Rainbow Trout (Oncorhynchus mykiss) Summer Habitat Use in Lake Spokane, Washington

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Rainbow Trout (*Oncorhynchus mykiss*) Summer Habitat Use in Lake Spokane, Washington

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By

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MASTER’S THESIS

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ABSTRACT

Construction of dams dramatically alters the hydrology of rivers, influencing a wide variety of water quality characteristics directly impacting fish species. These physical alterations will interact with increasing temperatures, due to climate change, reducing thermal habitat for cold-water fish species. Rainbow Trout are sensitive to changes in their habitat and prefer water temperatures < 20 °C and DO levels ≥ 5.0 mg/L. The overarching goal of this study is to document Rainbow Trout movements in an environment that experiences oxygen stress and high water temperatures not meeting preferred levels.

Lake Spokane is a 38.62 km long reservoir on the Spokane River located between Long Lake and Nine Mile Falls Dam in Washington State. Long Lake has three reaches, riverine, transitional, and lacustrine, and experiences low DO and high temperatures. The objectives of this project were to 1: Determine summer habitat use of Rainbow Trout from tracking data that provides location, depth, and temperature. 2: Compare habitat use and variation between two sequential years. 3: Use water quality and tracking data to predict future habitat characteristics Rainbow Trout will select for, based on past use. Hypotheses were 1: Tagged Rainbow Trout will leave the lower lacustrine zone during the summer period and select locations within the upper lacustrine and transitional zone. 2: Rainbow Trout will inhabit the upper hypolimnion and lower metalimnion for cooler water temperatures and higher DO during the summer period.

To determine summer salmonid habitat utilization 20 and 25 triploid Rainbow Trout were acoustically tagged and released in Lake Spokane in the spring of 2017 and 2018 respectively. Weekly tracking events followed a pre-determined grid, and were conducted to determine location, water column depth, and water temperature for each tagged fish. Locations of the Rainbow Trout were then compared to the water quality (DO, pH, and
temperature) from six to ten sampling locations. Parameters were collected on a bi-weekly basis from June to September, and monthly for May and October.

Data analysis consisted of using tracking date to make monthly kernel density maps in Geographic Information Systems and a combination of tracking data and water quality data for a range bagging model in Program R. Monthly kernel density maps showed locations selected during two summers (2017 and 2018). The probability of presence of Rainbow Trout will be determined from water quality data and Rainbow Trout depth and temperature selections. Range bagging is the presence-only model in Program R that was used to store, average, and predict frequency of selections of depth, temperature, DO, and pH.

Kernel density maps for 2017 and 2018 revealed similar patterns of selected locations. Early in the tracking season (July and April respectively) revealed Rainbow Trout primarily selecting areas in the mid-range of the lacustrine reach, with a few individuals within the mid-range of the transitional reach. As the tracking season progressed into late July, selections in 2018 were within the transitional reach unlike the previous year. August selections were nearly identical with Rainbow Trout selecting locations throughout the entire reservoir, except for the riverine reach. As temperatures cooled in September Rainbow Trout were found to school in similar areas throughout the mid-range of the lacustrine and transitional reaches. October was the only month that revealed different patterns of use between years. In 2017 the Rainbow Trout remained in small schools of fish in the two reaches, but in 2018 the fish exhibited the same pattern as August of both years.

Depth selections in 2017 were more variable earlier in the season between 0 and 16 m. After the August 4th tracking event, depth selections averaged less than 6 m. Water temperatures were correlated with depths, fish that were shallow experienced warmer temperatures as high as 23.6 °C. As temperatures cooled, temperatures at the surface were as
low as 8.4 °C. Depth selections in 2018 were more consistent across the entire season with two patterns being revealed. Either Rainbow Trout selected depths less than 6 m or were found between 6 and 15.6 m. Therefore Rainbow Trout experienced warmer temperatures of 18.0 to 20.4 °C during the peak of the season. Deeper fish were found at temperatures at, or below, 19.6 °C. When temperatures cooled, fish were found at 14.8 °C.

Range bagging for both years revealed that Rainbow Trout were more likely to select intermediate water temperatures within the range of 0 to 30 °C and shallower depths (< 16 m) in the range of 0 to 20 m. With those selections falling between 10 and 22 °C and depths of 5 m or less. The predicted DO and temperature range bagging revealed that fish were going to select warmer temperatures (nearing 25 °C) at a wide range of DO between 4.0 and 13.0 mg/L. However, the 2018 model showed fewer Rainbow Trout selecting DO as low as 4.0 mg/L, falling between 5.0 and 11.0 mg/L. The final range bagging models for predicted DO and predicted pH revealed a wide range of DO being selected in 2017 with a higher probability of presence between 7.5 and 13.0 mg/L for 2018. Similarly, the predicted pH was over a wider range between 4 and 9 for 2017, but fell between 6 and 9 for 2018.

The most surprising conclusions of this study were that Rainbow Trout were selecting depths within the epilimnion and upper metalimnion. Therefore were found at temperatures bordering the upper temperature limit at 20 °C and above. Furthermore, these fish selected locations throughout much of the reservoir during the warmest period of the season in August, the time period expected for Rainbow Trout to find cold-water refuge. Literature suggests that there were more location selections due to increased movement to locate cold-water refuge, perhaps not finding it, and surviving until temperatures cooled. Although they did not appear to be selecting the riverine section, as shown by the data, there were individuals that were not during the 2018 season, and then were found in the upper
transitional reach. The lack of data for location selections within the riverine reach are believed to be due to the limitations of acoustic telemetry. Therefore, tracking adaptations would need to be made for future studies.

The range bagging model could be improved with using water quality data set over a finer scale from a prediction model developed by Portland State University. For example, the probability of presence of Rainbow Trout were shown at DO levels as low as 4.0 mg/L, this could not occur because it is the level of asphyxiation. In addition to improving the predictive power of the range bagging model and changing tracking methods, a diet and growth study could be conducted to understand Rainbow Trout health.

Although Rainbow Trout in this study were shown to have survived selecting warmer water temperatures, particularly in August, these fish may be thermally stressed and attempting to locate cold-water refuge. These fish may be pushed towards the surface due to lower DO levels near 5.0 mg/L. Although this is still within the suitable limit for Rainbow Trout to survive, it is not at 9.0 mg/L and above which are suggested when temperatures are ≥ 15.0 °C to reduce stress. Therefore, even though these selections are made, there is still concern for increasing water temperatures and low DO with climate change. Studies of Rainbow Trout responses to climate change and habitat selections and understand behavior under, what had traditionally been believed to be, marginal conditions.
INTRODUCTION

The construction of dams on rivers dramatically alters their hydrology. Dams influence the water temperature, water quality, and available habitat for aquatic organisms, directly impacting fish species. These physical alterations are likely to interact with increasing temperatures due to climate change, resulting in an estimated 47 - 50% reduction of thermal habitat for more than one cold-water fish species under a 2080s climate change scenario (Eaton and Scheller 1996; Stefan et al. 2001; Wenger et al. 2011). The species Rainbow trout were projected to lose 13% in length of suitable habitat by the 2040s, and 35% by 2080s (Wenger et al. 2011).

Rainbow Trout are sensitive to changes to their habitat (Powers 2014) and require cold-flowing water; high dissolved oxygen (DO); rocky substrate; an optimal 1:1 pool-to-riffle ratios (Powers 2014; Raleigh et al. 1984); stream cover; and stable riparian areas (Powers 2014). Due to this species’ higher sensitivity to elevated temperatures, it is a model organism for examining impacts of habitat changes (Powers 2014). Rainbow Trout prefer temperatures below 20 °C because lethal temperatures for salmonids typically fall between 22 – 26 °C (Powers DATE; Ebersole et al. 2001; Molony 2001; Stefan et al. 2001). However, Rainbow Trout can survive, or at least reside for several days, at temperatures between 0 °C and 29 °C (Ebersole et al. 2001). Some populations living at warmer temperatures may have access to cold-water refuges from stratification or ground water upwelling (Ebersole et al. 2001). If cold-water refuge are not readily available, Rainbow Trout individuals may relocate if not too thermally stressed to do so (Beitinger et al. 2000; Ebersole et al. 2001). If individuals are too thermally stressed to allow substantial movement, Rainbow Trout remain at warmer water temperatures until either they survived until temperatures cooled or mortality occurred (Ebersole et al. 2001).
Although Rainbow Trout typically select water temperatures below 20 °C, recent studies are finding that *Oncorhynchus* species are adaptable and can be found surviving in temperatures up to 29 °C (Beitinger et al. 2000; Molony 2001; Chen et al. 2015). Redband Trout (*Oncorhynchus mykiss gairdneri*) have been known to tolerate these higher temperatures in desert environments (Rodnick et al. 2004; Narum et al. 2010; Chen et al. 2015). These populations living in environmental ranges outside of the typical ranges for these species are believed to have responded to selective pressure and adapted to elevated temperatures (Narum et al. 2010). In northeast Oregon, there are streams that salmonids are known to survive in where temperatures exceed 26 °C daily for several hours (Ebersole et al. 2001). Similarly, there are hatchery stocks of Rainbow Trout in Western Australia that were cultured since the 1980’s that survive at 27.5 °C twice as long than wild strains (unpublished data) (Molony 2001; Chen et al. 2015). These stocks of Rainbow Trout were exposed to an extremely hot climate, and although it was initially difficult to establish a population, there is a successful line they use to stock Western Australia (Chen et al. 2015).

Myrick and Cech (2000) conducted laboratory studies on the effects of water temperatures on physiological variables of two California strains. Little attention had been given to strain-specific responses in California where water temperatures chronically exceeded 20 °C (Myrick and Cech 2000). An Eagle lake strain from an elevation of 1560 m and a 500 m lower elevation Mt. Shasta strain were compared. They were hypothesized to have different physiological responses to temperatures of 19, 22, and 25 °C, mimicking what fish may encounter in modified habitats. Data revealed that Rainbow Trout at increasing temperatures between 19 and 25 °C consumed less food, positive growth was slower than at lower temperatures, and fish consumed less DO (Myrick and Cech 2000). The data revealed that there were few differences in the two strains responses to higher temperatures, except
that Mt. Shasta fish grew faster and Eagle Lake fish consumed significantly less food. These few differences were attributed to the ability of thermal resistance and time period of exposure to higher temperatures. The Mt. Shasta strain experienced a longer period of exposure to warmer temperatures, and therefore exhibited better growth and food consumption (Myrick and Cech 2000). When compared to other Rainbow Trout strains, and other salmonids, acclimated to higher temperatures, it appeared that responses were similar regardless of origin (Myrick and Cech 2000).

Rainbow Trout near their southernmost extent in California are found living in temperatures exceeding their lethal limits, as high as 28.9 °C (Matthews and Berg 1997). Although these fish appear to survive these temperatures, stream surveys by the Los Padres National Forest revealed these fishes were instead found in cooler water temperatures in stratified pools (17.4 – 26.2 °C) and groundwater seeps (17.8 – 27.9 °C) during the day (Matthews and Berg 1997). Although they may find cooler water temperatures, there is likely a trade off with lower DO levels if they are locating groundwater seeps (Matthews and Berg 1997). DO levels at the bottom of pools where Rainbow Trout found refugia, were found to fluctuate between 0.2 to 8.8 mg/L over a 24-hour period (Matthews and Berg 1997).

Although there are optimal temperature ranges for salmonids, solely observing elevated temperatures is not appropriate when determining habitat selection when higher DO levels are required and may be more important of the two physical characteristics (Powers 2014). Optimal growth and development occurs for adult and juvenile Rainbow Trout when DO is at or above 5.0 mg/L (Molony 2001; Raleigh et al. 1984; Powers 2014). Mortalities increase below this level with asphyxiation occurring at 4.0 mg/L (Powers 2014; Molony 2001). One anthropogenic cause of low DO levels, is the construction of dams leading to
stratification. This impact, coupled with increasing average temperatures due to climate change, leads to increasingly exacerbated DO levels during the warmer seasons.

The overarching goal of this project is to describe movement patterns of Rainbow Trout in an environment that may experience high temperatures and oxygen stress. The specific location for this project is on the Spokane River where some research on Rainbow Trout distribution and movement has been done. Particularly focusing on the flowing segments, however, it is unknown what habitat may be available and suitable for Rainbow Trout. In particular, the Lake Spokane reservoir is where the uncertainty of available habitat is highest.

Lake Spokane experiences an increased residence time for the water flowing through this impoundment (Avista 2018). Due to the higher residence time nutrient overloading from point and non-point sources impacts the DO levels (Avista 2018). These point sources include waste water treatment and industrial facilities that discharges directly into the river. Non-point sources include tributaries, groundwater and storm-water runoff that largely are impacted by land use (Avista 2018). As a result the Washington Department of Ecology has determined that Lake Spokane does not meet water quality standards and falls under impaired bodies of water under the section 303d of the Clean Water Act (Avista 2018).

For the purpose of this study, my intention is to gain an understanding of salmonid summer habitat use in Lake Spokane, WA and determine if the water quality parameters that are selected are suitable for this species.
Objectives and Hypotheses

Objectives

1. Determine summer habitat use of Rainbow Trout from tracking data that provides location, depth, and temperature

2. Compare habitat use and variation between two sequential years

3. Use water quality and tracking data to predict future habitat characteristics Rainbow Trout will select for, based on past use

Hypotheses

1. Tagged Rainbow Trout will leave the lower lacustrine zone during the summer period and select locations within the upper lacustrine and transitional zone

2. Rainbow Trout will inhabit the upper hypolimnion and lower metalimnion for cooler water temperatures and higher DO during the summer period
MATERIALS AND METHODS

Study Site

On the Spokane River there are five dams that have permanently altered the environment, fragmenting the river, and creating a series of reservoirs and the associated lake-like conditions. Lake Spokane is one of these reservoirs on the Spokane River located approximately 25.75 kilometers northwest of Spokane, Washington (Figure 1). Nine Mile Dam was completed in 1908 at the upstream end, and this impoundment was created with the completion of Long Lake Dam in 1915 at the downstream end, creating a 38.62 km long reservoir (Figure 1). Lake Spokane contains three distinct zones, designated as riverine, transitional and lacustrine. The riverine zone begins at Nine Mile Dam and is approximately 5.63 kilometers (km) long with average depths of 1.5 meters (m). The transitional reach is approximately 21.05 km long with greater average depths and a defined littoral zone, and finally the lacustrine zone is the remaining 20.92 km. This zone has a max depth of 54.86 m with lake like conditions and, along with the transitional zone, experiences annual stratification with an epilimnion, metalimnion, and hypolimnion. The epilimnion is the surface layer that is warmed by solar radiation, the metalimnion is where the thermocline, or transition layer resides, and the hypolimnion is the bottom-most layer that has been known to become anoxic (devoid of oxygen) in this system (Avista 2018).

This reservoir provides many opportunities for recreational activities including angling for warm and cold-water sport fish and recently for triploid Rainbow Trout. Avista has stocked 155,000 triploids annually in the Lake Spokane Reservoir starting in the spring of 2014. However, it is unclear what patterns of movement these fish may exhibit, and what habitat in the lake they may be selecting, especially during summer months when the reservoir is stratified.
Figure 1. Location of Lake Spokane in Washington State shown in the red rectangle. Lake Spokane has three distinct zones, the riverine zone (5.63 km), transitional zone (21.05 km), and the lacustrine zone (20.92 km).
**Fish Capture and Collection 2017**

Twenty Rainbow Trout (457 mm and 800 g minimum) were acquired through angling events in May to procure fish that had acclimated to the reservoirs conditions. All anglers distributed themselves along the reservoir to prevent bias in capture locations. Single barbless hooks were used by all anglers to minimize injury to the Rainbow Trout and reduce handling time. All fish caught were held in a live well on the angler’s boat, until collected by myself on an additional boat outfitted for tagging. Fish were monitored for any injury (bleeding, listing, loss of equilibrium) prior to tagging, and only fish showing no signs of injury or extreme stress were tagged. Angling continued on a daily basis until 20 Rainbow Trout had been tagged and released.

**Fish Capture and Collection 2018**

Twenty-five Rainbow Trout (338 mm and 282.5 g minimum) were acquired through angling events beginning in March for an early release cohort (n=6) and ending in May for the second cohort (n=19). Angling methods started earlier in the season to allow for a longer tracking season to determine if there were differing patterns of habitat selection before water temperatures increased and DO levels fell.

**Tagging and Release**

Total length (mm) and weight (g) were measured to determine that they met the minimum size requirements for the tag size. The proposed guidelines regarding the maximum size of a tag relative to a fishes body weight ranges from 2 to 10.8% to not inhibit the fishes swimming ability (Brown et al. 1999). Fish selected for 2017 were approximately 457 mm, 800 g and for 2018, 338 mm and 282.5 g, leading to the tags being approximately 4% of the overall body weight to allow us to collect enough fish while staying towards the conservative end of that range. The minimum size requirements were smaller for 2018 due to the 2017 data giving us confidence that
a ping rate of 10 s instead of 5 would be sufficient for locating a fish. As a result the acoustic tags were smaller.

Rainbow Trout that met the minimum requirements were anesthetized with a physical anesthetic, low-voltage electroanesthesia (LVEA) (Hudson et al. 2011; Keep et al. 2015; Rous et al. 2015). The LVEA unit (Figure 2) consists of an aerated cooler containing two electrode plates that delivers a continuous non-pulse, direct current (DC), and a mesh cradle placed between the two. A DC non-pulsed current will interfere with the medullary motor paths in a fish, which in turn causes a loss of equilibrium while normal gill movement continues (Henyey et al. 2002). In order to keep the fish in this state, it must remain in the electrical field. Amperage of the unit is relatively low (10-25 milliamps), and voltage is less than 50 volts (Hudson et al. 2011).

The cooler of the LVEA unit was filled with water taken from Lake Spokane and the power source was set at zero volts before each fish had been placed in the cooler, head oriented towards the anode (Rous et al. 2015). Once the fish was properly oriented the voltage was increased by units of 0.1 volts until the fish reached stage IV anesthesia, not exceeding 30 volts. Stage IV anesthesia is when a loss of equilibrium occurs and the fish exhibits no response to external stimuli (Summerfelt and Smith 1990).

Once stage IV anesthesia had been reached the ventral side of the Rainbow Trout was brought above the water line by adjusting the mesh cradle. A 3 cm long incision was made anterior to the pelvic fins and girdle (Figure 3) to insert the acoustic tag that contained a complex sensor for water temperature and depth to obtain data in addition to location (Heupal and Webber 2012). The acoustic tags used for this study were purchased from the company Lotek Wireless. Specifications for these tags is provided in Table 1. After the acoustic tag had been placed within the coelomic cavity, two to three individual sutures (single use, uninterrupted surgeons’ knots) were used to close the incision. Lastly, a Floy tag with the Eastern Washington University
Fisheries Research Center (EWU FRC) phone number was injected just posterior of the dorsal fin. These Floy tags were different color from the rest of the stocked triploids that were tagged and released into the reservoir.

Following the surgery and tag injection, the power source to the unit was turned off to allow the fish to recover, regain equilibrium and begin to respond to external stimuli. Fish were determined ready for release if there was no excessive bleeding from the incision, there was no listing, and the fish was exhibiting normal swimming behavior (avoiding obstacles and responding to external stimuli). Once recovery was complete they were released at the site of their capture.

**Figure 2.** Low-voltage electroanesthesia unit. Unit consists of a cooler and A) two plates, which serves as the positive and negative anodes; B) BK precision power unit; C) inverter to provide power supply; D) deep cycle battery.
**Figure 3.** Acoustic tag implantation. Location of incision, circled in red, to implant acoustic tag before using two to three separate surgeons knots to close. The researcher is completing the second surgeon knot.

**Table 1.** Acoustic tags specifications purchased from Lotek Wireless 2017 and 2018.

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Sensor Type</th>
<th>Size Dimensions (mm)</th>
<th>Weight (g)</th>
<th>Life-span (days)</th>
<th>Transmission Interval</th>
</tr>
</thead>
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<td>2017</td>
<td>MM-M-11-45-TP</td>
<td>Temperature and pressure</td>
<td>10 x 83</td>
<td>19</td>
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<td>5</td>
</tr>
<tr>
<td>2018</td>
<td>MM-M-11-45-TP</td>
<td>Temperature and pressure</td>
<td>10 x 61</td>
<td>11.3</td>
<td>160</td>
<td>10</td>
</tr>
</tbody>
</table>
Range Testing

A consistent methodology for locating and tracking tagged fish increases efficiency and ensures consistency across tracking events. The most efficient way to track is to follow a grid of points that define overlapping areas of detectability within the study site. To develop the size of a tracking grid, the distance the tags used in a study needs to be determined. The distance between grid points is determined through the method of range testing.

Range testing was conducted on a bi-weekly basis in 2017 and monthly in 2018 at one of three locations on the reservoir (upper, middle, and lower) to account for changes in environmental conditions and limnology (Figure 4). To create the grid a test tag, with the same specifications as those implanted in the fish, was used to determine the range of detectability within the reservoir. The test tag was zip tied to a braided nylon rope, at one end of the rope a boat anchor had been affixed, and a vinyl inflatable buoy was attached to the rope on the opposite end. Where the tag was attached depended on the depths of our three testing locations (Figure 5).

The test tag unit was set up at one chosen location within the area that was tracked that day in 2017, and range testing began with the test tag at five meters below the surface, the middle of the water column (depth / 2), and/or five meters above the substrate. At each depth, the boat drove in two cardinal directions at three fixed distances. Lotek suggested that their tags could be detected close to 400 meters (both seasons). Therefore we began with distances increasing by 50 (50, 100, 150) meters for each depth to create a 300 meter cell (Figure 6). At each location we used a directional hydrophone with a 180° baffle purchased from Lotek Wireless to detect the test tag. We remained at each location for three minutes (180 sec), given that the test tag transmits every five seconds, this time period should correspond to a maximum of 36 detections.
The distance at which the test tag is detected 80% of the time determined the range of detectability for two weeks in 2017 and monthly for 2018. For the purpose of this study I used 80% of detectability to create overlap between the grid cells and reduce the chance of missing a fish due to habitat complexity. Grid cells were approximately 300 x 300 m in 2017.

In 2018 the tags transmitted once every 10 seconds and corresponded to a maximum of 18 detections at each point in two cardinal directions. Test tag depths for 2018 were based on the Rainbow Trout cohorts depth they were typically found at as per suggested by Kessel et al. (2014). The remaining range testing methods remained the same. Grid cells in 2018 were approximately and 150 x 150 m and two minutes at each grid point was sufficient with a detection of 3 pings in all cardinal directions while tracking.

**Figure 4.** Three potential range testing locations on Lake Spokane, WA to account for changes in limnology.
Figure 5. Diagram depicting buoy unit to be used for range testing on Lake Spokane, WA. The buoy was visible at the surface of the water, with the braided nylon rope secured to it and the weight keeping the unit in its location. The test tag was secured to the rope, at one of three depths, in the middle of the water column illustrated in this diagram.
Figure 6. Range testing example approximately the middle of the reservoir. The red marker at the center represents the test tag attached to the buoy unit. Each concentric circle is an additional 50 meters distance from the test tag (50, 100, 150). The x’s displays 6 of 12 potential locations the boat will stop for three minutes in two coordinal directions with the directional hydrophone. Figure is not to scale.

Tracking 2017

Tracking occurred once a week beginning July 8th, giving the fish a two-week acclimation period following tagging and ending November 6th 2017. A total of 20 tracking events were completed with alternating halves of the reservoir being covered. Manual tracking began at Long Lake Dam or at Tumtum, WA, with the use of a boat. I stopped at each location on the grid and placed the directional hydrophone into the reservoir initially directing the 180° baffle north. I then directed the hydrophone south, east, and west for 30 seconds each. This totaled a time of
two minutes at each grid point for the potential of 24 detections from a tag if it was within range for the entire duration. If no fish were detected, I moved to the next grid point.

When a fish was detected there was a tone prompt followed by a unique identification code that appeared on the laptop screen with an associated signal strength. Once a fish had been detected, I changed the direction of the baffle to determine which direction the signal strength was strongest. I moved in the direction of the signal strength in short bursts and then redeployed the hydrophone to determine if I had moved closer to the tagged fish, if I drove past it, or if the fish changed locations. Once the signal strength appeared to remain constant in the four cardinal directions, the location (Latitude and longitude), time, fish ID, temperature, and depth were recorded. Tracking then resumed at the next grid point.

**Tracking 2018**

Based on my experience in 2017, some changes in methodology were made in 2018 in order to reduce the chance of missing a fish that may move from an un-tracked area to a tracked area. In 2018 tracking occurred weekly starting April 21st and ending November 1st, 2018, totaling 26 events with no two-week acclimation period. Each tracking event typically covered the entire reservoir. In the event that one day was not enough to cover the entire reservoir, I returned the following day to complete the remainder of the study area.

Two additional tracking events below Lake Spokane were conducted to determine if any fish that were undetected entrained over Long Lake Dam. A tracking event on the last reservoir, Little Falls Pool, of the Spokane River. The second additional event occurred below Little Falls Pool covering the remaining free flowing segment of the Spokane River before the confluence with Lake Roosevelt, due to there being approximately 46.03 km to cover and time constraints, I focused on tributary mouths.
I also conducted a 24 hour tracking event to determine if the Rainbow Trout changed their depth selection in the water column or moved spatially over the course of the night. Rainbow Trout were located following normal tracking methods during the day, and were relocated approximately at 2 hour intervals. Night tracking began at 10 pm, beginning at the last known location of the Rainbow Trout from the previous set of coordinates recorded.
DATA ANALYSIS

Monthly Habitat Use

The kernel density tool in Geographic Information Systems (GIS) calculates the density of features within a given area by smoothing out the clusters in a dataset (Figure 7). The smoothing method of this tool places a kernel, or weight, to each data point and then sums them over a region. Areas that have a higher point density will have a larger sum versus those with fewer points. A visual output is generated by creating a gradual density change between all of the points and these can be used to develop maps. These maps are used to show patterns, and although there is no p-value or z-score associated with the densities, these show initial patterns (Silverman 1986).

In this case, a kernel density map will use individual Rainbow Trout point locations and calculate the density within Lake Spokane and show patterns of use. These maps were created for each month of the tracking season to increase the number of fish locations, or data per time period, as one tracking event (weekly) did not provide enough data for the GIS kernel density tool. The density for all of the Rainbow Trout locations is then calculated by adding the values of all kernel surfaces that overlay each other in Lake Spokane (Silverman 1986).
Figure 7. Kernel density example of point features within a defined area. InPts are the point features and the OuRas is the output of density with a low to high gradient. Figure courtesy of ArcGIS for Desktop. [http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/kernel-density.htm](http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/kernel-density.htm)

**Probability of Presence and Habitat Selection**

Kernel density maps will show common fish locations, however, a more sophisticated analysis is needed to correlate those locations with habitat characteristics. Because the resulting data set from tracking is presence only, we must select an appropriate model that works with no absence data and can predict habitat selections based on water quality. The model selected for this study is range bagging, run in program R, and is a presence only niche-model that provides a potential spatial distribution based on environmental conditions (Drake 2015). Range bagging uses environmental ranges in the study area to determine if habitat selection by a study organism is within its environmental niche, or a realized niche. This is an attempt to solve the issue of only having tagged Rainbow Trout presence data and no absence data at specific locations within the reservoir. Although we assume tagged fish are representative of all fish in the reservoir, we cannot be certain that there are no Rainbow Trout present in a habitat where no tagged fish are found.
This analysis uses a method called Bootstrap that analyzes only 50% of the data set at a time (Drake 2015). Within that 50% of the data set, Bootstrap stores the ranges of selections made by the Rainbow Trout and creates an individual model. Bootstrap then does this 99 more times, storing the ranges for a slightly different 50% of the data set. The range bagging will then average all 100 models and will determine how many Rainbow Trout selections, or points, are found within each of those models. This determines if there is a probability of presence of Rainbow Trout within the ranges of selection.

Not only will range bagging be used to analyze Rainbow Trout depths and temperatures to predict future selections, this method will also be used to analyze water quality characteristics. The water quality data that had been gathered by Avista was used to illustrate water quality conditions for Rainbow Trout at six and ten point locations, 2017 and 2018 respectively (Figure 8). Water quality samples were collected bi-weekly in June through September, and once a month in May and October. Water column measurements were collected at one meter increments down to ten meters, and then every three meters to the lake bottom. Water quality data collected were temperature, conductivity (μS/cm), DO (mg/L), DO saturation (%), Winkler DO (mg/L), pH, and secchi disk depths. For the range bagging, a subset of the water quality data was used, DO (mg/L), temperature, and pH.

The Rainbow Trout locations were compared to DO, temperature, and pH to determine frequency of selection of these characteristics over the season. Although there is enough data for the model to run from these point locations, it is at a course scale instead of fine scale set across the entire reservoir as a grid. Therefore, a water quality matrix needed to be developed that interpolates the water quality conditions between water quality sites. I averaged every five meters and averaged the temperatures, DO and pH, given they didn’t change more than a degree. These averages were then interpolated between the six or ten locations using a 3rd order polynomial to develop a matrix of all possible water quality combinations to predict the values
between water quality sites. The averaged data set is then used in program R for the range bagging models to predict Rainbow Trout selections.

Figure 8. Lake Spokane, WA water quality monitoring sites for 2017 and 2018.
RESULTS

Kernel Density and Habitat 2017

Nineteen out of the 20 fish were detected with a total of 147 locations recorded over 20 trips (Table 2). Fifteen of the fish were used in subsequent analysis, four of the remaining fish were presumed to be mortalities due to a lack of movement over a prolonged period of time and the fifth fish was never detected after release (Table 2). Rainbow trout that were presumed to be mortalities were removed from the tracking data set.

Results from a kernel density map aid in identifying locations and hotspots with the symbology gradient transitioning between dark blue to dark red. Dark blue indicates no presence of Rainbow Trout for that month. Lighter blue transitioning into light yellow indicates individual fish had been detected at least one tracking event during the month before moving to another location. Light red into dark red indicates locations where Rainbow Trout were more frequently found each tracking event.

July habitat use revealed that Rainbow Trout were schooling in the mid lacustrine reach with a smaller school towards the transitional reach and Tumtum, WA. There were a few Rainbow Trout that had moved towards Long Lake Dam, indicated by the lighter gradient of blue, with some of these individuals moving up or downstream near the hot spots shown in dark red (Figure 9a).
August habitat use revealed a surprising pattern. During the hottest month of the tracking season, it was anticipated that Rainbow Trout would limit movement, however the number of locations selected increased (Figure 9b). There were no obvious hotspots as Rainbow Trout were found through the entire lacustrine reach and most of the transitional reach with most of the selection occurring towards the upper lacustrine and lower transitional as indicated by the darker red in the gradient. There were fewer individuals that were found in the upper transitional and moving into the riverine reach, indicated by the lighter yellow and blue.
Habitat use in September quickly became localized unlike the movements in August (Figure 9c). The hotspots were found within the transitional reach as had been hypothesized with a lighter hotspot found in the mid-range of the lacustrine reach. Each hotspot had fringe areas, indicated with lighter yellow and blue, where individual Trout had moved to when found during one tracking event before moving back to the localized areas the following week. There was one fish indicated by light blue, which stayed near Long Lake Dam the entire season. However, this fish was not a mortality until it was caught by an angler in 2018.
The kernel density map for October also includes the one and only tracking event in November to finish out the tracking season (Figure 9d). The habitat use still showed Rainbow Trout schooling in similar areas, however, there were four locations where individuals were found consistently in comparison to September where there were only three. However, the fourth hotspot near Tumtum, WA, wasn’t used as frequently. These locations fell between the mid-range of the lacustrine reach and mid-range of the transitional reach. Between October 6th and the November 6th tracking events these small clusters of fish started moving downstream as a cohort (Figure 9d). The final tracking event on November 6th revealed that these fish were beginning to spread out across the reservoir, similar to earlier in the season.
Figure 9d. October and November habitat use of Lake Spokane, WA. November is included in this kernel density map due to only one tracking event occurring in November.

There was variation in depth, temperature, and location across the course of the summer and fall. Fish were found over a wider range of depths earlier in the summer between 0 m and 16 m from the surface (Figure 10). The August 4th tracking event is when the Rainbow Trout were beginning to select shallower depths. These depths averaged just above 6 m and as tracking progressed into September and October average depths were between 1.8 and 3.2 m within the surface. With exception of fishes 31100 and 31300 which were both found at depths greater than 6 m.
Figure 10. Lattice graph created in program R. Date is grouped into months along the X-axis and depth in meters increases along the Y-axis. The numbers 31100 through 29800 are the acoustic tag numbers for individual Rainbow Trout. Each cell below an acoustic number is the depth for those Rainbow Trout. Fish who only have a few detections were not relocated and fish 30600 was suspected to be a mortality after August and was removed from the data set.

Temperatures were correlated with depths, fish in shallower water experienced warmer temperatures while fish in deeper water experienced cooler temperatures. Temperature selections ranged between 8.4 °C, during the cooler months, and 23.6 °C for the Rainbow Trout nearer the surface during August. (Figure 11). As temperatures warmed during the season Rainbow Trout were found near their upper limit, however, these fish were not suspected to be mortalities due to
their continuous movement at that temperature and depth for the duration of the tracking event. Although temperatures cooled moving into October, depth selections were more consistent and remained shallow.

**Figure 11.** Temperature lattice graph created in program R. Date is grouped by month along the X-axis and temperature in Celsius increases along the Y-axis. Each number 31100 through 29800 is an acoustic number for an individual fish, and each cell below are the temperature selections for that Rainbow Trout. Fish 30600 was suspected to be a mortality after August and was removed from the data set.
Range bagging outputs

The range bagging outputs are in a 3-D format, with two characteristics and the third axis is the environment from which selections are made. Probability of presence is shown with a color gradient of dark blue (0% probability of presence) to dark red (100% probability of presence).

The first 2017 range bagging output predicted depth and temperature selections from the depth range 0 to 20 m and temperature of 0 °C to 30 °C (Figure 12). Rainbow Trout are more likely to select shallow depths at intermediate water temperatures relative to the temperatures and depths selected by the tagged fish. Fish are predicted to be found at depths shallower than 16 meters, the shape the points make is a wedge. As the depth increases there are fewer fish found with none predicted to select greater than 16 meters. In terms of temperatures, they are predicted to select between 10 °C and 25 °C. Similar to the 2017 data, and the base of the wedge is found throughout these temperatures at depths 5 m and less when looking at a 60% chance of presence and above.
Figure 12. Probability of presence as a function of depth and water temperature selections. Depth in meters 0-20 m, increases towards water temperature and water temperature in Celsius, increases from 0-30 °C. The z-axis represents the environment from which the Rainbow Trout are selecting.

The second range bagging graph determines probability of presence from predicted DO and water temperature (Figure 13). Predicted values for DO from the interpolated matrix are used for this range bagging model due to how water quality samples were collected on a course scale throughout the Lake Spokane impoundment. These predicted values came from the 3-order polynomial to interpolate values between the water quality sites and create a matrix of all possible combinations of DO, pH, temperature, and depth.

Ranges for temperature and predicted DO are 0 to 30 °C and between 4.0 mg/L, the level asphyxiation occurs, and 13.0 mg/L as the upper limit based on water quality data respectively. Predicted values show fish can be found throughout the entire DO range and are predicted to select warmer temperatures. A probability of ≥ 60% are predicted to select temperatures between
15 °C and 30 °C. The likelihood of Rainbow Trout selecting DO levels of 4.0 mg/L at temperatures greater than 25 °C is impossible and would result in mortalities.

![Figure 13](image)

**Figure 13.** Probability of presence as a function of predicted DO and temperature values. Predicted DO ranges from 4.0 mg/L to 13.0 mg/L moving towards the temperature axis. Water temperature ranges from 0 to 30 °C. The z-axis is the environment from which Rainbow Trout are selecting.

The third range bagging output predicted the probability of presence at predicted DO and pH levels (Figure 14). Predicted values for DO and pH were used for this range bagging model because the water quality samples collected were on a course scale. These predicted values came from a 3-order polynomial to interpolate values between the water quality sites and create a matrix of all possible combinations of DO, pH, temperature, and depth.

Probability of presence appears more distributed between both ranges, however, there is a less than 40% chance of presence at lower pH and lower DO levels. However, there are predictions of greater than 60% that Rainbow Trout will be present at DO levels of 4.0 mg/L at
higher pH levels. These predictions are still unlikely due to asphyxiation occurring at 4.0 mg/L. Rainbow Trout can survive at pH levels as low as 5.5, but prefer levels at 7 to 8.

**Figure 14.** Probability of presence as a function of predicted DO and pH levels. DO ranges from 4.0 mg/L to 13.0 mg/L and predicted pH ranges from 4 to 9. The z-axis is the environment from which Rainbow Trout are selecting.
Table 2. Fish detected during the 2017 tracking season presumed to be alive. Fish 30400, 30600, and 31200 are not included in this table due to being mortalities.

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<th>Acoustic Number</th>
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</tr>
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<td>29600</td>
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</tr>
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</tr>
<tr>
<td>31500</td>
<td>3</td>
</tr>
</tbody>
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Twenty-one of the twenty-five fish were detected with an additional six tags detected from the 2017 cohort (Table 3). There were a total of 215 locations recorded over 24 tracking events on Lake Spokane. Fish 36400, 38000, 37000, and 37500 were never detected. Mid way through the season two mortalities occurred, fish 31100 and 38200 were caught by anglers. Fish 31100 had suffered tearing of the gills from the lure the angler used and was unable to be released and fish 38200 was harvested. No other fish were presumed to have been mortalities.

The 2018 tracking season began on April 11th after ten of the fish were tagged and released. This extended tracking season allowed me to see Trout movements before temperatures warmed. There were two tracking events in April that revealed a similar selection in the mid-range of the lacustrine zone and a few individuals selected habitat within the transitional reach (Figure 15a).

April tracking showed only eight fish between LL0 and LL4, with 9 of 14 detections concentrated between LL1 and LL3a. This trend of finding few fish continued through early May with only six fish dispersed between LLO and LL1 within the lacustrine reach near Long Lake Dam. The early May trips had been the first occasion to find an increase in Rainbow Trout in the lower lacustrine reach. A potential explanation for so few fish being detected at the most downstream end may be the high flows occurring during and after tagging and high turbidity. Fish 31100, tagged in 2017, had been the only fish that had consistently selected habitat in the lower lacustrine all season, before being caught by an angler in 2018. May 26th was the first tracking event where turbidity and flows began to decrease. These improved conditions resulted in more fish being detected (n=14), but they still remained between LL0 and LL2.
Figure 15a. April habitat use of Lake Spokane, WA. April had two tracking events at the end of the month once all Rainbow Trout were tagged and released. High turbidity and flows were occurring during this tracking event.

May habitat use showed that Rainbow Trout moved toward the mid-range of the lacustrine reach downstream to Long Lake Dam. Although all of May showed these fish in the lacustrine reach, there were three distinct locations that fish grouped (Figure 15b). There were seven selections just upstream of Long Lake Dam near water quality site LL0, a second grouping of nine around LL1, and even fewer Rainbow Trout (5) located around LL1a. This initially was a concern due to higher flows that could lead to Rainbow Trout entrainment.
Figure 15b. May habitat use of Lake Spokane, WA. High flows and turbidity were occurring, but started to slow and settle out towards the end of the month.

June habitat use showed that the Rainbow Trout moved upstream away from Long Lake Dam. There was a hotspot in the mid-range of the lacustrine reach with a smaller school near Tumtum, Washington. June revealed that the Rainbow Trout selections were primarily found between LL1 and LL3 with a trend showing that fishes 37200, 37600, and 37900 staying between LL1 and LL1a in the lacustrine zone near the Lake Spokane Campground for the remainder of the season. Fishes 36100, 30900, and 38100 were schooling together outside of Tumtum, but weren’t found to continue to school the rest of the season. Outside of these two small schools of Rainbow Trout, no other groupings consistently occurred. July showed
upstream selections continued to occur with 22 of the detections being found between LL1a and LL4 moving out of the lacustrine zone into the transitional reach.

Figure 15c. June habitat use of Lake Spokane, WA.

July habitat use showed that the schools of Rainbow Trout moving upstream continued. A small school of three fish still remained in the mid-range of the lacustrine reach where they were located for the remainder of the tracking season. The other two hot spots were found in the bend outside of Tumtum, WA into the transitional reach. Lighter blue between localized areas were locations where a Rainbow Trout had been found for one tracking event before moving further upstream.
The transition between July and August included a period of increasing temperatures. During that time Rainbow Trout selections within the reservoir were becoming more spatially distributed moving back into the lower lacustrine reach. No Rainbow Trout were found above LL4 for all of August and the beginning of September.

August habitat use revealed a similar surprising trend as 2017. During the hottest month of the season, Rainbow Trout had the most movement and habitat selection in comparison to the rest of the season. Although this habitat use map looks nearly identical to the 2017 kernel density map, the outlying areas near Long Lake Dam, the upper transitional, and riverine reach had fewer Rainbow. Most of the fish were clustered towards the mid-range of the lacustrine reach into the mid-range of the transitional reach.
September habitat use showed the Rainbow Trout grouping up into similar areas from the earlier 2018 tracking data. The mid-range lacustrine reach had three more Rainbow Trout school with the original three fish. Two more areas selected upstream were outside of Tumtum, Washington with 9 detections, and 8 detections that were within the transitional reach, indicated by the light yellow and light blue where they moved between weeks. There were two that were in the upper transitional reach that were individuals that had either not been detected during the 2018 season or had been detected for a few tracking events before disappearing. This raised many questions on where these fish were located and undetected before temperatures cooled. The September 17th tracking event was the first to show Rainbow Trout selecting habitat between LL4 and LL5 within the upper transitional reach and a higher concentration of selections between LL1 and LL4. Although more Rainbow Trout were found within these
reaches, they were spatially distributed and were not schooling together. This trend continued into October with only a few fish detected above LL4.

**Figure 15f.** September habitat use of Lake Spokane, WA.

The October kernel density map has one tracking event on November 1st that was combined with the dates in October. The habitat use showed a similar trend to both year’s kernel density maps for August. Most of the reservoir was selected, with fewer Rainbow Trout near Long Lake Dam and near the Riverine reach. Selections were primarily between the upper
lacustrine and transitional reach.

**Figure 15g.** October habitat use of Lake Spokane. November is included in this map because there was only one tracking event on November 1st to finish out the tracking season.

The two additional tracking events below Long Lake Dam on September 6th, for Little Falls Pool, and remaining Spokane River on September 13th resulted in no missing Rainbow Trout being found. The 24-hour tracking event, a subset of eight fish were followed (Table 4) and revealed that a majority of these fish did not move more than 300 m from their locations where they were detected during the day. Furthermore, the fish that had selected depths within six meters of the surface did not change their depth selections during the night by more than one or two meters. Rainbow Trout that had selected depths at 6 to 15 meters did not change their selections during the night and remained in the same location.
Table 3. Rainbow Trout night depth and temperature selections from the 24-hour tracking event. Fish didn’t change depth selection in the water column by more than a meter.

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<th>Temperature (°C)</th>
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Depth selections did not vary substantially throughout the season with two patterns emerging. Rainbow Trout were either found less than 6 m within the surface or were found between 6 to 15.6 m (Figure 16). For the majority of the season these fish stayed at similar depth selections, at the first or second pattern. The fish that had been tagged in 2017 were not detected after June 17th when the battery life had ended. Of the 24 fish that were consistently found within 6 meters of the surface, 17 of fish were consistently within 3 meters of the surface.

**Figure 16.** Depth lattice graph created in program R. Date is grouped in months across the x-axis, and depth in meters increases along the y-axis. Each number 37600 through 35600 are unique acoustic numbers, and each cell below are that Rainbow Trouts’ depth selections. Rainbow Trout on the bottom row are from the 2017 cohort except for 35600.
Due to little variation in depth selections, Rainbow Trout remaining close to the surface experienced warmer temperatures in July and August with range of 18.0 to 20.4 °C (Figure 17). Three fish found deeper in the water column were found at temperatures averaging 15.6 °C. September temperatures began to cool staying at or below 19.6 °C and falling to below 14.8 °C for the remainder of the season for the fish near the surface.

**Figure 17.** Temperature lattice graph created in program R. Date is grouped in months along the x-axis, and temperature in Celsius, increases along the y-axis. 37600 through 35600 is a unique acoustic tag number, and the cell below each number is that Rainbow Trouts’ temperature selections. Fish on the bottom row are from the 2017 cohort except for 35600.

**Range bagging outputs**

Based on the 2018 data, the range bagging model predicting depth and temperature selections produced results similar to those observed in 2017 (Figure 18). Rainbow Trout are shown to continue to select shallower depths at intermediate water temperatures. The 2018 output is less of a wedge, and more of a block, however it still tapers off with an increase of depth. A greater than
or equal to 60% probability of presence suggests that fish will select between 10 °C and about 22 °C at depths of 5 m or less.

**Figure 18.** Probability of presence as a function of depth and water temperature selections. Depth ranges from 0 to 20 m and water temperatures increase from 0 °C to 30 °C. The z-axis is the environment from which Rainbow Trout select.

The second range bagging output for 2018 predicts the probability of Rainbow Trout presence from predicted DO levels and water temperatures ranging 4.0 – 13.0 mg/L and 0 – 30 °C respectively. The 2018 predictions for DO and temperature selections are more biologically believable than the 2017 model, which predicted Rainbow Trout would select DO levels as low as the asphyxiation level. Although there are still predicted selections of DO levels as low as 4.0 mg/L, greater than or equal to 60% probability of presence is at 5.0 mg/L and higher. Temperature selections for higher probability of presence is shown 5 °C to 30 °C, reaching and surpassing the upper limit for Rainbow Trout. However, when analyzing the output, the
probability of presence between 5.0 mg/L and approximately 11.0 mg/L at temperatures ranging between 5 °C and 25 °C are biologically likely so as to remain within the ranges suitable for Rainbow Trout.

**Figure 19.** Probability of presence as a function of predicted DO and water temperature. Predicted DO levels increases from 4.0 mg/L to 13.0 mg/L and water temperatures increases from 0 °C to 30 °C. The z-axis is the environment form which Rainbow Trout are selecting.

The third 2018 range bagging output determines the probability of presence from selected DO and pH levels ranging from 4.0 mg/L to 13.0 mg/L and 5 to 9 respectively. The 2018 predicted model still has a wider selection within the ranges in comparison to Figures 12 and 13, however, selections are more confined in comparison to the 2017 range bagging model. There are fewer predicted selections of DO levels as low as 4.0 mg/L and a pH level of 5. A greater than or equal to 60% probability of presence suggests selections to be between 6 and 9 for pH and DO levels 7.5 mg/L to 13.0 mg/L. These ranges are more biologically believable because the
DO levels are above the asphyxiation level and fall within the narrow pH range suitable for Rainbow Trout.

**Figure 20.** Probability of presence as a function of predicted DO and pH levels. Predicted DO levels increases 4.0 mg/L to 13.0 mg/L and predicted pH increases 5 to 9. The z-axis is the environment from which Rainbow Trout may select.
Table 4. Fish detected during the 2018 tracking season presumed to be alive. Six tags were still active for two months of the 2018 tracking season before the batteries are presumed to have died.

<table>
<thead>
<tr>
<th>Acoustic Number</th>
<th>Cohort Year</th>
<th>Number of Times Detected</th>
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<td>1</td>
</tr>
<tr>
<td>30500</td>
<td>2017</td>
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The most surprising conclusions are the depths and temperatures that a majority of the Rainbow Trout were selecting both seasons. I had hypothesized the Rainbow Trout would select depths in the upper hypolimnion and lower metalimnion, given that DO levels would be sufficient, to access cooler temperatures during the summer. However, a majority of both cohorts selected depths near the surface in the epilimnion resulting in the fish staying at warmer temperatures reaching presumed Rainbow Trout upper limits.

A tentative explanation for these data are that the fish may have been forced to the surface due to DO levels decreasing at greater depths. However, the water quality data from both years showed that DO levels were above the 4.0 mg/L threshold throughout the epilimnion and metalimnion. Although these levels were above 4.0 mg/L, if they are not greater than 9.0 mg/L, Rainbow Trout may not select those locations. If DO levels are suitable there may be other factors influencing the Rainbow Trout selections.

Furthermore, I had hypothesized that Rainbow Trout would select habitat within the upper lacustrine zone and transitional zones to locate areas with increased flow, but have greater depths with cooler temperatures. Unlike the lacustrine zone that has lake like conditions with either an anoxic hypolimnion or DO levels that fell below the threshold of 4.0 mg/L or the riverine section having low flows and high temperatures during the summer period. Although for the majority of the seasons the Rainbow Trout were typically found between LL1 and LL4, the upper lacustrine to mid transitional reach, there were fish that moved below LL1 on occasion.

Additionally, during August of both seasons the Rainbow Trout exhibited more movement in comparison to the rest of the season selecting habitat through the reservoir from LL0 to LL4. During the hottest portion of the tracking season, Rainbow Trout were expected to reduce their movement when temperatures would be at critical maximum levels. Some literature
proposes that salmonids that exhibit this behavior may be due to the fish trying to locate cold-water refuge (Ebersole et al. 2001).

Although looking at the kernel density maps it appears there were no Rainbow Trout in the riverine reach, I believe a subset of the 2018 cohort may have been selecting this habitat, or the one tributary that flows into Lake Spokane, the Little Spokane River, during the warmest portion of the year. This speculation is based on having 5 fish that had remained undetected for all, or a portion, of the season appearing at the most upstream end of the transitional reach as temperatures cooled. I believe this subset of fish remained undetected in the riverine reach due to the combination of shallow depths and high habitat complexity. Often this reach was un navigable because it was too shallow for a boat and would have been impossible to track by foot on a consistent basis. Furthermore, the high habitat complexity consisted of aquatic vegetation and larger boulders, which is one of the limitations of acoustic telemetry.

High habitat complexity can prevent detection because of how an acoustic signal is produced and travels through the water. An acoustic signal, or sound wave, is produced through converting the electrical energy stored in the tags battery into acoustic energy (Kessel et al. 2014). This acoustic energy is then transmitted into the surrounding aquatic environment through a transducer and can be detected by the coupled positioning (receiver that picks up the signal) system and reconverted into an electrical signal to be decoded and stored (Kessel et al. 2014). While this signal is traveling it will be reduced with an increase in salinity, temperature changes, turbidity, and substrate complexity (Kessel et al. 2014). An additional environmental condition that reduces the chance of detecting an acoustic signal is a deep water column that stratifies (Heupal and Webber 2012; Baktoft et al. 2015, Kessel et al. 2014).

Therefore, for future studies in this environment there would need to be additional tracking methods. Rafting the riverine section could be conducted in a zig zag pattern to cover
this reach while trying to solve the issue of high habitat complexity. An additional option could be the use of a PIT (passive integrated transponders) tag array to determine if these fish were entering and leaving the riverine section. A PIT tag is an additional internal tag between 8.5 and 23 mm that has a unique identification number and does not require a battery. This tag sends out a radio frequency instead of a signal that is only picked up when the fish passes over or through an antennae. The antennae array would need span the cross section of the river as the environment changes into the riverine reach, or the mouth of the Little Spokane River to determine these fish are entering and exiting.

The range bagging predictions for future habitat selections show Rainbow Trout are more likely to be found within intermediate water temperatures at shallower depths. These predictions were developed using both seasons tracking data to determine ranges within the environment. Predicted selections with the probability of presence being ≥ 60% and above were similar to the selections made by the majority of the tagged Rainbow Trout. These data were still surprising due to previous knowledge of the needs salmonids typically require as a cold-water species. Although these predicted selections are reasonable based on Rainbow Trout tolerances and actual selections, the additional range bagging models of DO and pH selections are not entirely accurate.

The predicted values of DO and pH were developed by creating a matrix of all possible combinations between DO, pH, temperature, and depths. Therefore some of these combinations could not be possible for selections such as DO levels as low as 4.0 mg/L in Figures 12 and 13. If Rainbow Trout were to be found at that level of DO they would become a mortality. Similarly, there were predictions of selecting temperatures above 25 °C. Although literature supports that Rainbow Trout can survive up to 29 °C, this only occurs when they are exposed to those temperatures for brief periods of time and have access to cold-water refuge.
Due to the predicted selections using predicted values, the environmental ranges and values need to be improved in order to develop a more accurate output. This can be done either by using a YSI meter to gather water quality measurements at a fine scale around each tagged fishes location or by using values from another model. Portland State University developed a water quality and hydrodynamic model that analyzes the relationship between temperature, nutrient, algae, DO, organic matter and sediment. The CE-QUEL-W2 model was used to model these relationships for Lake Spokane in 2010, therefore, if those values were obtained, they could be exchanged for the predicted values in the range bagging model. They were not used initially because they were not available.

An improved model could then be used to determine how much of the reservoir is suitable, or meets the same conditions Rainbow Trout are already selecting. Determining how much of the reservoir meets those conditions would aid in mapping out habitat that untagged Rainbow Trout may also be present, and potentially hone in on areas that need additional restoration and improvement, guiding future studies.

Although the Rainbow Trout in this study may survive warmer temperatures, particularly in August, these fish may be thermally stressed for that time period. Raising concern that with increasing temperatures and warmer than average summers, it will become increasingly difficult for Rainbow Trout to survive the summers. Furthermore, although DO is above the 4.0 mg/L level and appears to be adequate throughout the epilimnion and metalimnion, levels for Rainbow Trout are suggested to be a minimum of 9.0 mg/L and above for temperatures exceeding 15 °C (Raleigh et al. 1984). Therefore the relationship between DO and temperature should continue to be analyzed in regards to habitat use of Rainbow Trout in this reservoir. The water quality data showed that DO levels were near the minimum 9.0 mg/L at temperatures in the 20’s, although adequate for survival, these combinations may still be less than optimal.
For future directions, a diet and growth study of these Rainbow Trout could reveal if diet is an important component to the habitat use and if these Trout have a good condition factor with the environmental ranges in which they are surviving. Additional tracking studies would aid in determining how much of the riverine reach is used and how often, as well as determining if any of these fish may enter the only tributary. A fine scale water quality sampling method would improve on predicted values in the range bagging model to gain a better understanding, beyond this initial data set, of habitat selection over time.
LITERATURE CITED


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- Poster presentation, EWU Student Research and Creative Works Symposium, 2017
- Poster presentation, American Fisheries Society WA-BC Chapter Conference, 2016
- Oral presentation, National Conference of Undergraduate Research UNC Asheville, 2016

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- Oral presentation, American Fisheries Society WA-BC Chapter Conference, 2015
- Oral presentation, EWU Student Research and Creative Works Symposium, 2014
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