Movement and Home Range Study of Select Native Fishes in the Chehalis River, Washington State

Interim Report

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Executive Summary

Although mountain whitefish (*Prosopium williamsoni*) are one of Washington's native freshwater salmonids and undergo complex seasonal migrations (Davies and Thompson 1976, Baxter 2002, Boyer et al. 2017) and Washington State listed Pacific lamprey (*Entosphenus tridentatus*) as a Species of Greatest Conservation Need, we know very little information about these fishes in the Chehalis River Basin. Furthermore, detailed life history, distribution, and abundance information on mountain whitefish and Pacific lamprey were identified as data gaps in sections 3.1.1 Additional Species Data Gaps and 4.1.1 Species-Specific Life History and Population Data Gaps for In-Channel Species, respectively, in the Aquatic Species Enhancement Plan Data Gaps Report (Aquatic Species Enhancement Plan Technical Committee 2014).

Preliminary findings of our study showed several movement patterns by tagged mountain whitefish between August 2017 and May 2018 in the South Fork of the Newaukum River. To date, we have observed home ranges of 0.5 to 26.9 river kilometers (RKm). During the timeframe of our study, movements appear to be associated with changes in streamflow and temperature, with the largest movement observed corresponding to a large flood in October 2017 (4400 cfs and 10.1 ^{o}C). We also detected movements into a 3rd- and a 5th-order tributary of the South Fork Newaukum River, which expands the previously-known distribution of mountain whitefish in the Newaukum River and highlights the complexity of their movement patterns and connectivity requirements for migration. Observed movements are likely associated with pre- and post-spawning, overwintering, over-summering, and feeding migrations. Our results will help us understand the flows and temperature at which mountain whitefish and Pacific lamprey would need to be considered for passage at the proposed dam, informing the Environmental Impact Statement (EIS). For the Aquatic Species Restoration Plan (ASRP), our study will help to answer the question, "How will restoration actions (i.e., barrier removal and culvert replacement, placement of large woody debris (LWD), and riparian planting) that target salmon and steelhead influence other native fish species in the Chehalis River?" We must first know when these fish make use of proposed restoration areas and then how they move with respect to flow and temperature to understand how access to new habitat

(i.e., barrier removal) or changes in flow and temperature (i.e., from placement of LWD and riparian planting) may affect their movements.

Introduction

In order to access preferred habitats critical to completing their life cycle and meeting their resource needs, fish must undergo movements throughout the river system (Fausch et al. 2002, Albanese et al. 2004). The temporal and geographic scales over which fish move range from daily to seasonal movements at individual habitat units to multiple river basins (Kahler et al. 2001, Welch et al. 2006, Radinger and Wolter 2014). Fish movement allows for habitat selection to meet life history requirements, such as locating adequate spawning habitat (Quinn 2005, Starcevich et al. 2014), providing refuge from predators or environmental stressors including changes in flow or temperature (Bjornn 1971, Armstrong and Schindler 2013), and migrating to preferred foraging locations (Gowan and Fausch 2002). Fish have been found to move to diverse habitats in disparate locations, depending on their life stage, which requires longitudinal and lateral connectivity within their range (Fausch et al. 2002).

Environmental variables such as streamflow and temperature have been found to influence fish movement (e.g., Bjornn 1971, Baxter 2002, Boyer et al. 2017). In a coastal stream in British Columbia, seasonal changes in streamflow and temperature have been correlated with movement of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) to slower and deeper water (Bustard and Narver 1975). In the Wenaha River of northeast Oregon and southeast Washington, Baxter (2002) found that during times of high flow, mountain whitefish (*Prosopium williamsoni*) and largescale sucker (*Catostomus macrocheilus*) underwent upstream spring migrations towards cooler temperatures. Spawning migrations of Pacific lamprey (*Entosphenus tridentatus*) in the Smith River, a coastal watershed in southern Oregon, were also found to coincide with high-water events in winter and increasing temperature and flow in spring (Starcevich et al. 2014).

The construction of physical barriers or alteration of flow regimes so that natural patterns of longitudinal and lateral connectivity are interrupted have been shown to disrupt fish movement patterns in a range of river systems (Bunn and Arthington 2002). In addition, scientists have documented anthropogenically-influenced changes in temperature and streamflow to decrease aquatic biodiversity, including for fish populations (Poff et al. 1997, Larinier 2001, Bunn and Arthington 2002). Impacts on the fish movement and migration from barriers, such as dams, have led to the inclusion of fish ladders and trap-and-haul operations to enable fish passage (Larinier 2001). However, these mechanisms are not necessarily inclusive to all fish species and life stages.

The Chehalis River is the second-largest watershed in Washington State. It is a coastal system that remained a refuge for species during the last glaciation (McPhail and Lindsey 1986) and supports a diverse array of native freshwater fishes including catostomids, cottids, cyprinids, gasterosteids, petromyzontids, salmonids, and umbrids as well as a wealth of amphibian species. It is also one of the few watersheds in the state with no federally-listed endangered salmonid species. However, this rain-dominant system has been heavily influenced by silviculture, agriculture, and urbanization (Phinney and Bucknell 1975). While it maintains a large, relatively intact floodplain, urbanization of and building infrastructure on the floodplain have reduced its habitat complexity and function. Flooding in recent years (1996, 2007, and 2009) has led to the proposal of a flood reducing and water retention structure (hereafter "dam") in the headwaters area of the basin as well as extensive restoration planning.

In order to understand the potential impacts to native freshwater fishes from the proposed dam and restoration efforts (e.g., barrier removal and culvert replacement to increase fish passage, placement of large woody debris (LWD) to increase habitat complexity and riparian planting to decrease temperature), we seek to understand the movements and home ranges of select fishes present in the Chehalis River Basin and their associations with streamflow and temperature. For this study, we will investigate movements and home ranges of the native freshwater fishes mountain whitefish and Pacific lamprey. Mountain whitefish are believed to be among the most abundant species present in western rivers (Northcote and Ennis 1994) and Pacific lamprey are listed as a Species of Greatest Conservation Need in Washington State. However, there have been declines in both species' abundance throughout their range (Close et al. 2002, Paragamian 2002, Boyer et al. 2017). Our study will provide information about the timeframes, flows, and temperatures at which mountain whitefish and Pacific lamprey undergo movements. This information will help plan for fish passage at the proposed dam and inform the Environmental Impact Statement (EIS). Information provided by our study will also inform the Aquatic Species Restoration Plan (ASRP) by helping to answer the question, "How will restoration actions (i.e., barrier removal and culvert replacement, placement of large woody debris (LWD), and riparian planting) targeting salmon and steelhead influence other native fish species in the Chehalis River?" We must first know when these fish make use of proposed restoration areas and then how they move with respect to flow and temperature to understand how access to new habitat (i.e., barrier removal) or changes in flow and temperature (i.e., from placement of LWD and riparian planting) may affect their movements. Furthermore, detailed life history, distribution, and abundance information on mountain whitefish and Pacific lamprey were identified as data gaps in sections 3.1.1 Additional Species Data Gaps and 4.1.1 Species-Specific Life History and Population Data Gaps for In-Channel Species, respectively, in the Aquatic Species Enhancement Plan Data Gaps Report (Aquatic Species Enhancement Plan Technical Committee 2014) for the Chehalis River Basin. Our study objectives are as follows:

A. Describe movements and home ranges of mountain whitefish in a select tributary in the Chehalis River Basin.
B. Describe movements of Pacific lamprey in a select tributary in the Chehalis River Basin.
C. Identify and describe relationships observed between hydrological changes or environmental conditions (specifically flow and temperature) and fish movements.

Methods

Study Area

This study occurred in the Newaukum River Basin, a major tributary to the Chehalis River (Figure 1). The Newaukum River Basin is located in the southeast corner of the Chehalis Basin and is approximately 406 km^2 in size. It consists of the North Fork, Middle Fork, and South Fork branches and is largely a rain-dominant system with the headwaters of the larger North and South Forks originating in the foothills of the Cascades. The Newaukum River Basin was selected based on known occupancy of Pacific lamprey and mountain whitefish, known relative abundance of mountain whitefish (Winkowski et al. 2017), and considerations for land and river access.

Fish Collection and Tagging

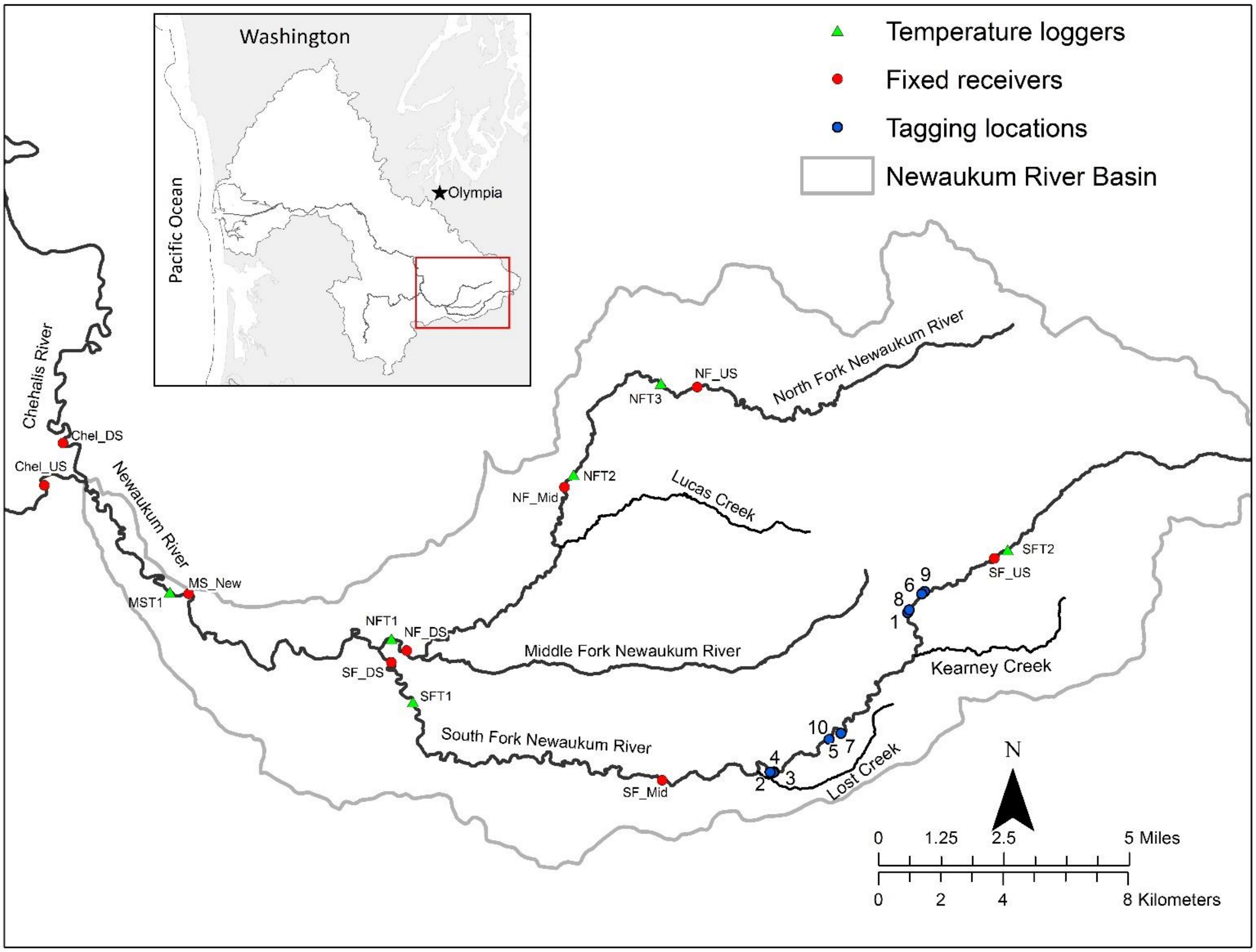
Mountain whitefish

We collected and tagged mountain whitefish in the South Fork Newaukum River from August – September 2017 using a combination of backpack electrofishing, hook and line, seining, and snorkeling. Captured fish greater than 225 g (corresponding to a tag weight < 2% of body weight) and not exhibiting distress were anesthetized using electronarcosis (EN), surgically implanted with a radio tag (Lotek, MST-930-M, 4.5 g, 9.5 x 32 mm, 245 d battery life), and injected a Floy tag (Floy Tag, T-Bar Anchor, FD-68B). Following surgery, tagged fish were monitored for 60-160 minutes in a live well prior to release.

Pacific lamprey

We constructed and deployed bicycle and tube traps in the Newaukum River to catch lamprey (Lampman 2011). As of May 5, 2018, no lamprey have been captured. Collected fish with dorsal gaps greater than 20 mm, clear eyes, firm body walls (Starcevich et al. 2014), and not exhibiting distress will be anesthetized using 40 mg/L Aqui-S 20E (INAD 11-741, 10% eugenol; AquaTactics, Kirkland, Washington) and surgically implanted with a radio tag. If the fish girth is > 10 cm, we used a Lotek tag, NTC-4-3L, 2.1 g, 8 x 18 mm, 306 d battery life or if the girth is < 10 cm, we used a Lotek tag, NTC-3-2, 1.1 g, 6 x 4 mm, 151 d battery life. Following surgery, tagged fish will be monitored for at least 60 minutes in a live well prior to release.

Figure 1: Map of Newaukum River Basin with sites of radio telemetry fixed receivers, temperature loggers, and radio tagging locations of mountain whitefish. Inset shows location of study area within the Chehalis River Basin, Washington.



Data collection

We tracked tagged mountain whitefish in the South Fork Newaukum River by foot two-three times a week during August and one-three times a week in September through May 5, 2018 using a mobile receiver (Lotek SRX 800) with a three-element yagi antenna or a truck-mounted omnidirectional antenna. We installed two fixed receivers (Lotek SRX-D2) in the Newaukum River Basin in September 2017 (MS_New and NF_DS; Figure 1) and an additional seven receivers (Chel_DS, Chel_US, NF_Mid, NF_US, SF_DS, SF_Mid, and SF_US; Figure 1) in April 2018 to add in the tracking process. After they were installed, we checked and downloaded data from each fixed receiver weekly.

We inferred fish movement based on individual tag detections over time from the mobile and fixed receivers. We also made visual observations of tagged fish, when possible, to confirm location and observe behavior. Based on fixed receiver locations, GPS-marked locations of mobile radio tracking detections, or snorkeling observations, we inferred locations of the tagged fish. In addition, implanted MST-930-M tags contain a motion-sensor that detects periods of no movement (> 12 hours), which we interpreted as a tag loss or fish mortality. In order to inform Objective C and describe the relationship between fish movements, stream temperature and streamflow, we installed temperature loggers (Onset Hobo Pendant Logger 64K UA-001-64) in six locations throughout our study area (MST1, NFT1, NFT2, NFT3, SFT1, and SFT2; Figure 1) and calculated an average daily stream temperature. We also summarized average daily flows from Aug. 1, 2017 to May 5, 2018 from a United States Geological Survey flow-monitoring gauge (USGS station 12025000) on the Newaukum River, WA.

Preliminary analyses

We calculated the range of movements and total distances traveled for each tagged fish. We calculated range by subtracting the upstream and downstream most river kilometer (RKm) visited by a fish and total distance by adding all the upstream and downstream movements traveled between individual detections. In order to inform our study objectives A and C, we considered whether tagged individuals primarily resided in the study area during the interrogation period, the degree to which individuals moved (e.g., range and total distances), and if fish moved with respect to flow and temperature. For this interim report, we have not yet quantitatively analyzed the relationship between movement, temperature, and flow.

Preliminary Results

Pacific lamprey collection efforts started in April 2018, so in this interim report we only present movements for mountain whitefish. We successfully implanted radio telemetry tags in 12 mountain whitefish ranging in length and weight from 280 mm to 360 mm and 286 g to 569 g, respectively (Table 1). However, one fish was recovered as a mortality within a week following tagging therefore was not considered representative of true fish movement. The data reported herein represent efforts up to and including May 5, 2018.

Fish movements

Our radio telemetry efforts showed several movement patterns of tagged mountain whitefish between August 2017 and May 2018 in the South Fork Newaukum River. As of May 5, 2018, the fixed receivers had not detected tagged fish, indicating that the fish resided wholly within the study area during this interrogation period (Objective A). Between August and September, we made numerous visual observations of tagged fish feeding and schooling with other mountain whitefish. In our work to describe mountain whitefish movement (i.e., total movement) and home range (i.e., the uppermost and lowermost RKm visited by any fish), although the tracking timeframe varied by fish, we discovered that the total distance traveled of tagged fish was 1.2 to 38.1 RKm and the range over which they traveled was 0.5 to 26.9 RKm (Table 1). The fish displayed several movement patterns. Five tagged individuals underwent total movements < 5 RKm over a range < 5 RKm. These fish moved a relatively short distance over a smaller range. Six tagged fish underwent total movements > 5 RKm but the range over which they moved varied. For example, two fish (28 and 51) underwent total movements and range of movement similar distances and three fish (21, 25, and 52) underwent total movements > 25 RKm over a relatively large range (> 15 RKm). However, one fish (24) underwent 17.8 RKm of total movements over a relatively small range (3.4 RKm).

When considering all fish movements together, total monthly movements were 2 to 59 RKm with the largest proportion of movement occurring in October (36%; Figure 2 panel a).

Ranges of monthly movements were 6 to 24 RKm with the largest range occurring in March (Figure 2 panel a). The proportion of upstream and downstream movements varied by month (Figure 2 panel b). In August, mountain whitefish mostly moved upstream (81%) whereas in September, November, and February, that shifted to mostly downstream (61%, 70%, 67%, respectively). In other months (October, December, January, March, and April), the proportions of upstream (50-55%) and downstream (45-50%) movements were similar (Figure 2 panel b). In addition, our tracking revealed that some tagged fish used Lost Creek and Kearney Creek, 3^{rd}- and 5^{th}-order tributaries located at approximately RKm 21 and RKm 31 of the South Fork Newaukum River, respectively. Fish moved into and out of Lost Creek (fish 21 and 52) and Kearney Creek (fish 24 and 25) in December 2017 (Table 1 and Figure 1).

Environmental conditions and fish movements

The average daily discharge for the mainstem Newaukum River (USGS gauge 12025000) from August 1, 2017 through May 5, 2018 ranged from approximately 30 to 4770 cfs (Figure 3 upper panel). Mean daily flow began to increase mid-September and remained variable throughout the fall and winter months. Mean daily stream temperature ranged from 2.5 to 22 ^{o}C between August 1, 2017 and April 25, 2018 (Figure 3 upper panel). Temperatures peaked in August 2017, decreased throughout the fall, and remained low (> 10 ^{o}C) from December through May 2018. The minimum daily temperature occurred February 23, 2018 (2.5 ^{o}C) and temperatures began to increase in March and April 2018.

The amount of total fish movements increased from August through October, with the highest total movement occurring prior to a large hydrological event in mid-October where average daily flows reached over 4400 cfs (10.1 ^{o}C; Figure 3). Additional daily movements > 4 RKm occurred in mid-December and early February when flows and temperatures were 1100 cfs at 7.0 ^{o}C and 650 cfs at 2.5 ^{o}C, respectively.

Table 1: Radio tagging and tracking information for mountain whitefish (WF) from August 7, 2017 through May 5, 2018. Tagging location number corresponds to locations on Figure 1. Boldface indicates maximum range and total distance in river kilometers (RKm). Fish use of a tributary (Trib.) is indicated with “Y” and tag fates are active (A) or motionless (M). The number of active days represents the range of days over which fish was successfully tracked.

Tag No.	Tagging date	Tagging location No.	Sp.	Length (mm)	Weight (g)	Total Distance (RKm)	Range (RKm)	Trib. use	Active days	Fate 5/3/18
21	8/7/17	1	WF	280	286	**38.1**	16.9	Y	269	A
24	8/7/17	1	WF	360	569	17.8	3.4	Y	269	A
26	8/15/17	3	WF	355	503	1.2	0.5		38	A
23	8/16/17	4	WF	360	474	3.0	4.4		51	M
22	8/17/17	5	WF	310	382	4.3	2.5		174	A
25	8/22/17	6	WF	298	321	36.0	**26.9**	Y	195	M
~~29~~	~~8/22/17~~	~~6~~	~~WF~~	~~335~~	~~407~~	~~0.2~~	~~0.2~~		~~6~~	~~M~~
27	8/23/17	7	WF	325	396	1.7	1.7		50	M
53	8/24/17	8	WF	345	479	3.0	0.5		137	A
51	9/13/17	9	WF	310	369	14.6	14.6		48	M
52	9/13/17	9	WF	308	397	25.3	16.7	Y	140	A
28	9/25/17	10	WF	325	373	6.3	6.3		23	M

Figure 2: Preliminary mountain whitefish movement results for the monthly proportion of total movements (hatched white bars in panel a) and monthly range of movements (i.e., the uppermost and lowermost RKm from which a fish was recorded; wide, grey bars in panel a); and the proportion of monthly total movements comprised of upstream (US, black bars) and downstream (DS, dark grey bar) movements (panel b) from Aug. 7, 2017 through May 5, 2018.

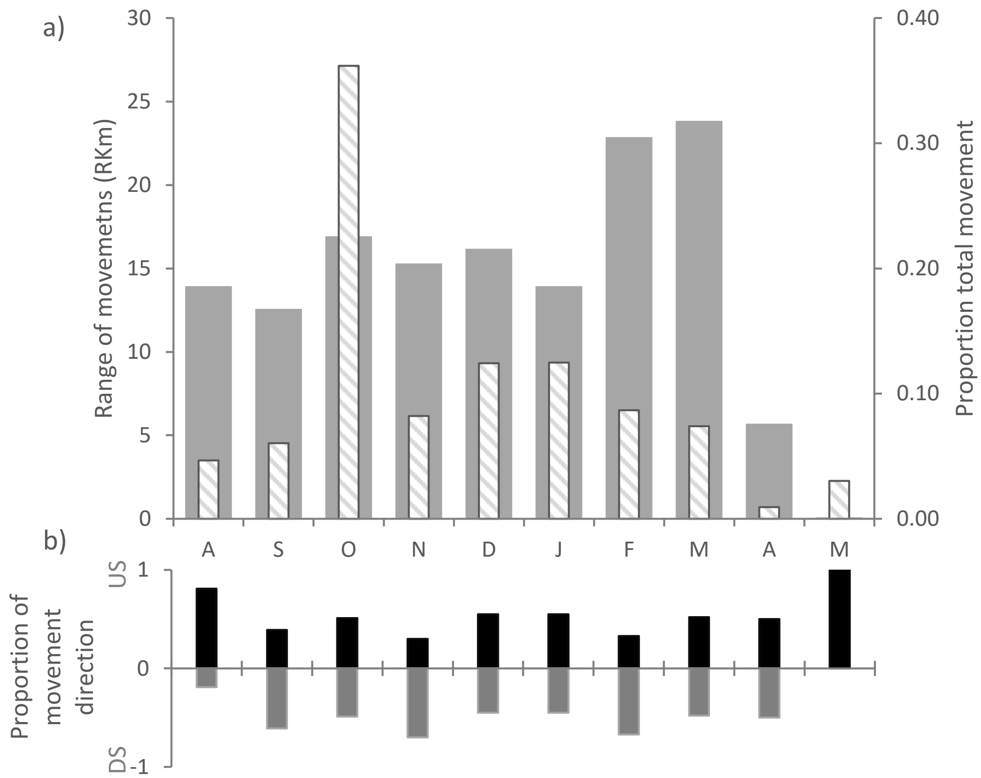
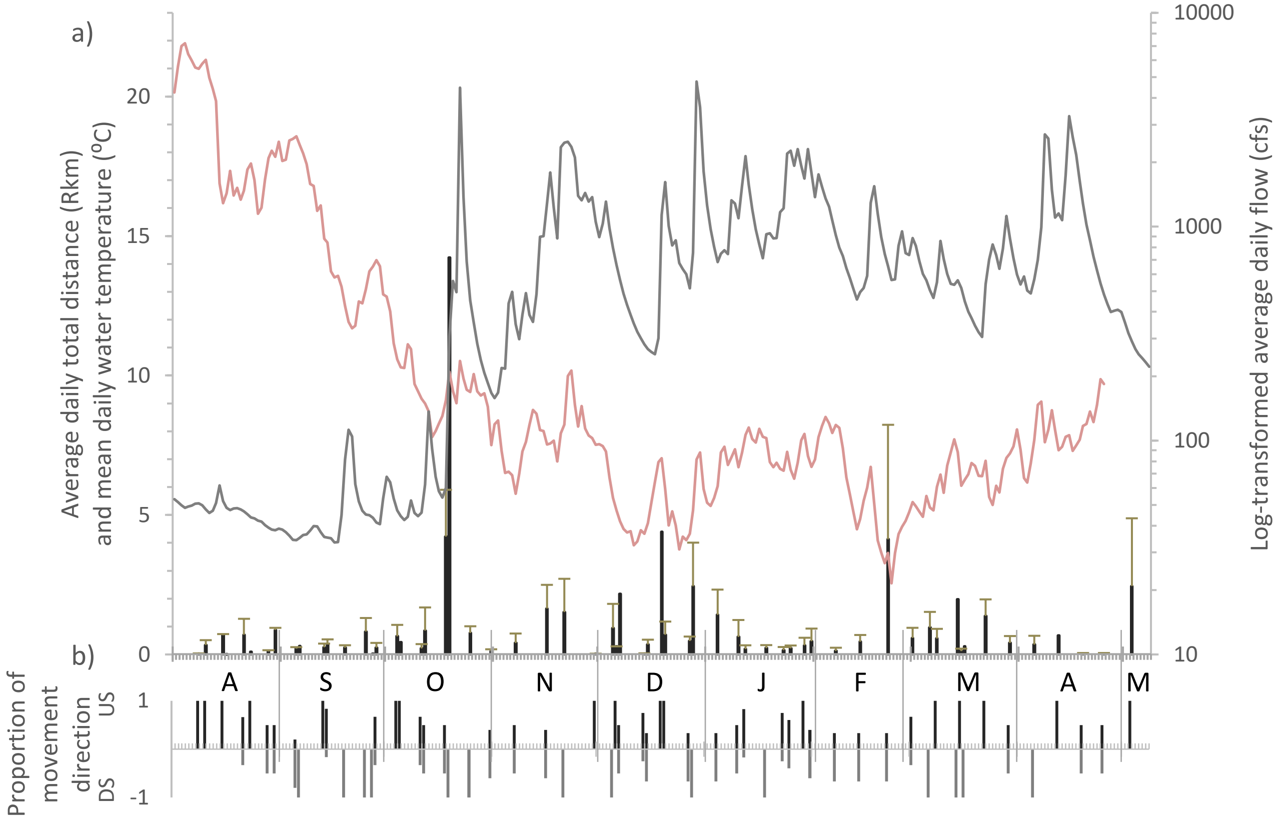


Figure 3: Preliminary results of daily mean total distance (RKm, black bars in panel a) and their standard error observed in relation to average daily temperature (⁰C, pink line in panel a) and log-scaled average daily discharge (cfs, grey line in panel a) from USGS gauge 12025000 on the Newaukum River, WA from Aug. 1, 2017 through May 5, 2018; as well as the proportion of total daily movements that were upstream (US, black bars in panel b) and downstream (DS, grey bars in panel b).



Discussion

Although mountain whitefish are one of Washington's native freshwater salmonids and have been shown to undergo complex seasonal migrations (Davies and Thompson 1976, Baxter 2002, Boyer et al. 2017), very little information is known about these fishes in the Chehalis River Basin. Preliminary findings of our study showed several movement patterns by tagged mountain whitefish from August 7, 2017 through May 5, 2018 in the South Fork of the Newaukum River, a significant tributary to the Chehalis River. Movements of tagged fish showed that ranges over which they migrate varied greatly and while most exhibited a range < 15 RKm, several made use of > 15 RKm, up to 26 RKm. Baxter (2002) found that the majority of tagged mountain whitefish maintained an annual range of < 30 RKm, similar to our findings, though he also found some fish had a range of > 180 RKm.

Mountain whitefish spawn in September through December (Wydoski and Whitney 2003) so fish movements we detected during that timeframe are likely associated with pre- and post-spawning migrations. Additional movements may align with overwintering, over-summering, and feeding migrations. In the Wenaha River of Oregon and Washington, Baxter (2002) found the majority of mountain whitefish tagged underwent downstream movements to overwintering areas in October and November, which aligns in timing with some movements we observed; however, we saw additional upstream and downstream movements throughout the winter months.

Our preliminary findings also confirmed that tagged fish make use of tributaries of the South Fork Newaukum River. While Kearney Creek is a 5^{th}-order stream, Lost Creek is a 3^{rd}-order stream that is considered to be used less often by mountain whitefish (Baxter 2002, Boyer 2016). These findings, therefore, expand the areas that mountain whitefish may seasonally occupy as well as their preferred habitats. Furthermore, our findings highlight the complexity of mountain whitefish movement patterns and migration requirements. Barriers to these mountain whitefish movements and migrations may negatively affect the perpetuation of their life history.

Preliminary movements appear to be associated with changes in streamflow, with the largest movement observed corresponding to a large flood in October 2017. However, statistical analyses relating streamflow and temperature to fish movements will occur following all tagging and tracking efforts and be included in our final report. In addition, tagging efforts of Pacific lamprey in the mainstem Newaukum River will provide information about pre-spawning movements and holding areas of these fish. With the addition of fixed radio tracking receivers to our mobile tracking efforts as well as temperature and streamflow data throughout our study area, we can now continuously monitor large-scale fish movements with respect to streamflow and temperature. This information will be used in the EIS and help us understand the flows and temperature at which mountain whitefish and Pacific lamprey undergo movements and will need to be considered for upstream or downstream passage at the proposed dam. Furthermore, this understanding will help inform the ASRP and answer the question, "How will restoration actions (i.e., barrier removal and culvert replacement, placement of LWD, and riparian planting) that target salmon and steelhead influence other native fish species in the Chehalis River?" As a first step, we must understand the distribution and timing of these fishes' movements to know when they make use of proposed restoration areas. Then, to understand how they may be affected by restoration actions, our results will show how access to new habitat (i.e., barrier removal) or changes in flow and temperature (i.e., from placement of LWD and riparian planting) may affect movements of these fishes.

References

Albanese, B., P. L. Angermeier, and S. Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia streams. Canadian Journal of Fisheries and Aquatic Sciences **61**:857-869.

Aquatic Species Enhancement Plan Technical Committee. 2014. Aquatic Species Enhancement Plan Data Gaps Report.

Armstrong, J. B., and D. E. Schindler. 2013. Going with the flow: spatial distributions of juvenile coho salmon track an annually shifting mosaic of water temperature. Ecosystems **16**:1429-1441.

Baxter, C. V. 2002. Fish movement and assemblage dynamics in a Pacific Northwest riverscape. Dissertation. Oregon State University.

Bjornn, T. C. 1971. Trout and Salmon Movements in Two Idaho Streams as Related to Temperature, Food, Stream Flow, Cover, and Population Density. Transactions of the American Fisheries Society **100**:423-438.

Boyer, J. k. 2016. Spawning and Early Life History of Mountain Whitefish in the Madison River, Montana. Montana State University, Bozeman, Montana.

Boyer, J. K., C. S. Guy, M. A. H. Webb, T. B. Horton, and T. E. McMahon. 2017. Reproductive Ecology, Spawning Behavior, and Juvenile Distribution of Mountain Whitefish in the Madison River, Montana. Transactions of the American Fisheries Society **146**:939-954.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental management **30**:492-507.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Board of Canada **32**:667-680.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific lamprey. Fisheries **27**:19-25.

Davies, R. W., and G. W. Thompson. 1976. Movements of mountain whitefish (Prosopium williamsoni) in the Sheep River watershed, Alberta. Journal of the Fisheries Board of Canada **33**:2395-2401.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes. BioScience **52**:483-498.

Gowan, C., and K. D. Fausch. 2002. Why do Foraging Stream Salmonids Move During Summer? Environmental Biology of Fishes **64**:139-153.

Kahler, T. H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences **58**:1947-1956.

Lampman, R. T. 2011. Passage, migration behavior, and autoecology of adult Pacific Lamprey at Winchester Dam and within the North Umpqua River basin, Oregon, USA.

Larinier, M. 2001. Environmental Issues, Dams and Fish Migration. Page 116 *in* G. Marmulla, editor. Dams, fish and fisheries: Opportunities, challenges and conflict resolution. FAO Fisheries and Technical Paper No. 419, Rome.

McPhail, J., and C. Lindsey, editors. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia system and rivers north to the Stikine). John Wiley & Sons.

Northcote, T., and G. Ennis. 1994. Mountain whitefish biology and habitat use in relation to compensation and improvement possibilities. Reviews in Fisheries Science **2**:347-371.

Paragamian, V. L. 2002. Changes in the species composition of the fish community in a reach of the Kootenai River, Idaho, after construction of Libby Dam. Journal of Freshwater Ecology **17**:375-383.

Phinney, L., and P. Bucknell. 1975. A Catalog of Washington Streams and Salmon Utilization. Volume 2 Coastal Region. Washington Department of Fisheries, Olympia, Washington.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The Natural Flow Regime. BioScience **47**:769-784.
Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. University of Washington Press, Seattle.
Radinger, J., and C. Wolter. 2014. Patterns and predictors of fish dispersal in rivers. Fish and Fisheries **15**:456-473.
Starcevich, S. J., S. L. Gunckel, and S. E. Jacobs. 2014. Movements, habitat use, and population characteristics of adult Pacific lamprey in a coastal river. Environmental Biology of Fishes **97**:939-953.
Welch, D. W., S. Turo, and S. D. Batten. 2006. Large-Scale Marine and Freshwater Movements of White Sturgeon. Transactions of the American Fisheries Society **135**:386-389.
Winkowski, J., E. Walther, and M. Zimmerman. 2017. Summer riverscape patterns of fish, habitat, and temperature in sub basins of the Chehalis River, 2013-2016. Washingtin Department of Fish and Wildlife, Olympia, WA.
Wydoski, R., and R. Whitney. 2003. Inland fishes of Washington. revised and expanded. Second edition. University of Washington Press, Seattle.