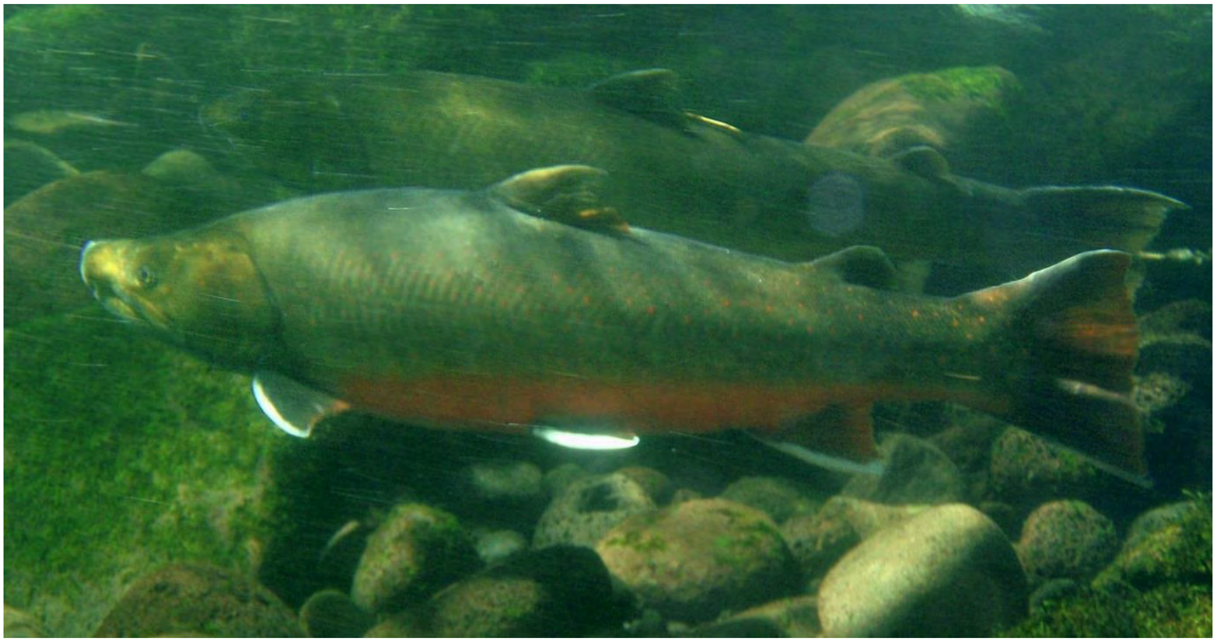
Lewis River Bull Trout: A Synthesis of Known Information



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I. Introduction

Bull trout (*Salvelinus confluentus*) were listed range-wide (coterminously) as a threatened species on November 1, 1999 (64 FR 58910). Previously, the Columbia River distinct population segment (DPS) of bull trout had been listed as threatened since June 10, 1998 (63 FR 31647). Factors contributing to the listing of bull trout include range-wide declines in distribution, abundance and habitat quality. Land and water uses that alter or disrupt habitat requirements of bull trout can threaten the persistence of the species. Examples of such activities include: water diversions, dams, timber extraction, mining, grazing, agriculture, nonnative fish competition and/or hybridization, poaching, past fish eradication projects, and channelization of streams. These threats are prevalent throughout the Columbia River subbasin (USFWS 2015a, 2015b). The bull trout Coastal Recovery Unit (CRU) has numerous core areas throughout the Olympic Peninsula, Puget Sound and lower Columbia River subbasins. The Lewis River core area consists of at least three putative local bull trout populations (USFWS 2002, 2015b).

The Lewis River Bull Trout Recovery Team (LRBTRT), a subgroup of the Lewis River Aquatics Coordination Committee (http://www.pacificorp.com/es/hydro/hl/lr.html#), is a partnership among U.S. Fish and Wildlife Service (USFWS), Washington Department of Fish and Wildlife (WDFW), PacifiCorp, U.S. Forest Service (USFS), U.S. Geological Survey (USGS), the Lower Columbia Fish Recovery Board (LCFRB), and other groups. The LRBTRT has regularly met for several years to identify and implement needed research, monitoring and recovery actions to benefit bull trout in the Lewis River subbasin. The LRBTRT was instrumental in developing information for the Lewis River core area that was incorporated into the final Recovery Unit Implementation Plan (RUIP) for the CRU. Following completion of the recovery plan and the RUIP, the LRBTRT began work to develop a management plan for bull trout in the Lewis River that supported the recovery plan. To fully develop this management plan, the need was identified to synthesize known information for bull trout in the subbasin.

This document comprises a synthesis of bull trout information collected in the Lewis River for over two decades, and is the first such compilation of information in the subbasin since Graves (1982). We have summarized the information on demographic characteristics, vital rates, spatial distribution, movement patterns and genetic diversity in an effort to identify data gaps and research and monitoring needs for the future. This information will initially inform the development of a bull trout management plan for the Lewis River core area and will be a living document to capture additional information as it becomes available.

II. Study Area

a. Subbasin Description

The Lewis River subbasin is located on the western flanks of the Cascade Mountains in southwest Washington State. The subbasin comprises the Lewis River Core Area for bull trout (USFWS 2015b), which includes the mainstem Lewis River and tributaries downstream to the confluence with the Columbia River, with the exclusion of the East Fork of the Lewis River (Figure 1). In addition to bull trout, Chinook salmon, coho salmon, chum salmon and steelhead trout are listed as threatened under the Endangered Species Act (ESA) and occur in the subbasin (LCFRB 2010). The northern and southern boundaries are defined by the crests of the drainage basin. Three hydro-electric projects owned and operated by PacifiCorp and Cowlitz County PUD form Merwin Lake, Yale Lake, and Swift Reservoir, each successively upstream. To date, upstream fish passage exists and is in operation at Merwin Dam, and downstream fish passage facilities exist and are in operation at Swift No. 1 Dam. No upstream fish passage is currently in operation at Yale and Swift dams and no downstream fish passage is in operation at Yale and Merwin dams. Approximately 16 river kilometers above Swift Reservoir, Lower Falls, the lowermost of a series of three natural barrier falls on the Lewis River, prevents upstream fish movement.

The region surrounding the Lewis River subbasin has a complex geologic history, having undergone volcanic activity, several glaciations, and glacial erosion and deposition. The river drains a 2,719 square kilometer area, flowing 150 kilometers southwestwardly before it joins with the Columbia River (PacifiCorp 2000, WSCC 2000). The major climatic influences are the proximity of the Pacific Ocean, terrain features, and alternating high and low pressure regions over the ocean. Average annual precipitation varies from 115 cm near Woodland to over 359 cm on nearby Mt. Adams (PacifiCorp 2000).

The eruption of Mt. St. Helens in 1980 affected water quality in the Muddy River and Pine Creek. Riparian vegetation was destroyed and mud flows and ash deposits have contributed high levels of fine sediments to Pine Creek, Muddy River, and the Lewis River above Swift Reservoir (PacifiCorp 2000). Evidence of the eruption still persists over 30 years after the eruption in the form of habitat degradation. However, the bull trout population in Pine Creek and bull trout use of the Muddy River watershed are, to some degree, indicators of habitat recovery on the south slope of Mt. St. Helens.

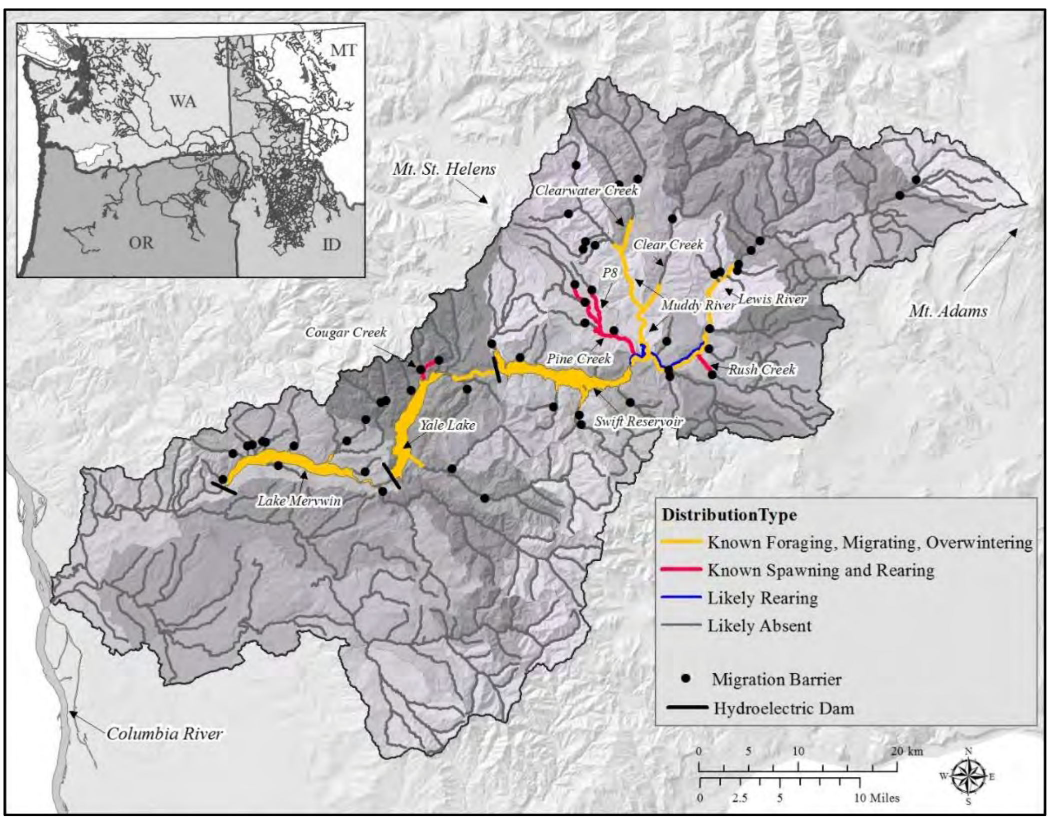

Figure 1. Spatial distribution of adfluvial bull trout, the only life history that has been documented in the Lewis River subbasin based on field sampling over the past four decades (1979 – 2016). Map inset shows

the Lewis River subbasin (white polygon in southwest WA) in relation to the distribution of bull trout (dark stream lines) in the coterminous United States.

b. Bull trout populations and life-history types present in the Lewis River subbasin

Currently, populations of bull trout within the Lewis River core area are found in tributaries associated with Yale and Swift reservoirs. Spawning and juvenile rearing occur in Cougar Creek (Yale population), and in Rush and Pine creeks (Swift population). Bull trout in the Lewis River are considered to be predominantly adfluvial, migrating from tributary spawning and rearing areas to reservoirs to forage and rear. There has been no confirmation of any resident (i.e., non-migratory) populations to date. Historically, bull trout were known to occur in the Muddy River (WDG 1957), but it was uncertain if they used that system for spawning and rearing. Bull trout currently use the Muddy River, but it is still unknown if there is spawning and/or rearing occurring there.

c. Habitat

i. Stream Temperature

Stream temperature data have been collected annually in the upper Lewis River subbasin by USFS since the mid-1970s to monitor water quality standards (e.g., GPNF 1996). Data collected after 1995 are available and stored in a USFS temperature database. The USFS-AREMP (Aquatic and Riparian Effectiveness Monitoring Program) have also collected stream temperature data in the subbasin. Additional temperature data have been collected specifically for bull trout-related studies (e.g., Clearwater BioStudies 2002, Lamperth et al. 2017, Pratt 2003) (Figure 2). In general, data were collected at 30 min or 60 min intervals with in-stream temperature sensors during the summer and early fall. In aggregate, these data suggest that known bull trout spawning and early rearing occur in the coldest stream reaches in the subbasin that are accessible to migratory bull trout (i.e., below migratory passage barriers). This suggests stream temperature is limiting the distribution of spawning and early rearing in the subbasin. Comprehensive time-series analyses (e.g., climate change analyses) or analyses linking temperature to bull trout behavior, biology and ecology (other than spawning and rearing) have not been performed with these data to date.

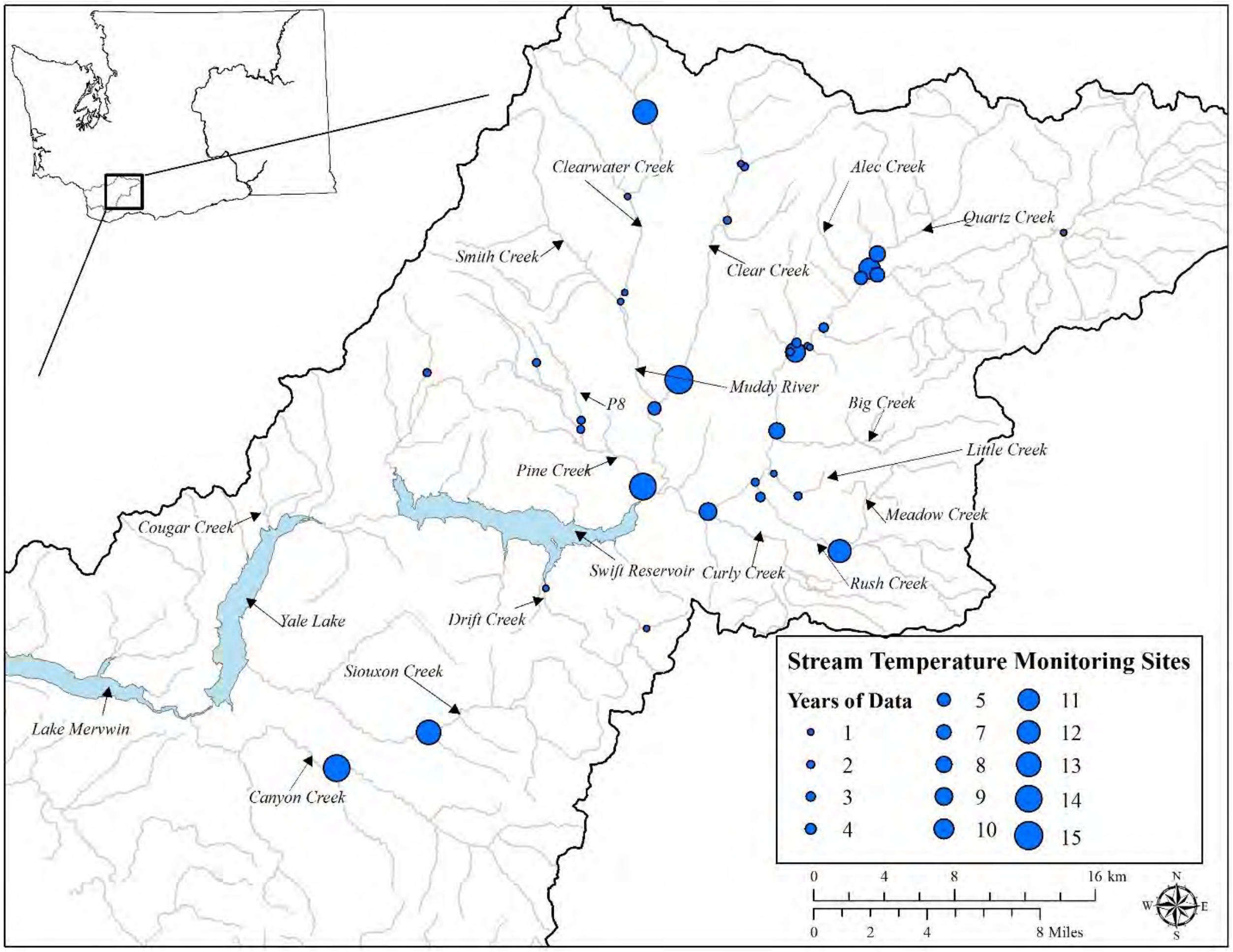

Figure 2. Location and number of years of available stream temperature data in the upper Lewis River subbasin. The locations include data collected as part of the USFS Mt. St. Helens Water Quality Monitoring Program, the USFS Aquatic and Riparian Effectiveness Monitoring Program, and an ACC Bull Trout Habitat Study (Lamperth et al. 2017).

ii. In-stream Habitat

Since the late-1980s, the USFS has conducted stream habitat inventory surveys in the upper Lewis River subbasin (Figure 3). During this time, approximately 55 named streams were surveyed, of which, over half were surveyed prior to 1996 when the current survey protocols were instated. Only about 10% of the streams have been surveyed more than once since 1996. The current protocol was designed to identify and inventory existing stream channel, riparian, and aquatic ecosystem conditions on a watershed scale (USFS 2012). As inventories are completed and repeated over time, they can be used to measure changes in habitat and can be applied as a basic monitoring tool. The data from these surveys is stored in the USDA-Forest Service NRM Aquatic Surveys Database (https://www.fs.fed.us/nrm/index.shtml). To date, no analyses have been performed with these data to assess bull trout-habitat relationships in the subbasin.

Additional in-stream habitat data have been collected to assess the quantity of potential anadromous fish habitat (PacifiCorp/Cowlitz PUD 2004; Al-Chokhachy et al. 2015*b*) and to model bull trout spawning and rearing occupancy (Lamperth et al. 2017).

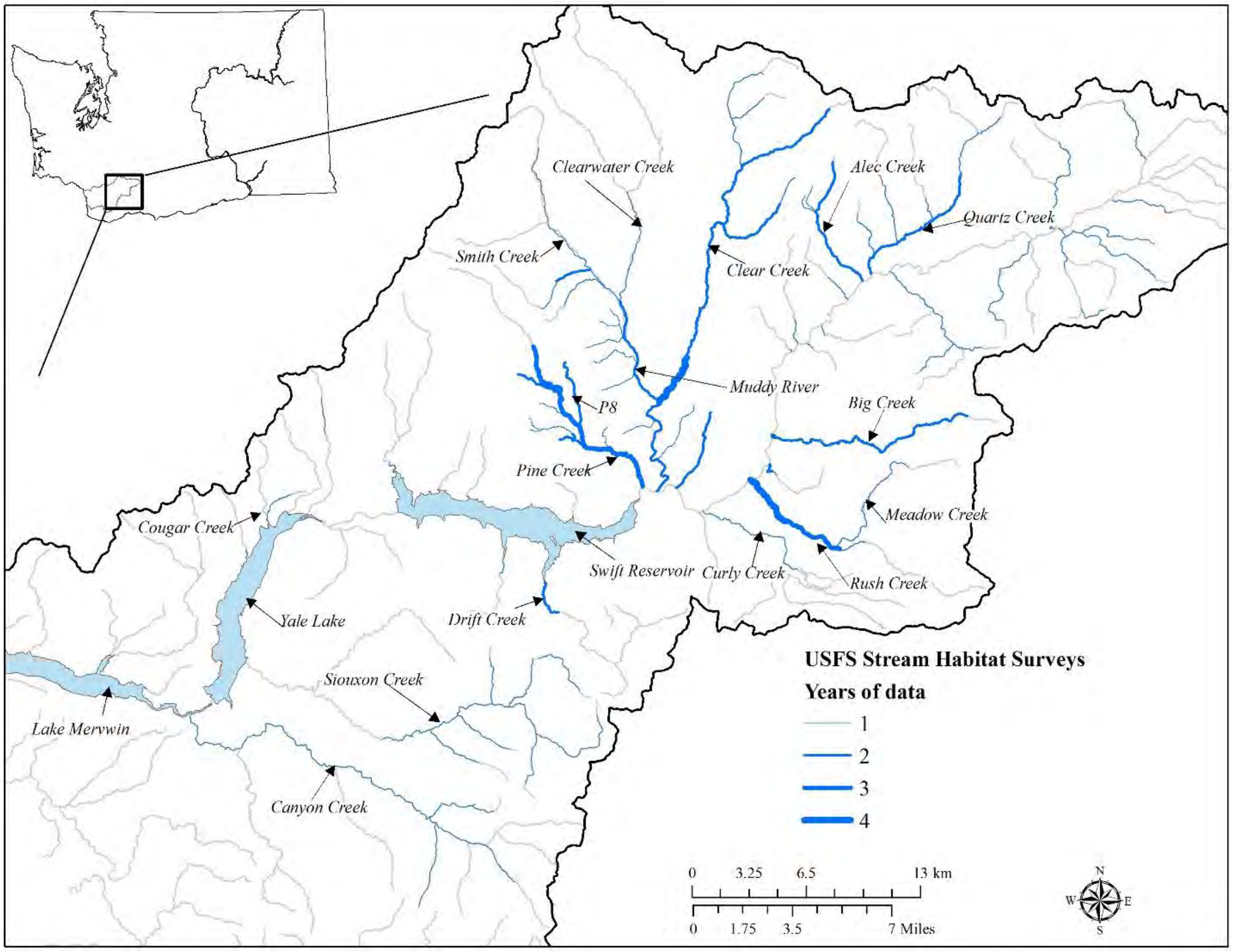

Figure 3. Location and number of years of data available from USDA-Forest Service stream inventory surveys.

d. Fishery management

Recreational fisheries in the Lewis River subbasin are managed by WDFW. Historically, bull trout in the Lewis subbasin could legally be harvested by anglers. Since 1992, with recognition of the declining population size and subsequent listing in 1998, retention or targeting of bull trout has been illegal for anglers in the Lewis River subbasin (i.e., the Lewis River and associated reservoirs and tributaries). Harvest and catch-and-release fisheries in the subbasin have continued to legally target other species, including: anadromous salmon, kokanee, steelhead, resident trout, and tiger muskies. Bull trout are incidentally encountered in some of these fisheries, primarily in Yale and Swift Reservoirs, the Lewis River above Swift Reservoir, and tributaries to these areas. Since 2018, the Lewis River from markers below Eagle Cliff Bridge (upper portion of Swift Reservoir) to the Muddy River (including Pine Creek) closes each year to all fishing from July 15 to the Saturday before Memorial Day to reduce incidental handling of bull trout during the main spawning migration period. This area had previously been open for trout harvest through November below Eagle Cliff Bridge and for catch-and-release through October above Eagle Cliff Bridge. The Lewis River above Muddy River will continue to be open for catch-and-release fisheries through October each year. As of 2018, WDFW enforcement officers were still encountering and citing anglers targeting bull trout in the upper Lewis River despite the long-standing regulations and signage in the area.

III. Demographic characteristics

a. Abundance

i. Estimates of abundance from mark/resight in Swift reservoir

Radio tracking studies in 1990, 1991 and 1994 revealed a pre-migrant congregation of adult bull trout at the Swift reservoir headwaters (Eagle Cliff; Faler and Bair 1992). The studies further indicated that most tagged bull trout migrated into either Rush or Pine creeks (tributaries to the Lewis River mainstem), with Rush Creek being preferred. These behavioral patterns have allowed the use of a mark-resight (snorkel) approach to estimate the number of bull trout staging in the Eagle Cliff area (Lewis River near the head of Swift Reservoir). The program NOREMARK® developed by Gary White of Colorado State University (White 1996) was used to generate these abundance estimates. NOREMARK® computed estimates of population size for a closed population with a known number of marked animals and one or more re-sighting surveys.

To fulfill the marking aspect of the estimator, pre-migrant bull trout were captured and tagged in May, June, and July (1996-2016) using tangle nets. Nets consisted of dyed green 6# monofilament, with depths of approximately 2 meters (m), lengths of 25 – 40 m, and mesh sizes of 2.5 – 7.5 centimeter (cm) stretched mesh. With the use of boats, nets were either drifted along the bottom in the Eagle Cliff area (where the North Fork Lewis River flows into Swift Reservoir) or set and allowed to passively trap fish unattended for up to 10 minutes. Angling, when appropriate, was also employed to capture staging bull trout. Once entangled or caught, bull trout were marked with uniquely colored anchor tags (Floy Tag & Mfg. Inc., Seattle, WA) between the last two rays in the posterior portion of the dorsal fin.

The resight portion of the estimate from 1996-2012 consisted of weekly snorkel surveys conducted eight times from August through September of index sites within Rush and Pine creeks and the Rush Creek confluence. Beginning in 2013, the resight locations changed from the confines of Rush and Pine to encompass only the confluences of Rush Creek, Muddy River, and Pine Creek within the North Fork Lewis River. This change was made to increase the opportunity for resight observations. There remains some uncertainty as to how comparable estimates from the two approaches are. During each snorkel count, biologists were equally spaced apart along a lateral line to alleviate double-counting fish. All marked and unmarked bull trout were enumerated. To estimate migration escapement to the re-sight areas, individual survey results were combined and then averaged. A 10 percent in-season tag loss was assumed in the estimate.

From 1996-2016, 2,130 bull trout were captured during Eagle Cliff marking activities. Estimates of migration abundance have been generated annually since 1994 (Figure 4, Table 1; Doyle 2016).

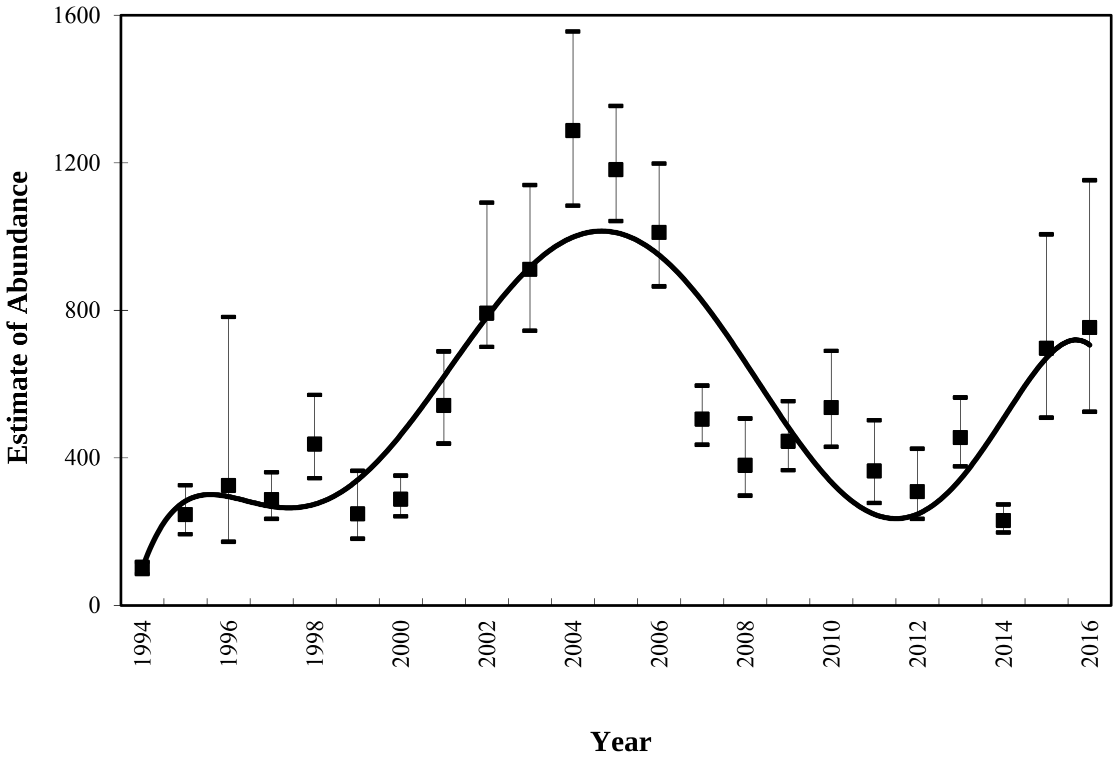

Figure 4. Annual estimates of bull trout (>360 mm) staging at the head of Swift reservoir in the upper Lewis River (bars represent the 95% confidence intervals).

Table 1. Estimates of annual bull trout (>360 mm FL) staging at the head of Swift reservoir in the upper Lewis River. Upper and lower bounds encapsulate the 95% confidence limits.

Year	Lower bound	Upper bound	Estimate
1994	85	118	101
1995	193	326	246
1996	173	782	325
1997	235	361	287
1998	345	571	437
1999	181	365	248
2000	242	352	288
2001	439	689	542
2002	701	1092	792
2003	745	1140	911
2004	1084	1556	1287
2005	1042	1354	1181
2006	865	1198	1011
2007	436	596	505
2008	298	507	380
2009	367	554	445
2010	430	690	536
2011	278	502	364
2012	235	425	308
2013	377	564	455
2014	198	274	230
2015	509	1006	697
2016	525	1153	753

ii. Estimates of abundance from redd counts in Cougar Creek and P8

Redd count methodology within Cougar Creek differs from most large-scale redd surveys. The stream is small enough to feasibly cover the entire length during each survey, and currently is the only known bull trout spawning stream in Yale Reservoir. Cougar Creek also lends itself nicely to these types of surveys because the water is extremely clear and has stable flow for most of the survey period. Also, redd life, the amount of time a redd remains visible, has an exceptionally long duration. Most, if not all, observed redds remain visible during the entire time-frame of the surveys.

P8 redd surveys differ from Cougar Creek in that only a mile long index reach is surveyed, rather than the entire available habitat. This index reach extends from the confluence of Pine Creek upstream for approximately one mile.

During each redd survey within Cougar Creek and P8, new redds were flagged and identified by Global Positioning Satellite (GPS) coordinates. The date, location of redd in relation to the flag, and GPS coordinates were all documented and written on the flagging. Subsequent surveys inspected each redd to see if they were still visible. If a redd was still visible, this was documented and written on the flagging with the date. When the redd was no longer visible, this was documented and noted on the flagging. Biologists also counted any bull trout observed within the vicinity of each redd.

Cougar Creek bull trout redd surveys have occurred annually since 2007. Since that time annual cumulative redd counts have ranged from 12 to 29 redds (Figure 5) (Doyle 2017). Bull trout redd surveys have occurred annually in P8 since 2008. Since that time cumulative redd counts have ranged from 13 to 48 redds (Figure 6) (Doyle 2017).

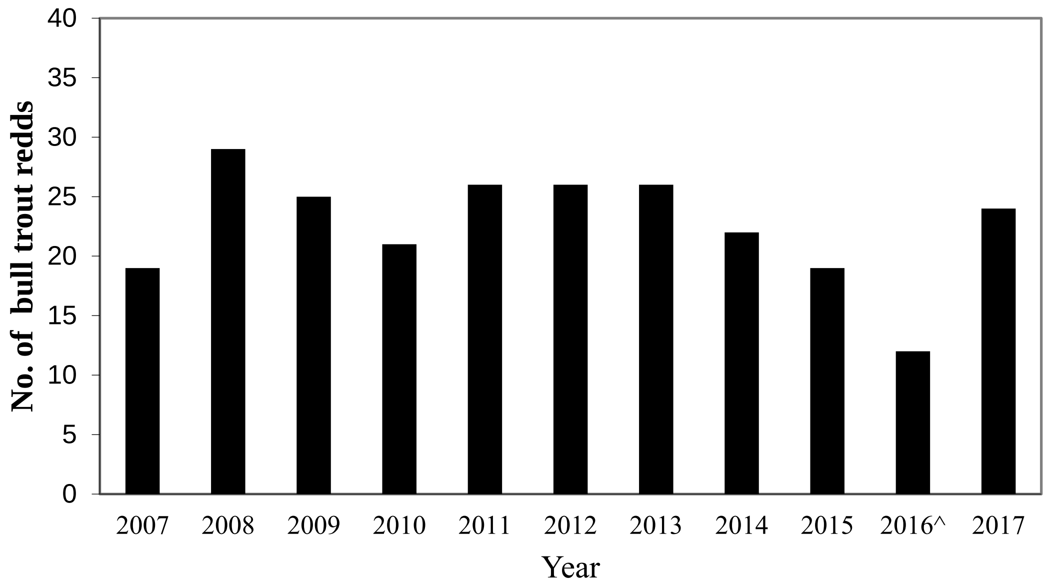

Figure 5. Annual cumulative bull trout redd counts from Cougar Creek. ^shortened survey season due to high flow event.

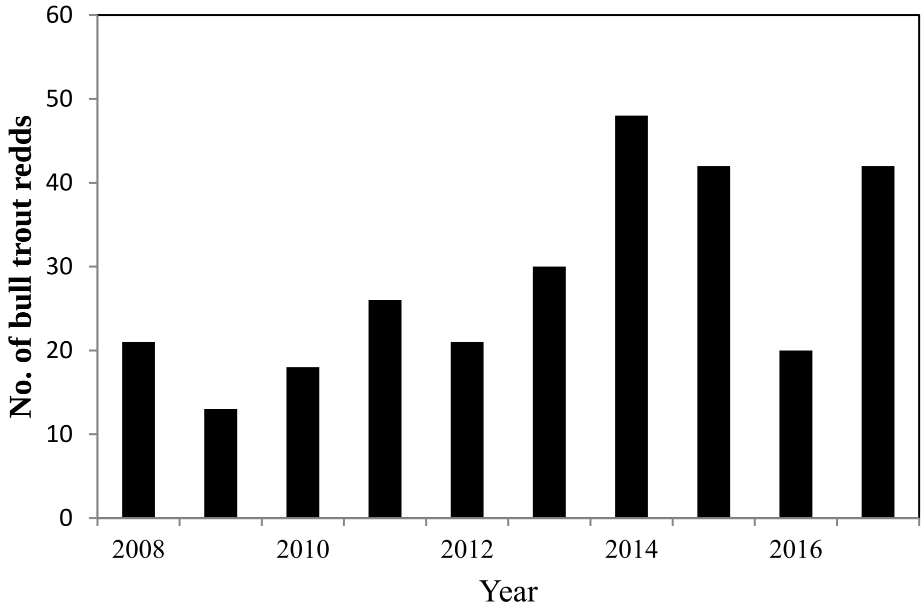

Figure 6. Annual cumulative bull trout redd counts from Pine Creek tributary P8. 2016 survey year truncated due to high flow event.

b. Effective population size

i. Estimates of effective number of breeders (Nb)

Estimation of effective population size (N_e) can provide information on the level of genetic variation within a population and how fast genetic variation may be lost through genetic drift (Luikart et al. 2010). The effective population size represents the size of an ideal population that would have the same rate of loss of genetic variation as the observed population (Wright 1931). Although general guidelines for minimum effective population sizes have been suggested (e.g., the 50/500 rule; Franklin 1980), evaluating temporal trends in estimates of N_e are often more useful than determining whether a population meets some minimum threshold. For example, a population that shows a large decrease in N_e over the course of one or two generations could be experiencing a genetic bottleneck or decline in abundance. Alternatively, an increase in effective size following implementation of new management actions could be one indication that the population is responding positively (Pers. Comm. Pat DeHaan, USFWS).

To evaluate $N_{e,}$ multiple years of genetic estimation of number of breeders (N_b) must first be attained. To estimate N_b on the Lewis River, genetic tissue from juvenile bull trout from the same cohort (presumably age 0) was attained from utilized spawning tributaries (Rush, Pine, and Cougar creeks) and assessed for genetic relatedness. To get maximum genetic representation, fish captures were spatially balanced as much as practical along the length of usable habitat within each stream. Surveys were timed such to ensure capture of prior year's brood fish, with less than 70 mm fork length (FL) the cut-off used to determine age-0 bull trout (Fraley and Shepard 1989). Individuals captured from large family groups were pared down to not skew available genetic representation (Adams and Doyle 2016). Genetic lab methods and materials used to assess N_b of collected juvenile tissue samples can be found in the annual Lewis River Genetics Report (Adams 2016).

To date, N_b has been evaluated from 2014 - 2017 in Pine and Rush creeks and 2015 - 2017 in Cougar Creek (Table 2, Table 3). Evaluations within Rush and Pine creeks in 2016 were further complicated from a hydraulic scouring event on December 15, 2015 which led to low redd survival and subsequent low juvenile capture during 2016 sampling (Doyle 2017).

Table 2. Number of age-0 bull trout collected by spawn year and spawning tributary to estimate effective number of breeders (Nb).

	Spawn Year			
Tributary	**2013**	**2014**	**2015**	**2016**
Pine Creek Mainstem	38	34	5	48
Rush Creek	54	53	17	36
P8	42	63	52	62
Cougar Creek	n/a	77	57	68

Table 3. Estimates of the effective number of breeders (N_b) with 95% confidence intervals (in parentheses) from bull trout spawning tributaries on the Lewis River in southwest WA.

	Spawn Year			
Tributary	**2013**	**2014**	**2015**	**2016**
Pine Creek	21.7 (16.4-29.2)	19.5 (15.2-25.1)	16.8 (13.2-21.6)	15.5 (12.7-18.8)
Rush Creek	18.4 (12.9-27.8)	23.0 (18-29.8)	7.4 (3.9-12.4)	12.8 (9.3-18.0)
Cougar Creek	na	18.7 (15.2-23.2)	18.2 (6.8-∞)	18.2 (14.0-23.7)

c. Sex ratio

There is no known information on sex ratio of bull trout in the Lewis River subbasin.

d. Age structure

Understanding age structure provides important information of the life history expressions of fishes, growth trajectories, and is a key aspect of age or size-structured population models (Al-Chokhachy et al. 2015a; McCubbins et al. 2016). Ages of bull trout in the Lewis River were evaluated using non-lethal samples from individuals captured in 2016 during field sampling at the head of Swift Reservoir and in Yale Reservoir. Once captured, individuals were sedated and, similar to Zymonas and McMahon (2009), the leading fin ray was excised from a pelvic fin and placed in an envelope to dry.

Fin rays were trimmed and set in small plastic tubes filled with Polytranspar Artificial Water mixed with Catalyst (Wasco), an epoxy like substance similar to Koch and Quist (2007). The fin rays were then sectioned using a Buehler isomet sectioning saw and diamond blade to thicknesses less than 1 mm. Fin rays were sectioned proximate to the base of the ray. However, in some instances multiple sections were needed to identify annuli across all ages (Zymonas 2006). After sectioning, fin rays were polished using fine grit sand paper and aged using a microscope. Fin rays were aged blindly (i.e., without prior knowledge of size) multiple times by the same reader (Al-Chokhachy), and individuals where annuli were not conclusive were not included in the analyses. The length and age data were used to model growth using the Von Bertalanffy growth function (VBGF) in Program R.

The average size of fish included in the growth analysis was 528 mm (range = 99 – 810 mm). Based on the VBGF the asymptotic length (L_∞) was estimated as 907 mm (95% CI = 829 – 1,027), the instantaneous rate which length approaches L_∞ (K) was 0.158 (95% CI = 0.12 – 0.20), and the age at length of 0 (t_0) was 0.259 (95% CI = -0.21 – 0.61; Figure 7a). According to this model, an 8-year old bull trout would be approximately 641 mm.

e. Age at maturity

Active (fish marking) and passive (antenna data) data were integrated to quantify patterns of movement and estimate size at migration as an indicator of sexual maturity for fish marked from 2011 through 2017. Antenna data were available from 2011 – 2017 in Pine Creek and 2012 – 2017 in P8. Only those individuals with clear migration patterns (i.e., detected at multiple antennas) and timing of migrations were considered for analysis of age at maturity. With these data, we visually displayed the proportion of marked fish by size class (50 mm increments) that demonstrated spawning migrations within a given year. Next, we used logistic regression to estimate the probability of undergoing the spawning migration as a function of the size at marking (GLM; MASS package, Venables and Ripley 2002; Program R). Given that the migration dataset was unbalanced with a greater number of fish that did not make spawning migrations during year of tagging (n = 112) than those that did migrate (n = 59), we adjusted our cutoff value to avoid the disproportionate influence of non-migrants and maximize both the sensitivity (correctly predict true migrations) and specificity (correctly predict absence of migrations) of the modeling results.

We found considerable variability in the age of sexual maturity and spawning behavior. The smallest fish making a spawning migration in the North Fork Lewis was 360 mm FL (3-4 years old). However, only 5% of the bull trout <450 mm FL were recaptured at the antennas during migrations within the same year as marking, implying fish within this size class are typically subadults and not sexually mature. We observed an increasing trend in the proportion of fish demonstrating spawning migrations with increasing body size of bull trout (Figure 7a). The lengths of all (i.e., proportion = 1) of the marked fish that demonstrated spawning migrations exceeded 650 mm FL. Logistic regression analyses indicated a significant positive relationship between length and the probability of spawning (β = 0.0184, SE = 0.003, *P*<0.001; Figure 7b). There was a moderate fit for the model based on the specificity (71.4%) and sensitivity (74.6%) using a cutoff of p = 0.35, which is demonstrated in the wide confidence intervals describing the relationship between bull trout length and the probability of spawning (Al-Chokhachy et al. *In review*).

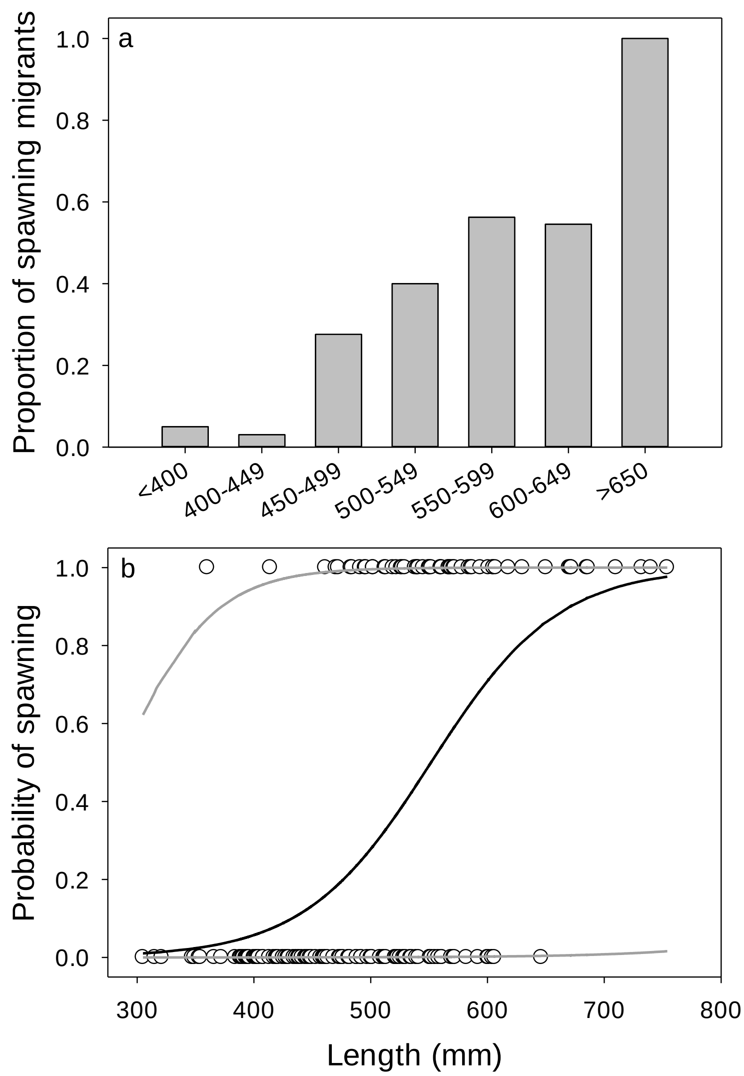

Figure 7. Patterns of subadult and adult bull trout migrations in the North Fork Lewis River above Swift Reservoir illustrating the proportion of fish demonstrating spawning migrations by size class (a) and the occurrence (1 = yes, 0 = no) of bull trout spawning migration within the year and the modeled probability of spawning from a generalized linear model (black line) with 95% CIs (grey lines) by individual size at marking (b).

IV. Vital Rates

a. Survival

Each year from 1997-2016 bull trout were marked with individual tags for estimates of abundance, survival, growth, and migration. Fish were not tagged in 2017 and 2018. Bull trout were sampled by drifting gill nets at a major pool feature (Eagle Cliff) just above the head of Swift Reservoir. Sampling typically occurred weekly from early May through early August and the average number of sample days during this study was 9.8 (SD = 1.9). All fish larger than 360 mm FL were marked with an external anchor tag (i.e., Floy Tags) at the base of the dorsal fin for estimates of adult abundance. Beginning in 2002, fish were also marked with PIT-tags in the dorsal sinus to allow for estimates of movement within the subbasin (see below). Upon full recovery where fish regained equilibrium, individuals were released near the point of capture.

We estimated survival using the time series of available data for bull trout in Swift Reservoir using mark-recapture data from active sampling only (1996 – 2016). These data included all fish marked and recaptured via marking efforts from gill net sampling at the mouth of Swift Reservoir. We estimated survival using a Cormack-Jolly-Seber (CJS) open mark recapture model in Program MARK (White and Burnham 1999). We included marked individuals larger than 360 mm (n = 1,385) in our analyses and considered two groups, subadults or fish <450 mm and adults ≥450 mm (see Al-Chokhachy et al. *In review* for more details).

Our results indicated recapture probability varied by stage and that apparent survival varied by year and stage (additive model). Survival analysis using CJS suggests that subadult survival (average = 0.66; SE = 0.04) was higher than adults (average = 0.45; SE = 0.04) during this period and that survival varied considerably across years (Figures 8). Additionally, our results also demonstrate a pronounced increase in apparent survival of both groups after 1998. Survival estimates were low compared to recent estimates for adfluvial bull trout elsewhere (Johnston and Post 2009).

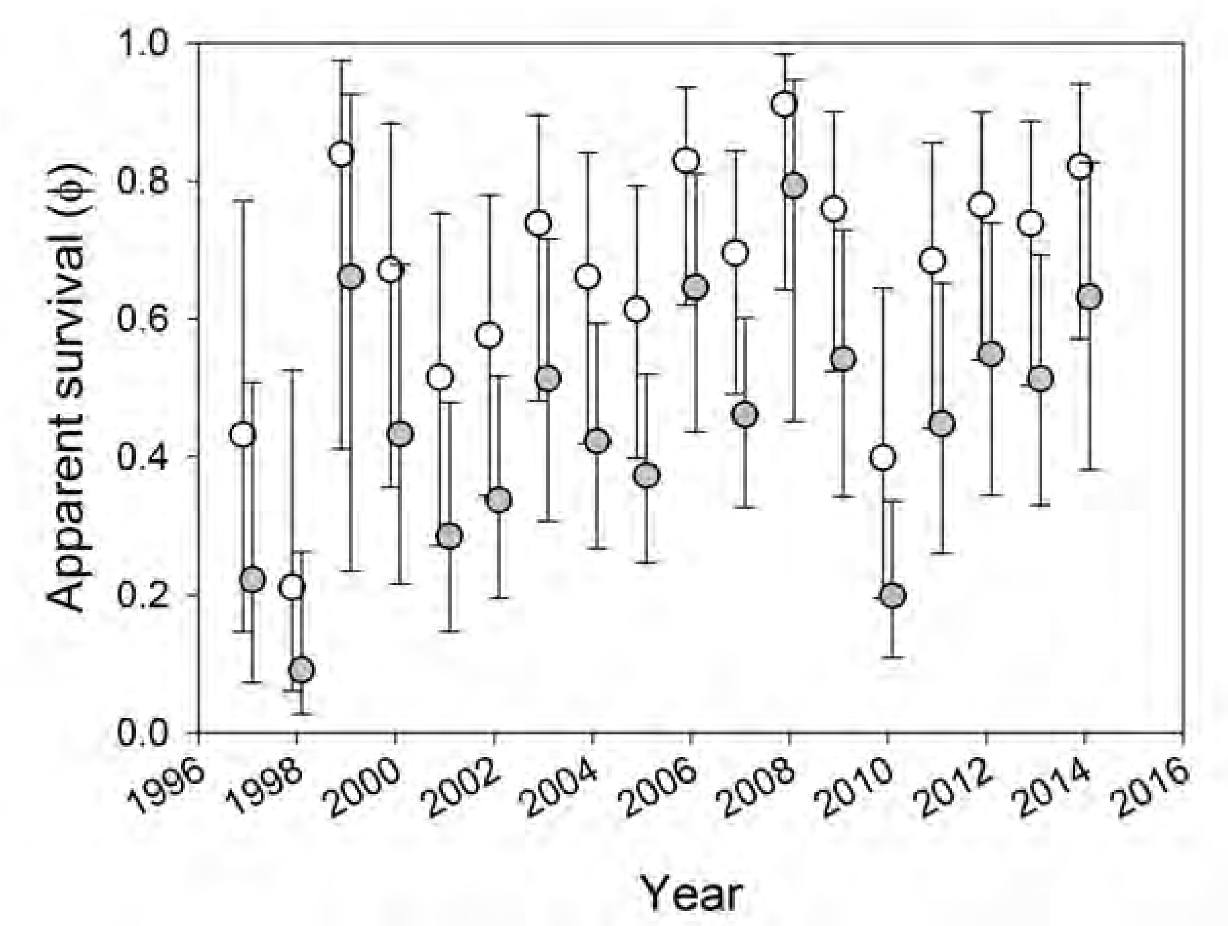

Figure 8. Annual estimates of apparent survival from a Cormack-Jolly-Seber mark recapture model for subadult (300 – 449 mm; white) and adult (450 mm ≤; grey) bull trout in the Lewis River upstream of Swift Dam.

b. Growth

Estimates of annual growth from mark-recapture data suggest little difference in growth patterns between bull trout in Yale Lake and Swift Reservoir (albeit low recapture numbers from Yale Lake; Figure 9). As expected, growth decreased with increasing size. Growth estimates were highly variable across individuals, which is consistent across bull trout populations (Johnston and Post 2009; Al-Chokhachy et al. 2015a). Growth estimates, where comparable, are similar to recent results from adfluvial bull trout in Canada (i.e., only comparable estimates; Johnston and Post 2009).

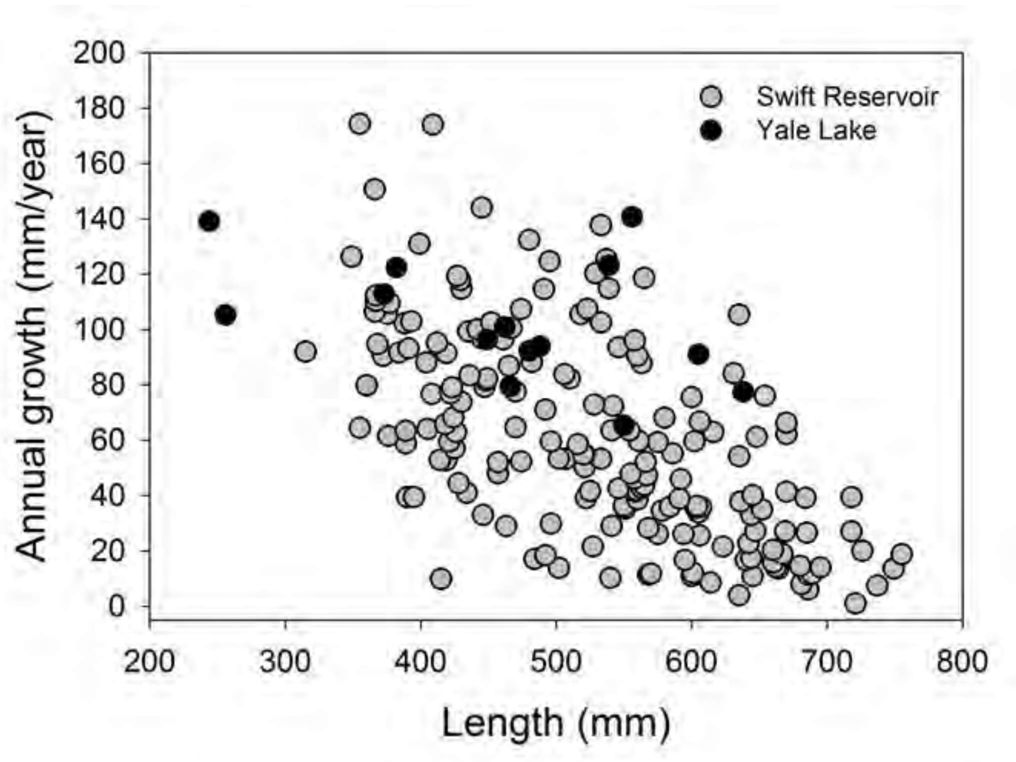

Figure 9. Estimates of bull trout annual growth (mm/year) from mark-recapture data in Yale Lake (black) and Swift Reservoir (grey) WA, USA.

c. Fecundity

There is no known information on fecundity of bull trout in the Lewis River subbasin.

V. Spatial Distribution

a. Length-frequency of bull trout in tributaries

Observations from systematic snorkel surveys in late summer in Pine Creek and P8, which cover a large portion of the contemporary spawning and rearing habitat, are indicative of an adfluvial bull trout population as described by others (Fraley and Shepard 1989; Downs et al. 2006). Specifically, the majority of individuals within the tributaries are ages-1 to age-3 bull trout, which are likely rearing prior to downstream migrations to the reservoir habitat for subadult rearing (Figure 10). As expected from life-history migrations, a number of adult (>450 mm) bull trout utilize tributaries during the late summer, prior to the onset of spawning (Starcevich et al. 2012).

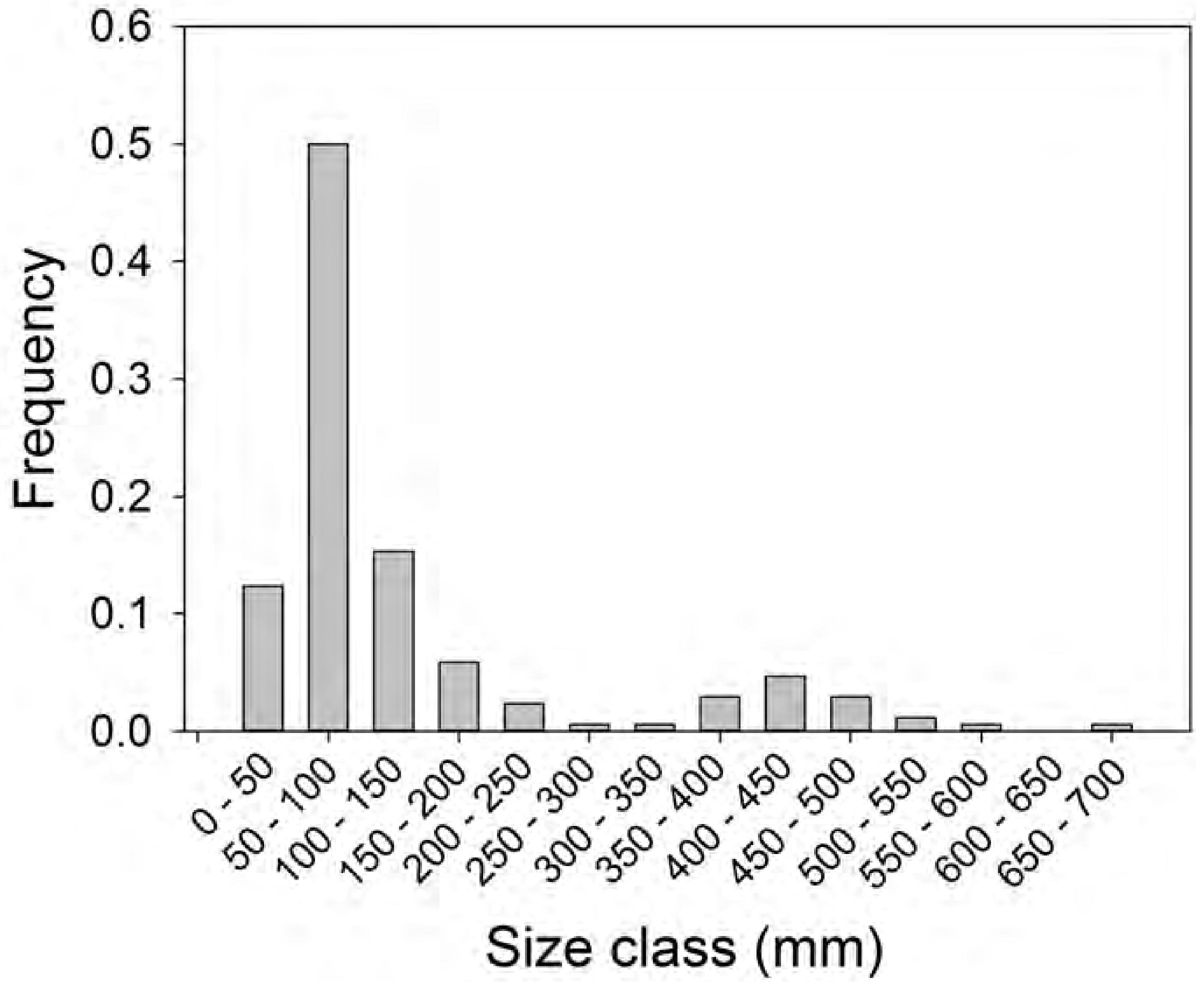

Figure 10. Length-frequency of bull trout observed in snorkel surveys (2013 – 2015) in Pine Creek and P8, the major spawning and rearing tributary in Swift Reservoir, WA.

b. eDNA

The LRBTRT worked closely with the Range-Wide Bull Trout eDNA Project (Young et al. 2017) to select eDNA sample sites to better understand the spatial distribution of bull trout within the upper Lewis River subbasin. Sites were selected to meet study objectives of the Range-Wide project (juvenile bull trout occurrence across the range of bull trout in the United States) and the interests of the LRBTRT (juvenile and adult occurrence in the upper Lewis River). Of the 442 sample sites that were identified during this process, water samples were collected from about half the sites (204 sites) in the summer and fall of 2016 (Figure 11) in accordance with methodology developed by the U.S. Forest Service (Carim et al. 2015). The 2016 sample locations included Cougar Creek (Yale), tributaries to Swift Reservoir and the NF Lewis River. Samples above adfluvial passage barriers were sampled in summer 2016; samples below adfluvial barriers were sampled in fall 2016. Samples were analyzed for bull trout eDNA by the U.S. Forest Service, Rocky Mountain Research Station, National Genomics Center for Wildlife and Fish Conservation, Missoula, Montana.

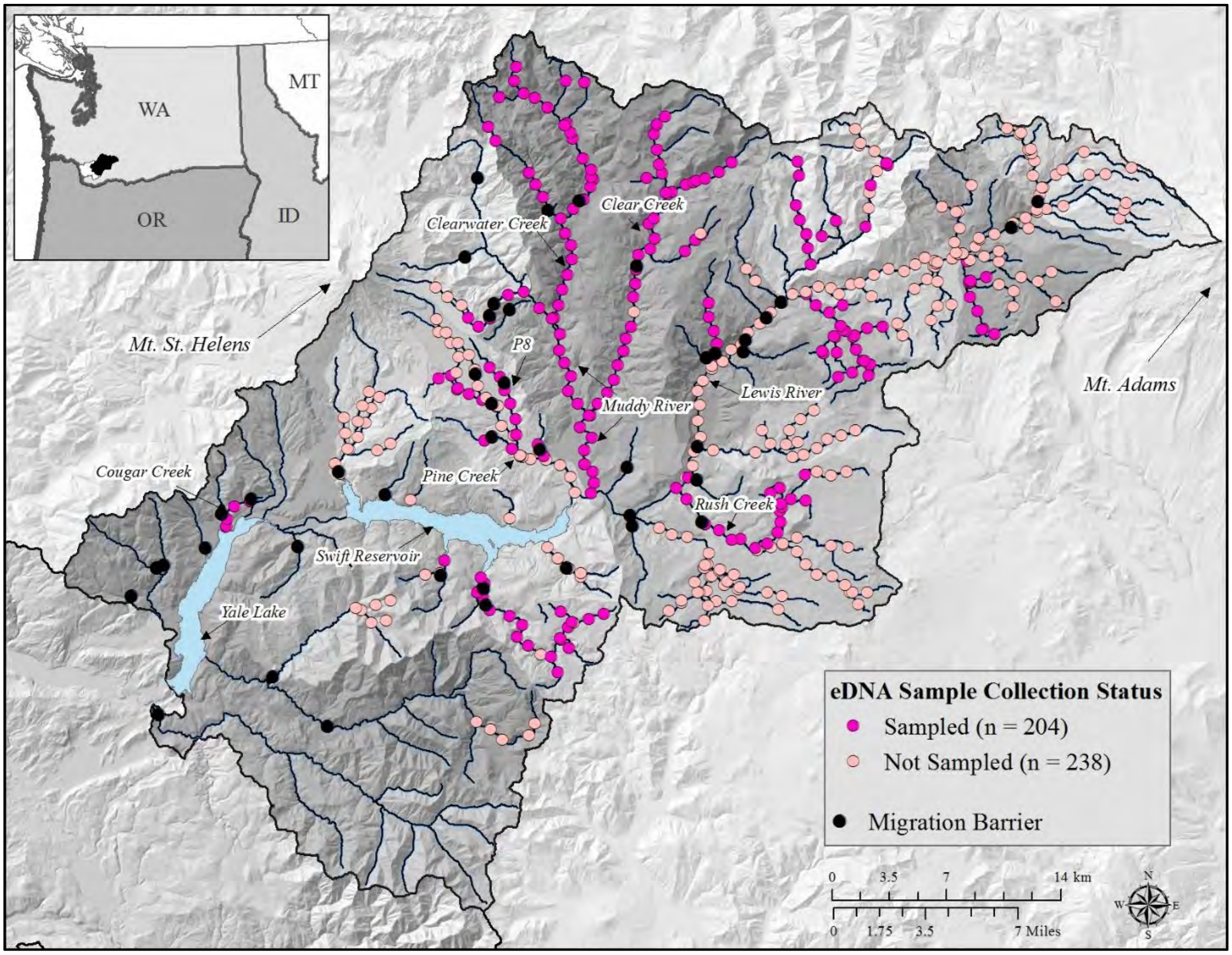

Figure 11. Location and sampling status of eDNA sites in the Lewis River subbasin.

Results of this work can be found at the bull trout eDNA survey results online map (Young et al. 2017; https://www.fs.fed.us/rm/boise/AWAE/projects/BullTrout_eDNA/SurveyStatus.html). Briefly, the results suggest that populations above migratory barriers are unlikely, and bull trout distribution in lotic habitat below passage barriers is likely restricted to the known spawning tributaries of Cougar, Rush, and Pine creeks.

c. Occupancy and distribution

In the late-2000s, a patch-based approach (RMEG 2008; Issak et al. 2009) was used to identify the distribution and occupancy of juvenile bull trout in the upper Lewis River subbasin. Potential habitat patches were identified using environmental characteristics and in-stream sampling was conducted within each patch to confirm presence or absence of bull trout. A total of 33 patches (range: 515-11,905 ha) were identified as potential bull trout habitats based on stream temperature-elevation relationships, stream order, and watershed area criteria (Hudson et al. 2010). Sample sites (50 m reaches) within patches were selected using a random, spatially-balanced design (Generalized Random-Tessellation Stratified, GRTS; Stevens and Olsen 2004) in Program R (Ihaka and Gentleman 1996).

Sampling was conducted using backpack electrofishing. Each 50 m reach was sampled from the downstream to the upstream boundary in a "stalk and shock" manner as described in Cook and Hudson (2008). All fish encountered were captured and identified; fork length (mm) and mass (g) were collected from each bull trout to facilitate size class determination. Since bull trout, brook trout (*S. fontinalis*), and hybrids potentially occupy these watersheds, *Salvelinus* species were carefully scrutinized for distinguishing features (e.g., vermiculation, black markings on fins, halos) before identification (Holton and Johnson 1996). All fish captured were released alive within the sampled reach.

Patches were considered occupied (by a population) if two age classes (as determined by size classes > 30 mm difference in fork length) of bull trout were captured in any combination of one or more reaches within a patch.

To account for false-absence rates (concluding that bull trout were absent when in fact they were present), we estimated probabilities of presence relative to site-specific detection probabilities (SSDP) and number of sites sampled. SSDP, or the probability of detecting a species where they are known to occur, was calculated by sampling 16 reaches in one occupied patch in the Pine Creek watershed. The SSDP for this patch was estimated to be 0.375 (bull trout were detected in 6 of the 16 sites) and was assumed to be the SSDP in all patches. Incorporating this SSDP into a model developed by RMEG (2008), if 3, 5, or 7 reaches were sampled within a patch and no bull trout were detected, the probability that bull trout occupied that patch would be less than 0.20, 0.10, or 0.05, respectively (Figure 12).

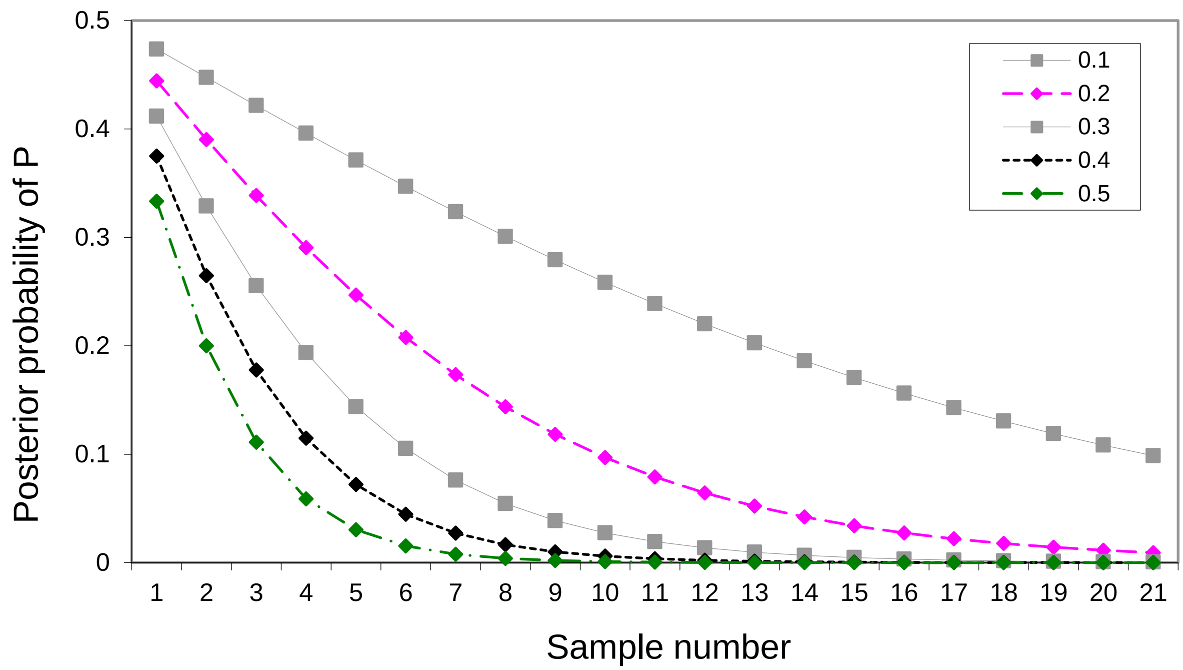

Figure 12. The relationship between the probability of bull trout presence in a patch (posterior probability of P) if no bull trout are detected and the number of reaches sampled (prior P of presence = 0.50). The curves represent various site-specific detection probabilities (SSDPs) ranging from 0.10 – 0.50.

Occupied patches of the Lewis River subbasin

A total of 12 patches (93 reaches) were sampled between 2006 and 2010 in the Lewis River subbasin. Occupancy by bull trout was confirmed in two of these patches, both in the Pine Creek watershed (Figure 13). For all other patches, we sampled at least 7 reaches within each patch and captured no bull trout, indicating a low probability of bull trout presence. Many of the patches (21) were not sampled because a barrier assessment coupled with sampling above barriers indicated a low probability of bull trout presence above barriers in the Lewis River subbasin.

Bull trout occupy Rush Creek and Cougar Creek (Faler and Bair 1992; PacificCorp 2009); however, these areas were not identified as patches due to their small watershed sizes. This suggests a limitation of the patch identification approach (RMEG 2008) used for this study as in some cases the approach does not account for downstream rearing habitat, such as reservoirs (e.g., Swift and Yale reservoirs) and large main-stem rivers (e.g., North Fork Lewis River).

Impassable waterfalls were present near or at the downstream extent of multiple patches (Big Creek, Chickoon Creek, Curly Creek, Miller Creek, Tillicum Creek, and Unnamed Trib. 9) making it unlikely that bull trout will naturally (re)colonize any of these patches. Additionally, the lack of bull trout in the Tillicum Creek patches, located above Lower Falls on the mainstem Lewis River, suggests a low probability that bull trout occupy putative patches above the falls or other natural barriers in the subbasin.

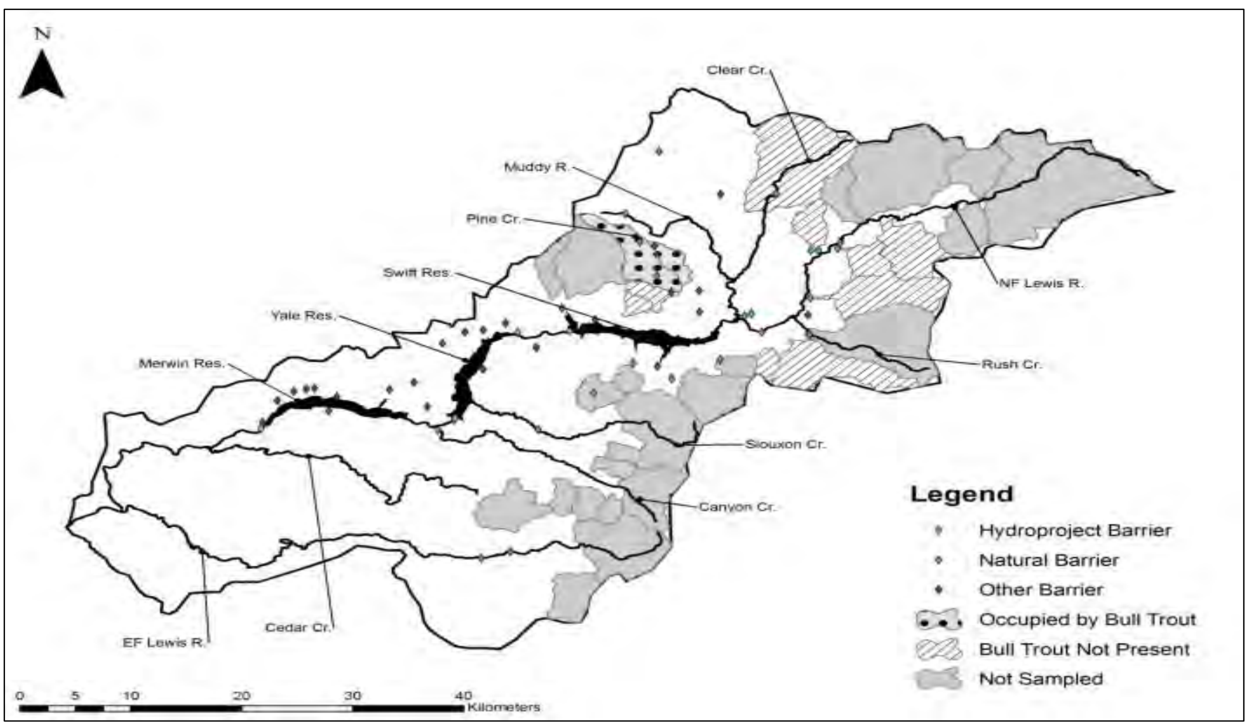

Figure 13. Lewis River subbasin patch structure. Grey patches with dots are occupied by bull trout, white patches with cross hatch are not occupied by bull trout, and grey patches have not been sampled. Diamonds represent known barriers.

VI. Movement patterns

a. PIT monitoring

Beginning in 2011, half-duplex PIT antennas were installed near the mouths of Pine Creek and Rush Creek to better understand adult bull trout movement patterns. The antennas spanned the width of the individual channels and detected fish marked with PIT-tags. Each year, the antennas were installed in the last week of July and operated continuously through the first week of November. Active (fish marking) and passive (antenna) data were integrated to quantify patterns of movement including recurrence of spawning migrations, proportion of migrants by tributary, and spatial patterns of movement for fish marked from 2011 through 2017. Antenna data were available from 2011 – 2017 in Pine Creek and 2012 – 2017 in P8. Only those individuals with clear migration patterns (i.e., detected at multiple antennas) and timing of migrations were considered when evaluating spawning migration patterns. Given that annual survival can influence estimates of recurrence of spawning patterns, we only included individuals ≥450 mm FL with at least three years of potential migration during 2011-2017 to evaluate the frequency of spawning migrations.

Movement data revealed information regarding frequency of spawning migrations and movements throughout the subbasin. Nearly 40% of the fish failed to make a spawning migration and 25.2%, 19.4%, 12.3, 3.2%, and 0.7% of marked fish made one, two, three, four, or five spawning migrations, respectively (Figure 14). The majority of the fish (80.5%) that made multiple spawning events were annual spawners (i.e., did not skip years).

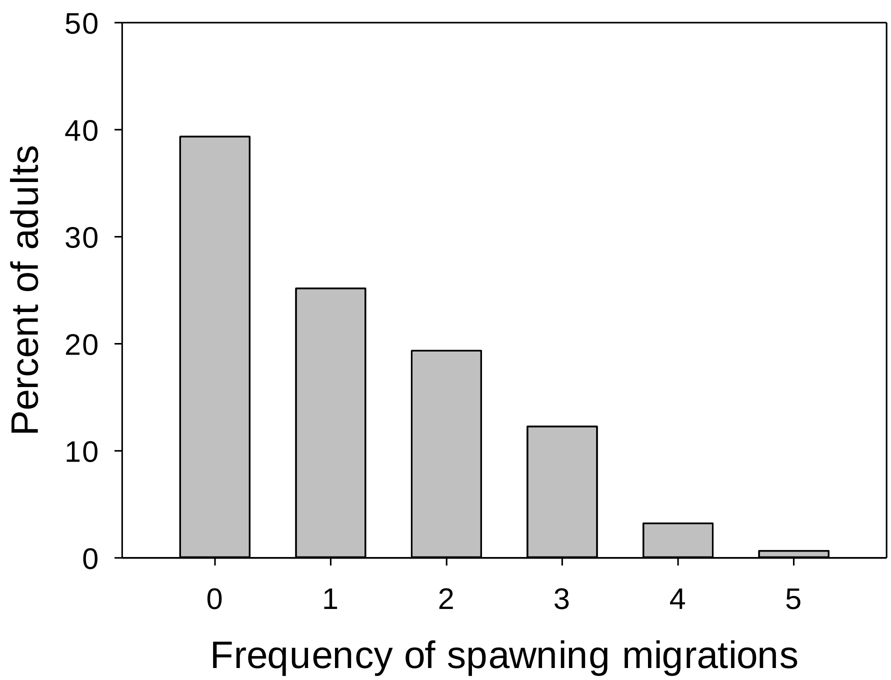

Figure 14. Patterns of movement of bull trout in the upper Lewis River above Swift Reservoir illustrating the percent of adults that were observed with different frequencies of spawning migrations.

Over the period of 2011-2017, bull trout appeared to increasingly rely on spawning in Pine Creek (Figure 15a). The number of fish detected in Rush Creek has declined since 2013, and due to antenna malfunction no fish were detected in Rush Creek during 2016. During 2013-2015, numerous bull trout were detected making movements into the Muddy River, a stream network where no spawning or early-life has been documented. Within the Pine Creek system, the proportion of marked bull trout detected at the mouth of Pine Creek antenna only and not the P8 antenna has generally increased since 2012, suggesting a large and increasing proportion of adult bull trout are spawning outside of P8 (Figure 15b). Despite these patterns, a high proportion of bull trout spawning appears to occur in P8 each year (average proportion = 0.52; range = 0.30 – 0.71).

Across years, the median date of upstream migration past the lowest antenna was year day 231 (20 August). The median date of upstream migration varied from year day 218 in 2012 to 237 in 2017 (Figure 16). We found no apparent evidence of linkages between the timing of upstream bull trout spawning migrations and Lewis River monthly discharge (US Geological Survey station 14216000). The average duration of bull trout in Pine Creek for the spawning period was 37.3 days (SD = 16.7 days). The downstream migrations typically occurred prior to rising hydrograph each year in autumn (Figure 16). For bull trout that entered P8, the median upstream migrating time from the mouth of Pine Creek to P8, a distance of 6.1 km, was 31.5 days (range = 2 – 51 days); downstream migration was considerably shorter (median = 1 day; range = 0 – 14 days). Bull trout that exhibited earlier seasonal migrations into the Pine Creek system tended to exhibit longer durations of spawning migrations than fish migrating upstream later in autumn (Figure 17).

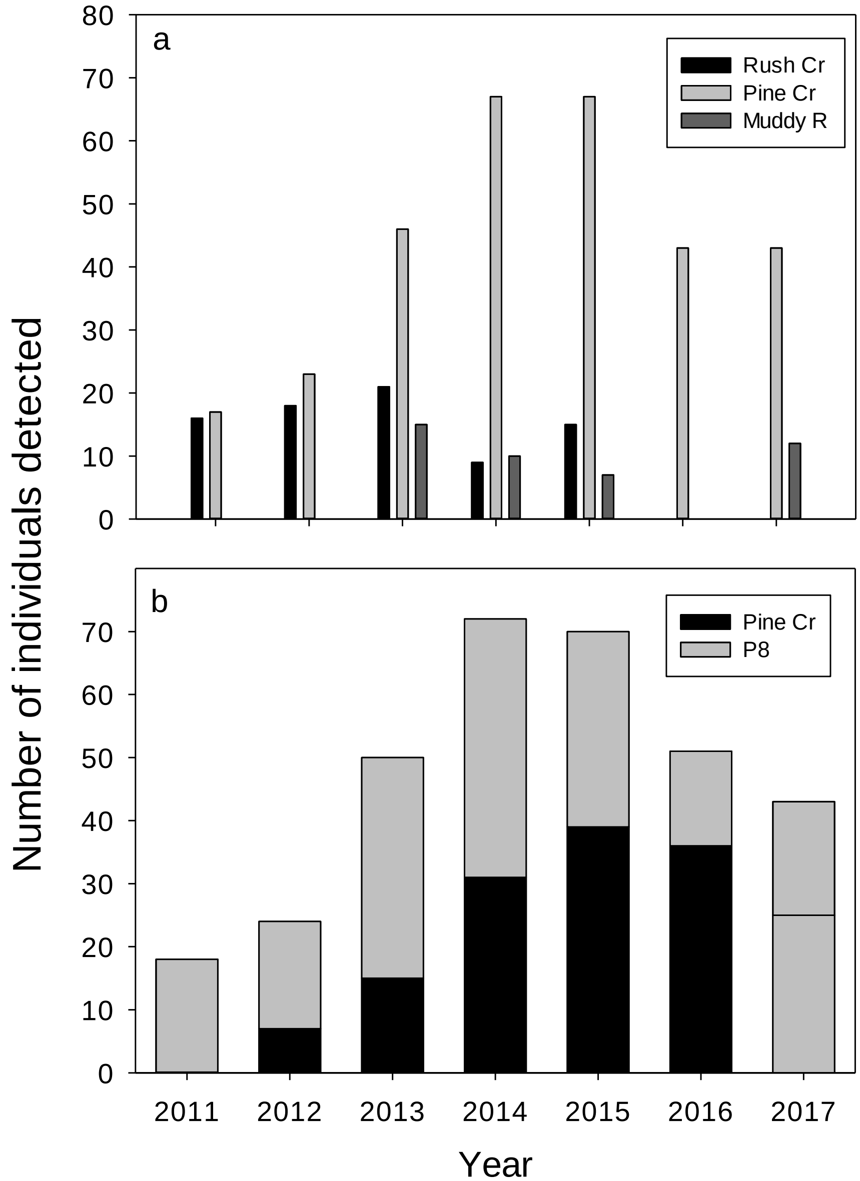

Figure 15. The yearly number of individual adult bull trout detected entering Rush Creek (black), Pine Creek (light grey), and the Muddy River (dark grey; a) and those within Pine Creek delineated by individuals detected at Pine Creek only (grey) and in P8 (black) by year (b). Note: no information was available from Rush Creek in 2016 nor P8 in 2011.

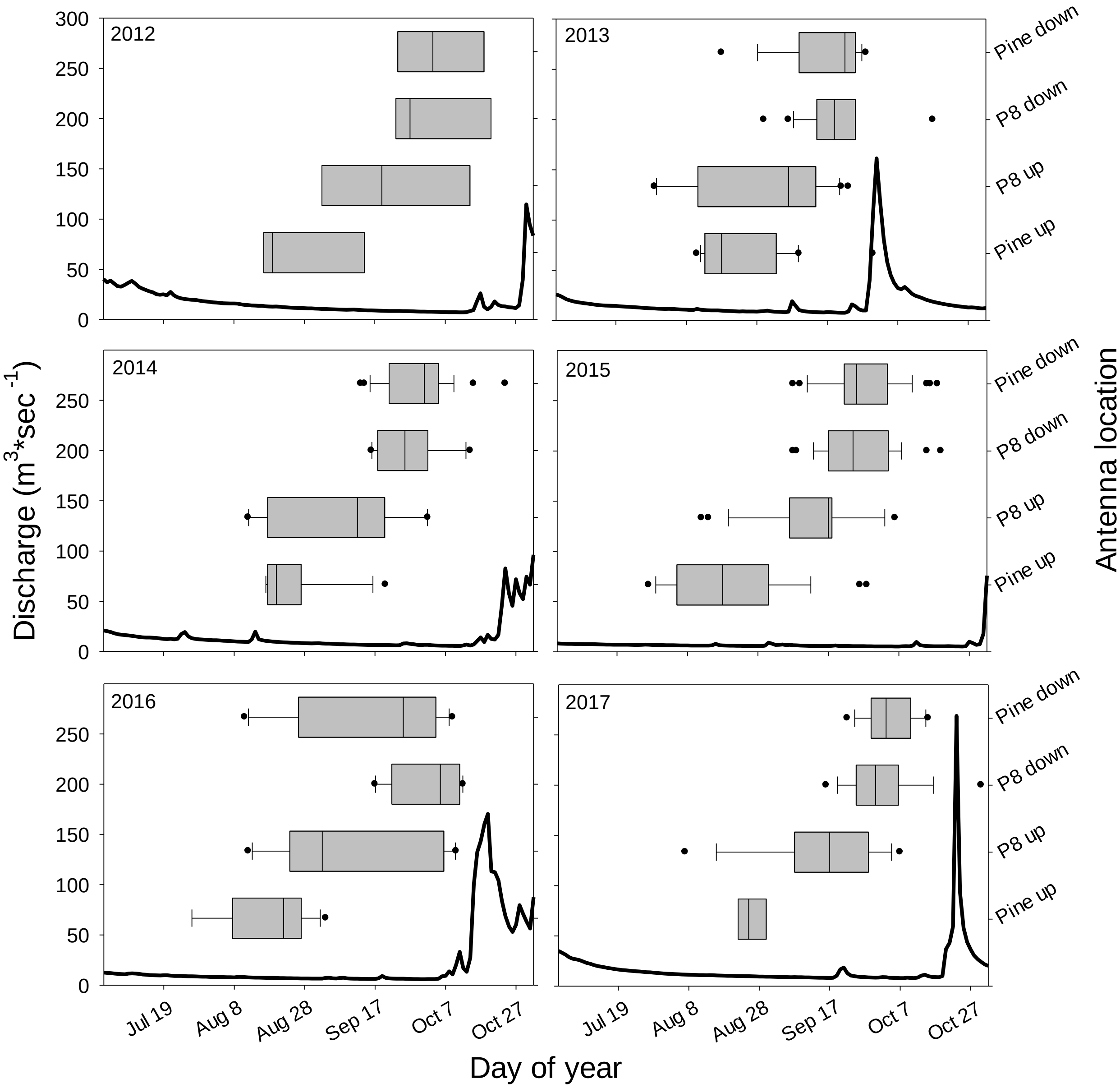

Figure 16. Boxplots of the date of bull trout migration into two of three known spawning tributaries, Pine Creek and P8 (2012 to 2017). PIT-tag data were delineated by antenna location and direction and daily average discharge from the US Geological Survey gage station (station 14216000) on the Lewis River above Swift Reservoir in WA, USA. Boxplots illustrate the median (line), quartiles (box), 5th and 95th percentiles (whiskers), and all outlier points (black). For antenna location, "up" refers to upstream migration and "down" refers to downstream migration.

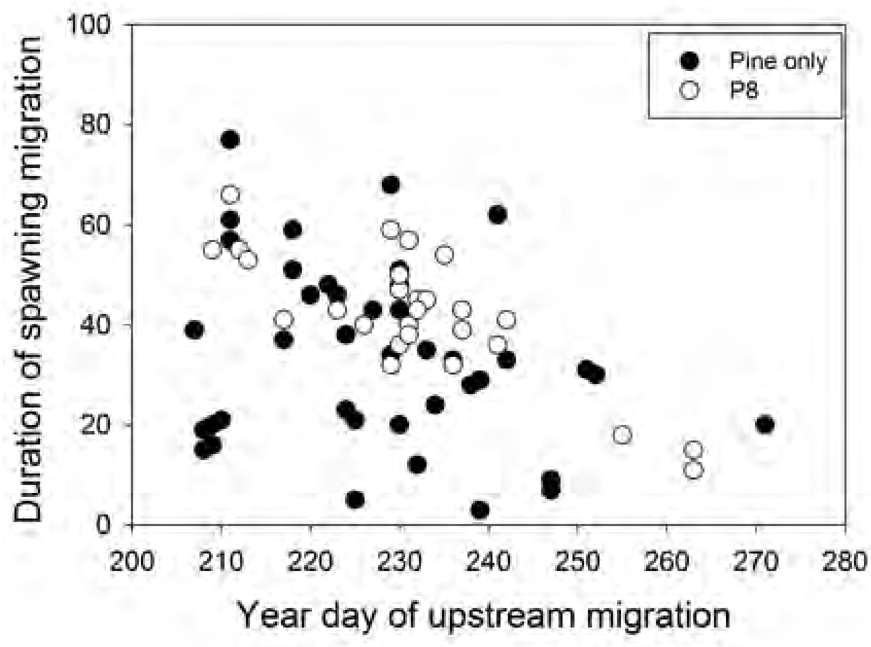

Figure 17. The relationship between the duration of bull trout spawning migrations (from date of upstream to downstream migration past a PIT-tag antenna on Pine Creek) and year day of upstream migration for individuals detected only in Pine Creek (black) and P8 (hollow).

b. Radiotelemetry

Bull trout were captured at the head of Swift Reservoir (where the NF Lewis River enters the reservoir) in June-July 2009 and May-June 2010 using tangle nets. Netting was conducted in cooperation with PacifiCorp and the WDFW. Nets were either set (by anchoring to shore or other stationary landscape feature) for approximately 10 minutes or active drift netting was conducted when river flows allowed.

Captured bull trout (>350 mm FL) were tagged using one of two different types of LOTEK radio tags. Bull trout approximately 360 mm to 525 mm FL were surgically implanted with a MCFT-3EM tag (8.9 g in air, 4.3 g in water, 11 x 49 mm, expected lifespan of 399 days). Bull trout larger than 525 mm FL were surgically implanted with a MCFT-3L tag (26 g in air, 11 g in water, 16 x 73 mm, expected lifespan of 1,686 days). Not all bull trout were radio tagged due to timing (e.g., too many fish captured during a single sampling event) and/or condition (e.g., stressed from being in net). Fork length (mm) and mass (g) were recorded for all radio tagged bull trout. Each fish also received a full-duplex PIT tag.

Mobile radio tracking was conducted by vehicle using a dipole antenna and a LOTEK SRX-400 telemetry receiver. Tracking occurred once a week prior to stationary antennas being installed. Detection of radio tagged bull trout was attempted along the north shore of Swift Reservoir and along the mainstem of the NF Lewis River. After stationary antennas were installed, mobile tracking occurred between all antenna sites when batteries were changed at those antennas.

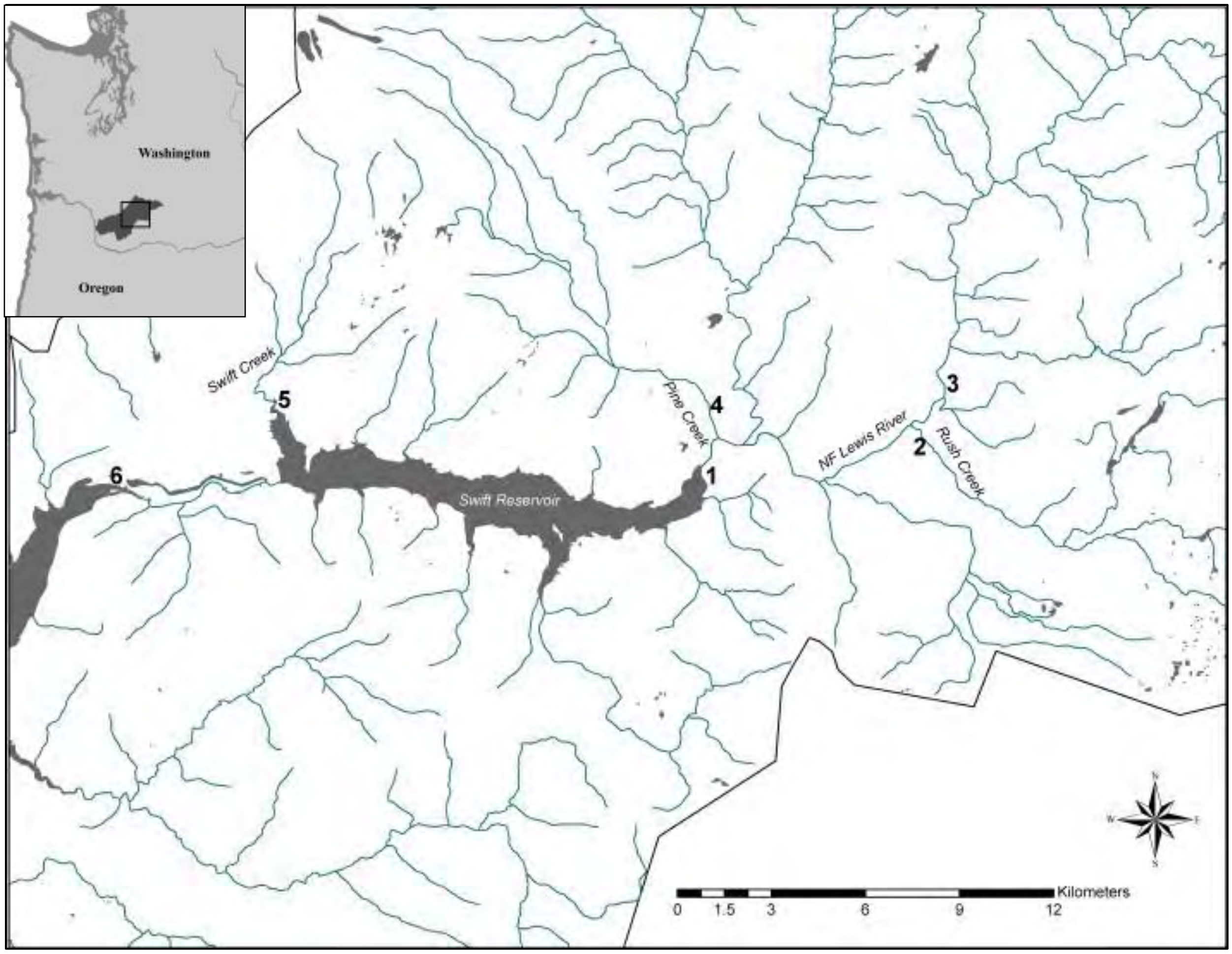

Figure 18. Stationary radio antenna sites within the study area. Sites included: 1) Eagle Cliff, 2) Rush Creek, 3) above Rush Creek, 4) Pine Creek, 5) Swift Creek, and 6) Beaver Bay.

Stationary antennas were established at five sites in August 2009: Eagle Cliff, Rush Creek, above Rush Creek, Pine Creek and Swift Creek (Figure 18). A sixth stationary site was established below Swift Reservoir at Beaver Bay in September 2009. Logged data was downloaded from the telemetry receiver and batteries replaced every ten days. The Rush Creek and Above Rush Creek antennas were shut down each winter due to inability to access. The other four stationary antennas operated continuously through December 2012.

Data were analyzed to determine: 1) temporal extent of bull trout movement upstream from Swift Reservoir, 2) the duration of migratory behavior (individually and collectively), 3) the duration of residence in each tributary (at both the individual and population levels), and 4) patterns of occupancy in the proportion of bull trout going only to Rush Creek, only to Pine Creek, to both creeks. Multiple years of data were analyzed to determine variation in these measures. Bull trout detected in multiple years were analyzed to determine variations in their individual migratory behavior and the implications of consistency or variation to the collective population(s).

In 2009-2010, a total of 54 bull trout were radio-tagged (359-711 mm FL). All fish were released in good condition at Eagle Cliff, the location of tagging. Fish exhibited a variety of behaviors. Bull trout were documented staging at Eagle Cliff in the spring and began moving upstream to Rush and Pine creeks in July. A few fish were detected moving into the mouth of Swift Creek during this staging period as well. A number of fish were detected using both spawning tributaries during this period of upstream migration prior to the spawning season in September and October. Some fish also moved above Rush Creek in the North Fork Lewis River, but then came back down to one of the two spawning tributaries. Most bull trout were detected in only one of these tributaries during the spawning season. However, a few fish were observed in both Rush and Pine creeks during September and October. After the spawning season, all tagged fish that had migrated to Rush and Pine creeks moved back down to Swift Reservoir by November. They remained in the reservoir until the following spring when they began staging at Eagle Cliff again.

c. Screw traps

A rotary screw trap was deployed for multiple seasons in the upper Lewis River subbasin starting in 2001. The trap was deployed in the mainstem Lewis River at Eagle Cliff near the head of Swift Reservoir in 2001 and 2013-2017, and in Rush Creek, approximately 150 m upstream of the mouth, in 2004-2005. In general, bull trout were not the focal species of the trapping operations (2004-2005 being the exception) and trap efficiency estimates (likely quite variable among years) were not generated. Therefore, no attempt was made to generate juvenile abundance estimates with the data, and the numbers of fish captured by year should not be viewed as a trend in abundance of juvenile bull trout in the upper Lewis River. Overall, not many juvenile bull trout were encountered in the screw trap operations. Trap operation dates likely did not cover the entire juvenile outmigration period, as capture date ranges often closely matched the trap operation date range (Table 4). The limited data that were collected provide some information on movement timing (dates bull trout were captured) and temporal extent of rearing in the Lewis subbasin upstream of Swift Reservoir (inferred from length data), the primary foraging and overwintering habitat for this population (Table 4, Figure 19). The years with the largest catch of bull trout (2004 and 2005) are coincident with trapping efforts in a spawning tributary (Rush Creek) and when the trap was operated for the longest time period among years (spring through early fall). These data suggest bull trout hatched in Rush Creek exhibit multiple rearing strategies. A proportion leave their natal stream as young of year (the majority of bull trout caught in Rush Creek were below 50 mm in length and most of these fish were captured in March – June). Others rear in Rush Creek for at least one year (evident by bull trout between ~70 – 150 mm) and moved out of their natal stream throughout the year. Length data from the Eagle Cliff trap, which is located downstream of all known spawning areas above Swift Reservoir, suggest bull trout generally rear in lotic habitat for 1 to 3 years (evident by bull trout lengths 100 mm and 250 mm) prior to entering the reservoir. This is consistent with snorkel observations in the upper Lewis river subbasin and is a typical rearing strategy of other adfluvial populations (Fraley and Shepard 1989; Johnston 2005; Ratliff et al. 2015).

Table 4. Number of juvenile bull trout captured and length statistics of the captured fish by year and trap location. Length was measured from each captured bull trout. Eagle Cliff is the Lewis River near the head of Swift Reservoir.

					Length (mm)				
Year	**Location**	**Trap operation dates**	**Range of capture dates**	**Number captured**	**Mean**	**SD**	**Median**	**Min**	**Max**
2001	Eagle Cliff	5/18 - 6/28	5/19 - 6/28	83	154.9	23.0	151.0	125	210
2013	Eagle Cliff	3/28 - 6/30	3/29 - 6/21	52	132.8	24.4	126.0	98	220
2014	Eagle Cliff	3/18 - 7/2	3/26 - 6/4	16	137.0	45.6	120.5	77	265
2015	Eagle Cliff	3/25 – 6/1	4/12 - 5/11	9	131.3	29.9	120.0	103	180
2016	Eagle Cliff	3/24 - 6/30	4/4 - 6/16	4	138.5	17.7	141.0	115	157
2017	Eagle Cliff	4/20 – 7/30	5/10 - 6/27	6	159.2	26.3	157.5	130	200
2004	Rush Creek	5/5 - 11/2	5/6 - 10/29	97	77.5	48.0	54.0	24	153
2005	Rush Creek	3/16 - 10/31	3/18 - 10/28	277	40.0	33.4	27.0	24	163

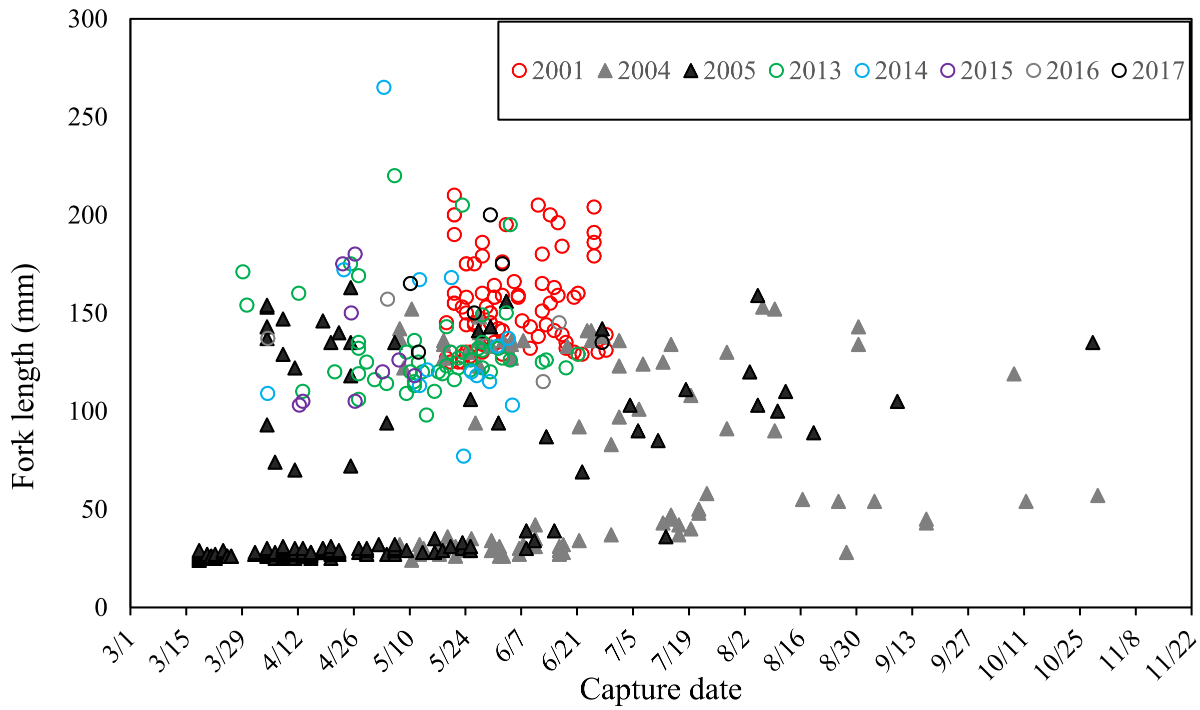

Figure 19. Date-length plot of juvenile bull trout captured in upper Lewis River subbasin screw traps. Open circles are from data the Eagle Cliff screw trap, closed triangles are data from the Rush Creek screw trap.

VII. Genetic diversity

Juvenile bull trout were collected via electrofishing in 2010 from the three Lewis River spawning tributaries: Cougar Creek (n=33), Pine Creek (n=53), and Rush Creek (n=33). Within Pine Creek, juveniles were collected in the mainstem of Pine Creek (n=23) as well as P8 (n=30), a small tributary to Pine Creek. Juvenile bull trout were used to characterize genetic variation within and among spawning tributaries and to develop a baseline dataset for population assignments. Detailed methodology for genetic analyses conducted can be found in DeHaan and Adams (2011). Results from that report are summarized below.

Estimates of genetic diversity were similar among all three tributaries (Table 5). Estimates of diversity were consistent with populations from western Washington (DeHaan et al., 2011) with the lowest in Pine Creek and greatest in Rush Creek. The overall level of variation observed among tributaries (global F_{ST}) was 0.163 and was significantly different from 0.0 (95% C.I. = 0.123 - 0.207). Pairwise estimates of variation ranged from 0.145, for the comparison between Pine and Rush creeks, to 0.191 between Pine and Cougar creeks (Table 6). Chi-squared contingency tests indicated that there were significant differences in allele frequencies among all three tributaries. However, the overall genetic differentiation between tributaries was relatively low compared to bull trout population in the Pacific Northwest (DeHaan et al., 2011). The fuzzy correspondence analysis (FCA) plot showed three distinct clusters of individuals, which corresponded to individuals from the three different tributaries (Figure 20). There were one or two individuals collected from each tributary that clustered with individuals from another tributary (Figure 20).

Table 5. Initial sample sizes from each tributary, number of full sibling families detected, adjusted sample sizes, and estimates of genetic diversity including the mean number of alleles per locus (A), allelic richness (A_R), expected heterozygosity (H_{exp}), and observed heterozygosity (H_{obs}) for bull trout collected from three Lewis River tributaries.

Tributary	Initial sample size	# Full sib families	Adjusted sample size	A	A_R	H_{exp}	H_{obs}
Cougar Creek	32	19	27	3,313	3.274	0.481	0.476
Pine Creek	53	16	33	3.250	3.087	0.466	0.453
Rush Creek	32	31	31	4.000	3.796	0.492	0.507
Mean				3.521	3.386	0.480	0.479

Table 6. Pairwise estimates of genetic variation (pairwise F_{ST}) among bull trout collected from three Lewis River tributaries. Estimates are based on 16 microsatellite loci.

	Cougar Creek	Pine Creek
Pine Creek	0.191	
Rush Creek	0.157	0.145

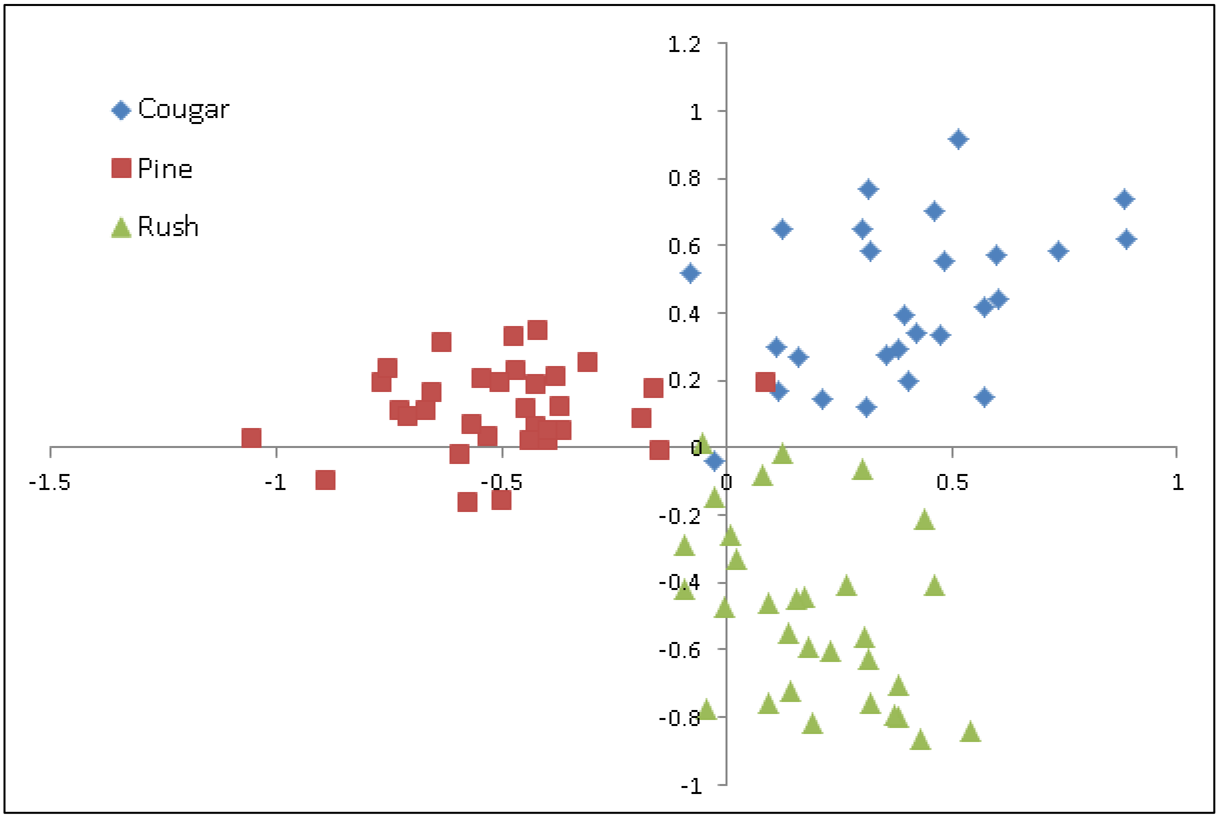

Figure 20. Fuzzy correspondence analysis (FCA) of Lewis River bull trout. Each point on the graph represents an individual bull trout in the analysis. Points that cluster closer together are more genetically similar. The first axis on the FCA plot accounted for 9.30% of the variation observed and the second axis accounted for 9.03% of the variation observed.

VIII. Limiting factors

The LRBTRT has identified a number of potential limiting factors for bull trout in the Lewis River including: spawning/rearing habitat, connectivity, reservoir conditions, forage base, handling impacts during research and monitoring activities, illegal fishing harvest and indirect (i.e., catch-and release) angling impacts, and interspecific competition. Investigations conducted to date have focused on stream temperature and in-stream habitat conditions and include: a) Pratt (2003), b) Meridian Environmental, Inc. (2007) and, c) Lamperth et al. (2017). Pratt (2003) evaluated three stream reaches proposed by USFWS as critical habitat for the Yale bull trout population and found that the temperature regime, among other factors, precluded the use of these habitats by bull trout. The main conclusion of the Meridian Environmental, Inc. (2007) study was that four of 16 streams evaluated had marginal to optimal bull trout habitat, but each of the four had a limiting factor (low discharge, warm incubation temperature, and/or frequent scour events) that likely contributed to lack of established bull trout presence. The main finding from the Lamperth et al. (2017) study is that bull trout spawning and rearing are likely limited by stream temperature (spawning and rearing) and in-stream habitat features (spawning) in reaches above Swift Reservoir. These three studies are more completely summarized below.

a. Evaluation of three proposed management scenarios to enhance three potential bull trout nursery habitats accessible to Lake Merwin and Yale Lake, Lewis River

In 2002, the USFWS proposed to designate three stream segments as critical (nursery) habitat for the Yale/Merwin bull trout population (USFWS 2002) despite little-to-no evidence that these stream reaches were used by bull trout. The stream reaches were the Swift bypass reach, Ole and Rain creeks, and lower Speelyai Creek (Figure 21). The impetus for this decision was to protect nursery habitat in addition to Cougar Creek, the single spawning area for this population (i.e., Cougar Creek), that could be used by colonizing bull trout and offset the risk of a single spawning tributary.

In this study, the best available data describing the habitat (discharge, sediment and bedload, and stream temperature) and fish community of the proposed areas were evaluated to determine whether conditions existed or could be enhanced by management actions to support spawning, incubation, and rearing of bull trout. The results showed that these areas likely did not have the conditions necessary to serve as nursery habitat, citing warm stream temperature as the primary factor limiting bull trout use of these habitats. For example, temperature during the incubation phase never dropped to suitable levels (2 - 4 °C) and, in most areas, never even dropped to marginally suitable levels (6 °C). Furthermore, the proposed management actions to enhance these habitats would not overcome the stream temperature deficiency, concluding that these areas likely could not support bull trout production.

This report presents Yale bull trout-specific data that can be used to parameterize the BayVAM model (Lee et al. 2000), a population viability assessment model, for futures analyses by the organizations working with Lewis River bull trout.

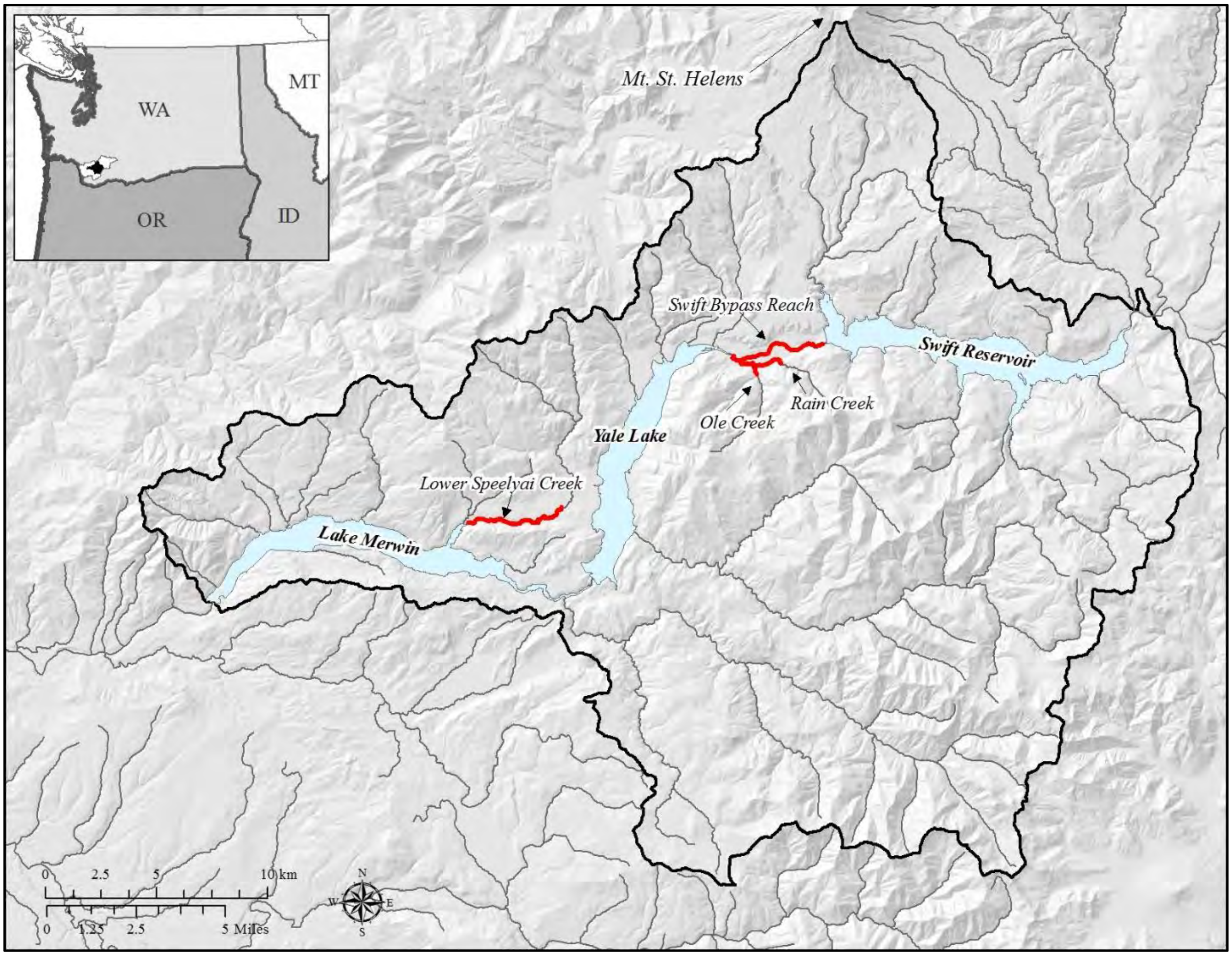

Figure 21. Stream reaches evaluated by Pratt (2003).

b. Lake Merwin and Swift Creek Reservoir tributary streams: bull trout limiting factors analysis

A study was conducted to determine whether suitable bull trout habitat existed in select tributaries to Lake Merwin and Swift Reservoir (Meridian Environmental, Inc., 2007). The objectives were to identify habitat attributes likely preventing the occurrence of bull trout in any of these tributaries, and to recommend actions to improve the habitat based on field data and professional judgement.

The study area included the accessible reaches of 16 tributaries draining into Lake Merwin (10 streams) and Swift Reservoir (6 streams; Figure 22). These streams were selected because: 1) bull trout occupancy was unknown in these streams and, 2) previous work suggested the habitat was accessible to anadromous salmonids, and thus should be accessible to migratory bull trout (PacifiCorp/Cowlitz PUD 2004).

A four-step approach was used to evaluate habitat suitability. In the first two steps, streams were categorized as having optimal, marginal, poor, or unknown potential for supporting a bull trout population based on habitat quantity (linear feet of accessible habitat), stream gradient, and temperature (Table 7). Habitat quantity and stream gradient were evaluated in the first step, temperature in the second step. In the third step, habitat and bull trout presence-absence (P-A) surveys were conducted in streams that had optimal, marginal, or unknown habitat potential based on the first two steps (i.e., streams with poor habitat potential were not further evaluated to minimize costs). After field data were collected, streams were subject to a Qualitative Habitat Assessment (QHA), the final step of the evaluation. Recommendations were provided to improve less than optimal habitat based on the QHA results.

Table 7. Initial bull trout habitat ranking categories.

Habitat parameter	Optimal	Marginal	Poor	Unknown
Flow	Perennial	Perennial	Seasonal[1]	Observations of late summer flow do not exist
Gradient	≤12%[4]	<20%	≥20%[2]	Unknown barrier presence
Maximum water temperature by mid-November[3] (spawning)	≤10°C	≤13°C	>13°C	Continuous water temperature data through the fall do not exist
Maximum water temperature (summer rearing)	≤16°C	≤18°C	>18°C	Continuous water temperature data through the summer do not exist

[1] PacifiCorp/Cowlitz PUD 2004 and anecdotal information (Pers. comm. J. Byrne, WDFW, July 2006).
[2] PacifiCorp/Cowlitz PUD 2004.
[3] Spawning may occur in Lewis River tributaries through November (Pers. comm. J. Byrne, WDFW, July 2006).
[4] Gradient of Rush Creek, known bull trout spawning tributary in the Lewis River subbasin.

Twelve of the 16 study streams had poor habitat potential/suitability due to insufficient habitat quantity and excessive stream gradient (four streams) or high water temperature (eight streams; maximum temperature range, 18.1 – 23.5°C) (Figure 22). The remaining four streams ranked as either optimal or marginal based on the initial habitat ranking. Of the four remaining streams, one was a tributary to Merwin (Brooks Creek) and three were tributaries to Swift Reservoir (Swift Creek, Drift Creek, and S10). P-A and habitat inventory surveys were conducted in these streams in 2006 and 2007. Bull trout were only detected in Swift Creek (three bull trout approximately 400 mm FL and 1 bull trout approximately 600 mm FL were detected during a snorkel survey on August 31, 2006), the only creek in the study where temperature was optimal for both summer rearing and fall spawning time periods.

Members of the Lewis River Aquatic Coordination Committee (ACC) completed the QHA on May 5, 2007. A series of tables was produced that: 1) described the physical habitat of each study tributary, 2) established a hypothesis concerning how bull trout may interact with the available habitat by life stage and, 3) ranked the reaches in terms of restoration and protection needs and in terms of limiting factors related to spawning, incubation, and rearing.

The limiting factors for the four streams with marginal or optimal habitat potential are reported in Table 8. Brooks and S10 are limited by naturally low discharge in summer and early fall that likely precludes adults from accessing the habitat for spawning and limits summer rearing potential. Brooks and Drift creeks are limited by warm incubation temperature (> 6°C) that would likely result in high egg mortality. Swift Creek is limited by regular large scour and bedload deposition events that would negatively affect egg incubation and juvenile rearing potential. The study concludes that there are no feasible restoration strategies to improve these streams to promote long-term bull trout spawning, incubation, and rearing.

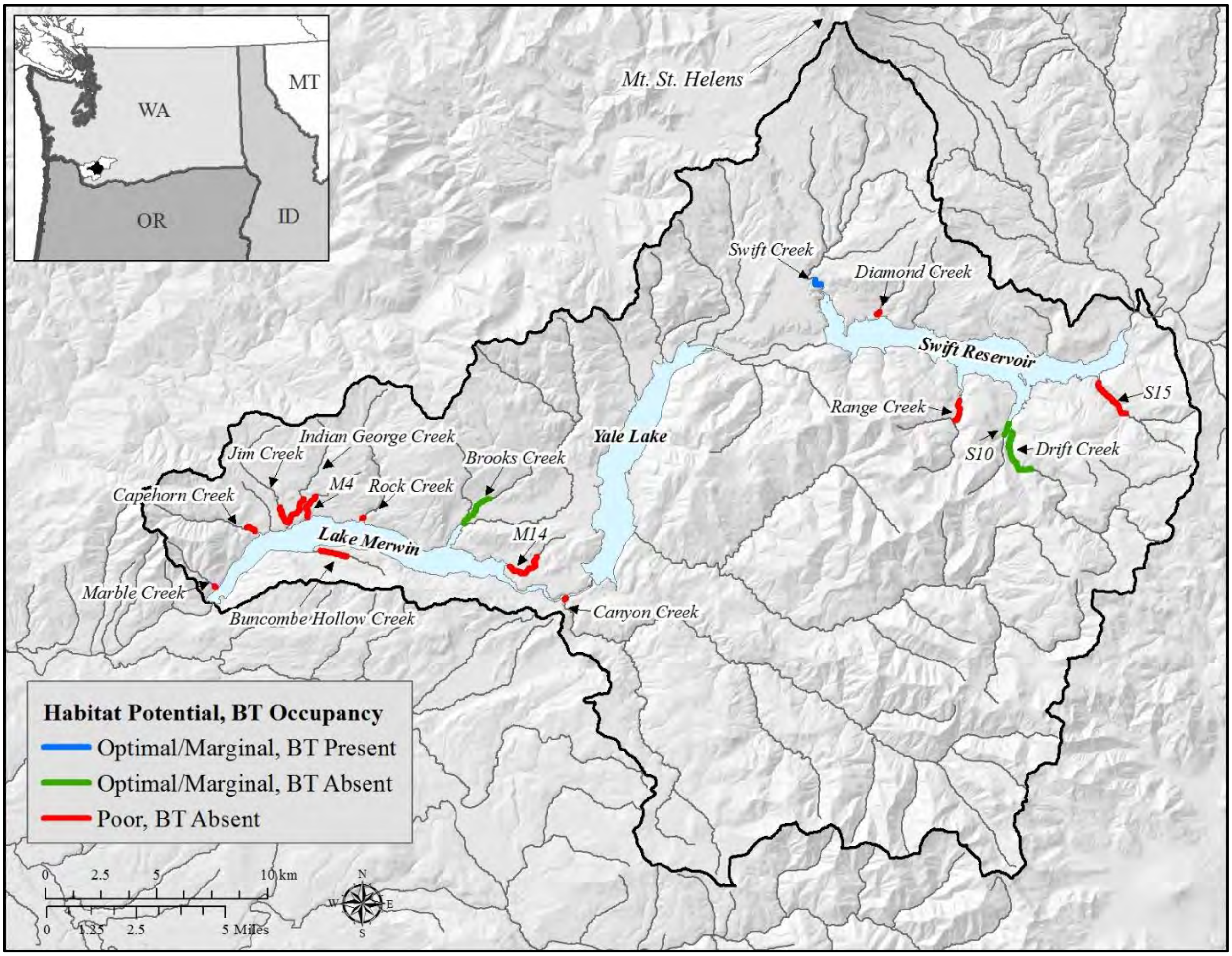

Figure 22. Study streams of the 2007 bull trout limiting factors analysis in select tributaries of Lake Merwin and Swift Reservoir. The spatial extent of habitat accessible to bull trout in each stream is indicated by the colored lines except for Marble and Canyon creeks where, for display purposes, the lines indicate a greater extent of accessible habitat than what actually exists (actual length of available habitat is < 40 ft in each stream).

Table 8. Factors likely preventing the occurrence of an established bull trout population in the four streams with marginal or optimal habitat potential.

Reservoir	Stream	Low discharge	Warm incubation temp	Frequent scour events
Merwin	Brooks Creek	X	X	
Swift	S10	X		
Swift	Drift Creek		X	
Swift	Swift Creek			X

c. Lewis River bull trout habitat restoration project identification assessment

Temperature and in-stream habitat data were collected in the upper Lewis River subbasin (above Swift Reservoir) as part of a study to help prioritize spawning and rearing habitat restoration actions (Lamperth et al. 2017). Temperature data were collected to identify the spatial extent of thermally suitable habitat below migratory passage barriers and within reaches deemed to have some level of restoration potential. In-stream habitat and redd locations in the Pine Creek watershed were used to model redd occurrence as a function of in-stream habitat. A total of 19 habitat variables were derived from the field data (Table 9) and were summarized at 100 m reaches. The habitat variables were screened prior to including them in the model to limit the suite of explanatory variables to those that contained information about redd occurrence and were uncorrelated. The resultant redd occupancy model was used to identify potential suitable spawning habitat within thermally suitable habitats of the upper Lewis River subbasin.

Table 9. List of habitat variables used to develop a redd occurrence model for bull trout in the upper Lewis River subbasin, WA. The variables were summarized at 100 m reaches.

Variable (units)	Description
Complex channel (P/A)	Presence or absence of more than one channel with flowing water.
Depth (m)	Mean stream depth
Width (m)	Mean wetted width
W/D	Width-to-depth ratio
CV depth (%)	Coefficient of variation of stream depth
CV width (%)	Coefficient of variation of width
CV W/D (%)	Coefficient of variation of width-to-depth ratio
Max depth (m)	Maximum depth
Cover (m^2)	Total area of cover. Cover defined as a slow water velocity area with some type of shelter, a minimum area of 0.5 m^2, and a minimum depth of 0.45 m. Shelter types include wood, overhanging vegetation touching the stream surface, undercut banks with horizontal depths > 0.5 m, turbulence, and depths > 0.80 m.
PSP (m^2)	Total area of potential spawning patches (*sensu* Isaak et al. 2007). PSP defined as a minimum area of 0.5 m^2 with gravel as the dominant substrate (intermediate axis length 2-64 mm), water depth 0.10-0.35 m, and minimum water velocity of 0.10 m/s (visually estimated). Criteria based on bull trout redd microhabitat characteristics (Kitano et al. 1994; Hagen and Taylor 2001; Wissmar and Craig 2004; for a review see McPhail and Baxter 1996).
LWD (no./100m)	Density of large woody debris. LWD defined as pieces of channel-forming wood, both > 5.0 m length and > 0.30 m diameter, within the active stream channel.
Pools (no./100m)	Density of pools. Includes pool habitat units and isolated pools within riffle habitat units.
Pool (m^2)	Total area of pool habitat units.
Riffle (m^2)	Total area of riffle habitat units.
Fines (m^2)	Total area of fine substrate. Defined as intermediate axis length < 2 mm (Cummins 1962).
Gravel (m^2)	Total area of gravel substrate. Defined as intermediate axis length of 2-64 mm (Cummins 1962).
Cobble (m^2)	Total area of cobble substrate. Defined as intermediate axis length of 64-256 mm (Cummins 1962).
Boulder (m^2)	Total area of boulder substrate. Defined as intermediate axis length > 256 mm (Cummins 1962).
Bedrock (m^2)	Total area of bedrock substrate.

A total of 9 habitat variables were retained through the variable selection process (Table 10). The global model relating redd occurrence to these 9 variables adequately fit the data (Hosmer-Lemeshow, $P = 0.50$) and the residuals of the model lacked spatial autocorrelation (Mantel's test, $P = 0.996$).

Table 10. Parameter estimates and scaled odds ratios for the global model relating bull trout redd occurrence to physical habitat variables in the upper Lewis River subbasin, WA. Log-transformed ($\log_e(x+1)$) values of Boulder (m^2), Fines (m^2), and Pool (m^2) were used in model.

Variable	Parameter estimate	Standard error	Scaling factor	Scaled odds ratio	95% CI for scaled odds ratio	*P*-value
Intercept	2.218	1.705				0.193
Complex channel	1.389	0.486	1	4.01	1.55 - 10.41	**0.004**
Depth (m)	-18.802	7.999	0.05	0.39	0.18 - 0.86	**0.019**
CV width (%)	-0.046	0.032	5	0.79	0.58 - 1.09	0.151
Width (m)	0.155	0.142	1	1.17	0.88 - 1.54	0.277
Boulder (m^2)	-0.092	0.126	1	0.91	0.71 - 1.17	0.464
LWD (no./100m)	0.040	0.067	1	1.04	0.91 - 1.19	0.546
PSP (m^2)	-0.032	0.069	1	0.97	0.85 - 1.11	0.644
Fines (m^2)	0.074	0.174	1	1.08	0.77 - 1.51	0.673
Pool (m^2)	0.043	0.196	1	1.04	0.71 - 1.53	0.827

A total of 512 models were generated that included unique combinations of the 9 retained habitat variables and, of these, 11 had strong support for being the best approximating model. Complex channel ($P = 0.004$) and Depth ($P = 0.019$) were the only variables present in all of the best supported models suggesting these variables contained the most information about redd occupancy with minor contributions from the other variables. For simplicity, the parameter estimates and odds ratios for the model with the lowest AICc score were used to understand the relationship between these variables and redd occurrence (Table 11).

Table 11. Parameter estimates and odds ratios for the bull trout redd occurrence model with the lowest AICc score.

Variable	Parameter estimate	Standard error	Scaling factor	Scaled odds ratio	95% CI for scaled odds ratio	*P*-value
Intercept	1.871	1.086				0.085
Complex channel	1.378	0.453	1.00	3.96	1.63 - 9.64	0.002
Depth (m)	-16.830	4.739	0.05	0.43	0.27 - 0.69	< 0.001

The model suggests bull trout redd occurrence was positively associated with the presence of complex channels and negatively associated with stream depth (Table 11). The odds of a bull trout redd occurring in a reach were four times greater if more than one channel (e.g., one main and one side channel) was present in the reach (odds ratio = 3.96). With a 5 cm increase in stream depth, the odds of a redd occurring in a reach decreased by more than two times (2.3 = 1/0.43).

Since complex channel and depth were the best predictors of bull trout red occurrence within thermally suitable habitat, these variables were used to better understand the quantity of potential suitable spawning habitat available to migratory bull trout within thermally suitable habitat in the upper Lewis River subbasin (Figures 23 and 24). Areas with complex channels and suitable stream depths are limited outside of the known spawning watersheds. It is important to note that thermally suitable habitat in this study was defined as reaches that had ≥ 25% probability of juvenile bull trout occurrence based on maximum daily temperature (Dunham et al. 2003). The assumption is that juvenile bull trout presence is indicative of suitable spawning and early rearing habitat. This liberal thermal suitability threshold resulted in ~ 22 km of habitat available to Swift Reservoir bull trout outside of the Pine and Rush creek watersheds. The spatial extent of which is shown in Figure 23. However, if we use a more conservative threshold and limit the study area to habitat that has ≥ 50% probability of occurrence, the length of thermally suitable habitat available to migratory bull trout is reduced to ~ 3 km (not shown on the map). This information in combination with the fact that the current spawning distribution in the Lewis River subbasin above Swift Reservoir is restricted to the coldest available habitat (i.e., Pine and Rush creek watersheds) suggests that stream temperature is limiting the distribution of spawning and rearing habitat in the subbasin.

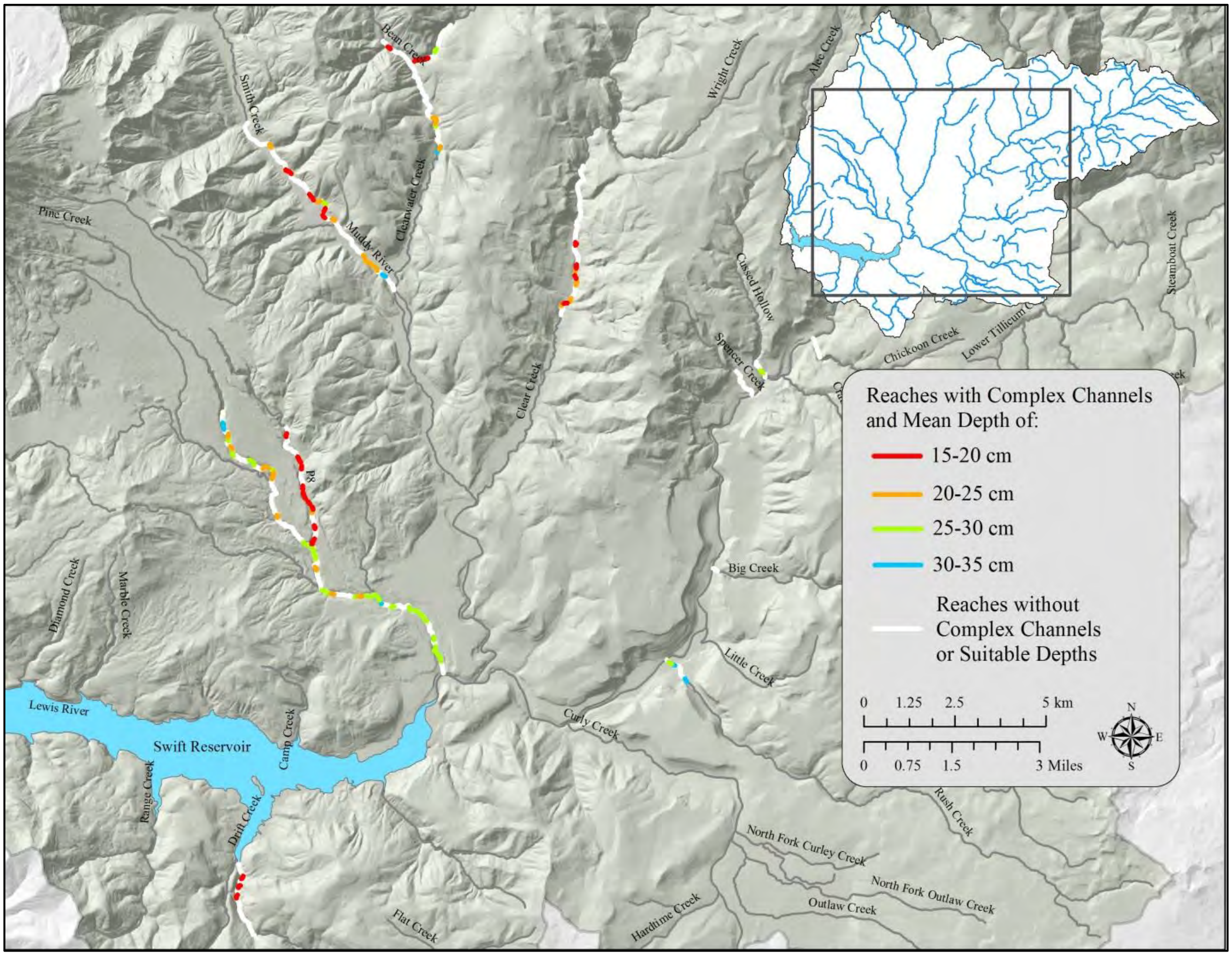

Figure 23. Location of 100 m reaches with both a complex channel and a suitable stream depth for spawning bull trout in the upper Lewis River subbasin, WA, with the inset identifying the location of the study area within the Swift drainage. Complex channels and stream depth were the top variables in a redd occupancy model developed with data from the Pine Creek watershed. These stream reaches represent nearly all thermally suitable habitat accessibly to migratory bull trout in the upper Lewis River subbasin. The probability of redd occurrence decreases with increasing depth.

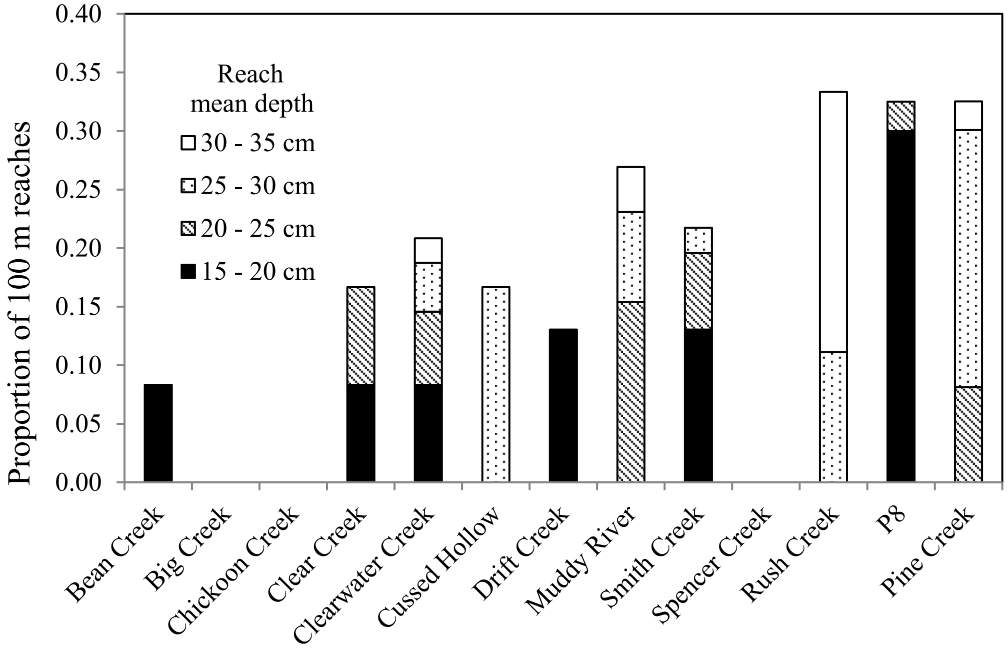

Figure 24. Proportion of 100 m reaches with both a complex channel and a suitable stream reach depth for spawning bull trout by stream in the upper Lewis River subbasin, WA. Complex channels and stream depth were the top variables in a redd occupancy model developed with data from the Pine Creek watershed. These streams represent nearly all of the thermally suitable habitat accessible to migratory bull trout in the upper Lewis River subbasin. The probability of redd occurrence decreases with increasing depth. Bull trout are known to spawn in Rush Creek, P8, and Pine Creek.

IX. Data gaps and Research Monitoring and Evaluation (RME) needs

The LRBTRT identified the following data gaps and RME needs for the Lewis River bull trout populations (not listed in order of priority):

- Effects of anadromous fish reintroduction on bull trout in the upper Lewis River subbasin above Swift Dam
- Fisheries related impacts (e.g., poaching, catch and release impacts)
- Connectivity/accessibility among Lewis River populations
- Recolonization of historically occupied areas (e.g., Muddy River) and expansion into other areas of the subbasin
- eDNA – long-term monitoring approach expanding on initial study in the subbasin
- Sex ratio – no information currently exists for Lewis River bull trout
- Fecundity – no information currently exists for Lewis River bull trout
- Age structure – limited years of data are available and are not sufficient to evaluate trends. Evaluating age structure trends is critical to understand the health of bull trout populations.
- Adult abundance/survival – need to determine the best method of evaluating (several different monitoring methods currently being used)
- Juvenile abundance/survival – no methods currently in use to estimate
- Juvenile movement patterns – limited information is available on timing of migrations and habitats used by different sizes/ages of juveniles.
- Life history strategies – a more complete understanding of different ways that bull trout use habitats in the Lewis River subbasin, and the relative success of each strategy
- Effectiveness/biological response from previous habitat restoration work in the Lewis subbasin
- Demographic thresholds – minimum viable populations
- Climate change vulnerability assessment specific to Lewis subbasin
- Population dynamics
- Analyses linking temperature to bull trout behavior, biology and ecology (other than spawning and rearing)
- Role of Yale and Swift reservoirs in supporting bull trout populations – prey, predators, temperature regimes, movement patterns, etc.
- Effective population structure – need to expand on initial work before conclusions can be made
- Limiting factors – expanding on work summarized in this document to better understand where and how Lewis River bull trout populations are being limited from expansion within the subbasin

X. Acknowledgements

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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