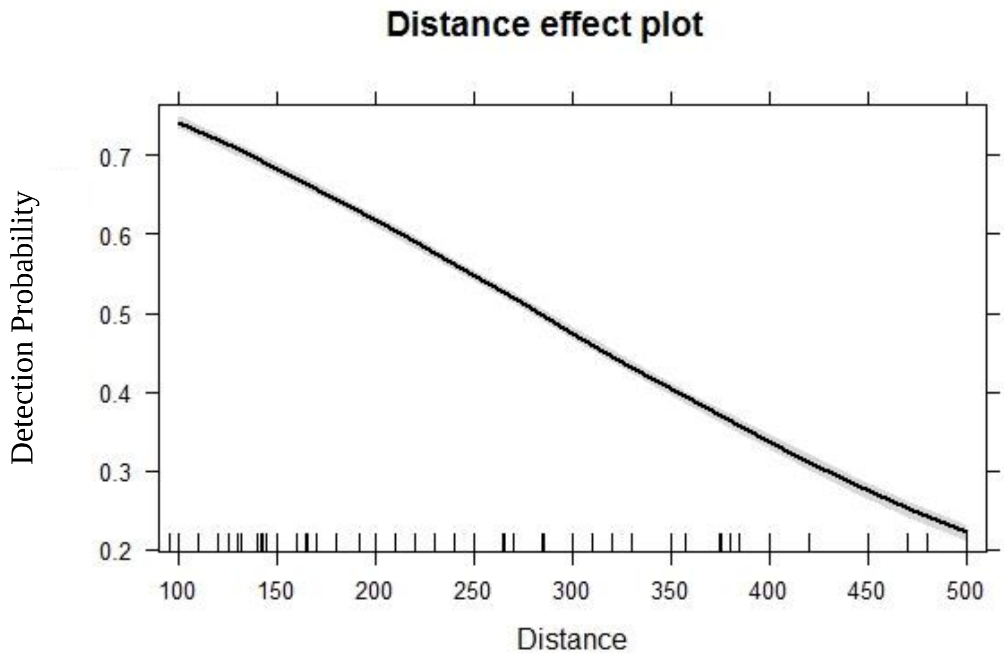


Figure 2-5. Distance effect plot of detection probability by distance from receiver in meters. Gray shading indicate 95% Confidence intervals.

Table 2-2. Summary of stationary range testing by receiver. Par = Parallel to Shore, Per = Perpendicular to Shore. RB = Right Bank, LB = Left Bank. * Denotes detection range across the reservoir. Page 1 of 2.

| **Receiver No.** | **Detection probability with distance by direction** | **Distance to shore from edge of detection range** | **Comments** |
|---|---|---|---|
| 5 | Par = Per | 490 m | Forms Gate |
| 6 | Par > Per | 410 m | Forms Gate |
| 7 | Par > Per | 82 m RB 360 m LB | |
| 8 | Par = Per | 270m RB 210 m LB | |
| 9 | Par > Per | 780 m LB | |
| 10 | Par < Per | 460 m RB | |
| 11 | Par > Per | 800 LB | |
| 12 | Par < Per | 540 RB | |
| 13 | Par < Per | 640 LB | |
| SP1 | Par < Per | 290 LB | Sanpoil Mouth |
| 14 | Par > Per | 70 m RB, 120 LB | |
| 15 | Par = Per | 160 m LB | |
| 16 | Par > Per | 450 m LB | |
| 17 | Par < Per | 240 m LB | |
| 19 | Par > Per | * | |
| 20 | Par < Per | 2,000m RB | |
| 21 | Par < Per | 280 m RB, 250 m LB | |
| SR 1 | Par > Per | * | Spokane River |
| SR 2 | Par = Per | 270 m LB | Spokane River |
| SR 3 | Par =Per | * | Spokane River |
| SR 4 | Par < Per | 125 m RB | Spokane River |
| SR 5 | Par = Per | * | Spokane River |
| 22 | Par < Per | 54 m RB | |
| 23 | Par > Per | 490 m RB | |
| 24 | Par = Per | 375 m RB | Forms Gate |
| 25 | Par > Per | 400 m LB | Forms Gate |
| 26 | Par < Per | 277 m LB | |
| 27 | Par < Per | 240 m LB | |
| 28 | Par < Per | 1,030 m LB | |
| 29 | Par < Per | 900 m RB | |
| 30 | Par < Per | 1,110 LB | |
| 31 | Par < Per | * | Rickey Point |

Table 2-2. Continued. Summary of stationary range testing by receiver. Par = Parallel to Shore, Per = Perpendicular to Shore. RB = Right Bank, LB = Left Bank. * Denotes detection range across the reservoir. Perpendicular indicates receivers tested in two directions. Page 2 of 2.

| Receiver No. | Detection probability with distance by direction | Distance to shore from edge of detection range | Comments |
|---|---|---|---|
| 32 | | 440 m RB | Perpendicular |
| 33 | Par < Per | 840 m LB | |
| 34 | Par > Per | * | |
| 35 | Par > Per | 30 m RB | |
| 36 | | * | Perpendicular |
| 37 | | 193 m RB | Perpendicular |
| 38 | | 586m RB | Perpendicular |
| 39 | | * | Perpendicular |
| 40 | | 110 m LB | |

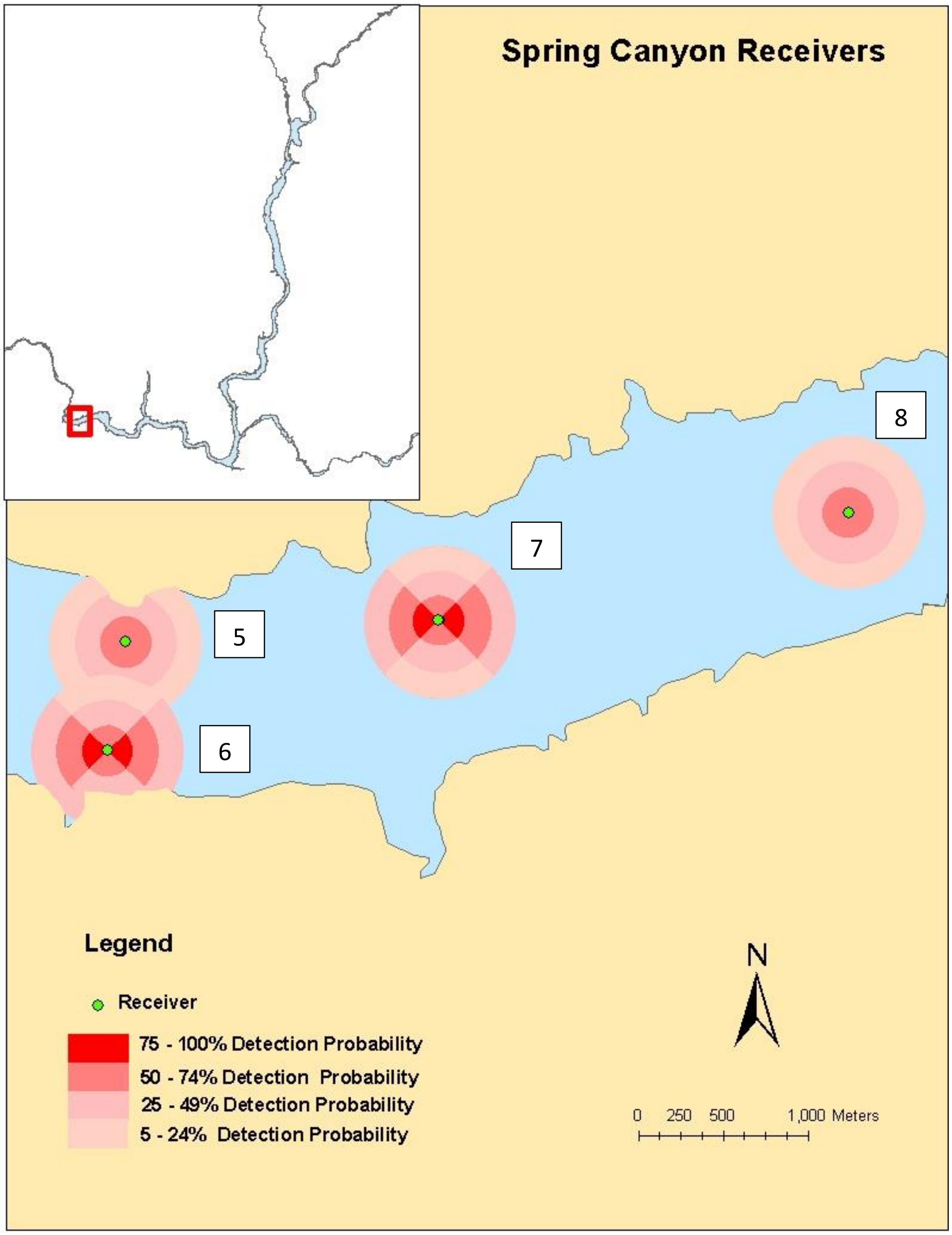


Figure 2-6. Output of detection probability from GLMM, receivers 6 and 7 have detection probability decrease the same with distance in all directions. Receivers 6 and 7 have detection probability generally higher parallel than perpendicular to shore.

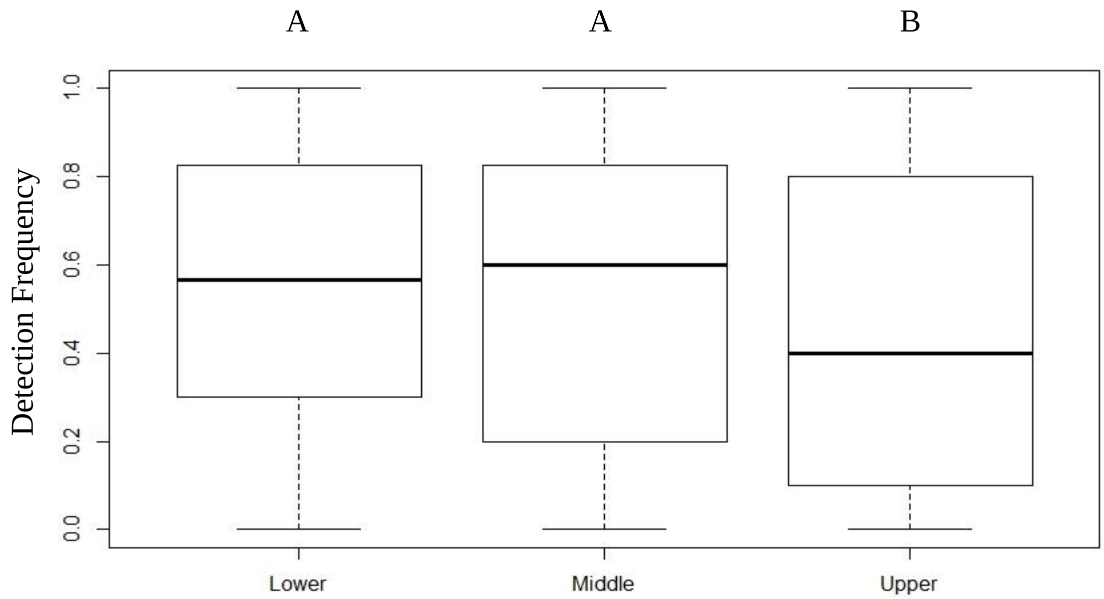


Figure 2-7. Boxplot of detection frequency within 165-330 m from receivers by region. Detection Frequency was higher in the lower than upper region (p<0.001).

Table 2-3. Comparison of Detection Frequency by Depth Class by range of distance from receivers for each region. With Kruskall-Wallis Chi Square and *p*-value (df=2).

| Region | Range | Kruskall-Wallis Chi Square | *p*-value |
|---|---|---|---|
| Lower | < 165 m | 3.75 | 0.15 |
| | 165-330 m | 0.65 | 0.72 |
| | 330-500 m | 3.68 | 0.16 |
| | | | |
| Middle | < 165 m | 8.12 | 0.02 |
| | 165-330 m | 6.12 | 0.04 |
| | 330-500 m | 12.24 | < 0.01 |
| | | | |
| Upper | < 165 m | 6.02 | 0.05 |
| | 165-330 m | 2.0 | 0.3 |
| | 330-500 m | 0.67 | 0.71 |

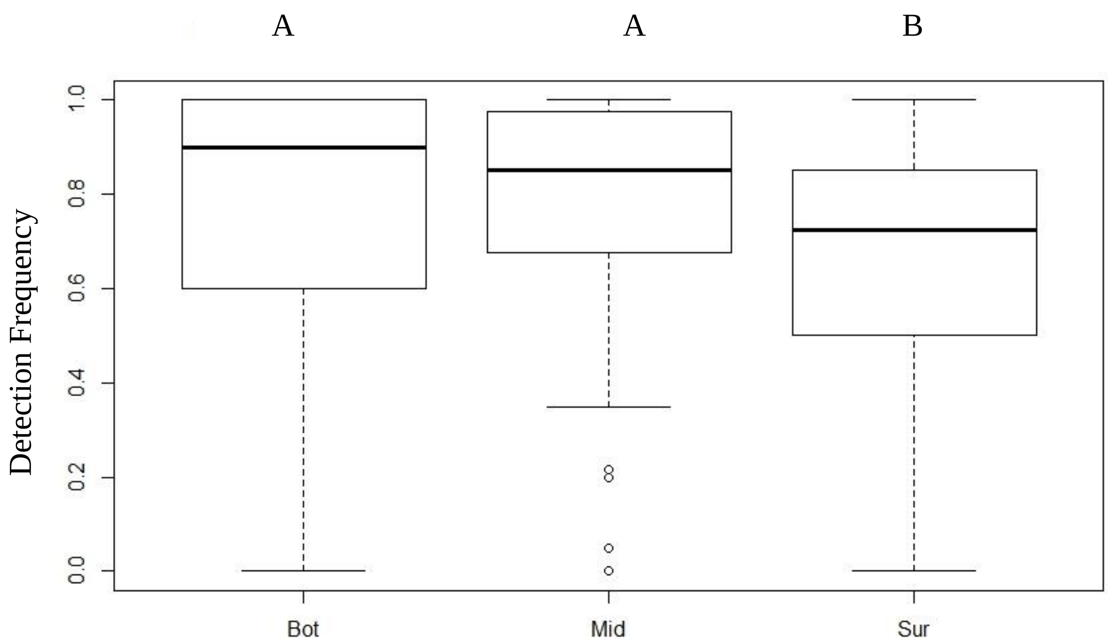


Figure 2-8. Boxplot of detection in the middle reservoir within 165 m of receivers by depth class.

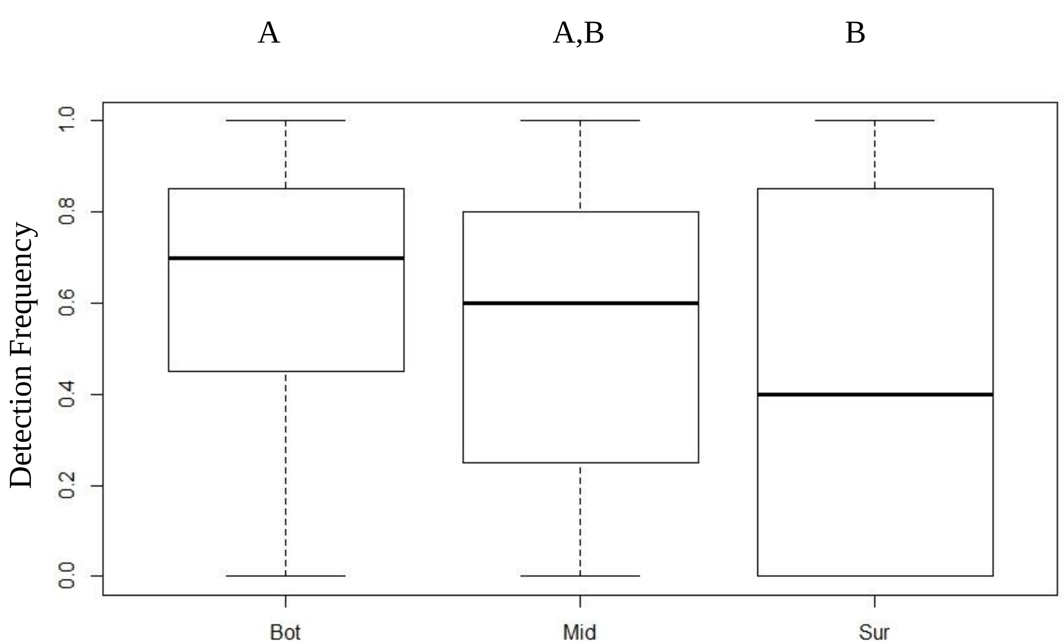


Figure 2-9. Boxplot of detection frequency within the middle reservoir 165-330 m from receivers by depth class.

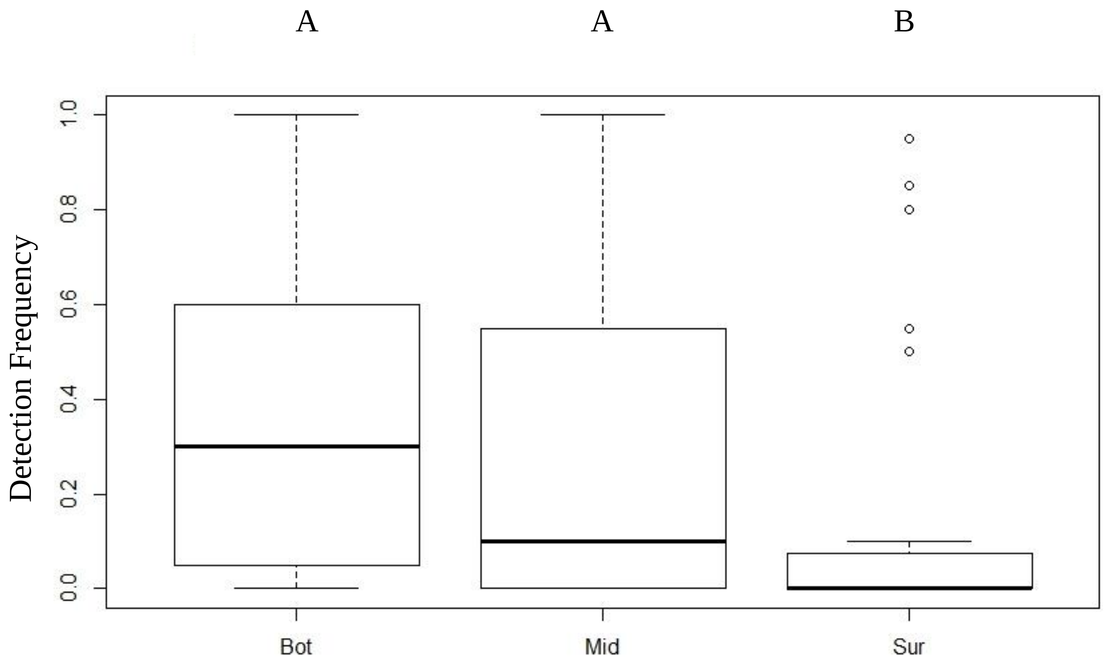


Figure 2-10. Boxplot of detection frequency in the middle reservoir within 330 to 500 m from receivers by depth class.

***Tagged Fish Trajectories***

Tagged fish trajectories (n=404) were determined from 40 acoustically tagged Redband Trout. Results of the percentage of trajectories detected by receiver are given in Tables 2-4 to 2-6. Also provided in these tables is the distance outside of the detection range for each receiver

There appears to be little trend in the proportion of fish detected on receivers (Figure 2-11) and the distance from the edge of the detection range to shoreline. Maximum detection range for all receivers was 500 m from receiver. For example, Plum Point West (receiver 9) detected 94% of the tagged fish that went by it, even though there is 780 meters from the edge of its detection range to the opposite shoreline (Table 2-4). Camel Rocks East (receiver 11) detected 37% of tagged fish that went by with 800 m between the edge of its detection range and opposite shoreline. There was little correlation between distance between edge of detection range and shoreline and the proportion of fish detected (Figure 2-11). Proportion of fish detected on receivers whose detection range extended across the reservoir ranged from 54-100%. It is important to note that the maximum detection range extends out to where 5% of transmissions were detected during stationary range tests and these fish passed by receivers over the course of four seasons. It is possible for fish to pass by these without being detected and that the detection range maybe different during seasons other than summer when our stationary range tests were conducted. However, comparisons across season indicated no significant difference in percent detected by season (Kruskal Wallis Chi Square = 3.4, df = 4, p =0.36).

Table 2-4. Ranking of receivers by percent of fish detected with number of tracks that passed by receivers and number detected from Spring Canyon to Seven Bays.

| Rank | Receiver | No. of Tracks | No. Detected | % Detected | Distance out of detection range |
|---|---|---|---|---|---|
| 1. | SP4 Sanpoil Buoy B | 181 | 175 | 97% | NA |
| 2. | 9 Plum Point West | 83 | 78 | 94% | 780m |
| 3. | Camel Rocks East | 33 | 28 | 85% | 540m |
| 4. | Spring Canyon Camp | 55 | 46 | 84% | 270m RB 210m LB |
| 5. | Halverson Canyon | 20 | 16 | 80% | NA |
| 6. | 10 Plum Point East | 39 | 31 | 79% | 460m |
| 7 | Seven Bays | 24 | 19 | 79% | 280m RB 250m LB |
| 8. | Whitestone Creek | 49 | 38 | 78% | 450 m |
| 9. | Whitestone Rock | 34 | 26 | 76% | 240 m |
| 10. | SP3 Sanpoil Middle | 119 | 87 | 73% | NA |
| 11. | Hanson Harbor | 58 | 40 | 69% | 160m |
| 12. | Hawk Creek | 21 | 14 | 67% | 2,000m |
| 13. | Sanpoil Mouth | 112 | 67 | 60% | NA |
| 14. | Burbot Creek | 16 | 9 | 56% | Range Complete |
| 15. | Keller Ferry East | 59 | 32 | 54% | 640m |
| 16. | Keller Ferry West | 88 | 46 | 52% | 70m RB 120m LB |
| 17. | Sanpoil Buoy A | 107 | 54 | 50% | 290m |
| 18. | Camel Rocks West | 43 | 16 | 37% | 800 m |
| 19. | Spring Canyon BL | 60 | 21 | 35% | 80 m RB 360 m LB |

Table 2-5. Ranking of receivers by proportion of fish detected with number of tracks that

passed by receivers and number detected from Fort Spokane to Mission Point.

| Rank | Receiver | No. of Tracks | No. Detected | % Detected | Distance out of detection range |
|---|---|---|---|---|---|
| 1. | SR1 Fort Spokane | 6 | 6 | 100% | Range Complete |
| 2. | SR3 Porcupine Bay | 12 | 11 | 92% | Range Complete |
| 3. | SR4 Harker Canyon | 12 | 11 | 92% | 125m |
| 4. | SR2 McCoy's Marina | 10 | 9 | 90% | 270m |
| 5. | 19 Hunters | 10 | 9 | 90% | Gate Receivers |
| 6. | 17 Castle Rock | 12 | 10 | 83% | 54m |
| 7. | 20 Bissel Island | 10 | 8 | 80% | 277m |
| 8. | 21 Gifford | 9 | 7 | 78% | 240m |
| 9. | 18 Wilmont Cove | 8 | 6 | 75% | 490m |
| 10. | 22 Mission Point | 9 | 1 | 11% | 1,030m |

Table 2-6. Ranking of receivers by proportion of fish detected with number of tracks that passed by receivers and number detected from Chalk Grade to Canadian Border.

| Rank | Receiver | No. of Tracks | No.Detected | % Detected | Distance outside detection range |
|---|---|---|---|---|---|
| 1. | 36 Near Border | 3 | 3 | 100% | NA |
| 2. | 28 Milepost 110 | 17 | 15 | 88% | Range Complete |
| 3. | 27 Nancy Creek | 14 | 12 | 86% | 840m |
| 4. | 23 Chalk Grade | 8 | 5 | 75% | 900m |
| 5. | 24 French Rocks | 8 | 6 | 75% | 1,110m |
| 6. | 34 Northport | 8 | 6 | 75% | 400m RB 110m LB |
| 7. | 33 Little Dalles Eddy | 10 | 7 | 70% | Range Complete |
| 8. | 31 Flat Creek Eddy | 11 | 7 | 64% | 193m |
| 9. | 26 Kettle Falls | 10 | 6 | 60% | 440m |
| 10. | 30 North Gorge | 13 | 7 | 54% | Range Complete |
| 11. | 29 Snag Cove | 14 | 7 | 50% | 30m |
| 12. | 35 Big Sheep Creek | 8 | 3 | 38% | NA |
| 13. | 32 China Bend | 11 | 4 | 36% | 586m |

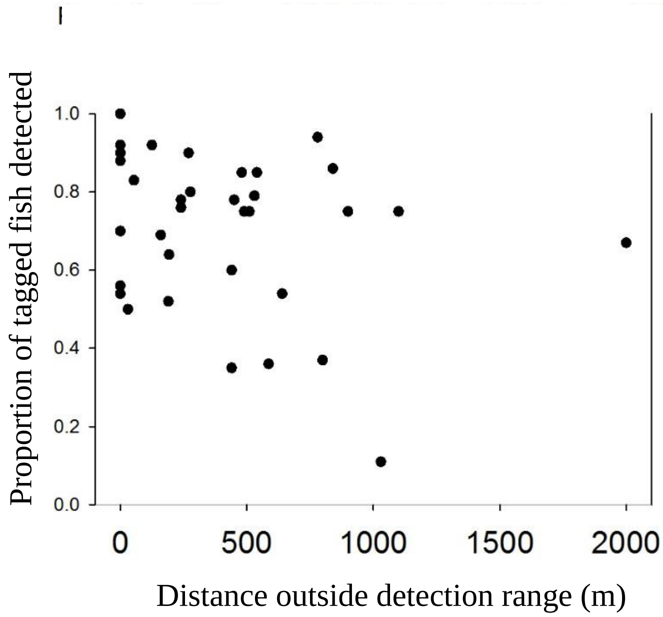


Figure 2-11. Scatterplot of proportion of fish detected to distance outside of detection. range to shoreline.

**Float Range Testing**

We float tested the receivers at Nespelem on 24 July 2015 with 10 second delay tag. The results of these tests indicated that majority of detections (22 of 33 detections) occurred when the transmitter was downstream of the receivers. This is likely due to the orientation of the receivers as we observed them not hanging straight down, but pointed downstream from the end of their cable at an angle due the current at this location. On one drift of the nine the transmitter was detected on both receivers. During the time of this float test the receivers were positioned directly across from each other.

On 8 August 2016 we again float tested the receivers at Nespelem. This time with a 1-3 minute random delay tag. A hydrophone was used to record the number of transmissions for each drift. Twenty drifts were conducted in total. The transmitter was detected on every drift by both receivers. Interestingly, the position of the receivers was different than the previous float test (Figure 2-12.), with one receiver moved downstream by the current and the other a new placement in a quiet eddy on the opposite bank upstream. Again the majority of detections were downstream of the receivers (65 of 114). In the previous year both receivers were oriented pointed downstream. In 2016 one receiver that was placed in the eddy was oriented pointed downward.   The detection frequency between the two receivers in this gate differed during this float test (Figure 2-12).

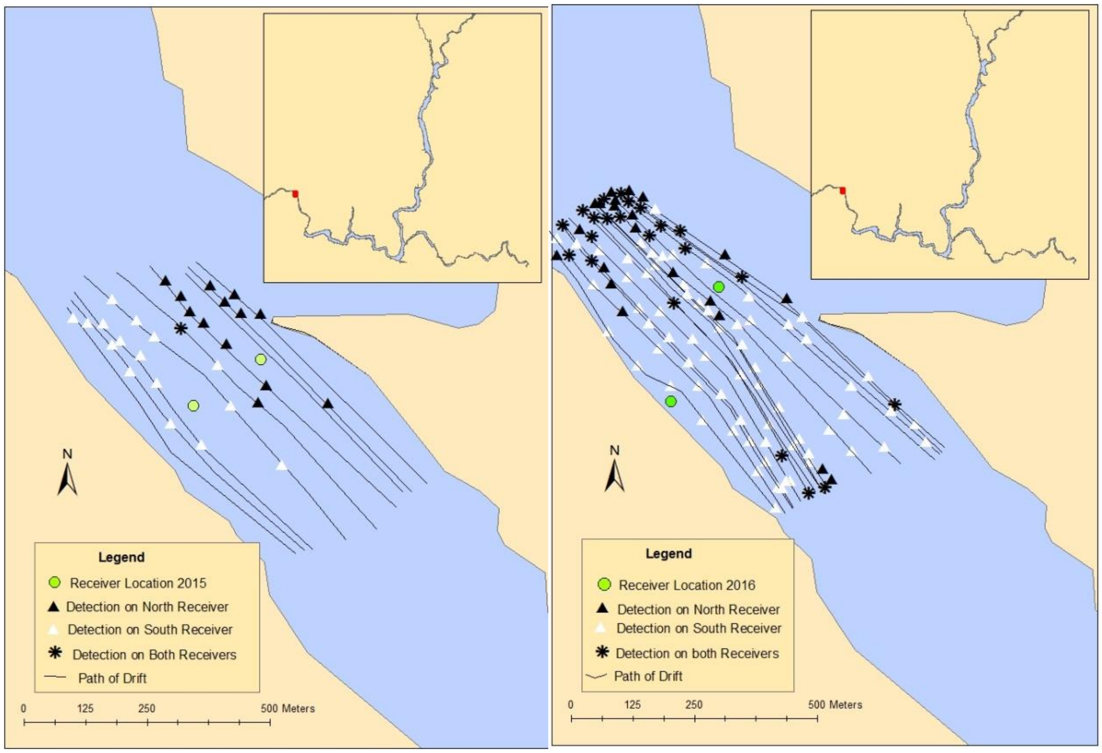


Figure 2-12. Layout of float range testing drifts in 2015 (left) and 2016 (right) with locations of detection by receiver along each drift. In 2016 receiver near south bank had a higher detection frequency ($p<0.001$).

## Discussion

As part of our range testing the farthest out we tested from the receivers was 500 m. Receiver detection range extended out to this distance for most receivers although detection probability was typically low at this distance (roughly 5-25%). Few receivers (8 of 42) had detection ranges that extended across the reservoir. The majority of receivers had areas outside their detection range to the opposite shore that ranged from 30 to 2,000 m. Receivers placed in the array are often positioned directly over the flooded river channel. This ensures the receiver is over the deepest water in the area, and maybe beneficial for detection range (Heupple et al. 2006). However, this has resulted in the placement of receivers close to one side of the reservoir. In a reservoir that averages 1.2 km in width (Stober et al. 1981) placement of receivers closer to one side of the reservoir can leave large areas past a receiver where transmitters cannot be detected.

My results indicate that detection was variable by receiver and region of the reservoir. When comparing the detection frequency among regions the only significant difference between regions was 165-330 meters from the receiver between lower and upper regions. The lower region receivers had higher detection than the upper at these distances. The lower reservoir is deeper than the upper reservoir and the shallower water may lead to the signal attenuating more quickly due to the signal weakening after bouncing off the bottom.

Depth did not impact detection in the lower or upper reservoir but it did in the middle reservoir. Five meters above the bottom and middle water column typically had better detection than the 5 meters below the surface. Selby et al. (2016) range tested receivers in a saltwater environment and noted that the 5-10 meter depth class was associated with significantly less detection frequency than other depths. Selby et al. (2016) cited wave action, and air bubbles as potential causes for increased signal attenuation at these depths. The bathymetry around receivers in the regions of the reservoir did vary. In the lower reservoir the 5 m above bottom depths tested were typically over 70 meters. In the middle reservoir these depths were variable, and in the upper reservoir these depth were typically 30-40 meters. The lower reservoir locations were typically deep and the upper reservoir locations were typically shallow whereas the middle reservoir locations were variable. This variability may explain why the middle reservoir detection frequency varies by depth and not in the other regions.

***Tagged Fish Trajectories***

When the stationary range testing data was used in conjunction with the trajectory analysis it showed insight into where fish are moving in relation to these receivers. There was little correlation between the distance from the edge of detection range to shoreline and proportion of tagged fish detected on receivers. Receivers with over 700 m from the edge of their detection range to shoreline detected between 10 to 94% of tagged fish that passed by them. Receivers whose detection range extended across the reservoir detected between 54 to 100% of tagged fish that passed by them. The lack of a trend in proportion of tagged fish detected in relation to distance outside receiver detection range is likely driven by fish preferentially moving along certain shorelines.  I propose that those receivers with a high proportion of tagged fish detected (example Plum Point West) fish were most likely passing on the side of the reservoir closest to the receiver. An extreme example is the Hawk Creek receiver which detected almost 70% of fish that passed by it even though there is 2km of the main body of the reservoir between it and the opposite shore. Receivers that detected a low proportion of fish (example Mission Point) fish were likely moving by the receiver near the shoreline opposite of the receiver. Reasons why fish move by certain areas of the reservoir are worthy of investigations on their own. Potentially these areas are more likely sought out by fish for food, shelter or other resources. Walston et al. (2014) did a similar analysis with 2014 tagged Redband Trout and we combined our data with this data set to capture a more complete picture of the receiver array in detecting this species.

Proportions of tagged Redband Trout detected by receivers between 2014 and 2016 are shown in Table 8. We see that all Spokane River receivers detected greater than 88% of the tracks that passed by them. Receivers that detected less than 60% of tracks that passed by them (with the exception of Spring Canyon Boat Launch) are located in the Upper Reservoir above RKM 1,084. It is important to note that the receivers in the Upper Array were originally put in place to track White Sturgeon. The tagged Redland Trout in this analysis may move differently than White Sturgeon.

These data have implications for understanding acoustic data for tagged Redband Trout. For example, in the Spokane Arm four of 17 Redbands tagged in the Spokane Arm were never detected (Witte and Scholz 2017). The detection range of the receivers in the Spokane Arm (Appendix A) and the proportion of tagged fish that are detected (>87%) on receivers in the Spokane Arm indicate that the vast majority of tagged fish in the

Table 2-7. Receivers organized by total percent of tracks detected for 2014-2016. Shown are number of tracks and percent detected for 2014-2015, and 2015-2016. (Page 1 of 2).

| Receiver | Tracks 14/15 | No. Detected 14/15 | % Detected 14/15 | Tracks 15/16 | No. Detected 15/16 | % Detected 15/16 | Total Tracks | Total Detected | Total % Detected |
|---|---|---|---|---|---|---|---|---|---|
| SR 3 | 29 | 29 | 100% | 12 | 11 | 92% | 41 | 40 | 98% |
| SP 4 | NA | NA | NA | 181 | 175 | 97% | 181 | 175 | 97% |
| Plum Pt W | 34 | 34 | 100% | 83 | 78 | 94% | 117 | 112 | 96% |
| SR 4 | 29 | 27 | 93% | 12 | 11 | 92% | 41 | 38 | 93% |
| Camel R. E | 34 | 33 | 97% | 33 | 28 | 85% | 67 | 61 | 91% |
| SR 2 | 27 | 23 | 85% | 10 | 9 | 90% | 37 | 32 | 89% |
| Spring C. Camp | 34 | 33 | 97% | 55 | 46 | 84% | 89 | 79 | 88% |
| SR 1 | 27 | 23 | 85% | 6 | 6 | 100% | 33 | 29 | 88% |
| Plum Pt East | 34 | 33 | 97% | 39 | 31 | 79% | 73 | 64 | 88% |
| Halverson | 28 | 26 | 93% | 20 | 16 | 80% | 48 | 42 | 88% |
| Gifford | 15 | 14 | 93% | 9 | 7 | 78% | 24 | 21 | 88% |
| French Rocks | 15 | 14 | 93% | 8 | 6 | 75% | 23 | 20 | 87% |
| Castle Rock | 15 | 13 | 87% | 12 | 10 | 83% | 27 | 23 | 85% |
| Northport | 11 | 10 | 91% | 8 | 6 | 75% | 19 | 16 | 84% |
| Seven Bays | 15 | 13 | 87% | 24 | 19 | 79% | 39 | 32 | 82% |
| Hawk Creek | 28 | 26 | 93% | 21 | 14 | 67% | 49 | 40 | 82% |
| Bissel Island | 11 | 9 | 82% | 10 | 8 | 80% | 21 | 17 | 81% |
| Whitestone R | 28 | 24 | 86% | 34 | 26 | 76% | 62 | 50 | 81% |
| Whitestone Cr | 28 | 24 | 86% | 49 | 38 | 78% | 77 | 62 | 81% |
| Burbot Creek | 28 | 26 | 93% | 16 | 9 | 56% | 44 | 35 | 80% |
| Wilmont | 15 | 12 | 80% | 8 | 6 | 75% | 23 | 18 | 78% |
| Big Sheep | 15 | 15 | 100% | 8 | 3 | 38% | 23 | 18 | 78% |
| SP 3 | 45 | 39 | 87% | 119 | 87 | 73% | 164 | 126 | 76% |
| Hunters | 15 | 10 | 67% | 10 | 9 | 90% | 25 | 19 | 76% |
| Kettle Falls | 15 | 13 | 87% | 10 | 6 | 60% | 25 | 19 | 76% |
| Nancy Creek | 15 | 10 | 67% | 14 | 12 | 86% | 29 | 22 | 76% |

Table 2-7. Receivers organized by total percent of tracks detected between 2014-2016. Shown are number of tracks and % percent detected for 2014-2015, and 2015-2016. (Page 2 of 2).

| Receiver | Tracks 14/15 | No. Detected 14/15 | % Detected 14/15 | Tracks 15/16 | No. Detected 15/16 | % Detected 15/16 | Total Tracks | Total Detected | Total % Detected |
|---|---|---|---|---|---|---|---|---|---|
| Milepost 110 | 15 | 9 | 60% | 17 | 15 | 88% | 32 | 24 | 75% |
| Hanson Harbor | 28 | 20 | 71% | 58 | 40 | 69% | 86 | 60 | 70% |
| SP 2 | 45 | 41 | 91% | 112 | 67 | 60% | 157 | 108 | 69% |
| Little Dalles | 15 | 10 | 67% | 10 | 7 | 70% | 25 | 17 | 68% |
| Keller Ferry E | 34 | 29 | 85% | 59 | 32 | 54% | 93 | 61 | 66% |
| Camel R. W | 34 | 34 | 100% | 43 | 16 | 37% | 77 | 50 | 65% |
| Snag Cove | 11 | 9 | 82% | 14 | 7 | 50% | 25 | 16 | 64% |
| Chalk Grade | 11 | 6 | 55% | 8 | 6 | 75% | 19 | 12 | 63% |
| SP 1 | 51 | 44 | 86% | 107 | 54 | 50% | 158 | 98 | 62% |
| Flat Creek | 11 | 6 | 55% | 10 | 7 | 70% | 21 | 13 | 62% |
| Keller Ferry W | 41 | 32 | 78% | 88 | 46 | 52% | 129 | 78 | 60% |
| Spring Cny BL | 34 | 31 | 92% | 60 | 21 | 35% | 94 | 52 | 55% |
| North Gorge | 11 | 5 | 45% | 13 | 7 | 54% | 24 | 12 | 50% |
| Mission Point | 11 | 9 | 82% | 9 | 1 | 11% | 20 | 10 | 50% |
| China Bend | 11 | 6 | 55% | 11 | 4 | 36% | 22 | 10 | 46% |

Spokane Arm are detected. These tagged fish that were never detected likely never left the Spokane Arm. If they did leave it would seem very likely that they would be detected. These fish that were not detected may have resided in the Spokane Arm in zones away from receivers.

***Float Range Testing***

The orientation of the receiver gate at Nespelem differed between 2015 and 2016 which played a role in the results we obtained. In 2015 the receivers were oriented directly across from each other approximately 150 m apart. When float tests were conducted with a seven second delay the tag was mostly detected downstream of the receivers. As both receivers were positioned in the current they were facing downstream rather than straight down. Therefore, the cone of detection was mostly downstream of the receivers. On only one drift out of nine was the tag detected by both receivers. The following year we obtained much more different results.

In 2016 the placement of receivers had changed. One receiver was moved downstream and the other disappeared. Biologists from the Colville Confederated Tribes placed a new receiver on the opposite bank and just upstream of the one that still remained. This receiver was placed in an eddy. During twenty floats the tag was detected on all drifts by both receivers. It was detected more often on the receiver placed in the eddy and about equally upstream and downstream of the gate. Previously, Stroud et al. (2011) conducted float tests on a Rufus Woods receiver just upstream before the receiver gate at Nespelem was put in place with a V-9 transmitter. Tests by Stroud et al. (2011) were conducted during times of high flow in late spring and determined the single receiver may only detect a tag on 36% of the drifts, whereas our tests occurred where during moderate flow in late summer. Currently it appears this gate is working during times of moderate flow.

***Conclusions***

Based on our assessment of the receiver array we have three suggestions. The first regards the placement of additional receivers. We suggest placing a receiver in between the ones at Spring Canyon to increase the overlap in detection range here. Another location to place a receiver is across from the receiver currently at the mouth of the Sanpoil River. Here, the current receiver detected 50% of tagged fish that went by it and the distance outside the detection range is 290 m to the other shore. Another receiver across from this one could have a detection range that encompasses the area currently out of range of the existing receiver. Lastly, there exists 4 receivers downstream of Grand Coulee to detect entrainment out of Lake Roosevelt. However, the possibility of entrainment out of Lake Roosevelt and into Banks Lake has never been addressed by acoustic telemetry. We suggest placing a receiver at the north end of Banks Lake off the inlet of the irrigation feeder canal to address this possibility. Potential sources of additional receivers to put in these locations include receivers that are poorly detecting fish at their current location such as the Spring Canyon Boat Launch which detected 35% of tagged fish that went by it whereas adjacent receivers detected 94 and 84% of fish that passed by them.

The second suggestion is additional evaluation of the acoustic array with tagged fish trajectories. I only looked at tags of Redband Rainbow Trout. The upper array was put in place to track White Sturgeon (Howell and McLellan 2007) it would be beneficial to do similar analysis of these receivers with White Sturgeon tag data to determine how well these receivers detect sturgeon that moved by them. Evaluating tracks of different species may show insight into how well the array works for detecting different species or what areas around receiver's different species are likely using.

The third suggestion is to float test the gate at Nespelem during times of increased flow. From 2016 tests in August this gate is working well during times of moderate flow. It would be beneficial to conduct tests during times of high flow to evaluate this gate.

This range testing has given insights into understanding tracking data of tagged fish in Lake Roosevelt. With suggestions of additional receiver placement this array can continue to be a valuable tool for current and future studies.

## Literature Cited

Dunn, O. J. 1964. Multiple comparisons using rank sums. Technometrics. 6, 241–252.

Heupel, M. R., J. M. Semmens, and A. J. Hobday. 2006. Automated acoustic tracking of Aquatic animals: scales, design, and deployment of listening station arrays. Marine and Freshwater Research 57: 1-13.

Howell, M. D. and J. G. McLellan. 2007. Lake Roosevelt White Sturgeon recovery project annual progress report 2005. United States Department of Energy, Bonneville Power Administration Portland, Oregon. Document ID# P108776: 47 pp.

Kendall, M. S., M. E. Monaco, and. A. Winship. 2016. Baffling telemetry detections can be useful: an acoustic receiver design to monitor organisms along reserve boundaries and ecotones. Animal Biotelemetry. 4: 2.

Kessel, S. T., S. J. Cooke, M. R. Heupel, N. E. Hussey, C. A. Simpfendorfer, S. Vagle, and A.T. Fisk. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. Reviews in Fish Biology and Fisheries. 24: 199-218.

McLellan, H. J., A. T. Scholz, B. D. Nine, and C. Lee. 2009. Annual assessment of Kokanee in Lake Roosevelt: 2008 Annual Report. United States Department of Bonneville Power Administration. Document ID No. P116037. 85 pp.

McLellan, H. J., A. T. Scholz, and A. Miller. 2010. Lake Roosevelt Kokanee Assessments 2009Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Document ID No. P122558: 152 pp.

Parsons, T. 2014. Wild kokanee tracking and movements in Lake Roosevelt, 2010. MS Thesis Department of Biology, Eastern Washington University, Cheney, Washington: 107 pp.

Selby, T. H., K. M. Hart, I. Fujisaki, B. J. Smith, C. J. Pollock, Z. Hills-Star, I. Lundgren, and M. K. Oil. 2016. Can you hear me now? Range-testing a submerged passive acoustic receiver array in a Carribbean coral reef habitat. Ecology and Evolution. 6: 4823-4835.

Scholz, A.T., A. O. Blake, M. N. Korst, D. H. P. Stroud, T. Parsons, M. Paluch, and H. J. McLellan. 2011. Annual assessment of hatchery kokanee, and sonic tracking of wild and hatchery kokanee in Lake Roosevelt: 2010 Annual Report. Bonneville Power Administration, Portland Oregon. Contract No. 00043471 Project No. 1994-043-00. 188 pp.

Stroud, D. H. P., A. O. Blake, H. J. McLellan, and A. T. Scholz. 2011. Annual Assessment of hatchery kokanee and sonic tracking of wild and hatchery kokanee In lake Roosevelt. 2011 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 297 pp.

Stroud, D. H. P., A. O. Blake, M. Vaughan, S. Warehime, H. McLellan, and A. T. Scholz. 2013 Annual assessment and sonic tracking of hatchery kokanee in Lake Roosevelt: 2013Annual Report. United States Department of Energy, Bonneville, Power Administration Portland, Oregon. 172 pp.

Stroud, A. G., D. H. P. Stroud, A. T. Scholz, H. J. McLellan, and B. Nichols, editors. 2014. Kokanee Salmon investigations and Redband Rainbow Trout ultrasonic Tracking in Franklin D. Roosevelt Lake, 2013 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 59 pp.

Stroud, A. G. 2015. Chapter 1: a dichotomous key for the identification of nine salmonids of the inland northwest using six diagnostic bones; and associated equations to estimate the length and weight from bones injested by piscivores or found in archeological sites. Chapter 2. Utilization of biotelemetry to define the movments of Lake Roosevelt Redband Trout, *Oncorhynchus mykiss gairdneri*. MS Thesis, Department of Biology Eastern Washington Universty, Cheney WA. 158 pp.

Walston, J. A. 2015. Effects of anesthetics on rainbow trout swimming ability and statistical comparison of the movements of acoustically tagged redband trout in. Lake Roosevelt MS Thesis, Department of Biology, Eastern Washington University, Cheney, Washington: 171 pp.

Walston, J. A., K. Magori, and A.T. Scholz. 2015. A comparison of the movements of Columbia River Redband Rainbow Trout (*Oncorhynchus mykiss* var. *gairdneri*) Tagged with Acoustic transmitters in different tributaries of Lake Roosevelt: A Synopsis of 2013 and 2014 data. United States Department of Energy, Bonneville Power Administration Portland, Oregon Project No. 1994-043-33 Contract No. 65961: 71 pp.

Welsh, J. Q, R. J. Fox, D. M. Webber, and D. R. Bellwood. 2012 Performance of remote Acoustic receivers within a coral reef habitat: implications for array design. Coral Reefs 31: 693-702.

Witte, B. T., and A. T. Scholz. 2017. A description of the utilization of Lake Roosevelt by Columbia River Redband Trout (*Oncorhynchus mykiss* var. *gairdneri*) tagged With Acoustic transmitters in several spawning tributaries of Lake Roosevelt, Washington: Acoustic tag detections from April 2015 – July 2016. United States Department of Energy, Bonneville Power Administration, Portland, Oregon Project No. 1994-043-00 Contract No. 69860: 76 pp.

**Appendix A Detection Probability Maps around Receivers.**

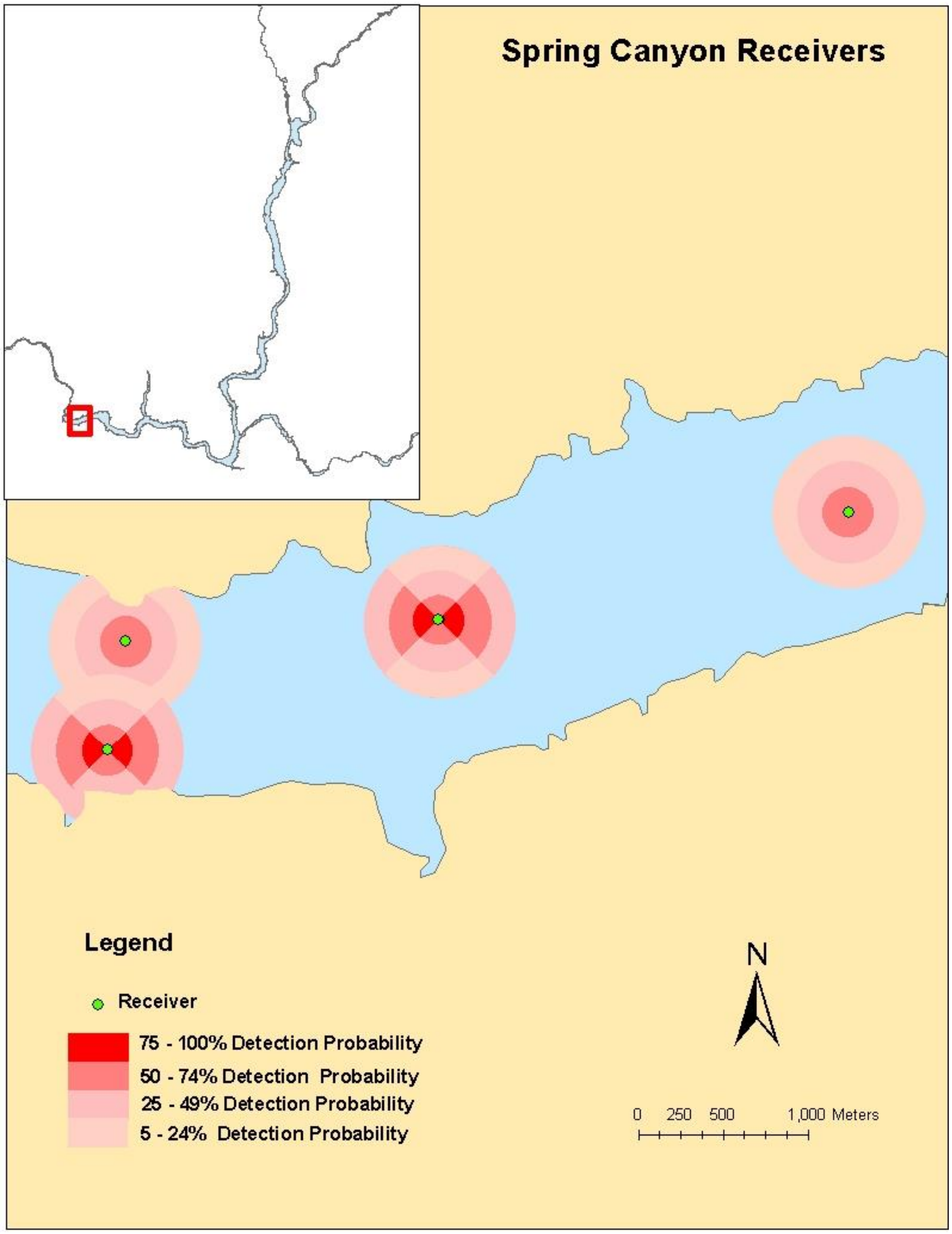


Figure A-1. Probability of detection around Spring Canyon Receivers

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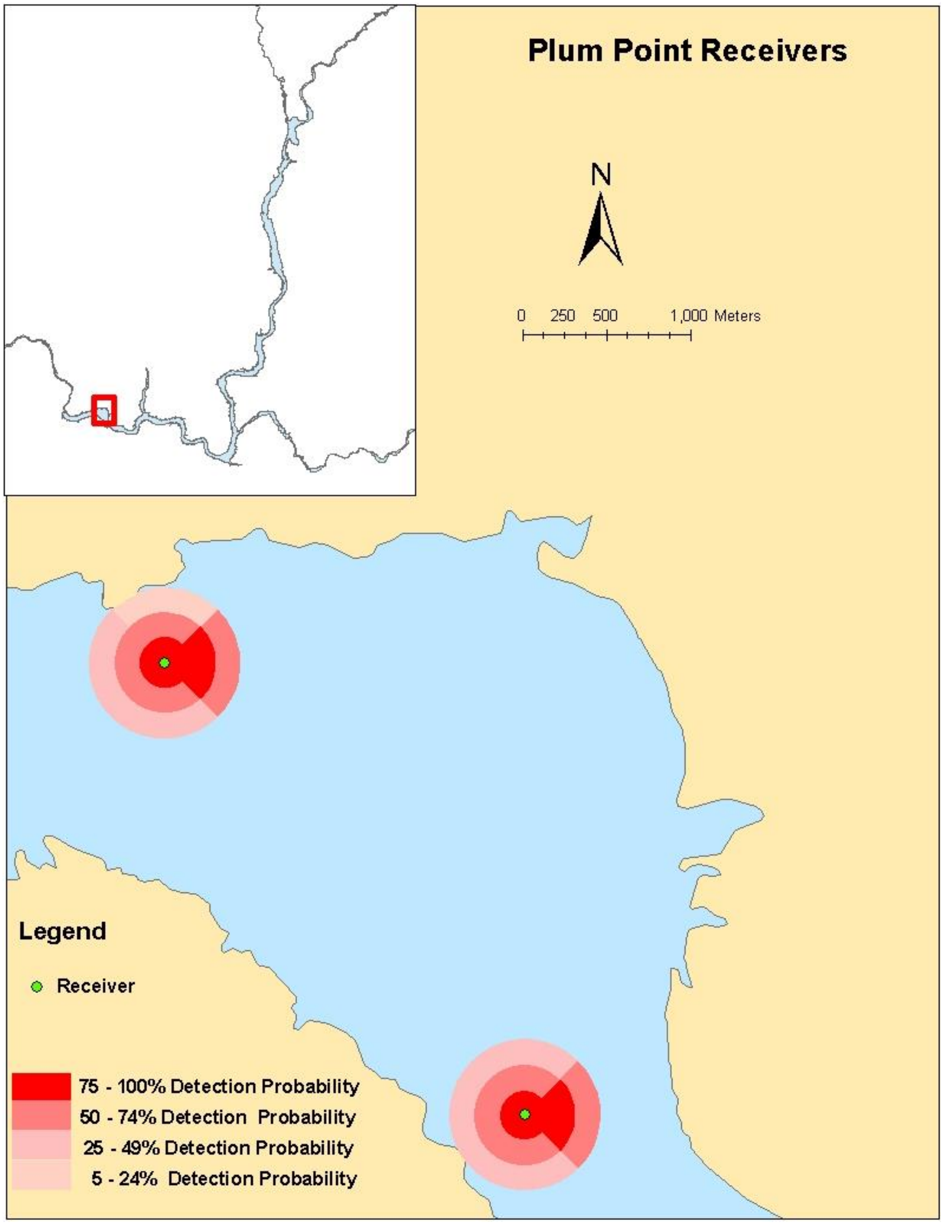


Figure A-2. Probability of detection around Plum Point receivers

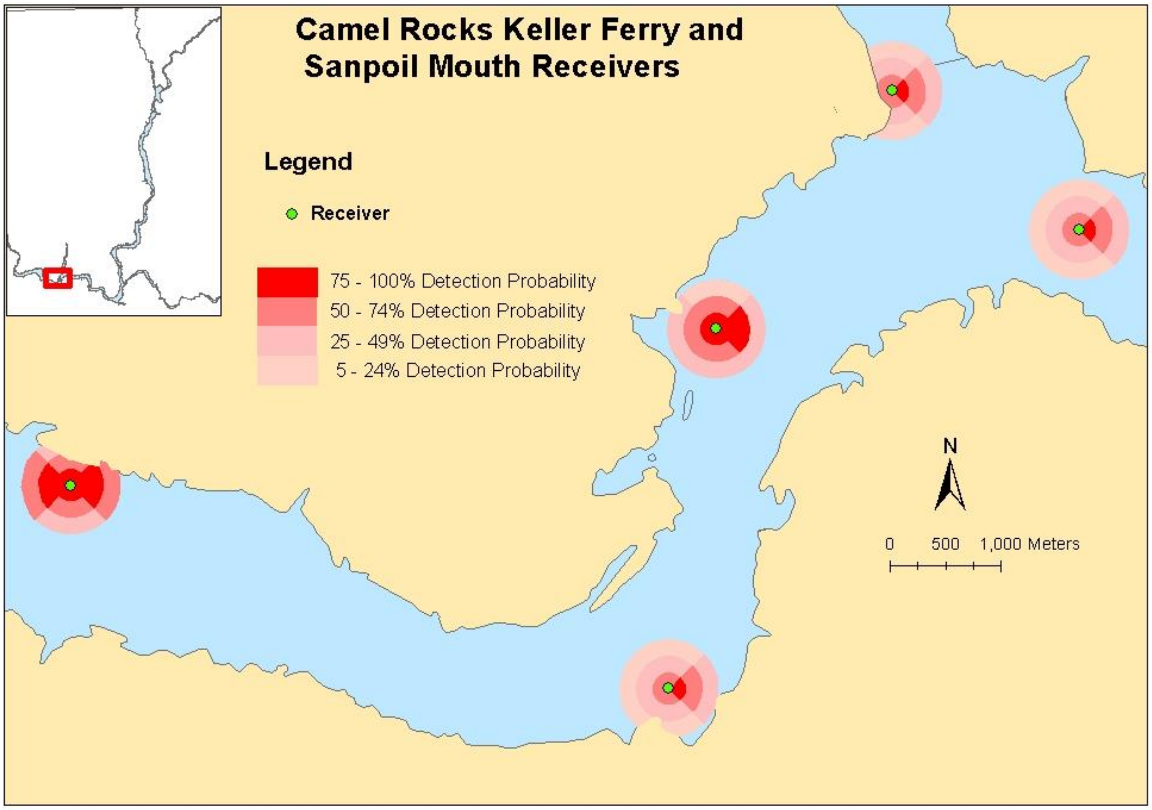


Figure A-3. Detection probability around receivers from Camel Rocks to Keller Ferry.

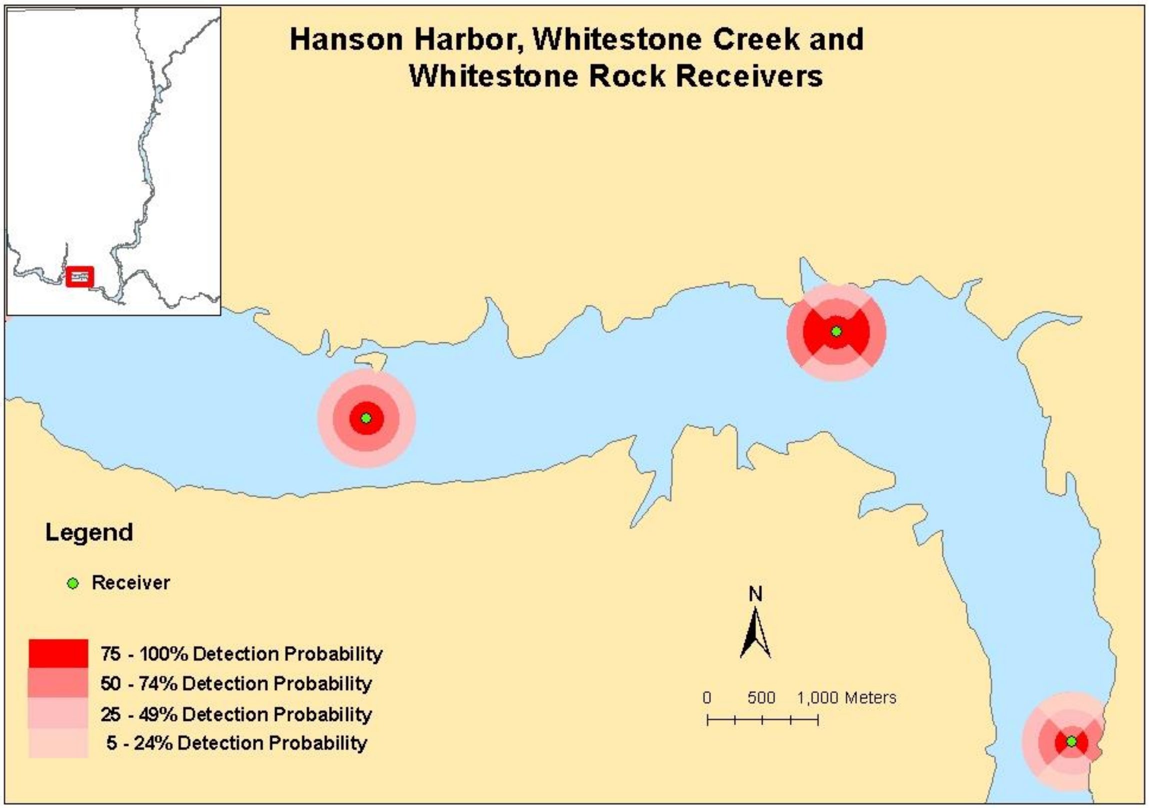


Figure A-4. Detection probability around receivers from Hanson Harbor to Whitestone Rock.

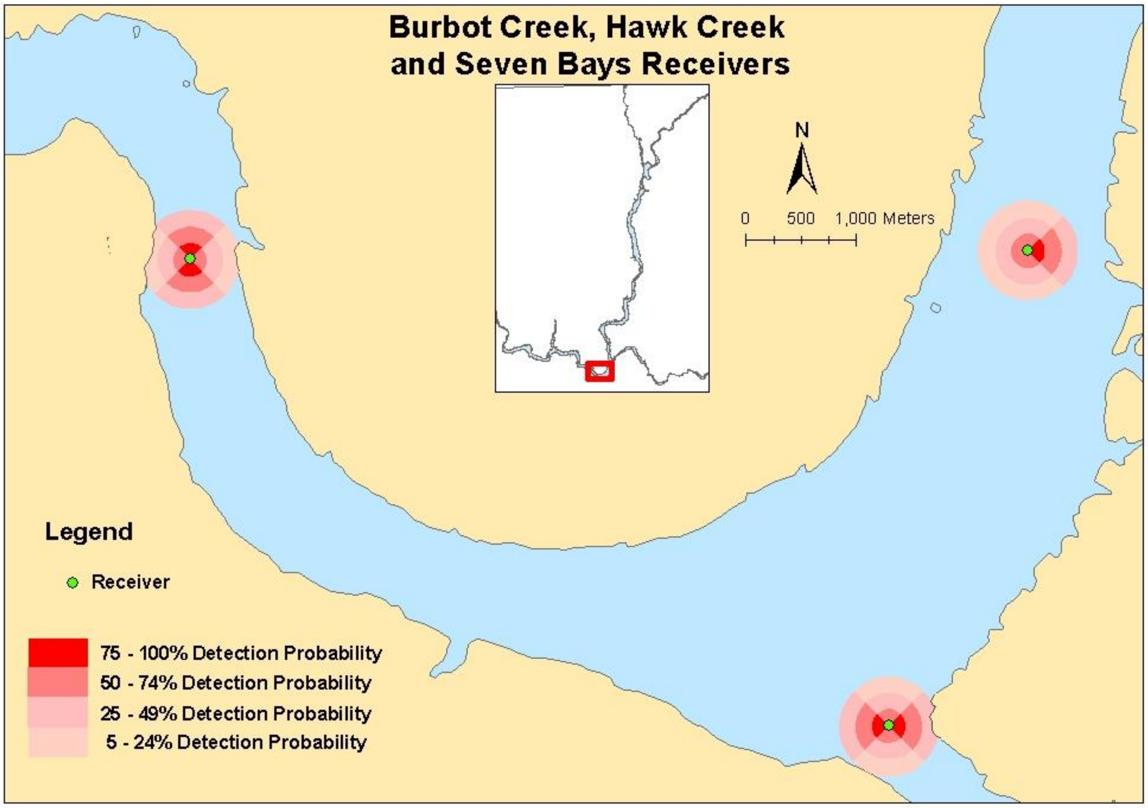


Figure A-5. Detection probability around receivers from Burbot Creek to Seven Bays

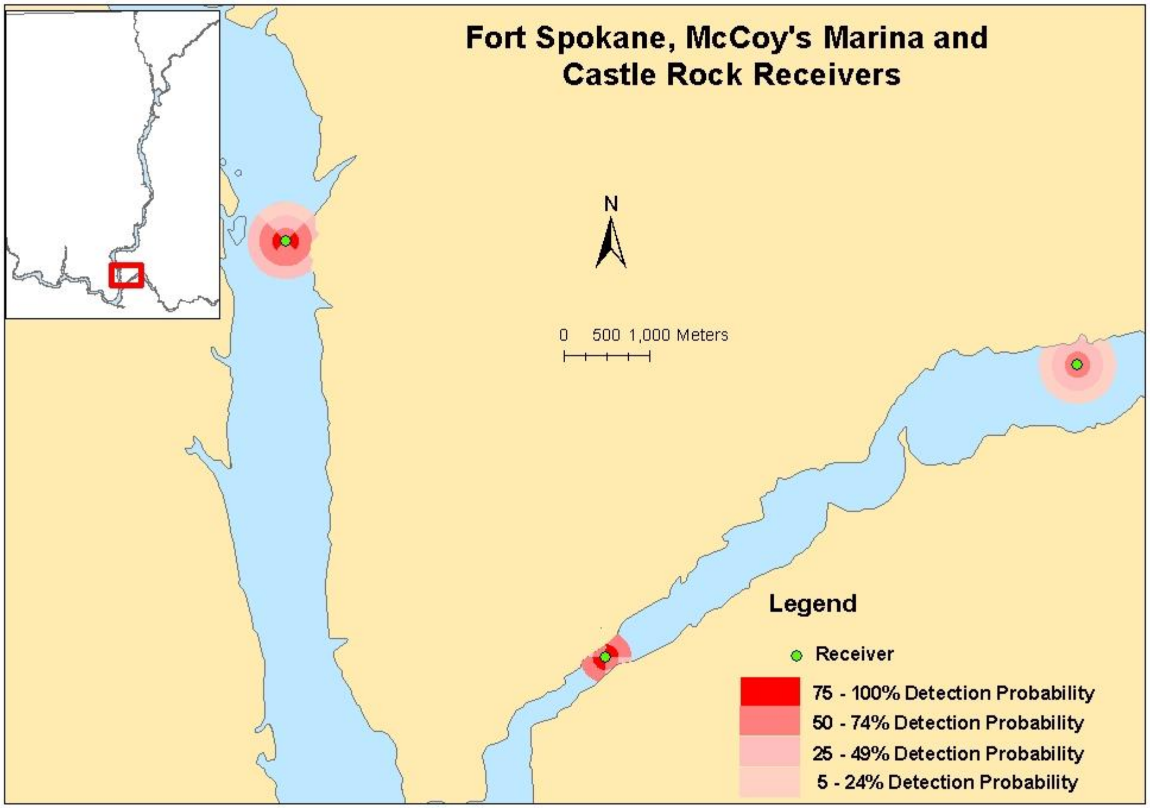


Figure A-6. Detection probability around receivers for Fort Spokane, McCoy's Marina, and Castle Rock.

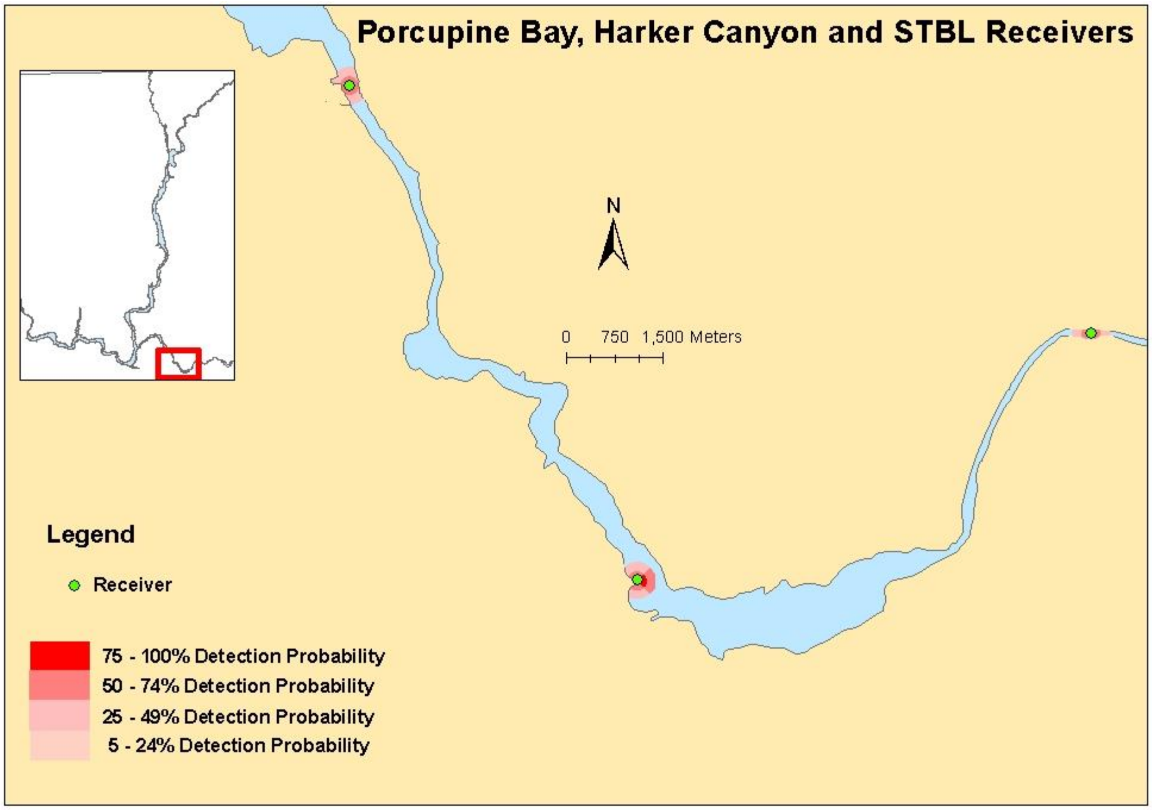


Figure A-7. Detection probability around receivers for Porcupine Bay, Harker Canyon and Spokane Tribal Boat Launch.

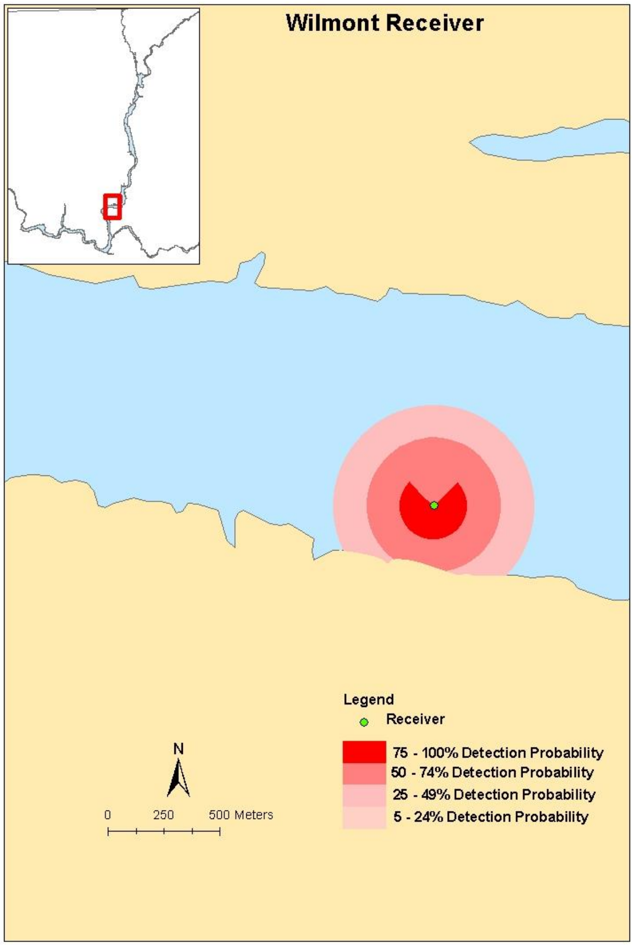


Figure A-8. Detection probability around Wilmont

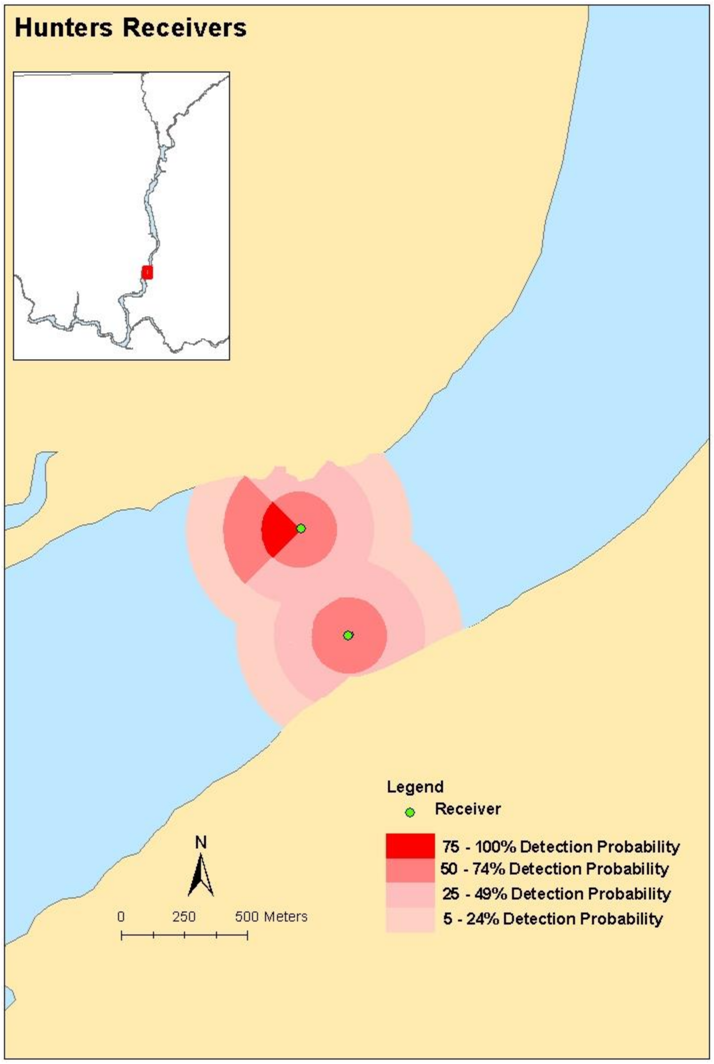


Figure A-9. Detection probability around Hunters.

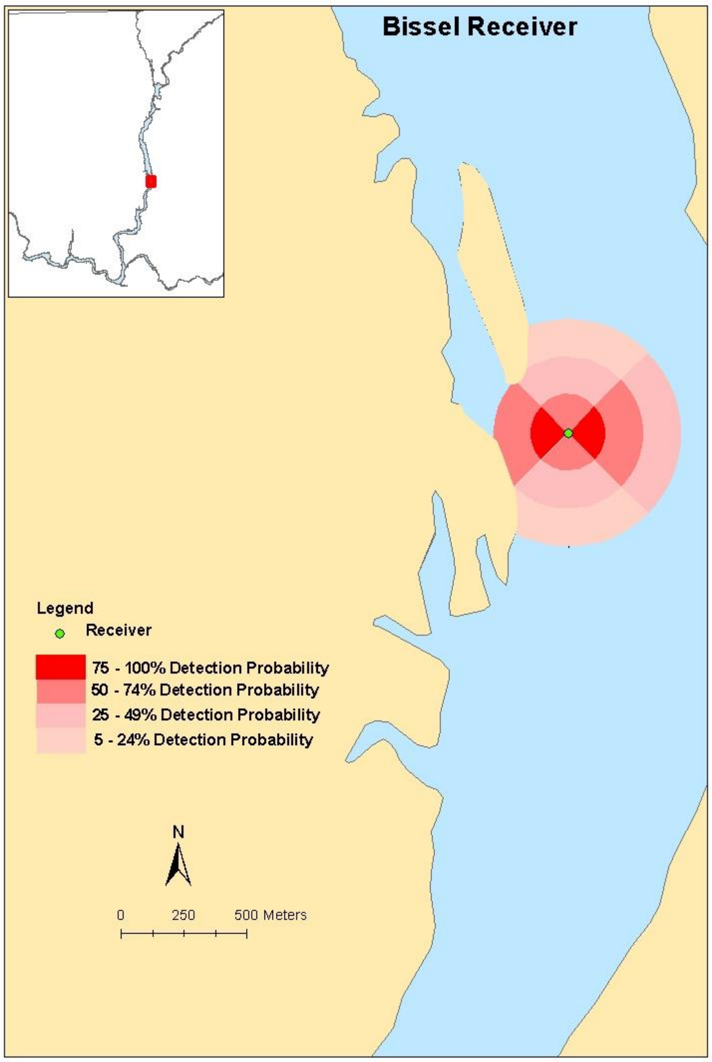


Figure A-10. Detection probability around Bissel Island.

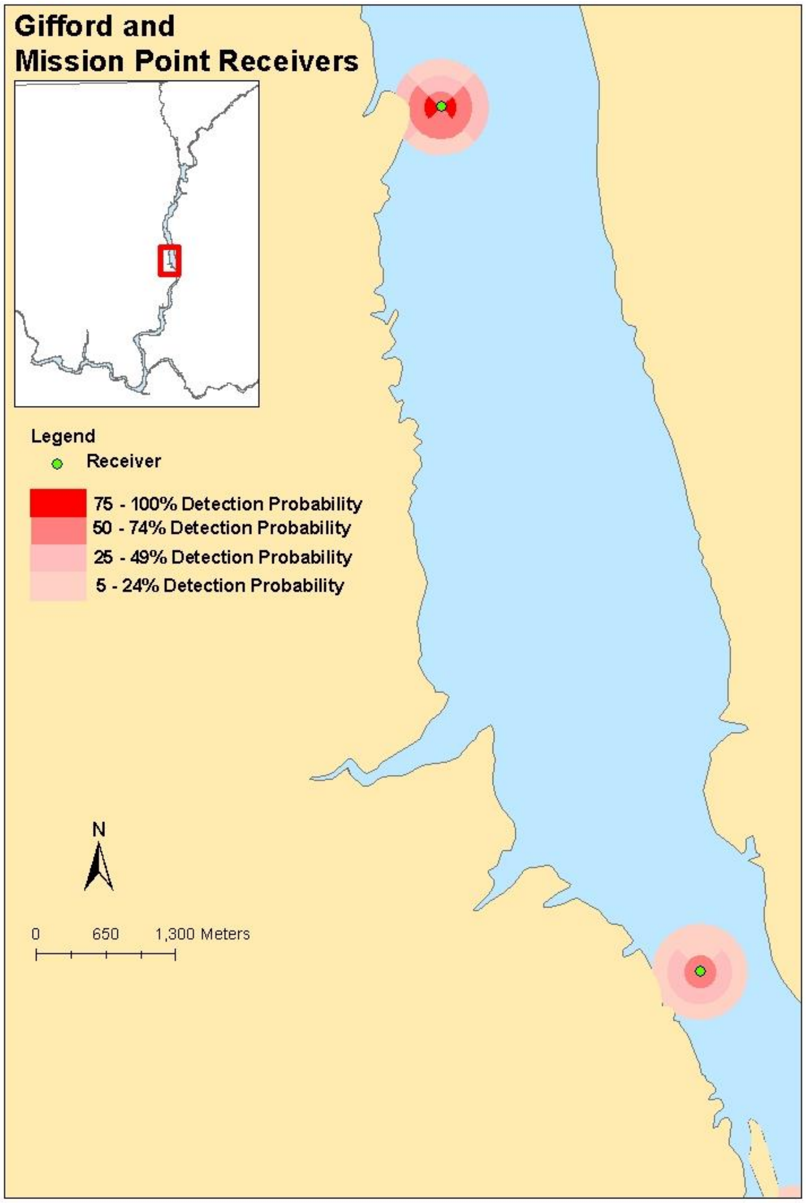


Figure A-11. Detection probability around Gifford and Mission Point.

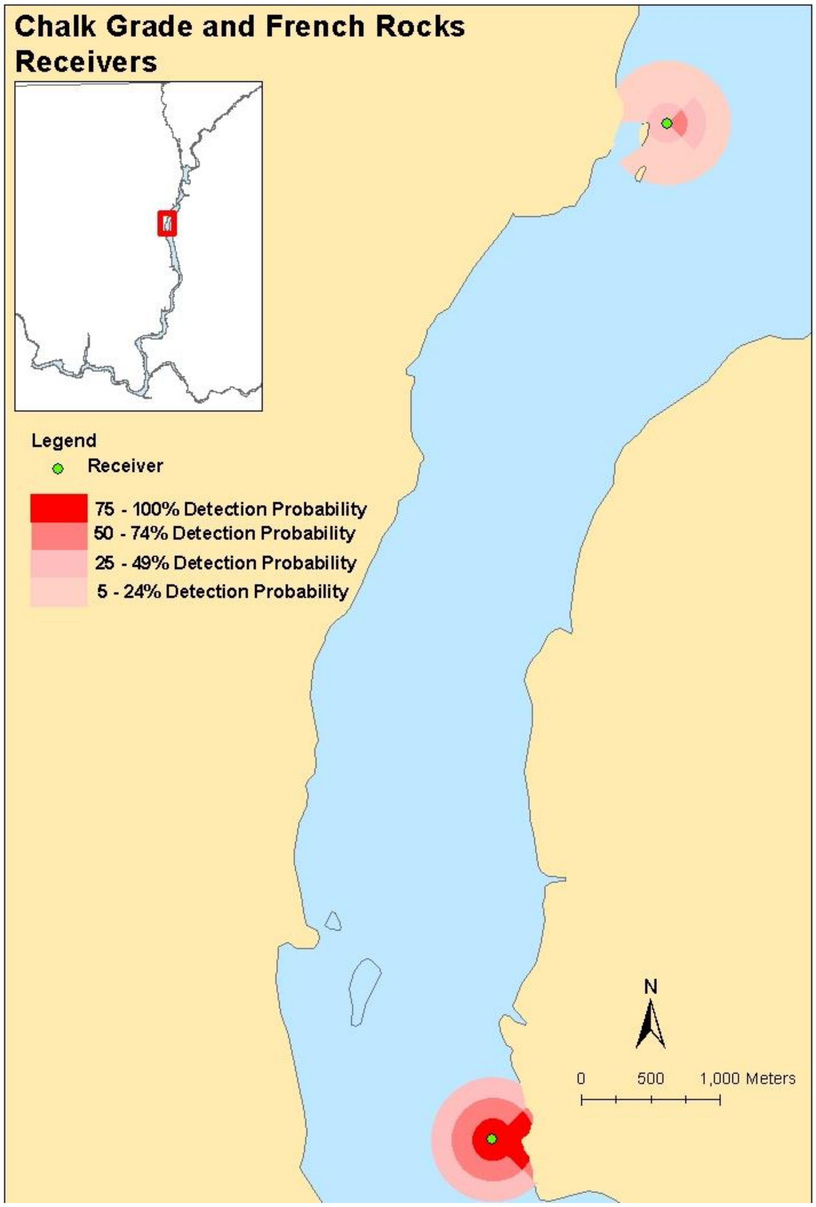


Figure A-10. Detection probability around Chalk Grade and French Rocks.

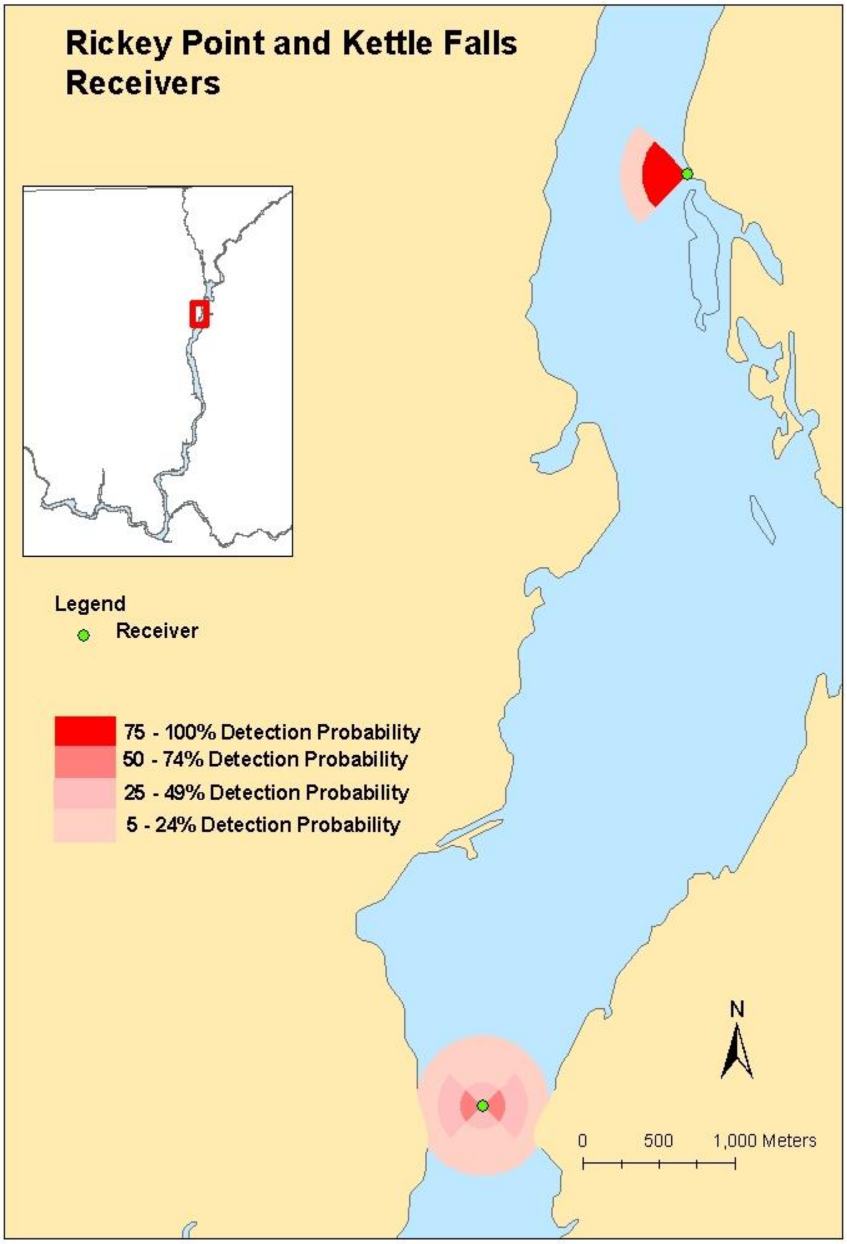


Figure A-11. Detection probability around receivers from Rickey Point to Kettle Falls.

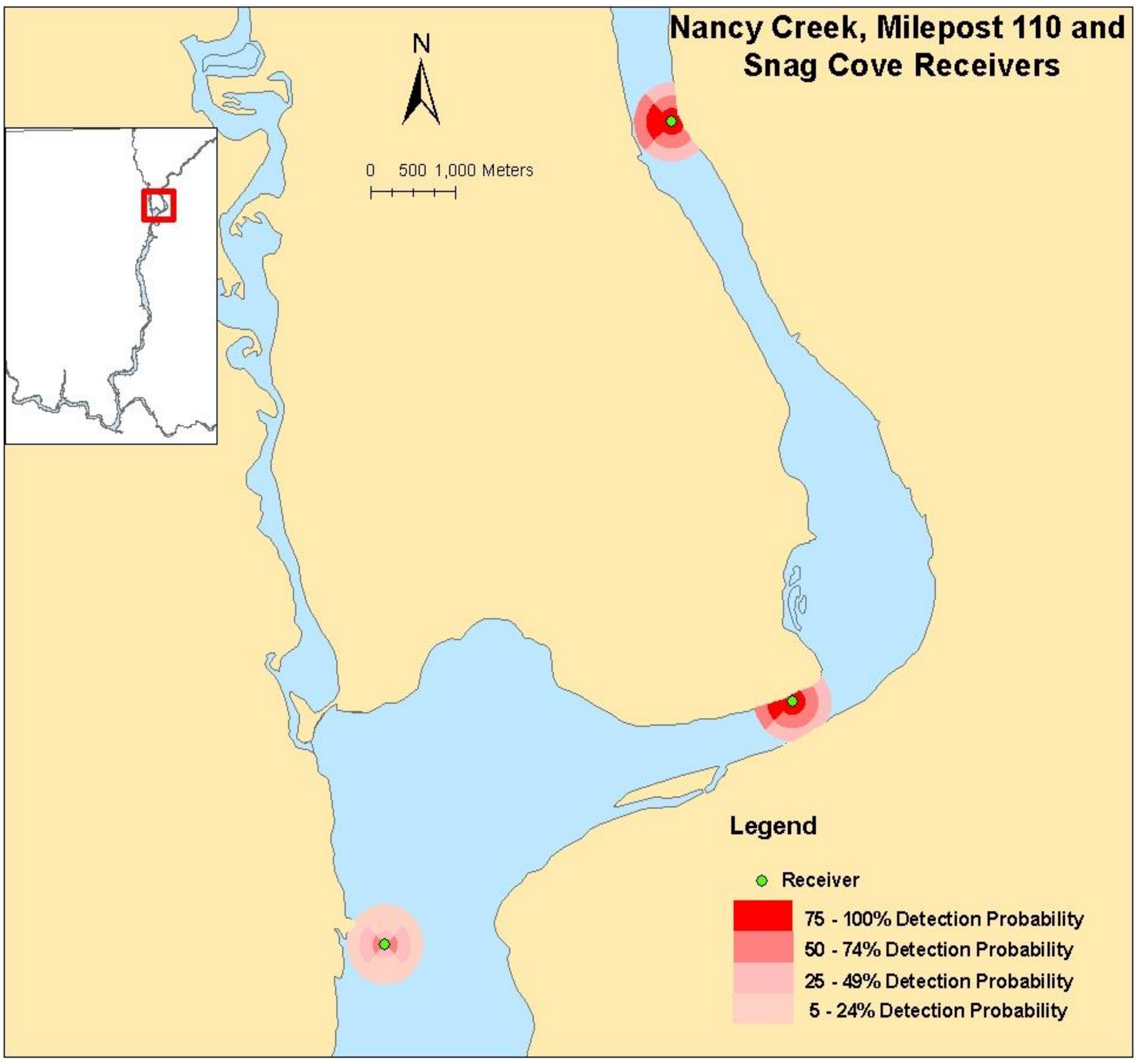


Figure A-12. Detection probability around receivers from Nancy Creek to Snag Cove.

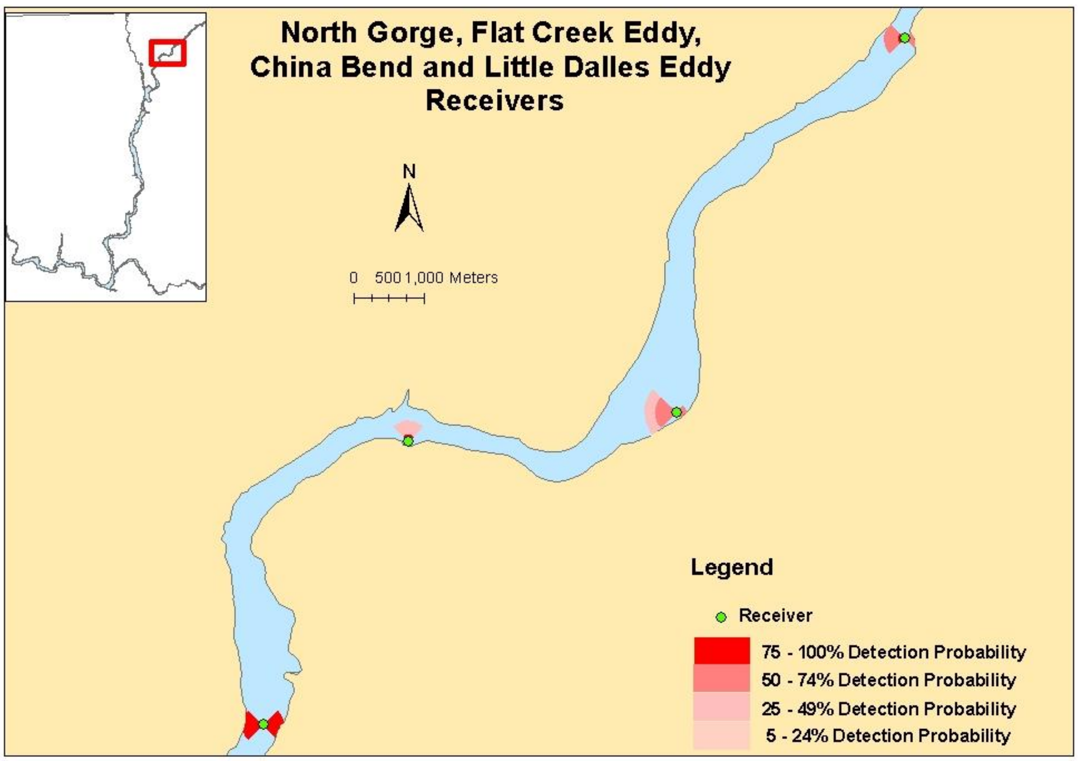


Figure A-12. Detection probability around receivers from North Gorge to Little Dalles Eddy.

# Chapter 3

A description of the utilization of Lake Roosevelt by Columbia River Redband Rainbow Trout *(Onchorhynchus mykiss* var. *gairdneri*) tagged with acoustic transmitters in several spawning tributaries of Lake Roosevelt, Washington: Acoustic tag detections from April 2015- July 2016.

Annual Report 1 August, 2015 – 31 July, 2016

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## Executive Summary

This study acoustically tracked Columbia River Redband Trout (*Oncorhynchus mykiss* var. *gairdneri*) tagged in different spawning tributaries of Lake Roosevelt, to determine:

1. The utilization distribution within Lake Roosevelt for each tributary population;
2. If Redband Trout return to the tributary they were originally tagged (homing); and
3. Entrainment at Grand Coulee Dam.

Data presented in this report encompasses acoustically tagged Redband Trout detected from April 2015 to July 2016. In spring 2015, Redband Trout were collected in tributaries of Lake Roosevelt, implanted with acoustic transmitters, and released at the site of capture in:

1. The Sanpoil River (enters Lake Roosevelt at Columbia River kilometer 991.0) where 15 Redband Trout were collected 12-13 km up the Sanpoil River from of this point.
2. The Spokane River (Enters Lake Roosevelt at Columbia River kilometer 1,027.2) where Redband Trout were collected at:
    a. Blue Creek at Spokane River kilometer 19.2 (n=9).
    b. Spring Creek at Spokane River kilometer 44.4 (n=7).
3. The Middle Reservoir at Columbia River kilometer (1,055.0- 1,061.2) where Redband Trout were collected at:
    a. Wilmont Creek at Columbia River kilometer 1,055.0 (n=8).
    b. Alder Creek at Columbia River kilometer 1,058.8 (n=2).
    c. Hunters Creek at Columbia River Kilometer 1,061.2 (n=7).

4. The Upper Reservoir at Columbia River kilometer (1,180.0-1,186.1). Where Redband Trout were collected at:
    a. Onion Creek at Columbia River kilometer 1,180.0 (n=15); and
    b. Big Sheep Creek Columbia River kilometer 1,186.1 (n=18).

Fish were collected by stationary weir traps, boat electrofishing, backpack electrofishing and angling. Fish were anesthetized prior to implantation of VEMCO© acoustic transmitters. All fish were allowed to recover from surgery prior to being released at the location of capture.

Eighty one fish (41 females, 21 males, and 19 unknown sex; average total length: 470 ± 68 mm were implanted with VEMCO acoustic transmitters and released from March 17 to June 1, 2015. Of these, 54 were detected on the Acoustic Receiver array, one was harvested by an angler and two were suspected to have died or expelled their tag.

Following release, fish were detected on an acoustic receiver array consisting of 74 VEMCO VR2W 69 kHz receivers positioned downstream of Grand Coulee Dam (RKM 940.0) to RKM 1,257.0 downstream of Hugh Keenlyside Dam in British Columbia. For a complete list of receiver locations see Appendix B.

Movements were modeled using a Dynamic Brownian Bridge Movement Model and utilization distribution (generation of maps showing the probability of occurrence in an area) modeling in the statistical software R in order to create individual trajectories and utilization distributions. Fish were grouped by region of the reservoir and their movements were compared using a Mantel's test (Spearman's correlation).

Homing was confirmed if fish PIT tags were detected on PIT tag arrays maintained by either the Colville Confederated Tribes, the Spokane Tribe of Indians, or Washington Department of Fish and Wildlife. Entrainment over Grand Coulee Dam was confirmed if a fish was detected on receivers located 13 km downstream of Grand Coulee Dam.

Comparisons of utilization distributions indicated fish tagged downstream of Hunters, Washington (Hunters, Wilmont, Blue, Spring Creeks, and Sanpoil River), were most often found in the lower 100 km of the reservoir, whereas those tagged upstream of Kettle Falls, (Onion and Big Sheep Creeks) rarely moved into the lower 100 km of the reservoir. The greatest distinction between utilization distributions was found to be between the most geographically separated groups of Redband Trout (Sanpoil and Upper Reservoir).

Overall, 10 acoustically tagged Redband Trout from 2015 were confirmed to have homed into their tagging stream the following year. Seven of these were from the Sanpoil River, one from Blue Creek and two from Big Sheep Creek. No fish detected on PIT tag arrays were detected in streams other than their original tagging stream.

No fish tagged in 2015 were confirmed to have entrained over Grand Coulee Dam. However, four fish were last detected on one of two receivers upstream of the dam. These receivers are located across from each other approximately two km upstream of Grand Coulee Dam. One is 180 meters from the north bank, and the other is 260 meters from the south bank. The most likely explanation for the disappearance of these fish is they entrained through Grand Coulee Dam. We believe this to be the most likely explanation, due to a previous study by LeCaire  (1998) who determined the majority of fish that entrain at Grand Coulee Dam entrain through the third powerhouse (on the north side of the dam). Three of the four fish were last detected at the north receiver. This receiver is approximately two kilometers from the third powerhouse. Since these fish were last detected on the north side of the river it is likely they entrained through the third powerhouse. After entraining through Grand Coulee Dam, transmitters may have been damaged, fish may have been consumed by predators (eagles or otters) or were not detected at downstream receivers, by either residing outside the range of receivers or by passing by receivers at a time of reduced detection ability by the receivers (i.e., high flows). One of the four was detected on the south receiver. This fish may have also entrained over Grand Coulee. Other possibilities to explain the disappearance of these fish include; 1) entrainment into Banks Lake, an irrigation storage reservoir where Stober et al. (1979) has documented entrainment of fish from Lake Roosevelt into Banks Lake; 2) Fish may have expelled transmitters outside the detectible range of receivers; or 3) Fish experienced mortality.

We plan to prepare a publication of Redband tracking data, collected from 2013-2016 for submission to a peer reviewed scientific journal.

## Introduction

The indigenous North American range of Rainbow Trout (*Oncoryhnchus mykiss*) encompasses an area from Southern California to Southwestern Alaska (Benke 1992). In this range there are five recognized varieties: Costal Rainbow Trout (*O. m*. var. *irideus*), Sacramento Redband Trout (*O. m*. var. *stonei*), Golden Trout (O. m. var *aguabonita*), Klamath River Redband Trout (*O. m*. var. *newberrii*), and the Columbia River Redband Trout (*O. m*. var. *gairdneri*) (Behnke 1992). However, this taxonomy is not completely agreed upon, as some authors recognize Golden Trout, as a distinct species (Lawrence et al. 2013). The Columbia River Redband Trout, hereafter referred to as Redband Trout, are endemic to the Columbia and Fraser River watersheds (Behnke 1992; Scholz and McLellan 2010; Scholz 2014). It is thought the Fraser and Columbia River Basins were connected during the last ice age, accounting for distribution of *O. m*. var. *gairdneri* in both drainages (McPhail and Lindsey 1986). Redband Trout were the most widely distributed salmonid in the Columbia River Basin, but have been lost from 34% of their historic distribution (Thurow et al. 1997). Currently Redband Trout are threatened by habitat degradation and introduced species, and are considered a species of special concern (Lee et al. 2012).

Redband Trout exhibit multiple life history strategies. These include non-migratory (reside in the same water body their entire lives), anadromous (migrate from freshwater to the ocean before returning to freshwater to spawn), and three forms of potadromous (migrate within freshwater) life histories. Potadromous strategies are fluvial-adfluvial (rear in natal tributary before migrating to a river and eventually return to their natal tributary to spawn), lacustrine adfluvial (rear in natal tributary before migrating to a lake and eventually return to natal tributary to spawn) and secondary lacustrine-adfluvial (occurs where fish once exhibited a fluvial life history, but due to dam construction that has converted the river to a reservoir, migrate to the reservoir before returning to their natal tributary (Northcote 1997). Redband Trout are iteroparous (spawn more than once in a lifetime) and are able to home back to streams of origin (Scholz and McLellan 2010).

Lake Roosevelt is a 243 km reservoir formed by Grand Coulee Dam (Stober et al. 1981). The dam was constructed without fish ladders and has blocked anadromous fishes from over 1,038 km of habitat (Mullen et al. 1992). Part of mitigation for the loss of anadromous fishes above Grand Coulee Dam is hatchery production of Rainbow Trout. These efforts have increased the number of fish for harvest, but have introduced a non-native variant of Rainbow Trout into Lake Roosevelt. Rainbow Trout stocked in Lake Roosevelt come from the Washington Department of Fish and Wildlife (WDFW) fish hatchery in Spokane, Washington. This stock, derived from 95% coastal Rainbow Trout (*O. m*. var. *irideus*), and 5% McCloud River Redband (*O. m*. var. *stonei*), was obtained from the Cape Cod Trout Company in Massachusetts (Crawford 1979). Naturally spawning native populations of Redband Trout (*O. m*. var. *gairdneri*) also still exist in Lake Roosevelt (Small et al. 2014). A genetic analysis of Redband Trout tissue samples collected across the reservoir found little evidence of hatchery trout introgression into Redband samples (Small et al. 2014). Evidence of metapopulation structuring was found, with Sanpoil River, Spokane River tributaries (Blue and Spring creeks), and Middle Reservoir tributaries (Alder, Wilmont, and Orapaken creeks) being more similar to each other than those from uppermost reservoir tributaries (Small et al. 2014). Currently, hatchery release of Rainbows into Lake Roosevelt consists of triploids to help ensure no mixing of nonnative Rainbow variants into the current Redband population.

Several life history strategies are present in Redband Trout in the drainages that lead into Lake Roosevelt (Brown et al. 2013; McLellan et al. 2015). Brown et al. (2013) implanted 125 Redband Trout with radio tags throughout the Sanpoil River Basin from 2011-2012. Of these 72 were classified as lacustrine adfluvial, 36 were classified as fluvial and 15 as resident. Interestingly, the lacustrine adfluvial fish were classified into two distinct groups; with 48 captured migrating into the Sanpoil River in the spring, and 24 captured migrating into the Sanpoil River in the fall (Brown et al. 2013). Some may still retain anadromy as 46 of 2,075 Redband Trout PIT tagged in the Sanpoil River between 2010 to 2012 were subsequently detected at locations 128 to 489 km downstream of Grand Coulee Dam (McLellan et al. 2015).

Lake Roosevelt has had a history of acoustic telemetry to monitor fish movements. White Sturgeon (*Acipenser transmontanus*), and both hatchery and wild Kokanee Salmon (*O. nerka*) movements have been monitored with acoustic telemetry in this reservoir (Howell and McLellan 2007; McLellan et al. 2009, 2010; Scholz et al. 2011; Stroud et al. 2012, and 2013; Seibert et al. 2015). From 2013 to 2016 Redband Trout movements have also been monitored with acoustic telemetry (Stroud et al. 2014; Stroud 2015; Walston 2015; Walston et al. 2015) to fill gaps in knowledge about how Redband Trout use Lake Roosevelt after leaving their spawning tributaries.

How Redband Trout utilize Lake Roosevelt is of interest to managers. It is known that availability of zooplankton is greater in the lower 100 km of reservoir than the upper 143km with the greatest densities occurring in the lower most 30 km (Chichosz et al.

1997). Diet analysis of both hatchery and wild Rainbow in Lake Roosevelt found Branchiopods, primarily *Daphnia* spp, were the most prevalent item found in Rainbow Trout stomachs during Lake Roosevelt monitoring surveys between 1988 and 1998 (Peone et al. 1990; Griffith and Scholz 1991; Thatcher et al. 1993, 1994; Cichosz et al. 1997; Cichosz et al. 1999). How Redband Trout use Lake Roosevelt after leaving their spawning tributaries is not well known. It is unknown if fish from tributaries in different sections of the reservoir all utilize areas with the highest *Daphnia* concentrations, or if these fish utilize different sections of the reservoir.

Entrainment of fish out of Lake Roosevelt has been documented (Stober et al. 1976; LeCaire 1998; McLellan et al. 2008) and reservoir operations can impact fish in Lake Roosevelt (McLellan et al. 2008). LeCaire (1998) used hydro acoustic survey methods to count fish moving through the three power houses at Grand Coulee Dam. LeCaire (1998) also used nets set in the forebay to determine the fish species present, and estimated approximately 83,000 Rainbow Trout (no distinction between hatchery and wild Rainbow Trout) entrained out of Lake Roosevelt over Grand Coulee Dam annually. McLellan et al. (2008) developed a model between reservoir operations (water retention time, and reservoir elevation) and hatchery Rainbow Trout success (tag return probability in Lake Roosevelt). Angler return of tagged rainbow trout was more likely to occur after shallow drawdowns than deep drawdowns (McLellan et al. 2008). Fish can also entrain out of Lake Roosevelt into Banks Lake via a pumping station and canal (Stober et al. 1976). Stober et al. (1976) reported 13 fish species that were captured in net sets in the Banks Lake Feeder Canal during July-September 1975. Rainbow Trout ranked 7th in relative abundance of 13 species collected in these net sets.

Understanding the movements and entrainment of Lake Roosevelt Redband Trout is important to help maintain their population. Maintaining their population is essential for the survival of Columbia River Redband Trout, and for the potential return of anadromous Redband Trout upstream of Grand Coulee Dam.

The aims of this study were to acoustically track Redband Trout, tagged in different spawning tributaries of Lake Roosevelt, to determine:

1. The utilization distribution and compare these distributions spatially for each tributary population;
2. If Redband Trout return to the tributary they were originally tagged (homing); and
3. Entrainment at Grand Coulee Dam.

# Methods

## Study Area

Lake Roosevelt (Figure 3-1), was created by Grand Coulee Dam at river kilometer (RKM) 953.6. At full pool the reservoir has a maximum depth of 122m, surface area of 33,490 hectares, and extends to the Canadian Border at RKM 1,192.0 (Stober et al. 1980). The reservoir serves three purposes, 1) Power production at Grand Coulee Dam, 2) System flood control and firming power production at downstream dams via flow regulation, and 3) Supplies irrigation water to the United States Bureau of Reclamation's Columbia Basin Project.

## Fish Collection

From March 17 to June 1, 2015 Redband Trout were collected from tributaries of Lake Roosevelt. Collection methods varied by location. Boat electrofishing and angling was used on the Sanpoil River 12-13 km upstream of its confluence with the Columbia River. Angling, backpack and boat electrofishing was used at Blue Creek. Angling was used at the Spokane River in the vicinity of Spring Creek. In the past two years EWU has collected fish within Spring Creek. However, due to an historic flood in 2014 that caused streamflow to go subsurface upstream of the mouth we opted to angle in the Spokane River. Angling, backpack, and boat electrofishing was used to collect fish at the middle reservoir tributaries (Wilmont, Alder and Hunters Creeks). A stationary weir trap was used in Onion Creek to collect fish, and angling was used to collect fish at Big Sheep Creek.

All Redband Trout were measured, total length (TL, mm), fork length (FL, mm), weighed (g), and scanned for a Passive Integrated Transponder (PIT) tag. Capture method, sex, maturity, acoustic tag and PIT tag numbers were recorded. A tissue sample from a rayed fin was collected and stored in 95% ethanol for genetic analysis. Fish were surgically implanted with acoustic transmitters and PIT tags (if they did not already have one).

***Surgical Tag implantation***

All fish were anesthetized prior to acoustic tag implantation. Fish collected in the Sanpoil River were immobilized by low-voltage electronarcosis (Hudson et al. 2011). This involved a cooler, two electrodes, mesh cradle, and power source. Fish were immobilized by a continuous (non-pulsed) direct current. This allowed for immobilization while opercular movement continued during the surgical procedure. Fish collected elsewhere were anesthetized with AQUI-S 20E© at a concentration of 28.5 mg of eugenol/L of water. Once stage IV anesthesia was reached (loss of equilibrium, no response to external stimuli, slowed opercular movements) fish were placed on a sponge surgery table and gills irrigated with a 14.25 mg of eugenol/L of water solution via a tube connected to a 20 L bucket.

The surgical site between the pectoral and pelvic fin was cleaned with betadine (Hamms 2005; Stroud et al. 2014) and a single incision just long enough to fit the respective size tag was made with a sterile single-use steel scalpel. The incision was deep enough to puncture the coelomic cavity, both acoustic tag and PIT tag was inserted through this incision, which was closed with two to four interrupted surgeons' knots (Wagner 2000 and 2005; Deters et al. 2010).

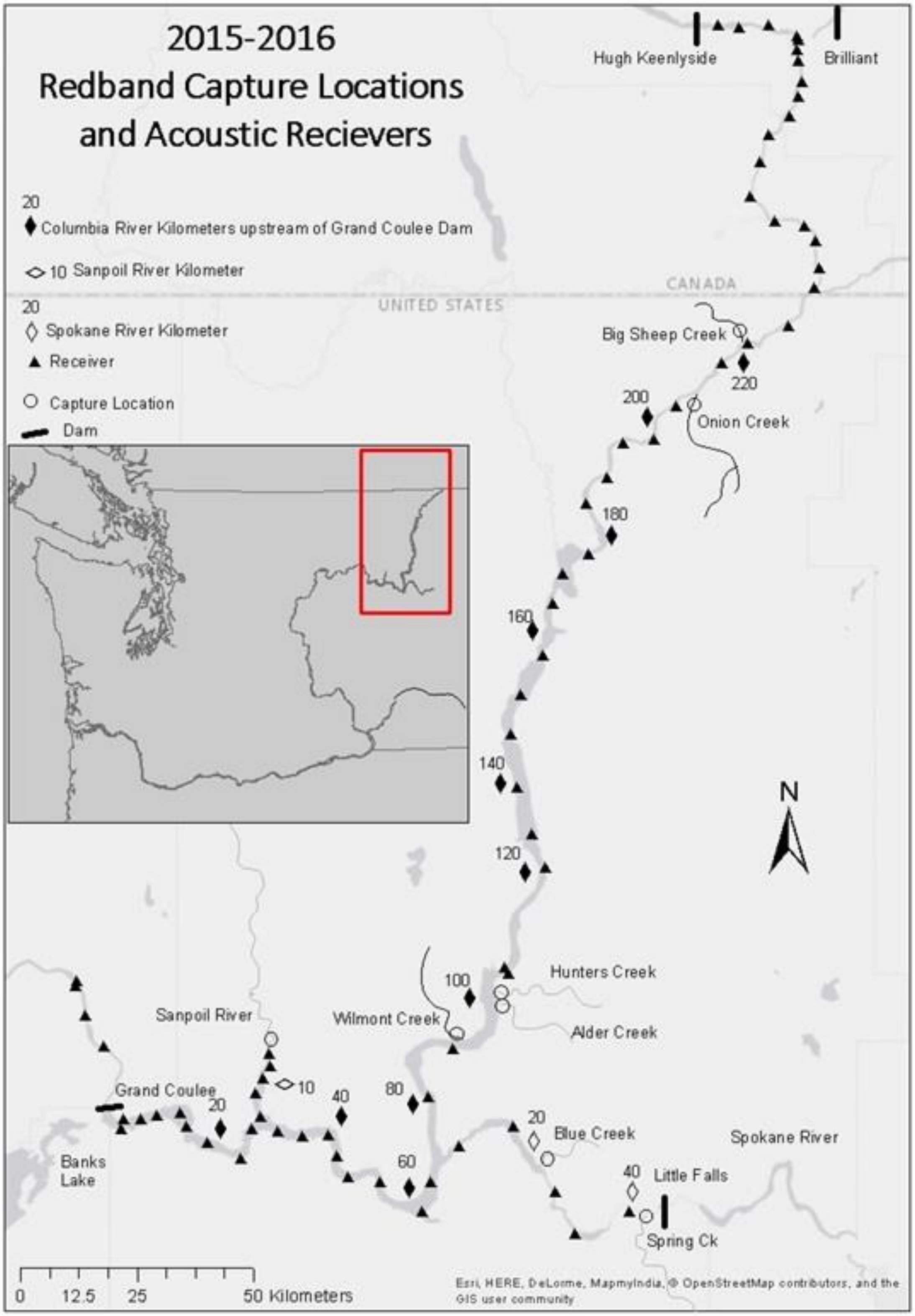



Figure 3-1. Map of Study Area depicting the locations of capture and receivers for 2015-2016.

Each fish was placed into a 30x30x70cm cooler filled with fresh water from site of capture to recover from the anesthetic. All fish were returned to the site of capture after recovering from the anesthetic. Between surgeries all non-disposable equipment was sterilized with a CIDEX OPA (CIVCO Medical Soulutions, Kaloa, Iowa) bath and rinsed three times with distilled water.

VEMCO© Acoustic transmitters in three sizes were used for tagging. These were the v-13 (11 grams (g) in air with a tag life of 1,117 days), v-9 (4.7 g in air with a tag life of 484 days), and the v-7 (1.6 g in air and a tag life of 395 days). Following Brown et al. (1999) we maintained a minimum threshold size for tagging fish at 2% of the fish's body weight for each tag type (example, ≥ 550 g fish for a v-13, ≥ 235 g fish for a v-9, and ≥ 80 g fish for a v-7).

**Acoustic Tracking and Field Data Collection**

An array of 64 Acoustic VEMCO VR-2W submersible receivers is in place on the Columbia River between RKM 940 and 1,256. An additional five receivers are placed in the inundated lower Sanpoil River, and five in the inundated lower Spokane River. The receivers downstream of Hunters, Washington (RKM 1,070) were downloaded and maintained by EWU. This maintenance occurred every two months, and included changing receiver batteries, buoy lights when necessary, and downloading data. The Spokane Tribe of Indians (STOI) maintained the receivers between Bissel Island (RKM 1,083) and the international border. B.C. Hydro maintains a receiver array from the international border to Hugh Keenlyside Dam. The receivers in Lake Roosevelt are attached to a white can buoy that is anchored to a 136 kg weight with a permaflex cable

(Figure 3-2). The receivers dangle 3 meters below the buoy on a cable separate from the anchor line.

**Detection Criteria**

Signal collisions and false detections, though uncommon, occur and may cause an inaccurate representation of the data. VEMCO© suggests all data are subjected to two criteria and if they fail to meet these criteria then those data should be removed from the dataset.

Criteria one refers to false detections. A false detection occurs when a receiving unit misinterprets environmental noise as a signal from a tagged fish. As a result, the receiver will detect and log a tag that is not there. Each acoustic tag comes with an "error detection code" that is a string of extra data sent with the unique ID coded tag transmissions. This extra data signals that the receiver has a genuine detection. If the extra data is not included in the transmission, the receiver will assign it as a false detection and will not log the code.

The second criterion for data refers to signal collisions. A signal collision is when two or more tags in the same area send a transmission at the same time. When the signals hit the receiver at the same time a disruption, scrambling, or mixing of signals occurs and has the potential to cause a receiver to log an invalid signal (Pincock 2012). The receiver may detect a signal similar to the type listed in criteria one, and as such, it will not be logged. If an invalid detection was found in the data, tag collisions were considered and the data were removed.

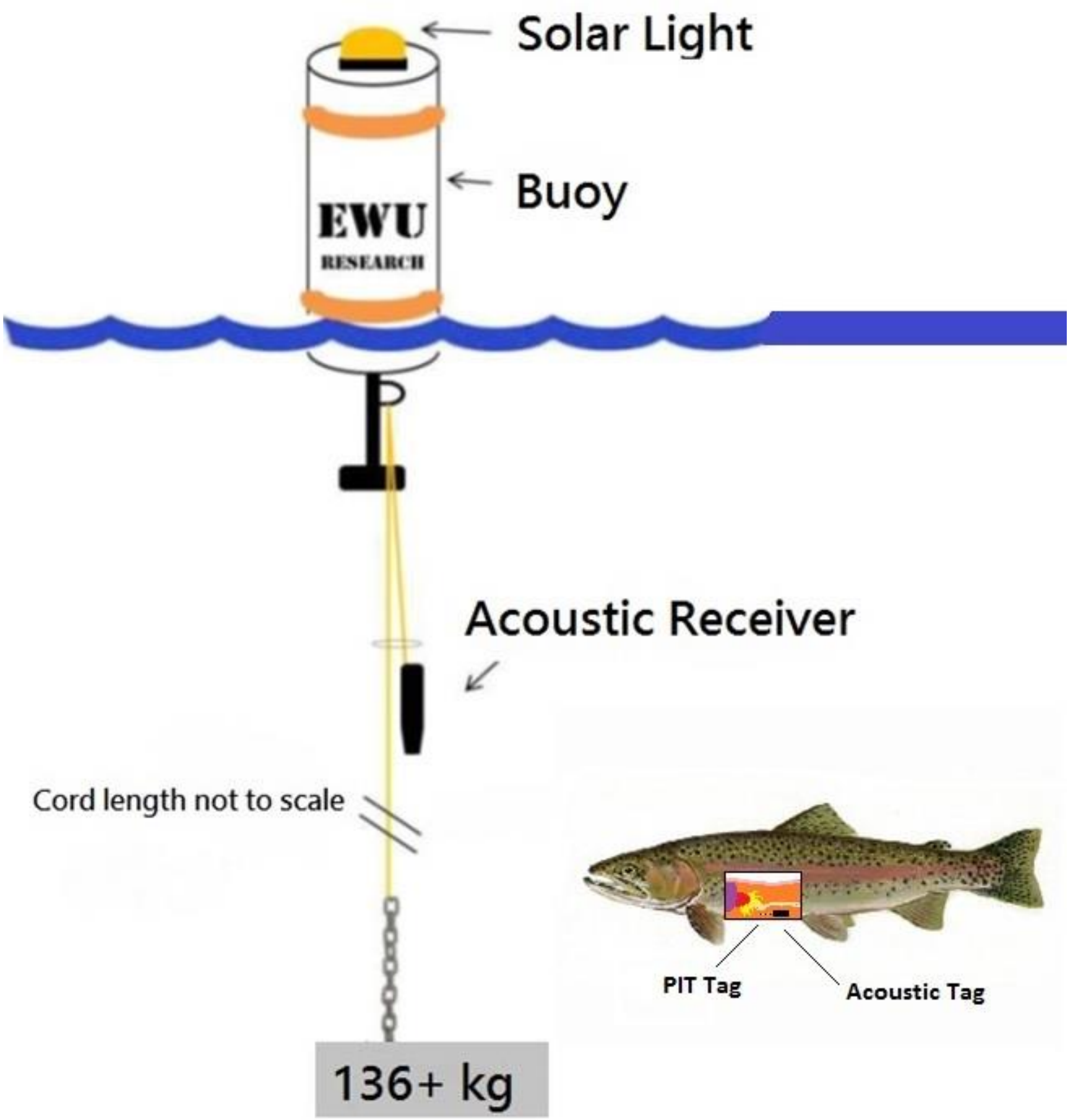



Figure 3-2. Typical anchor, cable, and buoy set up for acoustic receivers in Lake Roosevelt. With a depiction of tag placement within the fish.

Despite this, it is recommended that all logged transmissions must meet these criteria before acceptance (Pincock 2012). In order for the transmission to be verified, two or more detections had to be acquired from the same fish at the same receiver. These detections had to be within a reasonable amount of time between each other (<9 minutes based on a180 second nominal delay of the transmitter).

**Acoustic Data Analysis**

All acoustic data was downloaded from receivers and placed into a database for the duration of the study. Data were extracted from this database as a Microsoft Excel comma separated values (csv) file. This csv file was opened with the free statistical software R and analyzed. All analysis was done with R scripts developed by Walston et al. (2015).

Movement data was analyzed by a Dynamic Brownian Bridge Movement Model (DBBMM) to determine utilization distribution (UD) of fish from each tagging location. These utilization distributions are the probabilities of a fish occupying multiple areas, and are overlaid onto a map of the reservoir. The placement of receivers resulted in coarse locations and irregular time stamps that required the use of this state space modeling technique. The mathematics of this technique can be found in Horne et al. (2007). The method develops a trajectory (path of animal movements through an area), and interpolates where the animal is between locations of detection based on the amount of time that has passed between it being detected at those locations. Only fish that were detected on multiple receivers were used in this analysis. For a description of movements over the course of the entire tracking period for each individual fish see Appendix B.

We used the “move” package in R to estimate the trajectories in the DBBMM (Kranstauber et al. 2012.). These trajectories include spatial and temporal data that were constrained to the river channel with a process developed by Walston et al. (2015). Without constraining the trajectory to the river channel the DBBMM would show fish movements overland, which is unrealistic. With constrained trajectories a map of the utilization distribution (UD) was constructed. A UD for each fish was created and averaged for each tagging location. The averaged UD for each tributary group were compared to each other using a Mantel’s test with the “vegan” package in R. This was done by converting the average UD into a data matrix. Our locations for comparison were the Sanpoil River, Spokane Arm (Blue Creek, Spring Creek), Middle Reservoir (Wilmont, Alder ,and Hunters Creeks) , and Upper Reservoir (Onion and Big Sheep Creeks).

Mantel’s test is a correlation method in which dissimilarity/distance matrices are summarized as pairwise comparisons. This method is a correlation between entries of two matrices and since significance cannot be directly assessed Mantel’s test is asymptotic where it uses permutations of N rows and columns of the matrix (Legendre and Legendre 1998). As a formal hypothesis test, it summarizes the strength of correspondence between two matrices, and tests the null hypothesis that the two matrices are unrelated (Dutilleul et al. 2000). Because the null hypothesis is the two matrices are different, significance values were reported as q or 1-p and a q-value below the significance level of 0.05 indicated the two matrices were different. Since Mantel’s test can be biased by the resolution of the raster; Walston et al. (2015) tested comparisons of UD matrices of different tributary groups at different raster resolutions from 100 to 20,000. No difference in the q value or r value was found so the native resolution of 1875 was used for 2014/2015 data. We used this raster resolution for 2015/2016 data.

**Homing**

Homing was determined through the use of PIT tag data. PIT arrays are maintained by the Colville Confederated Tribes (CCT) on the Sanpoil River, on Blue and Alder Creeks by the Spokane Tribe of Indians (STOI), as well as Onion and Big Sheep Creeks by the Washington Department of Fish and Wildlife (WDFW).

**Entrainment**

Entrainment over Grand Coulee Dam was confirmed if a fish was detected on receivers located 13 km downstream of the dam in Rufus Woods Reservoir.

# Results

## Fish Tagging and Tracking

Eighty-one fish (41 females, 21 males, and 19 unknown sex; average total length: 470 ± 68 mm) were tagged from March 17 to June 1, 2015. EWU tagged all fish in 2015 except the fish in the Sanpoil River, which were tagged by the CCT. For sizes, sex, and condition of each fish tagged see Table 3-1.

## Tag Detections

Of the 81 fish tagged in 2015, 54 were detected on the acoustic receiver array. Of these 54, 39 were detected on multiple receivers, and 20 were detected into 2016. Only fish detected on multiple receivers were used to generate UD's for comparisons among the tributary groups. Summary of tag detections by each tributary group are given in Table 3-2.

## Sanpoil River

Fourteen of the 15 Redbands tagged in the Sanpoil River were detected on the receiver array. Interestingly, the one not detected on the receiver array was detected on a Colville Tribe maintained PIT tag array in the Sanpoil River on 4/19/2015 (four days after tagging). Of the 14 detected on the receiver array, two were detected at one receiver at the head of the Sanpoil Arm shortly after tagging, and were also detected on the same CCT maintained PIT tag array shortly after tagging. The other 12 were detected on multiple receivers. Ten were detected into

Table 3-1. Lake Roosevelt Redband Tagging with Location, Date, Acoustic Tag Size, ID, Total Length (TL), Weight (WT), Sex, Condition and PIT tag for each Redband tagged in 2015. ALD = Alder Creek, BGS Big Sheep Creek, BLU = Blue Creek, HUN = Hunters Creek, ONI = Onion Creek, SAN = Sanpoil River, SPR = Spring Creek, (Page 1 of 4).

| No. | Location | Date | Acoustic Tag | ID | TL(mm) | Wt(g) | Sex | Condition | PIT |
|---|---|---|---|---|---|---|---|---|---|
| 01 | SAN | 4/15 | v-9 | 58701 | 460 | 1020 | M | R | 900226000668685 |
| 02 | SAN | 4/15 | v-9 | 58700 | 475 | 1014 | U | Ma | 900226000668561 |
| 03 | SAN | 4/15 | v-9 | 58699 | 443 | 843 | U | Ma | 900226000668612 |
| 04 | SAN | 4/15 | v-9 | 58694 | 475 | 1128 | U | I | 900226000668583 |
| 05 | SAN | 4/15 | v-9 | 58693 | 515 | 1398 | U | I | 900226000668668 |
| 06 | SAN | 4/15 | v-9 | 58697 | 406 | 707 | U | I | 900226000668743 |
| 07 | SAN | 4/15 | v-9 | 58695 | 507 | 1230 | U | I | 900226000668719 |
| 08 | SAN | 4/15 | v-9 | 58696 | 423 | 757 | U | I | 900226000668542 |
| 09 | SAN | 4/15 | v-9 | 58688 | 386 | 596 | U | I | 900226000668529 |
| 10 | SAN | 4/15 | v-9 | 58698 | 509 | 1302 | U | I | 900226000668632 |
| 11 | SAN | 4/15 | v-9 | 58687 | 433 | 795 | U | I | 900226000668621 |
| 12 | SAN | 4/15 | v-9 | 58690 | 415 | 740 | U | I | 900226000668616 |
| 13 | SAN | 4/15 | v-9 | 58689 | 410 | 682 | U | I | 900226000668523 |
| 14 | SAN | 4/16 | v-9 | 58691 | 490 | 976 | F | PS | 900226000668627 |
| 15 | SAN | 4/16 | v-9 | 58692 | 508 | 1282 | U | I | 900226000668658 |
| 16 | BLU | 3/17 | v-13 | 59574 | 480 | 1297 | F | Ma | 985121013118531 |
| 17 | BLU | 4/1 | v-13 | 59572 | 521 | 1601 | F | Ma | 985121012449156 |
| 18 | BLU | 4/1 | v-13 | 59573 | 483 | 1146 | F | Ma | 985121012480819 |
| 19 | BLU | 4/1 | v-9 | 59576 | 500 | 1020 | F | Ma | 985121012215234 |
| 20 | BLU | 4/10 | v-9 | 59579 | 520 | 1444 | F | R | 985121012477354 |
| 21 | BLU | 4/10 | v-9 | 59580 | 430 | 836 | M | PS | 985121012994994 |
| 22 | BLU | 4/24 | v-7 | 33579 | 362 | 439 | M | R | 985121012448704 |
| 23 | BLU | 5/9 | v-7 | 33580 | 477 | 1020 | F | R | 985121013113500 |
| 24 | BLU | 5/9 | v-7 | 33582 | 199 | 92 | U | U | 985121012442119 |
| 25 | SPR | 3/26 | v-13 | 59571 | 477 | 914 | F | Ma | 985121013251123 |

Table 3-1 Continued. . Lake Roosevelt Redband Tagging with Location, Date, Acoustic Tag Size, ID, Total Length (TL), Weight (WT), Sex, Condition and PIT tag for each Redband tagged in 2015. ALD = Alder Creek, BGS Big Sheep Creek, BLU = Blue Creek, HUN = Hunters Creek, ONI = Onion Creek, SAN = Sanpoil River, SPR = Spring Creek, (Page 2 of 4).

| No. | Location | Date | Acoustic Tag | ID | TL(mm) | Wt(g) | Sex | Condition | PIT |
|---|---|---|---|---|---|---|---|---|---|
| 26 | SPR | 3/26 | v-9 | 59575 | 534 | 1202 | F | Ma | 985121012442115 |
| 27 | SPR | 4/4 | v-9 | 59577 | 570 | 1685 | F | Ma | 985121012192019 |
| 28 | SPR | 4/4 | v-7 | 33578 | 348 | 360 | U | U | 985121013232752 |
| 29 | SPR | 4/4 | v-9 | 59578 | 430 | 770 | U | U | 985121013248634 |
| 30 | SPR | 4/16 | v-9 | 59581 | 363 | 558 | F | PS | 985121012189053 |
| 31 | SPR | 4/29 | v-7 | 59582 | 495 | 1072 | F | PS | 985121012441476 |
| 32 | WIL | 4/15 | v-9 | 59583 | 410 | 1458 | M | R | 985121013241466 |
| 33 | WIL | 4/15 | v-9 | 59584 | 514 | 2504 | F | R | 985121012175721 |
| 34 | WIL | 4/15 | v-13 | 59565 | 422 | 1604 | U | U | 985121012195126 |
| 35 | WIL | 4/15 | v-9 | 59588 | 501 | 2396 | M | R | 985121012478552 |
| 36 | WIL | 4/15 | v-9 | 59589 | 549 | 3550 | F | R | 985121012450732 |
| 37 | WIL | 5/7 | v-9 | 59586 | 501 | 1952 | F | PS | 985121013234701 |
| 38 | WIL | 5/7 | v-9 | 59587 | 519 | 2490 | F | Ma | 985121012183165 |
| 39 | WIL | 5/7 | v-9 | 33587 | 246 | 138 | U | I | 985121012449749 |
| 40 | ALD | 4/10 | v-9 | 59566 | 488 | 1060 | M | PS | 985121012453215 |
| 41 | ALD | 4/24 | v-9 | 59585 | 516 | 1305 | M | R | 985121012190776 |
| 42 | HUN | 5/9 | v-7 | 33585 | 541 | 1534 | F | R | 985121012480373 |
| 43 | HUN | 5/9 | v-9 | 59590 | 495 | 1105 | M | R | 985121013249527 |
| 44 | HUN | 5/9 | v-9 | 59591 | 480 | 1201 | F | R | 985121013244093 |
| 45 | HUN | 5/9 | v-7 | 59594 | 449 | 800 | M | R | 985121012498573 |
| 46 | HUN | 5/9 | v-7 | 33583 | 361 | 479 | M | PS | 985121012502283 |
| 47 | HUN | 5/9 | v-7 | 33584 | 501 | 1270 | F | R | 985121013232753 |
| 48 | HUN | 5/9 | v-9 | 33586 | 496 | 1214 | F | R | 985121013249527 |
| 49 | ONI | 4/30 | v-9 | 59599 | 492 | 1148 | F | PS | 900226000653210 |

Table 3-1. Continued. . Lake Roosevelt Redband Tagging with Location, Date, Acoustic Tag Size, ID, Total Length (TL), Weight (WT), Sex, Condition and PIT tag for each Redband tagged in 2015. ALD = Alder Creek, BGS Big Sheep Creek, BLU = Blue Creek, HUN = Hunters Creek, ONI = Onion Creek, SAN = Sanpoil River, SPR = Spring Creek, (Page 3 of 4).

| No. | Location | Date | Acoustic Tag | ID | TL(mm) | Wt(g) | Sex | Condition | PIT Tag Number |
|---|---|---|---|---|---|---|---|---|---|
| 50 | ONI | 4/30 | v-7 | 33589 | 335 | 385 | M | R | 900226000653216 |
| 51 | ONI | 5/15 | v-9 | 23799 | 490 | 864 | M | PS | 900226000653110 |
| 52 | ONI | 5/15 | v-9 | 23800 | 515 | 1068 | F | PS | 900226000653013 |
| 53 | ONI | 5/19 | v-9 | 23802 | 485 | 892 | F | PS | 900226000653023 |
| 54 | ONI | 5/19 | v-9 | 23803 | 526 | 1977 | F | PS | 900226000653090 |
| 55 | ONI | 5/19 | v-9 | 23801 | 417 | 703 | F | PS | 900226000653003 |
| 56 | ONI | 5/19 | v-7 | 19060 | 461 | 825 | F | PS | 900226000653020 |
| 57 | ONI | 5/24 | v-7 | 19061 | 525 | 1067 | F | PS | 900226000653062 |
| 58 | ONI | 5/27 | v-7 | 19062 | 561 | 1068 | F | PS | 900226000653222 |
| 59 | ONI | 5/29 | v-7 | 19063 | 446 | 629 | F | PS | 900226000653131 |
| 60 | ONI | 6/1 | v-7 | 33581 | 465 | 710 | F | PS | 900226000653112 |
| 61 | ONI | 6/1 | v-7 | 19064 | 439 | 642 | F | PS | 900226000653219 |
| 62 | ONI | 6/1 | v-7 | 19066 | 461 | 740 | F | PS | 900226000653168 |
| 63 | ONI | 6/1 | v-7 | 19065 | 461 | 829 | F | PS | 900226000653016 |
| 64 | BGS | 4/6 | v-13 | 59568 | 551 | 1630 | M | R | 900226000653189 |
| 65 | BGS | 4/6 | v-13 | 59569 | 521 | 1321 | M | R | 900226000653052 |
| 66 | BGS | 4/6 | v-13 | 59570 | 562 | 1614 | M | R | 900226000653002 |

Table 3-1. Continued. . Lake Roosevelt Redband Tagging with Location, Date, Acoustic Tag Size, ID, Total Length (TL), Weight (WT), Sex, Condition and PIT tag for each Redband tagged in 2015. ALD = Alder Creek, BGS Big Sheep Creek, BLU = Blue Creek, HUN = Hunters Creek, ONI = Onion Creek, SAN = Sanpoil River, SPR = Spring Creek, (Page 4 of 4).

| No. | Location | Date | Acoustic Tag | ID | TL(mm) | Wt(g) | Sex | Condition | PIT Tag Number |
|---|---|---|---|---|---|---|---|---|---|
| 67 | BGS | 4/6 | v-9 | 59595 | 489 | 1046 | M | Ma | 900226000653181 |
| 68 | BGS | 4/6 | v-13 | 59567 | 483 | 1087 | F | Ma | 900226000653045 |
| 69 | BGS | 4/6 | v-9 | 59593 | 585 | 1607 | M | R | 900226000653097 |
| 70 | BGS | 4/24 | v-9 | 59596 | 517 | 1256 | F | R | 900226000653041 |
| 71 | BGS | 4/24 | v-9 | 59597 | 528 | 1108 | F | PS | 900226000653243 |
| 72 | BGS | 4/24 | v-9 | 59598 | 447 | 836 | M | R | 900226000653109 |
| 73 | BGS | 4/24 | v-7 | 33588 | 312 | 325 | M | R | 900226000653121 |
| 74 | BGS | 5/7 | v-9 | 59592 | 515 | 1085 | F | PS | 900226000653224 |
| 75 | BGS | 5/7 | v-9 | 23795 | 530 | 1180 | F | PS | 900226000136489 |
| 76 | BGS | 5/7 | v-9 | 23796 | 485 | 1032 | F | PS | 900226000653043 |
| 77 | BGS | 5/7 | v-9 | 33591 | 460 | 1039 | F | PS | 900226000653220 |
| 78 | BGS | 5/7 | v-7 | 33592 | 495 | 838 | F | PS | 900226000653241 |
| 79 | BGS | 5/7 | v-7 | 33590 | 439 | 900 | F | PS | 900226000653192 |
| 80 | BGS | 5/11 | v-9 | 23797 | 515 | 1025 | M | PS | 900226000653122 |
| 81 | BGS | 5/11 | v-9 | 23798 | 453 | 883 | M | PS | 900226000653140 |

**Blue Creek**

Seven of the nine Redbands tagged in Blue Creek were detected on the receiver array. Two were only detected at one receiver. One of these, tagged on April 1, 2015 was detected at McCoy's Marina in the Spokane Arm (Spokane River kilometer 11.1) on April 6, 2015.This fish has been continuously detected here from April 6, 2015-July 7, 2016. This fish was suspected to have died or expelled its tag at this location. Another was also only detected on this same receiver on April 16, 2015. Three were detected into 2016.

**Spring Creek**

Five of the seven Redbands tagged near Spring Creek were detected on the receiver array. One of the two not detected on the receiver array has been detected on a hydrophone approximately 1 km downstream of Little Falls Dam when EWU explored the Spokane River upstream of the Wynecoops Boat Launch receiver in July 2015. Another effort with a hydrophone was made in May 2016 and no acoustic tags were found in this section of the Spokane River. One was only detected at the Wynecoops Boat Launch receiver. Two were detected into 2016.

**Wilmont Creek**

Five of eight Redbands tagged in Wilmont Creek were detected on the receiver array. One was only detected at the Wilmont Receiver (100 km upstream of Grand Coulee Dam). The other four were detected on multiple receivers.

One tagged on April 15th 2016 was detected moving down to the lower reservoir to Plum Point by May 16, 2015. It was harvested by an angler and tag was returned to EWU. One tagged on April 15, 2015 moved down the reservoir to the Whitestone Rock Receiver (50 km upstream of Grand Coulee Dam), and has been continuously detected here from June 10, 2015 – July 7, 2016. This fish was suspected to have died or expelled its tag. Excluding the one suspected to have died/expelled its tag, one was detected into 2016.

**Alder Creek**

Neither fish tagged in Alder Creek was detected on the receiver array.

**Hunters Creek**

Three of seven Redband tagged in Hunter's Creek were detected on the receiver array. None have been detected into 2016. One was detected at the Hunters Receiver (117 km upstream of Grand Coulee Dam). None were detected into 2016

**Big Sheep Creek**

Eleven of the 18 Redbands tagged in Big Sheep Creek were detected on the receiver array. Six were detected at only one receiver with four at Big Sheep Receiver in the United States (232 km upstream of Grand Coulee Dam) and one at Northport (227 km upstream of Grand Coulee Dam). Five were detected on multiple receivers. Interestingly one detected only at Big Sheep in the United States on May 7, 2015 was next detected 56 km upstream of the international border in British Columbia from September 16 to 19, 2015. Two were detected into 2016.

## Onion Creek

Ten of 18 Redbands tagged in Onion Creek were detected on the receiver array. Two were detected into 2016. Three were detected on one receiver with one at Northport, one at Little Dalles (219 km upstream of Grand Coulee Dam), and one at Kettle Falls. Seven were detected on multiple receivers. Two were detected into 2016.

## Tags from 2014 Detected on Receiver Array

Seven tags from 2014 were detected into the time frame of this report. Three of these were only on one receiver. One tag was from Onion Creek and the other six were from the Sanpoil River. A summary of these can be found in Table 3-3.

## Utilization Distribution

The following (Figures 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, and 3-9) are outputs of the Dynamic Brownian Bridge Movement Model overlaid onto a map of the reservoir over the entire tracking period. The warmer colors (red) indicate areas of high probability of occurrence (more likely to utilize) and cool colors (green) indicate low probability of occurrence (less likely to utilize), normalized between 0 and 1.

Table 3-2. Summary of Redband Trout Transmitter Detections by Tributary, size of tag, tag life and number of days detected since tagging. *Denotes transmitter was detected at only one receiver (Page 1 of 2).

| Tributary and Year | Acoustic ID | Tag Size | Transmitter Life (days) | # of Days Detected | Date Tagged | Date of last detection |
|---|---|---|---|---|---|---|
| Sanpoil 2015 | 58687 | v-9 | 484 | 389 | 4/15/2015 | 5/8/2016 |
| | 58688 | v-9 | 484 | 354 | 4/15/2015 | 4/3/2016 |
| | 58689 | v-9 | 484 | 449 | 4/15/2015 | 7/7/2016 |
| | 58690 | v-9 | 484 | 346 | 4/15/2015 | 3/25/2016 |
| | 58691 | v-9 | 484 | 374 | 4/15/2015 | 4/25/2016 |
| | 58692 | v-9 | 484 | 264 | 4/15/2015 | 1/14/2016 |
| | *58693 | v-9 | 484 | 368 | 4/15/2015 | 4/18/2016 |
| | 58694 | v-9 | 484 | 373 | 4/15/2015 | 4/22/2016 |
| | 58695 | v-9 | 484 | 87 | 4/15/2015 | 7/11/2015 |
| | 58696 | v-9 | 484 | 98 | 4/15/2015 | 7/22/2015 |
| | 58697 | v-9 | 484 | 449 | 4/15/2015 | 7/7/2016 |
| | *58698 | v-9 | 484 | 3 | 4/15/2015 | 4/18/2015 |
| | 58699 | v-9 | 484 | 369 | 4/15/2015 | 9/23/2015 |
| | 58700 | v-9 | 484 | 427 | 4/15/2015 | 6/15/2016 |
| | | | | | | |
| Blue 2015 | 33579 | v-7 | 395 | 314 | 4/24/2015 | 3/3/2016 |
| | 33580 | v-7 | 395 | 323 | 5/9/2015 | 3/27/2016 |
| | 59572 | v-13 | 1019 | 423 | 4/1/2015 | 5/28/2016 |
| | 59573 | v-13 | 1019 | 21 | 4/1/2015 | 4/22/2015 |
| | 59576 | v-9 | 484 | 263 | 4/1/2015 | 12/19/2015 |
| | *59579 | v-9 | 484 | 6 | 4/10/2015 | 4/16/2015 |
| | | | | | | |
| Spring 2015 | *59571 | v-13 | 1019 | 466 | 3/26/2015 | 7/4/2016 |
| | 59575 | v-13 | 1019 | 41 | 3/26/15 | 5/5/2015 |
| | *59577 | v-9 | 484 | 22 | 4/4/2015 | 4/26/2015 |
| | *59578 | v-9 | 484 | 125 | 4/4/2015 | 7/7/2015 |
| | 59581 | v-9 | 484 | 445 | 4/16/2015 | 7/4/2016 |
| | 59582 | v-9 | 484 | 22 | 4/29/2015 | 5/21/2015 |
| | | | | | | |
| Wilmont 2015 | 59565 | v-13 | 1019 | 320 | 4/15/2015 | 2/29/2016 |
| | 59584 | v-9 | 484 | 33 | 4/15/2015 | 5/18/2015 |
| | *59588 | v-9 | 484 | 3 | 4/15/2015 | 4/18/2015 |
| | 59589 | v-9 | 484 | 31 | 4/15/2015 | 5/16/2015 |
| | | | | | | |
| Hunters 2015 | 33585 | v-7 | 395 | 47 | 5/9/2015 | 6/25/2015 |
| | *33586 | v-7 | 395 | 52 | 5/9/2015 | 6/30/2015 |
| | 59591 | v-9 | 484 | 15 | 5/9/2015 | 5/24/2015 |

Table 3-2. Continued Summary of Redband Trout Transmitter Detections by Tributary, size of tag, tag life and number of days detected since tagging. *Denotes transmitter was detected at only one receiver (page 2 of 2).

| Tributary and Year | Acoustic ID | Tag Size | Transmitter Life (days) | # of Days Detected | Date Tagged | Date of last detection |
|---|---|---|---|---|---|---|
| Onion 2015 | 19062 | v-7 | 395 | 17 | 5/27/2015 | 6/13/2015 |
| | 19065 | v-7 | 395 | 24 | 6/1/2015 | 6/25/2015 |
| | 19066 | v-7 | 395 | 266 | 6/1/2015 | 2/22/2016 |
| | 23799 | v-9 | 484 | 112 | 5/15/2015 | 9/4/2015 |
| | 23800 | v-9 | 484 | 267 | 5/15/2015 | 2/6/2015 |
| | *23801 | v-9 | 484 | 3 | 5/19/2015 | 5/22/2015 |
| | 23802 | v-9 | 484 | 75 | 5/19/2015 | 8/2/2015 |
| | 23803 | v-9 | 484 | 8 | 5/19/2015 | 5/27/2015 |
| | 33581 | v-7 | 395 | 325 | 6/1/2015 | 4/21/2016 |
| | | | | | | |
| BGSC 2015 | *23795 | v-9 | 484 | 132 | 5/7/2015 | 9/16/2015 |
| | *33590 | v-7 | 395 | 334 | 5/7/2015 | 4/4/2016 |
| | *33592 | v-7 | 395 | 127 | 5/7/2015 | 9/10/2015 |
| | 59569 | v-13 | 1019 | 107 | 4/6/2015 | 7/21/2015 |
| | *59593 | v-9 | 484 | 4 | 4/6/2015 | 4/10/2015 |
| | 59595 | v-9 | 484 | 36 | 4/6/2015 | 5/11/2015 |
| | 59596 | v-9 | 484 | 475 | 4/24/2015 | 8/11/2016 |
| | 59597 | v-9 | 484 | 18 | 4/24/2015 | 5/11/2015 |
| | 59598 | v-9 | 484 | 152 | 4/24/2015 | 9/22/2015 |

Table 3-3. Summary of Redband Trout Transmitter Detections for fish tagged in 2014 that were detected through 2015 by Tributary, size of tag, tag life and number of days detected since tagging. *Denotes transmitter was detected at only one receiver.

| Tributary and Year | Acoustic ID | Tag Size | Transmitter Life (days) | # of Days Detected | Date Tagged | Date of last detection |
|---|---|---|---|---|---|---|
| Onion 2014 | * 14446 | v-9 | 484 | 488 | 5/9/2014 | 9/2/2015 |
| Sanpoil 2014 | 15253 | v-9 | 484 | 407 | 4/18/2014 | 5/30/2015 |
| | * 15254 | v-9 | 484 | 484 | 4/18/2014 | 8/15/2015 |
| | 15256 | v-9 | 484 | 478 | 4/18/2014 | 8/9/2015 |
| | * 15258 | v-9 | 484 | 432 | 4/18/2014 | 6/24/2015 |
| | 15259 | v-9 | 484 | 484 | 4/18/2014 | 8/15/2015 |
| | 15263 | v-9 | 484 | 484 | 4/18/2014 | 8/15/2015 |

***Sanpoil River***

Sanpoil River Redbands had areas of high utilization in the Sanpoil Arm and the reservoir downstream of the confluence of the Sanpoil and Columbia. Other areas of high use were near Seven Bays and the Spokane Arm (Figure 3-3).

***Blue Creek***

Blue Creek Redbands had areas of high use primarily in the Spokane Arm, and near Seven Bays (Figure 3-4).

***Spring Creek***

Spring Creek Redbands had areas of high use in the Spokane Arm and near Seven Bays (Figure 3-5).

***Wilmont Creek***

Wilmont Creek Redbands had areas of high use in the Reservoir below Gifford to Wilmont Cove, the lower Spokane Arm, and Seven Bays to Whitestone Rock and Plum Point to Spring Canyon (Figure 3-6).

***Hunters Creek***

Hunters Creek Redbands had areas of high use Wilmont Cove, Gifford, and Chalk Grade. (Figure 3-7).

***Onion Creek***

Onion Creek Redbands had areas of high use upstream of Kettle Falls and near Hunters and Wilmont Cove (Figure 3-8).

***Bigsheep Creek***

Big Sheep Creek Redbands had areas of high use upstream of Kettle Falls (Figure 3-9).

**Comparisons**

We grouped the tributary tagging groups by region of the reservoir for comparisons. This is because of the variable time spanning individual fish detection histories for 15 days to 15 months and variable number of fish from each tributary that were detected on multiple receivers. Fish from tagging tributaries were grouped by region, and their average UD were converted into a data matrix, and these matrices were than compared with a Mantel's test. Our groups were Sanpoil River, Spokane Arm (Blue and Spring Creek), Middle Reservoir (Wilmont and Hunters Creek), and Upper Reservoir (Onion and Bigsheep Creek). Results of these comparisons are found in Table 3-4. All groups were similar to each other in terms of their overlap with the exception of the Sanpoil and Upper Reservoir ($r = 0.051$, $q = 0.025$). These results indicate that there is little overlap in the utilization of the reservoir between these two groups of tagged Redbands.

**Homing**

Ten acoustically tagged Redband Trout, tagged in 2015 were confirmed to have homed into their tagging stream in 2016. In the Sanpoil River seven fish acoustically tagged in 2015 migrated up the Sanpoil River past CCT maintained PIT Tag arrays between January 29 and April 26, 2016 (Bryan Jones Colville Confederated Tribes Fish andWildlife pers comm). One Redband tagged in Blue Creek was confirmed on a STOI maintained PIT Tag array in March 2016 (Casey Flanagan STOI pers comm) and two tagged in Big Sheep were caught during a WDFW Big Sheep Creek angling survey on

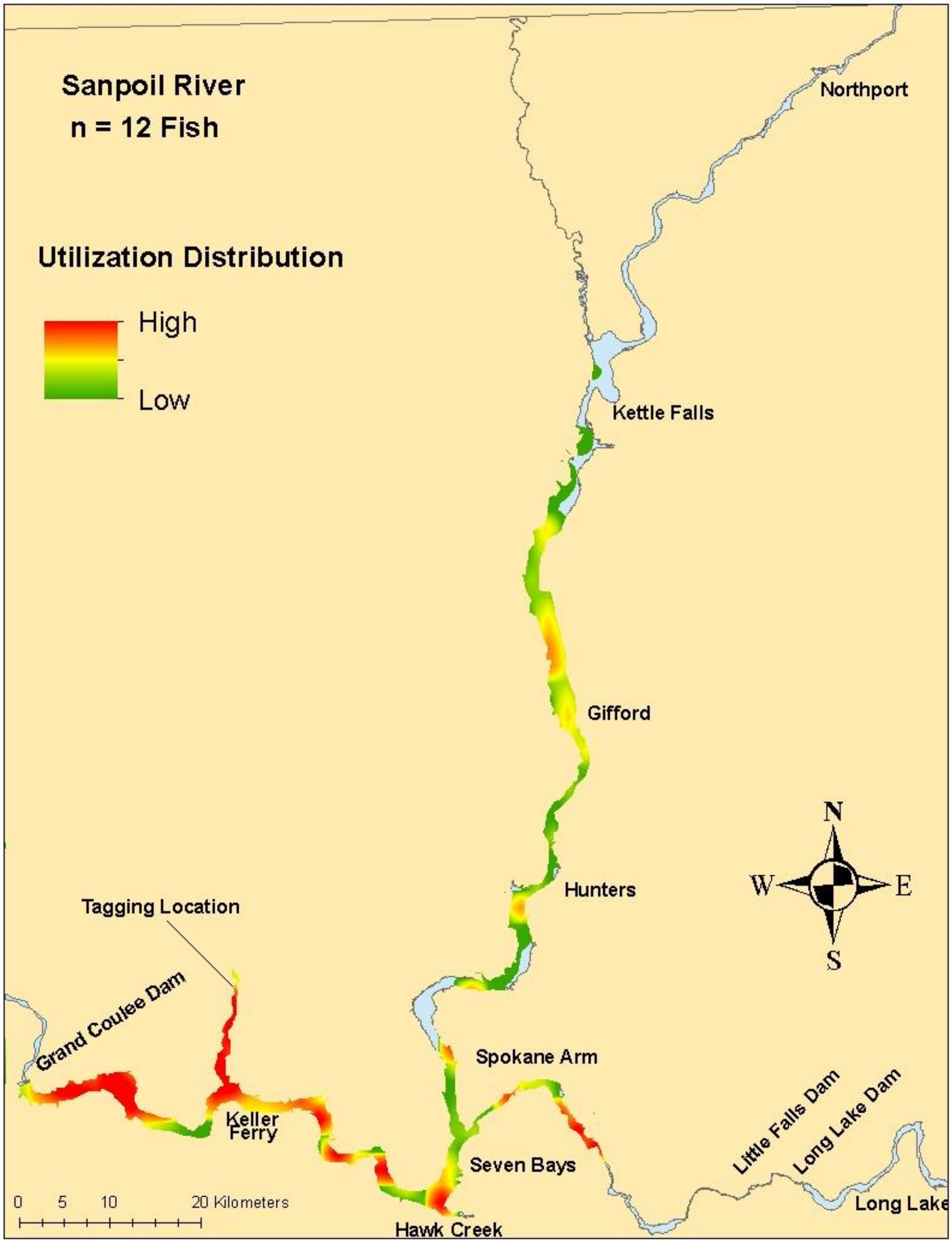



Figure 3-3. Utilization Distribution of Sanpoil River Redbands tagged in 2015.

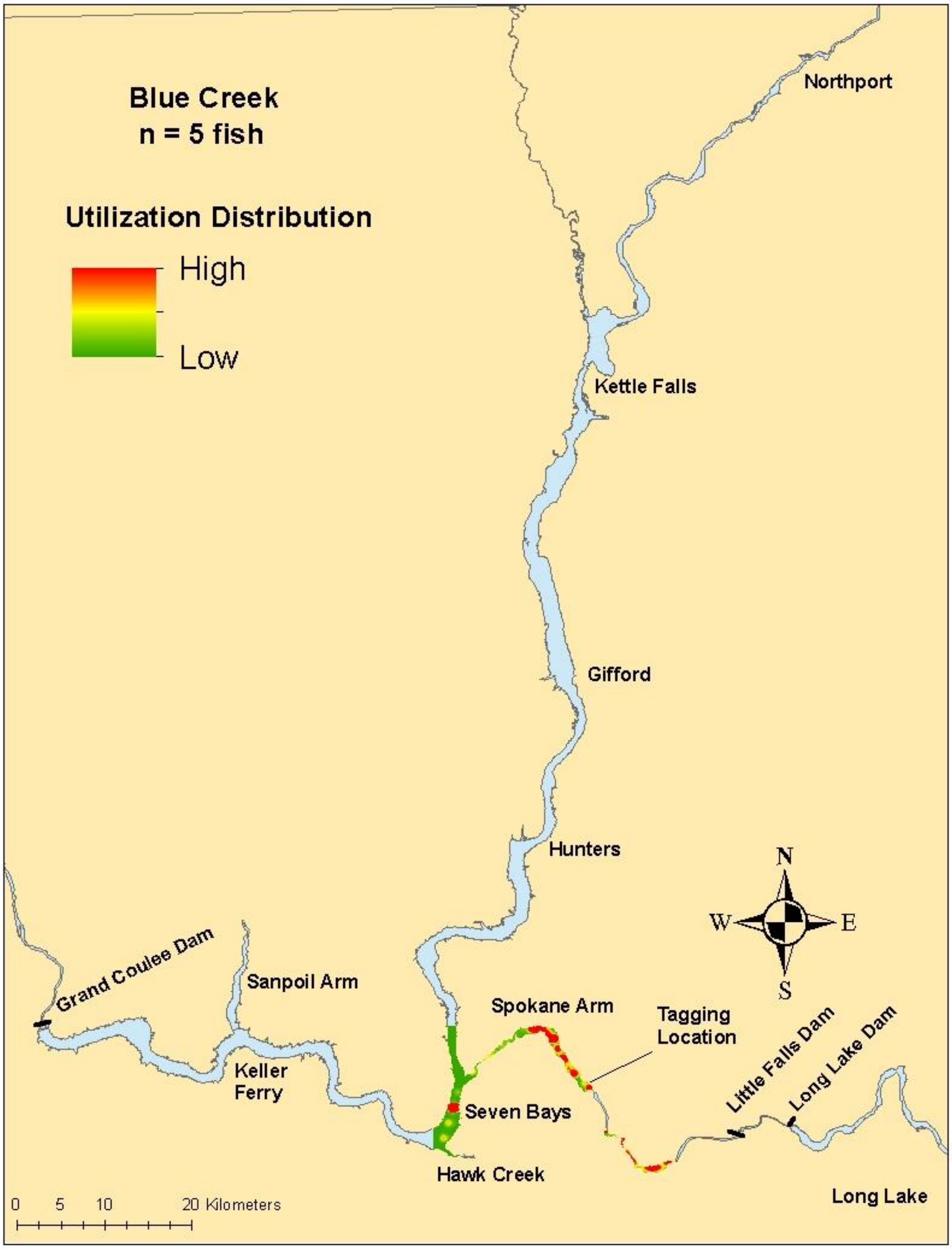



Figure 3-4. Utilization Distribution of Blue Creek Redbands tagged in 2015.

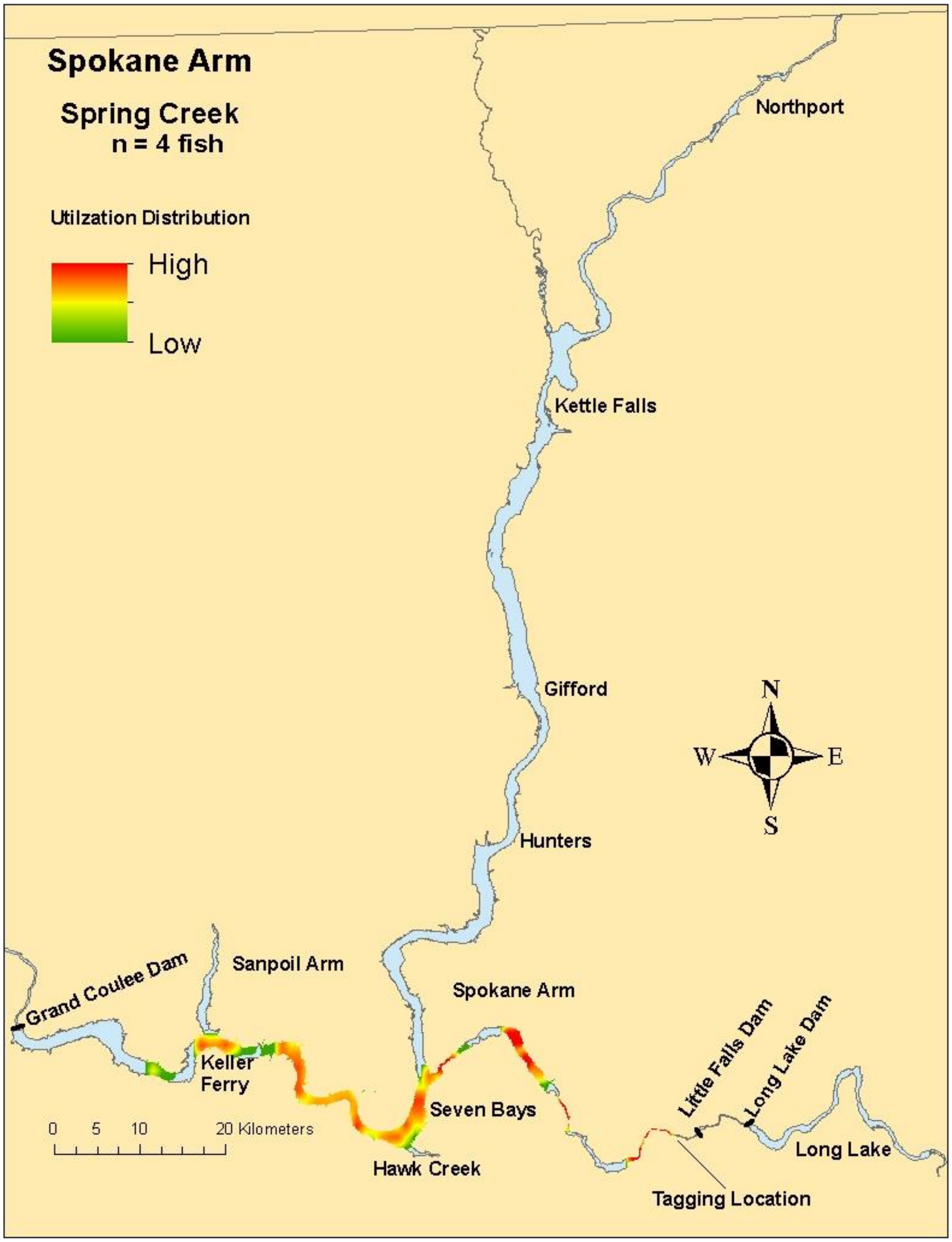



Figure 3-5. Utilization Distribution of Spring Creek Redbands tagged in 2015.

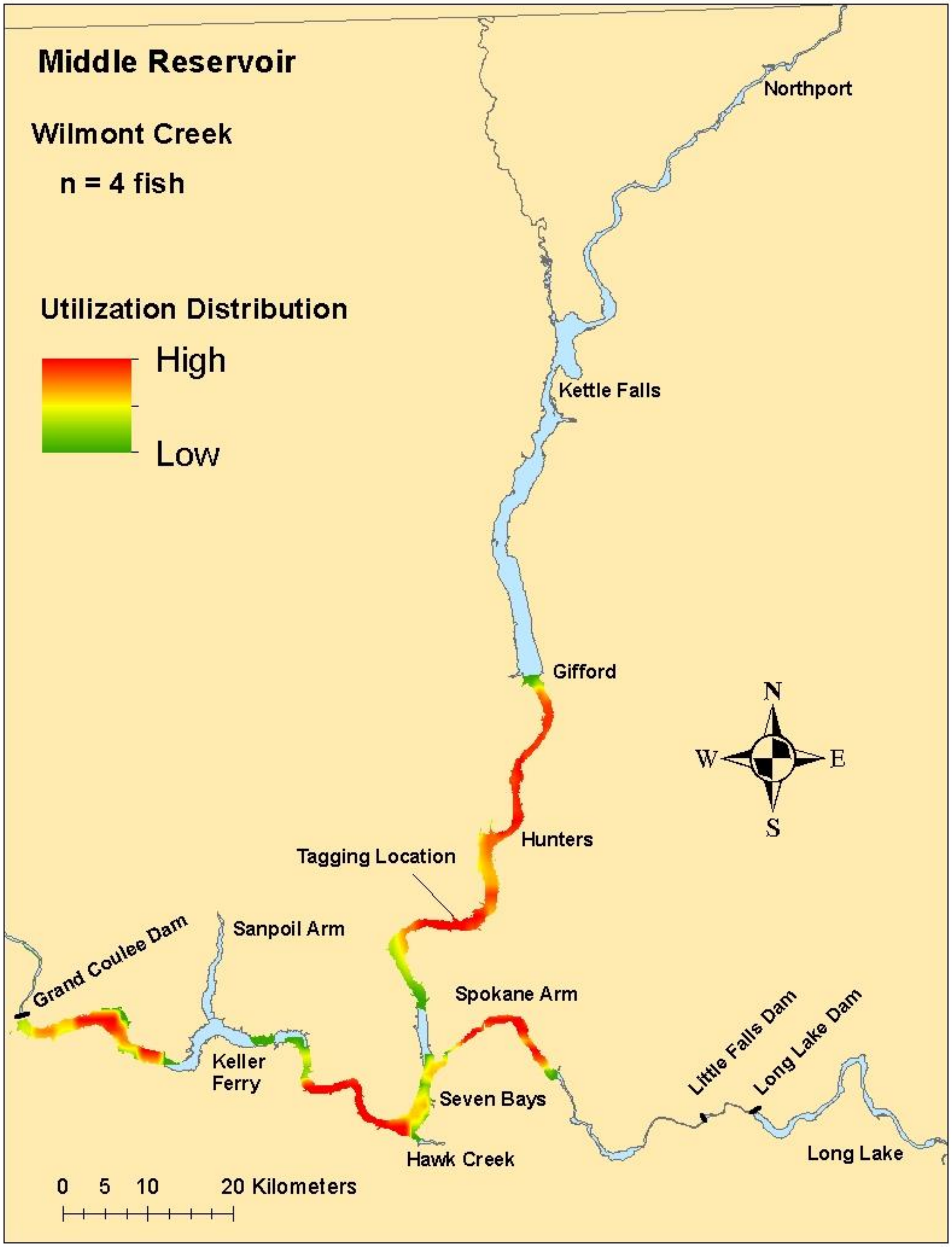



Figure 3-6. Utilization Distribution of Wilmont Creek Redbands tagged in 2015.

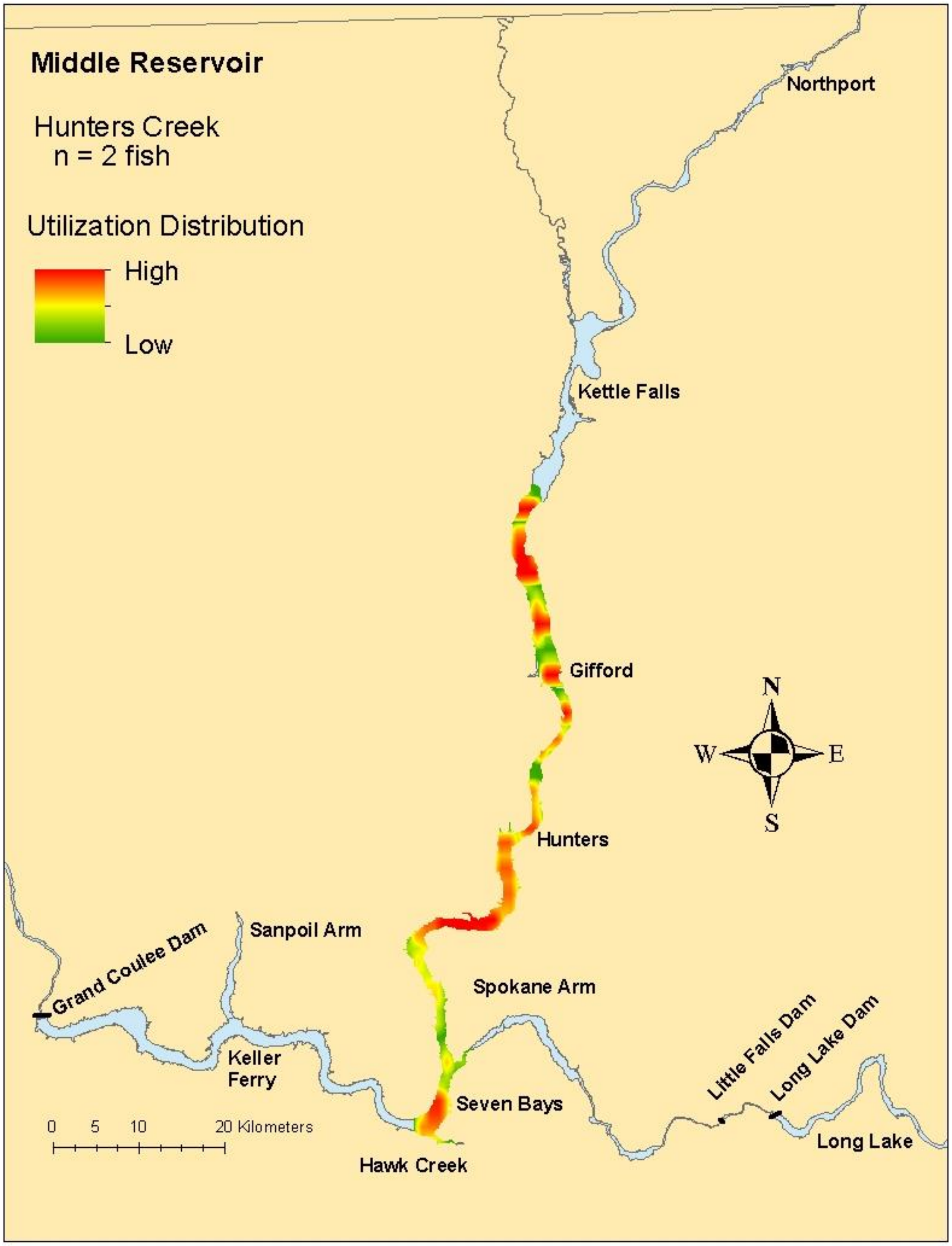



Figure 3-7. Utilization distribution of Hunters Creek Redbands tagged in 2015.

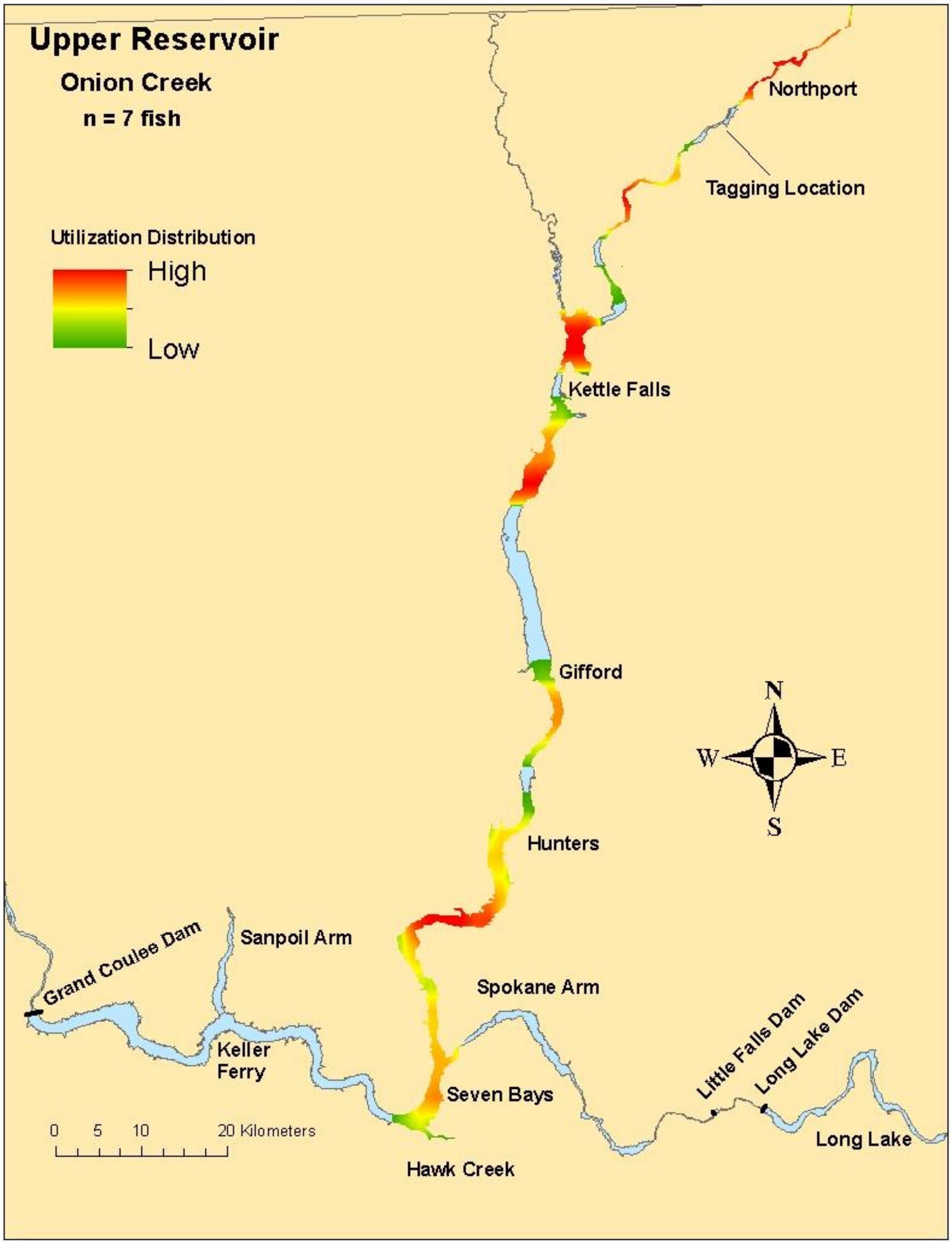



Figure 3-8. Utilization distribution of Onion Creek Redbands tagged in 2015.

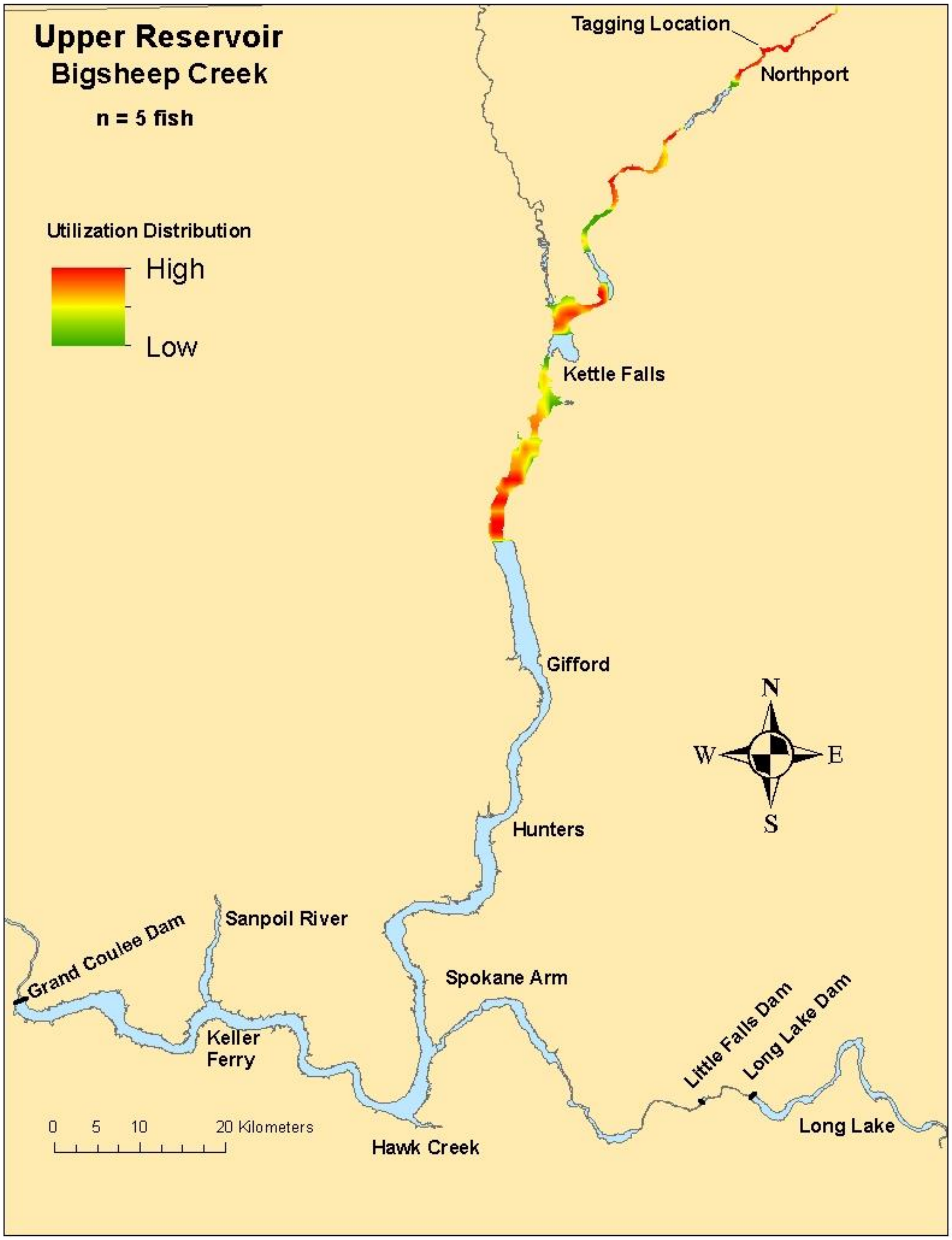



Figure 3-9. Utilization distribution of Big Sheep Creek Redbands tagged in 2015.

March 30, 2016 (Charles Lee WDFW pers comm.). All fish were adults when tagged. Sex, date tagged, homing location and date are given in Table 3-5.

Three fish displayed movements indicative of returning to their tagging location. One female tagged in Onion Creek resided in the reservoir near Keller for Winter 2015/2016. Between April 14 and April 21, 2016 this fish moved from Keller Ferry to Chalk Grade, a distance of approximately 115 km upstream. The last detection of this fish was at the Chalk Grade receiver, roughly 75 km downstream of its home stream. The transmitter was nearing the end of its predicted battery life. It is possible that this transmitter stopped working. However, the fate of this particular fish is unknown. A female from Big Sheep Creek not seen on the receiver array for 2015 was detected at the Big Sheep Creek receiver on April 4, 2016, suggesting that it moved back to Big Sheep Creek. Finally a female tagged in Spring Creek was detected on the uppermost Spokane River receiver on January 13, 2016. It's location of capture was in the vicinity of Spring Creek approximately 2.5km upstream of the uppermost Spokane River receiver. It was not detected on the aforementioned receiver again until May 6, 2016. These data suggest this fish moved in the vicinity of Spring Creek at a time appropriate for spawning.

**Entrainment**

During the time frame presented in this report (April 2015-July 8 2016) no Redband Trout tagged in 2015 were confirmed to have entrained over Grand Coulee Dam. Despite this four fish tagged in 2015 had their last detections on receivers upstream of Grand Coulee dam. One tagged at Spring Creek was last detected on 21 May 2015. It was detected twice on both receivers. A fish tagged in the Sanpoil was last detected 21 times on the North receiver and 5 times on the South receiver on 14 January 2016. A fish from the Sanpoil River was last detected on 3 April 2016 on the North receiver upstream of Grand Coulee Dam. Another fish from the Sanpoil was last detected on the North receiver upstream of Grand Coulee on 22 April 2016.

Table 3-4. Mantels Statistic *r* and *q*- value for each group comparison. Number of fish per group are Sanpoil (n=12), Spokane Arm (n=9), Middle Reservoir (n=6), and Upper Reservoir (n=12).

| Comparison | Mantel's Statistic *r* | *q*-value |
|---|---|---|
| Sanpoil / Spokane Arm | 0.350 | 0.999 |
| Sanpoil / Middle Reservoir | 0.726 | 0.999 |
| Sanpoil / Upper Reservoir | 0.051 | 0.025 |
| Spokane Arm / Middle Reservoir | 0.263 | 0.999 |
| Spokane Arm / Upper Reservoir | 0.232 | 0.875 |
| Middle Reservoir / Upper Reservoir | 0.938 | 0.998 |

Table 3-5. Redband Trout confirmed to have homed back to their stream of tagging during the following year from PIT tag array data.

| **Sex** | **Date Tagged** | **Homing Location** | **Date Homed** |
|---|---|---|---|
| Unknown | 4/15/2015 | Sanpoil | 2/28/2016 |
| Unknown | 4/15/2015 | Sanpoil | 1/29/2016 |
| Unknown | 4/15/2015 | Sanpoil | 3/21/2016 |
| Unknown | 4/15/2015 | Sanpoil | 3/25/2016 |
| Unknown | 4/15/2015 | Sanpoil | 3/22/2016 |
| Female | 4/15/2015 | Sanpoil | 4/26/2016 |
| Unknown | 4/15/2015 | Sanpoil | 3/20/2016 |
| Female | 4/24/2015 | Big Sheep Creek | 3/30/2016 |
| Male | 4/24/2015 | Big Sheep Creek | 3/30/2016 |
| Male | 4/24/2015 | Blue Creek | 4/26/2016 |

## Discussion

### Tag Detection History

In 2015/2016 54 of 81 transmitters were detected on the receiver array. Twenty seven transmitters from Redbands tagged in 2015 were never detected on the receiver array. Two fish, one 246 mm from Wilmont Creek, and one 199 mm from Blue Creek were never detected after tagging. It is possible these may have been residents of the stream they were tagged in, and never left. Six transmitters from Onion Creek and seven from Big Sheep Creek were never detected. Previously, Walston et al. (2015) noted the receiver array upstream of Kettle Falls was not as adept at detecting transmitters as the lower part of the array. Upstream of Kettle Falls the environment is more riverine than the lower reservoir. The fast moving water coupled with the shallower depths in this area likely reduces the range that receivers can detected tags and make it more likely for tagged fish to swim by receivers without being detected. In the previous years of this study there has also been transmitters never detected on the receiver array. In 2014/2015, 22 of 60 transmitters were never detected on the receiver array (Walston et al. 2015) and in 2013/2014, 13 of 51 transmitters were never detected (Stroud et al. 2014).

Of the Redband Trout tagged in 2015 and detected on the acoustic receiver array, 18 had a detection history that extended into 2016. Walston et al. (2015) reported 13 Redbands tagged in 2014 having a detection history extending into the following year, and Stroud et al. (2014) reported 15 Redbands tagged in 2013 being detected into the following year. Both the transmitters that were never detected and the few transmitters being detected into the following year leads us to wonder what could have happened to cause the disappearance of those Redband Trout.

Mortality, either natural or angling may be responsible for the disappearance of tagged Redband Trout. The average size of Redband Trout tagged in 2015 was 470 mm (TL). At this size these fish would too large for most piscivorous fish in the reservoir such as Burbot (*Lota lota*), Smallmouth Bass (*Micropterus dolomeiu*), and Walleye (*Sander vitreus*). Eagles and River Otter (*Lontra canadensis*) are present around the reservoir, and may occasionally take large trout. Angling appears to be a major source of mortality in wild adult Redband Trout. From 2012-2014 it was estimated that 3,735 Redband Trout were harvested across Lake Roosevelt (McLellan 2015). Of these 3,500 were from the lower 80 km of the Reservoir (McLellan 2015). Across the whole reservoir estimated population of adult Redband Trout spawners is around 5,000 (McLellan 2015). Previously the harvest rules on Rainbow Trout in Lake Roosevelt consisted of a daily limit of 5 with two over 20 inches and did not distinguish between hatchery rainbows and wild Redband Trout with an intact adipose fin (WDFW 2016). The Washington Fish and Wildlife commission voted in 2016 to change the rules to only allow for retention of hatchery rainbow without adipose fin and require anglers to release all wild trout in the reservoir downstream of the Little Dalles (WDFW 2016).

Several acoustic transmitters from Redband Trout tagged in 2013-2015 have been returned by anglers. Two acoustic transmitters from 2015 have been returned by anglers, and three acoustic transmitters from fish in 2014 were returned (Walston et al. 2015). No Redband Trout tagged from 2013 to 2015 were marked with an external tag (example floy tag). It is possible that anglers did not see acoustic tags in the body cavity as they frequently fillet their fish at cleaning stations adjacent to boat launches. Thus the number of Redband Trout with acoustic tags caught by anglers could be far more than what was reported.

Redband Trout tagged in the Sanpoil River had the longest detection histories of any other tributary group. Of the 18 tagged in 2015 and detected into 2016, 10 were from the Sanpoil River. In the previous two years 9 of the 13 tagged in 2014 and detected into 2015, and 8 of the 15 tagged in 2013 and detected into 2014 were from the Sanpoil River. This may be related to the number of receivers in the lower reservoir. The lower 48 km of reservoir and the Sanpoil Arm have 21 of the 48 receivers in the 240 km long reservoir. Another difference is during 2014 and 2015 fish in the Sanpoil River were sedated with electronarcosis prior to tag implantation whereas fish in other tributaries were sedated with the chemical anesthetic AQUIS-20E. Fish sedated with chemicals may be sluggish for a short time after release even after the observer has deemed them recovered and may not be adept at evading predators as the side effects of the anesthetic wear off (Marking and Meyer 1985). However, in 2013 Sanpoil Redband Trout were also sedated with AQUIS-20E and had the greatest number of individuals detected into the following year.

**Utilization Distribution**

Utilization between fish tagged in the lower three regions of the reservoir (Sanpoil, Spokane Arm, and Middle Reservoir) had high overlap, whereas utilization between the Sanpoil and Upper Reservoir had low overlap. This was similar to observations of Redband Trout tagged in 2013 and 2014 (Walston et al. 2015;Table 3-6). In addition these data are in agreement with findings from Small et al. (2014) who found that Redband populations are most strongly distinguished at the regional level of the Reservoir, with the greatest differences occurring between the Sanpoil River and the

Upper Reservoir, whereas the Sanpoil, Spokane Arm and Middle Reservoirs were relatively similar to each other.

It appears the Redband Trout in the Upper Reservoir rarely move down into the lower regions of the reservoir. However, these data should be interpreted with caution since only one Big Sheep Creek fish detected on multiple receivers was detected into 2016. If more fish were detected into 2016 than we would have more confidence in determining utilization of these Upper Reservoir group of Redband Trout.

From three years of tagging, it seems Redband Trout in Lake Roosevelt infrequently use Canadian waters. Out of the 192 Redband Trout tagged over the three year course of this study five were detected in British Columbia. Interestingly, one tagged in Blue Creek in 2013 was detected in British Columbia, the other four were from the Upper Reservoir with one from Onion Creek in 2014, another from Onion Creek in 2015, and two from Big Sheep Creek in 2015. In 2015/2016 large spans of time (>80 days) occurred between when fish were last detected in the United States and when they were first detected in British Columbia. Therefore, no meaningful UD's could be generated. This is because the Dynamic Brownian Bridge Movement Model's ability to infer where the fish is between detections decreases as amount of time between detections increases. Of the three detected in British Columbia in 2015 two were detected on one receiver and one was on two receivers in British Columbia. B.C. Hydro maintains 21 receivers in the Columbia between Hugh Keenlyside dam and the International Border. It is likely these receivers are subjected to the same reduced detection ranges as ones in the Columbia between Kettle Falls and Northport, owing to fast moving shallow water.

**Homing**

Lake Roosevelt Redband Trout appear to home back to the stream of capture. In 2016 no Redband Trout returned to streams other than the one in which they were tagged, in. Although the number of fish confirmed to have homed or potentially homed was low (n=13 out of 81). It is possible that Redband Trout in Lake Roosevelt may not spawn every year as seen with rainbow trout elsewhere (Torvik 2013).

In previous years of this study Redband Trout also homed to their tagging stream. Five tagged in the Sanpoil in 2013 returned to the Sanpoil, and six tagged in 2014 returned there in 2015. One tagged in Alder in 2013 homed in 2014, and three tagged in Big Sheep in 2013 homed in 2014. Also an acoustically tagged Redband from Blue Creek in 2013 was recaptured in Blue Creek on April 1, 2015 (B. Witte, pers obs.). In total 26 acoustically tagged Redband Trout were confirmed to home back to the stream they were tagged in, with no instances of acoustically tagged Redbands entering streams where they were not tagged in.

Interestingly, two fish confirmed to home back to their tagging streams in 2016 had moved from locations upstream of their tagging stream. A Sanpoil River fish that had after moving to the upper Columbia. This fish moved downstream on the Columbia 170 km over the course of 14 days to the mouth of the Sanpoil before being detected on a PIT tag array upstream of the Sanpoil mouth. A Blue Creek fish quickly moved 20 km down the Spokane River in March from Harker Canyon to the mouth of Blue Creek before being detected on a PIT tag Array in Blue Creek. These results add to the evidence of the strong tendency for Lake Roosevelt Redband Trout to home.

Table 3-6. Comparison of Utilization Distributions by years. Data from 2013/2014 and 2014/2015 was provided by Walston et al. (2015). Spokane = Blue and Spring Creek, Middle Reservoir = Wilmont and Hunters Creek, Upper Reservoir = Big Sheep and Onion Creeks.

| UD1 | UD2 | Mantel statistic *r* | *q*-value |
|---|---|---|---|
| 2013/2014 Overall Comparisons | | | |
| Sanpoil | Spokane | 0.789 | 0.999 |
| Sanpoil | Alder | 0.789 | 0.998 |
| Sanpoil | Big Sheep | 0.045 | 0.020 |
| Spokane | Alder | 1.000 | 0.999 |
| Spokane | Big Sheep | 0.622 | 0.999 |
| Alder | Big Sheep | 0.632 | 0.999 |
| 2014/2015 Overall Comparisons | | | |
| Sanpoil | Spokane | 0.910 | 0.999 |
| Sanpoil | Alder/Wilmont | 0.973 | 0.999 |
| Sanpoil | Big Sheep/Onion | 0.064 | 0.019 |
| Spokane | Alder/Wilmont | 0.836 | 0.999 |
| Spokane | Big Sheep/Onion | 0.617 | 0.998 |
| Alder/Wilmont | Big Sheep/Onion | 0.584 | 0.998 |
| 2015/2016 Overall Comparisons | | | |
| Sanpoil | Spokane | 0.350 | 0.999 |
| Sanpoil | Middle Reservoir | 0.726 | 0.999 |
| Sanpoil | Upper Reservoir | 0.051 | 0.025 |
| Spokane | Middle Reservoir | 0.263 | 0.999 |
| Spokane | Upper Reservoir | 0.232 | 0.875 |
| Middle Reservoir | Upper Reservoir | 0.938 | 0.998 |

Small et al. (2014) determined that each tributary population of Redband Trout in Lake Roosevelt was genetically distinctive from one another, although there was evidence of metapopulation structuring, with fish from the Sanpoil, Spokane, and middle reservoir tributaries belonging to one metapopulation while those from the upper reservoir (in Big Sheep and Onion Creeks) belonging to a second metapopulation. Tracking data indicated that although the only significant difference between the utilization distributions was between the Sanpoil River and the upper reservoir tributaries, utilization distributions of Sanpoil, Spokane and middle reservoir tributaries were similar to each other and were distinctly different from the upper reservoir tributaries.

**Entrainment**

No Redband Trout tagged in 2015 were confirmed to have entrained. Four fish may have possibly entrained. Three of the four last detected near Grand Coulee dam had all or the majority of their last detections on the north receiver. If they did entrain it may have been through the third powerhouse, located on the north side of Grand Coulee dam and where most entrainment through the dam occurs (LeCaire et al. 1998). During all years of the study a total of eight Redband Trout have been confirmed to have entrained. In addition 11 other acoustically tagged fish have their last know detections at receivers approximately two km upstream of Grand Coulee Dam.

There are several possibilities to explain the disappearance of these Redband Trout last detected above Grand Coulee Dam. The first is entrainment over the dam where the fish resided in the river below the dam and does not pass by the receivers located 13 km downstream or passes by these receivers at a time of reduced detection ability. Between 2013 and 2016, 11 Redband Trout were last detected at one of two receivers approximately two kilometers upstream of Grand Coulee Dam. Three were last detected on the southern receiver, five were detected on both receivers and three were last detected on the northern receiver. LeCaire (1998) demonstrated the majority of entrainment through Grand Coulee Dam occurs through the third powerhouse on the north side of the dam. Fish last detected on the north receiver may have continued to swim downstream along the north bank and eventually entrain. Fish detected on both receivers may have also entrained.

A second possibility is entrainment into Banks Lake an irrigation storage reservoir of the Columbia Basin irrigation project which receives water from a pumping station at Grand Coulee Dam (Stober et al. 1976). Stober et al. (1976) had difficulties when sampling the Banks Lake Feeder Canal with gill nets for fish that entrain from Lake Roosevelt due the various amounts of flow encountered. From July-September 1975, Stober et al. (1976) captured 188 fish in 285 hours of net tests in the Banks Lake Feeder Canal and only presented a list of fish encountered by relative abundance. Rainbow Trout were encountered in these net sets, although they ranked 7th in relative abundance out of 13 fish species encountered. These are the only data collected on entrainment of fish from Lake Roosevelt into Banks Lake.

The intake for this feeder canal is located on the south bank of the river and has 12 four meter diameter pipes that are located 30 meters under the surface when the reservoir is at full pool (Johnson et al. 2005). Of the 11 Redband Trout that were last detected near Grand Coulee during the three years of our current study; seven were last detected between April 3 and August 30. Water is pumped into Banks Lake each year from March-October to accommodate irrigation needs of the Columbia Basin Project.

Therefore, it is possible these fish entrained into Banks Lake. This possibility appeared to be overlooked during the previous years of this study (Stroud et al. 2014, Walston et al. 2015). We do not mean to imply this is the best explanation for the disappearance of these tagged Redband Trout, but it should be taken in consideration with the other possibilities. Future studies with acoustic telemetry on this reservoir must address these possibilities for fish that are last detected above Grand Coulee Dam. Perhaps with acoustic telemetry surveys downstream of Grand Coulee Dam, and the installation of an acoustic receiver at the upper end of Banks Lake.

**Future Directions on Lake Roosevelt Redband Trout**

Important information regarding Redband Trout in Lake Roosevelt has been gathered from this acoustic telemetry study. This study has spanned three years, and has implanted tags into 192 Redbands from eight tributary streams. What was generally found across the three years were; 1) adult Redband Trout appeared to be subjected to high mortality in Lake Roosevelt; 2) All groups had individuals move in the lower Reservoir, but Upper Reservoir fish appeared to have very little overlap in areas of the reservoir utilized with fish from the Sanpoil River; 3) Redbands strongly homed back to their stream of tagging; and 4) Entrainment of adult Redband Trout does occur over Grand Coulee Dam. In addition more Redbands were last detected shortly upstream of Grand Coulee Dam (n =11) than were confirmed to have entrained over it (n = 8).

We plan to prepare a publication encompassing all three years of data for submission into a peer reviewed journal. The method used to analyze this data is unique in that it has only been used for telemetry data on terrestrial animals. Walston et al. (2015) was able modify this method for telemetry data gathered on animals that have a defined barrier, such as the confines of a waterbody for fish. The method Walston et al. (2015) developed is applicable to similar data collected from other fish telemetry studies and is likely of interest to the fisheries community.

Maintaining this population of Redband Trout is essential for the survival of Columbia River Redband Trout, and for the return of anadromous fish above Grand Coulee Dam. Redband Trout have diverse life history strategies and appear to retain anadromy even after their environment is altered. McLellan et al. (2015) PIT tagged Redband Trout in the Sanpoil River with some individuals appearing in the Columbia downstream of Rock Island Dam. These fish may be exhibiting anadromy and if so, Lake Roosevelt Redband Trout could be a potential source for reestablishing the anadromous form of Columbia River Redband Trout above Grand Coulee Dam.

## Literature Cited

Behnke, R. J. 1992. Native Trout of Western North America. American Fisheries Society. Monograph 6, Bethesda, Maryland. 231 pp.

Brown, R. S., K. V. Cook, R. S. Klett, A. H. A. Colotelo, R. W. Walker, B. D. Pfugrath, and B. J. Belgraph. 2013. Spawning and overwintering movements and habitat use of wild Rainbow Trout in the Sanpoil River, Washington. Battelle Pacific Northwest Division, Richland, Washington. Report No. PNWD-4386: 149 pp.

Brown, R. S., S. J. Cooke, W. G. Anderson and R. S. McKinley. 1999. Evidence to challenge the “2%” rule for biotelemetry. North American Journal of Fisheries Management 19: 867-871.

Cichosz, T. A., J. P. Shields, and K. Underwood. 1997. Lake Roosevelt monitoring/data collection program. Annual Report 1996 . United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Report No. 32148–2: 325 pp.

Cichosz, T., J. Shields, and K. Underwood. 1999. Lake Roosevelt monitoring/data collection program. Annual Report 1997. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Report No.32148–3: 182 pp.

Crawford, B. A. 1979. The origin and history of the trout brood stocks of the Washington Department of Game. Washington State Game Department, Olympia, Washington. Fishery Research Report. 78 pp.

Deters, K. A., R. S. Brown, K. M. Carter, and J. W. Boyd. 2010. Performance assessment of suture type, water temperature, and surgeon skill in juvenile Chinook Salmon surgically implanted with acoustic transmitters. Transactions of the American Fisheries Society. 139: 888-899.

Dutilleul, P., J.  D. Stockwell, D. Frigon, and P. Legendre. 2000. The Mantel test versus Pearson's correlation analysis: assessment of the differences for biological and environmental studies. Journal of Agricultural and Biological Environmental Studies. 5: 131–150.

Griffith, J. R., and A. T. Scholz. 1991. Lake Roosevelt fisheries monitoring program. United States Department of Energy, Bonneville Power Administration, Portland, Oregon Annual report 1990. United States. Report No. 91819-3: 232 pp.

Harms, C. A. 2005. Surgery in fish research: common procedures and postoperative care. Lab Animal. 34(1): 28-34: 164 pp.

Horne, J. S., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology. 88(9):2354-2363.

Howell, M. D. and J. G. McLellan. 2007. Lake Roosevelt White Sturgeon recovery Project annual progress report 2005. United States Department of Energy, Bonneville Power Administration Portland, Oregon. Document ID# P108776: 47 pp.

Hudson, J. M., J. R. Johnson, and B. Kynard. 2011. A portable electronarcosis system for anesthetizing salmonids and other fish. North American Journal of Fisheries Management  31: 335-339.

Johnson, R. L., C. A. McKinstry, C. B. Cook, D. K. Tano, D. M. Faber, S. Francis, M. A. Simmons, C. S. Simmons, R. S. Brown, S. L. Thorsten, and R. LeCaire. 2005. Strobe Light deterrent efficacy test and fish behavior determination at Grand Coulee Dam third powerplant forebay. Battelle Pacific Northwest Divison, Richland, WA. Report Prepared for Bonneville Power Administration. Contract DE-AC05-76RL01830.

Lawrence, M. P., H. Espinosa-Perez, L. T. Findley, C. R. Gilbert, R. N. Lea, N. E Mandrak, R. L. Mayden, and J. S. Nelson. 2013. Common and scientific names of fishes from the United States, Canada, and Mexico 7th Edition. American Fisheries Society, Bethesda, Maryland. 243 pp.

Lee, C., J. McLellan, and L. C. King. 2012. Upper Columbia River Redband Trout Stock Assessment: Resident Fish Stock Status Project 2012 Annual Progress Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Document ID No. P136352: 80 pp.

LeCaire, R. 1998. Chief Joseph Kokanee enhancement project: 1996 - 1997 annual report. United States Department of Energy, Bonneville Power Administration, Portland,Oregon. Document ID # 113: 92 pp

Legendre, P. and L. Legendre. 1998. Numerical ecology, second English ed. Elsevier Science BV, Amsterdam. 853 pp.

Kranstauber, B., R. Kays, S. D. LaPoint, M. Wikelski, and K. Safi. 2012. A dynamic brownian bridge movement model to estimate utilization distributions for heterogeneous animal movements. Journal of Animal Ecology 81: 738-746.

Marking, L. L., and F. P. Meyer. 1985. Are better anesthetics needed in fisheries? Fisheries. 10: 2-5.

McPhail J. D. and Lindsey C. C. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia system and rivers north to the Stikine) In: Hocutt C.H., Wiley E. O.,editors. The Zoogeography of North American Freshwater Fishes. New York, USA: John Wiley and Sons: 615–637.

McLellan, H. J., S. G. Hayes, and A. T. Scholz. 2008. Effects of reservoir operation on hatchery coastal rainbow trout in Lake Roosevelt, Washington. North American Journal of Fisheries Management 28: 1201-1213.

McLellan, H. J., A. T. Scholz, B. D. Nine, and C. Lee. 2009. Annual Assement of Kokanee in Lake Roosevelt: 2008 Annual Report. United States Department of Energy, Bonneville Power Administration. Document ID No. P116037. 85 pp.

McLellan, H. J., A. T. Scholz, and A. Miller. 2010. Lake Roosevelt Kokanee Assessments: 2009 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Document ID No. P122558: 152 pp.

McLellan H. J. 2015. Lake Roosevelt rainbow trout harvest regulation change request draft. Presented to Redband Trout Technical/Coordination Group, Spokane, Washington. 9 July 2015: 21pp.

McLellan, H. J., B. W. Jones, and E. A. Simonsen. 2015. Colville Confederated Tribes resident fish research, monitoring, and evaluation. 2012 annual report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon.Project No. 2008-109-00. 30 pp.

Mullen, J. W., K. R. Williams, G. Rhodus, T. W. Hillman, and J. D. McIntyre. 1992. Production and habitat of salmonids in mid-Columbia River tributary streams. United States Fish and Wildlife Service, Monograph I. Washington D.C. 216 pp.

Northcote. T. H. 1997. Potanodromy in salmonidae- living and moving in the fast lane. North American Journal of Fisheries Management. 17(4)1029-1045.

Peone, T. L., A. T. Scholz, J. R. Griffith, S. Graves, and M. G. Thatcher. 1990. Lake Roosevelt monitoring program: Annual report August 1988-December 1989. United States Department of Energy, Bonneville Power Administration, Portland OR. Report No. DOE/BP-91819-2. 234 pp.

Pincock, D. G. 2012. False Detections: What they are and how to remove them from detection data. AMIRIX Systems Incorporated, Application Note: Document #: DOC-004691 Version 03. 1-14 pp.

Scholz, A. T. and H. J. McLellan. 2010. Fishes of the Columbia and Snake River basins in eastern Washington. Eagle Printing Press. Cheney, Washington. 771 pp.

Scholz, A. T., A. O. Blake, M. N. Korst, D. H. P. Stroud, T. Parsons, M. Paluch, and H. J. McLellan. 2011. Annual asseeement of hatchery kokanee, and sonic tracking of wild and hatchery kokanee in Lake Roosevelt: 2010 Annual Report. Bonneville Power Administration, Portland Oregon. Contract No. 00043471 Project No. 1994-043-00. 188 pp.

Scholz, A. T. 2014. Fishes of eastern Washington: A natural history (4 volumes). LithoArt Printers Spokane, Washington. Volume I (pp. 1 – 545); Volume II (pp.546 – 909);Volume III (pp. 910 – 1427); Volume IV (pp.1428 – 2,089).

Seibert, J. R., A. L. Miller, and P. B. Nichols. 2015. Draft Lake Roosevelt White Sturgeon recovery project annual progress report April 2013 - March 2014. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Contract No. 65088000 Project No. 1995-027-00). 50 pp.

Small, M. P., C. Lee, H. McLellan, C. Flanagan, and V. Smilansky. 2014. Lake Roosevelt wild Rainbow Trout genetic study, draft report. Combined report for greater Lake Roosevelt Redband genetic assessment, WDFW Molecular Genetics Lab. 36 pp.

Stober, Q. J., R. W. Tyler, G .L. Thomas, L. Jensen, J. A. Knutzen, D. L. Smith, and R. E. Nakatani.1976. Operation effects of irrigation and pumped/storage on the ecology of Banks Lake, Washington. Third Annual Progress Report June 1, 1975 to May 31, 1976. Contract Number 14-06-100-7794. United States Bureau of Reclamation, Boise, Idaho: 313 pp.

Stober Q. J., M. E. Kopache, and T. H. Jagielo. 1981. The limnology of Lake Roosevelt, 1980. Fisheries Research Institute College of Fisheries University of Washington Seattle, Washington: 116 pp.

Stroud, D. H. P., A. O. Blake, H. J. MclEllan, and A. T. Scholz. 2012. Annual assessment of hatchery kokanee and sonic traking of wild and hatchery kokanee in Lake Roosevelt: 2011 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 297 pp.

Stroud, D. H. P., A. O. Blake, M. Vaughan, S. Warehime, H. McLelland, and A. T. Scholz. Annual assessment and sonic tracking of hatchery kokanee in Lake Roosevelt: 2013. Annual Report. United States Department of Energy, Bonneville Power Administration,  Portland, Oregon. 172 pp.

Stroud, A. G., D. H. P. Stroud, A. T. Scholz, H. J. McLellan, and B. Nichols, editors. 2014. Kokanee Salmon investigations and Redband Rainbow Trout ultrasonic tracking in Franklin D. Roosevelt Lake, 2013 Annual Report. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. 59 pp.

Stroud, A. G. 2015. Chapter 1: a dichotomous key for the identification of nine salmonids of the inland northwest using six diagnostic bones; and associated equations to estimate total length and weight from bones injested by piscivores or found in archeological sites. Chapter 2. Utilization of biotelemetry to define the movments of Lake Roosevelt Redband Trout, *Oncorhynchus mykiss gairdneri*. MS Thesis, Department of Biology, Eastern Washington Universty, Cheney WA. 158 pp.

Thatcher, M. G., A. McDowell, J. Griffith, and A. T. Scholz. 1993. Lake Roosevelt Fisheries Monitoring Program: Annual report 1991. Prepared by Spokane Tribe of Indians, Department of Natural Resources, Wellpinit, Washington and Eastern Washington University, Department of Biology, Upper Columbia United Tribe Fisheries Center, Cheney, Washington. Prepared for United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Project No. 88-63, Contract No. DE-8179-88D P91819: 237 pp + 156 pp appendix.

Thatcher, M. C., J. C. Griffith, A. C. McDowell, and A. T. Scholz. 1994. Lake Roosevelt fisheries monitoring program: Annual report 1992. Prepared by Spokane Tribe of Indians, Department of Natural Resources, Wellpinit, Washington and Eastern Washington University, Department of Biology, Upper Columbia United Tribe Fisheries Center, Cheney, Washington. Prepared for United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Project No. 88-63- Contract No. DE-8179-88 DP91819: 179 pp + 132 pp appendix.

Thurow, R. F., D. C. Lee, and B. E. Rieman. 1997. Distribution and status of seven native Salmonids in the interior Columbia River basin and portions of the Klamath River and Great basins. North American Journal of Fisheries Management 17(4):1094-1110.

Torvik, S. 2013. Kept fish project to aid steelhead. Methow Grist. Published 8 Novemeber 2013

Trammell, J. L., D. E. Fast, D. R. Hatch, W. J. Bosch, R. Branstetter, A. L. Pierce. 2016 Evaluating steelhead kelt treatments to increase iteroparous spawners in the Yakima River Basin. North American Journal of Fisheries Management. 36: 876-887.

Wagner G. N. and E. D. Stevens. 2000. Effects of different surgical techniques, suture material and location of incision site on the behavior of rainbow Trout (*Oncorhynchus mykiss*). Marine Freshwater Behavioral Physiology 33:103–114.

Wagner, G. N. and S. J. Cooke. 2005. Methodological approaches and opinions of researchers involved in the surgical implantation of telemetry transmitters in fish. Journal of Aquatic Animal Health. 17: 160-169.

Walston, J. A. 2015. Effects of anesthetics on rainbow trout swimming ability and statistical comparison of the movements of acoustically tagged redband trout in Lake Roosevelt. MS Thesis, Department of Biology, Eastern Washington University, Cheney, Washington: 171 pp.

WDFW. 2016. New fishing rules in effect on Lake Roosevelt to protect redband rainbow trout. WDFW News Release. http://wdfw.wa.gov/news/dec2916a/.

# Appendix B

The following describes range of movements for each individual fish used in the analysis of this report. This appendix is organized by tagging location with a description of each fish's movements followed by a figure with the range of movements for a group of fish. All places referenced in the text can be found on Figure B-1 and on figures accompanying descriptions of fish movements. These movements are compared to previous years of this study.

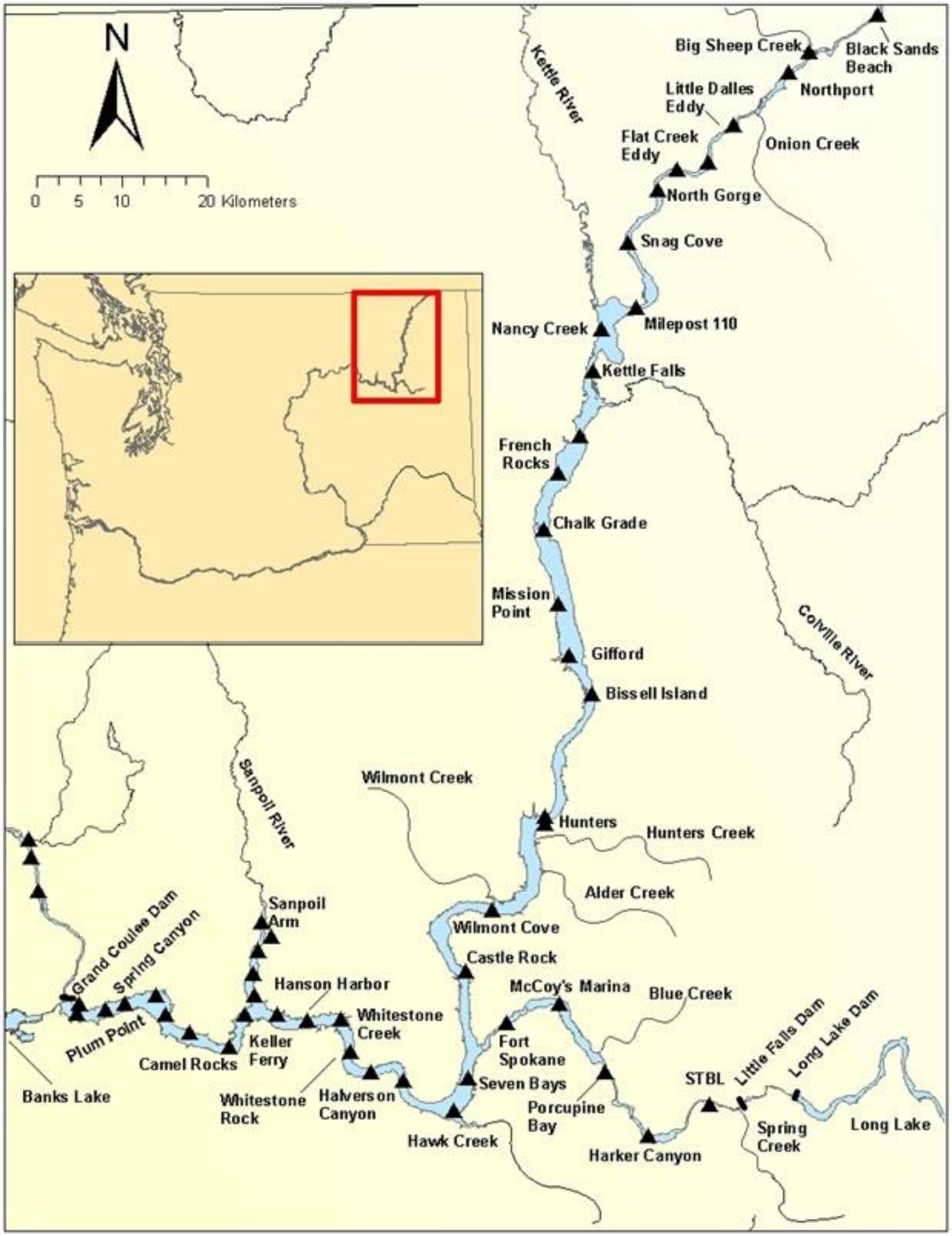



Figure B-1. Map depicting locations on Lake Roosevelt in the following section.

**Sanpoil River**

Movements for Sanpoil _1 (unknown sex, 433 mm, tagged 4/15/2015), Sanpoil_2 (unknown sex, 386 mm, tagged 4/15/2015), and Sanpoil_3 (unknown sex 410 mm tagged 4/15/2015), are described in the following three paragraphs with range of movements presented in Figure B-2.

Sanpoil_1 was first detected 10 days after tagging near the head of the Sanpoil Arm; it resided in the Sanpoil Arm until leaving on 5/12/2015. It then reentered the arm the same day where it remained until 6/8/2015. It then moved upriver to Halverson Canyon by 6/12/2015 and subsequently moved downstream reentering the Sanpoil Arm on 7/1/2015. It exited the Sanpoil Arm on 7/12/2015 and moved upriver again to Halverson Canyon by 7/13/2015. It resided here until 7/18/2015, and moved downstream to Camel Rocks by 8/28/2015. It then reentered the Sanpoil Arm on 9/7/2015. It then exited the Sanpoil Arm for the final time on 9/18/2015. It was detected between Keller Ferry and Whitestone Creek until 9/24/2015. It was continuously detected at Hanson Harbor from 9/24/2015-12/8/2015. Its PIT tag was detected on a Colville Tribe maintained PIT tag array on 3/22/2016 in the Sanpoil River main stem. It was last detected at Hanson Harbor on 5/8/2016.

Sanpoil_2 was first detected seven days after tagging near the head of the Sanpoil Arm; it remained in the Sanpoil Arm until leaving on 6/2/2015. It then reentered on 6/5/2015 and exited again on 6/11/2015 moving upriver to Whitestone Rock by 6/13/2015, and downriver to Spring Canyon by 6/20/2015. It reentered the Sanpoil Arm on 7/2/2015, and exited the Sanpoil Arm on 7/20/2015. It was detected between The Sanpoil Mouth and Whitestone Creek between 7/21/2015 and 8/26/2015. It then moved within the Sanpoil Arm until 3/28/2016 when it exited, to head downriver to Spring Canyon where it was last detected on 4/3/2016.

Sanpoil_3 was first detected four days after tagging; it remained in the Sanpoil Arm until 5/16/2015, moving downstream to Spring Canyon by 5/21/2015. It resided here until 6/5/2015 and moved upriver to Seven Bays by 6/23/2015. It entered the Spokane Arm on 7/2/2015 moving upstream to Porcupine Bay by 7/9/2015. It was detected here until 7/31/2015, it then moved down the Spokane Arm exiting on 8/7/2015. It was detected between Seven Bays and Hawk Creek until 9/20/2015. It then moved upriver to Castle Rock by 9/25/2015, where it was intermittently detected until 1/14/2016 before it moved downstream, and reentered the Sanpoil Arm on 2/28/2016. This fish was detected on a Colville Tribe maintained PIT tag array on the same date. It was not detected again on the acoustic receiver array until 6/9/2016. It exited the Sanpoil Arm on 6/10/2016 and moved upriver to Whitestone Rock by 6/13/2016. It subsequently moved downstream to Keller Ferry and back upstream to Whitestone Rock where it was last detected on 7/7/2016.

Movements for Sanpoil_4 (unknown sex, 415 mm, date tagged 4/15/2015), Sanpoil_5 (female 490 mm, date tagged 4/16/2015), and Sanpoil_6 (unknown sex, date tagged 4/16/2015) are described in the following three paragraphs with range of movements presented in Figure B-2.

Sanpoil_4 was first detected one day after tagging at the head of the Sanpoil Arm; it resided in the Sanpoil Arm until 5/3/2015. It then moved downstream to Spring Canyon by 5/17/2015, before it moved upstream to Castle Rock by 6/30/2015. From here, it moved downriver to Hawk Creek where it remained until 8/23/2015 before it moved downstream to Plum Point on 9/9/2015. It once again moved upriver to Castle Rock by 11/8/2015, where it remained until 11/20/2015. It moved downriver and reentered the Sanpoil Arm on 12/8/2015. It remained in the arm until 12/23/2015, before it moved downriver to Spring Canyon by 1/5/2016. It remained in the area between Spring Canyon and Keller Ferry until 3/20/2016 when it reentered the Sanpoil Arm. It moved up the Sanpoil Arm and its last acoustic detection was at the head of the Sanpoil Arm on 3/24/2016. This fish was detected on a Colville Tribe Maintained PIT tag array on 3/25/2016.

Sanpoil_5 was first detected four days after tagging at the head of the Sanpoil Arm; it resided in the Sanpoil Arm until 4/28/2015. It moved to Halverson Canyon by 5/15/2015 and reentered the Sanpoil Arm on 5/23/2015. It remained in the Sanpoil Arm until 5/29/2015 when it moved downriver to Spring Canyon on 6/5/2015. It then moved upstream and reentered the Sanpoil Arm the next day. It remained in the Sanpoil Arm until 6/30/2015 when it undertook a nearly reservoir long journey. It moved to Hunters by 7/17/2015, and moved in the area between Hunters and Seven bays until 3/9/2016. It then moved upstream from Hunters to Snag Cove by 4/11/2016. It then moved downstream to the Sanpoil mouth by 4/25/2016. Its last acoustic detection was on 4/25/2015 at the head of the Sanpoil Arm. This fish’s PIT tag was detected on a Colville Tribe Maintained PIT tag array the next day.

Sanpoil_6 was first detected seven days after tagging at the head of the Sanpoil Arm; it resided in the Sanpoil Arm until 5/10/2015. It moved downstream to Spring Canyon by 5/24/2015, and moved upstream to reenter the Sanpoil on 5/31/2015 where it resided until

6/30/2015. From here it moved upstream to Halverson Canyon by 7/14/2015, and then downstream to reenter the Sanpoil Arm on 7/29/2015. It left from here on 8/6/2015 and moved downstream to Plum Point by 8/8/2015. It resided in the Columbia between Keller Ferry and Plum Point until 10/4/2015. It then moved upstream to Wilmont Cove by 11/2/2015. It began moving downstream 10 days later, and reentered the Sanpoil Arm on 11/25/2015. It left the Sanpoil Arm for the last time on 12/11/2015, and was last detected at Spring Canyon on 1/14/16.

Movements for Sanpoil_7 (unknown sex, 475 mm, date tagged 4/15/2015), Sanpoil_8 (unknown sex 490 mm, date tagged 4/15/2015), and Sanpoil_9 (unknown sex, 508 mm date tagged 4/15/2015) are described in the following three paragraphs with range of movements presented in Figure B-3.

Sanpoil_8 was first acoustically detected four days after tagging; it was detected on a Colville Maintained PIT tag array on 5/9/2015. It reentered the Sanpoil Arm on 5/22/2015. It exited the Sanpoil on 6/11/2015 to Keller Ferry, reentered on 6/19/2015, exited on 6/25/2015, and reentered for the final time on 7/7/2015. It was last detected 5 km up the Sanpoil Arm on 7/11/2015

Sanpoil_9 was first detected 17 days after tagging; it resided in the Sanpoil arm until 6/2/2015.  It move moved downstream to Spring Canyon by 6/7/2015. It was detected downstream of Camel Rocks until its last detection at Plum Point on 7/22/2015.

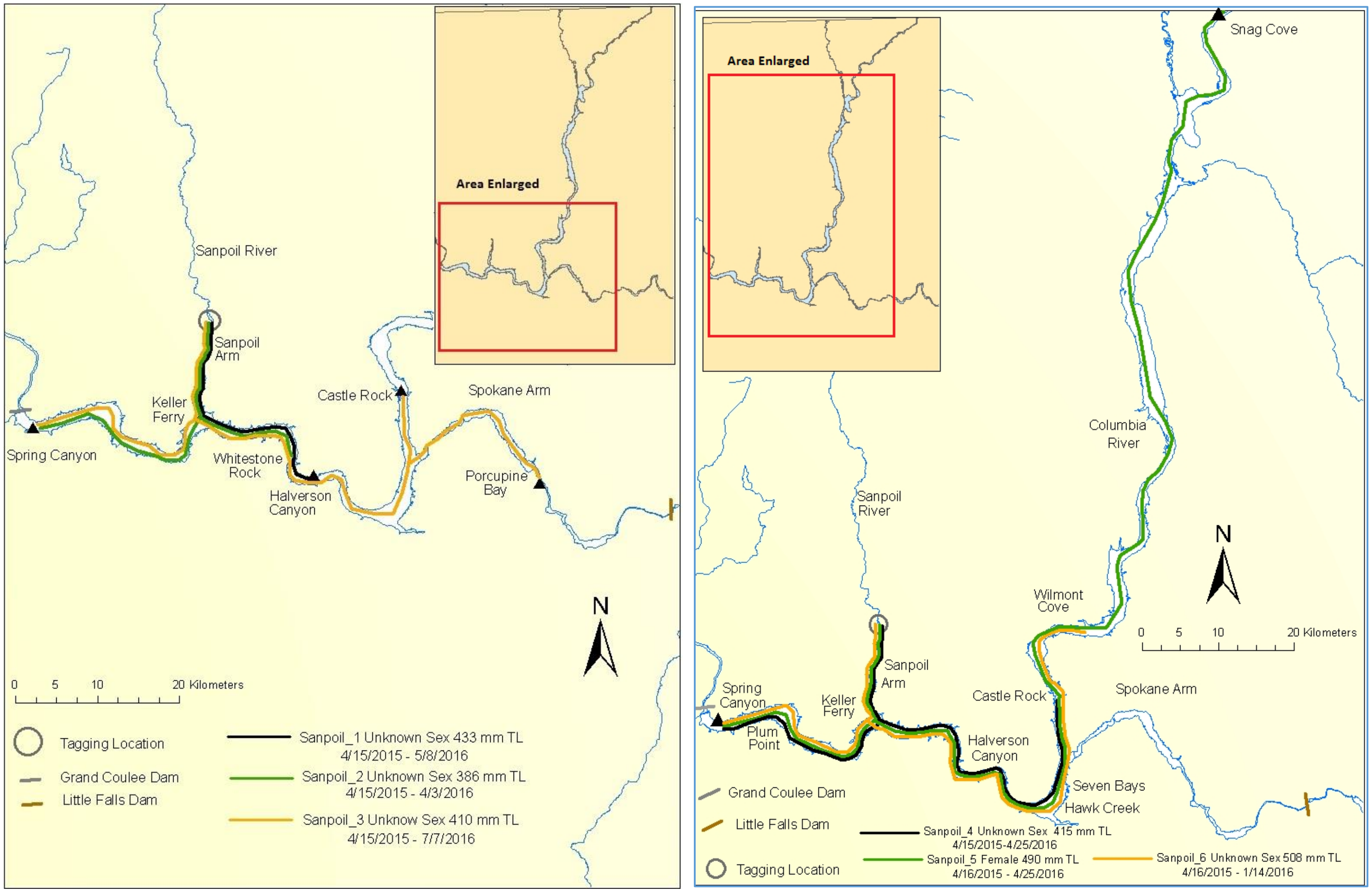



Figure B-2. Range of movements from Sanpoil River Redbands 1, 2, 3 (left) and range of movements from Sanpoil River Redbands 4, 5, and 6 (right). Included for each fish is sex, size and duration of detections.

Movements for Sanpoil_10 (unknown sex, 406 mm, date tagged 4/15/2015,), Sanpoil_11 (unknown sex 443 mm, date tagged 4/16/2015,) and Sanpoil_12 (unknown sex, 475mm date tagged 4/16/2015) are described in the following three paragraphs with range of movements presented in Figure B-3.

Sanpoil_10 was first detected four days after tagging; it resided in the Sanpoil Arm until 5/19/2015 when it was detected at Keller Ferry. It reentered the Sanpoil Arm on 6/4/2015, and exited the Sanpoil Arm on 7/7/2015, moving upriver to Whitestone Rock by 7/13/2015. Once again it reentered the Sanpoil Arm on 7/30/2015 where it remained from 12/21/2015 to 4/26/2016. It moved upstream to Whitestone Rock by 5/14/2016 and then downstream to Spring Canyon by 5/24/2016. It then reentered the Sanpoil Arm on 6/2/2016 where it remained until its last acoustic detection on 7/7/2016. This fish was harvested on 8/6/2016 by an angler near Whitestone Creek.

Sanpoil_11 was first detected 30 days after tagging; it resided in the Sanpoil Arm until 5/27/2015. It moved upriver to Seven Bays by 6/17/2015, and downriver to reenter the Sanpoil Arm on 7/5/2015. It remained in the Sanpoil Arm until 8/5/2015 when it moved upstream to Seven Bays by 9/3/2015. Its last acoustic detection was on 9/23/2015 at Seven Bays. Interestingly, the PIT Tag for this fish was detected passing through the PIT tag array in the Sanpoil River on 3/21/2016, suggesting that the transmitter failed prematurely as it was not detected on the 12 receivers between Seven Bays and the head of the Sanpoil Arm.

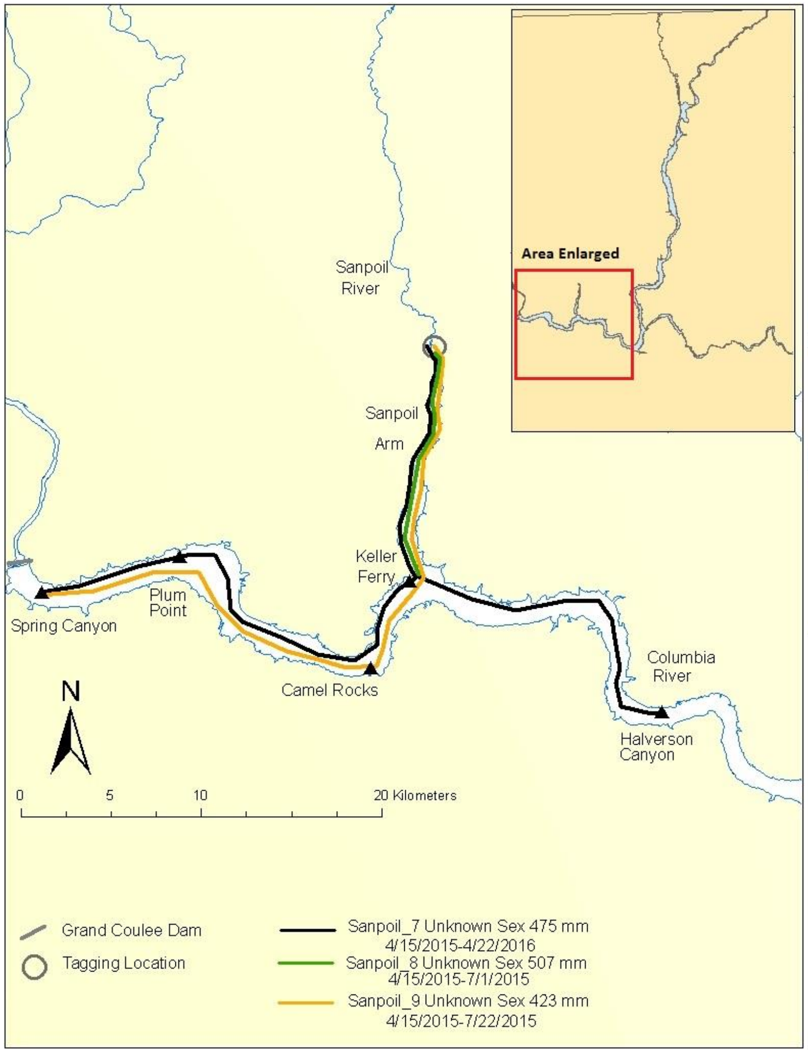
Sanpoil_12 was first detected 11 days after tagging; it resided in the Sanpoil Arm until 5/28/2015 when it moved downstream to Camel Rocks two days later. It then reentered the Sanpoil Arm on 6/5/2015 and remained until it briefly exited on 12/5/2015 and returned on 12/8/2015. It remained in the Sanpoil Arm for the rest of its detection history. It was absent between 1/29/2016-2/11/2016. During this time it was detected on a Colville Tribe maintained PIT Tag array on 1/29/2016. Its last detection was in the Sanpoil Arm on 6/15/2016.

**Blue Creek**

Movements for Blue_1 (male 362 mm, date tagged 4/24/2015), Blue_2 (female 477 mm, date tagged 5/9/2015), and Blue_3 (female 521 mm, date tagged 4/1/2015) are described in the following three paragraphs with range of movements shown in Figure B-4.

Blue_1 was first detected 23 days after tagging at Porcupine Bay. It moved upriver to STBL (Spokane Tribal Boat Launch also known as Wynecoop's) by 6/4/2015 where it was detected until 9/23/2015. From 10/18/2015 to 2/17/2016 it was detected between STBL and Harker Canyon, it then moved downstream to Porcupine Bay by 3/2/2016. Its last detection was the next day at Porcupine Bay. It was detected on a STOI maintained PIT tag array in Blue Creek on 4/26/2016.

Blue_2 was first detected three days after tagging at Porcupine Bay. It moved upstream to STBL by 5/13/2015. It remained here until 5/31/2015. It was detected again at McCoy's Marina on 6/3/2015. It remained here until 6/25/2015 before being detected at Porcupine Bay. It was detected between Porcupine Bay and Harker Canyon until 2/15/2016 when it moved downriver to Fort Spokane. It was detected here until 3/26/2016 before its last detection at Porcupine Bay on 3/27/2016.



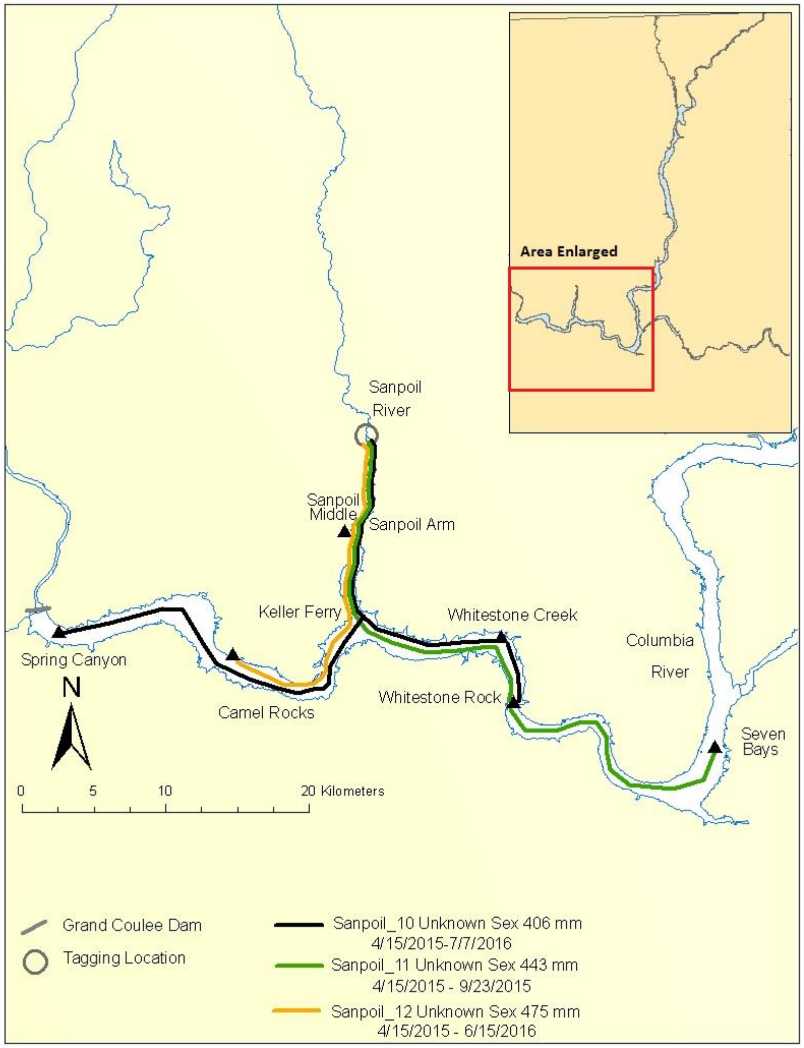




Figure B-3. Range of movements from Sanpoil River Redbands 7, 8, and 9 (left), and range of movements from Sanpoil River Redbands 10, 11, and, 12 (right). Included for each fish is sex, size and duration of detections.

Blue_3 was first detected 15 days after tagging at Harker Canyon; it was detected here until 6/5/2015. It then moved downstream to Porcupine Bay the next day and was intermittently detected here until its last detection on 5/28/2016.

Movements for Blue_4 (Female 483 mm, date tagged 4/24/2015), and Blue _5 (Female 500mm, date tagged 4/1/2015) are described in the following two paragraphs with range of movements shown in Figure C-4.

Blue_4 was first detected 10 days after tagging at Porcupine Bay, it then moved downstream, and exited the Spokane Arm on 4/12/2015. It was detected at Hawk Creek between 4/16/2015-4/21/2015. It then moved upriver to Seven Bays where it was last detected on 4/22/2015.

Blue_5 was first detected 16 days after tagging at Porcupine bay. It was detected at McCoy’s Marina on 4/23/2015, and it moved upstream to Porcupine Bay where it was intermittently detected from 5/3/2015 to 12/19/2015.

**Spring Creek**

Movements for Spring_1 (Female 477 mm, date tagged 3/26/2015), and Spring_2 (Female, 534 mm, date tagged 3/26/2015) are described in the following two paragraphs and range of movements are presented in Figure B-5.

Spring_1 was first detected 45 days after tagging at STBL. It moved down the Spokane Arm to Porcupine Bay on 5/15/2015. It remained here until 6/9/2015 and moved upstream to Harker Canyon on 6/11/2015. It remained at Harker Canyon until 10/29/2015 and moved to STBL on 10/31/2015. It then moved back to Harker Canyon on 11/8/2015 and moved back to STBL on 11/15/2015. There was no detections between 1/13/2016 and 5/6/2016 indicating this fish may have moved upstream and may have homed back to its spawning location. It was detected at STBL from 5/6/2016 to 6/22/2016 and was detected downstream at Harker Canyon from 6/25/2016 to its last detection on 7/4/2016.

Spring_2 was first detected on 4/30/2015, 34 days after tagging at STBL. It moved down the Spokane Arm to Harker Canyon on 5/3/2015, and Porcupine Bay from 5/3/2015 to its last detection on 5/5/2015.

Movements for Spring_3 (Female 363 mm date tagged 4/16/2015), and Spring_4 (Female 500mm, date tagged 5/21/2015) are described in the following two paragraphs with range of movements presented in Figure B-5.

Spring_3 was first detected six days after tagging at STBL. It moved down the Spokane Arm to Fort Spokane on 5/16/2015. It then moved back up the Spokane Arm to STBL by 7/21/2015, and then went back downstream to Porcupine Bay by 10/14/2015 and up to Harker Canyon on 11/1/2015. It was not detected again until 3/11/2016 at STBL. From here it went down the Spokane Arm to Fort Spokane on 4/22/2016. It moved down the reservoir to Seven Bays on 4/26/2016 and eventually was detected at Spring Canyon on 6/18/2016. It then moved back upstream to Camel Rocks on 6/28/2016, and was last detected at Plum Point on 7/4/2016.

Spring_4 was first detected 10 days after tagging at STBL. This fish quickly moved down the Spokane Arm and the main body of Lake Roosevelt. It was detected at Fort Spokane on 5/17/2015, Seven Bays on 5/17/2015 and at subsequent receivers downstream. Its last detection was on 5/21/2015 at Spring Canyon.

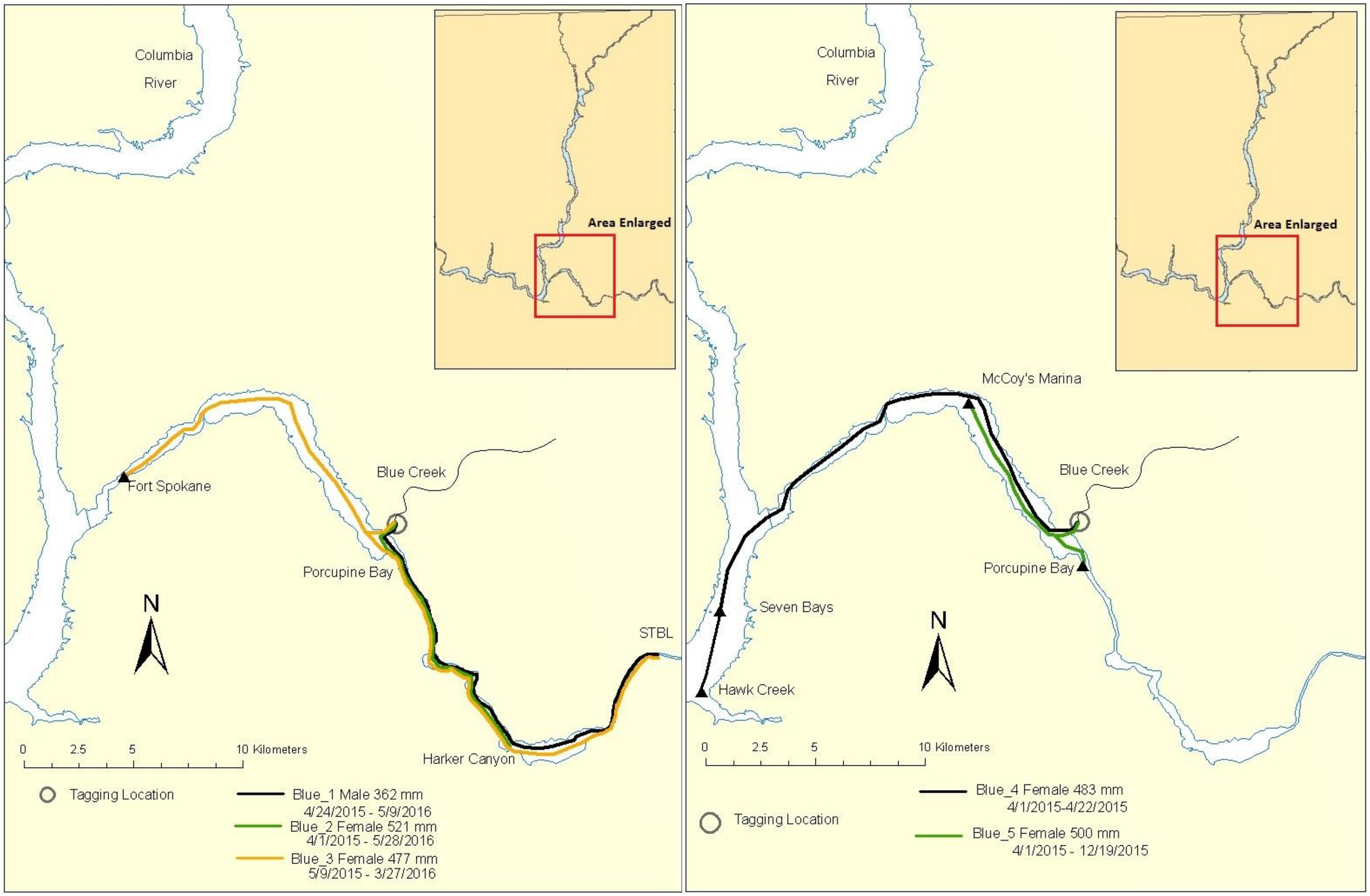



Figure B-4. Range of movements from Blue Creek Redbands 1, 2, and 3 (left) and range of movements from Blue Creek Redbands 4, and 5 (right). Included for each fish is sex, size and duration of detections.

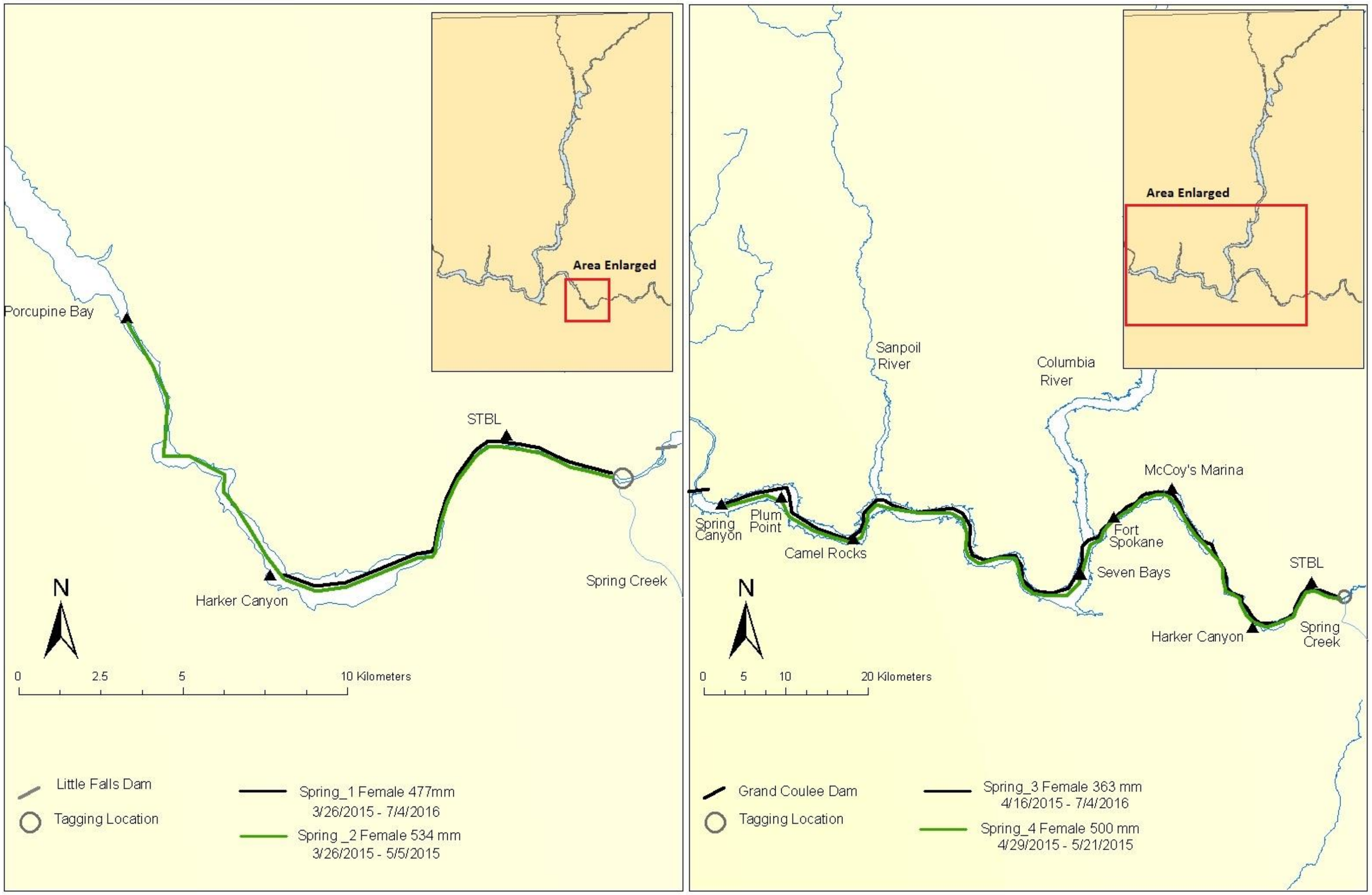



Figure B-5. Range of movements from Spring Creek Redbands 1, and 2 (left), and range of movements of Spring Creek Redbands 3, and 4 (right). Included with each fish is sex, size, and duration of detections.

**Wilmont Creek**

Movements for Wilmont_1 (Female 477 mm, date tagged 4/15/2015), and Wilmont_2 (Female, 534 mm, date tagged 4/15/2015) are described in the following two paragraphs and range of movements are presented in Figure B-6.

Wilmont_1 was first detected 15 days after tagging at Wilmont Cove. It was detected here until 8/22/2015 and moved up the Reservoir to Gifford by 8/30/2015. It was detected at Gifford until 9/3/2015. There was a hiatus in detections until it was last detected on 2/29/2016 at Hunters.

Wilmont_2 was first detected 30 days after tagging at Wilmont Cove it moved downstream to Whitestone Rock by 6/3/2015. It has been continuously detected from that date to 7/7/2016 and is suspected to have died or lost its tag.

Movements for Wilmont_3 (Female 514 mm, date tagged 4/15/2015), and Wilmont_4 (Female, 549 mm, date tagged 4/15/2015) are described in the following two paragraphs and range of movements are presented in Figure C-6.

Wilmont_3 was first detected four days after tagging at Wilmont Cove. It moved down to Halverson Canyon by 5/6/2015 and then back up the Reservoir entering the Spokane Arm at Fort Spokane on 5/7/2015. It moved up the arm to Porcupine Bay on 5/13/2015 and then back downstream last being detected at McCoy’s Marina on 5/18/2015.

Wilmont_4 was first detected one day after tagging at Wilmont Cove. It moved down the Reservoir briefly moving into the Spokane Arm at Fort Spokane on 4/17/2015. It continued to move down the reservoir to Spring Canyon by 5/9/2015 and then upstream to Plum Point where it was last detected on 5/16/2015. In late May this fish was harvested by an angler near Plum Point and its tag was subsequently returned.

**Hunters Creek**

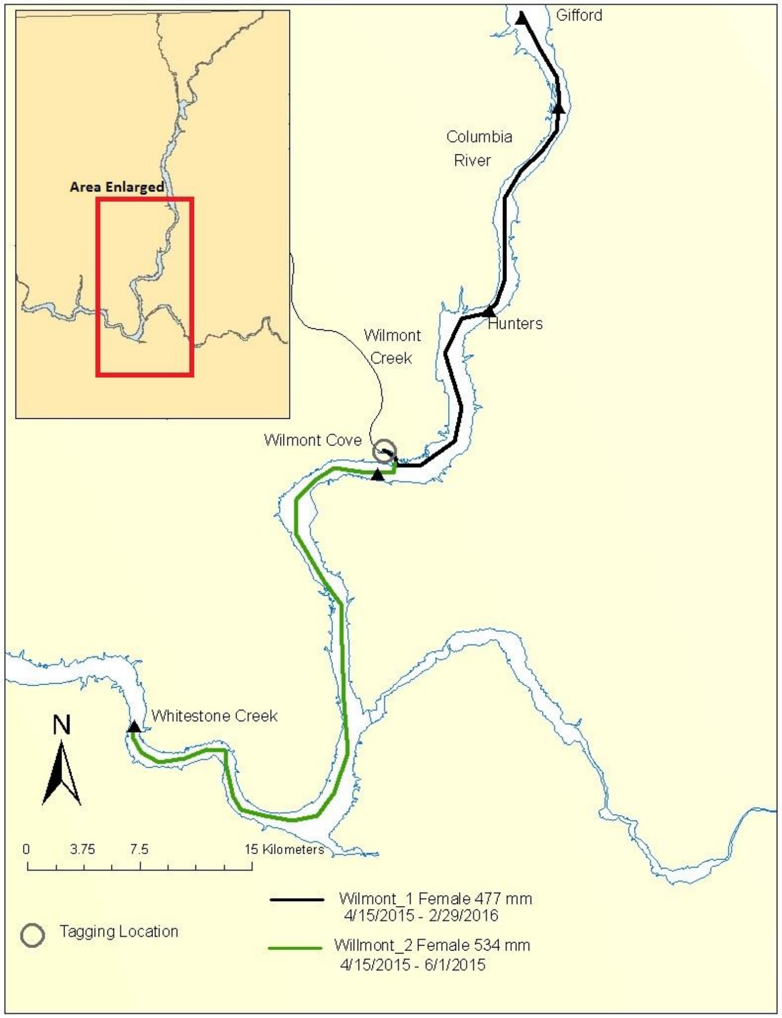
Movements for Hunters_1 (Female 496 mm, date tagged 5/9/2015), and Hunters_2 (Female, 480 mm, date tagged 5/9/2015) are described in the following two paragraphs and range of movements are presented in Figure B-7.

Hunters_1 was first detected 13 days after tagging at Hunters. It moved up the Reservoir to Bissel Island on 5/23/2015 where it was detected until 5/30/2015. It moved downstream to Hawk Creek by 6/16/2015 and then up to Wilmont Cove where it was last detected on 6/25/2015.

Hunters_2 was first detected four days after tagging at Hunters. This fish moved up the reservoir to Chalk Grade by 5/15/2015. It was detected here until 5/22/2015 before it moved downstream. It was last detected at Bissel Island on 5/24/2015.

**Onion Creek**

Movements for Onion_1 (Female 461 mm, date tagged 6/1/2015) Onion_2 (Female 461 mm date tagged 6/1/2015), and Onion_3 (Male 490 mm, date tagged 5/15/2015) are described in the following four paragraphs with range of movements presented in Figure B-8.



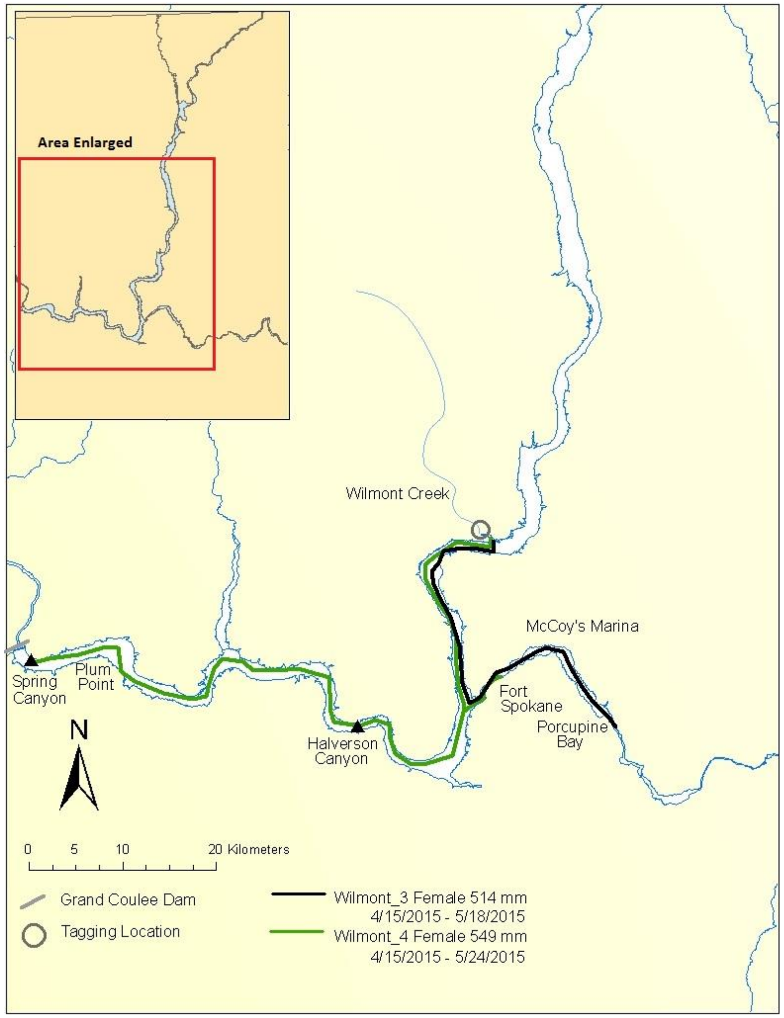




Figure B-6. Range of movements from Wilmont Creek Redbands 1, and 2 (left) and range of movements from Wilmont Creek Redbands 3, and 4 (right). Included for each fish is sex, size, and duration of detections.

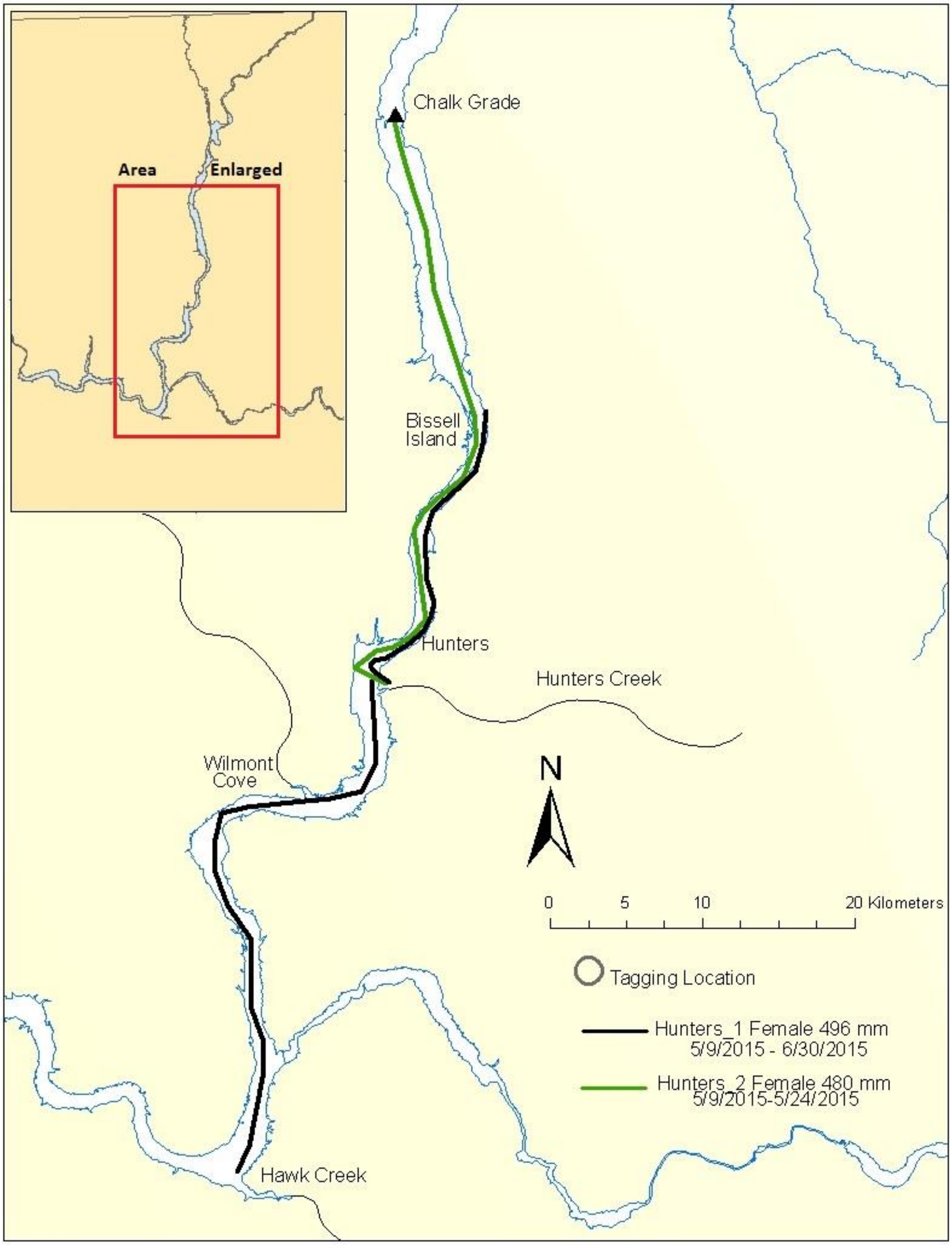



Figure B-7. Range of movements from Hunters Creek Redbands 1 and 2. Included for each fish is sex, size and duration of detections.

Onion_1 was first detected six days after tagging in British Columbia, 56 km upstream of the international border. It then moved down the Reservoir to French Rocks by 6/15/2015 where it was detected until 6/25/2015.

Onion_2 was first detected 30 days after tagging at Little Dalles Eddy. It moved upstream to Northport on 7/11/2015 where it remained until 9/8/2015. It then was detected at Big Sheep Creek from 9/10/2015 to 9/26/2015. It moved back downstream to Northport where it was detected between 10/3/2015 to its last detection on 2/22/2016.

Onion_3 was first detected seven days after tagging at Little Dalles Eddy. It moved downstream to Snag Cove by 5/26/2015 where it remained until 6/23/2015. It then moved upstream and was detected at Northport two days later. It resided at Northport until 8/15/2015, and moved downstream to Kettle Falls by 8/27/2015 where it was detected until its last detection on 9/4/2015.

Movements for Onion_4 (Female 515 mm date tagged 5/15/2015), Onion_5 (Female 485 mm date tagged 5/9/2015). Onion_6 (Female 526 mm date tagged 5/19/2015) and Onion_7 (Female 465 mm date tagged 6/1/2015) are described in the following three paragraphs with range of movements presented in Figure C-8.

Onion_4 was first detected three days after tagging at Little Dalles Eddy. It continued to move downstream to Milepost 110 by 5/20/2015 where it was detected until 7/14/2015. It then moved downstream and was detected at Hunters from 8/18/2015 to 11/8/2015. It then moved upriver to Northport by 12/25/2015 where it was detected until its last detection on 2/6/2016.

Onion_5 was first detected 24 days after tagging at Northport. It was detected here until 7/8/2015. It moved downstream to China Bend by 7/17/2015 and returned to Northport the following day. This fish was detected at Northport until its last detection on 8/2/2015.

Onion_6 was first detected 4 days after tagging at Northport. This fish moved downstream to Chalk Grade by 5/27/2015 where it was last detected.

Onion_7 was first detected 31 days after tagging at Flat Creek Eddy. It moved downstream to Milepost 110 by 8/10/2015 and remained here until 8/24/2015. It moved upstream to Snag Cove by 9/2/2015 and remained here until 9/24/2015. It was next detected at Hunters on 12/27/2015 and continued moving downstream, and was detected at Seven Bays on 1/29/2016. It was next detected in the mouth of the Sanpoil River on 3/4/2016. It continued downriver and was detected at Spring Canyon on 3/10/2016.It remained here until 4/15/2016 when it moved upstream briefly entering the Spokane Arm at Fort Spokane on 4/18/2016 and was last detected at Mission Point on 4/21/2016.

**Big Sheep Creek**

Movements for Big Sheep_1 (Male 521 mm, date tagged 4/6/2015), Big Sheep_2 (Male 489 mm date tagged 4/6/2015), and Big Sheep_3 (Female 517 mm date tagged 5/24/2015) are described in the following three paragraphs with range of movements presented in Figure B-9.

Big Sheep_1 was first detected 43 days after tagging at Little Dalles Eddy. It moved downstream to Kettle Falls by 5/22/2015 and was detected here until 7/21/2015.

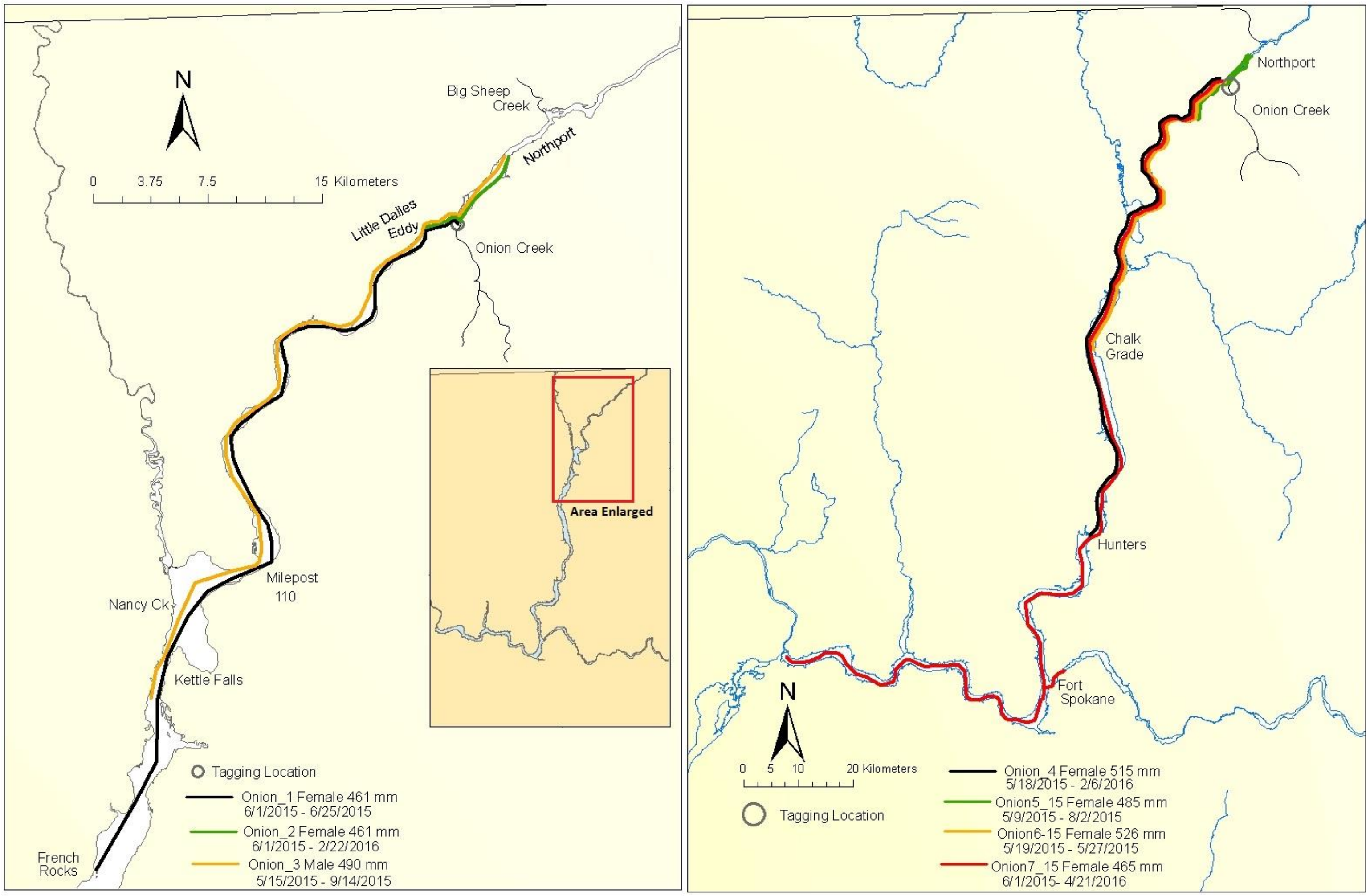



Figure B-8. Range of movements from Onion Creek Redbands 1, 2, and 3 (left) and range of movements from Onion Creek Redbands 4, 5. 6, and 7 (right). Included for each fish is sex, size and duration of detections.

Big Sheep_2 was first detected five days after tagging at the mouth of Big Sheep Creek. It remained here until 5/6/2015 before moving downstream to French Rocks by 5/9/2015. It was last detected at French Rocks on 5/11/2015.

Big Sheep_3 was first detected two days after tagging at the mouth of Big Sheep Creek. It was detected here until 5/14/2015. It was then detected downstream at Northport on 7/7/2015 and then upstream near Black Sands beach on 6/8/2015. It was last detected in the United States here on 6/9/2015.  It was next detected 56 km upstream of the International Border in early September 2015. There was a hiatus of detections until March 7, 2016 when it was detected 53 km upstream the international border. It then was detected the next day 56 km upstream of the International Border. It was then detected here continuously until August 11, 2016.

Movements for Big Sheep_4 (Female 581 mm, date tagged 4/24/2015), and Big Sheep_5 (Male 447 mm date tagged 4/24/2015) are described in the following two paragraphs with range of movements presented in Figure B-9.

Big Sheep_4 was first detected three days after tagging at Northport. It was subsequently detected downstream at French Rocks 5/3/2015 and at Chalk Grade on 5/7/2015. It was last detected on 5/11/2015 at Chalk Grade.

Big Sheep_5 was first detected 57 days after tagging at Northport. It was detected at Northport between 6/21/2015 to 7/10/2015. It was then detected at the mouth of Big Sheep Creek from 7/13/2015 to 8/17/2015. The last string of detections were at Northport between 8/23/2015 to 9/22/2015.

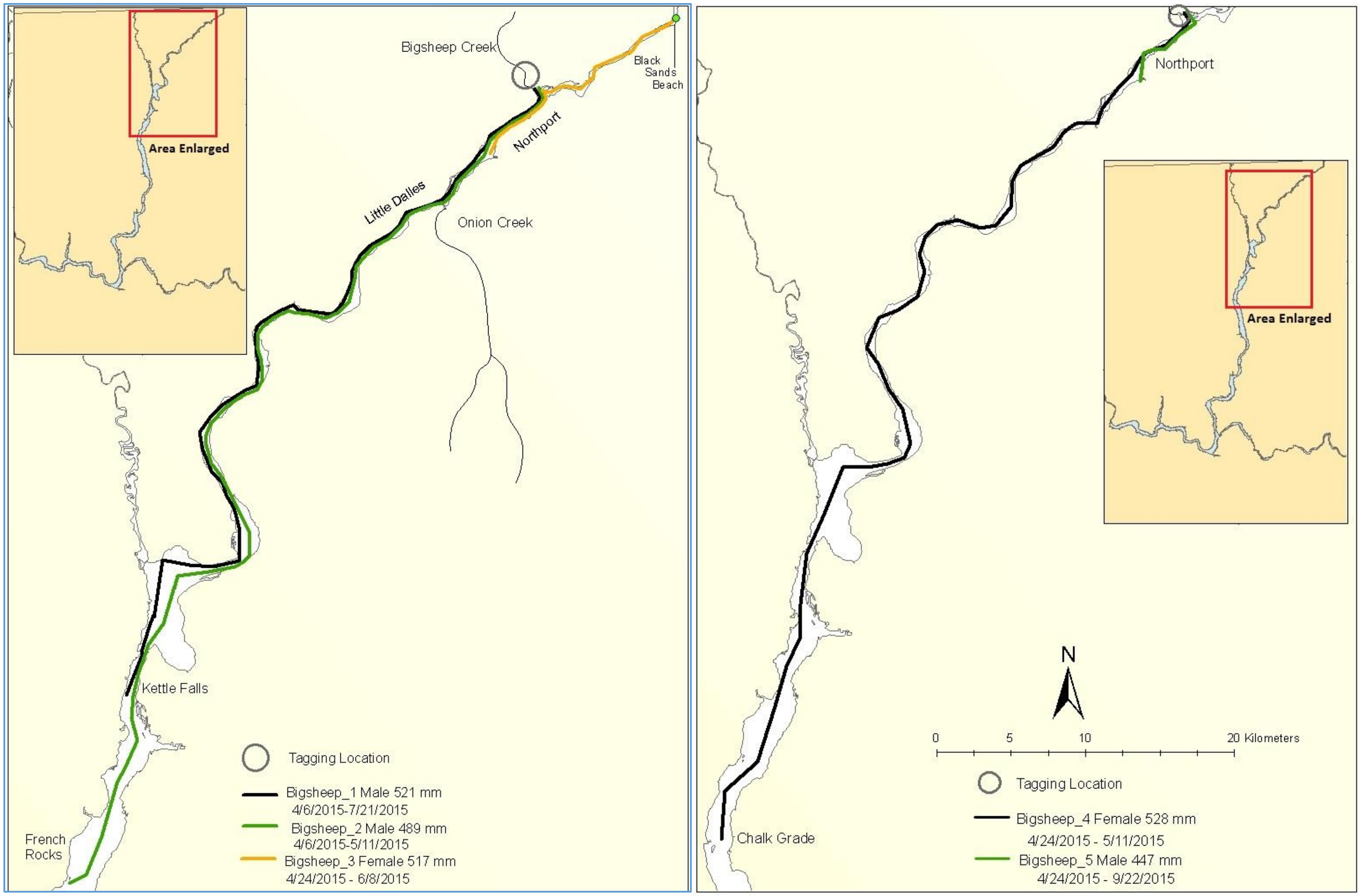



Figure B-9. Range of movements from Big Sheep Creek Rebands 1,2,and 3 (left) and range of movements for Bg Sheep Creek Redbands 4, and 5 (right). Included for each fish is sex, size and duration of detections.

## Comparison of the Range of Movements to Previous Years

### *Sanpoil River*

Most Sanpoil River Redbands were only detected on Sanpoil River receivers or on receivers in the main stem of the Columbia River between Grand Coulee Dam and Seven Bays (72 km upstream of Grand Coulee Dam) in all three years of the study: 1) Of 12 detected on multiple receivers in 2015/2016 (present study), all were detected on receivers in the Sanpoil River and 9 were only detected on receivers in the Columbia River between Grand Coulee Dam and Seven Bays; 2) Of 11 detected on multiple receivers in 2014/2015 (Walston et al. 2015), all were detected in the Sanpoil River and seven were only detected downstream of Seven Bays; 3) of 13 detected on multiple receivers in 2013/2014 (Stroud et al. 2014) nine were never detected above Seven Bays. However, in all three years of the study, a few fish from the Sanpoil exhibited extraordinary movements outside of this normal range of activity: 1) in 2015/2016 (present study), one Sanpoil River fish was detected at Snag Cove (196 km upstream of Grand Coulee Dam, although it later homed back to the Sanpoil River during its spawning migration), another was detected in the mainstem Columbia at Castle Rock (82 km upstream of Grand Coulee Dam), and a third at Porcupine Bay on the Spokane River (99 km upstream of Grand Coulee Dam); 2) In 2014/2015 (Walston et al. 2015) one was detected as far as Castle Rock, another at Hunters (110 km upstream of Grand Coulee Dam), a third at Chalk Grade (145 km upstream of Grand Coulee Dam), and a fourth at French Rocks (152 km upstream of Grand Coulee Dam); 3) In 2013/2014 (Stroud et al. 2014) one was detected at Porcupine Bay, another at Castle Rock, a third at Wilmont

Cove (93 km upstream of Grand Coulee Dam), and a fourth at Nancy Creek (175 km upstream of Grand Coulee Dam).

***Spokane Arm***

Blue Creek Redbands were typically detected in the Spokane Arm. Of the five detected on multiple receivers four never left the Spokane Arm. The one that did moved down the Columbia to Seven Bays. This is in contrast to what was seen in previous years. In 2014/2015 only one was detected on multiple receivers and moved out of the Spokane Arm to Spring Canyon (Walston et al. 2015). In 2013/2014 three were detected on multiple receivers, with one that moved out of the Spokane Arm and up the Columbia to Hugh Keenlyside Dam, and the other two moved down the Columbia to Spring Canyon (Stroud et al. 2014).

Spring Creek Redbands typically resided in the Spokane Arm. Three were detected in 2015 between The Wynecoops receiver and The McCoy's Marina receiver. One quickly left the Spokane Arm in 2015, being detected at Seven Bays on May 17, 2015 it was last detected at Spring Canyon (2 km upstream of Grand Coulee Dam) on May 21, 2015. Another left the Spokane Arm in April 2016 and resided around Spring Canyon from June to July 2016.

Previously, acoustic tracking information for Spring Creek Redband Trout has been elusive. Stoud et al. (2014) stated there appeared to be detection issues in the Spokane Arm since out of four Spring Creek Redbands tagged in 2013 one was detected on the receiver array. Of five Redband tagged by Walston et al. (2015) in 2014 three were detected and two of those were detected on multiple receivers. The 2013 Redband moved out of the Spokane River to Hunters but was detected for four days. Of the two 2014 Redbands one moved to Plum point and the other never left the Spokane Arm.

***Middle Reservoir***

We captured two Redbands we tagged in Alder Creek where in 2013 five where tagged, and 11 were tagged in 2014 (Walston 2015). In the previous years a trap was used to collect fish, but was not put to use in 2015. The fish tagged in 2015 were both males, one was post spawn caught on a barbless jig at the mouth of Alder Creek, and the other was caught in the stream by backpack electrofishing. Neither of these were detected on the receiver array. However, five were detected in 2013, and six were detected in 2014 (Walston 2015).

Alder Creek Redbands displayed diverse movements in 2013 and 2014. In 2013 three were detected on multiple receivers. All moved downstream of Alder Creek with one to Keller Ferry, one to Hawk Creek and another to Castle Rock. These were detected for twenty five, three and fourteen days respectively. In 2014 four were detected on multiple receivers. One moved upstream to Bissel Island, one moved upstream to French Rocks and downstream to Whitestone Rock, another moved between Hunters and Whitestone Creek, and the last moved upstream to Kettle Falls. These were detected for four months, nine months, and eight months, and twenty one days respectively.

Wilmont Creek Redbands were typically detected in the lower middle reservoir below Wilmot Cove (100 km upstream of Grand Coulee Dam). Two deviated from the trend of being detected in the lower middle reservoir with one moving up to Gifford (131 km upstream of Grand Coulee dam) and another entered the Spokane, being detected as far upstream as McCoy's Marina. Redbands were only previously tagged in 2014 in

Wilmont Creek. Two were detected on multiple receivers and both moved downstream to Spring Canyon. One of these did entrain over Grand Coulee Dam (Walston et al. 2015). Hunters Creek Redbands were only tagged in 2015, but had short detection histories. Three were detected on the array with two detected on multiple receivers. All seven Redbands were tagged on May 9, 2015, and all were ripe adults. We were pressed for time in getting transmitters out and decided to implant them into these fish. We have thought that perhaps most of these fish expelled the transmitters after spawning. On two occasions (March 25 and May 28, 2016) we searched Hunters Creek from the mouth, upstream to the plunge pool where we tagged Redbands the previous year, with a hydrophone and were unable to detect any tags.

***Upper Reservoir***

Onion Creek Redbands did not appear to follow a recognizable trend. Three did not move below Kettle Falls, and four moved down as far as French Rocks and Hunters, with one moving as far downstream as Spring Canyon and subsequently back upstream. Onion Creek Redbands were only previously tagged in 2014. All four detected on multiple receivers moved downstream of Onion Creek with one that entrained over Grand Coulee Dam, one to Bissell Island (129 km upstream of Grand Coulee Dam), Chalk Grade (151 km upstream of Grand Coulee Dam), and Snag Cove (Walston et al. 2015).

Big Sheep Creek Redbands were rarely detected downstream of Gifford, Washington (175 km upstream of Grand Coulee dam) during the three years of this study: 1) In 2015/2016 (present study) of five, the furthest downstream any were detected was French Rocks (159 km upstream of Grand Coulee Dam); 2) Of three detected on multiple receivers in 2014/2015 (Walston et al. 2015) two never moved downstream of French

Rocks; 3) Of seven detected on multiple receivers in 2013/2014 (Stroud et al. 2014) five were never detected below Gifford (131 km upstream of Grand Coulee Dam). However, in previous years of this study Big Sheep Creek Redbands made movements outside this range of activity. In 2014/2015 one was detected as far downstream as Spring Canyon. In 2013/2014 one was detected at Bissel Island and another entrained over Grand Coulee Dam.

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Publications and Reports:

Mettler, A. J., B. T. Witte, and A. T. Scholz. 2015. Biological characteristics of Umatilla Dace (*Rhinichthys umatilla*) in the Colville River, Washington. Northwest Naturalist 96: 230-233.

Walston, J. A., A. T. Scholz, B. Witte, and J. Hatem. 2015. First record of the fish assemblage on Turnbull National Wildlife Refuge, Spokane County, Washington 2013. Intermountain Journal of Science 21: 10-14.

Witte, B. T., and A. T. Scholz. 2017. A description of the utilization of Lake Roosevelt by Columbia River Redband Trout (*Oncorhynchus mykiss* var. *gairdneri*) tagged with acoustic transmitters in several spawning tributaries of Lake Roosevelt, Washington: Acoustic tag detections from April 2015 – July 2016. United States Department of Energy, Bonneville Power Administration, Portland, Oregon Project No. 1994-043-00 Contract No. 69860: 76 pp.